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SHIP STABILITY-II

NUTSHELL SERIES
BOOK 5

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

PREFACE

Like all the other books in the Nutshell Series, this book is intended to enable officers to study whilst at sea.

The subject has been divided into three parts:- 'Ship Stability I, II and III' (Nutshell Series Books 4, 5 and 6) such that all three cover the syllabus for Master F.G, parts I & II for First Mate F.G, and part I for Second Mate F.G and Navigational Watchkeeping Officer. The three parts are in continuation with no repetition of any portions.

In the second edition, minor changes have been made, especially in chapter 22 - Curve of Statical Stability.

Bombay,
1st August 1986

(H.SUBRAMANIAM)

SHIP STABILITY II

CONTENTS

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CHAPTER 19

CALCULATION OF BM

AND KM; KM CURVES

The transverse BM, also referred to as BM_T, is the vertical distance between the COB and the transverse metacentre, M or M_T, and is calculated by the formula:

$$BM = \frac{I}{V}$$

Where I is the moment of inertia, or the second moment, of the water-plane area about the centre line of the ship, expressed in m^4.
V is the vol of displacement in m^3
BM so obtained, would be in metres.

Rectangular water-planes:

The moment of inertia of a rectangle about its centre line (I or I*CL) is given by the formula: $I = LB^3 \div 12$. So for a rectangular water-plane:

$$BM = I/V = LB^3/12V$$

Note: The vessel need NOT be box-shaped for its water-plane to be rectangular.

For a box-shaped vessel, $V = L \times B \times d$.

$BM = I/V = LB^3/12V = LB^3/12LBd = B^2/12d.$

For a triangular shaped vessel $V = LBd/2$

$BM = I/V = LB^3/12(LBd/2) = B^2/6d.$

Note: Though the vessel is triangular shaped, the water-plane is a rectangle. B is the breadth of the water-plane.

Shipshapes

The moment of inertia of the water-plane area of a ship about its centre line can be calculated by using Simpson's Rules as illustrated in the next chapter. The I, thus calculated, divided by V would give the BM or BMl.

Example 1

Find the GM of a box-shaped vessel 20 x 6 x 5 m, if draft = 3 m and KG = 1.8 m.

KB = draft/2 = 3/2 .... = 1.5 m
$BM = B^2/12d = (6 \times 6) \div (12 \times 3)$ = 1.0 m
KM = KB + BM .... = 2.5 m

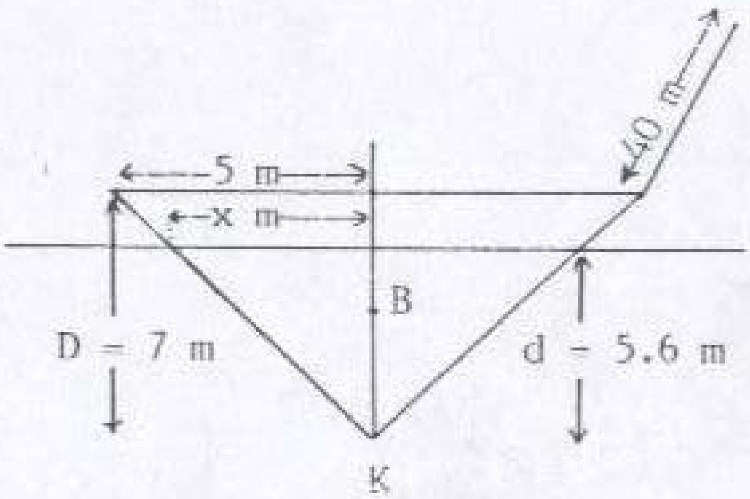
GM = KM - KG = 2.5 - 1.8 = 0.7 m answer.

Example 2

A vessel has the form of a triangular prism of length 40 m, breadth 10 m and depth 7 m. Find the KM at 5.6 m draft.

Let the half breadth of the water plane = X metres. With reference to the figure on the next page and considering similar triangles: X/5.6 = 5/7. X = 4.0 metres.

Breadth of the water-plane = 2 x 4 = 8 m



KB = draft x 2/3 = 5.6 x 2/3 = 3.733 m
BM = $B^2/6d$ = (8 x 8)/(6 x 5.6) = 1.905 m
KM = KB + BM .... = 5.638 m

Example 3

A vessel 50 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a triangle. The rectangle is 10 m broad & 5 m high. The triangle is apex downwards, 10 m broad at the top and 6 m deep. Calculate the KM at 8 m draft.

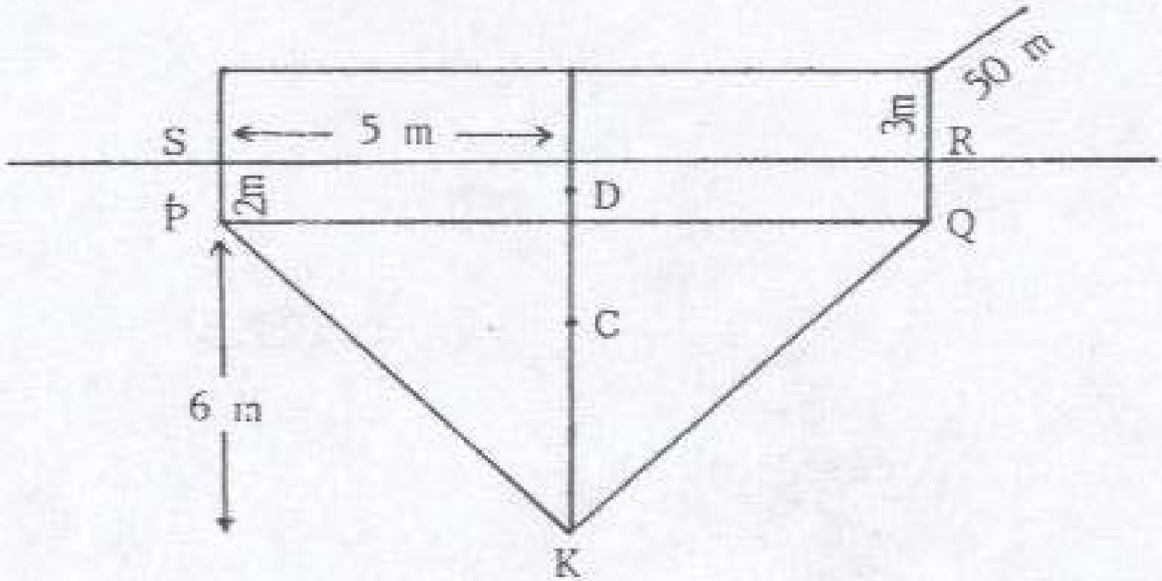
To find the KB, take moments of area about K. (See figure on next page).

$$KB = \frac{(\text{Area PQK} \times KC) + (\text{Area PQRS} \times KD)}{\text{Total area PKQRS}}$$

$$= \frac{(10 \times 6 \times 1/2)4 + (10 \times 2)7}{(10 \times 6 \times 1/2) + (10 \times 2)} = 5.2 \text{ m}$$

Volume of displacement = Area PKQRS x L

= 50 x 50 = 2500 m^3.



Since water-plane is rectangular,

$I*CL = LB^3/12 = 50 \times 10^3/12 = 4166.667\ m^4$

BM = I/V = 4166.667/2500 = 1.667 metres.

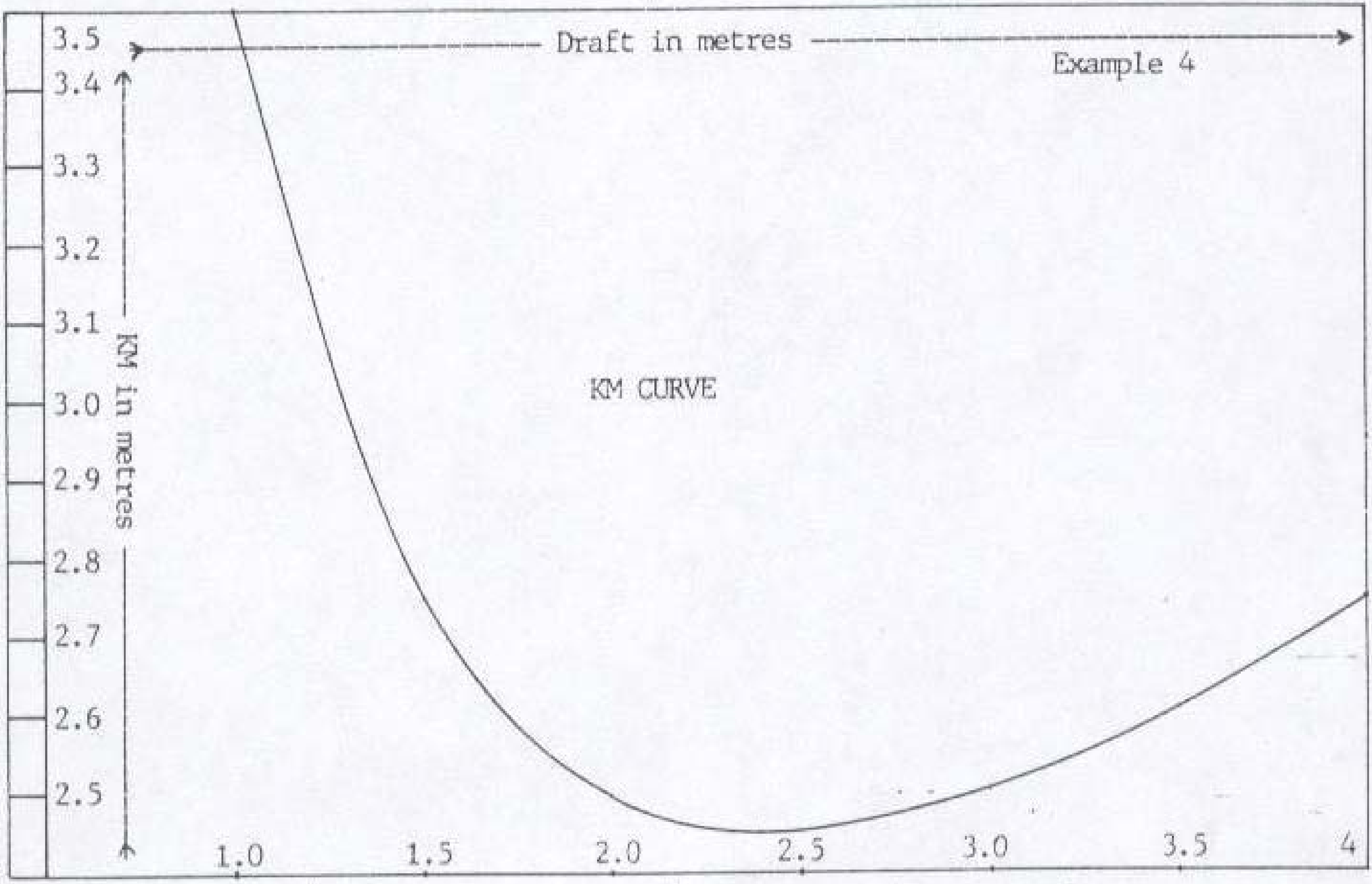
KM = KB + BM = 5.200 + 1.667 = 6.867 m.

Example 4

A box-shaped vessel is 32 m long and 6 m broad. Construct the KM curve between the drafts of 1 m & 4 m. From the curve, find the KM at 1.75 m draft.

$KM = KB + BM = d/2 + B^2/12d = d/2 + 3/d.$

For the various drafts, KB and BM are calculated and tabulated on page 6.


Example 4
Draft in metres
KM in metres
KM CURVE
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
1.0
1.5
2.0
2.5
3.0
3.5
4

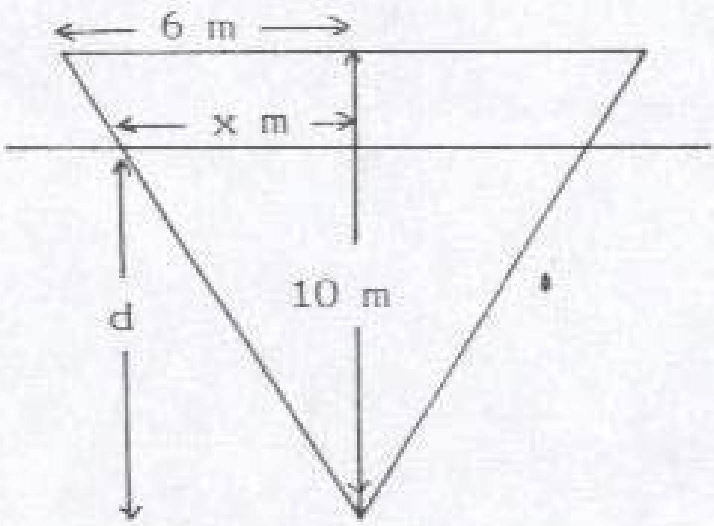
Draft	KB	+	BM	=	KM
1.0 m	0.5 m		3.0 m		3.5 m
1.5	0.75		2.0		2.75
2.0	1.0		1.5		2.5
2.5	1.25		1.2		2.45
3.0	1.5		1.0		2.5
3.5	1.75		0.857		2.607
4.0	2.0		0.75		2.75

A graph should be constructed, to a suitable scale, with draft on one axis & KM on the other, as shown on page 5.

From the curve, KM at 1.75 draft = 2.6 m

Example 5

A barge 60 m long is in the form of a triangular prism 12 m broad at the top and 10 m deep. Construct the KM curve upto 5 m draft and from it, find the KM at 4.6 m draft.

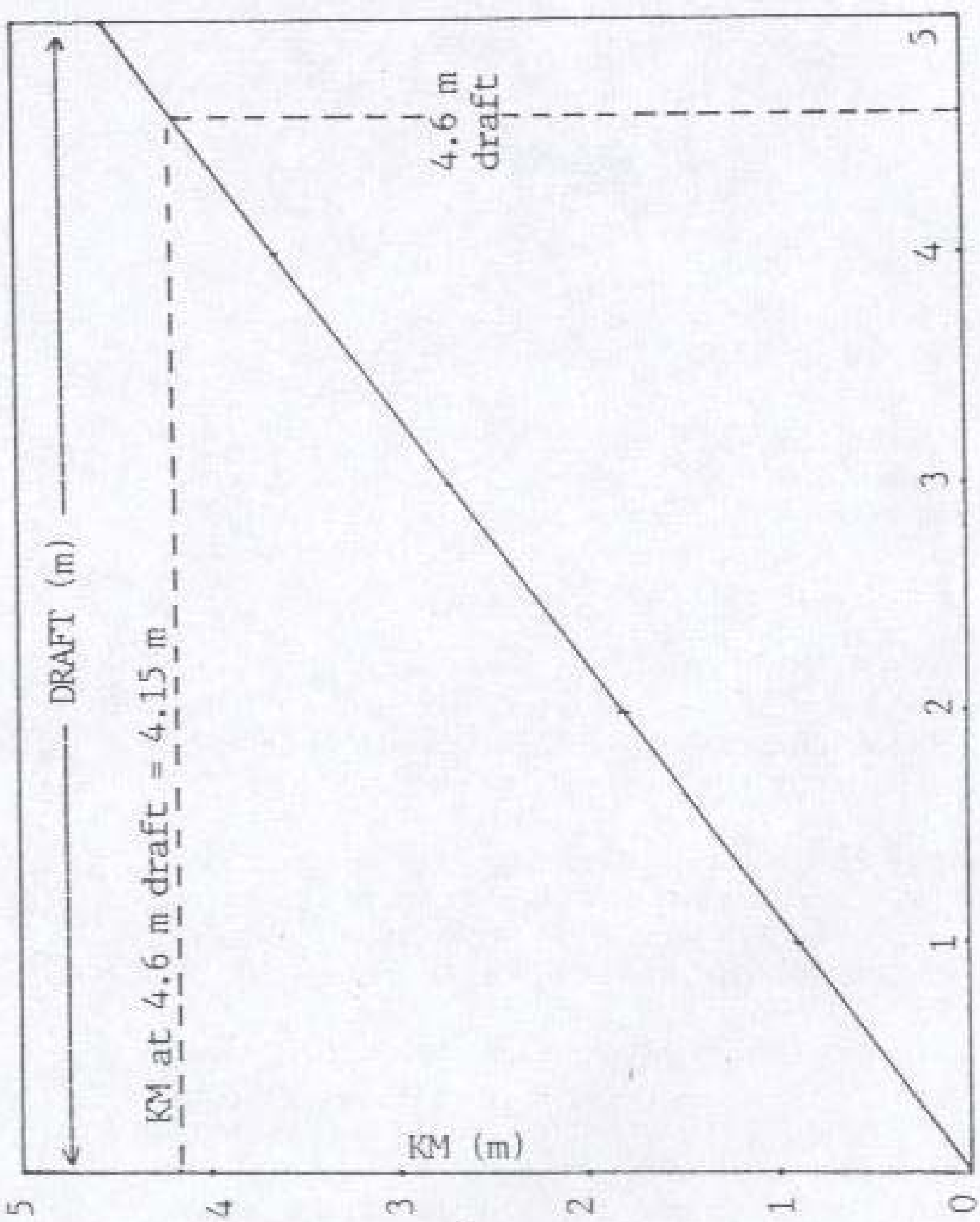


By the principle of similar triangles,

x/d = 6/10 so x = 0.6d and B = 1.2d.

$$KM = KB + BM = 2d/3 + (1.2d)^2/6d = 0.907d$$

draft	KM m	draft	KM m	draft	KM m
1 m	0.907	2 m	1.814	3 m	2.721
4 m	3.628	5 m	4.535	6 m	5.442



Exercise 15

Calculation of BM & KM; KM curves

1 A box-shaped barge is 40 x 25 x 10 m. Draft = 6 m. KG = 8 m. Find KM & GM.

2 A box-shaped vessel 45 m x 8 m x 6 m, displaces 1476 t. Find the KM in SW.

3 A box-shaped barge is 52 x 20 x 12 m. SW draft 7.922 m. Find KM in RD 1.015

4 A box-shaped vessel 180 x 24 m floats at 8 m SW draft. Find KM in SW & FW.

5 Find the GM of a box-shaped vessel 120 m x 18 m when afloat at 10 m SW draft. KG is 6.9 m & FSM is 2000 tm.

6 Calculate the list when 30 t of cargo is shifted 10 m transversely on a box shaped vessel 100 x 16 m. SW draft 7 m; KG 5.5 m; FSM 4800 tm.

7 Draw the KM curve for a box-shaped vessel 90 x 12 m between 2m draft & 7 m. From the curve, find the minimum KM and the draft at which it occurs.

8 A barge is shaped like a triangular prism, 20 m broad at the top and 10 m deep. It is 45 m long and displaces 2952 t. Find the KM in salt water.

9 The underwater portion of a barge is in the shape of a prism, apex downwards, 14 m wide at the top, 8 m deep and 40 m long. Draw the KM curve upto 6 m draft and from the curve find the KM at (a) 2.5 m and (b) 4.75 m.

10 A ship of W 10250 t, KB 5.6 m, KG 8.3 m floats in SW. If I*CL is 45000 m^4, & FSM is 2050 tm, find the GM fluid.

11 A barge 45 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a triangle. The rectangle is 8 m broad and 5 m high. The triangle is apex downwards, 8 m broad and 3 m deep. If W is 1620 t, find the KM when in FW.

12 A barge 50 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a semi-circle. The rectangle is 10 m broad & 4 m high. The semi-circle has a diameter of 10 m and its geometric centre is 3 m above the keel. Find the KM at 6 m draft ($\pi = 22/7$).

13 Two barges, each 52 m long and 9 m broad **at the waterline**, float upright at 3 m even keel draft. KG = 3 m. One barge is rectangular while the other is a triangular prism floating apex downwards. Compare their GM.

14 Two box-shaped barges each 100 m long float at 4 m draft & have KG = 3.5 m. One barge is 10 m broad and the other is 12 m. Compare their initial GM.

15 A homogenous log of square cross-section has RD = 0.72. Prove, by calculation, whether it can float with one side (of the square) parallel to the waterline.

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CHAPTER 20

SIMPSON'S RULES

Simpson's Rules are very popular among mariners and naval architects because of their simplicity. They may be used to calculate the area, volume and geometric centre of the space enclosed by a straight line and a curve.

Calculation of areas

Equidistant points are chosen along the straight line, also called the axis, and the distance between them is called the common interval or 'h'. From each of these points, the perpendicular distance to the curve is measured off and called the ordinate or 'y'. Each ordinate is multiplied by a different number chosen from a series of numbers called Simpson's Multipliers and the product is obtained. The area contained between the axis, the curve and the end ordinates is calculated by the formula:

$$\text{Area} = Kh \text{ (sum of products)}$$

where K is a constant.

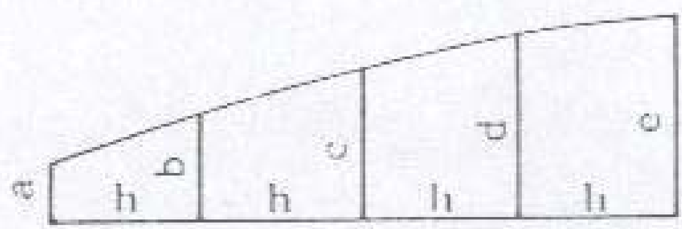
There are three Simpson's Rules & for each, there are different multipliers. The value of the constant 'K' also is different for different rules. If y and h are in metres, the area obtained would be in square metres.

Simpson's First Rule

Area = (h/3) x (sum of products)

Here, K = 1/3 and Simpson's Multipliers are 1 4 1 if there are three ordinates, 1 4 2 4 1 if there are five ordinates, 1 4 2 4 2 4 1 if the ordinates are seven 1 4 2 4 2 4 2 4 1 for nine ordinates, 1 4 2 4 ....2 4 1 for any further odd number of ordinates.

This rule is usable wherever the number of ordinates chosen is an odd number and it gives accurate results if the curve is a parabola of the second order (i.e., where the equation of the curve is $y = ax^2 + bx + c$, in which a, b and c are constants). This rule gives good results for ship-shapes and is hence used extensively by shipyards. Illustration of this rule is as follows:



Ordinate x (y)	Simpsons multiplier (SM)	= Product for area
a	1	1a
b	4	4b
c	2	2c
d	4	4d
e	1	1e

Sum of products = 1a + 4b + 2c + 4d + 1e

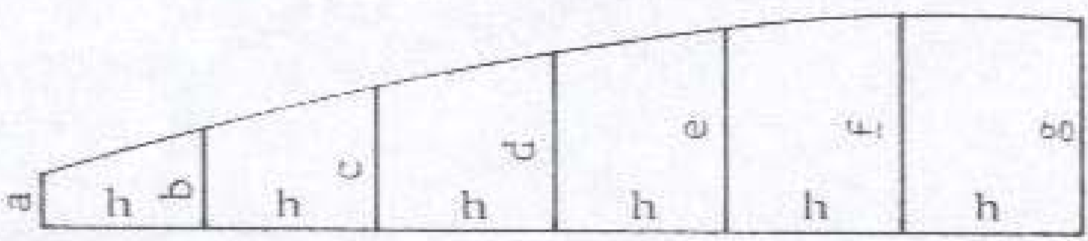
Area = (h/3) x (1a + 4b + 2c + 4d + 1e).

Simpson's Second Rule

Area = (3h/8) x (sum of products)

Here, K = 3/8 and Simpson's Multipliers are 1 3 3 1 if there are four ordinates, 1 3 3 2 3 3 1 .....for seven ordinates, 1 3 3 2 3 3 2 3 3 1 ..for ten ordinates, etc. This rule is usable wherever the number of ordinates chosen is 4, 7, 10, 13, 16, 19, 22, 25, etc. This rule gives accurate results if the curve is a parabola of the third order (i.e., where the equation of the curve is $y = ax^3 + bx^2 + cx + d$, where a, b, c and d are constants).

