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SHIP STABILITY-III

NUTSHELL SERIES

BOOK 6

BY CAPT. H. SUBRAMANIAM

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Dedicated to my mother, without whose patient and constant encouragement, this book would not have been possible.

Capt/Dr.P.S.VANCHISWAR
Ph.D., Extra Master
Resident Professor,
World Maritime University,
Malmo, Sweden.

15th Feb 1986

F O R E W O R D

Enthusiasm, perseverance & dedication are the qualities that come to my mind when I think of Captain H. Subramaniam. Enthusiasm because of the way in which he goes about, not only his work, but also his 'hobby' of writing technical books! Perseverance because of his starting to write the next book as soon the earlier one is complete, thereby writing six books in less than ten years! Dedication to his work because he does not let his book writing interfere with his main occupation - teaching. In fact, I have heard from those who have had the good fortune to have been his students, that his dedication to teaching is total.

Capt.Subramaniam's Nutshell Series of books are very popular today, especially among officers of developing countries, because of two reasons. Firstly, his books are written in simple, straight-forward English. He has managed to avoid using difficult expressions and complex sentences. Secondly, he has maintained a practical approach throughout, bearing in mind the actual use to which the student can apply the knowledge gained from these books.

Stability III deals with the subject at the Master's level. The author's practical method of calculating the stability particulars of a ship in a damaged condition is unique. His chapter on stability of ships carrying bulk grain is certainly what a shipmaster needs to know. His decision to include chapters on shear force and bending moment, in this book on ship stability, will be welcomed by all students for the Certificate of Competency as Master F.G. The author's expertise in teaching is clearly evident in this book.

I congratulate the author for his efforts and hope that he will continue to write on other maritime subjects.

(P.S.Vanchiswar)*

* Resident Professor, World Maritime University, Malmo, Sweden. Previously Nautical Adviser to the Govt. of India and Chief Examiner of Masters and Mates. Was Chairman of the Committee - "Master and Deck Department" - at the STCW Conference (1978) held by the International Maritime Organisation.

P R E F A C E

The subject of Ship Stability has been covered in three parts:

Ship Stability I (Nutshell Series Book 4) consists of 18 chapters and adequately covers the syllabuses for Second Mate F.G & Navigational Watch Keeping Officer.

Ship Stability II (Nutshell Series book 5) starts with chapter 19 and goes on to chapter 32 such that both, Ship Stability I and II, cover the syllabuses for First Mate F.G & Mate H.T.

Ship Stability III (Nutshell Series Book 6) starts with chapter 33 and goes on to chapter 49 such that all three, Ship Stability I, II and III, cover more than the syllabuses for Master F.G. and Master Home Trade.

As far as possible, a practical approach has been maintained to enable ship's officers to put the knowledge to practical use on board ship.

It is hoped that Marine Engineers also may find these books useful.

Bombay
1st March 1986

(H.Subramaniam)

SHIP STABILITY III

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CHAPTER 33

BILGING OF AN END COMPARTMENT

The increase in draft, and the effect on GM, resulting from bilging an end compartment is the same as that caused by bilging an amidships compartment of similar dimensions. Since the student is expected to have studied the effects of bilging amidships compartments in Chapter 32 in Ship Stability II, needless repetition has been avoided here.

The bilging of an end compartment causes the COB of the ship to be longitudinally displaced away from the bilged compartment. Since the position of the COG of the ship remains unaffected by bilging, the consequent longitudinal separation of the COB and the COG (i.e., $\overline{BG}$) results in a trimming moment ($W.\overline{BG}$). Bilging an end compartment, therefore, causes a change in the trim of the ship.

The foregoing statement can be illustrated simply by the worked examples that follow. However, before proceeding with the worked examples, it is necessary to know the theorem of parallel axes as applicable to rectangles. The theorem of parallel axes with respect to other regular shapes is explained in chapter 41, before the worked examples on centre of pressure.

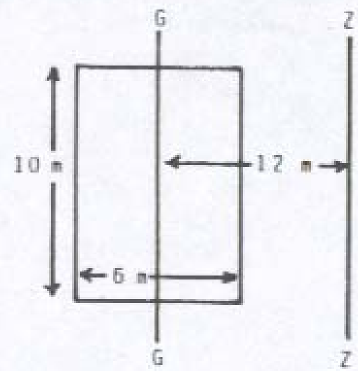
Theorem of parallel axes: If I*GG is the moment of inertia of an area about an axis passing through its geometric centre, and ZZ is an axis parallel to GG, then

$$I^*ZZ = I^*GG + Ay^2$$

where 'y' is the distance between the axis GG and the axis ZZ.

Case 1

If L = 10 m, B = 6 m & y = 12 m, I*ZZ = ?



$$I^*ZZ = I^*GG + Ay^2$$

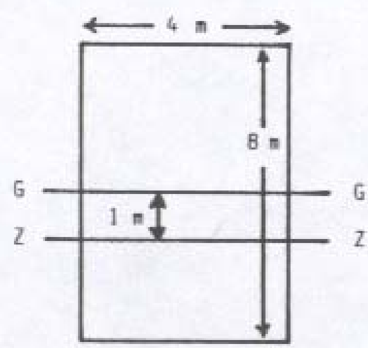
$$= \frac{LB^3}{12} + LB(y^2)$$

$$= 180 + 8640$$

$$= 8820 \text{ m}^4.$$

Case 2

If L = 8 m, B = 4 m & y = 1 m, I*ZZ = ?



$$I^*ZZ = I^*GG + Ay^2$$

$$= \frac{BL^3}{12} + LB(y^2)$$

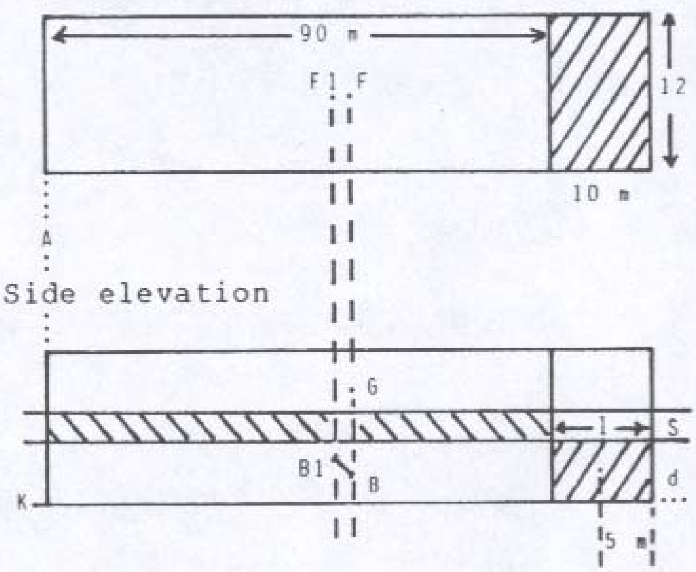
$$= 170.667 + 32$$

$$= 202.667 \text{ m}^4.$$

Example 1

A box-shaped vessel 100 m long & 12 m wide floats at an even keel draft of 6 m in SW. The compartment at the forward end, 10 m long and 12 m broad, is empty. Find the new drafts fwd and aft if this compartment gets bilged.

Plan view at waterline



Before bilging, AB = AG = AF = 50 m.

V = 100 x 12 x 6 = 7200 m^3) unchanged by
W = 7200 x 1.025 = 7380 t) bilging.

$$S = \frac{\text{volume of lost bouyancy}}{\text{intact water-plane area}}$$

$$S = \frac{lbd}{LB-lb} = \frac{10 \times 12 \times 6}{1200 - 120} = \frac{720}{1080} = 0.667 \text{ m}$$

Final hydraft = 6.000 + 0.667 = 6.667 m.

Note: Since the intact underwater volume is rectangular and 90 m long, its AB and AF are both = 45 m.

$\overline{BG}$ = AG - new AB = 50 - 45 = 5 metres.

Since the COG is fwd of the new COB, the trim caused will be by the head.

TM = W.$\overline{BG}$ = 7380 x 5 = 36900 tm by head.

Trim caused or Tc = TM ÷ MCTC. However the new MCTC has to be calculated.

MCTC = (W.GML) ÷ 100L or (W.BML) ÷ 100L

GML = KML - KG. Since KG is not given here, BML may be used instead of GML. Note: The 'L' to be used in this formula is the total length of the water-plane i.e., the LBP of the ship.

$$BML = I^*COF \text{ of intact WP} \div V = \frac{12(90^3)}{12(7200)}$$

$$BML = 101.25 \text{ m.}$$

$$MCTC = \frac{W.BML}{100L} = \frac{7380(101.25)}{100(100)} = 74.723 \text{ tm.}$$

Tc =TM ÷ MCTC= 36900 ÷ 74.723 = 493.8 cm

Tc = 4.938 m by the head.

$$Ta = \frac{AF(Tc)}{L} = \frac{45(4.938)}{100} = 2.222 \text{ m.}$$

$Tf = Tc - Ta = 4.938 - 2.222 = 2.716$ m.

	fwd	aft
New hydraft	6.667 m	6.667 m
Tf or Ta	+2.716	−2.222
New drafts	9.383 m	4.445 m

Note: If the transverse GM in the bilged condition is asked, the method of calculation is the same as that in Chapter 32, in Ship Stability II.

Example 2

If in example 1 the permeability of the compartment is 40 %, find the drafts fwd and aft.

Before bilging, AB = AG = AF = 50 metres

$V = 100 \times 12 \times 6 = 7200\ m^3$)unchanged by
$W = 7200 \times 1.025 = 7380$ t)bilging.

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$= \frac{10 \times 12 \times 6(40/100)}{100(12) - 10(12)(40/100)}$$

$$S = 0.250 \text{ metre.}$$

New hydraft = $6.000 + 0.250 = 6.250$ m.

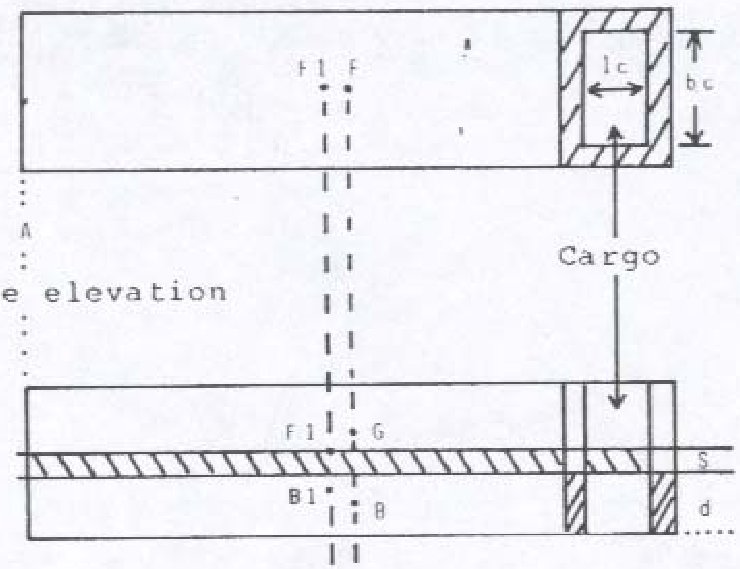
Note 1: The new COB will be the geometric centre of the combined volume of the rectangle 90 m long and the cargo immersed in the bilged compartment. AB is not 45 m as was in example 1.

Note 2: Since the water-plane is

uniform at all drafts after bilging, new AB = new AF.

Plan view at waterline

Side elevation



As explained in chapter 32, in Ship Stability II,

$$lc = l\sqrt{\frac{100 - p}{100}} = 10\sqrt{0.6} = 7.746 \text{ metres.}$$

$$bc = b\sqrt{\frac{100 - p}{100}} = 12\sqrt{0.6} = 9.295 \text{ metres.}$$

where lc & bc are the length and breadth of the cargo.

Area of cargo = $7.746 \times 9.295 = 72 \text{ m}^2$.

<u>To find new AB & AF</u>

Alternative 1

To find new AB, moments of vol about A.

Rectangle(its AB) =
 90(12)6.25(45) = 6750(45) = 303750 m^4.
Submerged cargo(its AB)=
 (72 x 6.25)95 = 450(95) = 42750 m^4.
Total volume(its AB) =
 7200(new AB) .... = 346500 m^4.

New AB = 346500 ÷ 7200 = 48.125 metres.
In this case, new AF also = 48.125 m.

Alternative 2

To find new AF, moments of area about A.

Rectangle(its AF) =
 (90 x 12)45 = 1080(45) = 48600 m^3.
Submerged cargo(its AF) =
 72 x 95 .... = 6840 m^3.
Intact WP area(its AF) =
 1152 x new AF .... = 55440 m^3.

New AF = 55440 ÷ 1152 = 48.125 metres.
In this case, new AB also = 48.125 m.

Alternative 3

To find new AF, moments of area about A.

Original WP area(its AF) =
 1200 x 50 .... = 60000 m^3.
Area lost(its AF) =
 48 x 95 .... = 4560 m^3.
Intact WP area(its AF) =
 1152 x new AF .... = 55440 m^3.

New AF = 55440 ÷ 1152 = 48.125 metres.
In this case, new AB also = 48.125 m.

$\overline{BG}$ = AG - new AB = 50 - 48.125 = 1.875 m
Since the COG is fwd of the new COB, the trim caused will be by the head.

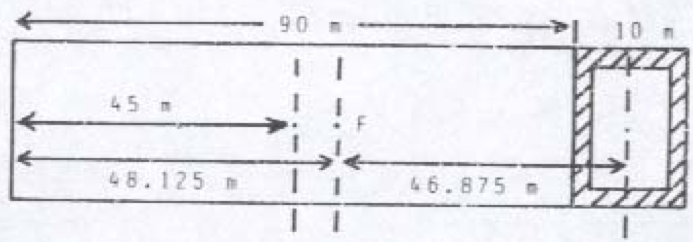
TM = W.$\overline{BG}$ = 7380(1.875) = 13837.5 tm.

Tc.= TM ÷ MCTC. However the MCTC in the bilged condition has to be calculated.

MCTC = W.GML ÷ 100L or W.BML ÷ 100L.
Since KG is not given, BML has to be used instead of GML.

Note: In this formula, L represents LBP.

BML = I*COF of intact WP area ÷ V



I*COF intact WP area = I*COF rectangle + I*COF cargo area

I*COF rectangle =

$$\frac{12(90^3)}{12} + (12)90(3.125^2)$$

$$= 729000 + 10546.875 = 739546.875 \text{ m}^4.$$

I*COF cargo =

$$\frac{9.295(7.746^3)}{12} + 72(46.875^2)$$

$$= 360 + 158203.125 \ldots = 158563.125 \text{ m}^4.$$

I*COF intact WP area =

$$739546.875 + 158563.125 = 898110 \text{ m}^4.$$

BML = 898110 ÷ 7200 = 124.738 metres.

MCTC = (7380 x 124.738) ÷ (100 x 100)

MCTC = 92.057 tm.

Tc = TM ÷ MCTC = 13837.5 ÷ 92.057

Tc = 150.3 cm = 1.503 m by the head.

$$Ta = \frac{AF(Tc)}{L} = \frac{48.125(1.503)}{100} = 0.723 \text{ m.}$$

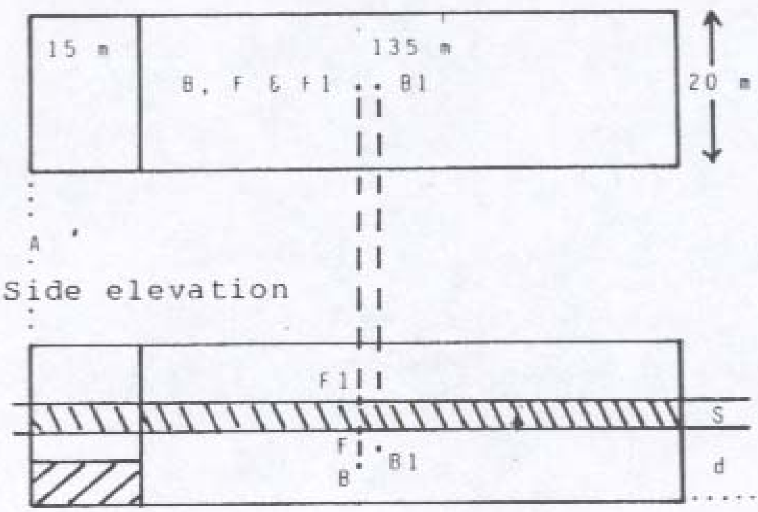
Tf = Tc - Ta = 1.503 - 0.723 = 0.780 m.

	Fwd	Aft
Final hydraft	6.250 m	6.250 m
Tf or Ta	+0.780	-0.723
Final drafts	7.030 m	5.527 m

Example 3

A box-shaped vessel 150 m long and 20 m wide floats at an even keel draft of 8 m in SW. The aftermost compartment, 15 m long & 20 m wide, has a water-tight flat 1 m above the keel, separating the LH & the DB tank. Calculate the drafts fwd & aft if this empty DB tank is bilged.

Plan view at waterline



$V = 150 \times 20 \times 8 = 24000 \text{ m}^3$) unchanged
$W = 24000(1.025) = 24600$ t) by bilging.

Before bilging AG = AB = AF = 75 metres.
After bilging AF = 75 m but new AB >75 m

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}} = \frac{15 \times 20 \times 1}{150 \times 20}$$

$$S = 0.100 \text{ metre.}$$

New hydraft = 8.000 + 0.100 = 8.100 m.

To find new AB, moments of vol about A:

Original vol (its AB) =
24000 x 75 ....= 1,800,000 m^4.

Volume lost (its AB) =
300 x 7.5 ....= - 2,250 m^4.

Balance after loss ......= 1,797,750 m^4.

Volume regained (its AB) =
300 x 75 ....= + 22,500 m^4.

New volume (new AB) =
24000 x new AB ....= 1,820,250 m^4.

New AB = 1,820,250 ÷ 24000 = 75.844 m.

$\overline{BG}$ = new AB - AG = 75.844 - 75 = 0.844 m

Since AG < new AB, Tc will be by stern.

TM = W.$\overline{BG}$ = 24600 x 0.844 = 20762.4 tm.

MCTC = W.GML ÷ 100L or W.BML ÷ 100L

Since KG is not given, BML may be used.

$$BML = \frac{I*COF\ intact\ WP\ area}{Volume} = \frac{20(150^3)}{12(24000)}$$

$$BML = 234.375\ m.$$

$$MCTC = \frac{24600(234.375)}{100 \times 150} = 384.375\ tm.$$

It is obvious from the foregoing calculation that, in this case, BML & MCTC are unchanged by bilging.

$$Tc = \frac{TM}{MCTC} = \frac{20762.4}{384.375} = 54.0\ cm = 0.540\ m.$$

$$Ta = \frac{AF(Tc)}{L} = \frac{75(0.54)}{150} = 0.270\ metre.$$

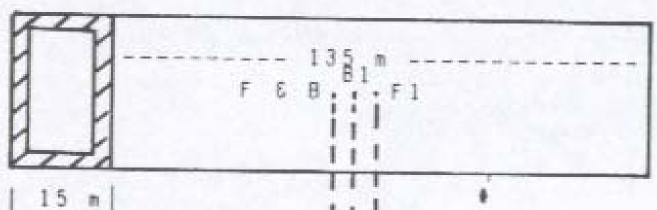
Tf = Tc - Ta = 0.540 - 0.270 = 0.270 m.

	Fwd	Aft
Final hydraft	8.100 m	8.100 m
Tf or Ta	-0.270	+0.270
Final drafts	7.830 m	8.370 m

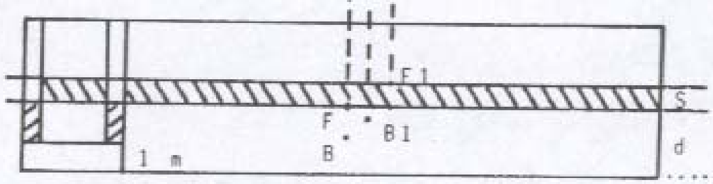
Example 4

If in example 3, the bilging occurred in the LH (full of general cargo; p = 60%) and not in the DB tank, find the new drafts fwd and aft.

Plan view at waterline



Side elevation



V = 150 x 20 x 8 = 24000 m^3) Unchanged
W = 24000(1.025) = 24600 t) by bilging

Before bilging, AG = AB = AF = 75 metres
After bilging, AB>75 m, AF>75 m, but AB and AF are NOT equal.

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{15 \times 20 \times 7(60/100)}{(150 \times 20) - 15 \times 20(60/100)} = 0.447 \text{ m}$$

New hydraft = 8.000 + 0.447 = 8.447 m.

$$lc = l\sqrt{\frac{100 - p}{100}} = 15\sqrt{0.4} = 9.487 \text{ m.}$$

$$bc = b\sqrt{\frac{100 - p}{100}} = 20\sqrt{0.4} = 12.649 \text{ m.}$$

Area of cargo = 9.487 x 12.649 = 120 m^2.

To find new AF, moments of area about A:

Cargo area (its AF) =
120 x 7.5 ....= 900 m^3.

Rectangle (its AF) =
135 x 20 x 82.5 ....= 222,750 m^3.

Intact WP area (its AF) =
2820 (new AF) ....= 223,650 m^3.

New AF = 223,650 ÷ 2820 = 79.309 m.

To find new AB, moments of vol about A:

Rectangle (its AB) =
135(20)8.447(82.5) = 1,881,569.25 m^4.

Submerged cargo (its AB) =
120 x 7.447 x 7.5 = 6702.3 m^4.

DBT (its AB) =
15 x 20 x 1 x 7.5 = 2250.00 m^4.

Total vol (its AB) =
24000(new AB) .....= 1,890,521.55 m^4.

New AB = 1,890,521.55 ÷ 24000 = 78.772 m

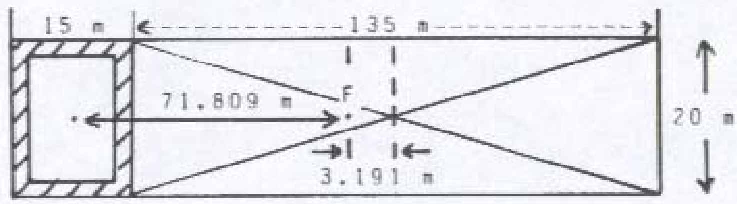
$\overline{BG}$ = new AB - AG = 78.772 - 75 = 3.772 m
Since AG < new AB, Tc will be by stern.

TM = W.$\overline{BG}$ = 24600 x 3.772 = 92791.2 tm.

Tc = TM ÷ MCTC and MCTC = W.BML ÷ 100L.

BML = I*COF intact water-plane ÷ Volume

I*COF WP = I*COF rectangle + I*COF cargo



$$\text{I*COF rect} = \frac{20(135^3)}{12} + (20)135(3.191^2)$$
$$= 4128117.698\ m^4.$$

I*COF cargo area =
$$\frac{12.649(9.487^3)}{12} + 120(71.809^2)$$
$$= 619683.937\ m^4.$$

I*COF intact WP area = 4747801.635 m^4.

BML = 4747801.635 ÷ 24000 = 197.825 m.

$$\text{MCTC} = \frac{24600 \times 197.825}{100 \times 150} = 324.433 \text{ tm.}$$

$$\text{Tc} = \frac{92791.2}{324.433} = 286.0 \text{ cm} = 2.860 \text{ metres.}$$

$$\text{Ta} = \frac{\text{AF(Tc)}}{\text{L}} = \frac{79.309(2.86)}{150} = 1.512 \text{ m.}$$

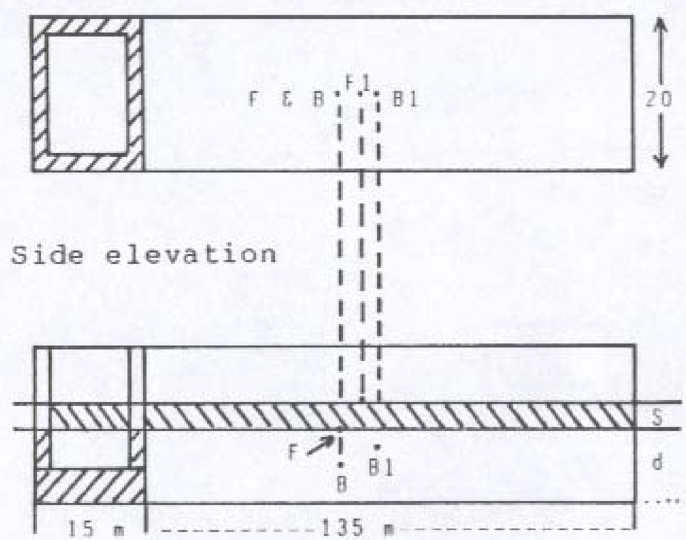
Tf = Tc - Ta = 2.860 - 1.512 = 1.348 m.

	Fwd	Aft
Final hydraft	8.447 m	8.447 m
Tf or Ta	-1.348	+1.512
Final drafts	7.099 m	9.959 m

Example 5

If in example 4, the DB tank also was bilged, find the new drafts fwd and aft.

Plan view at waterline



V = 150 x 20 x 8 = 24000 m^3) Unchanged
W = 24000(1.025) = 24600 t) by bilging

Before bilging, AG = AB = AF = 75 metres
After bilging, AB>75 m, AF>75 m, but AB and AF are NOT equal.

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{15(20)1 + 15(20)7(60/100)}{150(20) - (15)20(60/100)} = 0.553 \text{ m.}$$

New hydraft = 8.000 + 0.553 = 8.553 m.

The following particulars of the vessel, already calculated in example 4, are applicable here without any change:

AF = 79.309 m, BML = 197.825 m, MCTC = 324.433 tm, lc = 9.487 m, bc = 12.649 m, cargo area = 120 m^2.

To find new AB, moments of vol about A:

Rectangle (its AB) =
135(20)8.553(82.5) = 1,905,180.75 m^4.

Submerged cargo (its AB) =
120(7.553)7.5 .....= 6,797.70 m^4.

Total volume (new AB) =
24000(new AB) .....= 1,911,978.45 m^4.

New AB = 1,911,978.45 ÷ 24000 = 79.666 m

$\overline{BG}$ = new AB − AG = 79.666 − 75 = 4.666 m

Since AG<new AB, Tc will be by the stern

TM = W.$\overline{BG}$ = 24600 x 4.666 = 114783.6 tm

$$Tc = \frac{114783.6}{324.433} = 353.8 \text{ cm} = 3.538 \text{ metres.}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{79.309(3.538)}{150} = 1.871 \text{ m}$$

Tf = Tc − Ta = 3.538 − 1.871 = 1.667 m.

	Fwd	Aft
Final hydraft	8.553 m	8.553 m
Tf or Ta	-1.667	+1.871
Final drafts	6.886 m	10.424 m

Exercise 31
Bilging an end compartment

1 A box-shaped vessel 200 m long & 25 m wide floats at an even keel draft of 9 m in SW. The aftermost compartment, 20 m long and 25 m wide, which was empty, gets bilged. Find the new drafts fwd and aft.

2 A box-shaped vessel 180 m long & 18 m wide is afloat in SW at an even keel draft of 8 m. The forward-most compartment has a DB tank, 15 m long, 18 m wide & 1.5 m high, full of SW. Find the new drafts fwd & aft if this DB tank gets bilged.

3 A vessel 160 m long and 20 m wide is box-shaped and afloat in SW at an even keel draft of 7.6 m. The forward-most DB tank is 16 m long, 20 m wide and 1.2 m deep. Find the new drafts fwd & aft if this tank, which was empty, gets bilged.

4 A vessel 150 m long and 14 m wide is box-shaped and afloat in SW at an even keel draft of 8 m. The after-most compartment, 18 m long & 14 m wide, is full of cargo. Find the new drafts fwd & aft if this compartment, having p = 30%, gets bilged.

5 A box-shaped vessel 175 m long & 18 m

wide is floating in SW at an even keel draft of 6.6 m. The forward-most compartment is 18 m long & 18 m wide and has a DB tank 1 m high. The LH, full of cargo, gets bilged. Calculate the final drafts fwd & aft, assuming p = 36%.

6 In example 5, if the empty DB tank also gets bilged, find the new drafts fwd and aft.

7 A box-shaped vessel 200 m long & 20 m broad is afloat in SW at an even keel draft of 8 m. There is a DB tank at the forward end, 18 m long, 20 m wide and 1.4 m high, which has HFO of RD 0.95 to a sounding of 0.5 m. Find the new drafts fwd and aft if this tank gets bilged.
(Hint: Bilging means that sea water can freely go in and out of the compartment and so can HFO. The HFO is NOT, therefore, in the ship anymore. So find the new W, the new AG and the new hydraft assuming that the HFO is pumped out. Then bilge the tank, find the new even keel AB, as in past questions, & complete the calculation.)

8 A box-shaped tank vessel, 200 m long and 20 m wide, is afloat in SW at an even keel draft of 6.2 m. The after-most tanks (No:8 P C & S) are each 16 m long. The wing tanks are 6 m broad each and the centre tank is 8 m broad. All three tanks are empty. Find the new drafts fwd & aft if both the wing tanks - No:8 P and No:8 S - are now bilged.

9 A box-shaped tank vessel, 160 m long and 18 m wide, is afloat in SW at an even keel draft of 9 m. The forward-most tanks (Nos:1 P C &S) are each 20 m long. The wing tanks are 5 m broad each while the centre tank is 8 m broad. No:1 C, which had SW ballast to a sounding of 15 m, gets bilged. Find the new drafts fwd and aft. (Hint: Find the new W, the new AG, & the new hydraft assuming that No: 1 C is discharged. Then bilge it, find the new even keel AB, as done in past questions, and complete the calculation).

10 A box-shaped vessel, 100m long & 12 m wide, floats at an even keel draft of 6 m in SW. The forward-most compartment, 10 m long & 12 m wide, full of general cargo, gets bilged. If the drafts are then observed to be 7.03 m fwd & 5.53 m aft, calculate the approximate permeability of the compartment.

-oOo-

CHAPTER 34

BILGING OF AN INTERMEDIATE COMPARTMENT

Having studied the effects of bilging an amidships compartment (chapter 32) and an end compartment (chapter 33), the calculations involving the bilging of an intermediate compartment should not present any difficulty to the student. Hence not many worked examples are given here.

The calculations in earlier chapters started with the vessel on an even keel. In this chapter, bilging of a compartment has been considered also when the vessel has an initial trim. This provides an interesting aspect of study.

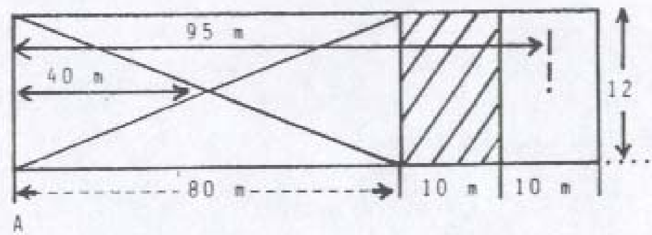
Example 1

A box-shaped vessel 100 m long and 12 m wide floats at an even keel draft of 6 m in SW. No:2 hold, 10 m long & 12 m broad, is empty. The forward bulkhead of this hold is 10 m from the forward end of the ship. Find the drafts fwd and aft if this hold is bilged.

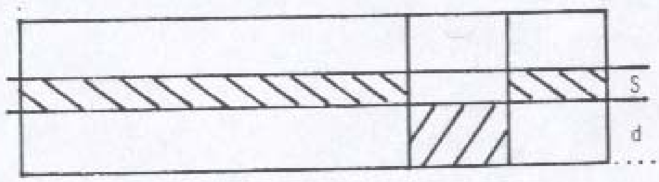
V = 100 x 12 x 6 = 7200 m^3) Unchanged by
W = 7200 x 1.025 = 7380 t) bilging.

Before bilging, AB = AG = AF = 50 metres
After bilging, AB = AF' = < 50 metres.

Plan view at waterline



Side elevation



$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{lbd}{LB - lb} = \frac{10 \times 12 \times 6}{1200 - 120} = \frac{720}{1080} = 0.667 \text{ m}$$

Final hydraft = 6.000 + 0.667 = 6.667 m.

To find new AF, moments of area about A:

Large rect (its AF) =
80 x 12 x 40 ....= 38,400 m^3.

Small rect (its AF) =
10 x 12 x 95 ....= 11,400 m^3.

Intact WP (its AF) =
1080 (new AF) ....= 49,800 m^3.

New AF = 49,800 ÷ 1080 = 46.111 metres.

In this case, new AB also = 46.111 m.

$\overline{BG}$ = AG - new AB = 50 - 46.111 = 3.889 m
Since AG > new AB, Tc will be by head.

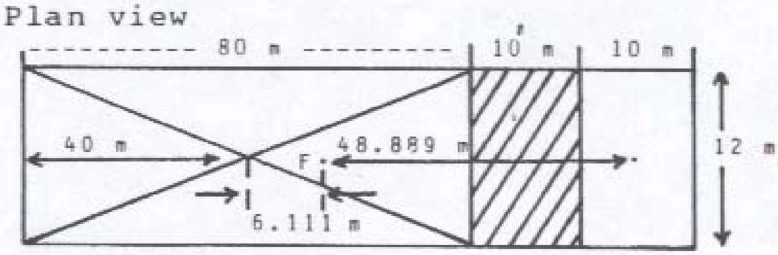
TM = W.$\overline{BG}$ = 7380 x 3.889 = 28,700 tm.

Tc = TM ÷ MCTC and MCTC = W.BML ÷ 100L.

BML = I*COF intact WP ÷ Volume of displ.

I*COF intact WP area =
I*COF large rect + I*COF small rect.

Plan view



I*COF large rect =

$$\frac{12(80^3)}{12}+(12)80(6.111^2)=547{,}850.548\ m^4.$$

I*COF small rect =

$$\frac{12(10^3)}{12}+120(48.889^2) = 287{,}816.119\ m^4.$$

I*COF intact WP ....= 835,666.667 m^4.

BML =835,666.667 ÷ 7200= 116.065 metres.

$$MCTC = \frac{W.BML}{100L} = \frac{7380(116.065)}{100 \times 100} = 85.656\ tm$$

$$Tc = \frac{TM}{MCTC} = \frac{28{,}700}{85.656} = 335.1\ cm = 3.351\ m.$$

$$Ta = \frac{AF(Tc)}{L} = \frac{46.111(3.351)}{100} = 1.545 \text{ m.}$$

$$Tf = Tc - Ta = 3.351 - 1.545 = 1.806 \text{ m.}$$

	Fwd	Aft
New hydraft	6.667 m	6.667 m
Tf or Ta	+1.806	-1.545
New drafts	8.473 m	5.122 m

Example 2

If in example 1, the bilged compartment had permeability = 65%, find the drafts fwd and aft.

$V = 100 \times 12 \times 6 = 7200 \text{ m}^3$) Unchanged by
$W = 7200 \times 1.025 = 7380 \text{ t}$) bilging.

Before bilging, AB = AG = AF = 50 metres

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{10(12)6(65/100)}{1200 - 120(65/100)} = \frac{468}{1122} = 0.417 \text{ m.}$$

New hydraft = 6.000 + 0.417 = 6.417 m.

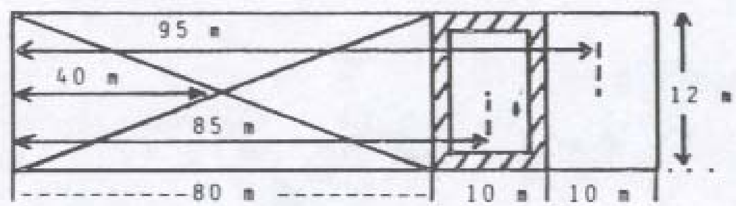
$$lc = l\sqrt{\frac{100 - p}{100}} = 10\sqrt{0.35} = 5.916 \text{ metres.}$$

$$lb = b\sqrt{\frac{100 - p}{100}} = 12\sqrt{0.35} = 7.099 \text{ metres.}$$

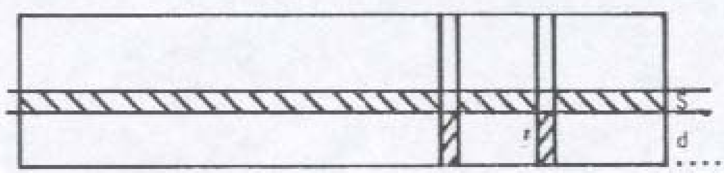
Area of cargo = 5.916 x 7.099 = 42 m^2.