Illustration of the Second Rule:



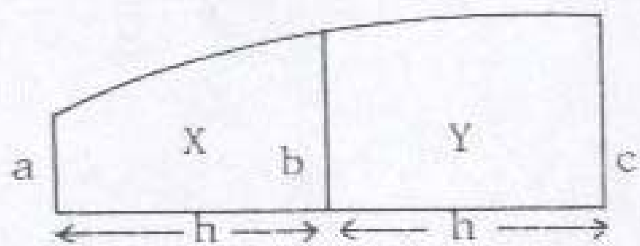
y	x	SM	=	Product
a		1		1a
b		3		3b
c		3		3c
d		2		2d
e		3		3e
f		3		3f
g		1		1g

Sum = 1a + 3b + 3c + 2d + 3e + 3f + 1g

Area = (3h/8) (sum of products as above)

Simpson's Third Rule

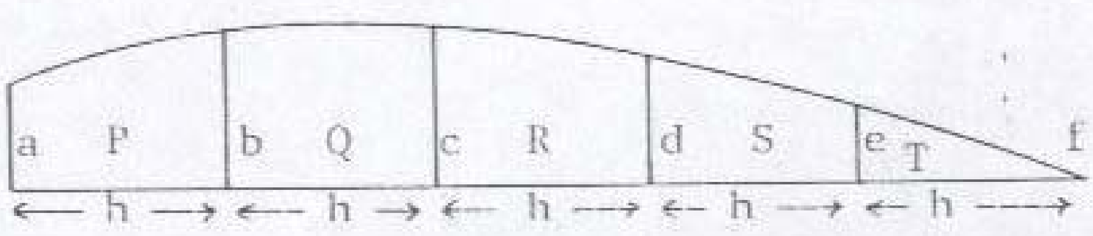
This rule is also called the five-eight-minus-one rule. If three consecutive ordinates are known, the area between any two of them can be calculated by this rule. Here K = 1/12 and SM are 5, 8 and -1. The use of this rule may be illustrated as follows:



Area X = (h/12) (5a + 8b - c)
Area Y = (h/12) (5c + 8b - a)

The trapezoidal Rule

If the value of the common interval 'h' is made very small, part of the curve between any two ordinates may be considered to be straight. The shape now gets divided into several trapezoids. Since the area of a trapezoid is the product of half the sum of the parallel sides and the perpendicular distance between them, the area of the given shape may be obtained by plane geometry without the application of Simpson's Rules. This is illustrated below:



Area P = h (a + b)/2 = h (0.5a + 0.5b)
Area Q .... = h (0.5b + 0.5c)
Area R .... = h (0.5c + 0.5d)
Area S .... = h (0.5d + 0.5e)
Area T .... = h (0.5e + 0.5f)

Total = h (0.5a + b + c + d + e + 0.5f)

Area = h (sum of all intermediate ordinates and half sum of end ordinates)

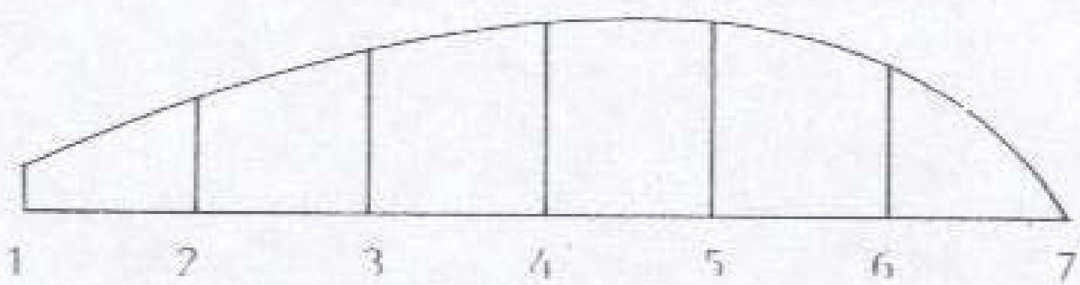
To obtain accurate results by this rule, the value of 'h' would have to be very small. This means more physical work in measuring out so many ordinates. Simpson's Rules are widely used by shipyards, in preference to the trapezoidal rule, as good accuracy can be obtained by using fewer ordinates.

Example 1

A ship's water-plane is 120 m long. The half-breadths, measured at equal intervals from aft, are:

0.1 4.6 7.5 7.6 7.6 3.7 & 0 m.

Find the water-plane area.



Note 1: if half-breadths are put through Simpson's Rules, the area obtained would be half the water-plane area. Double

this value would be the full area of the water-plane. If, instead, full breadths are used, the area obtained would directly be that of the full water-plane. In this question, half-breadths are given. Hence it would be simpler to use them as they are, the half-breadths then being called half-ordinates or semi-ordinates.

Note 2: Seven semi-ordinates means six equal intervals. So h = 120/6 = 20 m.

y/2	x SM	= Product
0.1	1	0.1
4.6	4	18.4
7.5	2	15.0
7.6	4	30.4
7.6	2	15.2
3.7	4	14.8
0.0	1	0.0
Sum of products		93.9

Half area = (20/3) (93.9) = 626 m^2.
Full area = 626 x 2 ..... = 1252 m^2.

Example 2

Example 1 had seven ordinates and could have been worked using Simpson's Second Rule as follows:

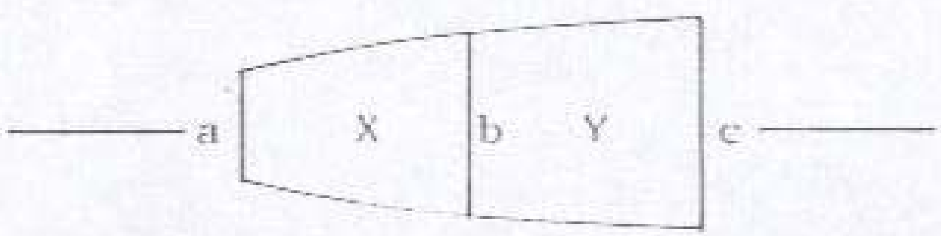
y/2	x SM	= Product
0.1	1	0.1
4.6	3	13.8
7.5	3	22.5
7.6	2	15.2
7.6	3	22.8
3.7	3	11.1
0.0	1	0.0
Sum of products		85.5

Half area = (20 x 3/8)(85.5) = 641.25 m^2
Full area = 641.25 x 2 .... = 1282.50 m^2

Note: Given the same particulars, the answers obtained by Simpson's First Rule & by Simpson's Second Rule are slightly different (less than 2.5% in this case). This is mentioned here to illustrate that the results obtained using Simpsons Rules are only very good approximations of the correct areas. The accuracy improves as the number of ordinates is increased i.e., the smaller the common interval, the greater the accuracy.

Example 3

The breadths of part of a ship's deck, at 5 m intervals are 13, 14 and 14.5 m. Find the area between the first two ordinates.



Area X = (h/12) (5a + 8b - c)

= (5/12)(65 + 112 - 14.5) = 67.708 m^2

Example 4

The half-breadths of a ship's waterplane 100 m long, at equal intervals from aft:

5.0 5.88 6.75 6.63 4.0 & 0.0 m.

Find the water-plane area and TPC in SW.

Note 1: Since the given number of semi-ordinates is six, none of Simpsons Rules is directly applicable to all of them as a whole. Part of the area can be calculated using one rule and the other part by another rule. The sum of the two part areas would give the area of the semi-water-plane. Double this value would be the area of the whole water-plane. Here are some possibilities:

(a) Area between the first and the third semi-ordinate by the first rule and the remaining area by the second rule.

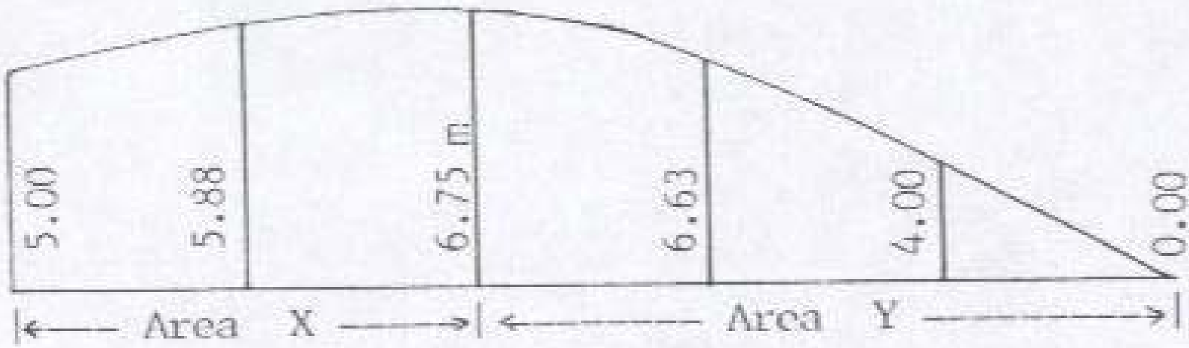
(b) Area between the first and the fourth semi-ordinate by the second rule & the remaining area by the first rule.

(c) Area between the first and the fifth semi-ordinate by the first rule and the remaining area by the third rule.

(d) Area between the first and the second semi-ordinate by the third rule & the remaining area by the first rule.

Note 2: The results obtained by different methods may differ slightly but would be within reasonable limits.

Note 3: The semi-ordinate which happens to be the boundary between the areas calculated separately is called the dividing semi-ordinate. It will be used twice - once in each calculation of part area. In this example, the third is the dividing semi-ordinate.



y/2	SM	Product
5.00	1	5.00
5.88	4	23.52
6.75	1	6.75
	Sum =	35.27

Area X
= (20/3)(35.27)
= 235.133 m^2.

y/2	SM	Product
6.75	1	6.75
6.63	3	19.89
4.00	3	12.00
0.00	1	0.00
	Sum =	38.64

Area Y
= (20)(3/8)(38.64)
= 289.800 m^2.

Semi-area = X + Y = 524.933 m^2.

Full area = 2 (524.933) = 1049.866 m^2.

TPC = 1.025A/100 = 1.025 (1049.866)/100

TPC = 10.761

Exercise 16
Areas by Simpson's Rules

1 Find the area of a boat cover 10 m long if breadths at equal intervals from fwd are 0, 2.25, 3, 2.25 & 0 m.

2 A small coaster's deck is 50 m long. Half-breadths at equal intervals from aft are 0.78, 2.89, 4.06, 2.34 & 0.31 metres. Calculate the deck area.

3 Find the area of a collision bulkhead 12 m high. The half-breadths at equal intervals from top are:

7, 4.8, 2.95, 2, 1.65, 1.3 and 0 m.

4 Find the area of a transverse bulkhead 10 m high whose half-breadths, at equal vertical intervals, are:

10, 9.3, 8.3, 7.1, 5.7 and 3.8 metres

5 A ship's water-plane is 150 m long. Half-breadths at equal intervals from aft are: 2.97, 6.15, 7.84, 8.48, 8.06 7.21, 5.72, 3.6 & 0 m respectively.

Find: (a) The water-plane area.
(b) The area coefficient.
(c) The TPC in salt water.

6 Find the area of a tanktop 21 m long. Equidistant breadths are: 19.2, 18.0, 17.1, 16.2, 14.4, 12.0, 9.3 & 6.0 m.

7 The half-breadths of a water-tight bulkhead, at 2 m intervals from the bottom, are 1, 2.9, 4.2, 5.1 & 5.7 m.

Find (i) The area between the bottom two semi-ordinates (ii) the quantity of paint required to coat the entire bulkhead once, if the paint covers 10 square metres per litre.

8 A ship's water-plane is 90 m long. Half-breadths at equal intervals from forward are: 0.0, 2.5, 4.5, 6.5, 7.5, 8.5, 8.5, 8, 6 and 0 m respectively. Find (a) SW TPC (b) Area coefficient.

9 The breadths of a ship's water-plane 120 m long, at equal intervals from aft, are: 1.2, 9.6, 13.2, 15.0, 15.3, 15.6, 15.6, 14.7, 12.9, 9 & 0 metres. Find (a) The water-plane area.
(b) FWA if W = 6811 tonnes.

10 Find the area of a ship's deck 99 m long whose half-breadths at equal intervals from forward are 0.45, 2.10 3.75, 5.25, 6.45, 7.35, 7.80, 7.20, 5.85 and 3.00 metres respectively.

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Calculation of volumes

If cross-sectional areas are put through Simpson's Rules, the volume of an enclosed space having curved boundaries can be calculated. These cross-sectional areas must be equally spaced (must have a common interval) and may be either transverse (like areas of imaginary water-tight bulkheads) or horizontal (like water-plane areas at equal intervals of draft).

The application of Simpson's Rules is the same for calculation of volumes as for calculation of areas. If semi-areas are put through the Rules, the result obtained would be the semi-volume.

Example 5

Find the volume of displacement of a barge 48 m long whose under water transverse cross-sectional areas are:
19.6, 25, 17.5, 13 and 0 square metres.

Area	x	SM	=	Product
19.6 m^2		1		19.6
25		4		100.0
17.5		2		35.0
13		4		52.0
0		1		0.0
Sum of products				206.6

Vol = (SOP)h/3 = (206.6)12/3 = 826.4 m^3.

Example 6

The water-plane areas of a ship, at one metre intervals from keel upwards, are: 1730, 1925, 2030, 2100 and 2150 m^2. Find the W and the TPC in SW at 4 m draft.

Draft	WP area	SM	Product
4	2150 m^2	1	2150
3	2100	4	8400
2	2030	2	4060
1	1925	4	7700
0	1730	1	1730
Sum of products =			24040

Vol = (SOP)h/3 = (24040)1/3 = 8013.333 m^3

SW W = 8013.333 x 1.025 = 8213.7 tonnes.

TPC at 4 m draft = 1.025A/100

= 1.025(2150)/100 = 22.038.

Example 7

Given the following information, find the displacement at 6 m draft in SW:

Draft	6	5	4	3	2	1	0 m
TPC	61.5	61.7	61.8	61.8	61.7	57.4	51.3

Alternative 1

The given values of TPC can be converted into water-plane areas by the formula: TPC = 1.025A/100. The water-plane areas, put through Simpson's Rules, would give the volume of displacement. This volume x 1.025 = SW displacement at 6 m draft.

Alternative 2

TPC = 1.025A/100 or A = (TPC)100/1.025

Let X = 100/1.025 so A = TPC (X)

Draft	WP area	SM	Product
6	61.5X	1	61.5X
5	61.7X	4	246.8X
4	61.8X	2	123.6X
3	61.8X	4	247.2X
2	61.7X	2	123.4X
1	57.4X	4	229.6X
0	51.3X	1	51.3X
Sum of products =			1083.4X

Vol = (SOP)h/3 = 1083.4X/3 = 35232.52 m^3

W at 6 m = 35232.52 (1.025) = 36113.3 t.

Note: This problem may be solved using Simpson's Second Rule. W would then work out to 36157.5 t. (Difference < 0.15%).

Exercise 17
Volumes by Simpson's Rules

1 Given the following information, find the volume of displacement and the approximate mean TPC between the drafts of 8 m and 9 m:

Draft (metres)	7	8	9
WP area in m^2	2240	2295	2355

2 Find the volume of a lower hold 20 m long whose transverse cross-sectional areas at equal intervals from forward are 120, 116, 101 & 80 square metres.

3 Find the displacement at 5 m SW draft if the water-plane areas, in m^2, are:

Draft	6	5	4	3	2	1	0 m
Area	2550	2010	1920	1580	1300	920	780

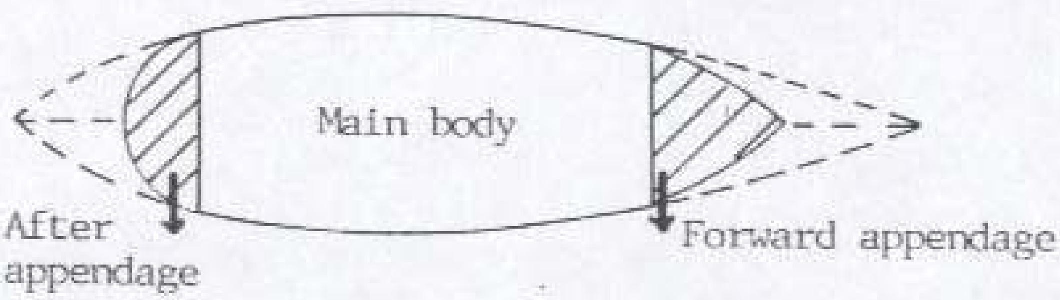
4 Find the quantity of coal (SF 4 m^3t^{-1}) that a coal bunker can hold if its cross-sectional areas, at 5 m intervals are 9, 11.3, 12.6, 12.4 & 11.2 m^2

5 Find W & TPC at 6 m FW draft, if the water-plane areas, in m^2, are:

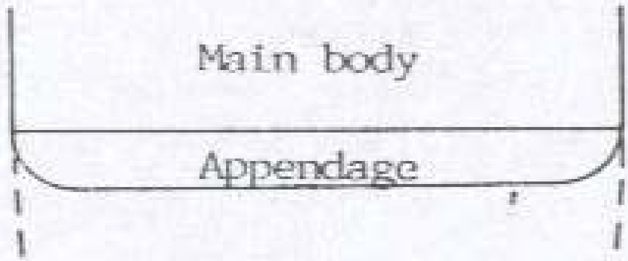
d	6	5	4	3	2	1	0 m
A	5855	5875	5893	5895	5900	5885	5850

Appendages

Appendages are those parts of a curved boundary where the curvature changes considerably. In calculations of water-plane areas, appendages may occur near the ends.



In calculations of under water volumes, appendages occur in the region of the double bottom tanks as the curvature of the shell plating changes sharply at the bilges.



Areas/volumes of appendages are usually calculated separately and then added to the area/volume of the main body.

Intermediate ordinates

The greater the number of ordinates used, the greater the accuracy of the result obtained by Simpson's Rules. Where the change of curvature is not too severe, calculation of the area/volume of the appendage and of the main body can be done as a single calculation. First, the ordinates in the appendage are spaced at the same common interval as in the main body. Next, intermediate ordinates (also called half stations) are inserted in the appendage midway between the regular ordinates, as illustrated in the figure on the next page wherein 'a' to 'g' are regular ordinates while 'x' and 'y' are intermediate ordinates or half stations. The calculation is then as follows:

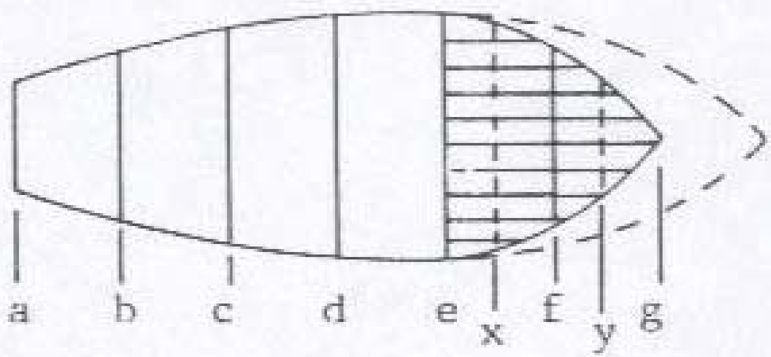
Area of main body = (sum of products)h/3

= (1a + 4b + 2c + 4d + 1e) (h/3)

Appendage area =(sum of products)(h/2)/3

= (1e + 4x + 2f + 4y + 1g)(0.5h)/3

= (e/2 + 2x + 1f + 2y + g/2) (h/3)



Total area = Main body + appendage

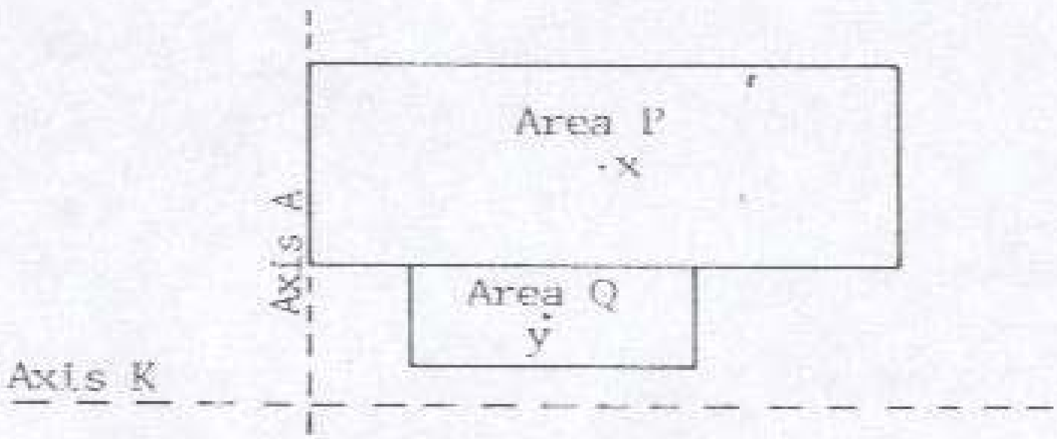
= [1a+4b+2c+4d+(1.5e)+2x+1f+2y+g/2](h/3)

Note: Simpson's Multipliers in the half station zone are halved except at the common ordinate for which the SM is 1.5. This holds good for half stations even where Simpson's Second Rule is used. If desired, the area/volume of the main body and of the appendage may be calculated separately and the results added together.

Geometric centres

The position of the geometric centre can be found by the principle of moments. A basic illustration is as follows:

In the following figure, x is the geometric centre of area P and y, that of area Q. Ax and Ay are the perpendicular distances of the geometric centres from axis A. Kx and Ky are the perpendicular distances from the axis K. Required to find the position of z, the geometric centre of the whole figure (ie, required to find Kz and Az).



Taking moments about axis K,

Area P(Kx) + area Q(Ky) = Area (P+Q)(Kz)

Kz, being the only unknown factor in the equation, can be obtained by calculation.

Taking moments about axis A,

Area P(Ax) + area Q(Ay) = Area (P+Q)(Az)

Az, being the only unknown factor in the equation, can be obtained by calculation.

Geometric centres by Simpson's Rules

Calculation of the position of the geometric centre of a space by Simpson's Rules also is based on the principle of moments. The geometric centre of a water-plane is the centre of flotation (COF) at that draft and AF is its distance from the after perpendicular of the ship. The geometric centre of the under water volume of a ship is its centre of buoyancy (COB) whose position is indicated by KB and AB. The calculation of the position of the geometric centre, by Simpson's Rules, is illustrated by the worked examples that follow.

Example 8

A ship's water-plane is 120 m long. Half breadths, at equal intervals from aft, are: 0.1, 4.6, 7.5, 7.6, 7.6, 3.7 & 0 m. Calculate the position of its COF.

Let A be the after end of the waterplane

h = 120/6 = 20 metres.

y/2 (m)	SM	Product for semi-area	Lever abt A	Product for semi-moment
0.1	1	00.1	0h	00.0h
4.6	4	18.4	1h	18.4h
7.5	2	15.0	2h	30.0h
7.6	4	30.4	3h	91.2h
7.6	2	15.2	4h	60.8h
3.7	4	14.8	5h	74.0h
0.0	1	00.0	6h	00.0h
	SOP =	93.9	SOP =	274.4h

AF = 274.4h/93.9 = 58.445 metres.

Note 1: Lever about A is the distance of the semi ordinate from the after end, in multiples of h. It may, if desired, be inserted directly in metres.

Note 2: Explanation of the final calculation of AF is as follows:

$$AF = \frac{\text{Mom abt A}}{\text{Total area}} = \frac{(\text{SOP for mom abt A})h/3}{(\text{SOP for full area})h/3}$$

$$= \frac{(\text{SOP for semi-moment})}{(\text{SOP for semi - area})} = \frac{274.4h}{93.9}$$

Example 9

The transverse cross-sectional areas, of the under water portion of a barge, at 12 m intervals from forward, are: 0, 13, 17.5, 25 and 19.6 square metres. The last ordinate is the after perpendicular of the barge. Calculate AB.

Area (m^2)	SM	Product for vol	Lever abt A	Product for mom
00.0	1	00.0	4h	00.0h
13.0	4	52.0	3h	156.0h
17.5	2	35.0	2h	70.0h
25.0	4	100.0	1h	100.0h
19.6	1	19.6	0h	00.0h
		SOP = 206.6		SOP = 326.0h

AB = 326.0h/206.6 = 18.935 metres.

Example 10

The water-plane areas of a ship are:-

Draft	5	4	3	2	1 m.
Area	2150	2100	2030	1925	1730 m^2.

Between the keel and 1 m draft, there is an appendage of 800 m^3 volume whose geometric centre is 0.7 m above the keel. Find the displacement and the KB of the ship at 5 m draft in salt water.

d (m)	WP area	SM	Product for vol	Lever abt K	Product for mom about K
5	2150	1	2150	5h	10750h
4	2100	4	8400	4h	33600h
3	2030	2	4060	3h	12180h
2	1925	4	7700	2h	15400h
1	1730	1	1730	1h	1730h
		SOP =	24040	SOP =	73660h

KB of main body = 73660h/24040 = 3.064 m

Vol of main body = (h/3)(SOP for volume)

= 8013.333 m^3.

Taking moments about the keel,

[Main body]+[appendage] = [total volume]
8013.333(3.064)+800(0.7) = (8813.333) KB

KB of ship = 2.849 metres.

W in SW = 8813.333(1.025) = 9033.7 t.

Example 11

Half-breadths of a ship's water-plane, at equal intervals from aft, are:

5, 5.88, 6.75, 6.63, 4, 2.38 & 0 metres.

The common interval between the first five semi-ordinates is 20 m and between the last three is 10 m. The total length of the water-plane is 100 m. Find the area of the water-plane and the position of its COF.

y/2 (m)	SM	Product for semi-area	Lever abt A	Product for semi-moment
5.00	1	5.00	0h	00.00h
5.88	4	23.52	1h	23.52h
6.75	2	13.50	2h	27.00h
6.63	4	26.52	3h	79.56h
4.00	1.5	6.00	4h	24.00h
2.38	2	4.76	4.5h	21.42h
0.00	0.5	0.00	5h	00.00h
		SOP = 79.30		SOP = 175.50h

AF = 175.5h/79.3 = 44.262 metres.

Semi-area = (SOP) h/3 = 528.6667 m^2.

Full area = 2(528.6667) = 1057.333 m^2.

Example 12

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 1 m, are:

0, 3.25, 4.4, 5.15, 5.65, 5.9 and 6.0 m.

Find the distance of the geometric centre of the bulkhead from (a) the inner boundary and (b) the deckhead. (c) Find the thrust on this bulkhead when the tank is full of salt water.

Note 1: The distance of the GC from the inner boundary of the tank can be calculated by taking levers, in multiples of h or directly in metres, from the stbd side, as done in earlier examples.

Note 2: The distance of the GC of each ordinate y, from the deckhead, is y/2. This is the lever to be used to calculate the distance of the GC of the bulkhead from the deckhead.

Note 3: In the calculation below,

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

(1) Ord in (m)	(2) SM	(3) Product for area	(4) LEVER	(5) Product for mom about stbd side	(6) LEVER	(7) Product for mom about deck head
0.00	1	0.00	6h	00.00h	0.000	00.000
3.25	3	9.75	5h	48.75h	1.625	15.844
4.40	3	13.20	4h	52.80h	2.200	29.040
5.15	2	10.30	3h	30.90h	2.575	26.523
5.65	3	16.95	2h	33.90h	2.825	47.884
5.90	3	17.70	1h	17.70h	2.950	52.215
6.00	1	6.00	0h	00.00h	3.000	18.000
		SOP 73.9	SOP	184.05h	SOP	189.506

GC from stbd = 184.05h/73.9 = 2.491 m.

GC to deckhead = 189.506/73.9 = 2.564 m.

Area = (SOP)3h/8 = 73.9(3/8) = 27.713 m^2

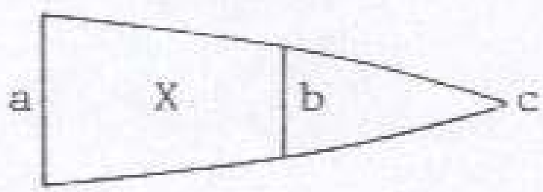
Thrust = depth of GC x density x area

= 2.564(1.025)27.713 = 72.833 t.

Note 4: To save time and effort during calculation, column 6 may be taken as full y and then the sum of products of column 7 may be divided by 2. If desired column 6 may be $y^2/2$ and put through SM to get column 7.

Example 13

The breadths of the forecastle of a barge, at 2 m intervals from aft, are:- 3.31, 2 & 0 m. Calculate the area & the position of the geometric centre of the space between the first two ordinates.



Area X = (5a + 8b − c)h/12

= (16.55 + 16 − 0)2/12 = 5.425 m^2

Moment of area X about 'a'

= (3a + 10b − c)(h^2/24)*

= (9.93 + 20 − 0)4/24 = 4.988 m^3.

GC of X from 'a' = 4.988/5.425 = 0.919 m

Note: The formula marked * is called the **three-ten-minus-one rule** for use in such cases.

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Exercise 18

Simpson's Rules

1 Calculate the area and the position of the COF of a ship's water-plane whose half-breadths, at 10 m intervals from aft, are: 0, 6, 8, 8.5, 8.5 7.5, 6.5, 4.5, 2.5 and 0 metres.

2 The breadths of a transverse watertight bulkhead, at 2 m intervals from the bottom, are: 2, 5.8, 8.4, 10.2 & 11.4 m. Find (a) its area, (b) the distance of its geometric centre from the top and (c) the thrust when it is pressed up with SW to a head of 6 m above the top.

3 The half-breadths of a transverse W/T bulkhead, at 2 m vertical 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 total area of the bulkhead and the distance of its GC from the bottom of the appendage.

4 Find KB and displacement at 4 m draft in SW, if the water-plane areas are:-

Draft	5	4	3	2	1	0	m
Area	2010	1920	1580	1300	920	780	m^2

5

Draft	6	5	4	3	2	1	0	m
TPC	22.6	22.2	21.6	20.9	19.7	17.8	14.6	

Find W and KB at 6 m SW draft.

6 The half-breadths of a tank top, at 3 m intervals from forward, are:

3, 4.65, 6, 7.2, 8.1, 8.55, 9 & 9.6 m

Find the area and the distance of its geometric centre from forward. (Suggestion: Use Rule 1 for the first five semi-ordinates & Rule 2 for the last four).

7 The water-plane areas of a ship are:-

Draft	6	5	4	3	2	m
Area	2190	2150	2100	2040	1920	m^2

Below 2 m draft there is an appendage having a volume of 3200 m^3, whose GC is 1.2 m above the keel. Find the KB and W of the ship at 6 m draft in SW.

8 Find the W and KB at 5 m draft in SW, given the water-plane areas as under:

d	5 m	4	3	2	1	0.5	0.0
A	6380	6320	6225	6090	5885	5740	5560

9 The half-ordinates of a ship's water-plane, at equal intervals from fwd, are: 0, 1.5, 2.78, 3.75, 4.2, 4.5, 4.2, 3.9, 3.3 and 2.25 m. The common interval between the last four semi-ordinates is 3 m & between the others is 6 m. Find the distance of the GC from the ship's after end. (Suggestion: Use Simpson's Rule 2 with half-stations aft).

10 The half-breadths of a ship's water-plane 180 m long, at equal intervals

from aft, are: 2.8, 4, 5.2, 6, 6.4, 6.8, 6.6, 6, 4.2 and 0 metres. Midway between the last two given figures, the half-breadth is 2.4 m. Find the area of the water-plane and the distance of the COF from the after end.

11 The breadths of a ship's water-plane 144 m long, at equal intervals from forward, are: 0, 9, 12.9, 14.7, 15.6, 15.8, 15.8, 15.6, 15.3, 15, 13.2, 9.6 and 0 m. The intermediate ordinate beween the first two is 6 m & between the last two, is 6.6 m. Find the area of the water-plane and the distance of the COF from amidships.

12 The half-breadths of a ship's water-plane, at 12 m intervals from aft are 0.0, 3.3, 4.5, 4.8, 4.5, 3.6, 2.7 and 1.5 m. The half-breadth, midway between the first two from aft, is 2 m. At the forward end is an appendage by way of a bulbous bow 4.5 m long. Its area is 24 m^2 and its GC, 2 m from the forward extremity. Find the area of the water-plane and the position of the COF.

13 The transverse cross-sectional areas of a lower hold 21 m long, at equal intervals from forward, are 120, 116, 101 and 80 m^2. Find the volume of the hold and the distance of its GC from the after bulkhead.

14 The transverse cross-sectional areas, of a ship's under-water portion 90 m long, are: 0.5, 22.9, 49, 73.5, 88.5, 83, 58.6, 31.8, 14.2, 8.1 and 4.5 m^2.

The last given area is at the after perpendicular of the ship. The spacing between the last three sections is half the common interval between the rest. Find the displacement in SW and the AB.

15 The after bulkhead of the starboard slop tank of a tanker is 6 m high. It is bounded on the top by a horizontal deck, towards amidships by a vertical fore-and-aft bulkhead, and on the the starboard side by the shell plating. The breadths of this bulkhead at equal vertical intervals are: 3, 3.15, 2.85, 2.1, 1.1 and 0 metres. Find the area of this bulkhead and the distances of its GC from the bottom and from the inner boundary.

16 Three consecutive half-breadths of a bulkhead 6 m high, starting from the bottom, are: 5, 9 and 10 m. Find the area and position of the GC of the bottom three metres of this bulkhead.

17 The cross-sectional areas of a coal bunker, at 4 m intervals from forward are: 15, 42 and 45 m^2. Find the mass of coal (SF 4 m^3/t) that could be contained between the first two given cross-sectional areas & the distance of its GC from the after bulkhead.

18 Rework question 6 of this exercise, using Simpson's First Rule for the first seven ordinates and Simpson's Third Rule for the last three. (Compare the area and COF obtained in both cases).

19 The half-breadths of a ship's water-plane 150 m long, from forward, are:

2.97, 6.15, 7.84, 8.48, 8.06, 7.21, 5.72, 3.60 and 0 metres respectively.

Find the area using the trapezoid rule. (Compare your answer with that of question 5 of exercise 16).

20 The breadths of the deck of a ship, measured at 15 metre intervals from forward, are:

6.2, 13.8, 21.9, 26.4, 22.4, 14.7 and 7.4 metres respectively.

Assuming that Simpson's First Rule is correct, find the % error that would be obtained by using:
(a) The trapezoidal rule and
(b) Simpson's Second Rule.

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CHAPTER 21

ANGLE OF LOLL -

CALCULATION; REMEDIAL ACTION

Unstable equilibrium and angle of loll were described in chapters 10 & 11 in Ship Stability I. A vessel at the angle of loll is in an extremely precarious and dangerous situation - wrong action or no action on the part the ship's staff may cause the ship to capsize. Even no action is dangerous because consumption of fuel and water from the double bottom tanks would cause increase of KG making the vessel more unstable, thereby increasing the angle of loll.

The angle of loll can be calculated by a simple formula derived from the wall-sided formula:

$$GZ = \sin\theta\,(GM + \tfrac{1}{2}BM\tan^2\theta)$$

At the angle of loll, GZ = zero. So

$$\sin\theta\,(GM + \tfrac{1}{2}BM\tan^2\theta) = 0$$

So $\sin\theta = 0$ or $(GM + \tfrac{1}{2}BM\tan^2\theta) = 0$

At the angle of loll, $\theta \neq 0$ so $\sin\theta \neq 0$

$GM + \tfrac{1}{2}BM\tan^2\theta = 0$ and $\tan^2\theta = -2GM/BM$

$\tan\theta = \sqrt{\dfrac{-2GM}{BM}}$ Where θ = Angle of loll
GM = The initial GM
BM = BM when upright

Since this formula is derived from the wall-sided formula, it can be applied only when the immersed wedge and the emerged wedge are identical in shape.

Example

M.V.VIJAY is afloat at 6 m draft. Find the angle of loll if KG = 8.424 metres.

Referring to appendix I of this book,

KM =	8.234 m	KM =	8.234 m
KB =	3.205 m	KG =	8.434 m
BM =	5.029 m	GM =	−0.200 m

$$\text{Tan}\ \theta = \sqrt{\frac{-2GM}{BM}} = \sqrt{\frac{-2(-0.2)}{5.029}} = 0.28203$$

Angle of loll = θ = 15.75° or 15° 45'

Remedial action

1) Press up all slack tanks.
2) Run up SW into the DB tank which has the smallest moment of inertia about its centre line. If this tank is not on the centre line of the ship, then on the lower side first, and after it is full, its counter part on the higher side.
3) Repeat action 2 with another tank and so on until the ship becomes stable.
4) If discharging or jettisioning deck cargo, do so from the higher side first, then from the lower side. If using ship's own gear, due allowance must be made for the shift of COG, of each sling of cargo, from the UD to the derrick head during the operation.

Justification for such action

At the angle of loll, any existing free surface effect must be eliminated/ minimised first. FW or HFO may require to be transferred internally such that the tanks finally remaining slack are those with the smallest moment of inerţia about the tank's centre line.

While running up ballast into a DB tank, FSE would be created. This must be kept to a minimum. The necessity to fill up the tank with the smallest 'i' about its centre line is, therefore, vital. So also, the necessity to fill up only one tank at a time.

If the tank being ballasted is not on the centre line of the ship, but on either side like No:2 P and No:2 S, then fill up the lower side tank first i.e., if the ship is lolled to starboard, then fill up No:2 S first. After it is full, fill up No:2 P. The reasons for this:

Let 'A°' be the angle of loll to starboard at first.
'p°' be the reduction in the angle of loll by completely filling up either No:2 P or No:2 S.
'q°' be the list caused by filling up either No:2 P or No:2 S.
'R°' be the resultant inclination after completely filling up either No:2 P or No:2 S.

If No:2 S is run up first, $R = A - p + q$
If No:2 P is run up first, $R = A - p - q$
In both cases, final R is to starboard.

It appears as if filling up the higher side tank would produce better results but it is not really so. The ship can loll to either side. If after the higher side tank is run up, wave action caused the ship to loll over to the other side (port side in this case), the ship would flop over to A - p + q to port and the momentum of flopping over will carry the inclination well beyond this. Since the GZ formed near the angle of loll is very small, the ship would heel over to port much more than A - p + q and take a very long time to return to this angle of inclination. If during this time (a) any openings went underwater &/or (b) a wave struck the ship adversely and/or (c) any cargo shifted, the ship may capsize.

By filling up the lower side tank first, the inclination would increase a bit to A - p + q at first, but this would be gradual and would last only until No:2 P also is run up.

The same line of reasoning is applicable when considering discharge or jettision of cargo from the upper deck.

If the ship is in calm waters, such as inside a dock, the possibility of flopping over to the angle of loll on the other side may not be there. In such a case, ballasting the higher side tank or discharging deck cargo from the lower side may prove more effective and immediate.

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Exercise 19
Angle of loll

1 A vessel has an initial GM of -0.3 m & BM of 5 m. Find the angle of loll.

2 M.V.VIJAY is lying at the angle of loll of 16° to port, at 6.2 m hydrostatic draft. Find her initial GM.

3 M.V.VIJAY is unstable and lolling 12° to starboard at a hydrostatic draft of 6.8 m. Find the minimum quantity of cargo to shift by a shore crane, from the upper deck to the lower hold, through a vertical distance of 10 m to make the ship stable.

4 A box-shaped vessel 100 x 12 x 8 m is lying at an angle of loll of 18°. If her mean draft is 4 m, find her KG.

5 A homogenous wooden log of square cross-section has RD = 0.68. Would it float in FW with one face parallel to the water? If not, calculate the angle of inclination.

6 What should the RD of a homogenous log of square cross-section be for it to float in FW with one face parallel to the surface of water?

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CHAPTER 22

CURVE OF

STATICAL STABILITY

A curve of statical stability is a graph wherein the righting lever (GZ) is plotted against the angle of heel. It is drawn, by the chief officer, for the displacement and KG of that voyage.

Referring to the illustration on the next page, the information that may be obtained from a curve of statical stability is as follows:

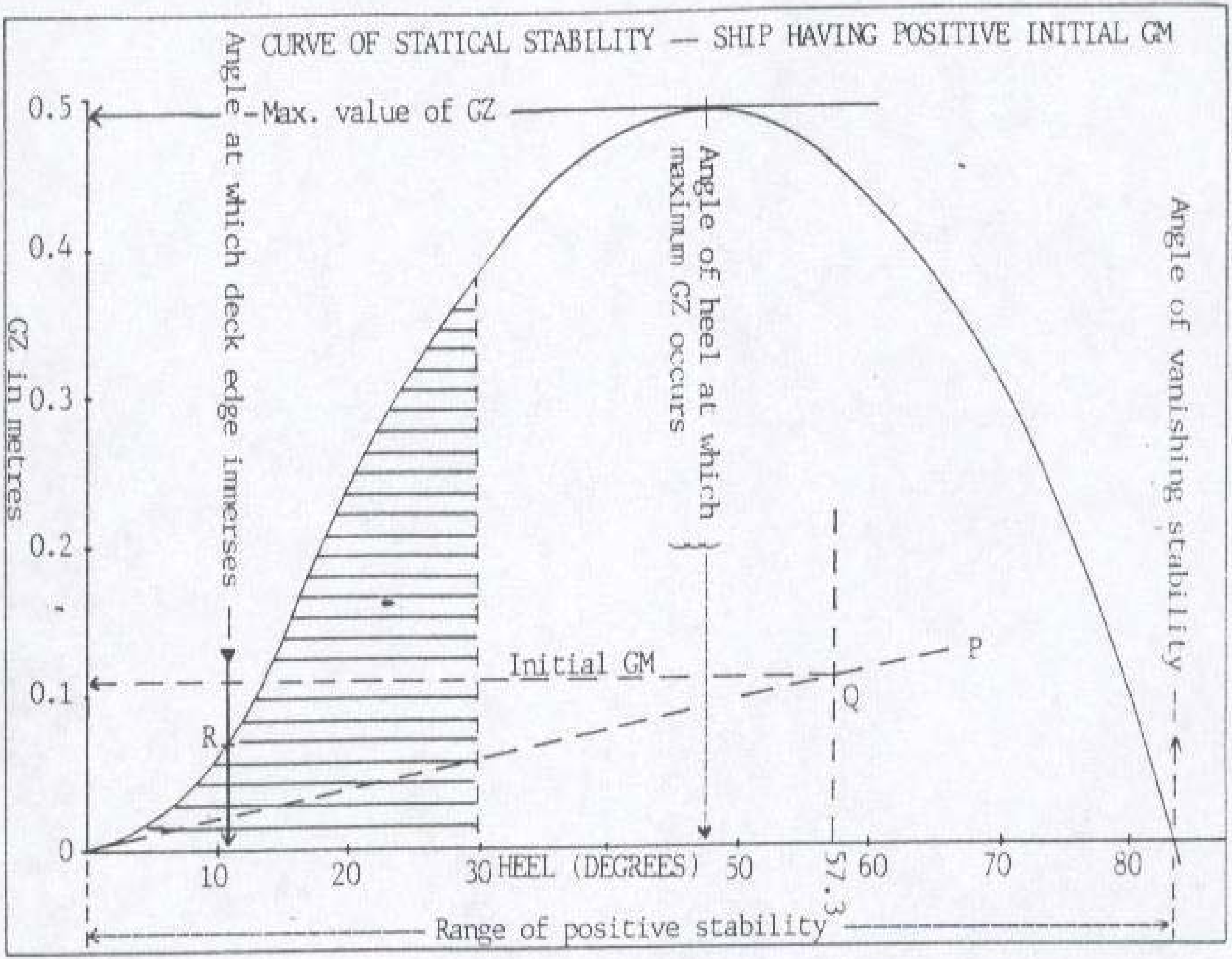
1 The maximum value of GZ.

2 The angle of heel at which maximum GZ occurs.

3 The angle of vanishing stability. This is the angle of heel at which GZ becomes zero again.

4 The range of positive stability. In normal cases, this would be from zero degrees to the angle of vanishing stability but in cases where the ship is initially unstable, it will not be from zero degrees onwards but from some other value as shown later in this chapter.

5 The initial metacentric height. A tangent is drawn to the curve at the


CURVE OF STATICAL STABILITY — SHIP HAVING POSITIVE INITIAL GM
Max. value of GZ
Angle at which deck edge immerses
Angle of heel at which maximum GZ occurs
Angle of vanishing stability
Initial GM
P
Q
R
GZ in metres
0.5
0.4
0.3
0.2
0.1
0
10
20
30
HEEL (DEGREES)
50
57.3
60
70
80
Range of positive stability

origin (OP in the figure). A perpendicular is erected at 57.3° heel to meet the tangent (Q in the figure). The distance of the point of intersection from the base line, measured on the GZ scale, indicates the initial GM.

Note: In actual practice, the reverse happens. The initial fluid GM is cut off on the perpendicular at 57.3° to arrive at point Q in the figure. Q & O are joined by a straight line and while drawing the curve, it is ensured that the curve coincides with line OQ for the first few degrees.

6 The angle of heel at which the deck edge immerses. This is the angle of heel at which the point of contra-flexure of the curve occurs (point R in the figure).

7 The moment of statical stability at any given angle of heel. The GZ for the given angle of heel is obtained from the curve and multiplied by the displacement of the ship.

8 The dynamical stability of the ship at any given angle of heel. This is the work done in heeling the ship to the given angle. This is dealt with in more detail in chapter 40 in Ship Stability III.

Dynamical stability at $\theta°$ heel = W x A

where W: ship's displacement in tonnes
A: area between the GZ curve and the base line, upto $\theta°$ heel, expressed in metre-radians.

Once the curve of statical stability has been drawn, the area under the curve upto any angle of heel can be calculated using Simpson's Rules. This area, multiplied by the displacement of the ship, would give the dynamical stability in tonne-metre-radians. In the figure on page 44, the area under the curve upto 30° has been shaded for illustration.

The curve would be the same whether the ship is heeled to starboard or to port. The only difference would be the direction of GZ - when heeled to port, GZ acts to starboard and when heeled to starboard, GZ acts to port.

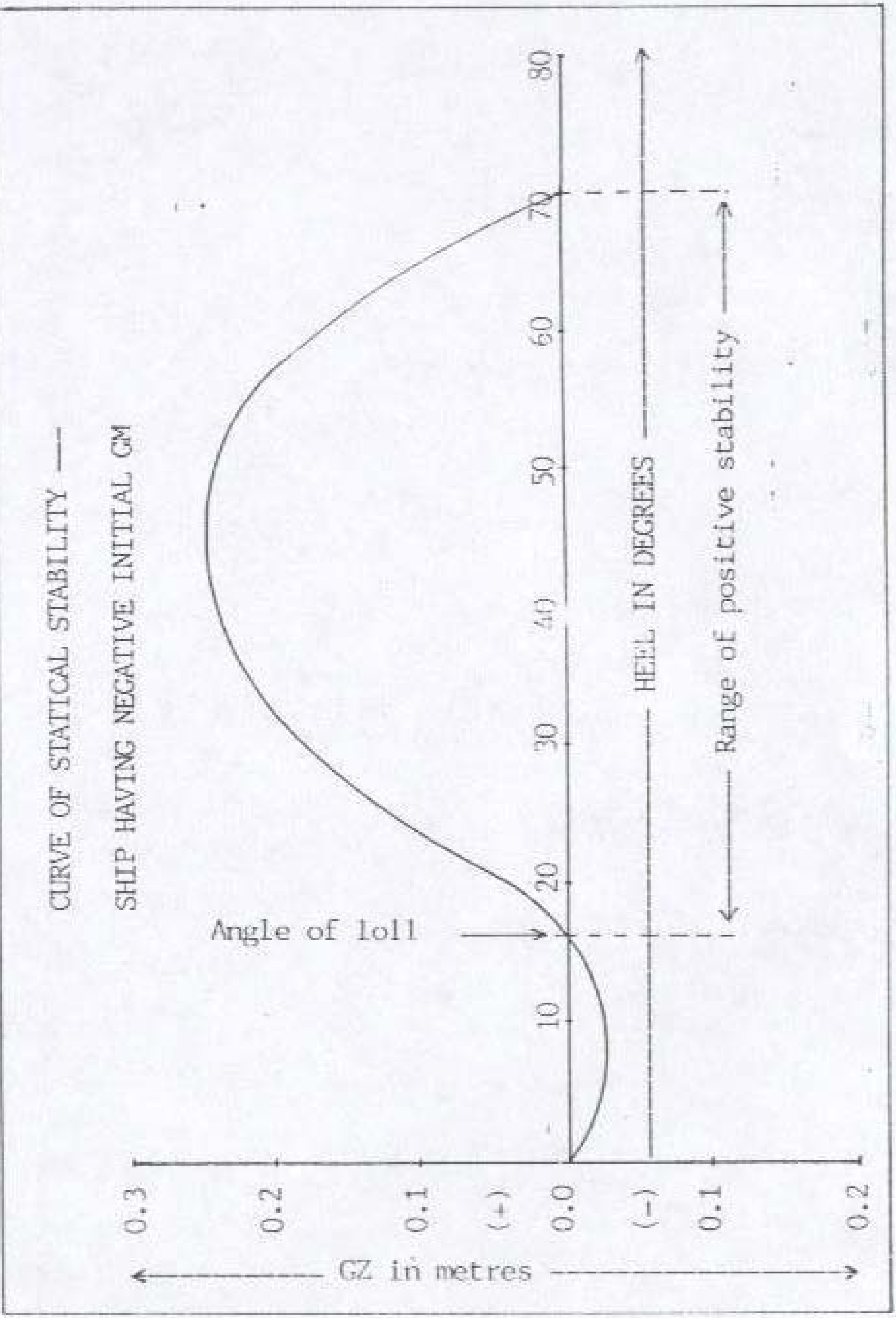
The information required by the chief officer to construct a curve of statical stability, for the displacement and KG of the voyage, is supplied by the shipyard in the form of either Cross Curves or KN curves which are explained in the next two chapters.