To find new AF, moments of area about A:

Plan view at waterline



Side elevation



Large rect (its AF) =
  80 x 12 x 40 ....= 38,400 m^3.
Small rect (its AF) =
  10 x 12 x 95 ....= 11,400 m^3.
Cargo area (its AF) =
  42 x 85 ....= 3,570 m^3.
Intact WP (its AF) =
  1122 (new AF).............= 53,370 m^3.

New AF = 53,370 ÷ 1122 = 47.567 metres.
In this case, new AB also = 47.567 m.

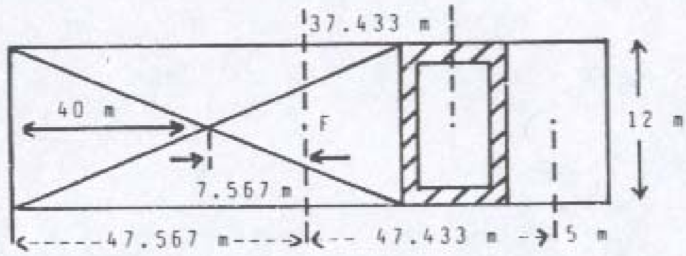
$\overline{BG}$ = AG - new AB = 50 - 47.567 = 2.433 m

$$Tc = \frac{TM}{MCTC} \quad \text{and} \quad MCTC = \frac{W.GML}{100L} \quad \text{or} \quad \frac{W.BML}{100L}$$

BML = I*COF intact WP area ÷ Volume

I*COF intact WP = I*COF large rect + I*COF small rect + I*COF cargo area.

Plan view at waterline



I*COF large rect =

$$\frac{12(80^3)}{12}+(12)80(7.567^2) = 566{,}969.109 \text{ m}^4$$

I*COF small rect =

$$\frac{12(10^3)}{12} + 120(47.433^2) = 270{,}986.739 \text{ m}^4$$

I*COF cargo area =

$$\frac{7.099(5.916^3)}{12}+42(37.433^2)=58{,}974.128 \text{ m}^4$$

I*COF intact WP ....= 896,929.976 m^4

BML = 896929.976 ÷ 7200 = 124.574 metres

$$MCTC = \frac{7380 \times 124.574}{100 \times 100} = 91.936 \text{ tm}$$

$$Tc = \frac{TM}{MCTC} = \frac{7380(2.433)}{91.936}=195.3 \text{ cm} = 1.953 \text{ m}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{47.567 \times 1.953}{100} = 0.929 \text{ m.}$$

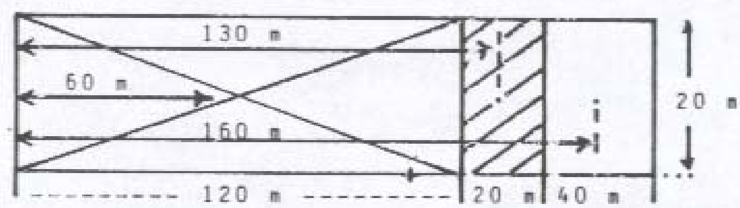
Tf = Tc - Ta = 1.953 - 0.929 = 1.024 m.

	Fwd	Aft
New hydraft	6.417 m	6.417 m
Tf or Ta	+1.024	-0.929
New drafts	7.441 m	5.488 m

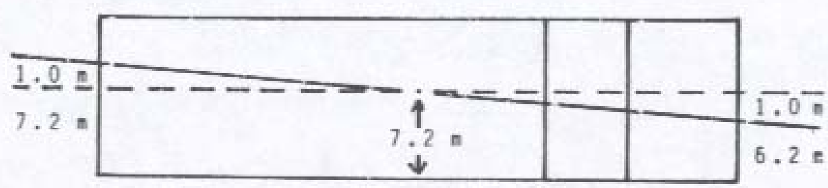
Example 3

A box-shaped vessel 180 m long and 20 m wide floats in SW at a draft of 6.2 m fwd & 8.2 m aft. No:3 LH, beginning 40 m from the forward end is 20 m long and empty. Find the new drafts fwd and aft if this hold is bilged.

Plan view at waterline



Side elevation



V = 180 x 20 x 7.2 = 25920 m^3) Unchanged
W = 25920 x 1.025 = 26568 t) by bilging

The AG of the ship is not known directly so the first step is to calculate it.

Trim in cm $= \dfrac{W.\overline{BG}}{MCTC}$ or $\overline{BG} = \dfrac{MCTC \times trim}{W}$

$$\overrightarrow{BG} = \frac{MCTC \times 200}{W} = \frac{W.BML}{100L} \times \frac{200}{W} = \frac{BML}{90}$$

$$= \frac{I*COF}{V(90)} = \frac{20(180^3)}{12(25920)90} = 4.167 \text{ metres}$$

Since trim is by stern AG < even keel AB
On even keel, AB would be = 90 metres.

So AG of ship = 90 - 4.167 = 85.833 m.

Even keel condition
AG = 90 metres
AB = 90 metres
Trim = nil

Given condition
AG = 85.833 m
AB = 90.000 m
V/l trims until
new AB = AG

Bilged condition
AG = 85.833 m
AB < 90 m due to
bilging. So trim
has to be found.

Assuming even keel condition:

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{20 \times 20 \times 7.2}{180(20) - 20(20)} = \frac{2880}{3200} = 0.9 \text{ metre.}$$

New hydraft = 7.200 + 0.900 = 8.100 m.
In this case, new AB & new AF are equal.

To find new AF, moments of area about A:

120(20)60 + 40(20)160 = 3200(new AF)

New AF = 85 m. New AB also = 85 metres.

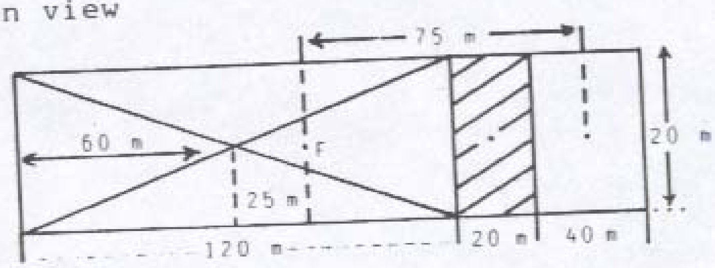
New $\overline{BG}$ = AG - AB = 85.833 - 85 = 0.833 m
Since AG > new AB, Tc is by the head.

TM = W.$\overline{BG}$ = 26568 x 0.833 = 22131.144 tm

$$Tc \doteq \frac{TM}{MCTC} \text{ and } MCTC = \frac{W.GML}{100L} \text{ or } \frac{W.BML}{100L}$$

BML = I*COF intact WP ÷ Volume of displ.

Plan view



I*COF intact WP =
I*COF large rect + I*COF small rect.

I*COF large rect =
$$\frac{20(120^3)}{12}+(20)120(25^2)=4380{,}000.000 \text{ m}^4.$$

I*COF small rect =
$$\frac{20(40^3)}{12}+(20)40(75^2) = 4606{,}666.667 \text{ m}^4.$$

I*COF intact WP ......= 8986,666.667 m^4.

BML = 8986,666.667 ÷ 25,920 = 346.708 m.

$$MCTC = \frac{26568 \times 346.708}{100 \times 180} = 511.741 \text{ tm.}$$

$$Tc = \frac{TM}{MCTC} = \frac{22131.144}{511.741} = 43.2 \text{ cm} = 0.432 \text{ m.}$$

$$Ta = \frac{Tc(AF)}{L} = \frac{0.432(85)}{180} = 0.204 \text{ metre.}$$

$$Tf = Tc - Ta = 0.432 - 0.204 = 0.228 \text{ m.}$$

	Fwd	Aft
Final hydraft	8.100 m	8.100 m
Tf or Ta	+0.228	-0.204
Final drafts	8.328 m	7.896 m

Example 4

If in example 3, the permeability of the hold was 60%, find the new drafts, fwd & aft, after bilging.

The following particulars, already calculated in example 3, are unchanged by bilging: $V = 25{,}920 \text{ m}^3$, $W = 26{,}568$ t, AG = 85.833 metres.

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

Assuming even keel condition:

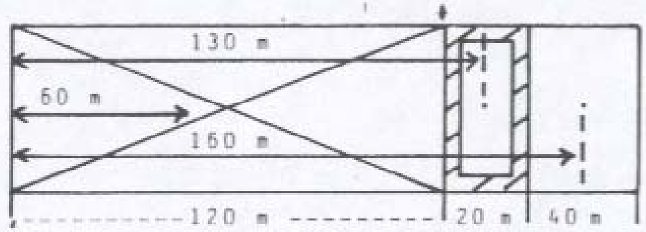
$$S = \frac{20 \times 20 \times 7.2 \times 60/100}{180(20) - (20)20(60/100)} = 0.514 \text{ m.}$$

New hydraft $= 7.200 + 0.514 = 7.714$ m.

In this case, new AF & new AB are equal.

To find new AF, moments of area about A:

Plan view



$$lc = l\sqrt{\frac{100 - p}{100}} = 20\sqrt{0.4} = 12.649 \text{ m.}$$

$$bc = b\sqrt{\frac{100 - p}{100}} = 20\sqrt{0.4} = 12.649 \text{ m.}$$

Area of cargo = 20 x 20 x 0.4 = 160 m^2.

Intact WP area (its AF) = (120 x 20)60 + (40 x 20)160 + (160 x 130) = 292,800 m^3.

New AF $= \frac{292,800}{3,360} =$ 87.143 m also = new AB.

New $\overline{BG}$ = New AB - AG = 87.143 - 85.833

New $\overline{BG}$ = 1.310 m.

Since AG < new AB, Tc will be by stern.

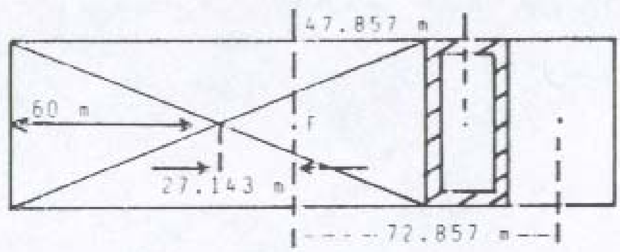
TM = W.BG = 26568 x 1.310 = 34,804.08 tm.

$Tc = \frac{TM}{MCTC}$ and $MCTC = \frac{W.GML}{100L}$ or $\frac{W.BML}{100L}$

BML = I*COF intact WP ÷ Volume of displ.

I*COF intact WP area = I*COF large rect + I*COF small rect + I*COF cargo area

Plan view



I*COF large rect = $[20(120^3) \div 12]$ + $(20)120(27.143^2)$...= 4,648,181.877 m^4.

I*COF small rect = $[20\ (40^3) \div 12]$ + $(20)40(72.857^2)$....= 4,353,180.625 m^4.

I*COF cargo = $[12.649(12.649^3) \div 12]$+ $160(42.857^2)$ ......= 296,008.850 m^4.

I*COF intact WP area = 9,297,371.352 m^4.

BML = 9,297,371.352 ÷ 25,920 = 358.695 m

$$MCTC = \frac{26568 \times 358.695}{100 \times 180} = 529.434 \text{ tm.}$$

$$Tc = \frac{TM}{MCTC} = \frac{34804.08}{529.434} = 65.7 \text{ cm} = 0.657 \text{ m}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{87.143(0.657)}{180} = 0.318 \text{ m.}$$

Tf = Tc - Ta = 0.657 - 0.318 = 0.339 m.

	Fwd	Aft
Final hydraft	7.714 m	7.714 m
Tf or Ta	-0.339	+0.318
Final drafts	7.375 m	8.032 m

Exercise 32

Bilging an intermediate compartment

1 A box-shaped vessel 180 m long & 24 m wide floats in SW at drafts of 9.5 m fwd & 8.5 m aft. An empty compartment 22 m long & 24 m wide, whose after bulkhead is 50 m from the after end of the vessel, gets bilged. Calculate the new drafts fwd and aft.

2 A box-shaped vessel 200 m long & 20 m wide is afloat in SW at drafts of 6 m fwd & 8 m aft. No: 2 LH, 24 m long & 20 m wide, has ρ = 70%. Its fwd bulkhead is 30 m from the fwd end of the vessel. Find the new drafts fwd & aft if this LH gets bilged.

3 A box-shaped OBO ship 160 m long and 18 m wide is in SW drawing 6.4 m fwd and 7.2 m aft. No: 2 hold, on the centre line of the ship, is 25 m long and 12 m wide. Its forward bulkhead is 40 m from the forward end of the ship. Find the new drafts if this hold, having ρ = 80%, gets bilged.

4 If the ship in question 3 had a DB tank 25 m long, 18 m wide & 1.6 m high, below No 2 hold, calculate the new drafts if the bilging occurred only in the hold and not in the DB tank. Note: Hold is only 12 m broad.

5 If in question 4, the DB tank also got bilged, along with the hold, find the new drafts fwd and aft.

-oOo-

CHAPTER 35

BILGING OF A

SIDE COMPARTMENT

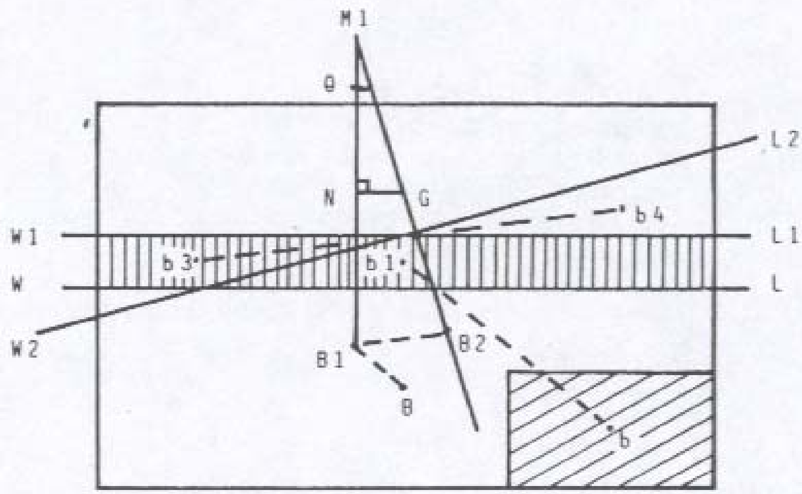
Having studied the effects of bilging an amidships compartment (chapter 32), an end compartment (chapter 33) and an intermediate compartment (chapter 34), calculations involving bilging of a side compartment is just one more step.

In addition to sinkage, change of KB, possible change of BM and possible change of trim, bilging of a side compartment causes list.

Before bilging, the COB and COG of the ship were in a vertical line. Because of bilging a side compartment, the COB of the ship shifts away from the bilged compartment and towards the volume of buoyancy regained. The COB is now transversely separated from the COG by the distance $\overline{BG}$. This $\overline{BG}$ divided by the new GM fluid gives the tan of the angle of list, as illustrated in the following figure wherein:

WL is the waterline before bilging.
B is the COB before bilging.
G is the COG of the ship - its position is unaffected by bilging.
Diagonally shaded area is the volume of lost buoyancy and whose geometric centre is indicated by 'b'.
Vertically shaded area is the volume of buoyancy regained by parallel sinkage

and whose geometric centre is indicated by 'b1' in the figure.
W_1L_1 is the new waterline after bilging and parallel sinkage.



K E E L

B_1 is the COB after bilging and parallel sinkage. Note: BB_1 is parallel to bb_1.
GN is the transverse separation between B_1 and G after bilging and parallel sinkage - the moment so formed causes the ship to heel over to the side on which the bilging occurred.
b_3 & b_4 are the geometric centres of the emerged and immersed wedges.
B_2 is the final position of COB.
Note: B_1-B_2 is parallel to b_3-b_4 and B_2 is vertically below G.
W_2L_2 is the final waterline.
M_1 is the new metacentre after bilging.
NM_1 is the new metacentric height.
θ is the angle of list due to bilging.

From the figure, it is apparent that: $\tan\theta = NG \div NM_1$. NG is generally known as $\overline{BG}$ and NM_1 is the new initial GM. The formula then becomes $\tan\theta = \overline{BG} \div$ New GM.

Calculation of list due to bilging a side compartment can be illustrated by the worked examples that follow:

Example 1

A vessel 200 m long & 20 m wide is box-shaped and afloat in SW at an even keel draft of 8 m. A DB tank on the starboard side is rectangular, 12 m long, 10 m wide, 1.2 m deep & empty. Calculate the list if this tank is now bilged, given that KG = 7.5 m and FSM = 820 tm.

$V = 200 \times 20 \times 8 = 32000\ m^3$) Unchanged
$W = 32000 \times 1.025 = 32800$ t) by bilging

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{12 \times 10 \times 1.2}{200 \times 20} = \frac{144}{4000} = 0.036 \text{ metre.}$$

New hydraft = 8.000 + 0.036 = 8.036 m.

To find new KB, moments about keel:

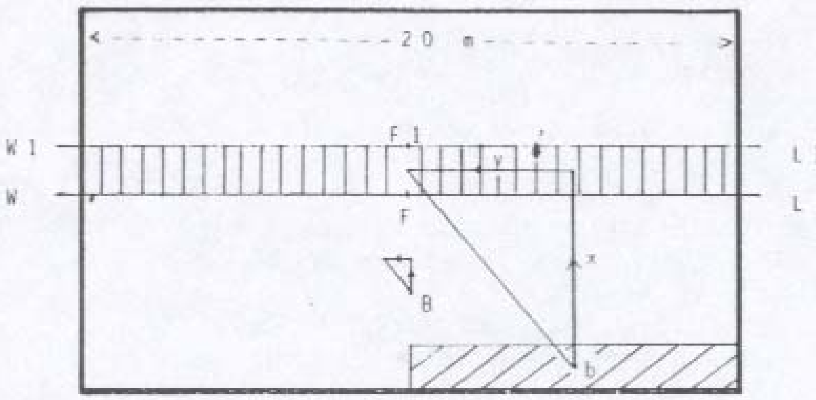
$$32000(\text{new KB}) = 32000(4) - 144(0.6) + 144(8.018)$$

New KB = 4.033 metres.

Alternative method -see figure next page

$$BB_1\uparrow = \frac{xv}{V} = \frac{7.418(144)}{32000} = 0.033 \text{ metre.}$$

New KB = Old KB + $BB_1\uparrow$ = 4.033 metres.



BMT = I*COF intact water-plane ÷ volume

$$= \frac{LB^3}{12V} = \frac{200\ (20^3)}{12(32000)} = 4.167 \text{ metres.}$$

KMT = New KB + BMT = 4.033 + 4.167 = 8.2

GM = KM − KG = 8.2 − 7.5 = 0.700 metres

FSC = 820 ÷ 32800 .... = 0.025 metre.

GM fluid or GMF.......... = 0.675 metres

$$\overline{BB_1} = \frac{yv}{V} = \frac{5(144)}{32000} = 0.0225 \text{ metre.}$$

Note: $\overline{BB_1}$ is the same as $\overline{BG}$.

Tan θ = $\overline{BG}$ ÷ GMF = 0.0225 ÷ 0.675 = 0.0333

θ = 1.91° or 1° 55' to starboard.

Example 2

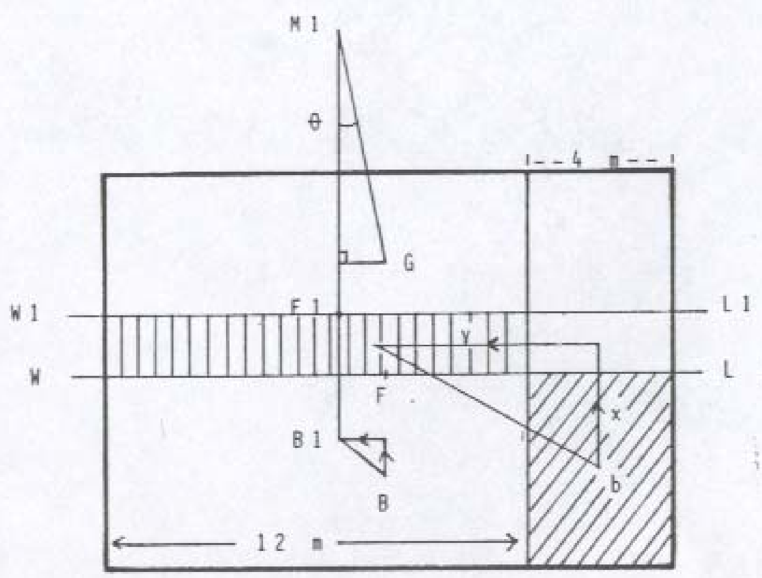
A box-shaped tanker 180 m long and 16 m wide is afloat in SW at an even keel draft of 7.5 m. The wing tanks are each 4 m broad and the centre tanks, 8 m. The KG is 5.5 m and FSM 1200 tm. Calculate the list if No:3 starboard tank, which is 15 m long and empty, is now bilged.

$V = 180 \times 16 \times 7.5 = 21600 \text{ m}^3$) Unchanged
$W = 21600 \times 1.025 = 22140$ t) by bilging

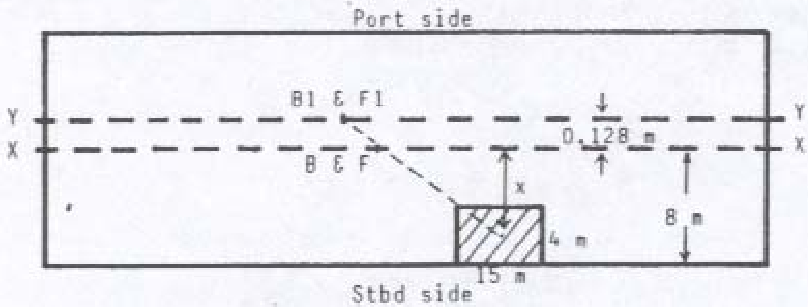
$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{15 \times 4 \times 7.5}{2880 - 60} = \frac{450}{2820} = 0.160 \text{ metre.}$$

New hydraft = 7.5 + 0.160 = 7.660 metres.



Plan view at waterline



After bilging & parallel sinkage, the area of the water-plane is constant at all drafts. So F1 and B1 will be in the same vertical line and:

New KB = new hydraft ÷ 2 = 3.830 metres.

To find $\overline{FF1}$, the transverse separation between F and F1, moments of area about the starboard side:

Total area (its dist) − area lost (its distance) = balance area (its distance).

2880 x 8 − 60 x 2 = 2820(its distance)

Dist of F1 from starboard side = 8.128 m

$$\overline{FF1} = 0.128 \text{ metres.}$$

Alternative method

$$\overline{FF1} = \frac{ax}{A} = \frac{60(6)}{2820} = 0.128 \text{ m.}$$

In this case, $\overline{FF1} = \overline{BB1}$.

I*XX whole water-plane

$$= \frac{180(16^3)}{12} = 61440 \text{ m}^4.$$

I*XX lost area

$$= \frac{15(4^3)}{12} + 60(6^2) = 2240 \text{ m}^4.$$

I*XX intact water-plane..... = 59200 m^4.

I*YY intact water-plane

$= \text{I*XX intact water-plane area} - Ay^2$

$= 59200 - 2820(0.128^2) = 59153.797 \text{ m}^4$

Note: F is the centroid of intact area. Hence the minus sign in the formula.

BMT = I*YY intact water-plane ÷ volume

= 59153.797 ÷ 21600 = 2.739 metres.

KMT = KB + BMT = 3.830 + 2.739 = 6.569 m

GM = KM - KG = 6.569 - 5.5 = 1.069 m

FSC = FSM ÷ W = 1200 ÷ 22140 = 0.054 m

GM fluid or GMF.............. = 1.015 m

$$\tan\theta = \frac{\overline{BB1}}{GMF} = \frac{0.128}{1.015} = 0.12611$$

$\theta = 7.188°$ or 7° 11' to starboard.

Example 3

A box-shaped vessel, 150 m long and 17 m wide, is afloat in FW at an even keel draft of 8 m. A rectangular compartment on the starboard side is 16 m long and 8.5 m wide. If KG = 6.0 m and FSM = 900 tm, and permeability is 60 %, find the list if this compartment gets bilged.

$V = 150 \times 17 \times 8 = 20400\ m^3$) Unchanged
$W = 20400 \times 1.000 = 20400\ t$) by bilging

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

$$S = \frac{16 \times 8.5 \times 8 \times 60/100}{150(17) - 16(8.5)60/100} = \frac{652.8}{2550-81.6}$$

$$S = \frac{652.8}{2468.4} = 0.265\ m$$

New hydraft = 8 + 0.265 = 8.265 metres.

Length of cargo = lc =

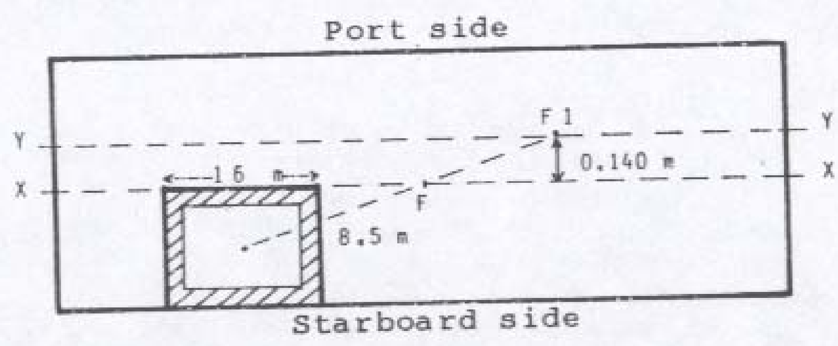
$$l\sqrt{\frac{100-p}{100}} = 16\sqrt{0.4} = 10.119 \text{ metres.}$$

Breadth of cargo = bc =

$$b\sqrt{\frac{100-p}{100}} = 8.5\sqrt{0.4} = 5.379 \text{ metres.}$$

Area of cargo = $16 \times 8.5 \times 0.4 = 54.4\ m^2$

Plan view at waterline



After bilging & parallel sinkage, the area of the water-plane is constant at all drafts. So F1 & B1 will be in the same vertical line and the new KB will be half the new draft. New KB = 4.132 m.

To find $\overline{FF1}$, the transverse separation between F & F1, moments about stbd side:

Total area (its dist) - area lost (its distance) + cargo area (its distance) = balance area (its distance).

2550 (8.5) - 136 (4.25) + 54.4 (4.25) = 2468.4(its distance from starboard side)

Dist of F1 from stbd side = 8.640 metres

$$\overline{FF1} = 8.640 - 8.500 = 0.140 \text{ metre.}$$

Alternative method

$$\overline{FF1} = \frac{ax}{A} = \frac{81.6(4.25)}{2468.4} = 0.140 \text{ metre.}$$

In this case $\overline{FF1} = \overline{BB1}$.

I*XX whole waterplane

$$= \frac{150(17^3)}{12} = 61412.500 \text{ m}^4.$$

I*XX compartment area

$$= \frac{16(8.5^3)}{12} + 136(4.25^2) = -3275.333 \text{ m}^4.$$

I*XX cargo area

$$= \frac{10.119(5.379^3)}{12} + 54.4(4.25^2)$$

$$= +1113.838 \text{ m}^4.$$

I*XX intact water-plane = 59251.005 m^4.

I*YY intact water-plane

$$= \text{I*XX intact water-plane} - Ay^2.$$

$$= 59251.005 - 2468.40\ (0.140^2)$$

$$= 59202.624\ m^4.$$

$$\text{BMT} = \text{I*YY intact water-plane} \div \text{volume}$$

$$= 59202.624 \div 20400 = 2.902 \text{ metres.}$$

New KM = new KB + new BM = 7.034 metres.

GM = KM - KG = 7.034 - 6.000 = 1.034 m.

FSC = FSM ÷ W = 900 ÷ 20400 = 0.044 m.

GM fluid or GMF .... = 0.990 m.

$$\tan\theta = \frac{\overline{BB1}}{GMF} = 0.141414$$

$\theta = 8.049°$ or 8° 03' to starboard.

Exercise 33
Bilging a side compartment

1 A box-shaped vessel 180 m long & 20 m wide is afloat in SW at an even keel draft of 7 m. A rectangular DB tank on the port side is 16 m long, 10 m wide and 1 m high is empty. Calculate the list if this DB tank is bilged if the KG = 7.5 m and FSM = 1000 tm.

2 A box-shaped tanker 200 m long & 24 m wide is afloat in FW at an even keel draft of 12 m. The wing tanks are 6 m broad and the centre tanks, 12 m. The KG is 8.5 m and the FSM 1800 tm. Find

the list if number 4 starboard wing tank, 18 m long & empty, gets bilged.

3 A box-shaped vessel 175 m long & 18 m wide is afloat in SW at an even keel draft of 10 m. A rectangular compartment 15 m long extends 6 m in breadth from the port shell plating. This compartment runs all the way from the keel up to the upper deck and has p = 40 %. KG 6.8 m & FSM 800 tm. Find the list if this compartment gets bilged.

4 A box-shaped vessel 150 m long & 16 m wide floats in SW at an even keel draft of 9 m. It has a longitudinal water-tight bulkhead on its centre line and DB tanks 1.2 m high. KG is 6.0 m and FSM = 900 tm. A hold 12 m long, on the port side, having p = 30 %, gets bilged. Find the list.

5 If in question 4, the empty port DB tank, directly below the hold, also gets bilged, find the list.

6 A box-shaped vessel 120 x 14 m is in SW at an even keel draft of 8 m. KG 5.8 m, FSM 560 tm. A rectangular DB tank on the stbd side, 15 x 7 x 1 m, half full of HFO RD 0.95, is bilged. Find the list. **Hint:** After bilging, the HFO is not in the ship anymore. Calculate the GG1 to port, the new W, the new KG and new FSM, assuming that the HFO is discharged. Then bilge the tank, obtain BB1 to port, compute the final $\overline{BG}$ and thence the list. As usual on ships, assume KG of this tank = 0.5 m, regardless of sounding.

CHAPTER 36

BILGING - PRACTICAL

SHIPBOARD CALCULATIONS

After studying chapters 32, 33, 34 & 35, the student would have a very clear idea of the effects on stability of bilging a compartment. In those chapters, the ship was considered to be box-shaped so that the concept of the principles involved could be absorbed without the diversion that would have resulted from having too many variable parameters. It would not be proper to leave the student at that: without orienting his conceptual knowledge towards practical use on board ships, wherein the details given in the hydrostatic table would have to be modified, by the officer concerned, before he can use them for calculations involving bilging.

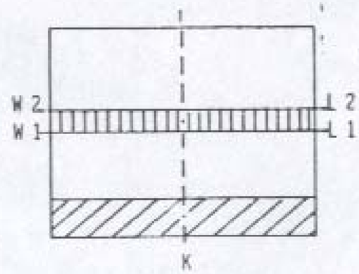
In this chapter, use has been made of Appendix I, of this book, wherein suitable extracts of the hydrostatic particulars of an imaginary general cargo ship m.v.VIJAY have been given. The calculations have been divided into two parts - part A: bilging of a DB tank and part B: bilging of a cargo hold.

PART A - Bilging of a DB tank

Example 1

M.v.VIJAY is afloat in SW at an even

keel draft of 4.8 m. An empty DB tank 21.5 m long, 20 m wide and 1 m deep, whose AG is 60 m, gets bilged. Referring to appendix I of this book, calculate the revised hydrostatic particulars for the bilged condition.



Vol of lost buoyancy

= 21.5 x 20 x 1

= 430 cubic metres.

Before bilging:

Draft	W in SW	u/w volume	vol of disp
4.8 m	9451 t	9220.488 m^3	9220.488 m^3
Due to bilging		+430	
After bilging		9650.488 m^3	9220.488 m^3

Entering hydrostatic table wih new u/w volume of 9650.488 m^3 (i.e. W = 9891.8 t) new draft = 5.000 m.

After bilging, though the draft is 5.000 m, volume of displacement = 9220.488 m^3, and W = 9451 tonnes.

In the following table, (1) and (2) indicate the particulars for the intact hull in SW, as taken from the hydrostatic table, while (3) indicates the revised particulars for the bilged condition.

	Draft	W	TPC	MCTC	AB
(1)	4.8	9451	21.97	164.3	72.016
(2)	5.0	9891	22.06	165.7	72.014
(3)	5.0	9451	22.06	177.8	72.574

	AF	KB	KMT	KML
(1)	71.970	2.576	8.828	263.9
(2)	71.913	2.685	8.686	254.3
(3)	71.913	2.781	9.061	266.1

Calculations in support of (3) above are as follows:

Draft & W: The method how the values in (3) 'have been arrived at has already been explained.

TPC & AF: These depend on the area and shape of the water-plane at the draft at which the ship is floating. In the bilged condition, the draft is 5 metres, corresponding to the waterline W2 L2 in the foregoing figure.

New KB: Taking moments about the keel,

New volume (new KB) =
Old volume (its KB) - volume lost (its KB) + volume regained (its KB)

9220.488 (new KB) =
9220.488 (2.576) - 430 (0.5) + 430 (4.9)

New KB = 2.781 metres.

Note: The KB of the volume of buoyancy regained has been taken to be the mean of the two drafts 4.8 and 5.0 metres.

OR

$$BB_1\uparrow = \frac{dv}{V} = \frac{(4.9 - 0.5)\ 430}{9220.488} = 0.205 \text{ m.}$$

New KB = Old KB + $BB_1\uparrow$ = 2.576 + 0.205

New KB = 2.781 m.

KMT & KML: From hydrostatic table, for 5 m draft, intact hull:

KMT	8.686 m	KML	254.3 m
KB	2.685 m	KB	2.685
BMT	6.001 m	BML	251.615

I*CL 57908.186 m^4 I*COF 2428023.380 m^4.

Note: BM = I ÷ V or I = BM(V). In the intact condition, at 5 m draft, volume of displacement = W ÷ 1.025 = 9649.756 m^3. The value of I is obtained by multiplying BM by V.

The above values of the moment of inertia, calculated for 5 m draft, with hull intact, hold good in the bilged condition also, because they depend only on the water-plane area - the waterline corresponding to W2 L2 in the foregoing figure.

In the bilged condition, the volume of displacement = 9220.488 m^3.

New BMT = 57908.186 ÷ 9220.488 = 6.280 m

New KMT = new KB + new BMT = 2.781+6.280

New KMT = 9.061 m.

New BML =2428023.380÷9220.488= 263.329 m

New KML = new KB+new BML = 2.781+263.329

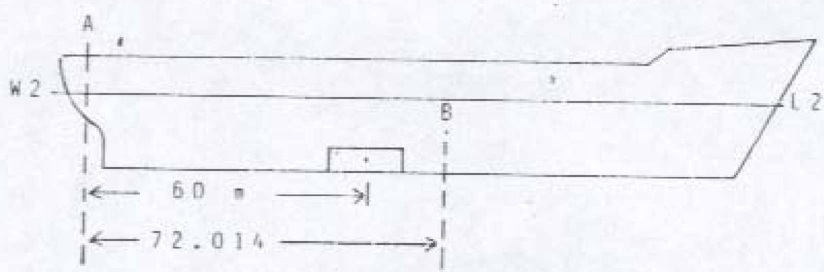
New KML = 266.110 m.

MCTC:

$$\text{New MCTC} = \frac{W\ (\text{new BML})}{100L} = \frac{9451\ (263.329)}{100(140)}$$

New MCTC = 177.766 tm.

New AB:



Moments of volume about A,

New volume (new AB) = u/w volume at 5 m draft (its AB) - volume lost (its AB)

9220.488 (new AB) =
9650.488 (72.014) - 430 (60)

New AB = 72.574 m.

Example 2

Find the drafts, fwd & aft, in example 1.

Since the vessel was on an even keel at 4.8 m draft, AG = AB = 72.016 m before bilging. After bilging, AB = 72.574 m.

$\overline{BG}$ = AB - AG = 72.574 - 72.016 = 0.558 m

Tc will be by the stern because AG < AB.

$$Tc = \frac{W.BG}{MCTC} = \frac{9451\ (0.558)}{177.8} = 29.7\ cm$$

$$Tc = 0.297\ \text{metre.}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{71.913(0.297)}{140} = 0.153\ m.$$

$$Tf = Tc - Ta = 0.297 - 0.153 = 0.144\ m.$$

	Fwd	Aft
Final hydraft	5.000 m	5.000 m
Ta or Tf	-0.144 m	+0.153 m
Final drafts	4.856 m	5.153 m.

Example 3

If at the end of example 1, KG = 7.6 m, FSM = 1000 tm, and a heavy lift of 50 t is shifted 10 m to starboard, find the resultant list.

GM = KMT - KG = 9.061 - 7.600 = 1.461 m
FSC = FSM ÷ W = 1000 ÷ 9451 = 0.106 m
GM fluid .... = 1.355 m

$$\tan\theta = \frac{dw}{W.GM} = \frac{10 \times 50}{9451(1.355)} = 0.03904$$

$\theta = 2.236°$ or $2° 14'$ to starboard.

Example 4

M.v.VIJAY is afloat in FW at drafts of 5.6 m fwd and 6.6 m aft. A DB tank 22 m long, 15 m wide and 1.2 m deep has AG = 100 m. Find the hydrostatic particulars, referring to appendix I of this book, if this empty tank now gets bilged.

Fwd 5.6 m, aft 6.6 m

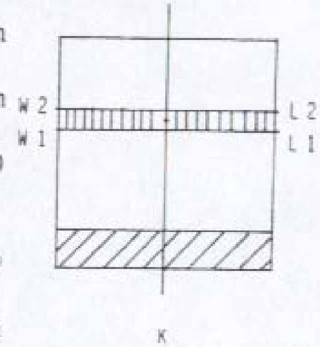
Trim 1.0 m by the stern

Mean 6.1 m, AF 71.401 m

Corr = $\frac{AF(trim)}{L}$ = 0.510

Hydraft = 6.600 - 0.510

Initial hydraft 6.110 m



(1) and (2) below have been derived from the hydrostatic table and are for the intact hull condition:

		Draft	W	TPC	MCTC
(1)	SW	6.110	12371.2	22.50	173.8
(2)	FW	6.110	12069.4	21.95	169.6

	AB	AF	KB	KMT	KML
(1)	71.948	71.393	3.262	8.204	214.1
(2)	71.948	71.393	3.262	8.204	214.1

$$\text{Trim} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{100(169.6)}{12069.4}$$

Initial $\overline{BG}$ = 1.405 metres.

Since the trim is by the stern, AG < AB.

AG of ship = AB - $\overline{BG}$ = 71.948 - 1.405

AG of the ship = 70.543 m.

	u/w volume	vol of disp
Before bilging	12069.4 m^3	12069.4 m^3
Due to bilging	+ 396.0 m^3	
After bilging	12465.4 m^3	12069.4 m^3

Entering the hydrostatic table with u/w volume of 12465.4 m in FW (i.e 12465.4 x 1.025 = 12777.0 t in SW at constant draft), draft = 6.289 metres.

Lines (3) and (4) below are derived from the hydrostatic table, assuming the hull to be intact. Line (5) is for the bilged condition, for which relevant explanations are given subsequently.

	Draft	W	TPC	MCTC
(3) SW	6.289	12777.0	22.584	175.4
(4) FW	6.289	12465.4	22.034	171.1
(5) FW	6.289	12069.4	22.034	183.5

	AB	AF	KB	KMT	KML
(3)	71.928	71.259	3.355	8.160	209.4
(4)	71.928	71.259	3.355	8.160	209.4
(5)	71.007	71.259	3.446	8.409	216.3

Explanations for line (5)

TPC and AF: These depend on the area & shape of the water-plane at the draft at which the ship is floating. In the bilged condition, the draft in FW is 6.289 m - W2 L2 in the foregoing figure.

New KB: Taking moments about the keel,

New volume (new KB) = old vol (its KB) - vol lost(its KB) + vol regained (its KB)

12069.4 (new KB) =
12069.4 (3.262) - 396 (0.6) + 396 (6.2)

New KB = 3.446 metres.

Note: KB of the volume of buoyancy

regained has been taken to be the mean of the two drafts 6.110 and 6.289 m.

Alternative method:

Intact volume at 6.289 m draft(its KB) - vol lost (its KB) = new vol (new KB)

12465.4(3.355)-396(0.6)= 12069.4(new KB)

New KB = 3.445 metres.

KMT and KML: From the hydrostatic table, for 6.289 m draft, considering the hull to be intact:

KMT	8.160 m	KML	209.400 m
KB	3.355 m	KB	3.355 m
BMT	4.805 m	BML	206.045 m

I*CL 59896.247 m^4, I*COF 2568433.343 m^4.

Note 1: BM = I ÷ V or I = BM(V). I*CL & I*COF have been obtained by multiplying BMT & BML by the volume of displacement at 6.289 m draft in FW with the hull considered to be intact.

Note 2: The above values of I hold good for the bilged condition also as they depend only on the shape and area of the intact water-plane, corresponding to W2 L2 in the foregoing figure.

In the bilged condition, volume of displacement = 12069.4 m^3.

New BMT = I*CL ÷ V = 4.963 metres.

KMT = new KB + new BMT = 3.446 + 4.963

KMT = 8.409 metres.

New BML = I*COF ÷ V = 212.805 metres.

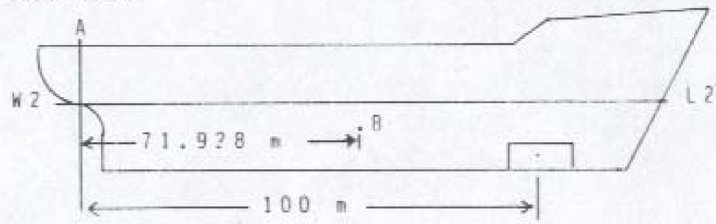
KML = new KB + new BML = 3.446 + 212.805

KML = 216.251 metres.

$$\text{New MCTC:MCTC} = \frac{W.BML}{100L} = \frac{12069.4(212.805)}{100(140)}$$

New MCTC = 183.459 tm.

New AB:



Intact vol at 6.289 m draft, in FW, (its AB) - vol lost(its AB) = new vol(its AB)

12465.4(71.928) - 396(100) = 12069.4(AB)

New AB = 71.007 metres.

Exercise 34
Bilging DB tank - actual ship

1 M.v.VIJAY is afloat in DW of RD 1.015 drawing 4.6 m fwd and 5.8 m aft. A DB tank 20 m long, 18 m wide and 1.2 m deep has AG = 90 m and is empty. If this tank now gets bilged, find the hydrostatic particulars referring to appendix I of this book.

2 In question 1, find the drafts fwd & aft after bilging.

3 If in question 2, KG = 8 m, FSM = 1200 tm, and a weight of 50 t is shifted 10 m to stbd, find the list.

4 M.v.VIJAY is in SW drawing 6.0 m fwd & 5.0 m aft. A DB tank of AG 20 m, 21 m long, 16 m wide and 1 m deep, has HFO of RD 0.95 in it to a sounding of 0.40 m. Calculate the hydrostatic particulars, referring to appendix I of this book, if this tank now gets bilged. **Note:** As usual on ships, assume that the KG of this tank = 5 m regardless of the sounding.

5 In question 4, find the new drafts fwd and aft after bilging.

6 If in question 5, KG = 7.5 m and FSM before bilging was 8500 tm, find the list when a weight of 80 t is shifted 10 m to port.

7 M.v.VIJAY is in SW at an even keel draft of 4.6 m. A DB tank 20 m long, 10 m wide and 1.2 m deep is full of SW ballast. The AG of the tank is 100 m. Find the new hydrostatic particulars if this tank gets bilged, referring to appendix I of this book.

8 In question 7, find the new drafts fwd and aft.

9 M.v.VIJAY, at 6 m even keel draft in SW, collides with a barge. The fore peak tank, full with 102 t of FW (AG

135 m, KG 4 m) gets bilged. Since the top of this tank was below the original water line, the ship's waterplane area is not adversely affected. Referring to Appendix I of this book, find i) the new hydrostatic particulars & ii) the new drafts fwd & aft.

PART B - Bilging of a cargo hold.

Stability calculations, after a cargo hold gets bilged, are complex & tedious. Such calculations are not always solvable on board owing to the limitations of the information available to the shipmaster. However, an idea of the possible calculations that can be made, to a fair amount of accuracy, is given here in the following worked examples.

Though an empty hold has been bilged, in the worked examples that follow, the student who has studied the earlier chapters on bilging, should be able to solve similar such problems even when the bilged compartment has cargo in it.

Example 5

M.v.Vijay is afloat in SW at drafts of 4.11 m fwd & 5.11 m aft. No 2 LH, AG 104 m, is 20 m long, 18 m wide & empty. No 2 DB tank, one metre deep, is situated directly below No 2 LH. While coming alongside, a tug collides with this ship causing No 2 LH to get bilged above the level of the tank top. Calculate the hydrostatic particulars after the accident, assuming that No 2 LH is rectangular.

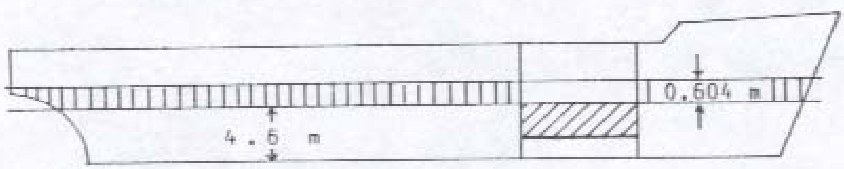
Fwd 4.11 m, aft 5.11 m, trim one metre by stern, Mean 4.61 m, AF = 72.011 m

$$\text{Correction} = \frac{AF\ (trim)}{L} = 0.51\ m.$$

Initial hydraft = 5.11 - 0.51 = 4.6 m.

W = 9013 t, vol of displ = 8793.171 m^3.
vol lost = 20(18)(4.6-1) = 1296 m^3.
Sum of the two volumes = 10089.171 m^3.

If the hull was intact and the volume of displacement was 10089.171 m^3, W would have been 10341.4 t and the draft, as per hydrostatic table, would have been 5.204 metres.



Actually, in No 2 LH, the space between the waterline at 4.6 m draft and 5.204 m draft, having a volume of 217.44 m^3 (i.e 20 x 18 x 0.604) is dead space - it is neither lost nor regained as volume of buoyancy. So the ship will sink in excess of 5.204 m draft in order to regain this 217.44 m^3. During this sinkage, only the intact water-plane area will contribute to volume of buoyancy regained. Since this sinkage in excess of 5.204 m draft will be very small, the water-plane area may be considered to be constant.

From hydrostatic table, considering the hull to be intact:

TPC at 5.204 m draft = 22.142.

$$TPC = \frac{1.025A}{100} \quad \text{or} \quad A = \frac{22.142(100)}{1.025}$$

WP area at 5.204 m draft = 2160.195 m^2.
Area lost in No 2 LH = 360 m^2.
Intact water-plane area = 1800.195 m^2.

Sinkage in excess of 5.204 m draft

$$= \frac{\text{vol yet to regain}}{\text{intact WP area}} = \frac{217.44}{1800.195} = 0.121 \text{ m}$$

Final hydraft = 5.204 + 0.121 = 5.325 m.

Line (1) below contains the hydrostatic particulars for the intact hull at 5.325 m draft in SW while line (2) is for the bilged condition in SW at the same draft.

	Draft	W	TPC	MCTC
(1)	5.325	10610.5	22.19	167.975
(2)	5.325	9013	18.50	146.403

	AB	AF	KB	KMT	KML
(1)	72.006	71.789	2.853	8.500	240.463
(2)	66.353	65.364	2.799	8.341	230.208

Calculations in support of line (2) above are given in the following pages.

W check:

U/w vol at 5.325 m draft = 10351.707 m^3
Dead space 20(18)(5.325-4.6) = 261 m^3
10090.707 m^3
vol of lost buoyancy = 1296 m^3
Vol of disp by subtraction 8794.707 m^3

Vol of disp as per original hydraft is 8793.171 m^3. The difference is insignificant, indicating that the calculation is correct.

$$W = 8793.171 \times 1.025 = 9013 \text{ tonnes.}$$

New TPC: TPC at 5.325 m draft, assuming that the hull is intact = 22.19.

$$TPC = \frac{1.025A}{100} \quad \text{or} \quad A = \frac{100(22.19)}{1.025}$$

At 5.325 m draft,
total water-plane area = 2164.878 m^2.
Area lost in No 2 LH = 360 m^2.
Intact water-plane area = 1804.878 m^2.

$$\text{New TPC} = \frac{1.025(1804.878)}{100} = 18.500 \text{ t}$$

New AF: Moments of area about A,

Intact WP area (its AF) = entire WP area (its AF) - area lost in No 2 LH (its AF)

1804.878 (its AF) =
2164.878 (71.789) - 360 (104)

New AF = 65.364 metres.

New AB: Moments of volume about A,

Intact volume (its AB) = entire vol at 5.325 m (its AB) - u/w vol No 2 (its AB)

8793.171 (New AB) =
10351.707 (72.006) - 1557 (104)

Note: U/w volume in No 2 LH =
$20(18)(5.325 - 1) = 1557\ m^3$.

New AB = 66.353 m.

New KB: Moments of volume about the keel,

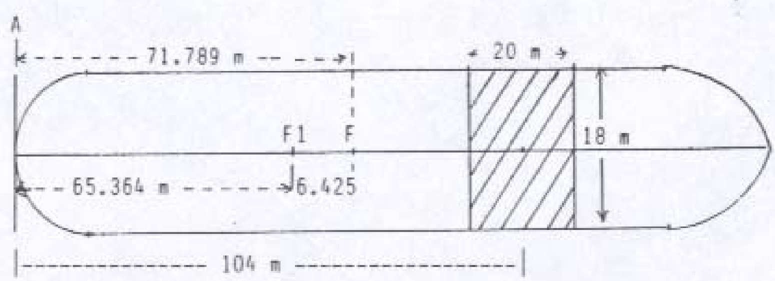
Intact vol(its KB) = entire vol at 5.325 m draft (its KB) - u/w vol No 2 (its KB)

8793.171 (its KB) =
10351.707 (2.853) - 1557 (3.163)

Note: KB of u/w vol No 2 = $\left(\frac{4.325}{2} + 1\right)$

New KB = 2.799 metres.

New KMT & KML:



From hydrostatic table, at 5.325 m draft in salt water, assuming hull to intact:

	Transverse	Longitudinal
KM	8.500 m	240.463 m
KB	2.853 m	2.853 m
BM	5.647 m	237.610 m

V 10351.707 m^3.

I*CL 58456.089 m^4, I*COF 2459669.1 m^4.

Note: BM = I ÷ V or I = BM (V). The I, so calculated, for the intact WP may be modified for the WP area in the bilged condition and divided by the actual volume of displacement to get the BM for the bilged condition.

I*CL intact WP =
I*CL entire WP - I*CL area lost in No 2

$$= 58456.089 - \frac{20(18^3)}{12} = 48736.089 \text{ m}^4.$$

$$BMT = \frac{I}{V} = \frac{48736.089}{8793.171} = 5.542 \text{ metres}$$

KMT = new KB + new BMT = 2.799 + 5.542

New KMT = 8.341 metres.

$$I{*}COF1 \text{ entire WP} = I{*}COF + Ah^2$$

$$= 2459669.1 + 2164.878\ (6.425^2)$$

$$= 2549036.616 \text{ m}^4.$$

$$I{*}COF1No\ 2 \text{ area} = \frac{18(20^3)}{12} + 360(38.636^2)$$

$$= 549386.579 \text{ m}^4.$$

I*COF1 intact WP
= I*COF1 entire WP - I*COF1 lost area

I*COF1 intact WP = 1999650.038 m^4.

Double check of I*COF1 above:

I*COF intact WP
= I*COF entire WP - I*COF area lost

$$I*COF \text{ area lost} = \frac{18(20^3)}{12} + 360(32.211^2)$$

$$= 385517.468 \text{ m}^4.$$

$$I*COF \text{ intact WP} = 2459669.1 - 385517.468$$

$$= 2074151.633 \text{ m}^4.$$

$$I*COF1 \text{ intact WP} = I*COF - Ah^2$$

$$= 2074151.633 - 1804.878(6.425^2)$$

$$= 1999645.142 \text{ m}^4.$$

Resumption of calculation

$$BML = \frac{I*COF1}{V} = \frac{1999650.038}{8793.171} = 227.409 \text{ m}$$

$$KML = \text{new KB} + \text{new BML} = 2.799 + 227.409$$

New KML = 230.208 metres.

New MCTC:

$$\text{New MCTC} = \frac{W.BML}{100L} = \frac{9013\ (227.409)}{100(140)}$$

New MCTC = 146.403 tm.

Example 6

In example 5, find the drafts fwd & aft.

To find KG of ship:

Draft	W	MCTC	AB
4.600	9013	162.7	72.017

$$\text{Trim} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim (MCTC)}}{W}$$

$$\overline{BG} = \frac{100\ (162.7)}{9013} = 1.805 \text{ metres.}$$

Trim is by the stern, so AG < AB.

$$AG = AB - \overline{BG} = 72.017 - 1.805 = 70.212 \text{ m}$$

$$\text{Final } \overline{BG} = AG - AB = 70.212 - 66.353$$

$$\text{Final } BG = 3.859 \text{ metres.}$$

Since AG > AB, Tc will be by the head.

$$Tc = \frac{W.BG}{MCTC} = \frac{9013(3.859)}{146.403} = 237.6 \text{ cm} = 2.376 \text{ m}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{65.364(2.376)}{140} = 1.109 \text{ m.}$$

$$Tf = Tc - Ta = 2.376 - 1.109 = 1.267 \text{ m.}$$

	Fwd	Aft
Final hydraft	5.325 m	5.325 m
Tf or Ta	+1.267 m	-1.109 m
Final drafts	6.592 m	4.216 m

Example 7

If in example 6, 150 t of FW is

transferred from the fore peak tank to the after peak tank through a distance of 130 m, and 150 t from No 2 DBT to No 8 DBT, through a distance of 80 m, find the new drafts fwd & aft.

$$Tc = \frac{150(130)+150(80)}{146.403} = 215.2 \text{ cm} = 2.152 \text{ m}$$

$$Ta = \frac{AF\ (Tc)}{L} = \frac{65.364\ (2.152)}{140} = 1.005 \text{ m.}$$

$$Tf = Tc - Ta = 2.152 - 1.005 = 1.147 \text{ m.}$$

	Fwd	Aft
Initial drafts	6.952 m	4.216 m
Tf or Ta	- 1.147 m	+ 1.005 m
Final drafts	5.805 m	5.221 m

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CHAPTER 37

CALCULATION OF LIST BY GZ CURVE

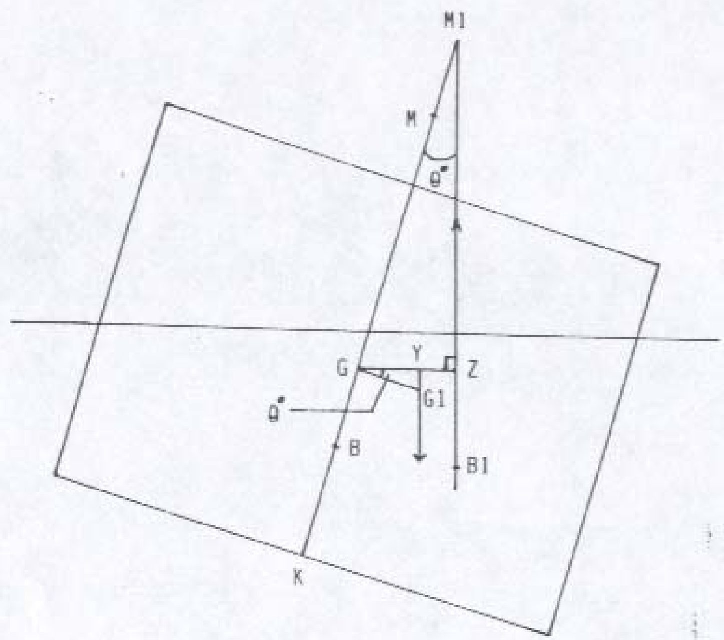
Calculation of list has hitherto been advocated by use of the formula Tan θ = GG1/GM. Use of this formula has been illustrated in chapter 13 (Ship Stability I). That method of calculation suffers from lack of accuracy because it assumes that the initial GM, and hence the transverse KM, remains constant despite changes in the angle of inclination. A more accurate method of computing the angle of list would be by use of the curve of statical stability. For examination purposes, it is suggested that wherever the list, calculated by the formula, exceeds five degrees, the GZ curve method should be used.

The attention of the student is invited to chapter 22 (Ship Stability II) wherein the curve of statical stability of a ship with a list has been illustrated. In such a case, the ship is in stable equilibrium - GZ to one side is considered positive and to the other side, negative.

A transverse shift of the COG of the ship ($\overline{GG_1}$) to one side causes a reduction of GZ when the ship inclines to that side and vice versa. This reduction of GZ, or upsetting lever, can be calculated by the formula:

Red of GZ or upsetting lever = $\overline{GG_1}.\text{Cos}\ \theta$

Origin of the formula:



In the foregoing figure, let us first consider the ship heeling over only due to external forces.

KG is the final fluid KG of the ship.

B is the COB when the ship is upright.

GM is the initial metacentric height.

B1 is the COB after the ship heels.

M1 is the new metacentre after heeling.

GZ is the righting lever caused by heel.

θ is the angle of heel considered.

If the COG of the ship is now shifted transversely from G to G_1, parallel to the keel, and the vertical through G_1 cuts GZ at Y: angle Y = 90°, angle YGG_1 = angle of heel = θ & GY = $\overline{GG_1}(\cos\theta)$. Since GY is the reduction of GZ due to transverse shift of COG, the formula may be stated as:

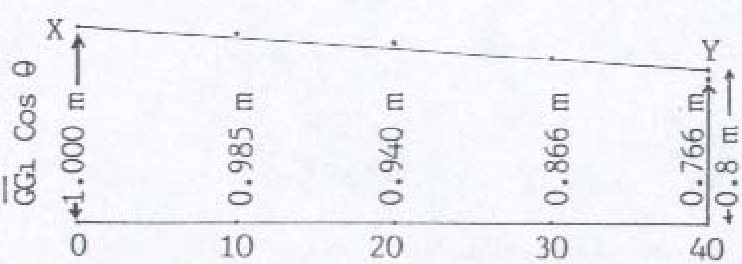
Red of GZ or upsetting lever = $\overline{GG_1}.\cos\theta$

This upsetting lever may be allowed for in either of two ways:

Method 1

The curve of statical stability is drawn, as usual, for the final fluid KG of the ship, as shown in chapters 23 and 24 (Ship Stability II). The $\overline{GG_1}$ is calculated by the formula $\overline{GG_1} = \overline{dw}/W$.

If $\overline{GG_1}(\cos\theta)$ is plotted for values of θ from 0° to 40°, it will be noticed that this curve very nearly coincides with a straight line drawn from $\overline{GG_1}$ at 0° heel to $0.8(\overline{GG_1})$ at 40° heel, as illustrated in the following figure wherein $\overline{GG_1}$ is assumed to be 1.000 m. Hence $\overline{GG_1}\cos\theta$ at 0° = 1.000, at 10° = 0.985, at 20° = 0.940, at 30° = 0.866 & at 40° = 0.766 m.



Hence the upsetting arm curve may be drawn as follows:

$\overline{GG_1}$ is laid off upwards from the 0° heel position on the x-axis, arriving at a point called X. $0.8(\overline{GG_1})$ is laid off upwards from the 40° heel position on the x-axis, arriving at Y. Points X and Y are joined by a straight line which represents the upsetting lever at any angle of heel upto about 30°. The angle of heel at which the righting arm curve (GZ curve) and the upsetting arm curve (line XY) intersect, is the list.

Method 2

The curve of statical stability is drawn only after the value of GZ, at each angle of heel, is reduced by $\overline{GG_1}(\text{Cos } \theta)$. The GZ at 0° heel would necessarily be negative. The angle of heel at which the modified GZ curve cuts the x-axis is the angle of list.

Example 1

M.v.VIJAY is in SW displacing 13000 t. KG = 7.788 m, FSM = 1372 tm. A tractor weighing 50 t is to be shifted 10 m to starboard. Calculate the resultant list.

FSC = 1372/13000 =	0.106	m
Solid KG .... =	7.788	m
Fluid KG .... =	7.894	m
KM (appendix I) =	8.139	m
Initial fluid GM =	0.245	m

Note: Though the normal practice is to subtract FSC from the solid GM in order to obtain the fluid GM, the above change in procedure has been adopted for convenience, in this case, because the fluid KG may be required, later on, in case the the list by formula exceeds 5°.

$\overline{GG_1} = \overline{dw}/W = 50(10)/13000 = 0.03846$ m.

$\text{Tan } \theta = \overline{GG_1}/GM = 0.03846/0.245 = 0.15699$

$\theta = 8.922°$ or 8° 55' to starboard.

Since the list exceeds 5°, it is preferrable to obtain a more accurate answer by the GZ curve.

From appendix II,

θ°	KN	-	KG Sin θ	=	GZ
0	0.000		7.894 Sin 0°		0.000 m
5	0.798		7.894 Sin 5°		0.110 m
10	1.595		7.894 Sin 10°		0.224 m

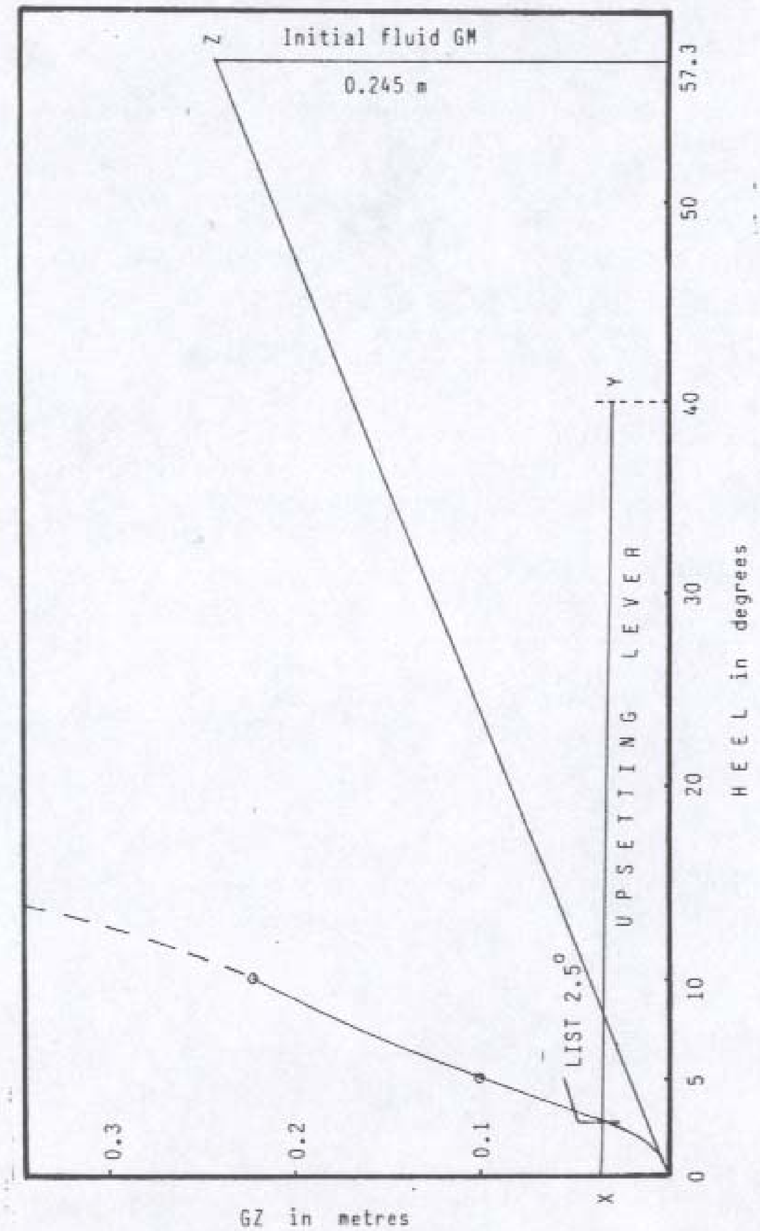
Note: It is not necessary to draw the entire curve of statical stability just to compute the value of list.

Method 1

Upsetting lever at 0° and at 40° heel = $\overline{GG_1}$ and 0.8 $\overline{GG_1}$ = 0.038 and 0.030 metre.

The graph on the next page shows both the righting arm and the upsetting arm curves on which the value of list is readily apparent.

In order to correctly get the shape of the curve in the vicinity of the origin, a perpendicular is erected at 57.3° heel and the initial fluid GM laid off upward

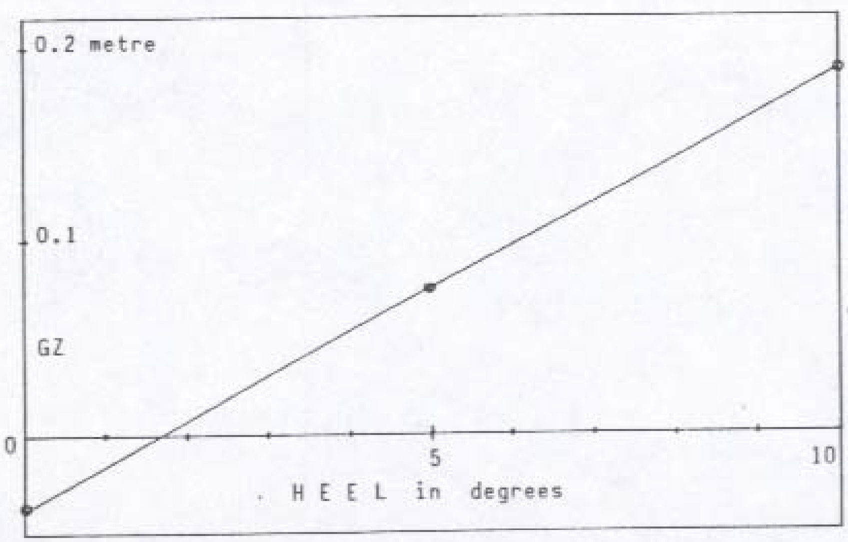


to arrive at point Z. Point Z and the origin are joined by a straight line &, while drawing the curve of statical stability, it is ensured that the curve coincides with this line for the first few degrees. It is this technique that makes method 1 a little more accurate than method 2.

Method 2

$\theta°$	Full GZ	$-$ $\overline{GG}1$ Cos θ	= Reduced GZ
0	0.000 m	0.038 Cos 0°	−0.038 m
5	0.110 m	0.038 Cos 5°	+0.072 m
10	0.224 m	0.038 Cos 10°	0.186 m

The graph below shows the values of reduced GZ plotted against the corresponding values of heel.



LIST 1.7° to starboard

The list, calculated by the formula, was 8.9° but, by the GZ curve, is only 2.5° by method 1 and 1.7° by method 2. In the case of this ship, the change of KM, due to change of angle of heel, is considerable even for small angles of heel. The results by use of the formula become less accurate if the fluid GM is small.

Note: The above curves are only for stbd heel because $\overline{GG1}$ is to starboard.

The student may, if he so desires, draw the entire curve for both, the starboard and the port sides, in order to understand the topic better. The correction to GZ, obtained by the formula $\overline{GG1}$ (Cos θ), would be additive to the port side because $\overline{GG1}$ is to stbd.

Example 2

M.v.VIJAY is in SW at a displacement of 13700 t. KG is 7.0 m and FSM 1400 tm. 300 t of cargo is loaded on the upper deck, KG 12 m, 6 m to port of the centre line of the ship. Calculate the list caused.

GG1↑ = dw/W = 5(300)/14000 = 0.107 m.

Final KG solid = 7.000 + 0.107 = 7.107 m
FSC = FSM/W = 1400/14000 ..... = 0.100 m
Final fluid KG .... = 7.207 m
KM from appendix I.. .... = 8.073 m
Initial fluid GM .... = 0.866 m

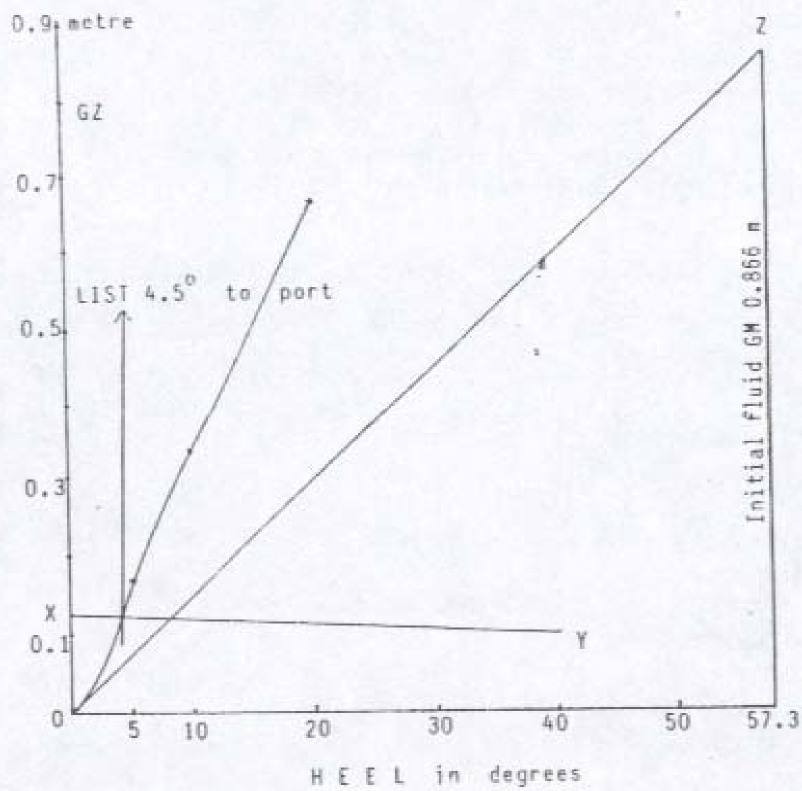
$\overline{GG1}$ = $\overline{dw}$/W = 6(300)/14000 = 0.12857 m.
Tan θ = $\overline{GG1}$/GM = 0.12857/0.866 = 0.14846
By formula, θ = 8.444° or 8° 27' to port

Since the list exceeds 5°, it is preferrable to obtain a more accurate answer by the GZ curve. (Use appendix II).

θ°	KN	-	KG Sin θ	=	GZ
0	0.000		7.207 Sin 0°		0.000 m
5	0.793		7.207 Sin 5°		0.165 m
10	1.581		7.207 Sin 10°		0.330 m
20	3.130		7.207 Sin 20°		0.665 m

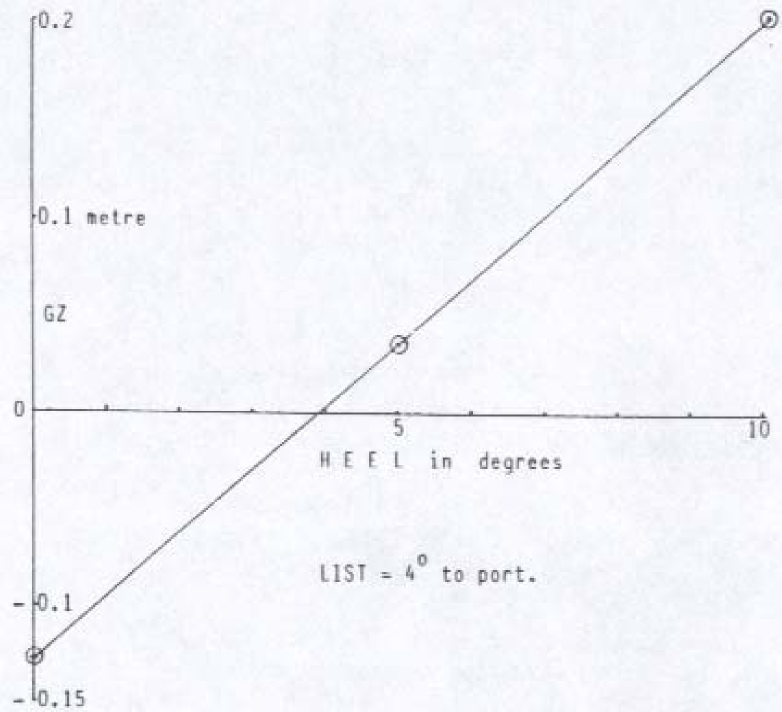
Method 1

Upsetting levers at 0° and at 40° heel = $\overline{GG_1}$ and $0.8(\overline{GG_1})$ = 0.129 and 0.103 metre



Method 2

θ°	Full GZ	− $\overline{GG1}$ Cos θ	= Reduced GZ
0	0.000 m	0.129 Cos 0°	−0.129 m
5	0.165 m	0.129 Cos 5°	+0.037 m
10	0.330 m	0.129 Cos 10°	0.203 m
20	0.665 m	0.129 Cos 20°	0.544 m



Exercise 35
List by GZ curve

1 M.v.VIJAY is in a SW dock, displacing 12575 t; KG 7.6 m; FSM 1372 tm. Calculate the list, to the nearest degree, if a 125 t locomotive is loaded on the upper deck (KG 16 m) 6 m to starboard of the centre line.