Curve when initial GM is negative

An illustration of the GZ curve of a vessel, when it is initially unstable, is given on page 47. It will be seen therein that the range of positive stability is from the angle of loll onwards, not from zero.

Since the angle of loll could be to port or to starboard, the curve would be the same regardless of the direction of inclination of the ship. If the ship was lolled to port, GZ may be considered + when it resists further inclination to port and vice versa.

-oOo-


CURVE OF STATICAL STABILITY —
SHIP HAVING NEGATIVE INITIAL GM
Angle of loll
HEEL IN DEGREES
Range of positive stability
GZ in metres
0.3
0.2
0.1
(+)
0.0
(−)
0.1
0.2
10
20
30
40
50
60
70
80

Curve when ship is listed

When a ship with a positive initial GM has a list, it means that its COG is off the centre line due to asymmetrical distribution of weights on board. The vessel is at rest at the angle of list. The GZ curve will NOT, therefore, be exactly the same for starboard and for port.

An illustration of the GZ curve for a ship with an initial list is given on the next page. As mentioned earlier in this chapter, the GZ of a ship in stable equilibrium acts towards port when heeled to starboard and vice versa. In this case, because the heel to port and to starboard is shown on the same graph, GZ is plotted as positive when acting in one direction, say towards port (ship heeled to starboard), and negative when acting towards starboard (ship heeled to port). It is emphasized here that, on either side of the angle of list, the GZ curve would NOT be symmetrical.

A curve of statical stability can be used to find the angle of list accurately, specially when the angle is large, and this is discussed in chapter 37 in Ship Stability III.

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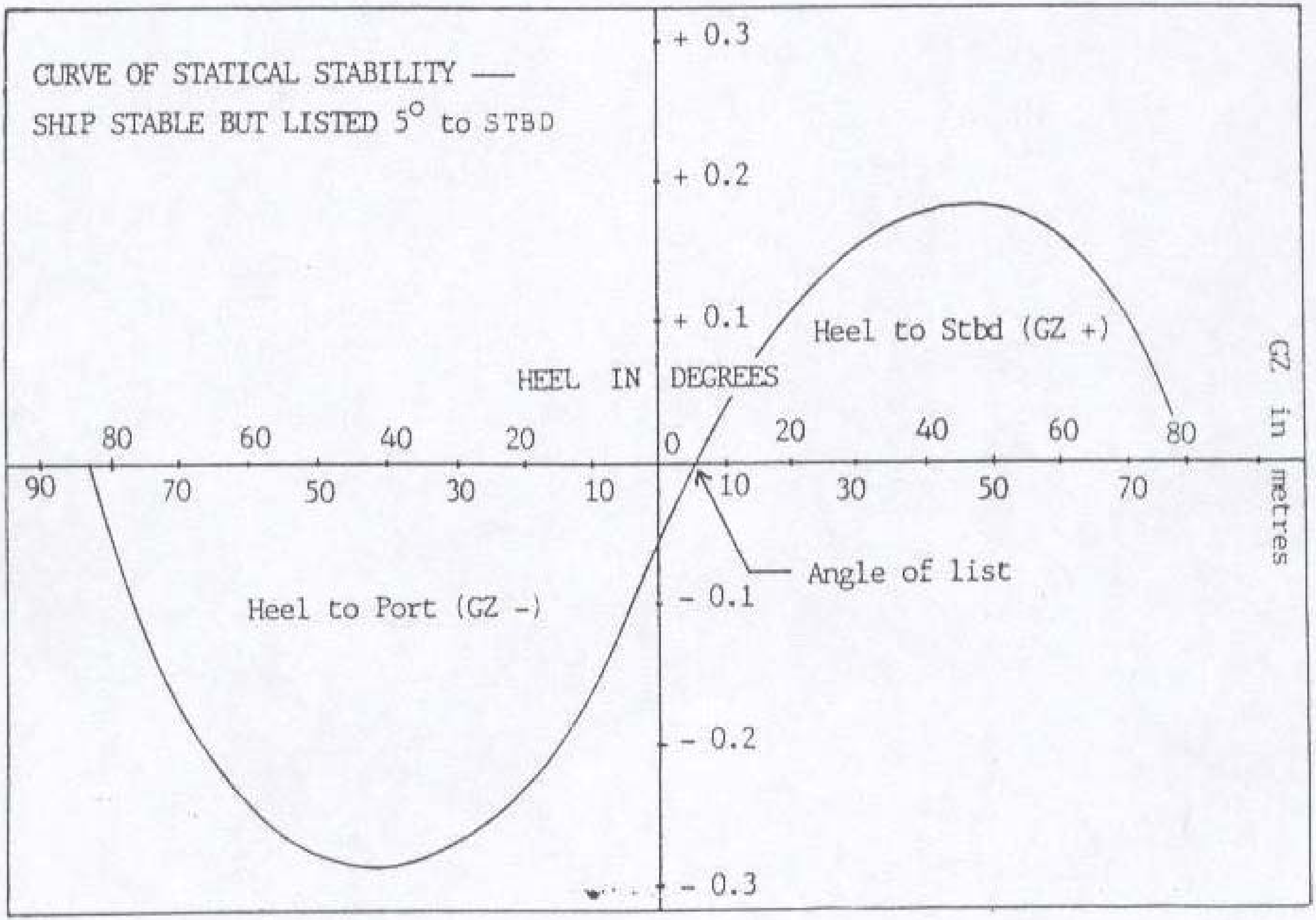

CURVE OF STATICAL STABILITY —
SHIP STABLE BUT LISTED 5° to STBD
HEEL IN DEGREES
GZ in metres
Heel to Stbd (GZ +)
Heel to Port (GZ -)
Angle of list
+ 0.3
+ 0.2
+ 0.1
- 0.1
- 0.2
- 0.3
0
10
20
30
40
50
60
70
80
90

CHAPTER 23

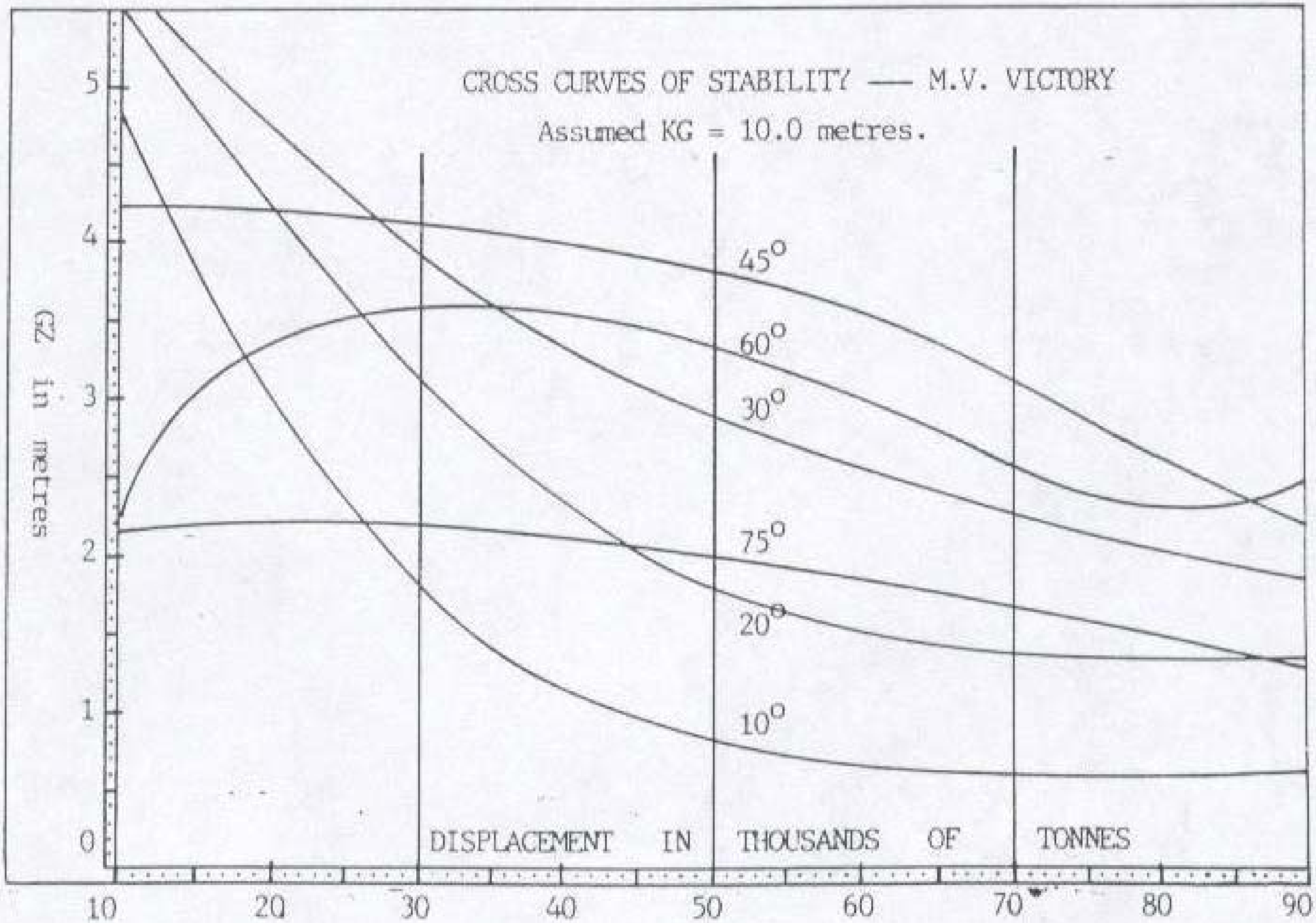
CROSS CURVES

OF STABILITY

As explained in the previous chapter, a curve of statical stability is a curve constructed, for the displacement and KG of each voyage, by the chief officer. The information required to construct such a curve may be given by the shipyard in the form of 'Cross Curves' or in the form of 'KN Curves'. The former is explained here and the latter, in the next chapter.

GZ is a function of KG, KM and θ (the angle of heel). KM depends on draft. For the sake of convenience, the shipyard uses displacement in salt water, instead of draft. The variables, therefore, are GZ, θ, displacement in SW and KG.

Based on their calculations, the shipyard constructs a graph with GZ along the y-axis and displacement along the x-axis. Separate curves are drawn for different values of θ - say 10°, 20° 30°, 45°, 60° and 75°. These curves may cross one another, hence the name 'Cross Curves'. The graph is constructed for an assumed value of KG which is stated clearly therein. In this manner, all the variables affecting GZ are allowed for. The next page contains the cross curves for the bulk carrier m.v. VICTORY. Using the displacement for that voyage, the GZ for the various angles of heel can be


CROSS CURVES OF STABILITY — M.V. VICTORY
Assumed KG = 10.0 metres.
GZ in metres
0
1
2
3
4
5
45°
60°
30°
75°
20°
10°
DISPLACEMENT IN THOUSANDS OF TONNES
10
20
30
40
50
60
70
80
90

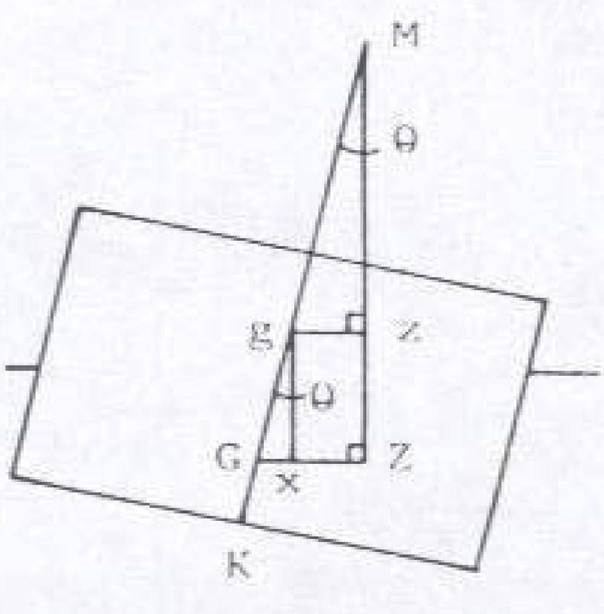
obtained from the cross curves. However, these values of GZ would be correct only for the assumed value of KG. In the case of M.V. VICTORY, the assumed value of KG is stated to be 10 m. Corrections would have to be applied to obtain the correct values for the actual KG of that voyage.

Note: For this purpose, KG means fluid KG. Fluid KG = Solid KG + FSC.

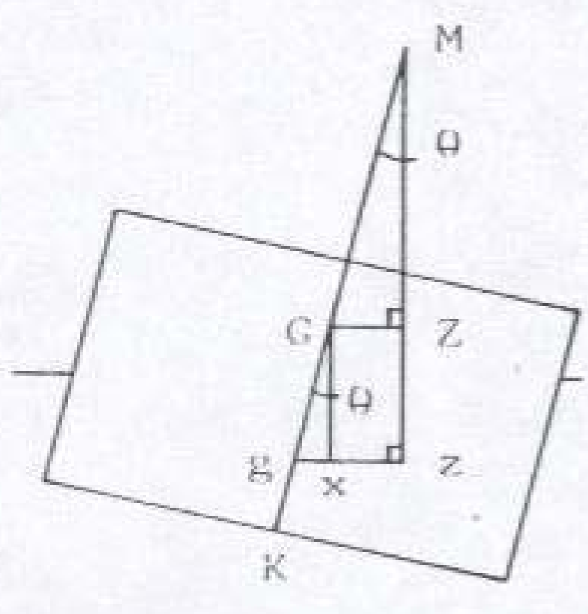
In the following figures,

θ = angle of heel in degrees.
Kg = assumed height of COG for which the cross curves were constructed.
KG = Actual height of COG of that voyage inclusive of FSC.
gz = righting lever at θ° heel if height of COG is Kg.
GZ = actual righting lever at θ° heel when the height of COG is KG.

Case 1: When KG < Kg



Case 2: When KG > Kg



gx is drawn ‖ to zz	gx is drawn ‖ to zz
GZ = xZ + xG = gz + xG = gz + gG(Sin θ)	GZ = xZ = gz - gx = gz - gG(Sin θ)
Correction to apply to gz to obtain GZ is PLUS gG (Sin θ).	Correction to apply to gz to obtain GZ is MINUS gG (Sin θ).

Example 1

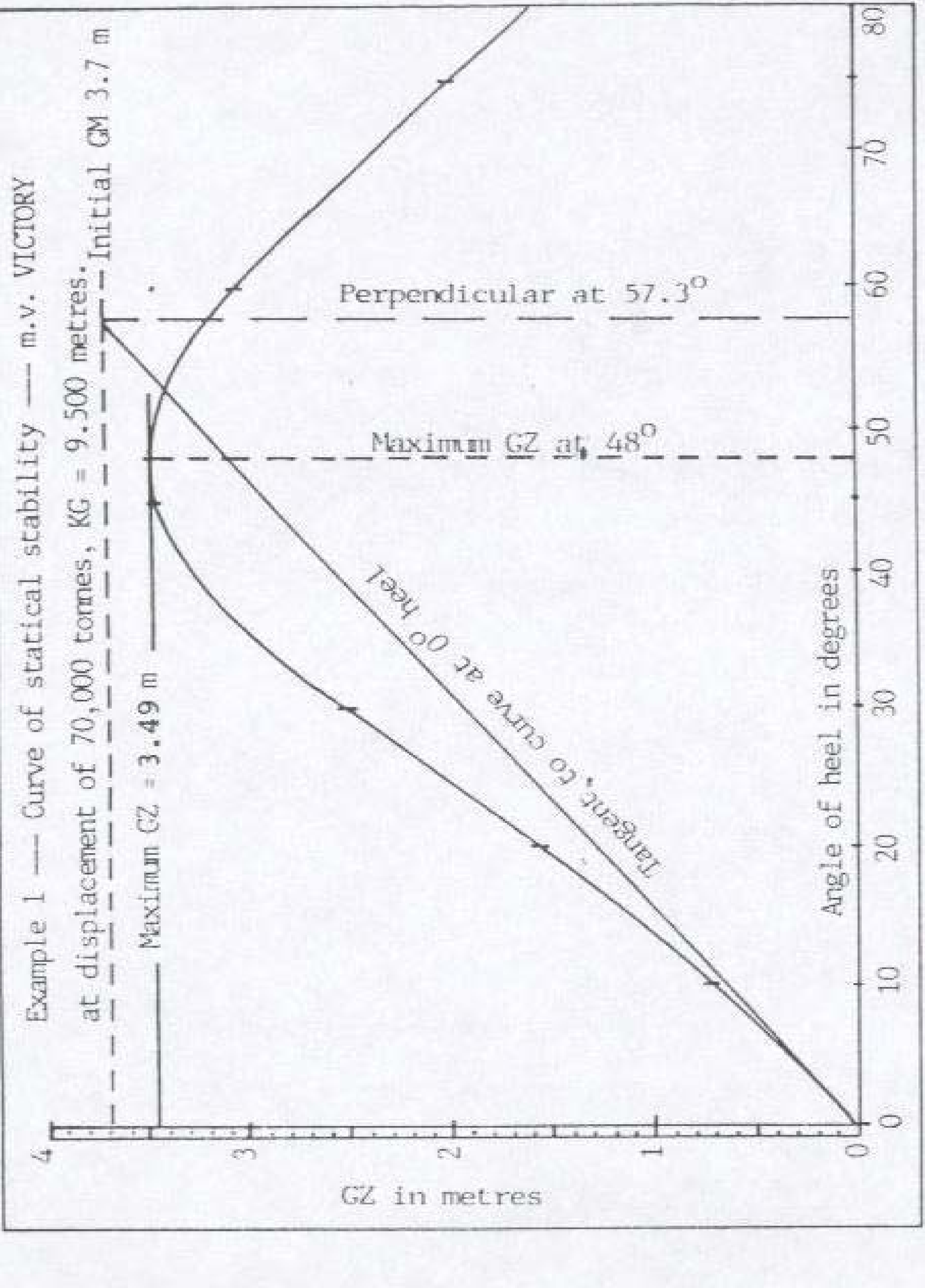
Construct the curve of statical stability of m.v.VICTORY when W = 70,000 t, KG solid = 9.41 m, FSM = 6300 tm. From the curve, find the maximum GZ and the angle of heel at which it occurs. Also find the initial GM in that condition.

FSC = FSM/W = 6300/70,000 = 0.090 metre.

KG fluid = 9.410 + 0.090 = 9.500 metres.

From the cross curves of this ship on page 51, gz values for the various angles of heel, for W of 70,000 t, are extracted. Since KG fluid is 9.5 m and Kg is 10 m, the correction of +gG(Sin θ) is applicable to gz to obtain GZ.

θ	gz	+ gG Sin θ	= GZ
0°	0.00	0.5 Sin 0°	0.000 m
10°	0.60	0.5 Sin 10°	0.687
20°	1.38	0.5 Sin 20°	1.551
30°	2.25	0.5 Sin 30°	2.500
45°	3.13	0.5 Sin 45°	3.484
60°	2.58	0.5 Sin 60°	3.013
75°	1.68	0.5 Sin 75°	2.163



Example 1 — Curve of statical stability — m.v. VICTORY
at displacement of 70,000 tonnes, KG = 9.500 metres. Initial GM 3.7 m
Maximum GZ = 3.49 m
Perpendicular at 57.3°
Maximum GZ at 48°
Tangent to curve at 0° heel
GZ in metres
Angle of heel in degrees
0
1
2
3
4
10
20
30
40
50
60
70
80

GZ can now be plotted against θ, using a suitable scale, as shown on page 54. The curve should be faired as necessary to make it smooth and regular. The points should NOT be joined by short straight lines. The desired information may then be read off from the curve.

Note: Since the fluid GM was required to be read off the curve, the calculated GM could not be used to construct the curve.

Example 2

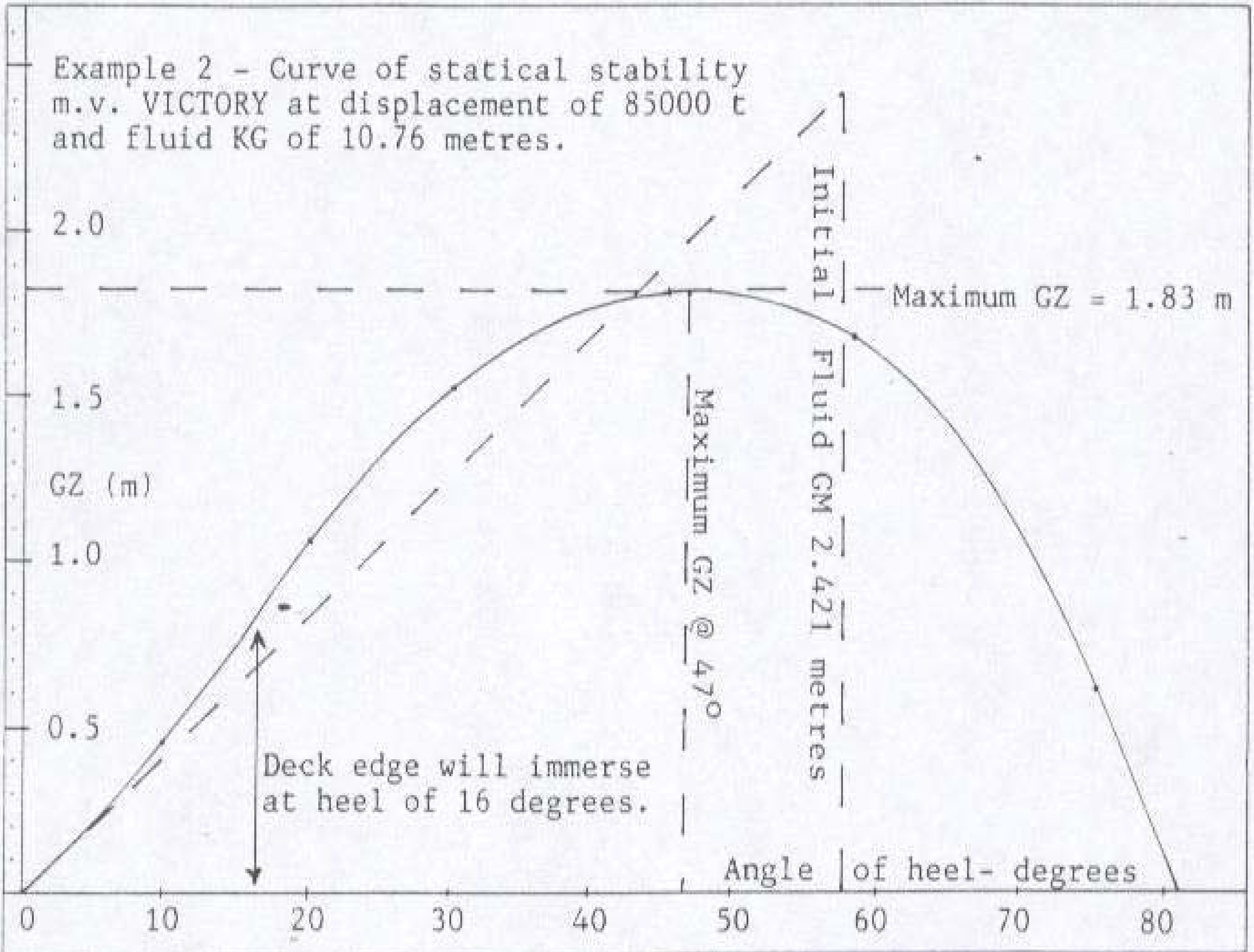
Construct the GZ curve of m.v.VICTORY when W = 85000 t, KG solid 10.68 m, FSM 6761 tm. From the curve, find (a) Max GZ and the the angle at which it occurs (b) the range of positive stability and (c) the angle of heel at which the deck edge would immerse.