2 M.v.VIJAY has W = 8000 t, KG = 7.354 metres, FSM = 1082 tm. The following transverse shiftings were done:

200 t 4 m to starboard
100 t 2 m to port
100 t 4 m to port
200 t 15 m to starboard.

Calculate, to the nearest degree, the final list.

3 M.v.VIJAY has W = 10000 t, KG = 6.814 metres and FSM = 1420 tm. If 200 t of cargo is shifted 10 m down & 10 m to port, find the list to the nearest degree.

4 M.v.VIJAY has KG = 6.3 m, FSM = 2148 tm, W = 12000 t. A 200 t transformer is to be loaded by the ship's jumbo derrick whose head is 24 m above the keel. Find, to the nearest degree:
(i) The list when the derrick picks up the transformer, from the wharf, with an outreach of 15 metres to starboard.
(ii) The list after the transformer has been placed on the upper deck (KG 10 m) 7 m to stbd of the centre line.

5 M.v.VIJAY, having W = 14212 t, KG = 7.4 m, FSM = 2026 tm, is listed 4° to port. It is proposed to discharge a 112 t locomotive from the upper deck (KG = 12 m) 8 m to starboard of the centre line. Find, to the nearest degree, the final list.

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CHAPTER 38

ANGLE OF LOLL

BY GZ CURVE

In Chapter 11 (Ship Stability I), 'Angle of loll', and the behaviour of a ship in that condition, has been described. In Chaper 21 (Ship Stability II), a formula to calculate the approximate value of the angle of loll has been derived. The remedial action in such a condition has also been discussed. In Chapter 22 (Ship Stability II), the curve of statical stability of an unstable vessel has been illustrated. With a view to avoid needless repetition, this chapter is confined only to obtaining the angle of loll by constructing a part of the GZ curve and comparing the result with that obtained by the formula.

Since the formula is based on the 'Wall-sided' formula (see Chapter 21 in Ship Stability II), it is accurate only until the deck edge immerses.

Example 1

M.v.VIKRAM is in SW. W = 16635 t, KG = 8.69 m and FSM = 998 tm. The stability data book indicates that KM = 8.25 m, KB = 4.252 m and KN values as follows:

Heel	0	5	10	15	20
KN (m)	0	0.756	1.501	2.227	2.974

Heel	25	30	40	45	60
KN (m)	3.699	4.393	5.647	6.134	7.165

Find, to the nearest degree, the angle of loll by: (i) formula & (ii) GZ curve.

KG solid ...... = 8.690 m
FSC = 998/16635 = 0.060 m
KG fluid ...... = 8.750 m
KM .... = 8.250 m
GM fluid ...... = 0.500 m

KM = 8.250 m
KB = 4.252 m
BM = 3.998 m

$$\text{Tan } \theta = \sqrt{\frac{-2GM}{BM}} = 0.50013$$

θ by formula = 26.57° i.e., 27° ans (i).

θ	KN	KGSin θ	GZ
0	0	0	0
5	0.756	0.763	-0.007
10	1.501	1.519	-0.018
15	2.227	2.265	-0.038
20	2.974	2.993	-0.019
25	3.699	3.698	+0.001
30	4.393	4.375	+0.018
40	5.647	5.624	+0.023
45	6.134	6.187	-0.053
60	7.165	7.578	-0.413 m

From the curve on the following page, the angle of loll = 24.75°.

Answer (ii) = 25°.

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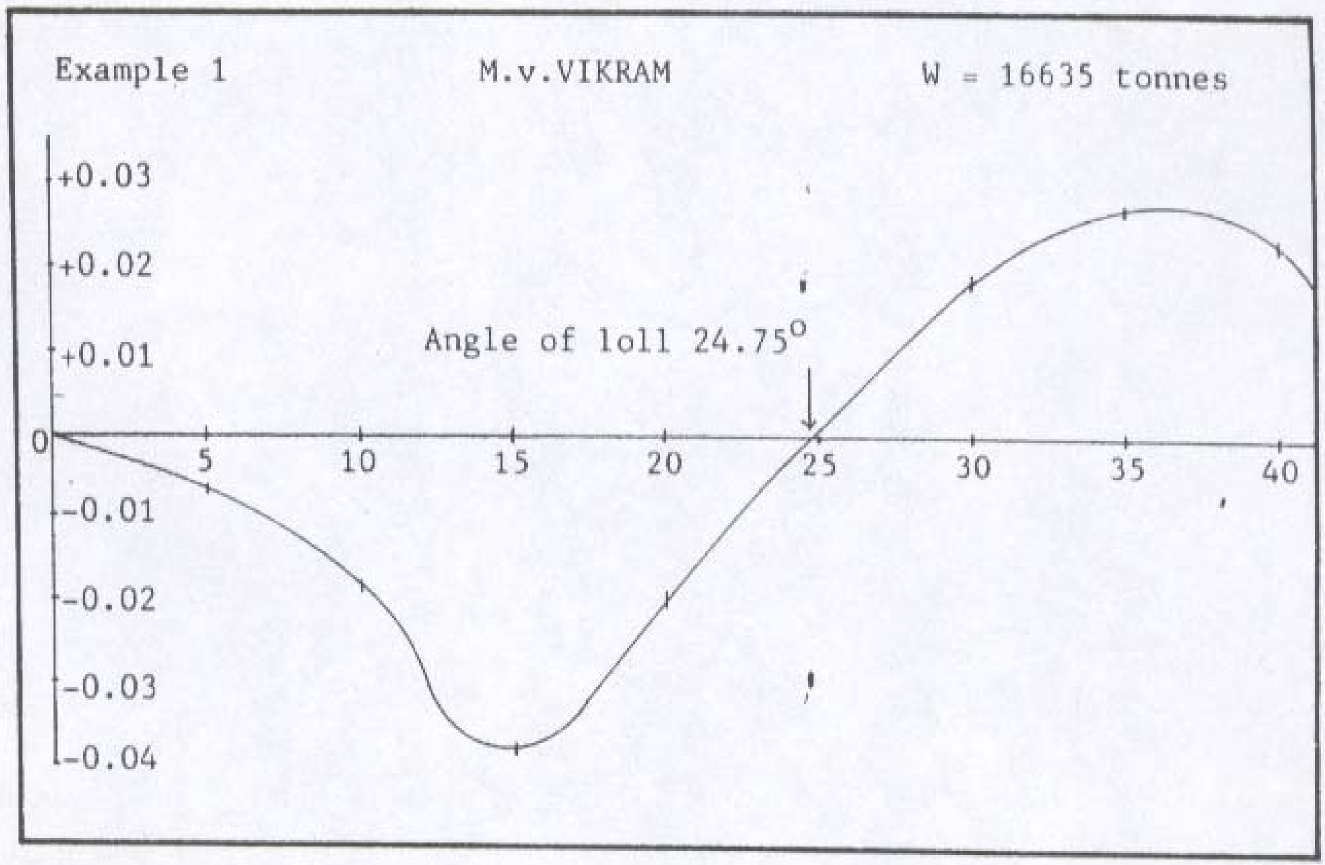
Example 1
M.v.VIKRAM
W = 16635 tonnes
+0.03
+0.02
+0.01
0
-0.01
-0.02
-0.03
-0.04
5
10
15
20
25
30
35
40
Angle of loll 24.75°

Exercise 36
Angle of loll by GZ curve

1 M.v.VINAYAK, W 12000 t, KG 8.660 m, FSM 4572 tm, KM 8.441 m, KB 3.20 m.

Heel	0	5	10	15°
KN	0	0.772	1.538	2.272 m

Heel	20	30	40	60°
KN	3.033	4.554	5.925	7.498 m

Find the angle of loll to the nearest whole degree by:
(i) the GZ curve and (ii) the formula.

2 M.v.VISHNU, W 9540 t, KG 9.200 m, FSM 1908 tm, KM 8.970 m, KB 2.623 m.

Heel	0	5	10	15°
KN	0	0.819	1.620	2.397 m

Heel	20	30	40	60°
KN	3.202	4.727	6.060	7.685 m

Find the angle of loll to the nearest whole degree by:
(i) the GZ curve and (ii) the formula.

3 M.v.VASUDEV, W 14300 t, KG 8.850 m, FSM 2145 tm, KM 8.258 m, KB 3.724 m.

Heel	0	5	10	15°
KN	0	0.755	1.504	2.227 m

Heel	20	30	40	60°
KN	2.974	4.459	5.799	7.330 m

Find the angle of loll to the nearest whole degree by:

(i) the GZ curve and (ii) the formula.

4 M.v.VASANTHY, W 17000 t, KG 8.550 m, FSM 2550 tm, KM 8.265 m, KB 4.331 m.

Heel	0	5	10	15°
KN	0	0.755	1.502	2.229 m

Heel	20	30	40	60°
KN	2.978	4.362	5.620	7.138 m

Find the angle of loll to the nearest whole degree by:
(i) the GZ curve and (ii) the formula.

5 M.v.VENUGOPAL, W 70000 t, KG 13.95 m, FSM 3500 tm, KM 13.254 m, KB 5.563 m. From the cross curves, for assumed KG of 10 m, the following were obtained:

Heel	0	10	20
GZ	0	0.600	1.380

Heel	30	45	60°
GZ	2.250	3.130	2.580 m.

Find the angle of loll to the nearest whole degree by:
(i) the GZ curve and (ii) the formula.

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CHAPTER 39

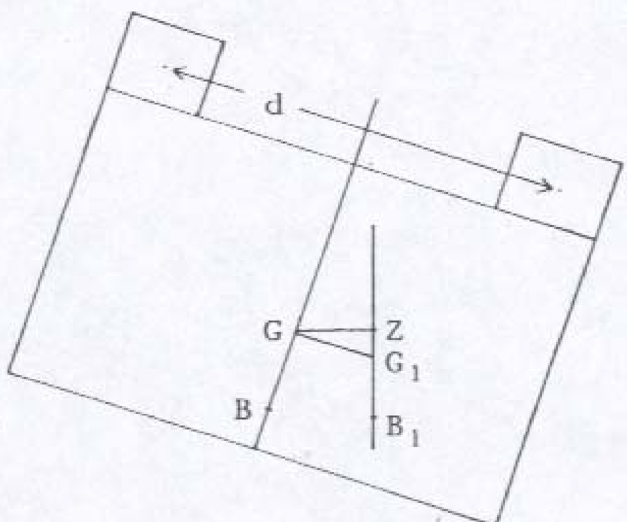
LIST WHEN

INITIAL GM IS ZERO

When the initial GM fluid is zero, and a weight is shifted transversely, the approximate list caused can be calculated by formula:

$$\text{Tan } \theta = \sqrt[3]{\frac{2\overline{GG_1}}{BM}}$$

The derivation of the formula is as follows:



In the above figure, B & G are the initial positions of the COB and the COG. G_1 is the position of the COG after the transverse shift of weight.

The ship will now incline transversely until the COB shifts to B_1, which is directly under G_1. If the horizontal line GZ is now inserted, it will be noticed that GZ represents the listing lever which is similar to the righting lever!

As per the 'Wall sided formula,'

$$GZ = \sin\theta\left(GM + \frac{BM \tan^2\theta}{2}\right)$$

But, as seen from the foregoing figure,

$$GZ = \overline{GG_1}\cos\theta$$

$$\text{So } \overline{GG_1}\cos\theta = \sin\theta\left(GM + \frac{BM \tan^2\theta}{2}\right)$$

Inserting GM = 0, and dividing both sides by Cos θ:

$$\overline{GG_1} = \frac{BM \tan^3\theta}{2} \quad \text{or} \quad \tan\theta = \sqrt[3]{\frac{2\overline{GG_1}}{BM}}$$

However, this formula is based on the 'Wall sided formula' and is, as such, subject to its limitations.

A more accurate result may be obtained by drawing the GZ curve for the fluid KG and displacement of the ship and applyirg the $\overline{GG_1}\cos\theta$ correction as done in chapter 37.

Example 1

M.v.VIJAY is in SW displacing 13,000 t. KG = 8.033 m, FSM = 1372 m. Find the list if a weight of 25 t is shifted 10 m to starboard. (Use appendices I and II).

FSC = FSM/W = 1372/13000 = 0.106 metre.
Solid KG .... = 8.033 metres
Fluid KG .... = 8.139 metres

From appendix I, KM = 8.139 m
Fluid KG = 8.139 m
Initial fluid GM = 0.000 m

Note: The normal practice is to subtract FSC from the solid GM in order to obtain fluid GM. The above procedure has been adopted, in this case, as fluid KG is needed to work this problem by the GZ curve.

BM = KM - KB = 8.139 - 3.406 = 4.733 m

$$\overline{GG_1} = \frac{dw}{W} = \frac{10(25)}{13,000} = 0.01923 \text{ metre}$$

$$\text{Tan } \theta = \sqrt[3]{\frac{2\overline{GG_1}}{BM}} = \sqrt[3]{\frac{2\ dw}{W\ BM}} = 0.20105$$

List = 11.37° by formula.

θ	KN	- KG Sin θ	= GZ
0°	0	8.139 Sin 0°	0.000 m
5°	0.798	8.139 Sin 5°	0.089 m
10°	1.595	8.139 Sin 10°	0.182 m

Upsetting lever at 0° heel = $\overline{GG_1}$(Cos 0°)
= 0.019 metre

Upsetting lever at 40° heel = $\overline{GG_1}$ (0.8)
= 0.015 metre

By constructing part of the GZ curve and inserting the upsetting lever, as shown in chapter 37, the list is found to be only 2°, as against 11.37° obtained by using the formula.

Since working through the GZ curve is the same as done in chapter 37, and since the formula shown here is of casual interest giving approximate results only, no exercise has been set on the portion covered in this chapter.

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CHAPTER 40

DYNAMICAL STABILITY

Dynamical stability, at any angle of heel, is the work done in heeling the ship to that angle. It is expressed in tonne-metre-radians. It is the product of the displacement of the ship and the area under the curve of statical stability upto the angle of heel for which it is desired to calculate the dynamical stability.

It may be possible to calculate the area under the curve directly from the GZ values, without actually drawing the GZ curve, provided sufficient values of GZ are available, at constant intervals of heel, for the application of Simpson's Rules. However, if the given intervals of heel are unsuitable - too few or irregular - the curve of statical stability would have to be drawn and the values of GZ read off at the desired intervals of heel.

Example 1

M.v.VIJAY is in SW at a displacement of 15400 t, KM = 8.034 m, KG = 6.1 m & FSM = 3050 tm. Calculate the dynamical stability at 40° heel. (Use appendix II).

KG fluid = 6.100 + 0.198 = 6.298 metres.

θ	KN	KGSin θ	GZ
0	0	0	0
5	0.796	0.549	0.247
10	1.575	1.094	0.481
20	3.112	2.154	0.958
30	4.641	3.149	1.492
45	6.546	4.453	2.093
60	7.615	5.454	2.161
75	7.923	6.083	1.840 m

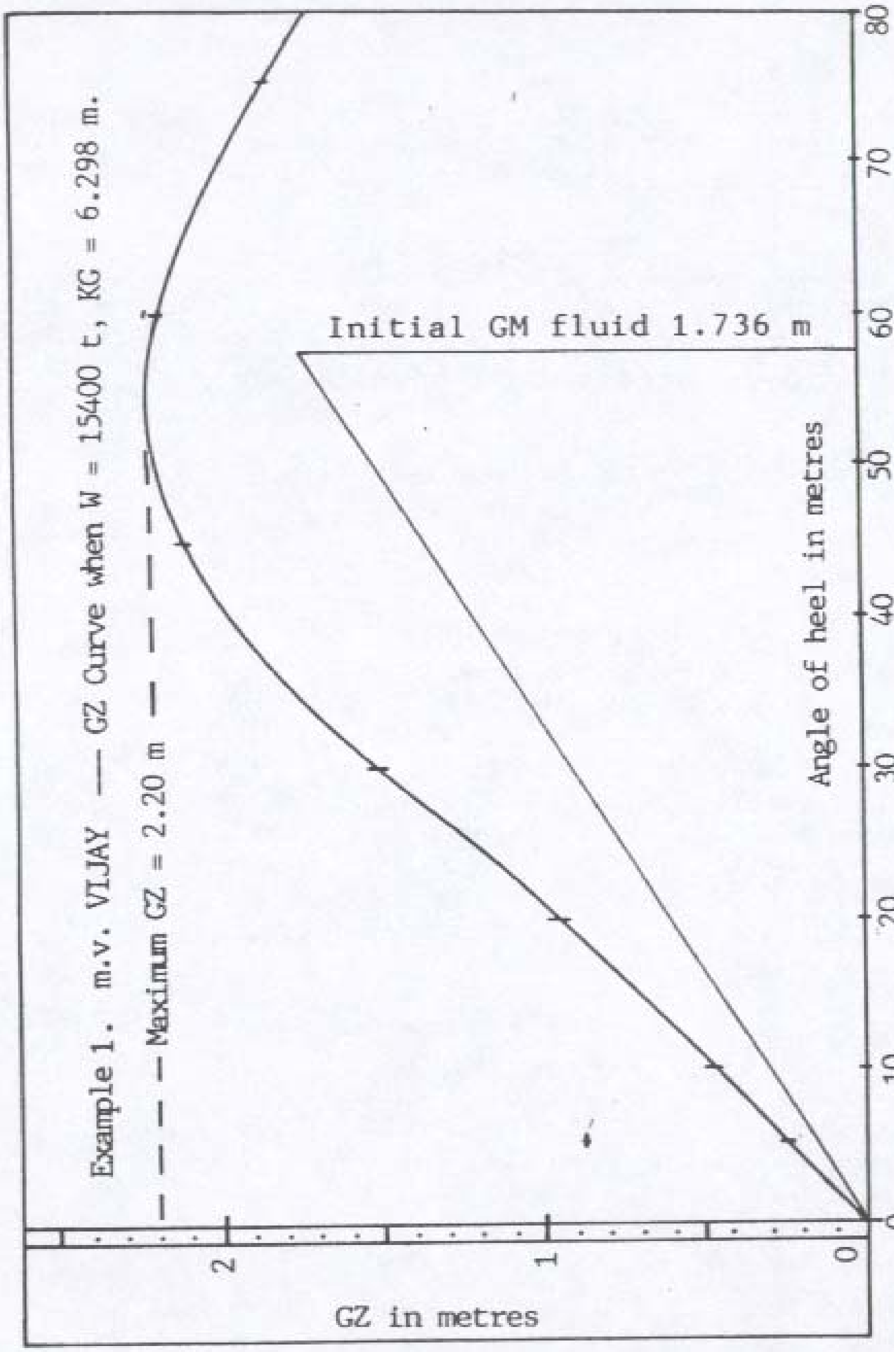
From the curve of statical stability on the next page:

Heel	GZ	SM	Product for area
0	0	1	0
5	0.247	4	0.988
10	0.481	2	0.962
15	0.725	4	2.900
20	0.958	2	1.916
25	1.225	4	4.900
30	1.492	2	2.984
35	1.800	4	7.200
40	1.975	1	1.975
		SOP	23.825

$$\text{Area upto } 40° = \frac{5(23.825)}{3} \text{ metre-degrees}$$

$$= \frac{5(23.825)}{3(57.3)} \text{ metre-radians}$$

Note: It is suggested that the area under the curve be kept as a fraction until the final answer. If it is rounded off to three decimal places and then multiplied by W, a certain amount of inaccuracy would creep in.


Example 1. m.v. VIJAY — GZ Curve when W = 15400 t, KG = 6.298 m.
— — Maximum GZ = 2.20 m
Initial GM fluid 1.736 m
Angle of heel in metres
0
10
20
30
40
50
60
70
80
GZ in metres
0
1
2

Dynam stability at 40° = $\dfrac{15400(5)23.825}{3(57.3)}$

= 10672.048 tonne-metre-radians.

Note: With a common interval of 10°, the accuracy of the calculation would have been less and the answer would have been found to be 10556.033 tonne-metre-radians.

Example 2

In example 1, find the dynamical stability at 30° heel.

The values of GZ at 15° & 25° heel are from the curve of statical stability drawn for example 1.

Heel	GZ	SM	Prod for area
0	0	1	0
5	0.247	4	0.988
10	0.481	2	0.962
15	0.725	4	2.900
20	0.958	2	1.916
25	1.225	4	4.900
30	1.492	1	1.492
		SOP	13.158

OR

Heel	GZ	SM	Prod for area
30	1.492	1	1.492
35	1.800	4	7.200
40	1.975	1	1.975
		SOP	10.667

SOP 0° to 40° heel = 23.825
SOP 30° to 40° heel = 10.667
SOP 0° to 30° heel = 13.158

Area upto 30° = $\frac{5}{3}(13.158)$ metre-degrees

= $\frac{5(13.158)}{3(57.3)}$ metre-radians

Dynamical stability at 30°

$$= \frac{15400 \times 5 \times 13.158}{3 \times 57.3}$$

= 5893.927 tonne-metre-radians

Note: A less accurate result would be obtained by using a common interval of 10°, and applying Simpson's Second Rule, giving an answer of 5854.620 tonne-metre-radians.

STABILITY REQUIREMENTS AS PER LOADLINE RULES 1968 (UK) AND 1979 (INDIA)

1) Initial GM to be not less than 0.15 m
2) Maximum GZ to be not less than 0.20 m
3) Max GZ to occur at a heel of not less than 30°.
4) The area under the GZ curve, in metre radians, shall be not less than:
   (a) 0.055 upto 30° heel.
   (b) 0.090 upto 40° heel or the angle of flooding, whichever is less.
   (c) 0.030 between 30° and 40° or the angle of flooding, whichever is less.

-o0o-

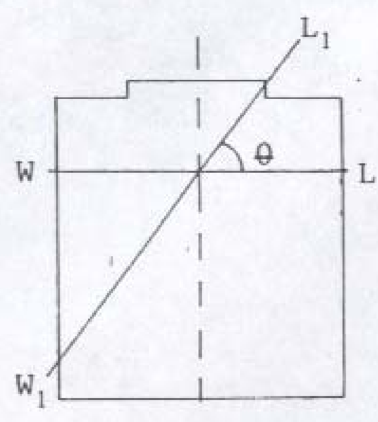
The angle of flooding is that angle of heel at which any non-watertight openings in the hull would immerse. Small openings through which progressive flooding cannot take place are excluded. The angle of flooding is usually well over 40°. If it is less than 40°, it would be clearly stated in the ship's stability information booklet supplied by the shipyard.

In most ships, the non-watertight openings that would immerse first, as a result of heel, would be the hatch coamings. Hatch covers are weathertight, not watertight. Coamings of cowl type ventilators, whose tops are likely to immerse before the hatch coamings, are usually provided with metal/wooden lids and canvas covers which may be put on, after unshipping the cowls, to prevent progressive flooding.

Some shipyards state the value of the angle of flooding in the GZ or KN tables against the displacement of the ship. An idea of the value of the angle of flooding may be obtained by inspecting the cross-sectional drawings of the ship but

(i) The volume of displacement must be constant at both the waterlines;

(ii) Changes in the breadth of the ship at various points along her length, superstructure, etc would make considerable difference.



Example 3

Verify whether, in example 1, m.v.VIJAY meets all the stability requirements under the Loadline Rules.

1) Solid GM = 8.034 - 6.100 = 1.934 m
   FSC = 3050/15400 .... = 0.198 m
   Initial GM fluid .... = 1.736 m
   Minimum required .... = 0.150 m
   Requirement (1) is satisfied.

2) As per curve drawn in example 1,
   Maximum GZ .... = 2.200 m
   Required value .... = 0.200 m
   Requirement (2) is satisfied.

3) As per curve drawn in example 1,
   Maximum GZ occurs at .... = 55°
   Maximum GZ should occur .. = or > 30°
   Requirement (3) is satisfied.

4) As calculated in examples 1 and 2,
   (a) Area upto 30° heel ... = 0.383 mr
       Minimum required ..... = 0.055 mr
       Requirement 4(a) is satisfied.
   (b) Area upto 40° heel ... = 0.693 mr
       Minimum required ..... = 0.090 mr
       Requirement 4(b) is satisfied.
   (c) Area between 30° & 40° = 0.310 mr
       Minimum required ..... = 0.030 mr
       Requirement 4(c) is satisfied.

The ship complies with all the stability requirements of the Loadline Rules.

Example 4

If, in example 3, the angle of flooding was given as 30°, state whether the ship complies with the stability requirements of the Loadline Rules.

The Rules require that the area under the curve between 30° and 40° or the angle of flooding, whichever is less, is atleast 0.03 mr. In this case, the area betwen 30° and the angle of flooding (i.e 30°) is zero! Hence, in this example, the ship does NOT satisfy all the stability requirements under the Loadline Rules. She complies with requirements 1, 2, 3, 4(a) and 4(b) but not 4(c).

Example 5

If in example 1, the angle of flooding was given as 35°, state whether the ship meets all the stability requirements under the Loadline Rules.

Referring to the calculations made in examples 1, 2 & 3, the ship complies with requirements 1, 2, 3 & 4(a).

Requirement 4(b): Area under the curve, upto the angle of flooding, to be at least 0.09 mr.

Heel	GZ	SM	Prod for area
25	1.225	-1	- 1.225
30	1.492	+8	+11.936
35	1.800	+5	+ 9.000
		SOP	+19.711

$$\text{Area } 30° - 35° = \frac{5(19.711)}{12} \text{ metre degrees}$$

$$= 0.143 \text{ metre radians}$$

Area 0° to 30° = 0.383 mr
Area 30° to 35° = 0.143 mr
Area 0° to 35° = 0.526 mr
Requirement = or >0.090 mr
Ship meets requirement 4(b)

Requirement 4(c): Area between 30° & the angle of flooding to be atleast 0.03 mr.

As calculated above, area between 30° & the angle of flooding is 0.143 mr. The ship complies with requirement 4(c).

In example 5, the ship meets all the stability requirements of the Loadline Rules.

Exercise 37
Dynam stability & LL Rules requirements.

In the following cases, verify which of the stability requirements under the Loadline Rules have been met and which have not. Use the appendices of this book, where necessary. Where the angle of flooding is not mentioned, assume that it is over 40°.

1 M.v.VICTORY, W = 70,000 t, KG = 9.41 m FSM = 6300 tm, KM 13.1 m. State also the dynamical stability at 40° heel.

2 M.v.VICTORY, W = 85,000 t, KG =10.68 m FSM = 6761 tm. State also the dynamical stability at 30° heel.

3 M.v.VIJAY, W = 13,250 t, KG = 6.427 m FSM = 1200 tm.

4 M.v.VIJAY, W = 10,777 t, KG = 7.8 m, FSM = 800 tm. State also the dynamical stability at 40° heel.

5 M.v.VIJAY, W = 19,943 t, KG = 7.326 m FSM = 1342 tm, KM 8.257 m, angle of flooding = 36°.

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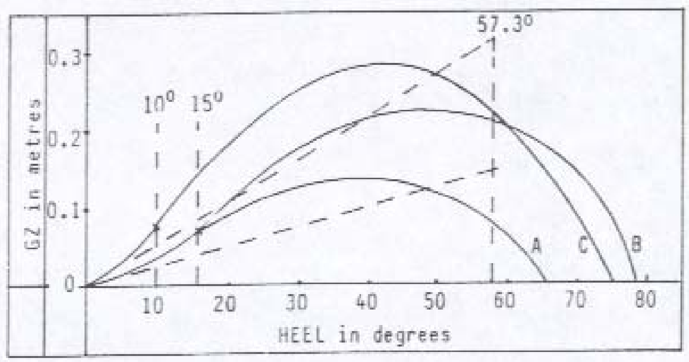
CHAPTER 41

EFFECT OF BEAM AND FREEBOARD ON GZ CURVE

The beam and the freeboard influence GZ considerably as illustrated below. In the following figure, curves A, B and C belong to three different box-shaped vessels whose draft, KG fluid and volume of displacement are the same.

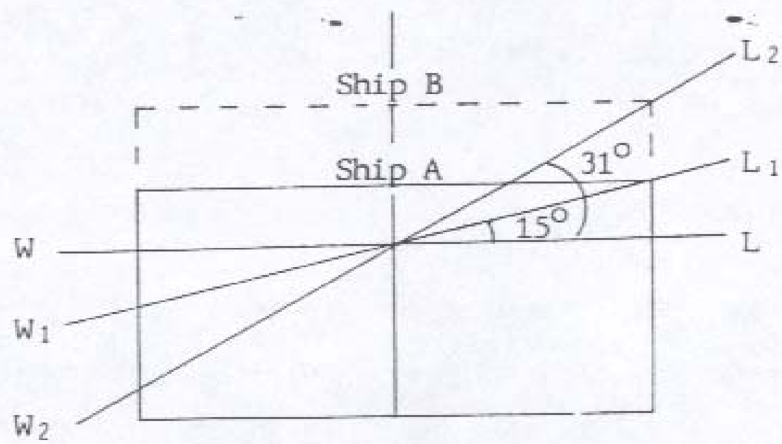


Effect of freeboard on GZ:-

Ship A's deck edge immerses at 15° heel. Ship B has the same breadth as ship A but has a greater freeboard. As seen from the following figure, the GZ values of ship B are the same as that of ship A until 15° - the heel at which A's deck edge immerses. On heeling further, the GZ of ship B is greater than that of ship A for the same angle of heel. This fact shows up clearly on inspecting curves A and B in the foregoing figure. The range of stability of ship B is greater, than that of ship A, because of its greater freeboard.

To sum up:- Greater freeboard means:

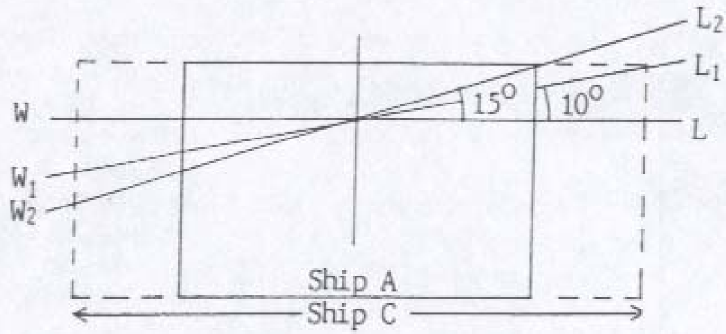
(i) No change in Initial Fluid GM.
(ii) Deck edge immerses at a greater angle of heel.
(iii) GZ values unaffected until the deck edge immerses but, thereafter, GZ values are greater.
(iv) Greater range of stability.



Effect of beam on GZ:-

Ship C, having the same freeboard as ship A, has greater beam (breadth). For ship-shapes, BM = I/V & for box-shapes, it is simplified as $BM = B^2/12d$, as explained in chapter 19 of Ship Stability II. Hence the GZ values of ship C are greater than those of ship A, at all angles of heel.

As apparent from the following figure, the deck edge of the broader ship immerses at a smaller angle of heel than that of a narrower ship. The range of stability also increases with increase in beam. All of the foregoing are apparent when inspecting curves A & C in the first figure of this chapter.



To sum up:- Greater beam (breadth) means

(i) Greater Initial Fluid GM.
(ii) Deck edge immerses at a smaller angle of heel.
(iii) Greater values of GZ at any heel.
(iv) Greater range of stability.

The actual calculations in support of the foregoing statements are beyond the scope of this book.

Box-shaped vessels have been taken for illustration so that the variable parameters have been kept to a minimum for the sake of easy comparison.

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CHAPTER 42

CHANGE OF TRIM

DUE TO CHANGE OF DENSITY

When a ship is in equilibrium, her COG & COB would be in the same vertical line. When she proceeds to water of another density, her volume of displacement, and hence her draft, would change. If the AB of the ship at the new draft, is different from the AB at the earlier draft, the COB would now be longitudinally separated from the COG by the the distance referred to, in earlier chapters, as $\overline{BG}$. The trimming moment, so formed, would be W.$\overline{BG}$. The ship would then alter her trim until the COB comes directly under the COG. The trim, so caused, can be calculated by using the hydrostatic particulars of the ship for the new draft at the new density. This simple phenomenon can be illustrated by the following example.

Example 1

M.v.VIJAY is in SW, drawing 3.60 m fwd & 6.40 m aft. Find the new drafts fwd and aft if she now proceeds to FW. (Use appendix I).

Fwd 3.600 m, aft 6.400 m, mean 5.000 m, trim 2.800 m or 280 cm by the stern. From appendix I, AF = 71.913 metres.

Correction to aft draft = AF (trim)/L

= 71.913 (2.8)/140 = 1.438 m

Initial hydraft = 6.40 - 1.438 = 4.962 m

SW draft	W (t)	MCTC tm	AB (m)
4.962	9807.4	165.434	72.014

Trim in cm = $\frac{W.\overline{BG}}{MCTC}$ or $\overline{BG} = \frac{trim(MCTC)}{W}$

Initial $\overline{BG} = \frac{280(165.434)}{9807.4} = 4.723$ metres

Since trim was by stern, AG was < AB.

AG of vessel = 72.014 - 4.723 = 67.291 m

So far, the calculation has been exactly the same as in example 5B of chapter 27 in Ship Stability II.

From appendix I,

	W (t)	draft	MCTC tm	AB m	AF m
SW	10052.6	5.073	166.212	72.013	71.887
FW	9807.4	5.073	162.158	72.013	71.887

$\overline{BG}$ = AB - AG = 72.013 - 67.291 = 4.722 m

Since AB > AG, final trim is by stern.

Trim = $\frac{W.\overline{BG}}{MCTC} = \frac{9807.4\ (4.722)}{162.158} = 285.6$ cm.

Ta = $\frac{AF(trim)}{L} = \frac{71.887\ (2.856)}{140} = 1.466$ m

Tf = Tc - Ta = 2.856 - 1.466 = 1.390 m

	Fwd	Aft
Final hydraft	5.073 m	5.073 m
Tf or Ta	-1.390 m	+1.466 m
Final drafts	3.683 m	6.539 m

The change of trim actually caused by this change in density of water displaced = 285.6 - 280 = 5.6 cm only.

This chapter is only meant to illustrate, in theory, that the trim of a ship is liable to slight change when the density of water displaced changes. It is not of much importance in practical operation of ships. Since the calculation is not only similar to, but simpler than, other problems on trim, no exercise has been set on this topic.

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CHAPTER 43

CENTRE OF PRESSURE

Centre of pressure is that point through which the thrust, or total pressure, may be considered to act. Pressure and thrust were explained in Chapter 2 in SHIP STABILITY I. Calculation of pressure and thrust on curvi-linear, immersed areas was done in Chapter 20 in SHIP STABILITY II. It is presumed that the student has gone through those chapters and, therefore, needless repetition is avoided here.

The depth 'z' of the centre of pressure (COP) below the water surface (WS) may be calculated by the formula:

$$z = \frac{I*ws}{Ad}$$

Where:

I*ws is the moment of inertia or second moment of the immersed area about the water surface expressed in quadro metres.

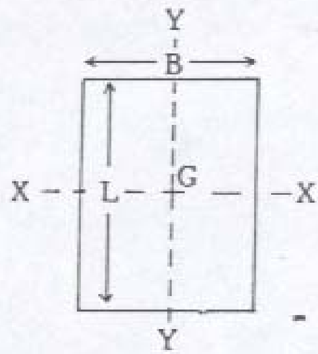
'A' is the area of the immersed portion in square metres.

'd' is the depth, in metres, of the geometric centre of the immersed portion below the water surface.

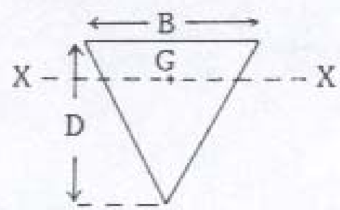
Standard formulae for the moment of inertia 'I' about an axis passing through the geometric centre of some regular shapes are given below. Students should learn these by heart.

$$I*YY = \frac{LB^3}{12}$$

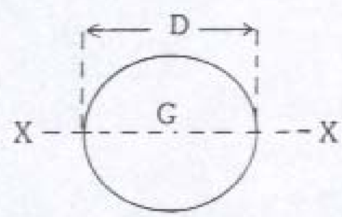
$$I*XX = \frac{BL^3}{12}$$



$$I*XX = \frac{BD^3}{36}$$



$$I*XX = \frac{\pi D^4}{64}$$



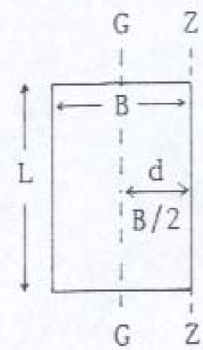
Once 'I' of an area, about an axis passing through its geometric centre, is known, 'I' about any other parallel axis can be calculated by the theorem of parallel axes.

Theorem of parallel axes: If I*GG is the moment of inertia of an area about an axis passing through its geometric centre, and ZZ is an axis parallel to GG, then

$$I^*ZZ = I^*GG + Ad^2$$

where 'd' is the distance between axis GG and axis ZZ.

Example 1:

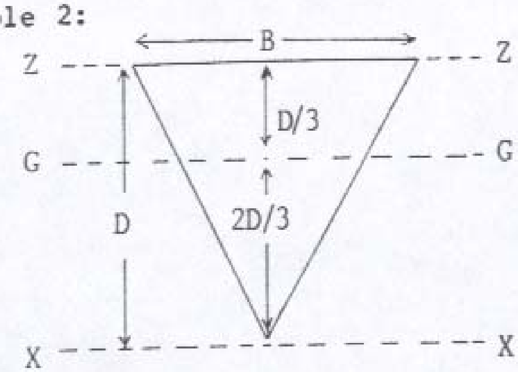


$$I^*ZZ = I^*GG + Ad^2$$

$$= \frac{LB^3}{12} + LB(B/2)^2$$

$$= \frac{LB^3}{3}$$

Example 2:



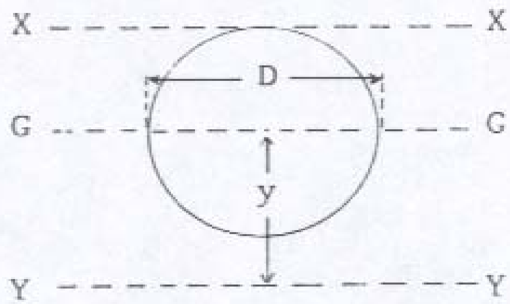
$$I^*ZZ = I^*GG + Ad^2 = \frac{BD^3}{36} + \frac{BD}{2}(D/3)^2 = \frac{BD^3}{12}$$

$$I^*XX = I^*GG + Ad^2 = \frac{BD^3}{36} + \frac{BD}{2}(2D/3)^2 = \frac{BD^3}{4}$$

Example 3:

$$I^*XX = I^*GG + Ad^2 = \frac{\pi D^4}{64} + \frac{\pi D^2}{4}(D/2)^2$$

$$= \frac{\pi D^4}{64} + \frac{\pi D^4}{16} = \frac{5\pi D^4}{64}$$



$$I^*YY = I^*GG + Ad^2 = \frac{\pi D^4}{64} + \frac{\pi D^2}{4}(y)^2$$

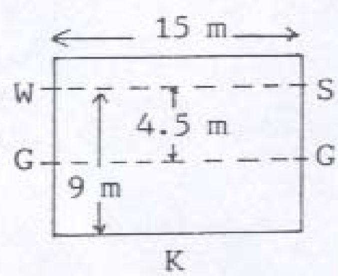
CALCULATION OF POSITION OF COP

Worked example 1

One side of a tank is a vertical, rectangular bulkhead 15 m long & 10 m high. Find KP (the height of the COP above the bottom of the tank) when the tank has SW in it to a sounding of 9 metres.

$$z = \frac{I^*ws}{Ad} = \frac{I^*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15(9^3)}{12}+15(9)(4.5^2)}{15(9)(4.5)}$$



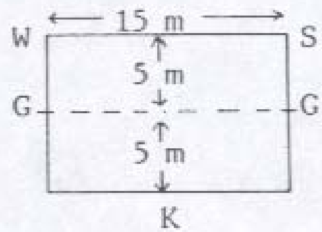
z = Depth of COP below ws	=	6.000 m
Sounding	=	9.000 m
KP (height of COP above bottom)		3.000 m

Worked example 2

Calculate KP (height of the COP above the bottom of the tank) in worked example 1, when the sounding is 10 m.

$$z = \frac{I*ws}{Ad} = \frac{I*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15(10^3)}{12}+15(10)5^2}{15(10)(5)}$$



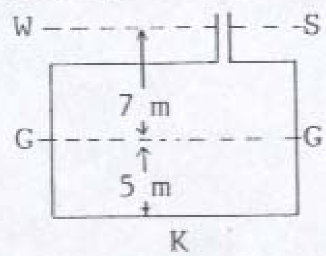
z = Depth of COP below ws	=	6.667 m
Sounding	=	10.000 m
KP (height of COP above bottom)		3.333 m

Worked example 3

Calculate KP (height of the COP above the bottom of the tank) in worked example 1, when the sounding is 12 m.

$$z = \frac{I*ws}{Ad} = \frac{I*GG + Ad^2}{Ad}$$

$$= \frac{\frac{15(10^3)}{12}+15(10)7^2}{15(10)(7)}$$

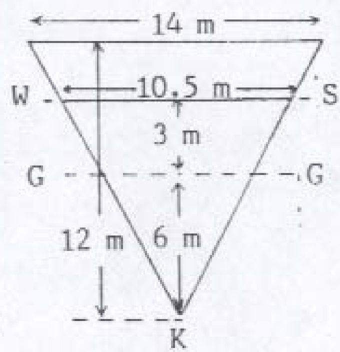


z = Depth of COP below ws	=	8.190 m
Sounding	=	12.000 m
KP (height of COP above bottom)		3.810 m

Worked example 4

One bulkhead of a tank consists of a triangle, apex downwards, which is 14 m broad and 12 m high. Calculate KP (height of the COP above the bottom of the tank) when the sounding is 9 metres.

By similar triangles, breadth of water surface = 10.5 metres.



$$A = \frac{10.5(9)}{2} = 47.25 \text{ m}^2$$

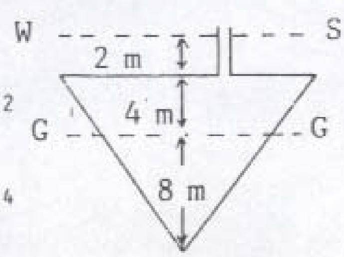
$$z = \frac{I*ws}{Ad} = \frac{I*GG + Ad^2}{Ad}$$

$$= \frac{\frac{10.5(9^3)}{36}+47.25(3^2)}{47.25(3)}$$

z = Depth of COP below ws	=	4.500 m
Sounding	=	9.000 m
KP (height of COP above bottom)		4.500 m

Worked example 5

Calculate KP (height of the COP above the bottom of the tank) when the sounding of the tank in worked example 4 is 14 m.



$$A = 14(12)/2 = 84 \text{ m}^2$$

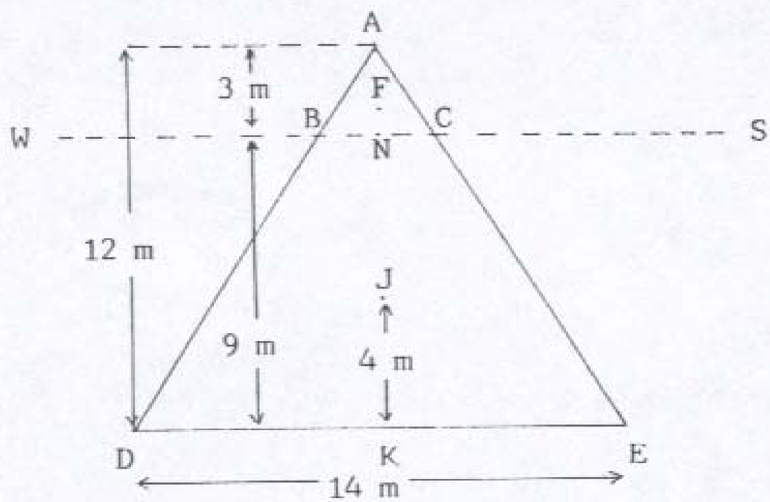
$$I*GG = \frac{14(12^3)}{36} = 672 \text{ m}^4$$

$$z = \frac{I*ws}{Ad} = \frac{I*GG + Ad^2}{Ad} = \frac{672 + 84(6^2)}{84(6)}$$

z = depth of COP below ws = 7.333 m
Sounding ... ... = 14.000 m
KP (height of COP above bottom) 6.667 m

Worked example 6

One bulkhead of a tank consists of a triangle, apex upwards, 14 m broad and 12 m high. Calculate KP (height of the COP above the bottom) when the sounding is 9 m.



By similar triangles, BC = 3.5 metres. Let F & J be the geometric centres of triangles ABC & ADE. To calculate the position of G, the geometric centre of trapezoid BCED (immersed area):

Taking moments about A,

Area ADE(AJ)-Area ABC(AF)= Area BCED(AG)

$84(8) - 5.25(2) = 78.75(AG)$

AG = 8.4 metres. NG = d = depth of geometric centre below ws = 5.4 metres.

To find I*ws of immersed area:

I*ws of ADE = I*JJ + A(JN^2)

$$= \frac{14(12^3)}{36} + 84(5^2) = 672 + 2100$$

$$= 2772 \text{ m}^4.$$

I*ws of ABC = I*FF + A(FN^2)

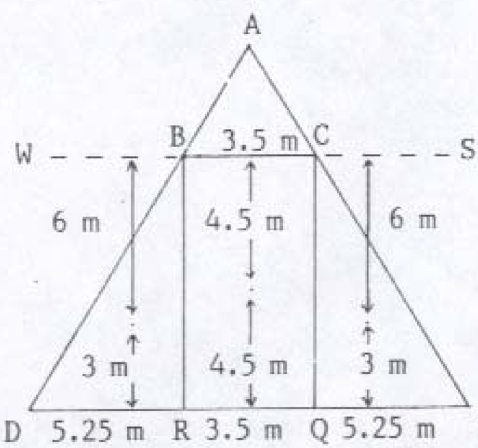
$$= \frac{3.5(3^3)}{36} + 5.25(1^2) = 2.625 + 5.25$$

$$= 7.875 \text{ m}^4.$$

I*ws BCED = I*ws ADE − I*ws ABC

$$= 2772 - 7.875 = 2764.125 \text{ m}^4.$$

Alternative method:



$$I^*ws \quad BCQR = \frac{3.5(9^3)}{3} = 850.500 \ m^4.$$

$$I^*ws \quad CQE = \frac{5.25(9^3)}{4} = 956.8125 \ m^4.$$

$$I^*ws \quad BRD = \frac{5.25(9^3)}{4} = 956.8125 \ m^4.$$

$$I^*ws \quad BCED \ \dots \ \dots \ \dots = 2764.125 \ m^4.$$

Note: In case the student is not able to readily follow the above steps, he is requested to refer to examples 1 & 2 on calculation of moments of inertia on the third page of this chapter.

To find d (depth of geometric centre of immersed area BCED):

Taking moments about ws, Area BCED(d) =

Area BCQR(4.5) +Area CQE(6) +Area BRD(6)

so that

$$78.75(d) = 31.5(4.5)+23.625(6)+23.625(6)$$

$$d = 5.4 \text{ metres.}$$

Completion of calculation:

$$z = \frac{I^*ws}{Ad} = \frac{2764.125}{78.75(5.4)} = 6.500 \text{ metres.}$$

$$KP = 9.000 - 6.500 = 2.500 \text{ metres.}$$

Compare the KP here with that of worked example 4 wherein the same tank had the same sounding but was apex downwards.

Exercise 38
COP - regular shapes

Find the thrust and KP (height of the COP above the bottom) of a vertical bulkhead in the following cases:

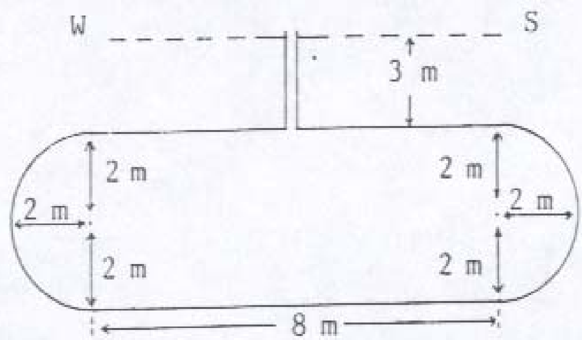
	Shape	Breadth	Height	Sounding	RD
1	Rectangle	16 m	10 m	10 m	1.025
2	Triangle apex down	15	10	10	1.000
3	Triangle apex up	14	10	10	1.010
4	Rectangle	12	9	6	1.015
5	Triangle apex down	11	9	6	1.012
6	Triangle apex up	10	9	6	1.012
7	Rectangle	12	8.4	11.4	1.000
8	Triangle apex down	16	8.4	11.4	1.015
9	Triangle apex up	12	8.4	11.4	1.005
10	Circle	4	4	4	1.025

11 One bulkhead of a ship's deep tank is a vertical rectangle 10 m broad & 6 m high. At what sounding would the COP be 2.5 metres above the bottom?

12 One side of a tank is a vertical bulkhead consisting of an isosceles triangle, 12 m broad & 6 m high, over a rectangle 12 m broad & 8 m high. Calculate the thrust and the KP (height of the COP above the bottom) when the tank has salt water in it to a sounding of 15 metres.

13 Calculate the thrust & KP of the tank in question 12, when the tank has FW in it to a sounding of 11 metres.

14 Calculate the thrust & KP (height of the COP above the bottom) of the vertical bulkhead, whose shape is given below, when run up with SW to a head of 3 metres (sounding = 7 m).



15 Divide KP by the sounding in each of the problems 1 to 9. It will be noticed that when the tank is just full or partly full:

Shape of immersed area	KP/S
Rectangular	1/3
Triangular (apex down)	1/2
Triangular (apex up)	1/4

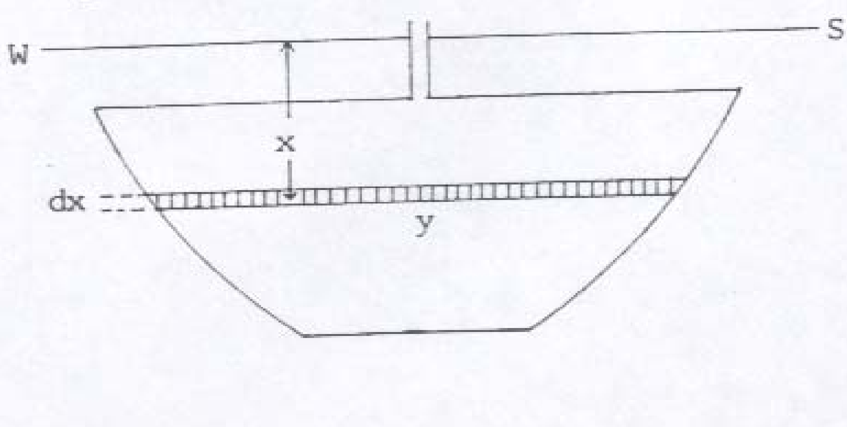
Note 1: Problem 6 does not fall into any of the above categories because the immersed area is neither rectangular nor triangular.
Note 2: Where the tank is **more than full** (where ws is above the top of the tank), the COP is **higher** than when the tank is just full.
Note 3: COP is always below the geometric centre of the immersed area, regardless of the sounding.

COP OF CURVI-LINEAR SHAPES

The position of the COP of a curvi-linear shape may be found by using Simpson's Rules. Since it is expected that the student would have already studied the use of Simpson's Rules to find areas, volumes, first moment and geometric centres, explained in chapter 20 in Ship Stability II, needless repetition has been avoided here.

The calculation of the position of the COP by Simpson's Rules may be done using either horizontal ordinates or vertical ordinates.

Using horizontal ordinates



Considering the elemental strip:

Area .... = y.dx

1st moment about ws = y.dx.x = yx.dx

By parallel axes, $I^*ws = \frac{y.dx^3}{12} + y.dx.x^2$

Since dx is very small dx^3 is negligible

Therefore, I^*ws elemental strip = $yx^2.dx$

Considering the whole immersed portion:

Area .... = $\int$ y.dx

1st moment about ws .... = $\int$ yx.dx

I^*ws .... = $\int yx^2.dx$

So if y, yx & yx^2 are put through Simpson's Rules, the immersed area, the first moment of area about ws and the moment of inertia of the immersed area about ws can be obtained. The calculation could then be completed as illustrated in the following example.

Worked example 7 - **Horizontal Ordinates.**

A lower hold bulkhead is 12 m high. The transverse widths in metres, commencing from the upper edge, at 3 metre vertical intervals, are:

15, 15.2, 15.4, 15.5 & 15 respectively.

Find KP (the height of the COP above the bottom) and the thrust when the hold is filled with SW to sounding of 14 metres.

1 y (m)	2 SM	3 Area func.	4 x	5 1st mom *ws func	6 x	7 I*ws function
15	1	15	2 m	30	2 m	60
15.2	4	60.8	5	304	5	1520
15.4	2	30.8	8	246.4	8	1971.2
15.5	4	62	11	682	11	7502
15	1	15	14	210	14	2940
	SOP 183.6		SOP 1472.4		SOP 13993.2	

(Abbreviation SOP = sum of products).

Note: Column 1 x column 2 = column 3
Column 3 x column 4 = column 5
Column 5 x column 6 = column 7

Note: $z = \dfrac{I*ws}{Ad} = \dfrac{h/3\ (\text{SOP for } I*ws)}{h/3(\text{SOP for 1st mom})}$

So z = SOP column 7 ÷ SOP column 5

Depth of COP = $z = \dfrac{13993.2}{1472.4} = 9.504$ m

KP = sounding − z = 14 − 9.504 = 4.496 m

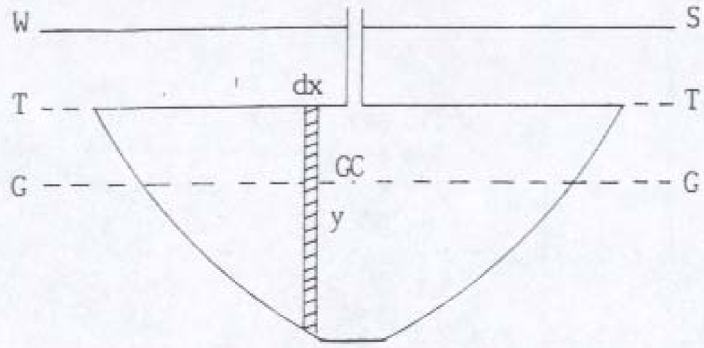
Thrust = pressure at GC x immersed area

= depth of GC x density x area

= 1st moment of area x density

$= 3 \times \dfrac{1472.4}{3} \times 1.025 = 1509.21$ t.

Using vertical ordinates



Considering the elemental strip:

Area .... = $y.dx$

1st moment about TT = $y.dx.y/2$ = $\frac{y^2.dx}{2}$

I*TT imm area = $\frac{y^3.dx}{3}$ (standard formula)

Considering the whole immersed portion:

Area........................... = $\int y.dx$

1st moment about TT .... = $\frac{1}{2}\int y^2.dx$

I*TT immersed area .... = $\frac{1}{3}\int y^3.dx$

So if y, $y^2/2$ and $y^3/3$ are put through Simpson's Rules, the immersed area, the first moment of area about TT and the moment of inertia of the immersed area about TT may be obtained. However, for the sake of convenience in calculation, y^2 and y^3 may be put through Simpson's

Multipliers and the SOP of the respective columns divided by 2 and 3, as shown in the following worked example.

Worked example 8 - **Vertical ordinates.**

A deep tank bulkhead is 12 m broad at the top. The vertical ordinates, at equidistant transverse intervals, are:

0, 3, 5, 6, 5, 3 and 0 m respectively.

Find KP (the height of the COP above the bottom) and the thrust when the hold is filled with SW to a head of 2 metres (sounding = 8 m).

The common interval in this case is 2 m.

1 y (m)	2 SM	3 area func.	4 y	5 y^2 func.	6 y	7 y^3 func.
0	1	0	0	0	0	0
3	4	12	3	36	3	108
5	2	10	5	50	5	250
6	4	24	6	144	6	864
5	2	10	5	50	5	250
3	4	12	3	36	3	108
0	1	0	0	0	0	0
	SOP	68	SOP	316	SOP	1580

Note: Column 1 x column 2 = column 3
Column 3 x column 4 = column 5
Column 5 x column 6 = column 7

$$\text{Area} = \frac{h}{3}(\text{SOP col } 3) = \frac{2}{3}(68) = 45.333 \text{ m}^2.$$

$$\text{1st moment about TT} = \frac{h}{3}(\text{SOP col } 5 \div 2)$$

$$= \frac{2(316)}{3 \times 2} = 105.333 \text{ m}^3.$$

$$\text{I*TT immersed area} = \frac{h}{3}(\text{SOP col } 7 \div 3)$$

$$= \frac{2(1580)}{3 \times 3} = 351.111 \text{ m}^4.$$

$$\text{Depth of GC below TT} = \frac{105.333}{45.333} = 2.324 \text{ m}$$

By theorem of parallel axes,

$$\text{I*GG} = \text{I*TT} - \text{area }(2.324^2)$$

$$= 351.111 - 45.333(2.324^2)$$

$$= 106.269^4 \text{m} .$$

$$\text{I*ws} = \text{I*GG} + \text{area }(4.324^2)$$

$$= 106.269 + 45.333(4.324^2)$$

$$= 953.859 \text{ m}^4.$$

$$z = \frac{\text{I*ws}}{\text{Ad}} = \frac{953.859}{45.333(4.324)} = 4.866 \text{ metres.}$$

$$\text{KP} = 8.000 - 4.866 = 3.134 \text{ metres.}$$

Worked example 9

The half-breadths of a transverse watertight bulkhead 10 metres high, measured at equal vertical intervals, are:

10, 9.3, 8.3, 7.1, 5.7 and 3.8 m.

Find the KP and the thrust when the hold is filled with SW to a sounding of 13 m.

Note 1: The number of ordinates being six, neither Simpson's Rule 1 nor Rule 2 is directly applicable.

Note 2: Half-breadths are given here.

1 y	2 SM	3 area func.	4 x	5 1st mom *ws func.	6 x	7 I*ws func.
10	1	10	3	30	3	90
9.3	4	37.2	5	186	5	930
8.3	1	8.3	7	58.1	7	406.7
	SOP	55.5	SOP	274.1	SOP	1426.7

Half the top area = $\frac{2(55.5)}{3}$ = 37.0 m^2.

1/2 1st mom*ws = $\frac{2(274.1)}{3}$ = 182.733 m^3.

1/2 2nd mom*ws = $\frac{2(1426.7)}{3}$ = 951.133 m^4.

1 y	2 SM	3 Area func.	4 x	5 1st mom *ws func.	6 x	7 I*ws func.
8.3	1	8.3	7	58.1	7	406.7
7.1	3	21.3	9	191.7	9	1725.3
5.7	3	17.1	11	188.1	11	2069.1
3.8	1	3.8	13	49.4	13	642.2
	SOP	50.5	SOP	487.3	SOP	4843.3

$$1/2 \text{ bottom area} = \frac{3}{8}(2)50.5 = 37.875 \text{ m}^2.$$

$$1/2 \text{ 1st mom*ws} = \frac{3}{8}(2)487.3 = 365.475 \text{ m}^3.$$

$$1/2 \text{ 2nd mom*ws} = \frac{3}{8}(2)4843.3 = 3632.475 \text{ m}^4.$$

Total 1/2 area = 37+37.875 = 74.875 m^2.
Total half first mom*ws = 548.208 m^3.
Total half second mom*ws = 4583.608 m^4.

$$z = \frac{I*ws}{Ad} = \frac{2(4583.608)}{2(548.208)} = 8.361 \text{ metres.}$$

KP = sounding - z = 13 - 8.361 = 4.639 m

Thrust = Ad(density) = 2(548.208)1.025

Thrust = 1123.826 tonnes.

Exercise 39
COP of curvi-linear shapes

1 The collision bulkhead of a tanker is 12 metres high. The breadths at equal intervals from top, in metres, are:

14, 9.6, 5.9, 4, 3.3, 2.6 & 0.

Find the thrust and the KP (height of the COP above the bottom) when the forepeak tank is filled with FW to a head of 5 metres.

2 Find the KP (height of the COP above

the bottom) and the thrust when the forepeak tank in question 1 is filled with SW to a sounding of 12 metres.

3 Find the KP and the thrust when the tank in question 1 is run up with DW (RD 1.015) to a sounding of 8 metres.

4 The half-breadths of a watertight bulkhead, at 2.5 metre vertical intervals from the bottom, are:

1, 2.9, 4.2, 5.1 & 5.7 m.

Find the KP and the thrust when the hold is flooded with SW to a sounding of 11.5 metres.

5 The vertical ordinates of the after bulkhead of the port slop tank of a tanker, measured from the horizontal deckhead downwards, spaced at equal athwartship intervals of one metre from the port side, are:

0, 3.25, 4.4, 5.15, 5.65, 5.9 and 6 m

Find KP (height of the COP above the bottom) and the thrust when the tank is full of slop (RD 0.98).

6 The after bulkhead of a tank on the starboard side is 3 m high. It is bounded on the top by a horizontal deck, towards amidships by a vertical fore & aft bulkhead and on the starboard side by the shell plating. The vertical ordinates of this bulkhead, at equal athwartships intervals of 1.8 m, are:

3, 2.85, 2.6, 2.1, 1.1 & 0 metres.

Find the KP (height of the COP above the bottom) and the thrust when the tank has DW (RD 1.016) to a head of 12 metres.

7 The half breadths of a transverse watertight bulkhead 14.2 m high, at 2.2 metre intervals from the top, are

10.6, 10, 9.3, 8.3, 7.1, 5.7 & 3.8 m.

Below the lowest semi-ordinate is a rectangular appendage 7.6 m broad and 1 m high. Find the KP (height of the COP above the bottom) and the thrust on the bulkhead when the hold is filled with SW.

8 The half-breadths of a transverse watertight bulkhead on a tanker, measured at regular vertical intervals, are:

10, 9.3, 8.3, 7.1, 5.7, 4.4 & 2.9 m.

The common interval between the first five semi-ordinates is 2.2 m, while that between the last three is 1.1 m. Calculate the KP (height of the COP above the bottom) and the thrust when the tank is full of SW to a sounding of 12.5 m.

9 The half-breadths of a collision bulkhead, at equal vertical intervals of 2 m from the top, are:

7, 4.8, 2.95, 2, 1.65 and 1.3 m.

Below the bottom semi-ordinate, there is a triangular appendage 2.6 metres broad and 1.2 metres high. Find the KP (height of the COP above the bottom) and the thrust when the fore-peak tank is run up with salt water to a sounding of 14 metres.
(Suggestion: Use Simpson's First Rule for the first three semi-ordinates & Simpson's Second Rule for the last four.)

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CHAPTER 44

THE INCLINING EXPERIMENT

The inclining experiment is performed by the shipyard in order to obtain the KG of the ship in the light condition. Once this is known, the KG can, thereafter, be calculated for any desired condition of loading, as illustrated in chapter 7 (Ship Stability I).

The inclining experiment should be done when the building of the ship is complete or nearly so. Any changes can, thereafter, be allowed for by calculation. This experiment may have to be performed again, during the life of the ship, if any large structural alterations are made. The result of the inclining experiment performed on one ship may be acceptable for sister ships.

Two pendulum bobs, attached to lines about ten metres or more in length, are suspended, in the open hatchway, at the centre line of the ship - one forward and the other, aft. Some shipyards use a third plumb bob amidships. The results obtained by the different bobs are averaged. For simplicity's sake, only one plumb bob is considered here. The bob itself, though suspended freely, may be immersed in a trough of oil or water in order to damp out oscillations.

A horizontal batten, graduated in centimetres, is fitted a short distance above the plumb bob. The batten is adjusted to be horizontal, by use of a spirit level, when the ship is perfectly upright.

The fact that the ship is upright can be verified by measuring the height of the top of the sheer strake from the waterline on each side of the ship. By simple geometry:

$$\text{Tan list} = \frac{2(\text{freeboard difference})}{\text{breadth of ship}}$$

Four equal weights are placed on deck, two on each side, at equal distances off the centre line. The weights are chosen to total about 1/500 of the light displacment. Most shipyards use concrete blocks of known weight.

One weight is shifted from starboard to port and, after allowing sufficient time for the ship to settle in the listed condition, the deflection of the pendulum is noted. The second weight is shifted from starboard to port and the deflection of the pendulum is noted. Both the weights are then shifted back to their original places - the deflection should again be zero. The procedure is then repeated by shifting the weights from port to starboard, one at a time.

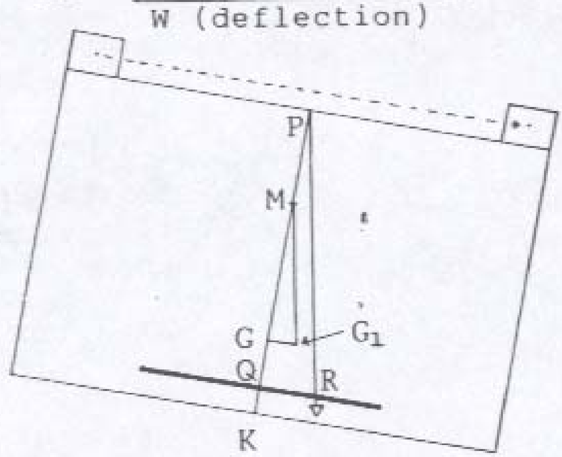
$$\text{Tan list} = \frac{\overline{GG_1}}{GM} = \frac{\bar{d}w}{W.GM}$$

Referring to the figure on the next page

$$\text{Tan list} = \frac{\text{deflection of pendulum}}{\text{length of plumb line}} = \frac{QR}{PQ}$$

$$\text{So } \frac{\text{deflection}}{\text{plumb length}} = \frac{dw}{W.GM}$$

$$GM = \frac{dw\ (\text{plumb length})}{W\ (\text{deflection})}$$



The GM for each shift of weight is calculated and the average initial fluid GM, in that condition, is obtained. The actual method of averaging varies between shipyards. Some average the deflections to port and starboard for the same weight shift. Some shipyards prefer to use weights of different values.

The KM for that displacement, and the FSC applicable, would have already been calculated by the shipyard. The KG solid for that condition is thus obtained:

KG solid = KM - GM fluid - FSC

By taking moments about the keel, due allowance is made for any weights that should go on or go off the ship so that the KG for the light condition is finally obtained.

Conditions necessary for accuracy:

1. Before the commencement of the experiment, the ship should be perfectly upright.

2. A large trim should be avoided.

3. The ship's initial GM should not be too small.

4. There should be no wind. If this is not possible, the ship should be heading into the wind.

5. All mooring lines to be slack.

6. Gangway to be well clear of jetty.

7. No other craft to be alongside.

8. The depth of water should be enough to ensure that the ship is freely afloat throughout this experiment.

9. All portable beams, derricks, boats, etc to be in proper sea-going condition.

10. Any loose weights to be secured.

11. All persons not directly connected with the experiment should be ashore. Those on board should stay on the centre line when deflections are being noted.

12. Boilers to be completely full/empty.

13. As far as possible, all tanks should be full or empty. If not possible, the value of FSM should be noted.

14. All bilges to be dry.

15. A record of each weight (and its KG) to go on or off the ship should be kept.

16. Drafts forward, aft and amidships and the density of water to be noted.

17. Due allowance must be made, in all calculations, for the weights placed on board for the conduct of the experiment.

18. The weights and the distances moved should be adjusted such that the list caused is reasonably small. If the list is insufficient, the deflection would be too small resulting in an inaccurate answer. If the list is more than a few degrees, the consequent increase of KG would render the result inaccurate.

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CHAPTER 45

STABILITY INFORMATION

SUPPLIED TO SHIPS

Regulation 10 of the International Load Line Convention 1966, & Regulation 22 of amended chapter II-1 of SOLAS 74 state in general terms that the master of a ship shall be supplied with sufficient information, approved by the government of the flag state, to enable him by rapid and simple processes to obtain guidance as to the stability of the ship under varying conditions of service.

The Merchant Shipping (Load Line) Rules 1968 of the United Kingdom, and the Merchant Shipping (Load Line) Rules 1979 of India specify the requirements of stability data in detail.

The following is a summary of the stability information required to be provided on board Indian and British ships under the above Rules:

1. The ship's name, official number, port of registry, gross and register tonnages, principal dimensions, draught, displacement and deadweight at the Summer load line shall be stated in the beginning of the stability booklet.

2. A profile view of the ship, and plan views as necessary, drawn to scale, showing the names and locations of all

main compartments, tanks, storerooms and accommodation for passengers and crew.

3. The capacity and the position of the COG (vertical and longitudinal) of every compartment available for cargo, fuel, stores and spaces for domestic water, feed water and water ballast. In the case of a vehicle ferry, the KG of a compartment shall be that estimated for the carriage of vehicles and not the volumetric centre of the compartment.

4. The estimated weight and position of the COG (vertical and longitudinal) of: (a) passengers and their effects and (b) crew and their effects, allowing for their distribution in the spaces they would normally occupy, including the highest decks to which they have access.

5. The estimated weight and position of the COG (vertical and longitudinal) of the maximum quantity of deck cargo that may reasonably be expected to be carried on exposed decks. If such deck cargo is likely to absorb water during passage, the arrival condition shall allow for such increase in weight. In the case of timber deck cargo, the absorption shall be assumed to be 15% by weight.

6. Information to enable calculation of the FSC of each tank in which liquids may be carried. A sample calculation to show how the information is to be used.

7. A diagram showing the load line mark and load lines with their corresponding freeboards.

8. A diagram or table giving the hydrostatic particulars - displacement, TPC, MCTC, AB, AF, KB, KMT, KML, water-plane areas and transverse cross-sectional areas for a range of drafts from the light waterline to the deepest permissible waterline. In the case of tables, the tabular interval shall be small enough for accurate interpolation. In case the ship has a raked keel, the base line for vertical distances shall be constant for all the particulars given/ used in calculations, including KG.

9. Diagrams or tables to enable the construction of the GZ curve, mentioning clearly the KG assumed in the given information. The allowance made for the stability and buoyancy provided by enclosed superstructures must be clearly stated. A sample calculation to show how the GZ curve is to be drawn.

10. Supplementary information to allow for the volume of timber deck cargo while drawing the GZ curve.

11. Calculation of GM and construction of the GZ curve shall include FSC.

12. Complete separate calculations, each with a profile diagram to scale showing the disposition of the main components of deadweight, under the following conditions:

(a) Light condition - with and without permanent ballast, if any.

(b) Ballast condition - departure port.

(c) Ballast condition - arrival port.

(d) Loaded condition - departure port.

(e) Loaded condition - arrival port.

(f) Service condition - departure port.

(g) Service condition - arrival port.

In the departure condition, fuel, FW and consumable stores are to be assumed full and in the arrival condition, they are to be 10% of their capacity.

In the loaded condition, each cargo space is to be assumed full of homogeneous cargo except where inappropriate as in the case of ships solely intended for the carriage of containers or vehicles. Sample calculations for loaded conditions shall be repeated for different stowage factors as appropriate.

Service conditions are conditions, other than those mentioned earlier, for which the ship is designed or which are desired by the shipowner.

13. Where the ship, in any of the sample conditions, does not satisfy the stability requirements under the Load Line Rules, such a warning shall be clearly marked on the sample calculation.

14. Where the shipyard feels that any particular loaded condition should be avoided, from the stress point of view, such a warning would be clearly given in the stability information supplied.

15. A copy of the report on the inclining test and the calculation therefrom, shall be included in the stability booklet. The inclining test on one ship may be acceptable for sister ships also.

16. The stability information booklet must have the approval of the government.

CHAPTER 46

STABILITY OF SHIPS

CARRYING GRAIN IN BULK

The word 'Grain' includes wheat, maize (corn), barley, oats, rice, rye, pulses, seeds and the processed forms thereof, whose behaviour is similar to that of grain in its natural state. 'In bulk' means loaded directly into the hold of a ship without any packaging. While carrying grain in bulk, the hazards involved are:

(1) Even though a compartment is filled completely with bulk grain at the port of loading, vibration and movement of the ship at sea causes the grain to settle down (by about 2% of its volume) resulting in the formation of void spaces at the top of the compartment. The hatch coaming, girders and other structural members that extend downwards from the deck head, obstruct free movement of grain during the final stages of loading. Void spaces, therefore, exist beyond such obstructions even though the compartment appears to be full at the time of loading. These voids add to the voids created by the settling down of bulk grain at sea.

(2) Bulk grain has a low angle of repose (about 20°). If the ship rolled greater than that, the grain would shift causing the ship to acquire a large list.

Filled compartments become partly filled later on at sea, thereby giving grain the freedom of movement during rolling. In view of these hazards, ships have to take special precautions when loading grain in bulk, regardless of whether the grain is loaded in only one hold or in more than one hold.

Chapter VI of SOLAS 1974 deals with ships carrying grain in bulk and is divided into Part A, Part B and Part C. Part A contains general provisions, Part B refers to calculation of assumed heeling moments and Part C deals with grain fittings and securing. Part A consists of thirteen regulations of which numbers 10, 11 and 4 are of significance here.