FSC = FSM/W = 6761/85000 = 0.080 metre.
KG fluid = 10.68 + 0.08 = 10.760 metres.
GM fluid = 13.181 - 10.76 = 2.421 metres
(KM taken from appendix II of this book)

Since KG fluid > Kg, gG (Sin θ) is MINUS

θ	gz	- gG Sin θ	= GZ
10°	0.58	0.76 Sin 10°	0.448
20°	1.30	0.76 Sin 20°	1.040
30°	1.90	0.76 Sin 30°	1.520
45°	2.35	0.76 Sin 45°	1.813
60°	2.28	0.76 Sin 60°	1.622
75°	1.35	0.76 Sin 75°	0.616

The curve is then drawn ensuring that it coincides with the line OQ for the first few degrees, as shown on the next page.


Example 2 - Curve of statical stability
m.v. VICTORY at displacement of 85000 t
and fluid KG of 10.76 metres.
2.0
1.5
GZ (m)
1.0
0.5
Maximum GZ = 1.83 m
Initial Fluid GM 2.421 metres
Maximum GZ @ 47°
Deck edge will immerse
at heel of 16 degrees.
Angle of heel- degrees
0
10
20
30
40
50
60
70
80

From the curve of statical stability,

(a) Maximum GZ = 1.830 m at 47° heel.
(b) Range of (+) stability = 0° to 81°.
(c) Deck edge would immerse at 16° heel.

Exercise 20
Cross curves of stability

1. Draw the curve of statical stability of m.v.VICTORY at W = 30,000 t, solid KG 10.983 m, FSM 9000 tm. From the curve, find the initial GM.

2. Bulker m.v. VICTORY is at 40500 t displacement, KM 16.124 m, KG solid 8.925 m, FSM 4738 tm. Draw the GZ curve and thence find the heel at which the deck edge would immerse.

3. Draw the curve of statical stability for the bulk carrier m.v.VICTORY when its W = 20200 t, KM = 26.464 m, solid KG = 9.78 m and FSM = 4444 tm. From the curve, find the maximum GZ and the angle of heel at which occurs.

4. Find the range of positive stability of the ship VICTORY by constructing the curve of statical stability for W of 55000 t (KM 14.03 m), KG solid of 10.691 m and FSM of 5129 tm.

5. M.v.VICTORY has a diplacement of 60,000 t (KM 13.663 m), KG solid of 9.243 m and FSM of 4200 tm. Draw the GZ curve and from it find the moment of statical stability at 35° heel.

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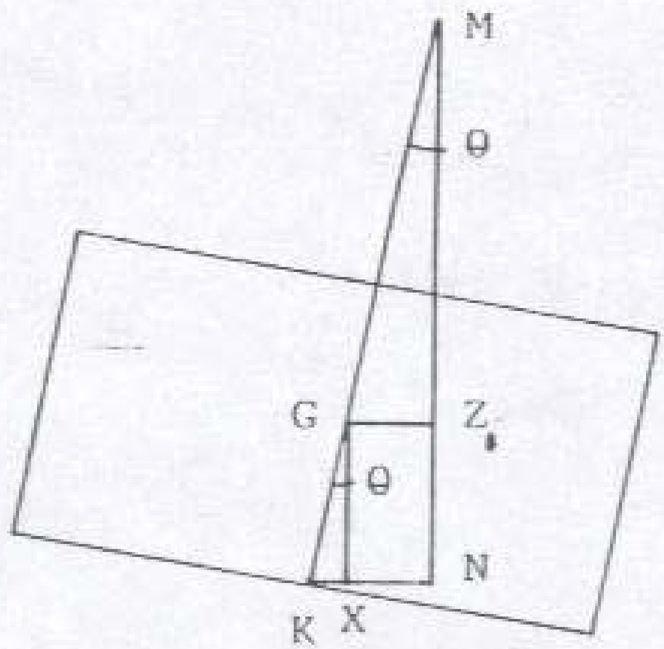
CHAPTER 24

KN CURVES

While using cross curves of stability the.correction gG(Sin θ), is sometimes positive and sometimes negative, depending on whether the actual fluid KG is less than or greater than the assumed Kg for which the curves were drawn. A bit of thought is necessary, each time, to decide on this and the chances of error are high - in his hurry, the chief officer may add this correction instead of subtracting it, or vice versa. In order to eliminate this possibility of error, some shipyards draw the cross curves for an assumed value of zero Kg,



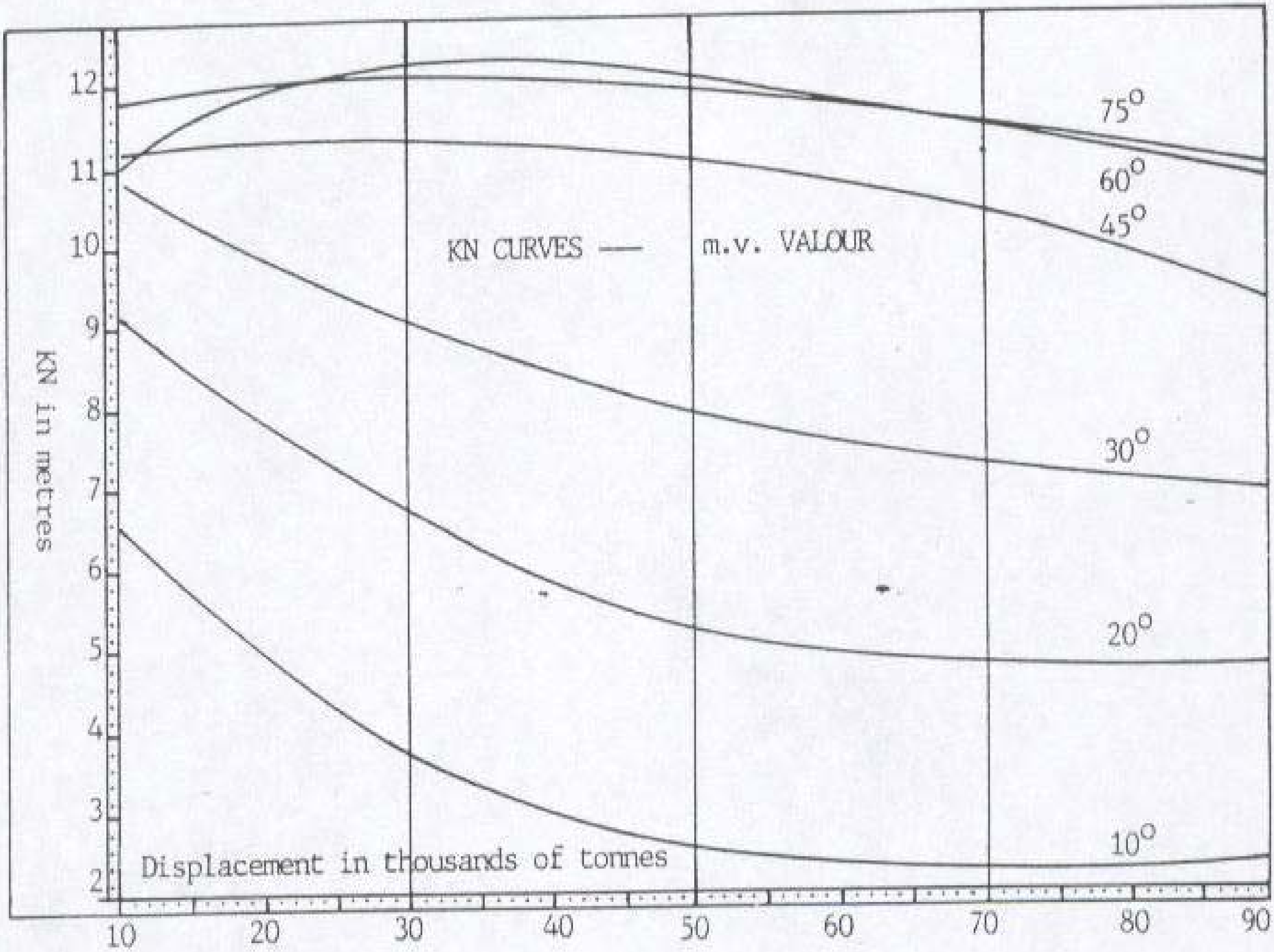
GZ = XN = KN - KX = KN - KG(Sin θ)

and thence call the righting lever KN instead of gz. Since the fluid KG of the voyage will always be positive, GZ < KN. KGSin θ is always to be subtracted from KN to obtain GZ. Hence the possibility of erroneous application of correction is eliminated.

The information regarding GZ or KN may be given in tabular form. The KN table of m.v.VIJAY is given below. The table is more convenient for use than the graph - high degree of accuracy can be obtained from a table contained in a small sheet of paper.

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


KN CURVES — m.v. VALOUR
KN in metres
Displacement in thousands of tonnes
75°
60°
45°
30°
20°
10°
12
11
10
9
8
7
6
5
4
3
2
10
20
30
40
50
60
70
80
90

For the same accuracy, curves in graphical form would have to be very much bigger in size.

The previous page shows the KN curves of m.v. VALOUR, a sister ship of m.v. VICTORY whose cross curves are given in the previous chapter. Having been built in different shipyards, one has cross curves, and the other, KN curves.

Example 1

Construct the GZ curve of m.v. VALOUR when displacing 65000 t, KM 13.420 m, KG solid 8.2 m, FSM 6500 tm. From the curve find the GZ at 70° heel.

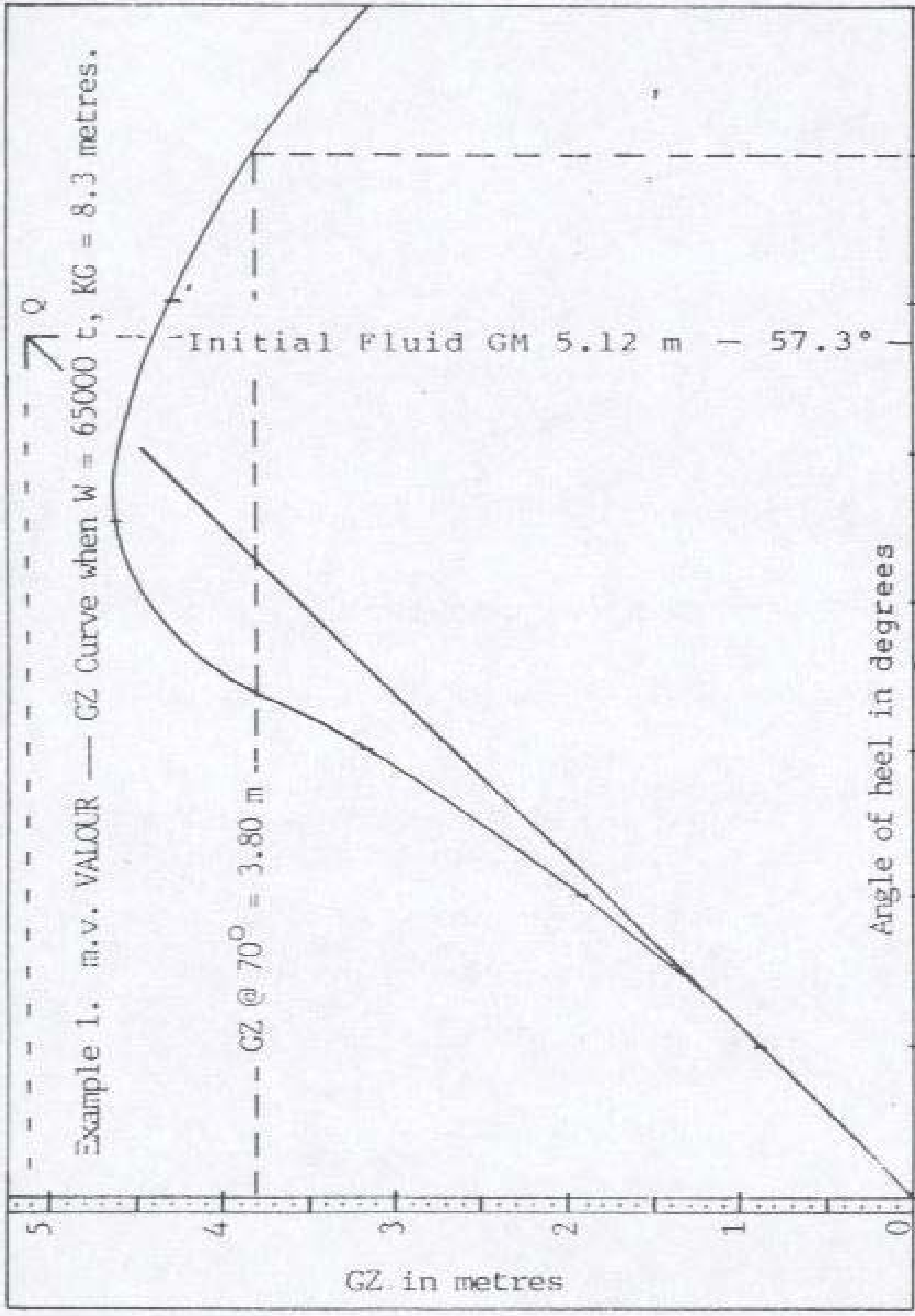
FSC = FSM/W = 6500/65000 = 0.100 metre.
KG fluid = 8.200 + 0.100 = 8.300 metres.
Initial GM fluid = 13.42 - 8.3 = 5.12 m.

From KN curves of m.v. VALOUR (page 60), KN values for W = 65000 t are obtained:-

θ	KN	- KG Sin θ	= GZ
10°	2.3	8.3 Sin 10°	0.859 m
20°	4.8	8.3 Sin 20°	1.961
30°	7.3	8.3 Sin 30°	3.150
45°	10.5	8.3 Sin 45°	4.631
60°	11.5	8.3 Sin 60°	4.312
75°	11.5	8.3 Sin 75°	3.483

Note: The initial fluid GM is laid off at 57.3° heel and line OQ is drawn. The curve is then constructed, ensuring that it coincides with line OQ for the first two or three degrees.

From the curve on the next page, GZ at 70° heel = 3.800 metres.


Example 1. m.v. VALOUR — GZ Curve when W = 65000 t, KG = 8.3 metres.
Q
Initial Fluid GM 5.12 m — 57.3°
GZ @ 70° = 3.80 m
GZ in metres
0
1
2
3
4
5
Angle of heel in degrees
0
10
20
30
40
50
60
70
80

Example 2

Construct the GZ curve for m.v. VIJAY when KG (solid) = 6.1 m, FSM = 3050 tm, W = 15400 t, KM = 8.034 m. Find max GZ.

FSC = FSM/W = 3050/15400 = 0.198 metre.
Fluid KG = 6.100 + 0.198 = 6.298 metres.
GM fluid = 8.034 - 6.298 = 1.736 metres.

From the KN table of m.v.VIJAY (page 59) interpolating for W = 15400 tonnes:

θ	KN	- KG Sin θ	= GZ
5°	0.796	6.298 Sin 05°	0.247 m
10°	1.575	6.298 Sin 10°	0.481
20°	3.112	6.298 Sin 20°	0.958
30°	4.641	6.298 Sin 30°	1.492
45°	6.546	6.298 Sin 45°	2.093
60°	7.615	6.298 Sin 60°	2.161
75°	7.923	6.298 Sin 75°	1.840

Note: The initial fluid GM is laid off at 57.3° heel and line OQ is drawn. The curve is then constructed, ensuring that it coincides with line OQ for the first two or three degrees.

The above values have been plotted, as a curve of statical stability (GZ curve), on the next page. Maximum GZ = 2.200 m.

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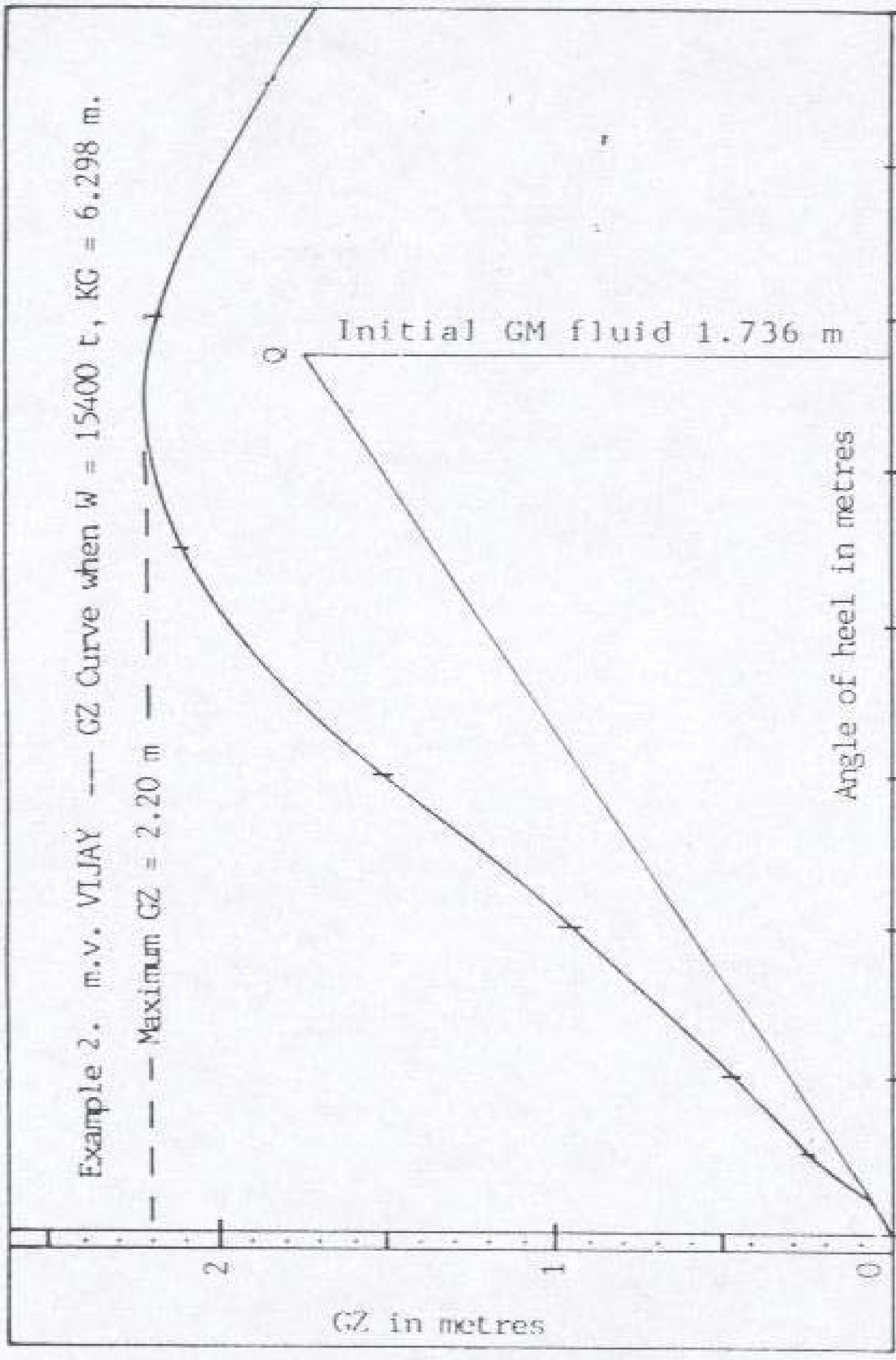
Example 2. m.v. VIJAY — GZ Curve when W = 15400 t, KG = 6.298 m.
Maximum GZ = 2.20 m
Initial GM fluid 1.736 m
Q
GZ in metres
0
1
2
Angle of heel in metres
0
10
20
30
40
50
60
70
80

Exercise 21

1. Construct the GZ curve of m.v. VALOUR when W = 81000 t, KG solid = 10.21 m, FSM = 6800 tm. From the curve find the GZ at 40° heel. (Take initial KM from appendix II).

2. Find the maximum GZ and the angle of heel at which it occurs for m.v.VIJAY when W = 19943 t, solid KG = 7.326 m, FSM = 1342 tm, KM = 8.461 m.

3. Construct the curve of statical stability for m.v. VALOUR when displacement = 26000 t, KG solid = 7.014 m FSM = 7200 tm. KM is 21.592 m. Find the maximum GZ and the angle at which it occurs.

4. M.v. VIJAY is displacing 13250 t with KG solid = 6.427 m and FSM = 1200 tm. Construct the curve of statical stability and from it, find the angles of heel at which GZ = 1.6 m. (Take initial KM from appendix I).

5. M.v.VALOUR is displacing 60000 t with solid KG = 8.661 m, FSM = 5020 tm and KM = 13.663 m. By constructing the curve of statical stability, find the angle of heel at which the deck edge would immerse.

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CHAPTER 25

LONGITUDINAL

STABILITY

When a ship is at rest in calm water, the COB & the COG will be in a vertical line as illustrated by figure X on the next page.

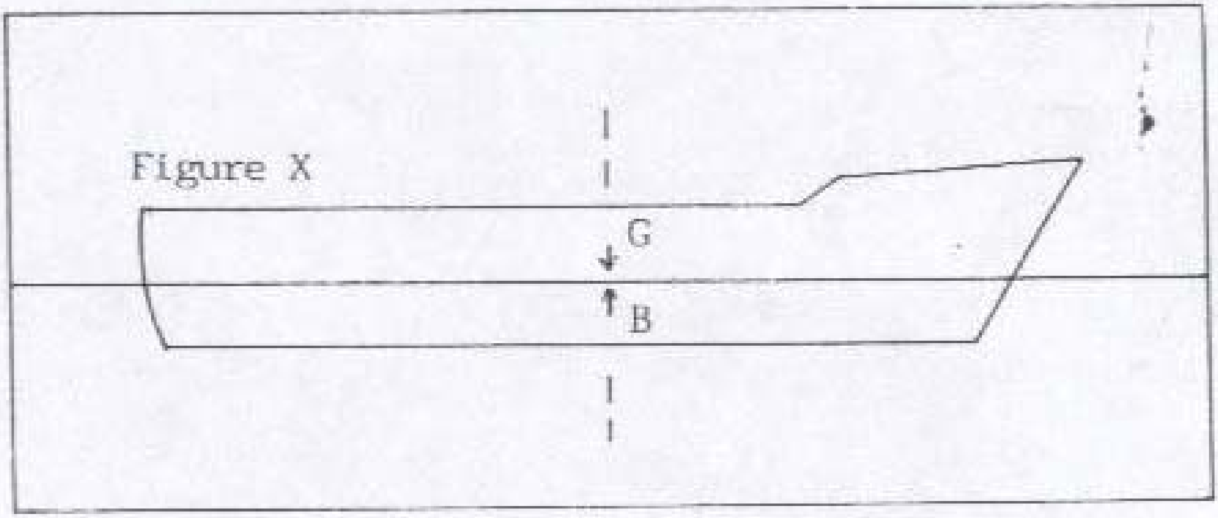
Pitch:

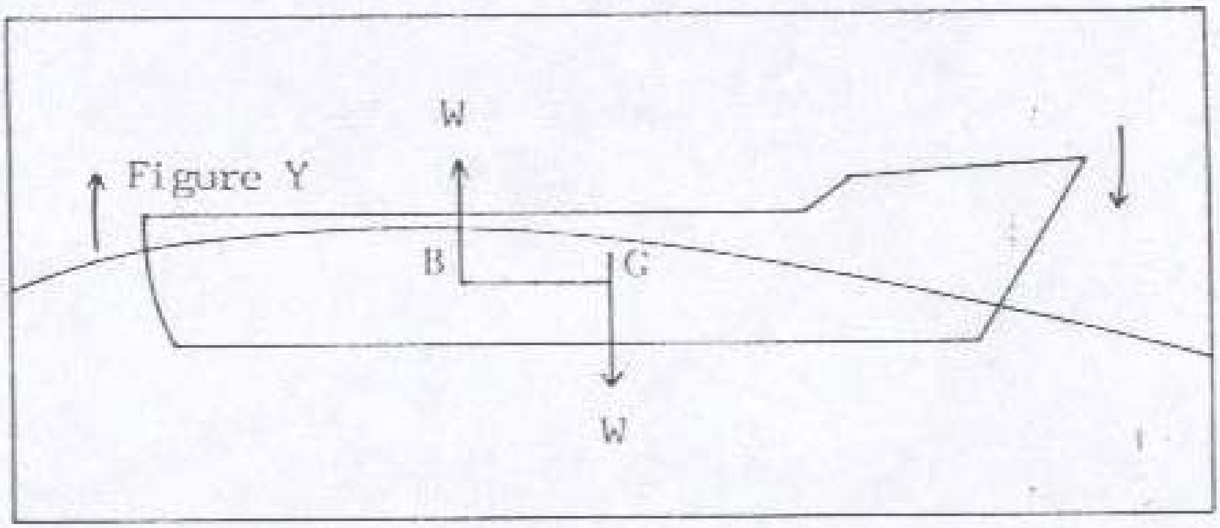
If waves cause an increase in the under-water volume aft, and a decrease fwd, the COB will shift aft. The forces of gravity and buoyancy now get separated by a fore and aft distance and form a couple which will cause the bow to dip downwards and the stern to lift upwards as shown in figure Y on the next page.

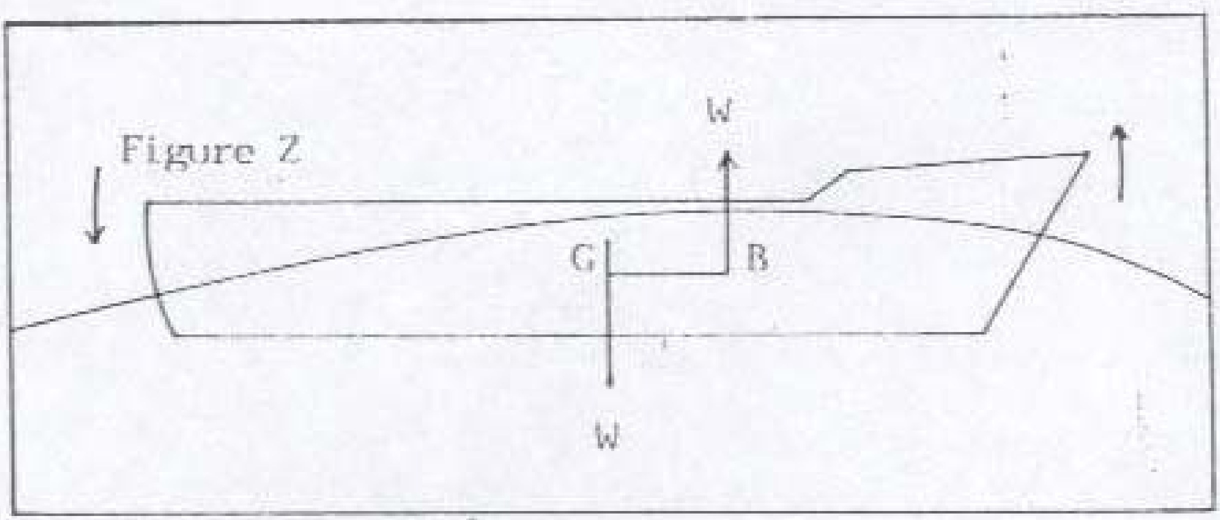
If waves cause an increase of underwater volume forward, and a decrease aft, COB will shift forward, and the forces of gravity and buoyancy will form a couple which will cause the bow to lift upwards and the stern to dip downwards as shown in figure Z on the next page. This up and down movement of the ship's ends, due to longitudinal shift of COB resulting from wave action, is called pitch.

During pitch, the COG of the ship does not move because no weights are loaded, discharged or shifted. Pitching is the longitudinal equivalent of rolling.

PITCHING







Trim:

The difference between the drafts fwd and aft, expressed in metres or in centimetres, is called trim. If the draft aft is greater than the draft fwd, the ship is said to be trimmed by the stern. If the draft fwd is greater, the ship is said to be trimmed by the head. If the drafts fwd and aft are equal (if trim is zero), the ship is said to be on an even keel.

Trim is the longitudinal equivalent of list, but with three main differences:

1) List is measured in degrees. Trim is expressed in metres or centimetres only.

2) In the sailing condition, the ship is usually upright but rarely on an even keel. In other words, list is normally absent whereas trim is normally present.

3) If the ship is listed, it is not important whether it is to port or to stbd. Trim must be by the stern, never by the head. If trimmed by the head, the steering qualities and speed, especially the former, would be adversely affected.

Consider a ship at rest, on an even keel in calm water. The COB and the COG would be in a vertical line as shown in figure 1 on the next page. If a weight of 'w' tonnes is shifted aft by a distance 'd' metres, the COG of the ship would shift by GG_1 metres, as shown in figure 2 on the next page. The forces of gravity and buoyancy would form a couple and cause

Figure 1

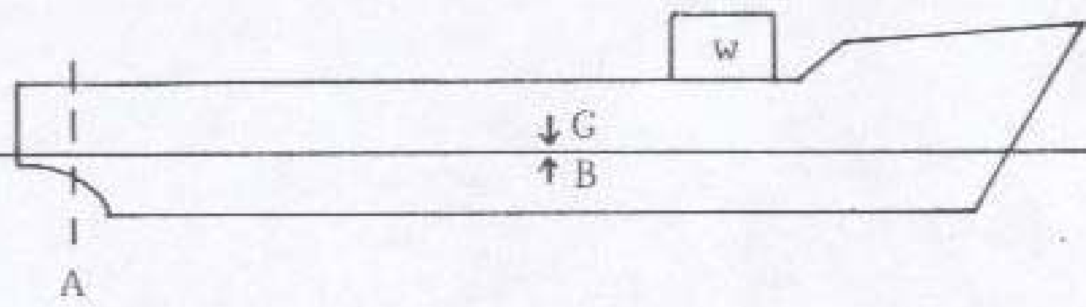


Figure 2

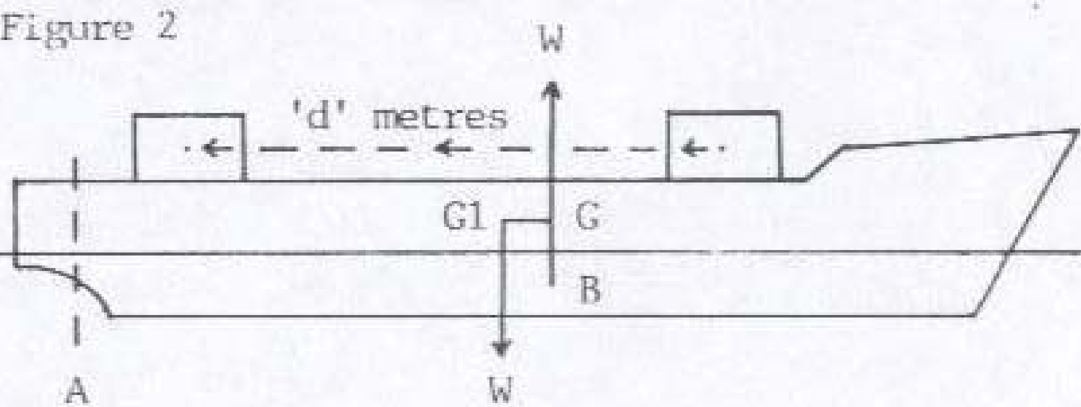
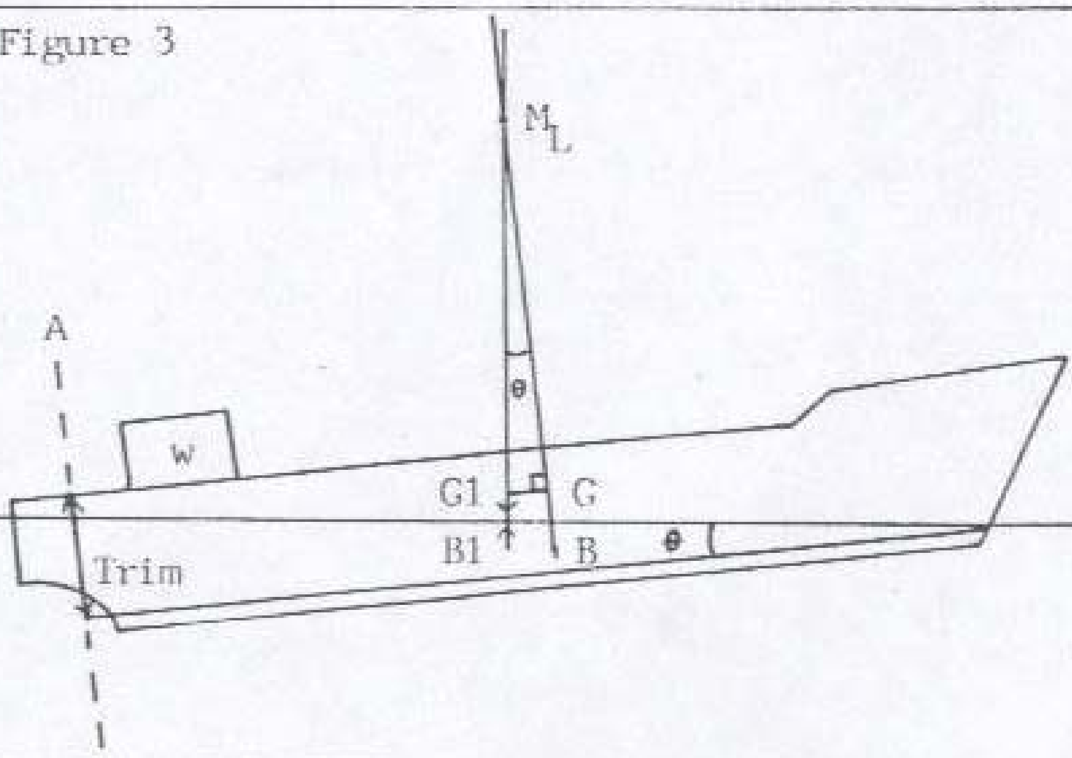


Figure 3



the stern to sink and the bow to rise. This would increase the underwater volume aft and decrease it forward - the COB will shift aft. This would continue until the COB comes vertically under G1, as shown in figure 3 on page 69.

In figure 3, M_L is the longitudinal metacentre - the point of intersection of the verticals through the COB when on an even keel and when trimmed. KM_L is the sum of KB and BM_L. KM_L is a function of draft and is given in the hydrostatic table/curves of the ship against draft.

Referring to figure 3 on previous page:

$$\frac{\text{Trim}}{L} = \frac{GG1}{GM_L} \quad \text{(since both = tan } \theta)$$

$$\text{But } GG1 = \frac{wd}{W} \quad \text{so} \quad \frac{\text{trim}}{L} = \frac{wd}{W \times GM_L}$$

$$\text{So trim (in metres)} = \frac{wd \times L}{W \times GM_L}$$

$$\text{Or trim (in cm)} = wd \times \frac{100 \times L}{W \times GM_L}$$

$$= wd \div \frac{W \times GM_L}{100L} = \frac{wd}{MCTC}$$

$$\text{Trim caused (in cm)} = \frac{\text{trimming moment}}{MCTC}$$

MCTC is called the moment to change trim by 1 cm. Since GM_L is very large (more than the ship's length), use of BM_L instead of GM_L will not make any appreciable change in the value of MCTC.

$$MCTC = W.GM_L/100L \simeq W.BM_L/100L$$

MCTC is calculated by using BM_L for the various salt water drafts and given in the ship's hydrostatic table/curves.

Centre of flotation (COF)

COF is that point about which the ship would pivot, when the trim is changed. COF is also called the tipping centre. It is the geometric centre of the water-plane area of the ship at that draft. The position of COF is indicated by its distance from the after perpendicular of the ship (AF) or by its distance forward or abaft amidships (HF). AF or HF, as the case may be, depends on the hydrostatic draft of the ship. Hence the values of COF are indicated against draft in the hydrostatic tables/curves of the ship.

Change of draft fwd & aft

If COF is amidships, the change of draft fwd and the change of draft aft would be equal. So if the trim caused (or Tc) is 40 cm by the stern, the stern would sink by 20 cm and the bow would rise by 20 cm as shown in figure 1 on page 145 of Ship Stability I.

If COF is not amidships, the change of draft at each end would be unequal:

$$\text{Change of draft aft (or Ta)} = \frac{AF}{LBP} \times Tc.$$

$$\text{Change of draft fwd (or Tf)} = Tc - Ta.$$

For example, if the trim caused (Tc) is 40 cm by stern, AF = 63 m, LBP = 140 m:

$$Ta = \frac{63 \times 40}{140} = 18.0 \text{ cm.}$$

$$Tf = 40 - 18 = 22.0 \text{ cm.}$$

Since Tc is by the stern, Ta will be + while Tf will be –. In other words, the draft aft will increase by 18 cm while the draft fwd will decrease by 22 cm. (See figure 2 on page 145 of Ship Stability I).

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CHAPTER 26

TRIM PROBLEMS

TYPE A

In this book, trim problems have been divided into three groups, A, B & C. In problems of type A, limited information is given: TPC, MCTC & AF are considered constant throughout. Trimming moments are taken about COF. Type A problems are useful in understanding the principles of trim and quesions of this type do come in examinations for certificates of competency.

Type B problems on trim are those where full hydrostatic particulars of a ship are given and where moments are taken about the after perpendicular of the ship.

Type C problems are those where full hydrostatic particulars of a ship are given but where moments are taken about amidships.

Types B and C have a similar approach to the solution of trim problems. They are more practical, than type A, and are extensively used by shipyards. In types B and C, TPC, MCTC, AF, etc are not considered constants. These values are obtained against draft, when necessary, from the hydrostatic particulars of the ship. Worked examples have been given the suffix A, B or C, as appropriate, to help distinguish the types.

Note: Mean sinkage or rise (calculated by the formula w ÷ TPC), and trim caused (calculated by the formula trimming moment ÷ MCTC), would be in centimetres NOT in metres.

TYPE A PROBLEMS

Example 1A - Shift of 'w' already aboard

A ship 100 m long has COF 3 m abaft amidships and MCTC = 250 tm. Present drafts are 5.8 m fwd and 6.2 m aft. Find the new drafts fwd & aft if 200 t of FW is transferred from the fore peak to the after peak through a distance of 90 m.

Trimming moment (or TM) = wd = 200 x 90
= 18000 tm by the stern

$$Tc = \frac{TM}{MCTC} = \frac{18000}{250} = 72 \text{ cm by the stern}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{47 \times 72}{100} = 33.8 \text{ cm}$$

$$Tf = Tc - Ta = 72 - 33.8 = 38.2 \text{ cm}$$

	fwd	aft
Original drafts	5.800 m	6.200 m
Tf or Ta	-0.382 m	+0.338 m
Final drafts ..	5.418 m	6.538 m

Note: Accuracy of calculation should be to three decimal places of a metre or one decimal of a centimetre.

Example 2A - Discharging a weight.

A ship 120 m long, COF 2.5 m abaft amidships (HF 2.5 m aft), MCTC 100 tm, TPC 25, floats at 7 m fwd and 10 m aft. Find the new drafts if 200 t is discharged from a position 50 m abaft amidships.

Mean rise = w ÷ TPC = 200 ÷ 25 = 8 cm.

$$Tc = \frac{wd}{MCTC} = \frac{200 \times 47.5}{100} = 95 \text{ cm by head.}$$

Note: d = distance from COF. Tc by head because cargo discharged was abaft COF.

$$Ta = \frac{AF \times Tc}{L} = \frac{57.5 \times 95}{120} = 45.5 \text{ cm.}$$

$$Tf = Tc - Ta = 95 - 45.5 = 49.5 \text{ cm.}$$

	fwd	aft
Original drafts	7.000 m	10.000 m
Mean rise	-0.080 m	-0.080 m
	6.920 m	9.920 m
Tf or Ta	+0.495 m	-0.455 m
Final drafts	7.415 m	9.465 m

Example 3A - Load/disch several weights.

A ship is 150 m long. MCTC = 300 tm, TPC = 30, COF is 4 m abaft amidships (HF 4 m aft). Present drafts are 6.1 m fwd & 8.3 m aft. Find the final drafts if the following operations are carried out:

4000 t loaded 24 m abaft H (HG 24 m aft)
2000 t cargo loaded, HG 50 m fwd.
1000 t cargo discharged from HG 30 m fwd
300 t SW run into AP tank, HG 70 m aft.

Weight Loaded t	Weight Disch t	Distance from COF, m	Trimming moment By head tm	Trimming moment By stern tm
2000	-	54 fwd	108000	-
-	1000	34 fwd	-	34000
4000	-	20 aft	-	80000
300	-	66 aft	-	19800
6300	1000	Total	108000	133800
5300	-	Final	-	25800

Mean sinkage = $\frac{w}{TPC} = \frac{5300}{30} = 176.7$ cm.

$Tc = \frac{TM}{MCTC} = \frac{25800}{300} = 86$ cm by the stern

$Ta = \frac{AF \times Tc}{L} = \frac{71 \times 86}{150} = 40.7$ cm.

$Tf = Tc - Ta = 86 - 40.7 = 45.3$ cm.

	fwd	aft
Original drafts	6.100 m	8.300 m
Mean sinkage	+1.767 m	+1.767 m
	7.867 m	10.067 m
Tf or Ta	-0.453 m	+0.407 m
Final drafts	7.414 m	10.474 m

Example 4A - To finish at a desired trim

A ship has to load 600 t of cargo. The drafts are 8.5 m fwd & 9.7 m aft. Space is available 60 m fwd & 40 m aft of COF, which is amidships. MCTC = 250 tm and TPC = 20. Find how to distribute this 600 t of cargo if the ship is to finish loading 0.5 m by the stern. State also the final drafts fwd and aft.

Present trim = 1.2 m by the stern
Desired trim = 0.5 m by the stern
T_c = 0.7 m by the head = 70 cm

$$T_c = \frac{TM}{MCTC} \quad \text{or} \quad TM = T_c \times MCTC$$

Reqd TM = 70 x 250 = 17500 tm by head.

Let the cargo loaded forward be X tonnes
So cargo loaded aft = (600 - X) tonnes

TM caused = 60X tm by head & 40(600 - X) tm by stern. Reqd to cause 17500 by head

So $60X - 40(600 - X) = 17500$
$X = 415$ t and $(600 - X) = 185$ t

Cargo to be loaded in the forward space = 415 t and in the after space = 185 t.

$$\text{Mean sinkage} = \frac{w}{TPC} = \frac{600}{20} = 30 \text{ cm} = 0.3 \text{ m}$$

	fwd	aft
Original drafts	8.500 m	9.700 m
Mean sinkage	+0.300 m	+0.300 m
	8.800 m	10.000 m
Tf or Ta = Tc/2	+0.350 m	-0.350 m
Final drafts	9.150 m	9.650 m

Example 5A - To find HF

A ship is afloat at drafts of 6.6 m fwd & 7.4 m aft. 500 t of cargo is loaded 54 m fwd of H (amidships) & 800 t is loaded 52 m abaft H. If the final drafts are 6.85 and 8.51 m fwd & aft respectively, and MCTC = 200 tm, find HF (the distance of the COF from amidships).

Initial trim = 0.800 m by the stern
Final trim = 1.660 m by the stern
Trim caused = 0.860 m by stern = 86 cm.

$$Tc = \frac{TM}{MCTC} \quad \text{or} \quad TM = 86 \times 200 = 17200 \text{ tm.}$$

Let the COF be X metres abaft H. Then TM caused by head = 500(54 + X) tm & by the stern = 800(52 - X) tm. Since loading caused 17200 tm by the stern,

$$800(52 - X) - 500(54 + X) = 17200$$

$$X = -2 \text{ metres.}$$

Note: The minus sign indicates that the assumed direction of COF, from H, is wrong. In this case, COF was assumed to be abaft H.

Answer: COF is 2 m fwd of H (HF 2 m fwd)

Example 6A - Load keeping draft constant

A ship 96 m long is floating at 5 m fwd and 6.4 m aft. MCTC = 180 tm, TPC = 16. COF is 2 m abaft H (HF 2 m aft). Find the location where a weight of 50 t should be placed so as to keep the aft draft constant.

Note: If the weight is loaded on the COF the ship would sink bodily (parallel sinkage) by w ÷ TPC. The draft at both perpendiculars would increase by the same amount. If the weight is now shifted fwd by d metres, the draft aft would decrease by Ta and the draft fwd would increase by Tf. For the draft aft to return to its original value, mean sinkage must equal Ta.

$$\frac{w}{TPC} = Ta = \frac{AF}{L} \times Tc = \frac{AF \times wd}{L \times MCTC}$$

$$\frac{46 \times 50d}{96 \times 180} = \frac{50}{16} \quad \text{or} \quad d = 23.5 \text{ m}$$

50 t should be loaded 23.5 m fwd of COF.

Example 7A - Desired value of draft aft.

A ship 100 m long, MCTC 280 tm, TPC 25, HF 2 m fwd, is afloat at drafts of 6 m fwd and 8 m aft. Find how many tonnes of SW must be run into the fore peak tank (COG 48 m fwd of H) to bring the draft aft to 7.8 m.

Reqd reduction of draft aft = 0.2 metres

Ta - mean sinkage = 0.2 m = 20 cm.

$$\frac{AF}{L} \times Tc - \frac{w}{TPC} = 20 \quad \text{or} \quad \frac{52}{100} \times \frac{dw}{MCTC} - \frac{w}{TPC} = 20$$

$$\frac{52}{100} \times \frac{46w}{280} - \frac{w}{25} = 20 \quad \text{or} \quad w = 440.25 \text{ t.}$$

Exercise 22
Trim problems - Type A

1 A ship 100 m long, draws 4 m fwd and 5.2 m aft. COF is 2 m abaft amidships MCTC 160 tm & TPC 15. 100 t of cargo is shifted from No:3 LH to No:1 LH through a horizontal distance of 32 m. Find the new drafts fwd and aft.

2 A ship 150 m long has HF = 3 m fwd, TPC = 21 and MCTC = 275 tm. Present drafts are 5.6 m fwd & 6.2 m aft. How many tonnes of SW must be transferred to the fore peak from the after peak, through a distance of 130 m, to bring the ship on an even keel?

3 The present drafts of a ship 140 m long are 8.1 m fwd and 9.9 m aft. TPC = 30, MCTC = 250 tm, HF = 3 m fwd. 300 t ballast was pumped out of No:5 DB tank, COG 50 m abaft H. Find the new drafts fwd and aft.

4 A ship is floating on an even keel draft of 10.2 m. TPC = 30, MCTC = 320 tm, HF = 2.5 m aft. LBP = 180 m. A 240 t heavy lift is loaded on deck, 40 m abaft COF. Find the new drafts at the fwd and after perpendiculars.

5 A ship of LBP 125 m, MCTC 318 tm, TPC 28, COF amidships (HF = 0 m), draws 7.9 m fwd and 10.4 m aft. Find the final drafts after the following operations have been carried out:

500 t loaded in No:2 LH 40 m fwd of H
200 t loaded in No:5 TD 50 m aft of H
100 t SW transferred from AP tank to FP tank, through a distance of 110 m.

6 The present drafts of a ship, whose length between perpendiculars is 142 m, are 10.2 m fwd & 11.6 m aft. MCTC = 170 tm. TPC = 32. HF = 3 m aft. Find the final drafts forward and aft after the following operations have been carried out:

1500 t cargo discharged from No:2 LH, 43 m fwd of amidships (HG 43 m fwd).