Regulation 10, titled 'Authorisation', requires that:

(a) Every ship loading bulk grain shall have a document of authorisation issued by, or on behalf of, the Administration stating that the ship is capable of complying with these regulations.

(b) The document shall accompany and refer to the grain loading stability booklet provided to enable the master to meet the requirements of regulation 4 - 'Intact Stability Requirements'. This booklet shall meet the requirements of regulation 11 - 'Grain Loading Information'. Both these regulations are described in the following pages.

(c) Such a document, grain loading stability data and associated plans may be in the language of the issuing country but a translation in English or in French shall be on board for the master to produce them for inspection, if required, by the government of the country of the port of loading.

(d) A ship without such a document of authorisation shall not load grain until the master demonstrates to the satisfaction of the Administration, or the Contracting Government of the port of loading on behalf of the Administration, that the ship, in its proposed loaded condition, will comply with the requirements of these regulations.

Regulation 11, titled 'Grain loading information', requires that sufficient information shall be available to enable the master to determine, in all reasonable loading conditions, the heeling moments due to grain shift calculated in accordance with Part B. Such information shall have the approval of the Administration and shall include:

(1) Ship's particulars.

(2) Light displacement and KG.

(3) Table of free surface corrections.

(4) Capacities and COG (vertical and longitudinal) of tanks and compartments.

(5) Curves or tables of grain heeling moments for every compartment, filled or partly filled, or combination thereof, including effects of temporary fittings.

(6) Tables of maximum permissible heeling moments or other information sufficient to allow the master to demonstrate compliance with regulation 4(c).

(7) Details of the scantlings of any temporary fittings and provisions to meet the requirements of Part C.

(8) Typical service conditions - loaded departure and arrival and, if necessary, intermediate worst service conditions.

(9) A worked example for the guidance of the master.

(10) Loading instructions in the form of notes summarising the requirements of this Chapter.

Regulation 4, titled 'Intact stability requirements', states that:

(a) The calculation required herein shall be based upon the stability information provided in accordance with amended Regulation 22 of chapter II - 1 of (SOLAS 74), or with the requirements of the Administration issuing the document of authorisation under regulation 10 of this chapter (i.e the Load Line Rules of the flag state).

(b) The intact stability characteristics of any ship carrying bulk grain shall be shown to meet, throughout the voyage, at least the following criteria after taking into account the heeling moments due to assumed shift of grain as described in Part B:

(i) The angle of heel due to the assumed shift of grain shall be not greater than 12°. The Administration granting the document of authorisation under regulation 10 may require a lesser angle of heel if it considers that experience shows it to be necessary. (For example, the permissible angle of heel might be limited to that at which the deck edge would immerse in still water.)

(ii) In the statical stability diagram, the net or residual area between the heeling arm curve and the righting arm curve upto the angle of heel of maximum difference between the ordinates of the two curves, or 40° or the angle of flooding (θf), whichever is the least, shall in all conditions of loading be not less than 0.075 metre radians.

(iii) The initial fluid GM shall be not less than 0.30 metre.

(c) Before loading bulk grain the master shall, if so required by the government of the country of the port of loading, demonstrate the ability of the ship, at all stages of any voyage, to comply with the stability criteria required by paragraph (b) of this regulation using the information approved and issued under regulations 10 and 11.

(d) After loading, the master shall ensure that the ship is upright before proceeding to sea.

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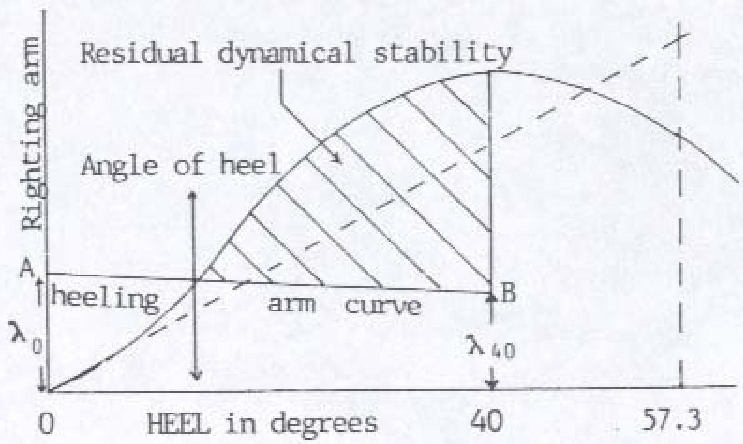
In Part B of chapter VI of SOLAS 74, the method of calculating the list under the assumed conditions of grain shift is illustrated by a diagram and some accompanying notes.



Note 1: $\lambda_0 = \dfrac{\text{volumetric heeling moment}}{\text{SF x Displacement}}$

Note 2: SF is volume per tonne of grain.

Note 3: $\lambda_{40} = 0.8 \times \lambda_0$.

Note 4: The heeling arm curve may be represented by the straight line AB.

Note 5: The righting arm curve shall be derived from cross curves which are sufficient in number to accurately define the curve and shall include cross curves at 12° and 40°.

Note 6: The KG of a filled compartment

shall be taken as that when it is filled to capacity, disregarding the assumed void on top.

Note 7: In a partly filled compartment, the vertical rise of the COG, as a result of the assumed transverse shift of grain, shall be compensated for by multiplying the transverse volumetric heeling moment by 1.12.

-oOo-

Calculation of list by use of the GZ curve has been explained in chapter 37 of this book. Hence the method followed in chapter VI of SOLAS 74 should be simple to understand. The heeling arm or upsetting lever at 0° heel = $\overline{GG_1}$. The heeling arm curve may be approximated by a straight line if its value at 40° is taken to be 0.8 $\overline{GG_1}$. This is the line AB shown in the figure in the previous page and Part B of chapter VI of SOLAS 74.

The volumetric heeling moment, in quadro metres, divided by the stowage factor of the grain loaded, in cubic metres per tonne, would give the heeling moment in tonne metres. This method has been adopted because the voids, and their assumed shift, are only dependant on the ship's geometry whereas the weight of cargo depends on the SF also.

$$\overline{GG_1} = \frac{\text{heeling moment in tonne metres}}{\text{Displacement}}$$

$$= \frac{\text{volumetric heeling moment}}{\text{SF x displacement}}$$

Appendix V of this book is an extract from the grain stability information of the general cargo vessel m.v. VIJAY. The volumetric heeling moments are given for each compartment when it is a 'filled compartment' and without any centre line division to restrict grain shift. The columns where the lower hold and the tween deck have been shown together are meant for use when the two compartments are loaded in common - the assumed voids in the lower hold would be filled up by flow of grain from the tween deck space, for which due allowance has been made in the assumed void at the top of the tween deck space, in accordance with Part B of chapter VI of SOLAS 74. The grain loading stability information would state the conditions necessary when resorting to common loading - such as keeping the tween deck hatchway and trimming hatches open, etc.

As per chapter VI of SOLAS 74, the KG shown is that for the full compartment disregarding the assumed void on top.

Appendix VI of this book is another extract from the grain loading stability information of the same cargo ship - m.v. VIJAY - showing the grain loading diagram of number 3 hold and tween deck. Similar diagrams would be given for all the other grain spaces also. This diagram gives the stability data - the volumetric heeling moment, volume of grain and its KG - for all possible levels of grain in this hold alone or in this lower hold and tween deck loaded in common. The only information needed to enter this diagram is the ullage of grain (vertical distance from the top of the hatch coaming of the upper deck to the surface of the grain) after trimming level. One curve gives the volume of grain while another curve gives its KG. For volumetric heeling moment, two curves are given here - one curve for loading in the lower hold alone and the other for loading in the lower hold and tween deck in common. When the hold is partly filled, if any centre line division is expected to be fitted to restrict shift of grain, the volumetric heeling moment would be considerably less and hence another pair of curves would be given - one for the lower hold alone and the other for the lower hold and tween deck loaded in common.

As per chapter VI of SOLAS 74, the volumetric heeling moment of a partly filled compartment must be multiplied by 1.12 to compensate for the vertical rise of the COG resulting from the transverse shift of grain. Hence the value of the volumetric heeling moment obtained from the grain loading diagram, in appendix VI of this book, must be multiplied by 1.12 whenever the compartment is partly filled.

While calculating the volumetric heeling moments, in accordance with chapter VI of SOLAS 74, the shipyard would have assumed a shift of grain surface to be: 15 degrees in filled compartments; 25 degrees in partly filled compartments.

Appendix VII of this book is the KN table of m.v.VIJAY to be used when loading grain. This is similar to appendix II but, in accordance with chapter VI of SOLAS 74, it gives the KN values at 12° and at 40° also.

The stability calculation, using the information provided, is illustrated by the following worked examples:

Example 1

M.v.VIJAY is in SW, loaded down to her marks with grain of SF 1.5. The KM, for the load displacement of 19943 tonnes, is 8.704 m. KG = 7.679 m, FSM = 1284 tm. All lower holds and tween decks are full and loaded in common. Using appendices V and VII of this book, verify whether the ship satisfies the requirements of Regulation 4 of chapter VI of SOLAS 74, given that the angle of flooding at the load displacement is over 40°.

FSC = FSM/W = 1284/19943	= 0.064 metre.
KG solid	= 7.679 metres
KG fluid	= 7.743 metres
KM for load displacement	= 8.704 metres
GM fluid	= 0.961 metre.

The initial GM fluid > 0.3 metre.

From appendix V, total volumetric heeling moment (common loading of all LH and TD spaces) = 5414 quadro metres.

$$GG_1 = \frac{\text{volumetric heeling moment}}{\text{SF of grain loaded} \times W}$$

$$= \frac{5414}{1.5(19943)} = 0.181 \text{ metre.}$$

Approximate calculation:

$$\text{Tan } \theta = \frac{\overline{GG_1}}{GM} = \frac{0.181}{0.961} = 0.188345$$

$$\text{Approximate list} = 10.67°$$

From appendix VII, righting lever:

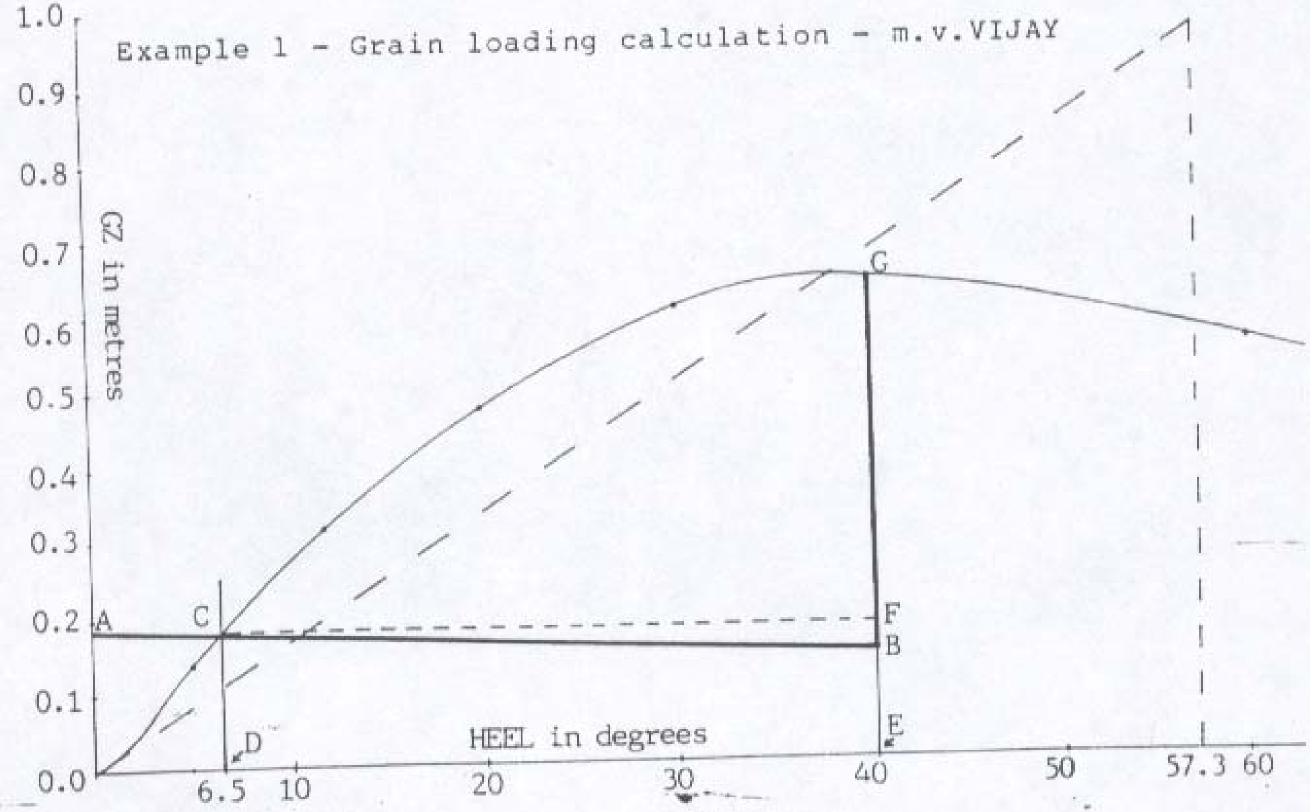
$\theta°$	KN	- KG Sin θ	= GZ m
0	0.000	7.743 Sin 0°	0.000
5	0.811	7.743 Sin 5°	0.136
12	1.925	7.743 Sin 12°	0.315
20	3.120	7.743 Sin 20°	0.472
30	4.475	7.743 Sin 30°	0.604
40	5.608	7.743 Sin 40°	0.631
60	7.268	7.743 Sin 60°	0.562
75	7.727	7.743 Sin 75°	0.248

Upsetting lever at 0° = $\overline{GG_1}$ = 0.181 m
& at 40° = 0.8$\overline{GG_1}$ = 0.8(0.181) = 0.145 m

The values of the righting arm and the upsetting arm obtained above, plotted on the next page, indicate that the list caused by the assumed shift of grain would be 6.5° which is well below the maximum allowed - 12°.

From the curves plotted on the next page it will be seen that:

Maximum difference between the righting arm and the upsetting arm occurs at about 43°. The angle of flooding is given to be over 40°. Hence the residual area is to be calculated between the angle of list (i.e., 6.5°) and 40°.


Example 1 - Grain loading calculation - m.v.VIJAY
GZ in metres
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
HEEL in degrees
6.5
10
20
30
40
50
57.3
60
A
B
C
D
E
F
G

The residual area may be calculated with a fair amount of accuracy as follows:

Measure off distance DC, the upsetting lever at the computed list, and lay it off as EF at 40°. In this case, DC = EF = 0.180 m. BE is the upsetting lever at 40° and so BF = 0.180 - 0.145 = 0.035 m. CF = DE = 40 - 6.5 = 33.5 degrees.

Area of triangle CFB = (33.5 x 0.035)/2
= 0.58625 metre degrees.

The area under the curve between CF & FG may be calculated using Simpson's Rules.

The residual area required is the sum of the two areas calculated as above.

CF may be divided into six equal parts and the seven ordinates measured off. In this case, the interval would be 33.5/6 = 5.583°, starting from 6.5°, and the ordinates would thus be measured off at 6.5, 12.08, 17.67, 23.25, 28.83, 34.42 & 40 degrees.

Station degrees	Ordinate metre	SM	Area function
6.50	0.000	1	0.000
12.08	0.135	4	0.540
17.67	0.255	2	0.510
23.25	0.345	4	1.380
28.83	0.410	2	0.820
34.42	0.445	4	1.780
40.00	0.451	1	0.451
		SOP	5.481

Area = 5.583(5.481) ÷ 3 = 10.20014 m deg

Sum of the areas = 10.20014 + 0.58625
= 10.78639 metre degrees
= 0.18824 metre radians

This is > 0.075 metre radians.

The ship in this condition, therefore, meets all the requirements of Regulation 4 of chapter VI of SOLAS 1974.

Example 2

M.v.VIJAY is displacing 11943 t in SW. KG = 7.18 m, FSM = 700 tm. A consignment of 2000 t of bulk grain, SF 1.25, is offered for shipment. No: 3 is the only empty hold available. Verify whether the ship would meet all the requirements of regulation 4 of chapter VI of SOLAS 74 without fitting any shifting boards on the centre line. Use the relevant appendices of this book where necessary.

Volume of grain = 2000 x 1.25 = 2500 m^3.

Entering the grain loading diagram of No 3 (appendix VI) with the volume of grain as 2500 m^3, the ullage is found to be 5.75 m. Entering the same diagram with ullage as 5.75 m, the KG of grain and the volumetric heeling moment are found to be 5.15 m and 4275 m^4.

Note: The tween deck hatchway must be properly closed and either battened down or overstowed with suitable cargo so that the bulk grain in the lower hold cannot shift into the tween deck space during rolling. If this is not done, the volumetric heeling moment must be taken from the other curve which is meant for common loading. This would give 6950 m^4!

Taking moments by keel for the final KG,

$11943(7.18) + 2000(5.15) = 13943(\text{New KG})$

New KG	=	6.889 m
FSC = FSM ÷ W = 700 ÷ 13943	=	<u>0.050</u> m
Final KG fluid	=	6.939 m
KM for final W of 13943	=	<u>8.076</u> m
Final GM fluid	=	1.137 m

The initial Fluid GM > 0.3 metre.

Note: The rise of COG, due to transverse shift of grain in a partly filled compartment, is to be compensated for by multiplying the transverse heeling moment by 1.12 in accordance with chapter VI of SOLAS 74.

Transverse volumetric heeling moment, from appendix VI, = 4275 quadro metres.

Volumetric heeling moment to be used

= 4275 x 1.12 = 4788 quadro metres.

$$\overline{GG_1} = \frac{\text{volumetric heeling moment}}{SF \times W}$$

$$= \frac{4788}{1.25 \times 13943} = 0.275 \text{ metre}$$

Approximate calculation of list:

$\text{Tan } \theta = \overline{GG_1}/GM = 0.275 \div 1.137 = 0.24186$

Approximate list = 13.6°.

From appendix VII, righting lever:

$\theta°$	KN	- KG Sin θ	= GZ m
0	0.000	6.939 Sin 0°	0.000
5	0.793	6.939 Sin 5°	0.188
12	1.892	6.939 Sin 12°	0.449
20	3.137	6.939 Sin 20°	0.764
30	4.696	6.939 Sin 30°	1.227
40	6.011	6.939 Sin 40°	1.551
60	7.722	6.939 Sin 60°	1.713
75	8.001	6.939 Sin 75°	1.298

Upsetting lever at 0° = $\overline{GG_1}$ = 0.275 m
& at 40° = $0.8\overline{GG_1}$ = 0.8(0.275) = 0.220 m

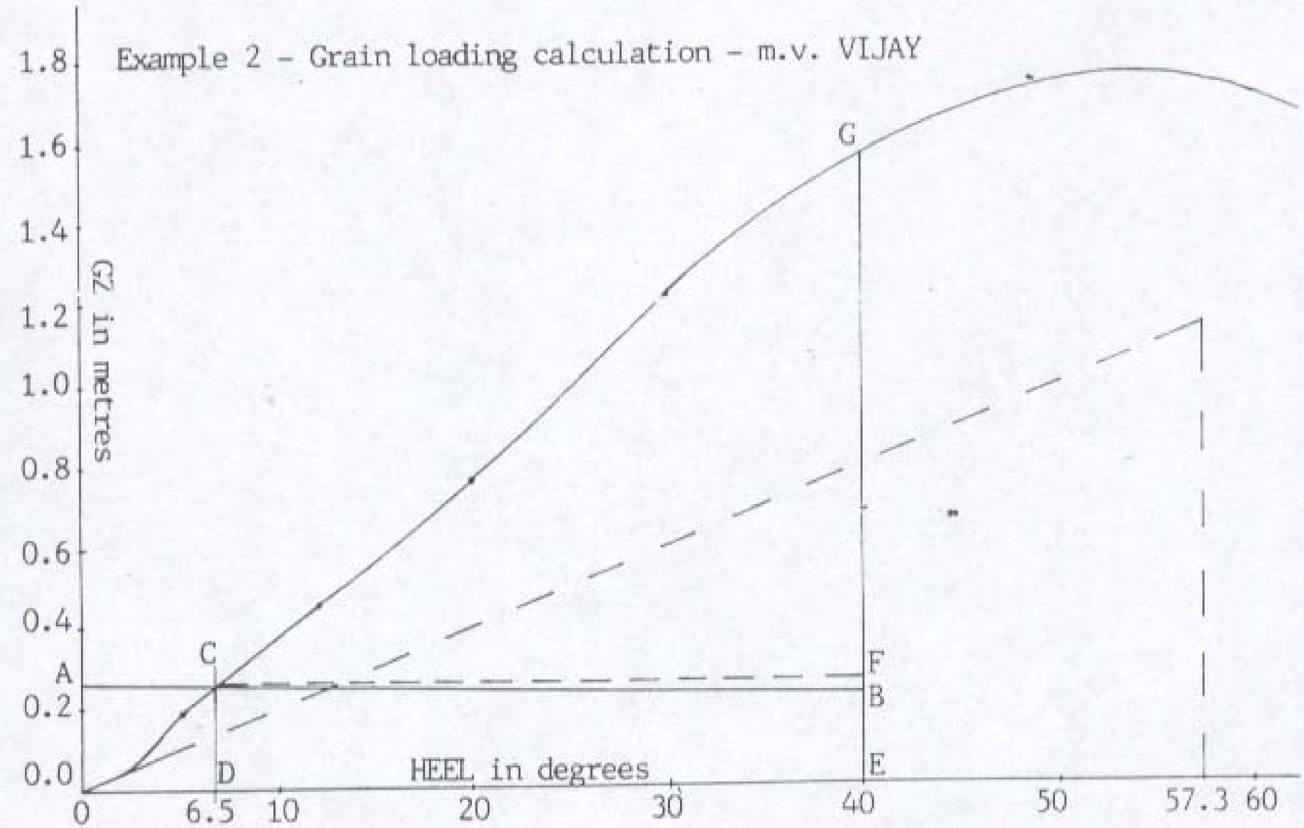
The values of the righting arm and the upsetting arm obtained above, plotted on the next page, indicate that the list caused by the assumed shift of grain would be 6.5° which is well below the maximum allowed - 12°.

From the curves plotted on the next page it will be seen that:

Maximum difference between the righting arm and the upsetting arm occurs at about 55°. The angle of flooding is known to be over 40°. Hence the residual area is to be calculated between the angle of list (i.e., 6.5°) and 40°.

As done in example 1, points A, B, C, D, E, F and G may be inserted on the graph on the next page and the residual area calculated in two parts and added together.

BF = EF - BE = 0.26 - 0.22 = 0.04 metre.


Example 2 - Grain loading calculation - m.v. VIJAY
GZ in metres
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
C
D
G
F
B
E
HEEL in degrees
0
6.5
10
20
30
40
50
57.3
60

Area of triangle CBF = 33.5 x 0.04 ÷ 2
= 0.67 metre degree.

By sheer chance, the list computed in this example is the same as that in example 1, despite a very different situation! Hence the ordinates may be measured off at the same station values as before at intervals of 5.583 degrees from 6.5 degrees.

Station degrees	Ordinate metre	SM	Area function
6.50	0.000	1	0.000
12.08	0.190	4	0.760
17.67	0.410	2	0.820
23.25	0.650	4	2.600
28.83	0.910	2	1.820
34.42	1.090	4	4.360
40.00	1.280	1	1.280
		SOP	11.640

Area = $\frac{5.583(11.640)}{3}$ = 21.66204 m degree

Sum of the two areas = 21.66204 + 0.6700

= 22.33204 metre degrees

= 0.389739 metre radian.

This is > than 0.075 metre radian.

The ship in this condition, therefore, meets all the requirements of Regulation 4 of chapter VI of SOLAS 1974.

-oOo-

CHAPTER 47

SHEAR FORCE AND

BENDING MOMENT IN BEAMS

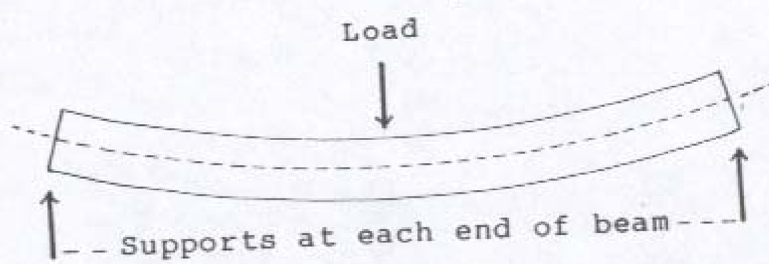
A 'beam' is a structural member that offers resistance to bending caused by applied loads. Unless stated otherwise a beam should be considered to be straight and homogenous - of uniform construction & constant cross-sectional area throughout its length.

The term 'light beam' means that the weight of the beam may be neglected in that problem.

The term 'concentrated load' means that the given force acts at a single point.

The term 'uniform load' denotes that the force is spread evenly over a given distance on the beam.

In this chapter, all forces are considered to be in the same plane - act either upwards or downwards only.



When a load is applied to a beam, it gets deflected (bent). In the above case the upper part suffers compression and gets shorter. The lower part suffers tension and gets longer. The middle part remains at its original length, as it does not experience any tension or compression, and is called the 'neutral axis'. That is why the top and bottom of a beam must have more material in them to provide greater strength to the beam. The beam need not be very strong at its neutral axis. It is for this reason that 'I' beams are most popular.

Normally, the beam would regain its original shape when the load is removed. But, if the beam is stressed beyond its elastic limit, the deflection would be permanent.

Shear force is a force which tends to break or shear a beam across (perpendicular to) its major axis. SF tends to cause one layer of the material to slide over an adjacent layer and thereby tends to cause the material to separate into two parts.

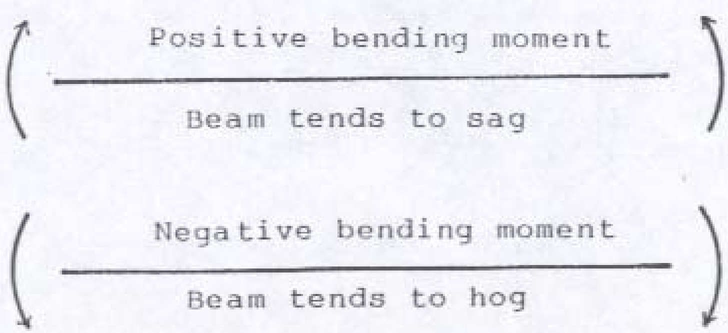
When a beam is in static equilibrium, the net resultant of all the forces acting on it must be zero. If the resultant force to one side of a point on the beam has a value 'x' in the upward direction, then the resultant force on the other side of that point must also be 'x' but in the downward direction. Therefore, at any point on a beam, SF is the algebraic sum of the forces acting on any one side of that point. In this book, the left side has been considered to calculate SF at any point.

Sign convention for SF: In this chapter, all upward forces are considered positive and all downward forces, negative.

Bending moment at any point on a beam is the total moment tending to alter the shape of the beam. Since the beam is in static equilibrium, the sum of the clockwise moments about any point on the beam is equal to the sum of the anti-clockwise moments about the same point. BM is, therefore, the algebraic sum of all the moments acting on any one side of the point under consideration.

Sign convention for BM: All clockwise moments to the left, and anti-clockwise to the right, of the chosen point are termed positive. In other words, bending moments that tend to cause the beam to sag are considered positive.

Clockwise moments to the right, and anti-clockwise to the left, of the chosen point are termed negative. In other words, bending moments that tend to cause the beam to hog are considered negative.



S.I. Units:

Force = mass x acceleration

where acceleration is in metres per sec^2 mass is in kilogrammes and force is in Newtons. The acceleration due to gravity being 9.81 m per sec^2, the gravitational force acting on a mass of 1 kg = 9.81 N.

In stability, the kilogramme is found to be too small a unit and hence mass is expressed in tonnes and the units of force would then be kilonewtons or kN.

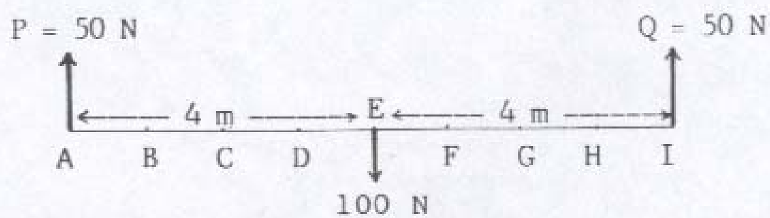
SI Units of BM would be 'N m' or 'kN m'.

Example 1

A light beam 8 m long is supported at its ends. If a mass of 10.1937 kg is placed at its centre, draw the SF and BM diagrams to scale.

Gravitational force = mass x g

= 10.1937(9.81) = 100 N.



Since the load is at the centre of the beam, the reactions (upward) at the ends (forces P and Q in the above figure) would be equal to 50 N each.

Calculation of SF:

Consider point A. To its left, there are no forces. So the SF at A should be zero. However, at a point just one mm away from A, the force to its left would be +50 N. So the SF at A may be said to be changing from zero to +50 N.

Consider point B. To its left, the sum of all the forces is +50 N. So SF at B = +50 N. At points C and D also, the value of SF is found to be +50 N.

Consider point E. One mm to the left of E, the SF is still +50 N. At a point one mm to the right of E, the sum of all the forces to the left = -50 N. So the SF at E may be said to be changing from +50 N to -50 N.

Consider point F. The sum of all the forces to its left = SF = -50 N. At points G and H also, the SF is found to be -50 N.

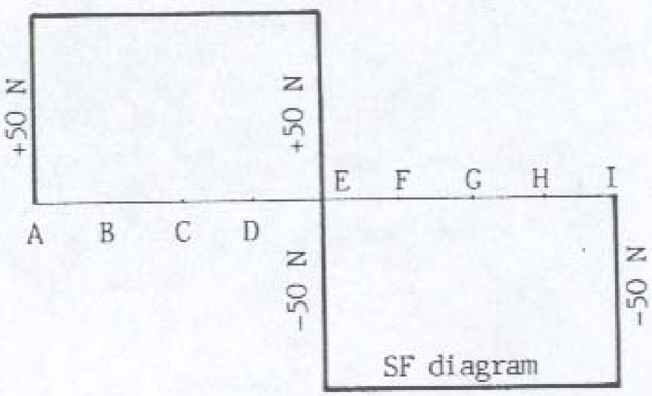
Consider point I. One mm to the left of I, the SF = -50 N, as was in points F, G and H. At I, the SF changes from -50 N to zero.

The values of shear force at each of the chosen points may be expressed, in the form of a table, as shown below. From the left end, at one metre intervals:

Point	A	B	C	D	E	F	G	H	I
SF	0				+50				0
(N)	+50	+50	+50	+50	-50	-50	-50	-50	-50

The SF diagram:

The values of SF, calculated for each of the chosen points, may be graphically depicted and is called the SF diagram:



Scale: Linear 1 cm : 1 m, SF 1 cm : 20 N

As mentioned earlier in this chapter, the algebraic sum of the SF acting on the beam must be zero because the beam is in static equilibrium. This means that the area enclosed by the SF curve, above and below the base line, must be equal. Since SF above the base line is termed positive and below termed negative, the algebraic sum must = zero.

Calculation of BM: **Method 1:**

Referring to the diagram on page 153, consider point A. There are no forces to the left of A. So the sum of moments to the left of A = BM at A = zero.

Consider point B. The moment of the only force to the left, about point B, is + (50 x 1) = 50 N m = BM at B.

Consider point C. The sum of moments of all the forces to the left, about point C, is (50 x 2) = 100 N m = BM at C.

Consider point D. The sum of moments of all the forces to the left, about point D, is (50 x 3) = 150 N m = BM at D.

Consider point E. The sum of moments of all the forces to the left, about point E, is (50 x 4) = 200 N m = BM at E.

Consider point F. The sum of moments of all the forces to the left, about F, is (50 x 5) - (100 x 1) = 150 N m = BM at F.

Consider point G. The sum of moments of all the forces to the left, about G, is (50 x 6) - (100 x 2) = 100 N m = BM at G.

Consider point H. The sum of moments of all the forces to the left, about H, is (50 x 7) - (100 x 3) = 50 N m = BM at H.

Consider point I. The sum of moments of all the forces to the left, about I, is (50 x 8) - (100 x 4) = 0 N m = BM at I.

Calculation of BM: Method 2:

The BM at any point on the beam is the area under the SF curve upto that point. Cover up the SF diagram with a paper. Keeping its left edge vertical, move it slowly to the right, thereby uncovering the SF diagram from the left.

At point A, the area uncovered so far = BM at A = zero.

At point B, the area uncovered so far = (50 x 1) = 50 N m = BM at B.

At point C, the area uncovered so far = (50 x 2) = 100 N m = BM at C.

At point D, the area uncovered so far = (50 x 3) = 150 N m = BM at D.

At point E, the area uncovered so far = (50 x 4) = 200 N m = BM at E.

At point F, the area uncovered so far = (50 x 4) - (50 x 1) = 150 N m = BM at F.

At point G, the area uncovered so far = (50 x 4) - (50 x 2) = 100 N m = BM at G.

At point H, the area uncovered so far = (50 x 4) - (50 x 3) = 50 N m = BM at H.

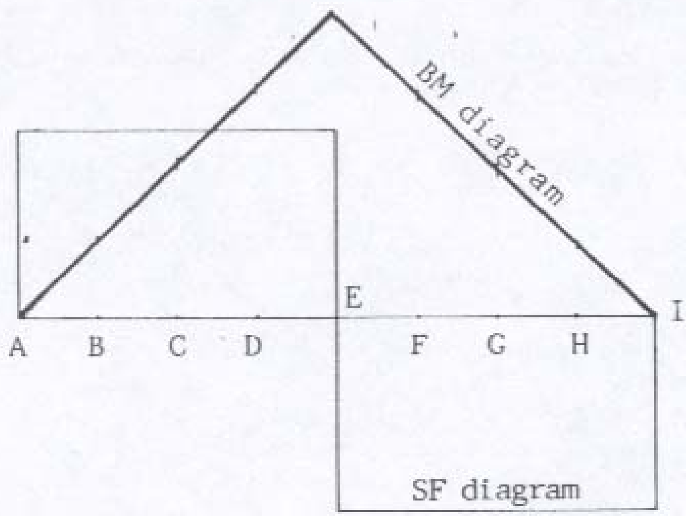
At point I, the area uncovered so far = (50 x 4) - (50 x 4) = 0 N m = BM at I.

The values of BM at each of the chosen points may be expressed, in the form of a table, as shown below. Commencing from the left end of the beam, at one metre intervals, BM in N m is:

Point	A	B	C	D	E	F	G	H	I
BM	0	50	100	150	200	150	100	50	0

The values of BM, calculated for each of the chosen points, may be graphically depicted as illustrated in the following figure:

The BM diagram:



Scales:- Linear 1 cm : 1 m
SF 1 cm : 20 N BM 1 cm : 50 N m

Important notes

The BM curve is drawn on the same base line as the SF curve. This is done for the sake of convenience in plotting and for easy reference.

The scales used herein are small owing to the small size of the pages in this book but, in order to obtain accurate results in problems of this type, the student is advised to use as large a linear scale as would comfortably fit on the paper used by him.

The scales used for SF and BM should be reasonably large. A common mistake made by students is to make the SF and

BM scales too large, being tempted to do so by the shape of the fools-cap size of paper used! This makes the diagrams look lop-sided and also makes it difficult to draw the curves. In example 1, the SF and BM diagrams were made up of straight lines but, as may happen frequently in later examples, they may be curved. The importance of this point would then become obvious. It is recommended here that the scales for SF and BM should be so adjusted that the vertical size of the entire diagram does not exceed the horizontal size.

Where the SF curve is a horizontal straight line, the BM curve would be a sloping straight line.

Where the SF curve is a sloping straight line, the BM curve would not be a straight line.

At the point where the SF curve crosses the base line, the BM curve would reach a peak or a trough - change direction in such a manner that if it was going away from the base line, it would thence bend towards the base line and vice versa. In example 1, there is only one peak and hence that is also the point of maximum BM. In subsequent problems, it will be seen that there may be more than one peak and/or trough of differing values of BM but, at each peak or trough of the BM curve, the value of SF at that point on the beam would be zero.

When looking for the maximum value of BM, it must be remembered that the numerical value is of primary importance. The sign + or - before the value of BM only indicates whether the beam tends to sag or hog at that point.

Wherever there is a concentrated load or force, SF and BM curves will suffer a drastic change at that point.