2000 t cargo discharged from No:4 LH, 37 m aft of amidships (HG 37 m aft).

500 t FW received in No:3 DB tank, 33 m fwd of amidships (HG 33 m fwd).

7 A ship left port drawing 8.2 m & 10 m F & A. LBP 160 m, TPC 32, MCTC 220 tm HF 2.4 m aft. En route she consumed 420 t HFO from No:4 DBT (HG 35 m aft) 220 t HFO from No:7 DBT (HG 60 m aft) 200 t FW from No:1 DBT (HG 60 m fwd). Find the arrival drafts fwd & aft.

8 A ship is 150 m long. MCTC = 200 tm, TPC = 25, HF = 2 m fwd. The present drafts are 8 m forward and 10 m aft. Calculate the initial hydrostatic draft. Space is available in No:1 LH (HG 60 m fwd) & in No:4 LH (HG 30 m aft). Find how much cargo to put in each of these spaces, if the ship is to finish loading at an even keel draft of 9.3 m.

9 A ship of LBP 200 m, MCTC 300 tm, TPC 35, HF 5 m aft, is presently drawing 7 m fwd and 11 m aft. Calculate the present hydrostatic draft. Space is available for loading in No:1 LH (HG 80 m fwd), and in NO:4 LH (HG 30 m aft). Calculate how much cargo to put in each of the two spaces in order to finish at a hydrostatic draft of 9.6 metres, trimmed 2 metres by the stern. State also, the final drafts forward and aft.

10 A ship was trimmed 0.5 m by the head. After loading 500 t in No:4 LH, HG 40 m aft, the trim was 0.5 m by the stern. If MCTC was 185 tm, find HF.

11 A ship of LBP 130 m and MCTC 175 tm, draws 7.2 m fwd and 7.8 m aft. 1600 t cargo was loaded in No:2 LH, HG 30 m fwd, and 1400 t in No:5 LH, HG 55 m aft. The drafts were then found to be 7.8 m fwd & 10.4 m aft. Find HF.

12 A ship drawing 7.6 m fwd & 8.4 m aft has LBP 140 m, HF 2.7 m aft, MCTC 170 tm, TPC 28. Find where 140 t may be placed if the after draft is to remain constant. State the draft forward after loading.

13 A ship 160 m long has MCTC 200 tm, TPC 30, HF 3 m aft, draft fwd 6.8 m, aft 7.8 m. From where may 'w' tonnes may be discharged such that the draft aft remains constant?

14 A ship of LBP 120 m, MCTC 300 tm, TPC 25, HF 2 m fwd, floats at 9.6 m fwd & 10.8 m aft. 200 t of deck cargo is to be loaded. Some shipside repairs are to be effected for which the fwd draft is to be maintained at 9.6 m. Find where this cargo may be loaded. State the final draft aft.

15 LBP 124 m, MCTC 180 tm, TPC 27, HF 2.5 m aft, draft fwd 5.8, aft 6.9 m. How many tonnes of SW must be run into the FP tank (HG 58 m fwd) in order to reduce the draft aft to 6.7 metres? State the final draft fwd.

16 A ship 160 m long has MCTC 200 tm, HF 2.8 m fwd, TPC 24. Present drafts are 7.4 m fwd & 8.8 m aft. 720 t cargo is to be loaded. Space is available in No:2 LH (HG 45 m fwd) and in No:4 LH (HG 35 m aft). Find how much to put in each if the draft aft is required to be 9 m on completion. What is the final draft fwd?

17 A ship arrives port drawing 7 m fwd & 10 m aft. HF = 0, MCTC 220 tm, TPC 25. Maximum permissible draft to cross a bar at the dock entrance is 9 m. Due to a damaged fore peak, the draft fwd is not to exceed 7 m. Find the minimum amount of cargo to discharge into barges from No:2 TD (HG 30 m fwd) and from No:4 TD (HG 50 m aft) so that both conditions are satisfied.

18 A ship arrives port drawing 8 m fwd & 10.5 m aft. LBP 166 m, HF 3 m aft, MCTC 175 tm, TPC 25. 250 t of dangerous deck cargo is to be discharged at anchorage from HG 73 m aft. How many tonnes of water must be transferred from the after peak tank to No:1 DBT through a distance of 140 m, to make the final trim 1 m by the stern? State the final drafts fwd & aft.

19 A ship arrives port drawing 8 m fwd & 9 m aft. LBP = 158 m, MCTC = 190 tm, TPC = 20 and HF is 2 m aft. The maximum draft allowed, to cross a bar, is 8.6 metres. There is no scope for transfer of any weights aboard. Hence it decided to off-load some cargo at anchorage. Find the minimum quantity

of cargo to off-load from No:4 TD, HG 40 m aft. State the final draft fwd.

20 A ship leaves port drawing 9 m fwd and 9.8 m aft. LBP = 170 m, MCTC = 160 tm, TPC = 24 and HF 1 m fwd. On passage she consumes the following:

520 t HFO from No:2 DBT, HG 50 m fwd,
200 t HFO from No:8 DBT, HG 60 m aft,
300 t FW from No:3 DBT, HG 30 m fwd.

How much FW must be transferred between the peak tanks, 150 m apart, to bring the trim to 0.3 m by the stern? State the final drafts fwd and aft.

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CHAPTER 27

TRIM PROBLEMS

TYPE B

Consider a ship on an even keel and refer to figures 1 and 2 in chapter 25 (page 69). COB and COG are in a vertical line. Due to shift of a weight aft, COB & COG get separated longitudinally. The forces of buoyancy and gravity form a couple which trims the ship by the stern. The moment of this couple = $W.GG_1$ and is called the trimming moment or TM.

The trimming lever GG_1 may be substituted by $AB \sim AG$ which is the longitudinal separation of COB & COG caused by shift of weight. The AB used here is the distance of the COB from the after perpendicular of the ship at that draft, when on even keel. For the sake of simplicity of expression in formulae, $\overline{BG}$ is used in this book to represent $AB \sim AG$ on the understanding that $\overline{BG}$ is the longitudinal separation of COB (on even keel) and COG of ship, NOT the actual slant distance. The trimming moment, or TM, is thus equal to $W.\overline{BG}$. TM, divided by MCTC, gives the trim. If COG lies abaft COB, trim will be by stern and vice versa. For working trim problems of type B, the hydrostatic particulars of m.v.VIJAY have been included as Appendix I of this book.

Procedure for most trim problems type B

1 Find the initial hydrostatic draft and thence the W, MCTC, AB & AF.
2 Find the initial AG, if not given.
3 Find the final W and the final AG by taking moments about A.
4 Find the final hydrostatic draft and thence the MCTC, AB & AF at that draft
5 Find the final $\overline{BG}$ and thence the final trim (Tc).
6 Split Tc (final trim) into Ta and Tf.
7 Apply Tf & Ta to the final hydrostatic draft & obtain final drafts fwd & aft.

Example 1B

M.v.VIJAY is floating in SW at an even keel draft of 5 m. Find the new drafts F & A if 200 t FW is transferred 30 m aft.

Note: This is similar to example 1A except that MCTC and AF have to be taken from the hydrostatic table of the ship.

From Appendix I, for SW draft 5 m,
MCTC = 165.7 tm and AF = 71.913 metres

$$Tc = \frac{TM}{MCTC} = \frac{200 \times 30}{165.7} = 36.2 \text{ cm by stern.}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{71.913 \times 0.362}{140} = 0.186 \text{ m.}$$

$$Tf = Tc - Ta = 0.362 - 0.186 = 0.176 \text{ m.}$$

	Fwd	Aft
Original drafts	5.000 m	5.000 m
Tf or Ta	0.176 m	+0.186 m
Final drafts	4.824 m	5.186 m

Example 2B

M.v.VIJAY is floating in SW at drafts of 4.8 m fwd and 6.8 m aft. AG is 69.04 m. Find the drafts fwd and aft if 1000 t of cargo is loaded in No:3 LH, AG 80 m.

Fwd 4.8 m, aft 6.8 m, trim 2 m by stern. Mean draft 5.8 m for which AF = 71.586 m

$$\text{Corrn} = \frac{AF}{L} \times \text{trim} = \frac{71.586}{140} \times 2 = 1.023 \text{ m}$$

Initial hydraft* = 6.8 - 1.023 = 5.777 m

* Abbreviation for 'Hydrostatic draft.'

For 5.777 m hydraft, W = 11620.4 tonnes.
Final W = 11620.4 + 1000 = 12620.4 t

From table, particulars for final W are:

W (t)	draft	MCTC	AB (m)	AF (m)
12620.4	6.220	174.78	71.937	71.313

Taking longitudinal moments about A,

11620.4(69.04) + 1000(80) = 12620.4 (AG)

Final AG = 69.908 m. Final AB = 71.937 m
Finally, COG is astern of COB. So final trim is by the stern. Final $\overline{BG}$ = 2.029 m

$$\text{Trim} = \frac{W.\overline{BG}}{MCTC} = \frac{12620.4(2.029)}{174.78} = 146.5 \text{ cm}$$

$$T_a = \frac{AF}{L} \times T_c = \frac{71.313(1.465)}{140} = 0.746 \text{ m}$$

$$T_f = T_c - T_a = 1.465 - 0.746 = 0.719 \text{ m}$$

	Fwd	Aft
Final hydraft	6.220 m	6.220 m
Tf or Ta	-0.719 m	+0.746 m
Final drafts	5.501 m	6.966 m

Example 3B

M.v.VIJAY is floating in SW at drafts of 4 m fwd & 5.8 m aft. AG is 68.930 m. The following operations were carried out:
No:2 LH (AG 102 m): 1800 t cargo loaded.
No:4 LH (AG 58 m): 1600 t cargo loaded.
No:1 DBT(AG 120 m): 160 t ballast out.
FP tank (AG 135 m): 100 t ballast out.
Find the final drafts fwd and aft.

Fwd 4 m, aft 5.8 m, trim 1.8 m by stern.
Mean draft 4.9 m for which AF = 71.942 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.942(1.8)}{140} = 0.925 \text{ m}$$

Initial hydraft = 5.8 - 0.925 = 4.875 m, for which W = 9616 t, from Appendix I.

Remarks	Weight t load	Weight t disc.	AG m	Moment abt A loaded	Moment abt A disch
Ship	9616	-	68.93	662831	-
Cargo	1800	-	102	183600	-
Cargo	1600	-	58	92800	-
Ballast	-	160	120	-	19200
Ballast	-	100	135	-	13500
Total	13016	260		939231	32700
Final	12756			906531	

Final AG = 906531/12756 = 71.067 metres.

From Appendix I, for final W of 12756 t:

Draft	MCTC tm	AB (m)	AF (m)
6.280	175.316	71.929	71.267

Final AG = 71.067 m, final AB = 71.929 m
Final trim by stern; final $\overline{BG}$ = 0.862 m

$$\text{Trim} = \frac{W.\overline{BG}}{MCTC} = \frac{12756 \times 0.862}{175.316} = 62.7 \text{ cm}$$

$$Ta = \frac{AF}{L} \times \text{trim} = \frac{71.267}{140}(0.627) = 0.319 \text{ m}$$

Tf = Trim - Ta = 0.627 - 0.319 = 0.308 m

	Fwd	Aft
Final hydraft	6.280 m	6.280 m
Tf or Ta	-0.308 m	+0.319 m
Final drafts	5.972 m	6.599 m

Example 4B

M.v.VIJAY is in SW drawing 6 m fwd & 7 m aft. 1000 t cargo is loaded in No:3 LH, AG 80 m. Find the final drafts fwd & aft

Note: AG of the ship is not given here but can be calculated using the given data and the hydrostatic table. This is the method normally used on board ships.

Fwd 6 m, aft 7 m, trim 1 m by the stern. Mean draft 6.5 m for which AF = 71.087 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.087 \times 1}{140} = 0.508 \text{ m}$$

Hydraft = 7 - 0.508 = 6.492 m for which:

Draft	W (t)	MCTC tm	AB (m)
6.492	13239.8	177.228	71.902

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

$$\overline{BG} = \frac{100(177.228)}{13239.8} = 1.338 \text{ m}$$

Since trim is by stern, AG < AB.

$AG = AB - \overline{BG} = 71.902 - 1.338 = 70.564$ m

AG of ship in given condition = 70.564 m

Remarks	Weight	AG (m)	Moment
Ship	13239.8	70.564	934253
Loaded	1000	80	80000
Final	14239.8		1014253

Final AG = 1014253 ÷ 14239.8 = 71.227 m

From Appendix I for final W = 14239.8 t:

Draft	MCTC tm	AB (m)	AF (m)
6.929	181.852	71.832	70.673

Since final AG < AB, final trim by stern

Final $\overline{BG}$ = 71.832 - 71.227 = 0.605 m

$$\text{Final Tc} = \frac{W.\overline{BG}}{MCTC} = \frac{14239.8(0.605)}{181.852} = 47.4 \text{ (cm)}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{70.673}{140} \times 0.474 = 0.239 \text{ m}$$

Tf = Tc - Ta = 0.474 - 0.239 = 0.235 m

	Fwd	Aft
Final hydraft	6.929 m	6.929 m
Tf or Ta	-0.235 m	+0.239 m
Final drafts	6.694 m	7.168 m

Example 5B

M.v. VIJAY floats in SW, drawing 3.6 m & 6.4 m fwd and aft. 2000 t cargo is to be loaded. Space is available in No:2, AG 102 m, and in No:4, AG 58 m. Find how much cargo to put in each space in order to finish with a trim of 1 metre by the stern. State the final drafts fwd & aft.

Fwd 3.6 m aft 6.4 m, trim 2.8 m by stern
Mean draft 5.0 m for which AF = 71.913 m

$$Corr = \frac{AF}{L} \times trim = \frac{71.913(2.8)}{140} = 1.438 \text{ m}$$

Initial hydraft = 6.4 - 1.438 = 4.962 m.

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

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

$$\overline{BG} = \frac{280(165.434)}{9807.4} = 4.273 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 72.014 - 4.273 = 67.291$ m

AG of ship in given condition = 67.291 m

From Appendix I for final W = 11807.4 t:

Draft	MCTC tm	AB (m)	AF (m)
5.860	171.781	71.972	71.552

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

$$\text{Final BG} = \frac{100 \times 171.781}{11807.4} = 1.455 \text{ m}$$

Final Tc by stern so final AG < final AB

Final AG = 71.972 - 1.455 = 70.517 m

Let cargo loaded in No:2 = X tonnes. So cargo loaded in No:4 = (2000 - X) tonnes

Remarks	Weight	AG (m)	Moment abt A
Ship	9807.4	67.291	659950
Cargo	X	102	102X
Cargo	2000-X	58	116000 - 58X
Final	11807.4		775950 + 44X

$$\text{Final AG} = \frac{775950 + 44X}{11807.4} = 70.517$$

X = 1288.0 t = quantity to load in No: 2
and (2000 - X) = 712 t to load in No: 4

$$Ta = \frac{AF}{L} \times Tc = \frac{71.552}{140} \times 1.000 = 0.511 \text{ m}$$

$$Tf = Tc - Ta = 1.000 - 0.511 = 0.489 \text{ m}$$

	Fwd	Aft
Final hydraft	5.860 m	5.860 m
Tf or Ta	-0.489 m	+0.511 m
Final drafts	5.371 m	6.371 m

Example 6B

M.v. VIJAY is in a SW dock drawing 5.8 m fwd & 6.8 m aft. The maximum permissible draft at the exit lock is 6.7 m. Space is available in No:1, AG 120 m, & in No: 4, AG 58 m. Find the maximum cargo that can be loaded & the distribution between the two holds.

Note: Maximum draft allowed = 6.7 m and maximum cargo is to be loaded. So, final drafts are to be 6.7 m fwd & aft.

Fwd 5.8 m aft 6.8 m, trim 1.0 m by stern
Mean draft 6.3 m for which AF = 71.251 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.251(1.0)}{140} = 0.509 \text{ m}$$

Initial hydraft = 6.80 - 0.509 = 6.291 m

Draft	W (t)	MCTC tm	AB (m)
6.291	12782.0	175.419	71.928

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

$$\overline{BG} = \frac{100(175.419)}{12782} = 1.372 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 71.928 - 1.372 = 70.556$ m

AG of ship in given condition = 70.556 m

From Appendix I for final draft = 6.7 m:

W (t)	MCTC tm	AB (m)	AF (m)
13714.5	179.250	71.872	70.902

Cargo to load = 13714.5 - 12782 = 932.5t

Final Tc = 0 so final AG = AB = 71.872 m

Let cargo to load in No: 1 be X tonnes, so cargo to load in No: 4 = (932.5 - X).

Remarks	Weight	AG (m)	Moment abt A
Ship	12782	70.556	901847
Cargo	X	120	120X
Cargo	932.5-X	58	54085 - 58X
Final	13714.5		955932 + 62X

$$\text{Final AG} = \frac{955932 + 62X}{13714.5} = 71.872$$

X = 479.90 t = quantity to load in No: 1
and (932.5-X) = 452.6 t to load in No: 4

Example 7B

M.v. VIJAY is in SW, drawing 6 m fwd and 6.8 m aft. From what location may 1200 t cargo be discharged if it is desired to keep the draft aft constant at 6.8 m? State the final draft fwd.

Fwd 6.0 m aft 6.8 m, trim 0.8 m by stern
Mean draft 6.4 m for which AF = 71.172 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.172(0.8)}{140} = 0.407 \text{ m}$$

Initial hydraft = 6.80 - 0.407 = 6.393 m

Draft	W (t)	MCTC tm	AB (m)
6.393	13014.1	176.337	71.915

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

$$\overline{BG} = \frac{80(176.337)}{13014.1} = 1.084 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 71.915 - 1.084 = 70.831$ m

AG of ship in given condition = 70.831 m

Final W = 13014.1 - 1200 = 11814.1 t

W (t)	Draft	MCTC tm	AB (m)	AF (m)
11814.1	5.863	171.805	71.972	71.550

Final draft aft = 6.8, hydraft = 5.863 m
So trim by stern (final AG < final AB),
and final Ta = 6.800 - 5.863 = 0.937 m.

$$Ta = \frac{AF}{L} \times Tc \quad \text{or} \quad Tc = \frac{L \times Ta}{AF}$$

$$Tc = \frac{140 \times 0.937}{71.55} = 1.833 \text{ m.}$$

Final draft fwd = 6.8 - 1.833 = 4.967 m.

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

$$\text{Final } \overline{BG} = \frac{183.3(171.805)}{11814.1} = 2.666 \text{ metres}$$

Final AG = final AB - final $\overline{BG}$

Final AG = 71.972 - 2.666 = 69.236 m.

Remarks	Weight	AG (m)	Moment abt A
Ship	13014.1	70.831	921802
Disch	1200	X	-1200X
Final	11814.1		921802-1200X

$$\text{Final AG} = \frac{921802 - 1200X}{11814.1} = \mathbf{69.236}$$

X = 86.53 m = AG of wt to be discharged.

Rough check by method 'A' (chapter 26):

$$Ta = \text{mean rise} \quad \text{or} \quad \frac{AF}{L} \times \frac{dw}{MCTC} = \frac{w}{TPC}$$

$$\frac{71.172}{140} \times \frac{d}{176.4} = \frac{1}{22.64} \quad \text{or} \quad d = 15.326 \text{ m}$$

AG of cargo = d + AF = 86.5 m approx.

Example 8B

M.v.VIJAY is in SW drawing 3.8 m fwd and 4.2 m aft. 800 t of deck cargo is to be loaded. In order to keep a damaged part of the hull above water, it is decided that the sailing draft fwd should be 3.8 m. Find where this cargo may be loaded & state the final draft aft.

Fwd 3.8 m aft 4.2 m, trim 0.4 m by stern
Mean draft 4.0 m for which AF = 72.127 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{72.127(0.4)}{140} = 0.206 \text{ m}$$

Initial hydraft = 4.20 - 0.206 = 3.994 m

Draft	W (t)	MCTC tm	AB (m)
3.994	7695.1	157.746	72.008

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

$$\overline{BG} = \frac{40(157.746)}{7695.1} = 0.820 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 72.008 - 0.820 = 71.188$ m

AG of ship in given condition = 71.188 m

Final W = 7695.1 + 800 = 8495.1 t

W (t)	Draft	MCTC tm	AB (m)	AF (m)
8495.1	4.363	160.984	72.014	72.064

Final draft fwd = 3.8, hydraft = 4.363 m
So trim by stern (final AG < final AB), and final Tf = 4.363 - 3.800 = 0.563 m.

$$Tf = \frac{\text{fwd length}}{L} \times Tc \quad \text{or} \quad Tc = \frac{L \times Tf}{140 - AF}$$

$$Tc = \frac{140 \times 0.563}{67.936} = 1.160 \text{ m.}$$

Final draft aft = 3.8 + 1.160 = 4.960 m.

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

$$\text{Final } \overline{BG} = \frac{116.0(160.984)}{8495.1} = 2.198 \text{ metres}$$

Final AG = final AB - final $\overline{BG}$
Final AG = 72.014 - 2.198 = 69.816 m.

Remarks	Weight	AG (m)	Moment abt A
Ship	7695.1	71.188	547799
loaded	800	X	+800X
Final	8495.1		547799 +800X

$$\text{Final AG} = \frac{547799 + 800X}{8495.1} = 69.816$$

X = 56.618 m = AG of cargo to be loaded.

Rough check by method 'A' (chapter 26):

$$Tf = \text{mean sinkage or } \frac{(140 - AF)\,dw}{L \times MCTC} = \frac{w}{TPC}$$

$$\frac{67.873}{140} \times \frac{d}{157.8} = \frac{1}{21.6} \quad \text{or} \quad d = 14.402 \text{ m}$$

AG of cargo = AF - d = 57.725 m approx.

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Example 9B

M.v.VIJAY is in SW at 3.6 & 6.4 m F & A. Cargo is to be loaded in No:2, AG 102 m, until the draft aft becomes 5.6 m. Find the amount to load & the final draft fwd

Note: This is an unique problem. Because w is not given, final W is not directly known. Final hydraft is not given. Hence the final hydrostatic particulars are not readily available. Using the initial hydrostatic particulars, the approximate value of w can be found by method 'A' (chapter 26). An accurate calculation is then made, assuming that the approximate calculated value of w is loaded. Then minor changes to the result can be made to bring the draft aft to exactly 5.6 m.

To find approx w: (see chapter 26)

Draft aft + sinkage - Ta = new draft aft
So 6.4 + mean sinkage - Ta = 5.6

Since both sinkage & trim will be in cm,

$$640 + \frac{w}{TPC} - \frac{AF}{L} \times \frac{dw}{MCTC} = 560$$

$$\text{or } \frac{AF}{L} \times \frac{dw}{MCTC} - \frac{w}{TPC} = 80$$

Mean draft	MCTC tm	AF (m)	TPC
5.000 m	165.700	71.913	22.06

$$\frac{71.913}{140} \times \frac{w(102 - 71.913)}{165.7} - \frac{w}{22.06} = 80$$

w = 1668.8 t approx.

Assuming that the cargo loaded is exactly 1668.8 t, to find the precise drafts fwd & aft:

Fwd 3.6 m aft 6.4 m, trim 2.8 m by stern
Mean draft 5.0 m for which AF = 71.913 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.913(2.8)}{140} = 1.438 \text{ m}$$

Initial hydraft = 6.40 - 1.438 = 4.962 m

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

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

$$\overline{BG} = \frac{280(165.434)}{9807.4} = 4.273 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 72.014 - 4.723 = 67.291$ m

AG of ship in given condition = 67.291 m

Remarks	Weight	AG (m)	Moment
Ship	9807.4	67.291	659950
Loaded	1668.8	102	170218
Final	11476.2		830168

New AG = 830168 ÷ 11476.2 = 72.338 m

From table, for W = 11476.2 t:

Draft	MCTC tm	AB (m)	AF (m)	TPC
5.713	170.689	71.983	71.623	22.339

New AG > new AB. So new Tc by the head.
New $\overline{BG}$ = 72.338 - 71.983 = 0.355 metres.