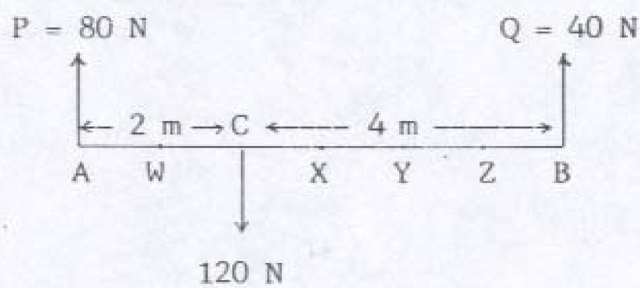
Wherever there is a uniform load or force, SF and BM curves will experience a gradual change along that part.

Example 2

A light beam 6 m long is supported at ends A and B. A mass of 12.232 kg is hung at point C, 2 m from end A. Draw the SF and BM diagrams to scale.

Gravitational force = mass x g

= 12.232(9.81) = 120 N.



To find P & Q the reactions at each end, moments about point A:

(120 x 2) = (Q x 6), so Q = 40 N.

Total force up = total force down.

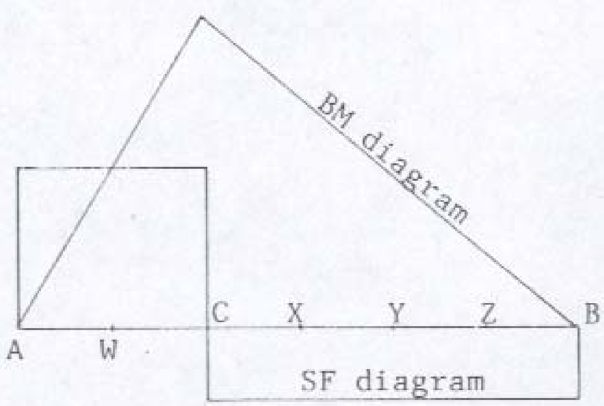
(P + Q) = 120, so P = (120 - 40) = 80 N.

The values of P and Q may be inserted in the figure on the previous page for easy reference while computing SF and BM.

Following the procedure explained in example 1, the values of SF and BM, at each point, are as given below:

Point	A	W	C	X	Y	Z	B
SF)	00		+80				00
(N))	+80	+80	-40	-40	-40	-40	-40
BM(N m)	00	80	160	120	80	40	00

The SF & BM diagram:



Note: The SF curve consists of two horizontal straight lines. So the BM curve consists of two sloping straight lines, as mentioned earlier in this chapter.

The scale used should be clearly mentioned on the diagrams. In this book, the scale has sometimes been omitted intentionally as the diagrams are only to illustrate the nature of the curves so that the student understands their construction.

Example 3

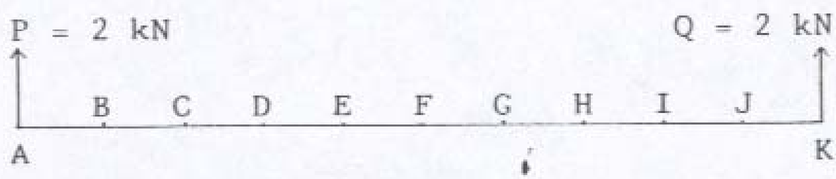
A uniform bar of length 10 m and mass 407.747 kg is supported at its ends. Draw the SF and BM curves to scale.

Gravitational force = load = mass x g

$$= 407.747(9.81) = 4000 \text{ N} = 4 \text{ kN}.$$

Since the bar is uniform and supported at its ends, the reactions (P and Q) at the ends are each 2 kN.

$$\text{Load per m run} = \frac{\text{load}}{\text{length}} = \frac{4}{10} = 0.4 \text{ kN}.$$



Calculation of SF

At A, SF is changing from 0 to +2 kN.

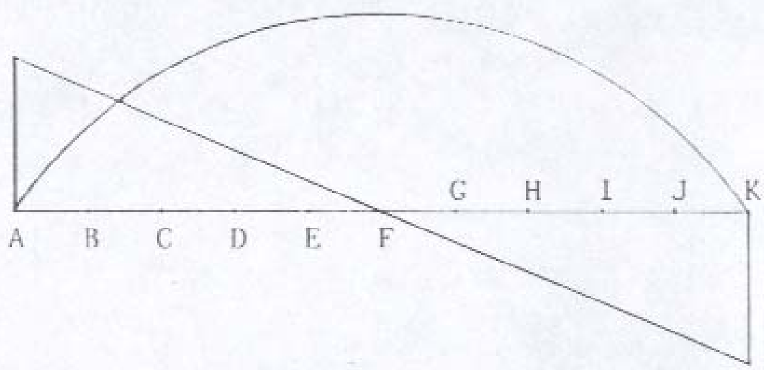
At B, SF = (+2 - 0.4) = +1.6 kN. The -0.4 kN is the weight of the one-metre section AB, which acts at the mid point of AB, which is to the left of point B.

At C, SF = (+2 - 0.8) = +1.2 kN. The -0.8 kN is the weight of the two-metre section AC which acts at B.

It is now obvious that for every 1 metre of length, the SF changes by -0.4 kN.

The SF, in kN, at each point would be:

A: 0 & +2; B: +1.6; C: +1.2; D: +0.8; E: +0.4; F: 0; G: -0.4; H: -0.8; I: -1.2 J: -1.6; K: -2 & 0.



After drawing the SF curve, the values of BM may be computed, as described earlier in this chapter, and the results obtained, in kN m, would be:

A	B	C	D	E	F	G	H	I	J	K
0	1.8	3.2	4.2	4.8	5.0	4.8	4.2	3.2	1.8	0

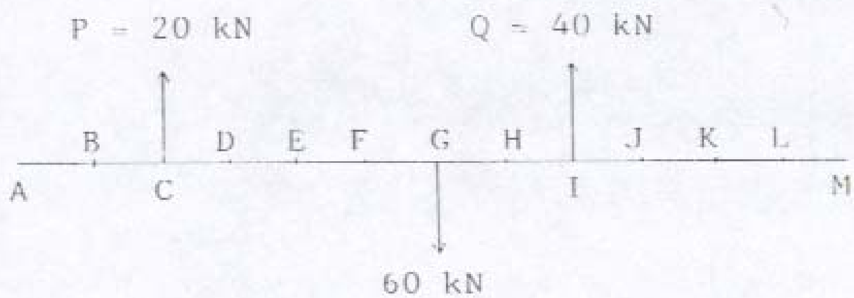
The values of BM may now be plotted to scale, and joined together, as shown in the above diagram.

Example 4

A beam of mass 6.116 t and length 12 m is suspended horizontally by two wires. The first wire is attached 2 m from the left end and the second wire, 4 m from the right end. Draw the SF and BM diagrams to scale.

Force of gravity = 6.116(9.81) = 60 kN.

Load per m run = 60/12 = 5 kN.



To find P & Q, the reactions at C & I, moments about point C:

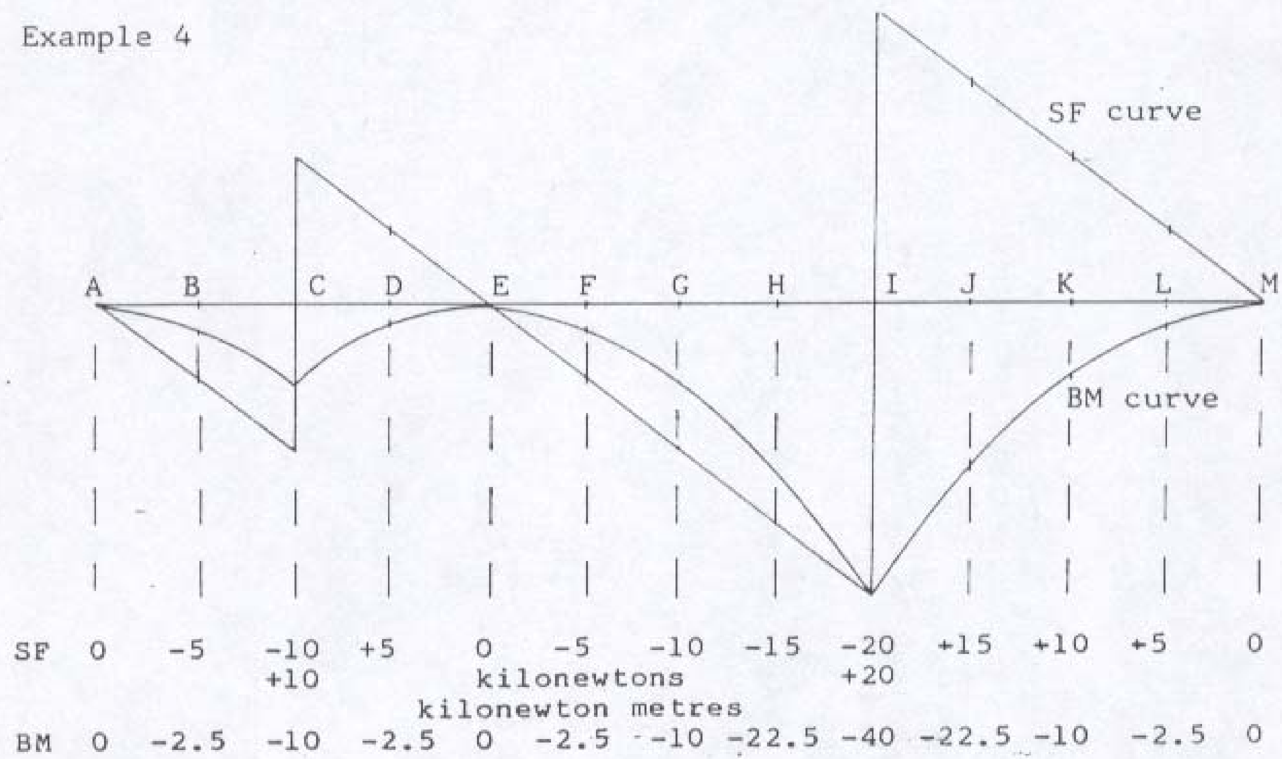
Note: For this purpose, the entire gravitational force is considered to act at point G, the COG of the beam. In the rest of the problem, the load will be considered separately per metre run.

(Q x 6) = (60 x 4) so Q = 40 kN.

(P + Q) = 60 so P = 60 - 40 = 20 kN.

The values of P and Q are inserted in the above figure for easy reference.

Example 4


SF curve
BM curve
A B C D E F G H I J K L M
SF 0 -5 -10 +10 +5 0 -5 -10 -15 -20 +20 +15 +10 +5 0
kilonewtons
kilonewton metres
BM 0 -2.5 -10 -2.5 0 -2.5 -10 -22.5 -40 -22.5 -10 -2.5 0

Following the procedure explained in the earlier examples, the values of SF and BM may be calculated for a number of points and the diagrams drawn as illustrated in the previous page.

In this case, the values of SF could have been calculated conveniently at two metre intervals and plotted without loss of accuracy in the SF diagram because it consists of three straight lines only. However, while calculating the values of BM at various points and plotting them, the shape of the curve would not be properly obtained, in this case, if the points considered were two metres apart instead of one metre.

The important notes contained in pages 158, 159 and 160 may now be re-read and verified by inspecting the SF and BM diagrams of this example.

An interesting feature, noticeable in this example, is that SF and BM may both be zero at the same point on the beam.

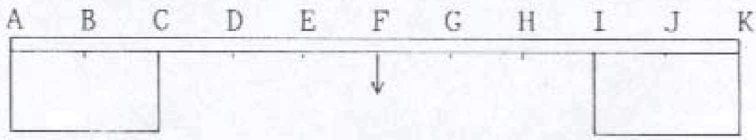
-oOo-

Example 5

A beam of mass 61.162 kg and length 10 m rests on two flat supports. Each support extends 2 m inwards from the end of the beam. A concentrated mass of 30.581 kg is placed on the centre of the beam. Draw the SF and BM diagrams to scale.

Gravit. force on beam = m x g = 600 N.
Gravit. force on concentr. mass = 300 N.

Total force downwards = 900 N. So total force upwards also = 900 N. Hence the reaction at each support = 450 N, spread over 2 m.



Reaction per metre, at each end = 225 N.

Weight of beam alone per metre = 60 N.

SF at A = 0. SF at B = +225 - 60 = 165 N
SF at C = (SF at B + 225 - 60) = 330 N

SF at D, E and one mm before F are 270, 210 and 150 N respectively. At F, SF changes by -300 to -150 N.

SF at G, H and I are -210, -270 & -330 N respectively.

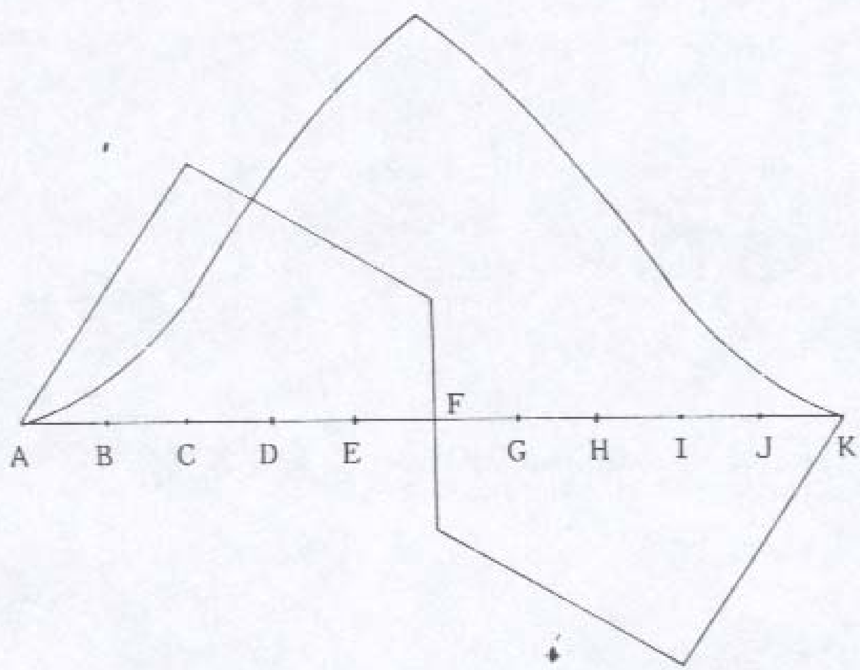
SF at J = (SF at I + 225 - 60) = -165 N.
SF at K = (SF at J + 225 - 60) = zero N.

The values of SF at various points may be tabulated as follows:

Point	A	B	C	D	E	F
SF (N)	0	165	330	270	210	150 -150

Point	G	H	I	J	K
SF (N)	-210	-270	-330	-165	0

The SF diagram may now be drawn to scale and then the BM values calculated as in earlier examples.



The values of BM, in N m, at various points may be tabulated as follows:

Point	A	B	C	D	E	F
BM	0	82.5	330	630	870	1050

Point	G	H	I	J	K
BM	870	630	330	82.5	0

The values of BM may now be plotted to scale as shown in the diagram above.

-oOo-

Exercise 40
SF and BM - Beams

1. A light beam 12 m long is supported at its ends. A concentrated load of 40 N is applied at its centre. Draw the SF and BM curves to scale.

2. A light beam AG, 6 m long, is supported at its ends. A load of 12 N is placed at E, such that GE = 2 m. Draw the SF and BM curves to scale.

3. A light beam AF, 10 m long, rests on its ends. B, C, D & E are points at 2 m intervals on this beam. Concentrated loads of 4, 5, 6 & 7 N are placed at B, C, D & E respectively. Draw the SF and BM curves to scale.

4. A beam AM, 12 m long and mass 61.163 kg, is suspended horizontally by two wires attached to points C and K, 2 m from each end. Draw the SF and BM diagrams to scale.

5. In question 4, if the support wire from point K is shifted to end M, draw the SF and BM diagrams to scale.

6. A beam, of mass 5096.84 kg and length 10 m, is supported at its ends. Two concentrated masses are placed on it: 4077.482 kg 3 m from the left end and 6116.248 kg 2 m from the right end. Draw the SF and BM diagrams to scale.

7. A beam AK, of 10193.68 kg mass and 10 m length, is marked A, B. ...K at one metre intervals. It is supported at

points C and H. A concentrated mass of 2038.736 kg is placed at end K. An uniform mass of 3058.104 kg is spread evenly between points B and E. Draw the SF and BM diagrams to scale.

8 A beam, of mass 61.162 kg and length 12 m, rests on two flat supports which extend 3 m inwards from each end. Draw the SF and BM diagrams to scale.

9 If in question 8, a concentrated load of 150 N is placed on the centre of the beam, draw the SF and BM diagrams to scale.

10 A beam AK, of mass 2038.736 kg and length 20 m, rests fully on a level surface. Points A, B, C....K are marked on it at two metre intervals. Three masses are placed on it as follows:

5096.84 kg spread evenly between points B & D;

3058.104 kg spread evenly between points F & G;

3058.104 kg spread evenly between points J & K.

Draw the SF and BM diagrams to scale.

State the maximum values of SF and BM and the points where they act.

-oOo-

CHAPTER 48

SHEAR FORCE AND BENDING MOMENT IN BOX-SHAPED VESSELS

For calculations involving SF and BM, a ship may be considered to be a beam whose length equals the length of the ship. When floating freely, the forces of gravity and buoyancy, acting on the ship, are equal.

The force of gravity, acting on the ship, would have different values at various places along the ship's length depending on the longitudinal distribution of the weights on board, including the weight of the hull itself.

The force of buoyancy also would have different values at various points along the length of the ship as it depends on the shape of the underwater part of the hull in the vicinity of the point under consideration.

If the vessel is box-shaped and on an even keel, the force of buoyancy would act evenly all along the length of the ship. If the box-shaped vessel is trimmed by the stern, buoyancy would be more at the stern and less at the bow, and vice versa, but the total buoyancy must always be equal to the total gravity experienced.

To facilitate calculation, the forces of buoyancy and gravity are split up on a 'per metre' basis. This is because the mass of each item considered is so great - in tonnes and not in kilogrammes - that a load has to act over a definite distance along the length of the ship and cannot be considered to act at a single point.

Using the ship's length as the base line, the values of 'weight per metre' and 'buoyancy per metre' are plotted to scale and the 'weights curve' and the 'buoyancy curve' are constructed. The area between the weights curve and the base line would give the total weight of the ship, while the area between the buoyancy curve and the base line would give the total buoyancy.

At any point along the length of the ship, the difference between the values of 'weight per metre' and 'buoyancy per metre' is called 'load per metre'. At certain parts of the ship, buoyancy would be greater than gravity - the load is then considered to be positive. Over other parts of the ship, gravity would be more than buoyancy - the load is then considered to be negative. The resultant load, or the sum total of the load, experienced by the ship must be zero - the area enclosed by the loads curve above the base line must equal the area enclosed by it below the base line.

Integration of the loads curve, upto any chosen point, would would give the SF at that point. In other words, the algebraic sum of the area enclosed by the loads curve, to one side of the chosen point, is the SF at that point. The values of SF may thus be calculated at various points along the length of the ship and the SF curve may be drawn.

The method of obtaining the BM curve, from the SF curve, is the same as that explained in the previous chapter.

Since the words 'displacement' and 'buoyancy' are used extensively in the subject of stability, and are expressed therein in tonnes (denoting the mass of water displaced), the unit used in this chapter also, for weight, buoyancy, load, etc is tonnes. It is considered essential to use this unit here, in preference to kilonewtons, in order to co-relate the subjects of ship stability and ship construction. Those desirous of using kilonewtons may multiply tonnes by 'g' - 9.81 m/sec/sec.

Example 1

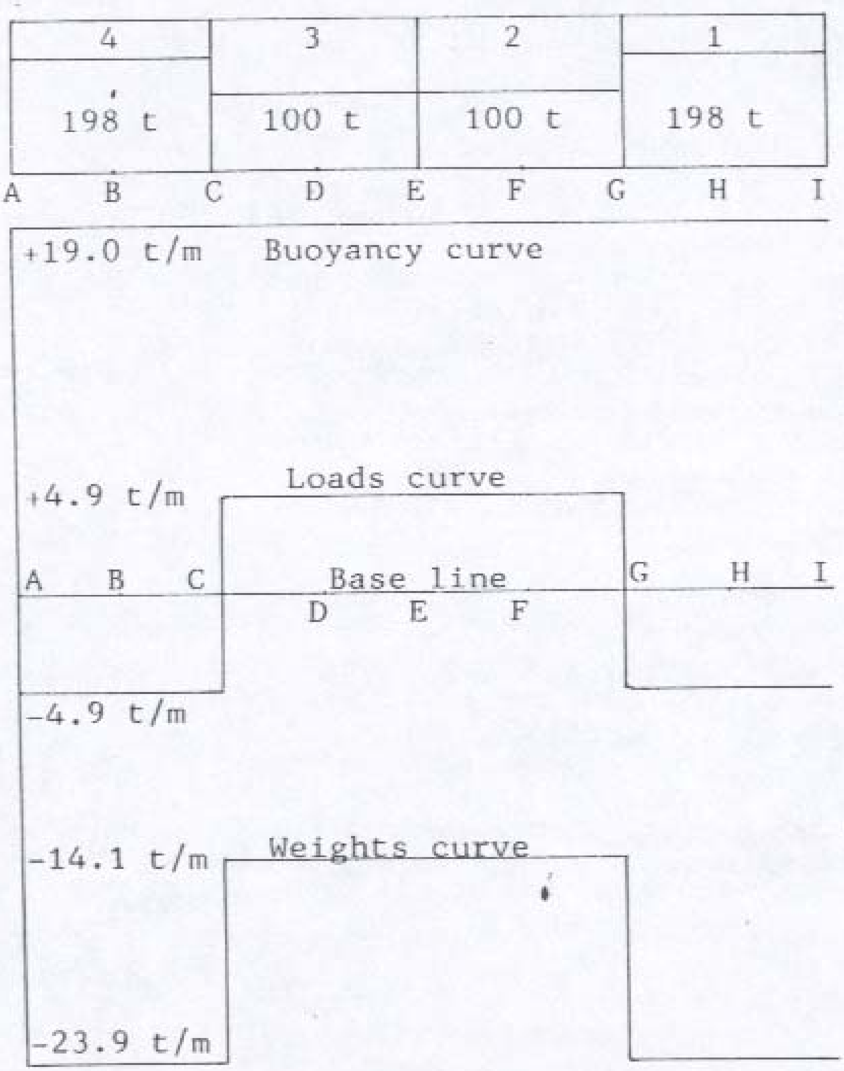
A box-shaped barge 40 m x 5 m has light SW draft = 0.8 m fwd & aft. It has four identical holds, each 10 m long. Cargo is loaded level as follows:

No 1 hold: 198 t, No 2 hold: 100 t,
No 3 hold: 100 t, No 4 hold: 198 t.

Draw the SF and BM curves to scale.

Light W = 40 x 5 x 0.8 x 1.025	=	164 t
Cargo loaded	=	596 t
Loaded W = Buoyancy	=	760 t

Weight/m run in holds:	1 & 4	2 & 3	
Cargo loaded .... =	19.8	10.0	t/m
Barge alone = 164/40 =	4.1	4.1	t/m
Total weight ..(-).. =	23.9	14.1	t/m
Buoyancy = +760/40.. =	+19.0	+19.0	t/m
Load .... =	-04.9	+04.9	t/m



Note: In the case of an actual ship, the weights curve would be very complex and the load per metre can be deduced at each location only after drawing the weights curve and the buoyancy curve.

At any point, SF is the area enclosed by the loads curve, upto that point.

SF at A = 0. SF at B = -4.9 x 5 = -24.5 tonnes (or -24.5 x 9.81 = -240.345 kN).

SF at C = -4.9(10) = -49 t or -480.69 kN

SF at D = -49 + (4.9 x 5) = -24.5 tonnes (or -240.345 kN).

SF at E = -49 + (4.9 x 10) = zero tonnes and so on.

Once the value of SF at various points has been calculated, the SF curve may be drawn, BM at each point calculated and the BM curve drawn to scale, as done in the previous chapter.

The results may be tabulated as under:

Point	A	B	C	D
SF (t)	0	-24.5	-49	-24.5
BM (tm)	0	-61.25	-245	-428.75

Point	E	F	G	H	I
SF	0	+24.5	+49	+24.5	0
BM	-490	-428.75	-245	-61.25	0

The SF and BM curves to scale are illustrated in the next page.

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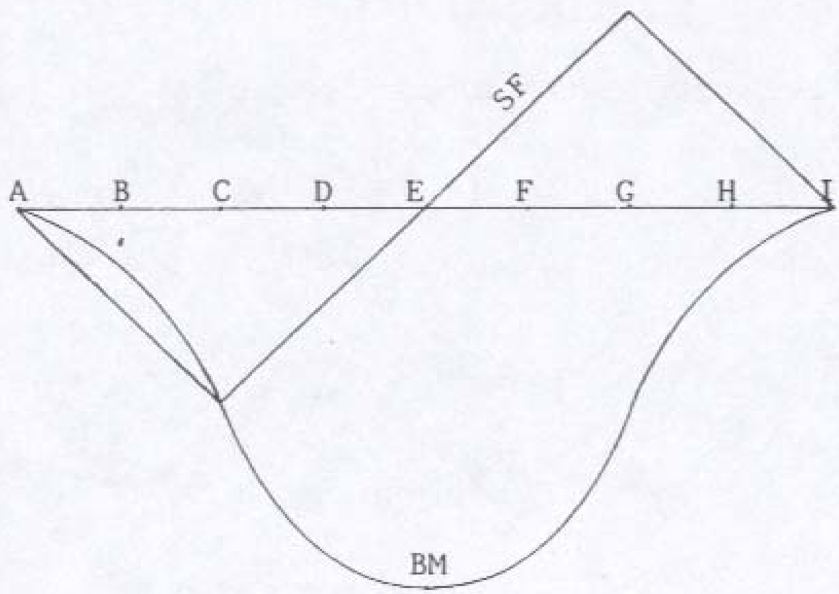
SF and BM curves of example 1:



Since BM is (-), the barge tends to hog.

Example 2

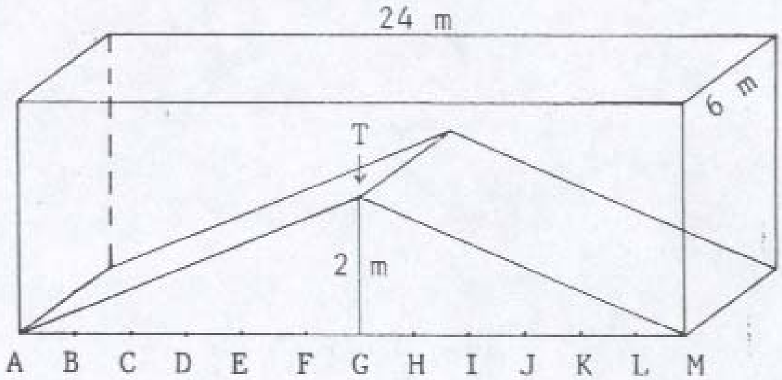
A box-shaped barge 24 x 6 m has a light draft of 0.778 m in FW. Ore of SF 0.5 is loaded 2 m high at the centre, sloping steadily downwards to 0 m at the forward and after ends. Draw the SF and BM diagrams to scale.

Light W = 24 x 6 x 0.778 x 1 = 112 t
Cargo loaded = volume ÷ SF = 288 t
Load W = buoyancy .... = 400 t

Buoyancy/m run = 400 ÷ 24 = 16.667 t/m

Weight of the empty barge per metre run
= 112 ÷ 24 = 4.667 t/m

Calculation of weight of cargo:



Note 1: AT and MT are straight lines.

Note 2: The height of ore, at any point, may be calculated by the principle of similar triangles.

Note 3: The weight per metre of cargo, calculated at each point, is valid only for that particular point. It is not valid over a length of one full metre. This may be illustrated by some simple examples:

(i) If a runner in a race crosses the finish line at a speed of 36 km/hour, that rate is valid only for the instant of crossing the line. He may not have run for a full hour!

(ii) The air pressure at a nozzle may be 100 kN/square metre though the cross sectional area of the nozzle may be only a few square centimetres!

At any point, cargo weight/m run

= volume of 1 m length of ore ÷ SF

= 1 x 6 x height of ore cargo ÷ 0.5

= 12 x height of ore cargo.

The following is a summary of the calculations at each point:

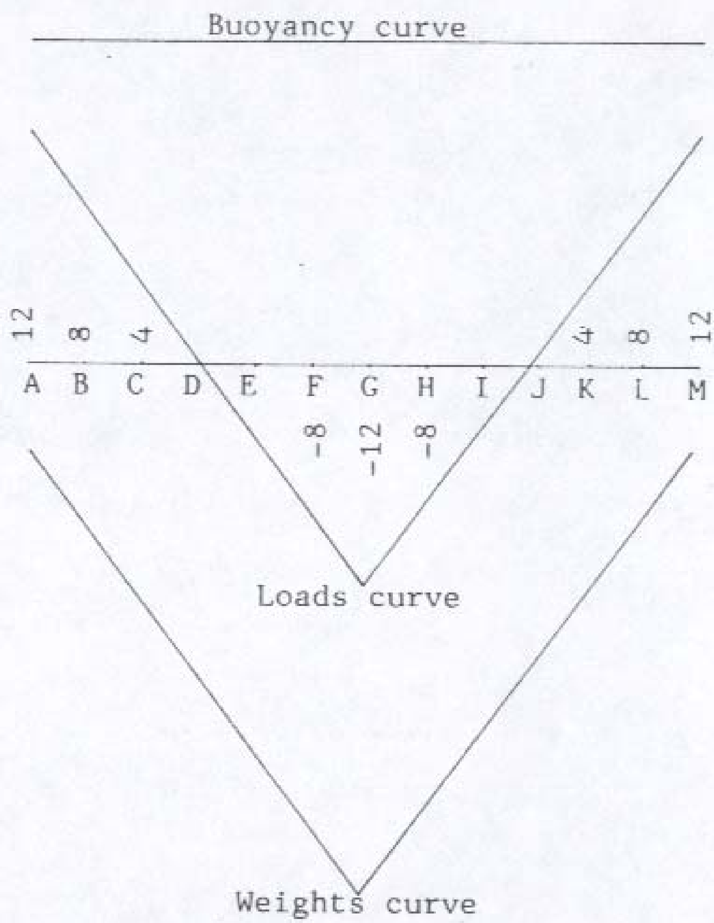
Point	A	B	C	D
Ore height m	0.000	0.333	0.667	1.000
Ore cargo t/m	0	4	8	12
Barge alone	4.667	4.667	4.667	4.667
Total wt t/m	4.667	8.667	12.667	16.667
Buoyancy t/m	16.667	16.667	16.667	16.667
Load t/m	+12	+8	+4	0

Point	E	F	G	H	I
Ht m	1.333	1.667	2.000	1.667	1.333
Ore	16	20	24	20	16
Barge	4.667	4.667	4.667	4.667	4.667
Total	20.667	24.667	28.667	24.667	20.667
Bncy	16.667	16.667	16.667	16.667	16.667
Load	-4	-8	-12	-8	-4

Point	J	K	L	M
Ore height m	1.000	0.667	0.333	0.000
Cargo t/m	12	8	4	0
Barge alone	4.667	4.667	4.667	4.667
Total wt t/m	16.667	12.667	8.667	4.667
Buoyancy t/m	16.667	16.667	16.667	16.667
Load t/m	0	+4	+8	+12

The diagrams on the next page illustrate the above results graphically.

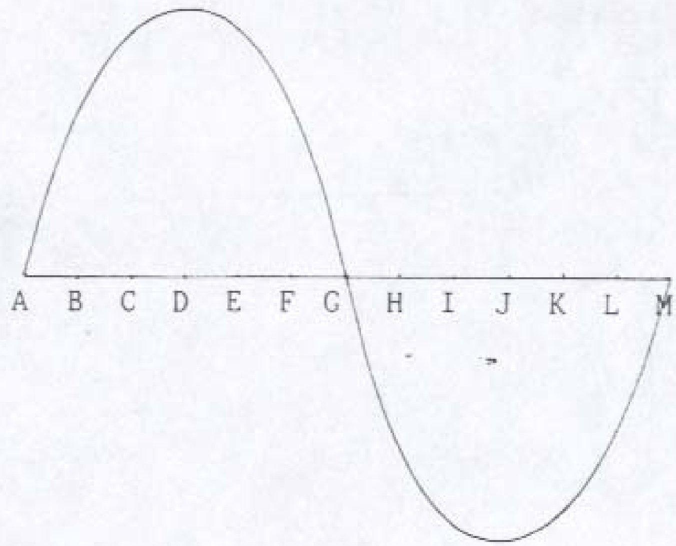
Loads curve of example 2:



Calculating the area under the loads curve, the SF at each point is as under:

A: 0, B: 20, C: 32, D: 36, E: 32, F: 20, G: 0, H: -20, I: -32, J: -36, K: -32, L: -20, M: 0.

The SF curve of example 2:



Using Simpson's Rules for area under the SF curve at each point:

<u>Area upto point B</u>

	Ord	SM	Prod
A	0	5	0
B	20	8	160
C	32	-1	-32

SOP for area 128

$$\text{Area} = \frac{2(128)}{12} \text{ tm}$$

$$= 21.333 \text{ tm}$$

<u>Area upto point C</u>

	Ord	SM	Prod
A	0	1	0
B	20	4	80
C	32	1	32

SOP for area 112

$$\text{Area} = \frac{2(112)}{3} \text{ tm}$$

$$= 74.667 \text{ tm}$$

Area upto point D

	Ord	SM	Prod
C	32	5	160
D	36	8	288
E	32	-1	-32
SOP for area			416

$$\text{Area} = \frac{2(416)}{12}\ \text{tm}$$

Area CD = 69.333
Upto C = 74.667
Upto D = 144 tm

Area upto point E

	Ord	SM	Prod
A	0	1	0
B	20	4	80
C	32	2	64
D	36	4	144
E	32	1	32
SOP for area			320

$$\text{Area} = \frac{2(320)}{3}\ \text{tm}$$

= 213.333 tm

Area upto point F

	Ord	SM	Prod
E	32	5	160
F	20	8	160
G	0	-1	0
SOP for area			320

$$\text{Area} = \frac{2(320)}{12}\ \text{tm}$$

= 53.333 tm

Area EF = 53.333
Upto E = 213.333
Upto F = 266.666

Area upto point G

	Ord	SM	Prod
A	0	1	0
B	20	4	80
C	32	2	64
D	36	4	144
E	32	2	64
F	20	4	80
G	0	1	0
SOP for area			432

$$\text{Area} = \frac{2(432)}{3}\ \text{tm}$$

= 288 tm.

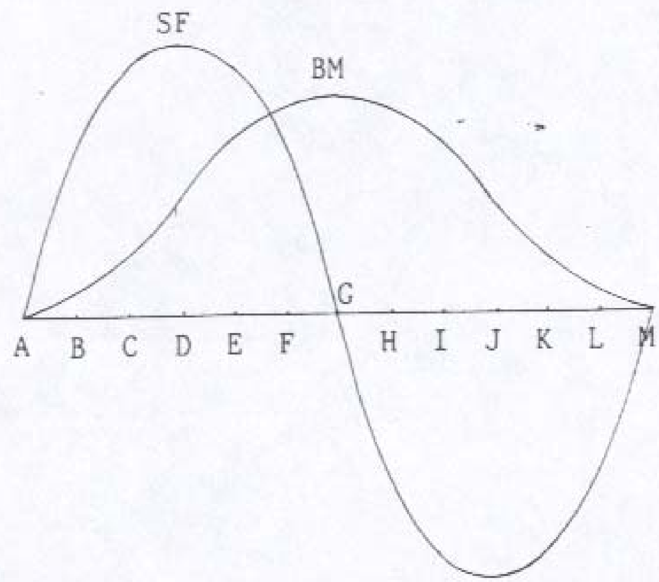
Since the SF curve, in this case, is symmetrical about amidships, the values of BM at M, L, K, J, I, and H are the same as those at A, B, C, D, E and F respectively. The values of BM are:

Point	A	B	C	D	E
BM tm	0	21.333	74.667	144	213.333

Point	F	G	H	I
BM tm	266.666	288	266.666	213.333

Point	J	K	L	M
BM tm	144	74.667	21.333	0

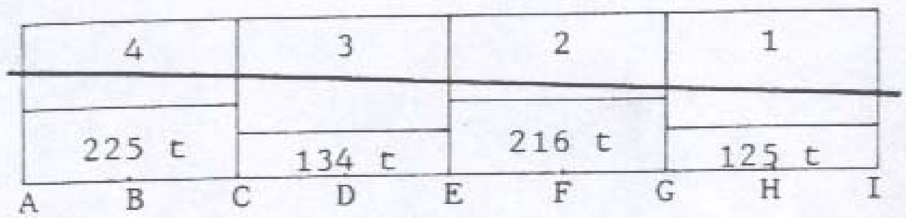
The BM curve may now be inserted on the same base line as the SF curve:



Since BM is (+), the barge tends to sag.

Example 3

A box-shaped barge, 32 m long and 5 m broad, is empty and afloat on an even keel. It has a four identical holds and its light displacement is 120 t. Bulk cargo is then loaded and trimmed level as follows: No 1: 125 t, No 2: 216 t, No 3: 134 t and No 4: 225 t. The final drafts are 4 m fwd and 6 m aft. Draw the SF and BM curves to scale.



At any point,
buoyancy/m = 1 x 5 x draft x 1.025 t/m.

The following is a summary of calculations for each point. It is left as an exercise for the student to arrive at the same values by himself.

Hold number 4

Point	A	B	C
Draft (metres)	6	5.75	5.5
Bouyancy/m (+)	30.750	29.469	28.188
Weight t/m (-)	31.875	31.875	31.875
Load t/m	-1.125	-2.406	-3.687

Hold number 3

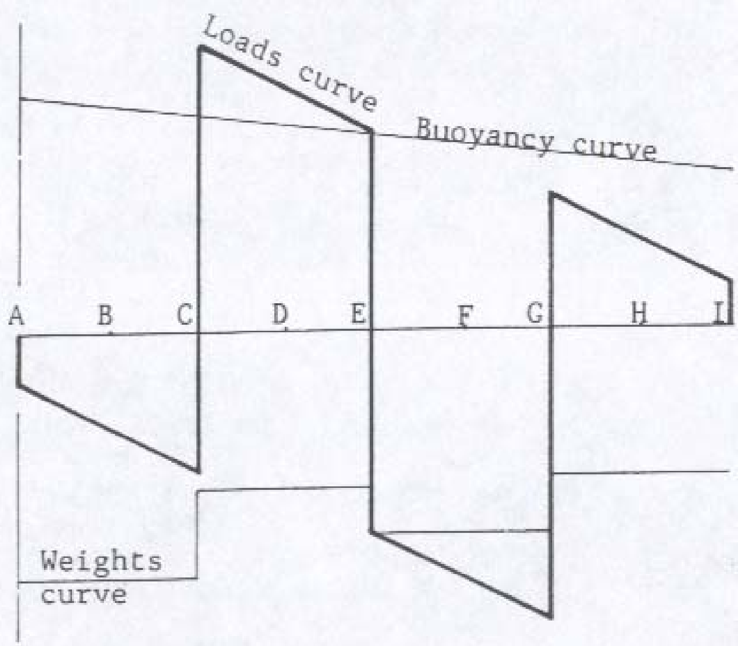
Point	C	D	E
Draft (metres)	5.5	5.25	5
Bouyancy/m (+)	28.188	26.906	25.625
Weight t/m (-)	20.500	20.500	20.500
Load t/m	+7.688	+6.406	+5.125

Hold number 2

Point	E	F	G
Draft (metres)	5	4.75	4.5
Bouyancy/m (+)	25.625	24.344	23.062
Weight t/m (-)	30.750	30.750	30.750
Load t/m	-5.125	-6.406	-7.688

Hold number 1

Point	G	H	I
Draft (metres)	4.5	4.25	4
Bouyancy/m (+)	23.062	21.781	20.5
Weight t/m (-)	19.375	19.375	19.375
Load t/m	+3.687	+2.406	+1.125



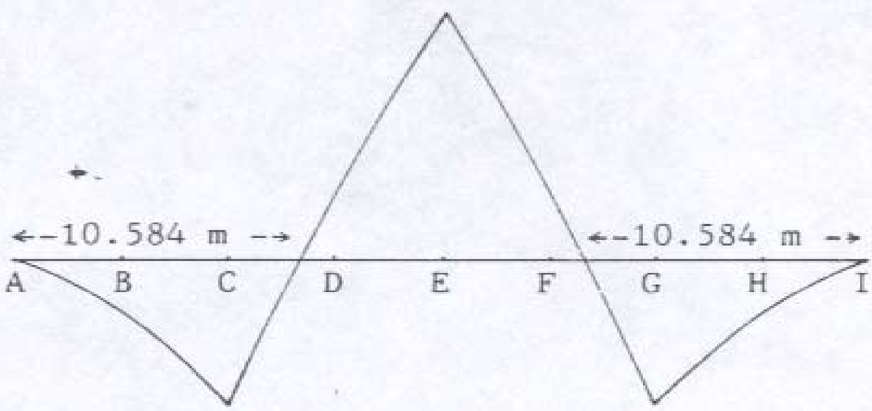
In the above diagram, a larger scale has been used for the loads curve than for the curves of buoyancy and weight.

The values of SF at each point:

Point	A	B	C	D
SF t	0	-7.063	-19.250	+8.938

E	F	G	H	I
+32	+8.938	-19.250	-7.063	0

The SF diagram of example 3:



By using Simpson's first and third rules and plane geometry:

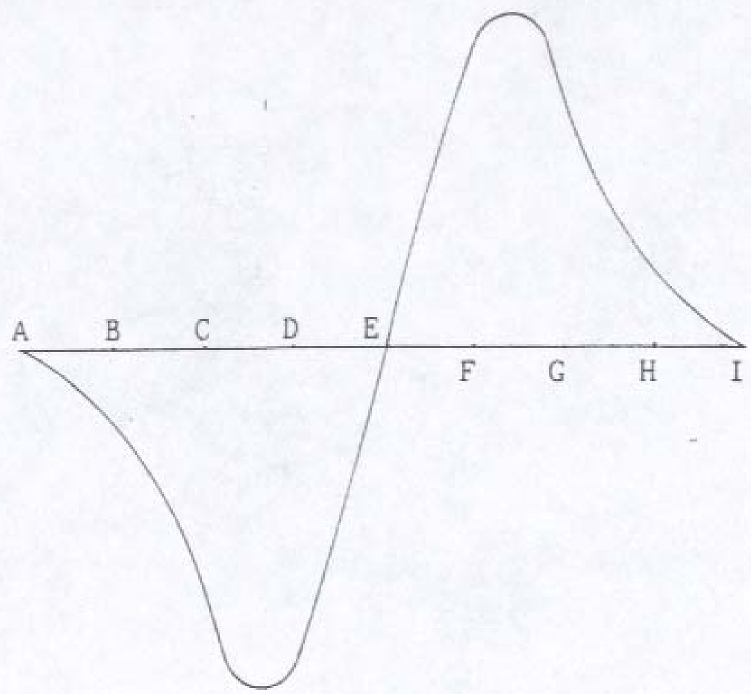
Point	A	B	C	D
BM tm	0	-12.418	-63.336	-81.876

E	F	G	H	I
0	+81.876	+63.336	+12.418	0

Maximum values of BM are:

-88.207 tm, 10.584 m from point A &
+88.207 tm, 10.584 m from point I.

BM curve for example. 3:



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Exercise 41
SF & BM in box-shaped vessels

1 A box-shaped barge is 36 m long and has light displacement = 198 t. It has four identical holds into which cargo is loaded and trimmed level as follows: 135 t in No:1, 162 t in No:2 162 t in No:3 and 135 t in No:4. Draw the SF and BM diagrams to scale.

2 A rectangular barge of length 40 m & light displacement 200 t, has five

identical holds into which bulk cargo is loaded and trimmed level as follows: 360 t in No:1, 720 t in No:2 720 t in No:4 and 360 t in No:5. No:3 hold is left empty. Draw the SF & BM diagrams to scale.

3 A box-shaped vessel 100 m long, 15 m wide, light displacement 1200 t, has five identical holds. 3000 t of bulk cargo is loaded and trimmed level: 1500 t in No: 2 and 1500 t in No: 4. Draw the SF and BM diagrams to scale.

4 A box-shaped barge 24 m long and 6 m wide has light displacement = 120 t. Iron ore (SF 0.6) is loaded, 3 m high at the forward & after ends, sloping steadily to zero at the centre. Draw the SF and BM diagrams to scale.
Note: The cargo has no slope in the athwartship direction.

5 A box-shaped barge 24 m long, 5 m wide, light displacement 96 t, has three identical holds. Ore of SF 0.5 is loaded as follows:

Nos 1 and 3 holds: 2 m high at the centre of the hold and sloping steadily down to zero at the forward and after ends of the hold. There is no slope in the transverse direction.

No 2 hold: 1 m high and trimmed level

Draw the SF and BM diagrams to scale.

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CHAPTER 49

SF & BM IN SHIPS

The principles involved in the calculation of SF and BM of ship shapes is the same as that illustrated in chapters 47 & 48. However the methods of arriving at the values of weight, buoyancy and load per metre, at each point, are complex and very tedious. In the case of ships, calculations have to be made for 'still water' and for 'wave conditions' as explained later in this chapter.

The weights curve:

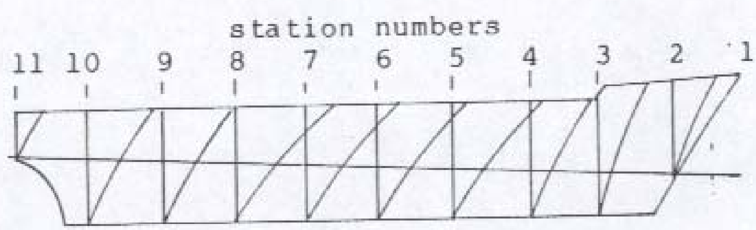
The weight of all the permanent features like the hull, superstructure, fittings, equipment, etc, are estimated and split up on a 'per metre basis' along the ship's length. This was a very tedious and time consuming process until the advent of computers. The weight of all variable factors such as cargo, fuel, stores, etc are then similarly dealt with but separately so that future changes in their values can be allowed for simply. The weights curve is then drawn, to scale, using the LOA as the base line.

The buoyancy curve

The use of Bonjean Curves (explained later in this chapter) simplifies the procedure of calculating the values of 'buoyancy per metre' considerably. The ship is divided into a number of stations spaced at equal longitudinal intervals of ten to fifteen metres. The first and last stations coincide with the forward and after tips of the hull. The exact value of the common interval is arrived at by dividing the length overall by the number of spaces chosen. For example, if the LOA is 149.16 m, and eleven stations have been chosen, the common interval would be 14.916 m.

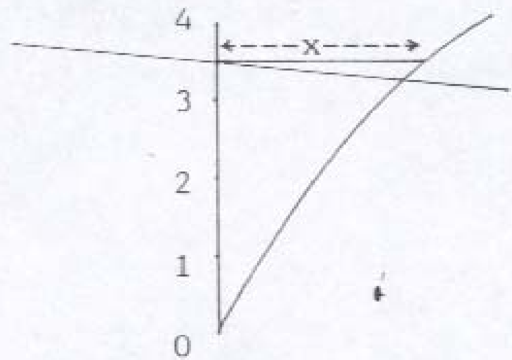
Bonjean Curves

A Bonjean Curve is a curve drawn with the draft of the ship along the vertical axis and the transverse cross-sectional area, of the immersed part of the hull, along the horizontal axis. One such curve is drawn for each station chosen:-



Still water buoyancy curve

The waterline at the proposed drafts fwd & aft is drawn as a straight line on the ships profile containing the Bonjean Curves and the transverse cross sectional area, of the immersed part of the hull, at each station, is obtained. One Bonjean Curve, on a larger scale, is shown below. The desired waterline cuts the station at a draft of 3.5 m. Horizontal distance 'x', read off the scale of the drawing, is the transverse cross sectional area of the immersed part of the hull at that station.



At each station, such area, multiplied by a length of one metre and by 1.025 would give the buoyancy per metre, in tonnes. The buoyancy curve can then be drawn to scale with the LOA as the base.

Adjustments

Suitable adjustments are made to the values of buoyancy per metre and weight per metre , if necessary, to ensure that the total calculated weight equals the total calculated buoyancy.

The loads curve

The load at various locations is deduced from the values of buoyancy and weight, obtained from the respective curves, and the curve of loads is then drawn. As explained in chapters 47 and 48, the resultant load on the ship should be zero - the area enclosed by the loads curve above and below the base line should be equal.

The SF & BM curves

The values of SF and BM are computed for various locations, as done in chapters 47 and 48, and the SF and BM curves are drawn to scale.

Wave conditions

Whilst at sea, waves would cause the buoyancy curve to change drastically. The ship would suffer maximum longitudinal stress when the wave length equals the length of the ship. This is because:

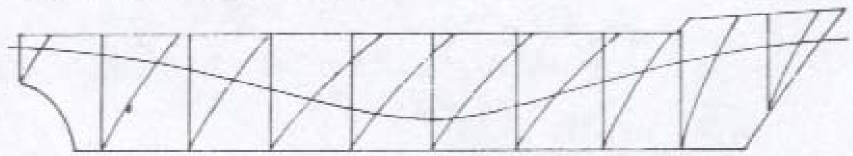
(i) It is then possible that the ends of the ship are supported by consecutive crests leaving the centre with little or no support - maximum sagging stress.

(ii) It is also possible that the centre of the ship is supported by a crest leaving the ends with little or no support - maximum hogging stress.

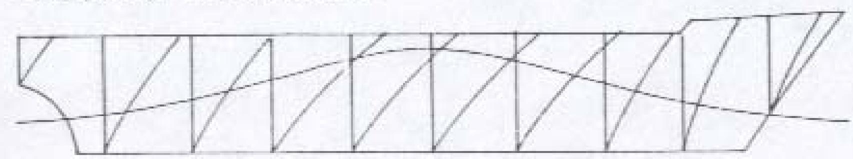
Shipyards make longitudinal stress calculations assuming that the wave length 'L' equals the length of the ship. A standard wave height of L/20 is used.

The assumed wave pattern is drawn, on a transparent plastic sheet, on the same scale as the ships profile. This is then placed over the ships profile such that, despite the sagging or hogging condition being considered, the total under water volume of the ship (volume of bouyancy) is constant as shown below:

Sagging condition:



Hogging condition:



The transverse cross sectional area of the immersed part of the hull, at each station, is read off using the Bonjean Curves and the value of buoyancy per metre obtained by multiplying by 1.025 as mentioned earlier in this chapter. The buoyancy curve can thus be drawn for the wave condition, separately for sagging and for hogging. Since the weights curve is not affected by wave action, the rest of the calculations may completed in the same manner as done for still water.

As the standard wave height of L/20 is an assumption, and not conclusive, some Classification Societies insist only on still water calculations but make enough safety allowance, in the permissible values of SF & BM, to allow for further stresses resulting from wave action.

Sample calculations are made by the shipyard, and supplied to the ship, for the various departure and arrival conditions similar to those found in the stability particulars book of the ship. Clearly mentioned therein would be any special stress related precautions or restrictions - for example: in a partly loaded sea going condition, whether a particular hold should not be left empty; under full load, whether jump loading is permitted and, if so, which alternate holds may be left empty, etc.

In conclusion

It is thus obvious that the calculation of SF and BM of a ship is a complex and tedious process. Manual calculation of the same is not possible, by the ship's staff, for each voyage. However, modern ships have computerised loadicators by which not only stability, but also stress calculations, can be made. These loadicators have the ship's data already programmed into them. Only the variable factors of the voyage, such as fuel oil, water, stores, cargo, etc are to be entered by the ship's staff. Print outs of the calculations should, each time, be carefully filed away as evidence, in case any kind of reference becomes necessary later on.

-o0o-

A N S W E R S

Exercise 31 (page 17)

1 S 1.000 m, BML 270 m, MCTC 622.688
BG 10 m, fwd 6.667 m, aft 14.074 m.

2 Final drafts fwd 8.000 m aft 8.000 m

3 S'0.12 m, BML 280.702 m, MCTC 437.334
BG 1.137 m, fwd 8.044 m, aft 7.396 m.

4 S 0.299 m, BML 213.834 m MCTC 245.481
BG 2.465 m, fwd 7.463 m, aft 9.192 m.

5 S 0.215 m, BML 350.529 m MCTC 426.839
BG 2.565 m, fwd 7.478 m, aft 6.197 m.

6 S 0.322 m, BML 350.529 m MCTC 426.839
BG 3.833 m, fwd 7.912 m, aft 5.998 m.

7 S 0.126 m, BML 418.850 m MCTC 683.333
BG 0.967 m, fwd 8.315 m, aft 7.853 m.

8 S 0.313 m, BML 468.638 m MCTC 595.638
BG 4.639 m, fwd 5.569 m, aft 7.549 m.

9 S 0.480 m, BML 225.704 m MCTC 340.079
BG 3.025 m, fwd 7.520 m, aft 9.664 m.

10 By one method 44.59 % and by another
46.7%. So answer = approximately 46%.

Exercise 32 (page 32)

1 S 1.253 m, BML 286.441 m MCTC 634.180
BG 2.371 m, fwd 9.541 m, aft 11.031 m

2 S 0.642 m, BML 431.372 m MCTC 619.019
BG 0.557 m, fwd 7.778 m, aft 7.520 m.

3 S 0.618 m, BML 302.849 m MCTC 379.954
BG 0.931 m, fwd 7.672 m, aft 7.180 m.

4 S 0.473 m, BML 302.849 m MCTC 379.954
BG 0.340 m, fwd 7.366 m, aft 7.186 m.

5 S 0.745 m, BML 302.849 m MCTC 379.954
BG 1.450 m, fwd 7.940 m, aft 7.174 m.

Exercise 33 (page 42)

1 List = 2.398° or 2° 24' to port.

2 List = 8.147° or 8° 09' to stbd.

3 List = 4.453° or 4° 27' to port.

4 List = 2.873° or 2° 52' to port.

5 List = 4.150° or 4° 09' to port.

Exercise 34 (page 53)

1 W 10197.2 t, RD 1.015, d 5.384 m,
TPC 21.997, MCTC 176.989, AB 71.237,
AF 71.764, KB 2.982 m, KMT 8.808 m,
KML 248.370 m.

2 Final drafts fwd 5.055 m, aft 5.730 m

3 List = 4.071° or 4° 04' to starboard.

4 W 10899.1 t, RD 1.025, d 5.609 m,
TPC 22.303, MCTC 181.973, AB 73.632,
AF 71.667, KB 3.082 m, KMT 8.620 m,
KML 236.829 m.

5 Final drafts fwd 5.763 m, aft 5.448 m

6 List = 4.752° or 4° 45' to port.

7 W 8767.0 t, RD 1.025, d 4.600 m, TPC 21.890, MCTC 174.870, AB 71.232, AF 72.013, KB 2.526 m, KMT 9.228 m, KML 281.775 m.

8 Final drafts fwd 4.600 m, aft 4.600 m

9 (i) W 12020.0 t, RD 1.025, d 6.001 m, TPC 22.451, MCTC 185.303, AB 71.412, AF 71.471, KB 3.199 m, KMT 8.271 m, KML 219.026 m.

(ii) Final drafts forward 6.005 m, aft 5.997 m.

Exercise 35 (page 73)

1 By formula 8.902°, by curve 3° stbd.

2 .. .. 11.310°, ... 8° stbd.

3 .. .. 6° .. .. 4° port.

4 .. (i) 9.567°, ... 3° stbd.
(ii) 3.889° .. not necessary.

5 .. .. 10.126°, ... 4° port.

Exercise 36 (page 78)

1 (i) By curve 26° (ii) By formula 26°

2 (i) .. .. 22.5 (ii) .. .. 20°

3 (i) .. .. 37.5 (ii) .. .. 30°

4 (i) .. .. 20° (ii) .. .. 25°

5 (i) .. .. 20° (ii) .. .. 24°

Exercise 37 (page 92)

1

Requirement	Actual	Minimum
(1) Initial GM fluid	3.600	0.150 m.
(2) Max GZ value	3.450	0.200 m.
(3) Heel at Max GZ	48°	30°
(4) Area under curve:		
(a) Upto 30° heel	0.604	0.055 mr
(b) Upto 40° heel	1.112	0.090 mr
(c) 30 - 40° heel	0.508	0.030 mr

Vessel meets all the requirements.

Dyn stab at 40° heel = 77881.617 tmr.

2

Requirement	Actual	Minimum
(1) Initial GM fluid	2.421	0.150 m.
(2) Max GZ value	1.830	0.200 m.
(3) Heel at Max GZ	47°	30°
(4) Area under curve		
(a) Upto 30° heel	0.369	0.055 mr
(b) Upto 40° heel	0.658	0.090 mr
(c) 30 - 40° heel	0.289	0.030 mr

Vessel meets all the requirements.

Dyn stab at 30° heel = 31329.843 tmr.

3

Requirement	Actual	Minimum
(1) Initial GM fluid	1.601	0.150 m.
(2) Max GZ value	2.150	0.200 m.
(3) Heel at Max GZ	51°	30°
(4) Area under curve		
(a) Upto 30° heel	0.359	0.055 mr
(b) Upto 40° heel	0.655	0.090 mr
(c) 30 - 40° heel	0.296	0.030 mr

Vessel meets all the requirements.

4

Requirement	Actual	Minimum
(1) Initial GM fluid	0.585	0.150 m.
(2) Max GZ value	1.310	0.200 m.
(3) Heel at Max GZ	42.5°	30°
(4) Area under curve		
(a) Upto 30° heel	0.224	0.055 mr
(b) Upto 40° heel	0.431	0.090 mr
(c) 30 - 40° heel	0.207	0.030 mr

Vessel meets all the requirements.

Dyn stab at 40° heel = 4645.583 tmr.

5

Requirement	Actual	Minimum
(1) Initial GM fluid	0.864	0.150 m.
(2) Max GZ value	0.950	0.200 m.
(3) Heel at Max GZ	49°	30°
(4) Area under curve (flooding at 36°)		
(a) Upto 30° heel	0.236	0.055 mr
(b) Upto 36° heel	0.380	0.090 mr
(c) 30 - 36° heel	0.144	0.030 mr

Vessel meets all the requirements.

Exercise 38 (page 109)

No	Thrust	KP m	No	Thrust	KP m
1	820 t	3.333	2	250 t	5.000
3	471.333	2.500	4	219.24	2.000
5	44.528	3.000	6	141.68	1.714
7	725.760	3.383	8	395.606	4.924
9	435.607	2.344	10	25.761	1.500
11	Sounding = 9 m		12	1266.9	4.401
13	717.000	3.593	14	228.401	1.752

Exercise 39 (page 118)

No	Thrust	KP m	No	Thrust	KP m
1	575.200	7.057	2	257.480	5.682
3	81.741	3.497	4	445.277	4.725

No	Thrust	KP m	No	Thrust	KP m
5	69.604	2.477	6	247.566	1.776
7	1331.759	5.741	8	1032.985	4.859
9	421.062	6.201			

Exercise 40 (page 169)

1	A	B	C	D	E	F	G
(	0			+20			0
SF (	20	20	20	-20	-20	-20	-20
BM	0	40	80	120	80	40	0

All points connected by straight lines

2	A	B	C	D	E	F	G
(	0				+4		0
SF (	4	4	4	4	-4	-4	-4
BM	0	4	8	12	16	8	0

All points connected by straight lines

3	A	B	C	D	E	F
(	0	6	6	-5	- 5	0
SF (	10	10	+1	+1	-12	-12
BM	0	20	32	34	24	0

All points connected by straight lines

4	A	B	C	D	E	F	G
(			-100				
SF (	0	-50	+200	150	100	50	0
BM	0	-25	-100	+75	200	275	300

	H	I	J	K	L	M
SF (	-50	-100	-150	-200	50	0
(				+100		
BM	275	200	+75	-100	-25	0

BM zero also at 2.536 m from each end.
SF - all straight lines. BM is curved.

5

	A	B	C	D	E	F	G
SF (	0	-50	+260	210	160	110	60
(			-100				
BM	0	-25	-100	+135	320	455	540

	H	I	J	K	L	M
SF (	10	-40	-90	-140	-190	-240
(						0
BM	575	560	495	380	215	0

Maximum BM 576 Nm 0.2 m to right of H.
BM = zero also at 0.4 m to right of C.

SF - all straight lines. BM is curved.

6

	A	B	C	D	E	F
SF (	0	60	55	50	5	0
(	65			10		
BM	0	62.5	120	172.5	180	182.5

	G	H	I	J	K
SF (	- 5	-10	-15	-80	-85
(			-75		0
BM	180	172.5	160	82.5	0

SF - all straight lines. BM is curved.

7

	A	B	C	D	E	F
SF (	0	-10	-30	+ 5	-15	-25
(			+25			
BM	0	- 5	-25	-10	-15	-35

	G	H	I	J	K
SF (	-35	-45	40	30	20
(		+50			0
BM	-65	-105	-60	-25	0

3.25 m from A, SF = 0, BM = -9.375 Nm.
SF - all straight lines. BM is curved.

8

	A	B	C	D	E	F	G
SF	0	50	100	150	100	50	0
BM	0	25	100	225	350	425	450

	H	I	J	K	L	M
SF	-50	-100	-150	-100	-50	0
BM	425	350	225	100	25	0

SF - all straight lines. BM is curved.

9

	A	B	C	D	E	F	G
SF	(0 (	75	150	225	175	125	+ 75 - 75
BM	0	37.5	150	337.5	537.5	687.5	787.5

	H	I	J	K	L	M
SF	-125	-175	-225	-150	-75	0
BM	687.5	537.5	337.5	150	37.5	0

SF - all straight lines. BM is curved.

10

	A	B	C	D	E	F
SF	0	11	-3	-17	-6	+ 5
BM	0	11	19	- 1	-24	- 25

	G	H	I	J	K
SF	-14	- 3	+ 8	+19	0
BM	-34	-51	-46	-19	0

SF is zero at 3.571 m, 9.091 m, 10.526 m and 14.545 m from A, at which BM is 19.64, -27.28, -23.69 and -51.85 kN m.

Maximum SF is 19 kN and occurs at J.

Maximum BM 51.83 kNm, 14.545 m from A.

SF - all straight lines. BM is curved.

Exercise 41 (page 186)

1

	A	B	C	D	E	F	G
SF	0	4.5	9	13.5	9	4.5	0
BM	0	6.75	27	60.75	94.5	114.75	121.5

	H	I	J	K	L	M
SF	- 4.5	-9	-13.5	-9	-4.5	0
BM	114.75	94.5	60.75	27	6.75	0

SF - all straight lines. BM is curved.

2

	A	B	C	D	E	F	G
SF	0	18	36	54	72	0	-72
BM	0	18	72	162	288	360	288

	H	I	J	K	L	M	N
SF	-144	-216	-108	0	108	216	144
BM	72	-288	-612	-720	-612	-288	72

	O	P	Q	R	S	T	U
SF	72	0	-72	-54	-36	-18	0
BM	288	360	288	162	72	18	0

SF - all straight lines. BM is curved.

3

	A	B	C	D	E	F
SF	0	300	600	150	-300	0
BM	0	1500	6000	9750	9000	7500

	G	H	I	J	K
SF	300	-150	-600	-300	0
BM	9000	9750	6000	1500	0

Maximum BM 10,000 tm occurs at 16,667 metres forward and aft of amidships.

SF - all straight lines. BM is curved.

4

	A	B	C	D	E
SF	0	-25	-40	-45	-40
BM	0	-26.7	-93.3	-180	-266.7

	F	G	H	I
SF	-25	0	25	40
BM	-333.3	-360	-333.3	-266.7

	J	K	L	M
SF	45	40	25	0
BM	-180	-93.3	-26.7	0

Both, SF line and BM line, are curved.

5

	A	B	C	D	E	F	G
SF	Ø	10	Ø	-10	Ø	Ø	Ø
BM	Ø	13.334	26.668	13.334	Ø	Ø	Ø

	H	I	J	K	L	M
SF	Ø	Ø	10	Ø	-10	Ø
BM	Ø	Ø	13.334	26.668	13.334	Ø

Both, SF line and BM line, are curved.

Appendix I

HYDROSTATIC TABLE OF M.V. 'VIJAY'

DRAFT	W t in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

W displacement — Load W 19943 t — LOA 150.00 m
A after perpendicular — Light W 6000 t — LBP 140.00 m
K keel — DWT 13943 t — GRT 10,000 Tons — NRT 5576 Tons

Appendix II

M.V.VIJAY

KN - Table

W	5°	10°	20°	30°	45°	60°	75°
6000	1.029	2.037	3.935	5.401	7.065	8.132	8.183
7000	0.953	1.890	3.717	5.247	7.041	8.185	8.322
8000	0.908	1.793	3.544	5.119	7.007	8.174	8.292
9000	0.875	1.724	3.415	5.012	6.962	8.106	8.254
10000	0.847	1.678	3.315	4.916	6.914	8.032	8.213
11000	0.827	1.642	3.241	4.843	6.863	7.957	8.166
12000	0.811	1.615	3.185	4.782	6.803	7.873	8.113
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896
17000	0.793	1.577	3.127	4.580	6.408	7.495	7.854
18000	0.795	1.584	3.140	4.547	6.321	7.419	7.810
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

Appendix II

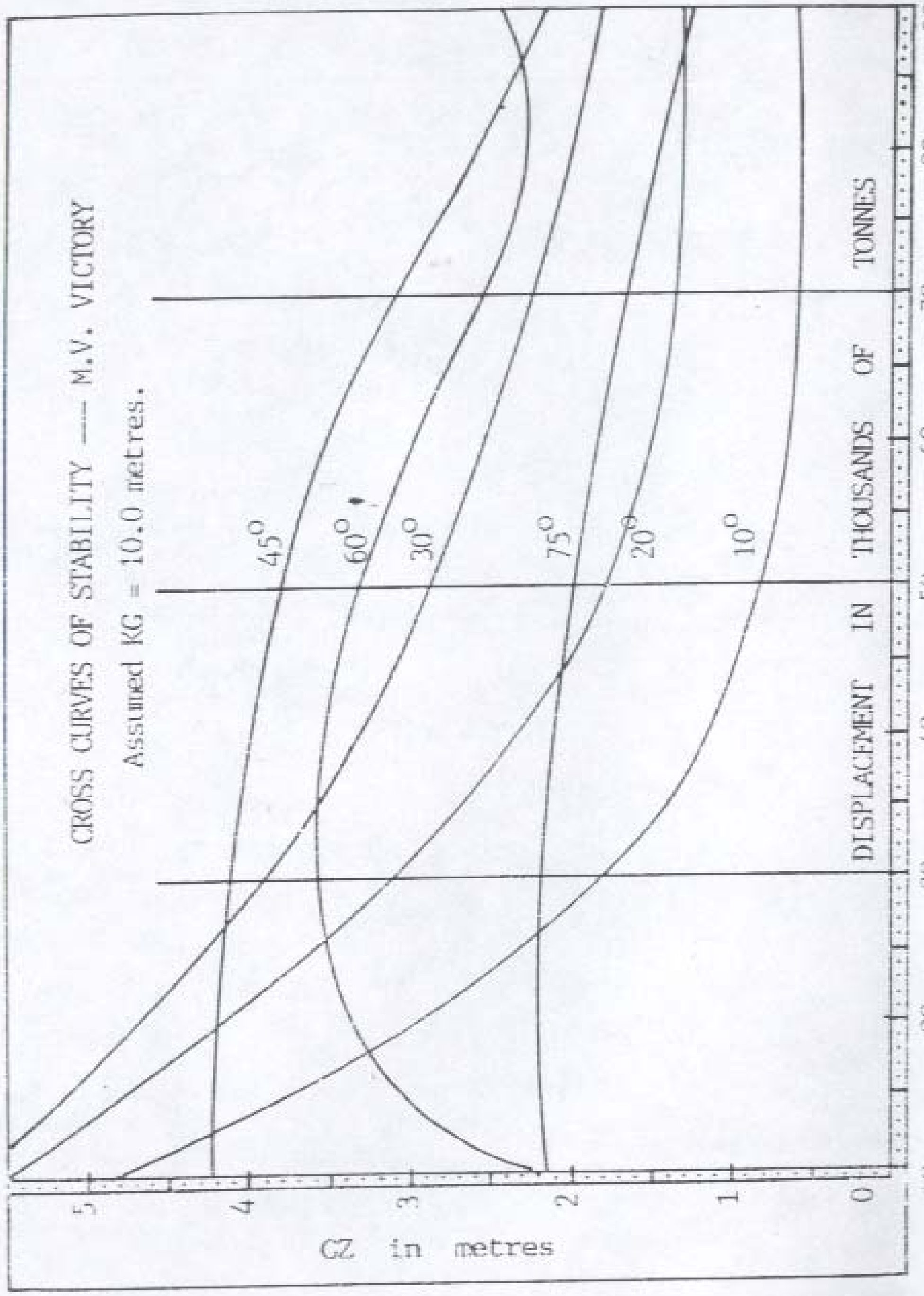
Hydrostatic particulars of m.v. VICTORY

d	W sw	TPC	MCTC	HB	HF	KB	KM_T	KM_L
11.00	70941	68.58	1083.0	5.37F	1.96F	5.64	13.24	366
11.20	72315	68.74	1091.3	5.30F	1.72F	5.75	13.22	362
11.40	73693	68.91	1099.5	5.23F	1.47F	5.85	13.20	358
11.60	75074	69.07	1107.8	5.16F	1.22F	5.95	13.18	354
11.80	76458	69.24	1115.9	5.09F	0.98F	6.06	13.17	351
12.00	77845	69.40	1124.0	5.02F	0.74F	6.16	13.16	347
12.20	79237	69.56	1131.3	4.94F	0.53F	6.26	13.16	343
12.40	80633	69.72	1138.4	4.87F	0.32F	6.37	13.16	340
12.60	82032	69.88	1145.5	4.79F	0.12F	6.47	13.16	336
12.80	83434	70.03	1152.4	4.71F	0.08A	6.58	13.17	333
13.00	84839	70.19	1159.1	4.62F	0.27A	6.68	13.18	329
13.20	86246	70.34	1165.8	4.54F	0.46A	6.79	13.19	326
13.40	87657	70.49	1172.3	4.46F	0.64A	6.89	13.21	323
13.60	89070	70.63	1178.8	4.38F	0.81A	7.00	13.22	320
13.80	90485	70.78	1185.1	4.29F	0.98A	7.10	13.25	316
14.00	91904	70.92	1191.3	4.21F	1.14A	7.21	13.27	313
14.20	93324	71.06	1197.4	4.13F	1.29A	7.31	13.30	310
14.40	94747	71.19	1203.3	4.04F	1.44A	7.42	13.33	308
14.60	96173	71.32	1209.2	3.96F	1.58A	7.52	13.36	305
14.80	97600	71.45	1215.0	3.88F	1.72A	7.63	13.39	302
15.00	99030	71.57	1220.7	3.79F	1.84A	7.73	13.43	299

d = draft in metres, K = keel, H = amidships.

LOA 245 m, LBP 236 m, GRT 42000 T, NRT 28000 T

Light W 14000 t, Load W 98000 t, Deadweight 84000 t


CROSS CURVES OF STABILITY — M.V. VICTORY
Assumed KG = 10.0 metres.
GZ in metres
0
1
2
3
4
5
10
20
30
40
50
60
70
80
90
DISPLACEMENT IN THOUSANDS OF TONNES
10°
20°
30°
45°
60°
75°

Appendix VII

m.v.VIJAY - KN Table

for cargo of bulk grain

W	5°	12°	20°	30°	40°	60°	75°
6000	1.029	2.417	3.935	5.401	6.610	8.132	8.183
7000	0.953	2.255	3.717	5.247	6.512	8.185	8.322
8000	0.908	2.143	3.544	5.119	6.418	8.174	8.292
9000	0.875	2.062	3.415	5.012	6.304	8.106	8.254
10000	0.847	2.005	3.315	4.916	6.284	8.032	8.213
11000	0.827	1.962	3.241	4.843	6.197	7.957	8.166
12000	0.811	1.929	3.185	4.782	6.129	7.873	8.113
13000	0.798	1.907	3.153	4.733	6.072	7.788	8.057
14000	0.793	1.891	3.136	4.694	6.007	7.718	7.998
15000	0.794	1.882	3.110	4.657	5.939	7.645	7.941
16000	0.798	1.883	3.116	4.618	5.869	7.571	7.896
17000	0.793	1.887	3.127	4.580	5.799	7.495	7.854
18000	0.795	1.895	3.140	4.547	5.730	7.419	7.810
19000	0.802	1.908	3.134	4.510	5.721	7.341	7.766
20000	0.812	1.926	3.119	4.473	5.601	7.264	7.725

Note: KN values are necessarily shown at 12° and 40° heel for grain calculations.

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Ship stability