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{11476.2 \times 0.355}{170.689} = 23.9 \text{ cm}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{71.623}{140} \times 0.239 = 0.122 \text{ m}$$

$$Tf = Tc - Ta = 0.239 - 0.122 = 0.117 \text{ m}$$

	Fwd	Aft
New hydraft	5.713 m	5.713 m
Tf or Ta	+0.117 m	-0.122 m
New drafts	5.830 m	5.591 m

Note 1: It is found that after loading 1668.8 t at AG 102 m, the draft aft is 5.591 m instead of 5.6 m, In actual practice, this is acceptable to ship's officers because:
a) 9 mm would not be noticeable visually
b) It is not feasible to load cargo at AG = exactly 102 m.

Note 2: Calculation by method A is very quick & would suffice in actual practice

Note 3: To obtain a theoretically exact draft of 5.6 m draft aft, a small change has to be made in the figure of 1668.8 t

By loading 1668.8 t in No:2, the draft aft has decreased 0.9 cm more than necessary. So a small quantity discharged, say 'Y' tonnes, from No:2 would give an exact result. Since TPC & MCTC are being used, the calculation in cm is:-

$$559.1 - \text{rise} + Ta = 560$$

$$559.1 - \frac{Y}{TPC} + \frac{AF \times dY}{L \times MCTC} = 560$$

$$\frac{71.623}{140} \times \frac{Y(102 - 71.623)}{170.689} - \frac{Y}{22.339} = 0.9$$

Y = 19.4 t. Actual cargo to load in No:2 hold = 1668.8 - 19.4 = 1649.4 tonnes.

Note: Since Y is only 19.4 t, the hydrostatic particulars would not change appreciably. So a simple calculation by method A would suffice to obtain the final drafts fwd and aft.

$$\text{Mean rise} = \frac{19.4}{22.339} = 0.900 \text{ cm} = 0.009 \text{ m.}$$

$$Tc = \frac{dw}{MCTC} = \frac{30.377(19.4)}{170.689} = 3.5 \text{ cm}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{71.623}{140} \times 0.035 = 0.018 \text{ m}$$

$$Tf = Tc - Ta = 0.035 - 0.018 = 0.017 \text{ m}$$

	Fwd	Aft
New drafts	5.830 m	5.591 m
Mean rise	0.009 m	0.009 m
	5.821 m	5.582 m
Tf or Ta	-0.017 m	+0.018 m
Final drafts	5.804 m	5.600 m

Example 10B

M.v.VIJAY is in FW drawing 3.2 m fwd and 5.8 m aft. 1350 t of cargo is loaded in No:3 LH, AG 85 m. Find the final drafts fwd and aft in FW.

Fwd 3.2 m aft 5.8 m, trim 2.6 m by stern
Mean draft 4.5 m for which AF = 72.035 m

$$Corr = \frac{AF}{L} \times trim = \frac{72.035(2.6)}{140} = 1.338 \text{ m}$$

Initial FW hydraft = 5.8 - 1.338 = 4.462

Draft	W (t)	MCTC tm	AB (m)	AF (m)
SW4.462	8711.5	161.734	72.016	72.043
FW4.462	8499.0	157.789	72.016	72.043

Note: FW data is obtained by modifying the SW values as explained in chapters 17 and 18 in Ship Stability I.

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

$$\overline{BG} = \frac{260(157.789)}{8499} = 4.827 \text{ m}$$

Since trim is by stern, AG < AB.
$AG = AB - \overline{BG} = 72.016 - 4.827 = 67.189$ m

Remarks	Weight	AG (m)	Moment
Ship	8499.0	67.189	571039
Loaded	1350.0	85	114750
Final	9849.0		685789

New AG = 685789 ÷ 9849 = 69.630 m.

Assuming same draft in SW & FW, for the sake of entering the hydrostatic table:
W in SW = W in FW(1.025) = 10095.2 t

Draft	W (t)	MCTC tm	AB (m)	AF (m)
SW 5.092	10095.2	166.346	72.013	71.880
FW 5.092	9849	162.289	72.013	71.880

Note: FW data is obtained by modifying the SW values as explained in chapters 17 and 18 in Ship Stability I.

Final AB = 72.013 m. Final AG = 69.630 m
AG < AB, so Tc is by stern, $\overline{BG}$ = 2.383 m

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{9849 \times 2.383}{162.289} = 144.6 \text{ cm}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{71.880(1.446)}{140} = 0.742 \text{ m}$$

$$Tf = Tc - Ta = 1.446 - 0.742 = 0.704 \text{ m}$$

	Fwd	Aft
Final FW hydraft	5.092 m	5.092 m
Tf or Ta	-0.704 m	+0.742 m
Final FW drafts	4.388 m	5.834 m

Example 11B

M.v.VIJAY is in DW of RD 1.013 at drafts of 4.2 m fwd & 3.6 m aft. Find the final drafts fwd & aft, in the same DW, after carrying out the following operations:
100 t pumped out of the FP tank AG 135 m
400 t HFO received in No:4 DBT, AG 60 m.
500 t cargo loaded in No:4 LH, AG 50 m.

Fwd 4.2 m aft 3.6 m, trim 0.6 m by head
Mean draft 3.9 m for which AF = 72.134 m

$$Corr = \frac{AF}{L} \times trim = \frac{72.134(0.6)}{140} = 0.309 \text{ m}$$

Initial DW hydraft = 3.6 + 0.309 = 3.909

Draft	W (t)	MCTC tm	AB (m)	AF (m)
SW3.909	7511.9	156.981	72.003	72.133
DW3.909	7424.0	155.143	72.003	72.133

Note: DW data is obtained by modifying the SW values for the same draft.

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

$$\overline{BG} = \frac{60(155.143)}{7424} = 1.254 \text{ m}$$

Since trim is by head, AG > AB.
$AG = AB + \overline{BG} = 72.003 + 1.254 = 73.257$ m

Remarks	Weight	AG (m)	Moment
Ship	7424	73.257	543860
SW	-100	135	-13500
HFO	+400	60	+24000
Cargo	+500	50	+25000
Final	8224		579360

Final AG = 579360 ÷ 8224 = 70.447 m.

Assuming same draft in SW & DW, for the sake of entering the hydrostatic table:

W in SW = W in DW(1.025/1.013) = 8321.4t

	Draft	W (t)	MCTC tm	AB (m)	AF (m)
SW	4.283	8321.4	160.305	72.013	72.081
DW	4.283	8224	158.428	72.013	72.081

Note: DW data is obtained by modifying the SW values for the same draft.

Final AG < final AB so final Tc by stern
Final $\overline{BG}$ = 72.013 - 70.447 = 1.566 m

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{8224 \times 1.566}{158.428} = 81.3 \text{ cm}$$

$$Ta = \frac{AF}{L} \times Tc = \frac{72.081}{140} \times 0.813 = 0.419 \text{ m}$$

$$Tf = Tc - Ta = 0.813 - 0.419 = 0.394 \text{ m}$$

	Fwd	Aft
Final hydraft	4.283 m	4.283 m
Tf or Ta	-0.394 m	+0.419 m
Final drafts	3.889 m	4.702 m

Exercise 23
Trim problems - Type B

1 M.v.VIJAY draws 4.5 m fwd & 6.5 m aft in SW. Find the new drafts if 100 t ballast is transferred from the after peak tank, AG 3.5 m, to the fore peak tank, AG 136.5 m.

2 M.v.VIJAY is in DW RD 1.015 drawing 6 m fwd & 5 m aft. Find the new drafts if 400 t cargo is transferred from No:1 LH AG 120 m, to No:3 LH AG 80 m.

3 M.v.VIJAY is in SW at drafts of 5.8 m fwd & 5 m aft. AG is 73.251 m. Find the new drafts if 600 t cargo is discharged from No:1 TD, AG 124 m.

4 M.v.VIJAY is in SW, drawing 3.6 m fwd & 4.8 m aft. AG is 69.651 m. Find the new drafts fwd & aft if the following operations are carried out:
2000 t cargo loaded in No:4, AG 60 m.
1000 t discharged from No:5, AG 20 m.
120 t SW run into AP tank, AG 3 m.

5 The drafts of m.v.VIJAY in SW are 4 m fwd & 3.6 m aft. AG is 72.854 m. Find the final drafts if the following operations take place:
1400 t cargo loaded in No:2, AG 98 m.
2100 t cargo loaded in No:5, AG 22 m.
120 t FW transferred from APT AG 3 m, to FPT AG 135 m.

6 M.v.VIJAY is drawing 5 m fwd & aft in SW. Find the new drafts if 1550 t of cargo is loaded in No:4 LH, AG 50 m.

7 The drafts fwd & aft of m.v.VIJAY in SW are 5 m & 6.8 m. 1900 t cargo is loaded in No:3, AG 84 m. Find the new drafts fwd & aft.

8 M.v.VIJAY arrives at a SW port drawing 4 m fwd & 5.9 m aft. Find the new drafts if 1600 t cargo is discharged from No:4, AG 60 m.

9 M.v.VIJAY draws 3.3 m fwd & 6.3 m aft in a SW port. 2000 t of cargo is to be loaded. Space is available in No:2, AG 100 m, and in No:4, AG 60 m. Distribute this cargo in order to finish trimmed 1.5 m by the stern. State the final drafts fwd & aft.

10 M.v.VIJAY is in FW, drawing 4.8 m fwd & 4 m aft. 1800 t cargo is yet to be loaded. Space is available in No:2, AG 105 m, and in No:5, AG 20 m. Find how much to put in each space to finish trimmed 1 m by the stern. State the final drafts fwd & aft.

11 The fwd & aft drafts of m.v. VIJAY in SW are 3.9 m & 4.9 m. Find how much cargo may go in No:1, AG 120 m, & in No:4, AG 55 m, to finish on an even keel draft of 5.8 m.

12 M.v.VIJAY floats in DW of RD 1.010 at an even keel draft of 6.6 m. Find how much cargo may be discharged from No:1, AG 118 m, and No:5, AG 16 m, to

finish on an even keel draft of 6 m, in the same dock.

13 M.v. VIJAY floats in SW, at drafts of 3.1 m fwd & 5.6 m aft. At what location must 500 t cargo be loaded if the after draft should remain at 5.6 m? State also, the final draft fwd.

14 M.v.VIJAY is in DW (RD 1.015) drawing 4.3 m fwd & 4 m aft. At what location should 800 t cargo be loaded if the final draft fwd is to be 4.3 m? State the final draft aft.

15 M.v. VIJAY is in FW, at an even keel draft of 4.9 m. Find the location from which 1200 t of cargo may be discharged in order to finish at a draft of 4.9 m fwd. State, also, the final draft aft.

16 M.v.VIJAY is in DW (RD 1.018) drawing 4.6 m fwd and 4 m aft. Find the location from which to discharge 1650 t cargo in order to finish with 4 m draft aft. State the final draft fwd.

17 M.v.VIJAY is in SW, drawing 3.5 m fwd & 4.9 m aft. What quantity of cargo may be loaded in No:4 LH, AG 58 m, if the final draft aft is to be 6 m? State the final draft fwd.

18 M.v.VIJAY is in DW (RD 1.013) drawing 5.2 m fwd and 6 m aft. 800 t of cargo is to be discharged. What should be the AG, of this cargo, if the final draft forward is to be 4.8 m? Also state the final draft aft.

19 M.v.VIJAY arrives at a saltwater port drawing 3.7 m fwd & 4.5 m aft. 4000 t of cargo is to be loaded, of which:

1000 t must go into No:2, AG 100 m,
1000 t must go into No:4, AG 56 m,
1000 t must go into No:3, AG 80 m.

How much cargo must be put into No:1, AG 120 m, and into No:5, AG 18 m, to finish trimmed 1 m by the stern. State the final drafts fwd and aft.

20 M.v.VIJAY arrives in DW (RD 1.016) at drafts of 6.8 m fwd & 7.0 m aft. Part of her bulk cargo is to be discharged as follows:

500 tonnes from No:1, AG 122 m,
500 tonnes from No:5, AG 18 m,
500 tonnes from No:3, AG 80 m.

A further amount of 1500 t is to be discharged, part from No:2, AG 100 m, & part from No:4, AG 56 m. Calculate the quantity to discharge from Nos:2 and 4, if the final trim is to be 0.8 metre by the stern. State the final drafts fwd and aft.

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CHAPTER 28

TRIM PROBLEMS

TYPE C

These problems are very similar to those of type B, except that all distances are expressed from amidships (H) instead of from the after perpendicular (A). These have the disadvantage that, each time, distances and moments have to be identified as forward of, or abaft, amidships. However, problems of type C have the advantage that the values used are much smaller than in problems of type B where the after perpendicular is used for reference.

Problems of type C are included here because the hydrostatic tables issued by some shipyards give distances from amidships only. The basic theory, and order of work, is very similar to that of type B. For working problems of type C, the hydrostatic table of m.v. VICTORY may be used. This is given as Appendix II at the end of this book.

Example 1C

M.v. VICTORY is afloat in SW at an even keel draft of 13 m. 300 t is shifted aft by 80 m. Find the new drafts fwd & aft.

From hydrostatic table, for 13 m draft, MCTC = 1159.1 tm and HF = 0.27 m aft.

$$Tc = \frac{TM}{MCTC} = \frac{300 \times 80}{1159.1} = 20.7 \text{ cm by stern.}$$

$$Ta = \frac{AF}{L}(Tc) = \frac{(L/2 - 0.27)}{236}0.207 = 0.103 \text{ m}$$

$$Tf = Tc - Ta = 0.207 - 0.103 = 0.104 \text{ m}$$

	fwd	aft
Final hydraft	13.000 m	13.000 m
Tf or Ta	-0.104 m	+0.103 m
Final drafts	12.896 m	13.103 m

Example 2C

M.v.VICTORY is afloat in SW at drafts of 12.8 m fwd and 14.8 m aft. HG is 1.669 m fwd. Find the new drafts fwd and aft if 3000 t of cargo is loaded in No:3 LH, HG 52 m fwd.

Fwd 12.8 m aft 14.8 m, trim 2 m by stern
For mean draft 13.8 m, HF = 0.98 m aft.

$$\text{Correctn} = \frac{HF}{L} \times \text{trim} = \frac{0.98(2)}{236} = 0.008 \text{ m}$$

Note: Trim is by stern and HF is aft. So correction to mean draft is positive. Refer to chapter 18 in Ship Stability I.

Initial hydraft =13.8 + 0.008= 13.808 m.

For 13.808 m hydraft, W = 90541.8 tonnes
Final W = 90541.8 + 3000 = 93541.8 t

From table, particulars for final W are:

W (t)	draft	MCTC tm	HB fwd	HF aft
93541.8	14.231	1198.303	4.116	1.313

Remarks	Weight	HG (m)	moment abt H
Ship	90541.8	1.669 fwd	151114 fwd
Cargo	+3000	52 fwd	156000 fwd
Final	93541.8		307114 fwd

Final HG = 307114/93541.8 = 3.283 m fwd.

Final HG 3.283 fwd, final HB 4.116 fwd.
COG is abaft COB so final trim by stern.
Final $\overline{BG}$ = 4.116 - 3.283 = 0.833 metres.

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{93541.8 \times 0.83}{1198.303} = 65 \text{ cm}$$

AF = L/2 - HF = 118 - 1.313 = 116.687 m.

$$Ta = \frac{AF \times Tc}{L} = \frac{116.687 \times 0.65}{236} = 0.321 \text{ m.}$$

Tf = Tc - Ta = 0.650 - 0.321 = 0.329 m.

	fwd	aft
Final hydraft	14.231 m	14.231 m
Tf or Ta	-0.329 m	+0.321 m
Final drafts	13.902 m	14.552 m

Example 3C

M.v.VICTORY is afloat in SW at drafts of 10 m fwd & 13.8 m aft. HG is 0.46 m aft. Find the new drafts fwd & aft after the following operations:

10,000 t of cargo loaded at HG 72 m fwd
6,000 t of cargo loaded at HG 52 m aft
1,500 t SW pumped out from HG 110 m fwd

Fwd 10 m aft 13.8 m, trim 3.8 m by stern
For mean draft 11.9 m, HF = 0.86 m fwd.

$$Corrctn = \frac{HF(trim)}{L} = \frac{0.86(3.8)}{236} = 0.014 \text{ m}$$

Trim by stern & HF fwd so correction (-)

Initial hydraft =11.9 - 0.014 = 11.886 m
by which the initial W = 77054.4 tonnes.

Remarks	Weight	HG (m)	moment abt H
Ship	77054.4	0.46 aft	35,445 aft
Cargo	+10000	72 fwd	720,000 fwd
Cargo	+ 6000	52 aft	312,000 aft
SW	- 1500	110 fwd	165,000 aft
Final	91554.4		207,555 fwd

Final HG = 207555/91554.4 = 2.267 m fwd

From table, particulars for final W are:

W (t)	draft	MCTC tm	HB fwd	HF aft
91554.4	13.951	1189.773	4.230	1.101

Final HG 2.267 fwd, final HB 4.230 fwd.
COG is abaft COB so final trim by stern.
Final $\overline{BG}$ = 4.230 - 2.267 = 1.963 metres.

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{91554.4 \times 1.963}{1189.773} = 151.1 \text{ cm.}$$

AF = L/2 - HF = 118 - 1.101 = 116.899 m.

$$Ta = \frac{AF(Tc)}{L} = \frac{116.899 \times 1.511}{236} = 0.748 \text{ m.}$$

Tf = Tc - Ta = 1.511 - 0.748 = 0.763 m.

	fwd	aft
Final hydraft	13.951 m	13.951 m
Tf or Ta	-0.763 m	+0.748 m
Final drafts	13.188 m	14.699 m

Example 4C

M.v. VICTORY is in SW drawing 12.2 m fwd and 16.2 m aft. 5000 t cargo is loaded into No:4 LH, HG 31 m fwd. Find the new drafts fwd and aft.

Fwd 12.2 m aft 16.2 m, trim 4 m by stern
For mean draft 14.2 m, HF = 1.29 m aft.

$$\text{Corrctn} = \frac{HF}{L} \times \text{trim} = \frac{1.29 \times 4}{236} = 0.022 \text{ m}$$

Trim by stern & HF aft so correction (+)

Initial hydraft =14.2 + 0.022= 14.222 m.

Draft	W (t)	MCTC	HB fwd
14.222	93480.5	1198.049	4.120

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

$$\overline{BG} = \frac{400(1198.049)}{93480.5} = 5.126 \text{ m}$$

Since trim is by stern, COG is abaft COB
Initial HG = 5.126 - 4.120 = 1.006 m aft

Remarks	Weight	HG (m)	Moment abt H
Ship	93480.5	1.006 aft	94041 aft
Cargo	+5000	31.00 fwd	155000 fwd
Final	98480.5		60959 fwd

Final HG = 60959 ÷ 98480.5 = 0.619 m fwd

From Appendix II, for final W 98480.5 t:

Draft	MCTC tm	HB fwd	HF aft
14.923	1218.510	3.825	1.794

Finally HG = 0.619 fwd & HB = 3.825 fwd.
COG abaft COB, so final trim is by stern
Final $\overline{BG}$ = 3.825 - 0.619 = 3.206 metres.

$$\text{Final Tc} = \frac{W.\overline{BG}}{MCTC} = \frac{98480.5(3.206)}{1218.51} = 259.1 \text{ (cm)}$$

AF = L/2 - HF = 118 - 1.794 = 116.206 m.

$$Ta = \frac{AF}{L} \times Tc = \frac{116.206 \times 2.591}{236} = 1.276 \text{ m}$$

Tf = Tc - Ta = 2.591 - 1.276 = 1.315 m

	Fwd	Aft
Final hydraft	14.923 m	14.923 m
Tf or Ta	-1.315 m	+1.276 m
Final drafts	13.608 m	16.199 m

Example 5C

M.v.VICTORY is afloat in SW drawing 11 m fwd & 14.4 m aft. 8000 t of cargo is yet to be loaded. Space is available in No:2 HG 72 m fwd, and in No:7, HG 31 m aft. Find how much to put in each space to finish loading 1.5 m by the stern. State the final drafts fwd and aft.

Fwd 11 m aft 14.4 m, trim 3.4 m by stern
For mean draft 12.7 m, HF = 0.02 m fwd.

Note: The student is advised to look into the hydrostatic table and obtain the HF by himself, in this case, as HF for 12.6 m draft is fwd whereas for 12.8 m, it is aft.

$$\text{Corrn} = \frac{HF}{L} \times \text{trim} = \frac{0.02(3.4)}{236} = <0.001 \text{ m}$$

Initial hydraft = mean draft = 12.700 m.

Draft	W (t)	MCTC	HB fwd
12.700	82733	1148.950	4.750

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

$$\overline{BG} = \frac{340(1148.950)}{82733} = 4.722 \text{ m}$$

Since trim is by stern, COG is abaft COB
Initial HG = 4.750 - 4.722 = 0.028 m fwd

Final W = 82733 + 8000 = 90733 tonnes, for which particulars from Appendix II:-

Draft	MCTC tm	HB fwd	HF aft
13.835	1186.184	4.276	1.008

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

$$\overline{BG} = \frac{150(1186.184)}{90733} = 1.961 \text{ m}$$

Final trim by stern, so COG is abaft COB
Final HG = 4.726 - 1.961 = 2.315 m fwd.

Let cargo to load in No:2 = X tonnes. So cargo to load in No:7 = 8000 - X tonnes.

Remarks	Weight	HG (m)	Moment abt H
Ship	82733	0.028 fwd	2317 fwd
No:2	X	72 fwd	72X fwd
No:7	8000-X	31 aft	24800-31X aft

Final moment = (2317+72X) - (24800-31X)
(Since final HG is fwd final mom is fwd)

Final HG = final moment/final W = 2.315

[(2317+72X) - (24800 - 31X)]/90733 = 2.315

X = 4424.5 t = cargo to load in No:2 LH
& (8000 - X) = 3575.5 t cargo in No:7 LH

AF = L/2 - HF = 118 - 1.008 = 116.992 m.

$$Ta = \frac{AF}{L'} \times Tc = \frac{116.992 \times 1.500}{236} = 0.744 \text{ m}$$

Tf = Tc - Ta = 1.500 - 0.744 = 0.756 m

	Fwd	Aft
Final hydraft	13.835 m	13.835 m
Tf or Ta	-0.756 m	+0.744 m
Final drafts	13.079 m	14.579 m

Example 6C

M.v.VICTORY is afloat in SW drawing 11 m fwd & 13 m aft. She is to sail on an even keel draft of 13.6 m. Find how much cargo to put in No:3, HG 52 m fwd, and in No:7, HG 32 m aft.

Fwd 11 m aft 13 m, trim 2 m by the stern
For mean draft 12.0 m, HF = 0.74 m fwd.

$$\text{Corrctn} = \frac{HF}{L} \times \text{trim} = \frac{0.74 \times 2}{236} = 0.006 \text{ m}$$

Trim by stern & HF fwd so correction (-)

Initial hydraft =12.0 - 0.006= 11.994 m.

Draft	W (t)	MCTC tm	HB fwd	HF fwd
11.994	77803.4	1123.757	5.022	0.747

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

$$BG = \frac{200(1123.757)}{77803.4} = 2.889 \text{ m}$$

Initial trim by stern:- COG is abaft COB
Initial HG = 5.022 - 2.889 = 2.133 m fwd

Draft	W (t)	MCTC tm	HB fwd	HF aft
13.60	89070	1178.800	4.380	0.810

Can load = 89070.0 - 77803.4 = 11266.6 t

Even keel:- final HG = HB = 4.380 m fwd.

Let cargo to load in No:3 = X tonnes. So cargo to load in No:7 = (11266.6 - X) t.

Remarks	Weight	HG (m)	Moment abt H
Ship	77803.4	2.133 fwd	165955 fwd
No:3	X	52 fwd	52X fwd
No:7	11266.6-X	32 aft	360531-32X aft

Final mom = (165955+52X) - (360531-32X)
(Since final HG is fwd final mom is fwd)

Final HG = final moment/final W = 4.380

[165955+52X - (360531-32X)]/89070 = 4.38

X = 6960.7 t = cargo to load in No:3 LH
11266.6 - X = 4305.9 t cargo in No:7 LH

Example 7C

M.v. VICTORY is in SW drawing 14 m fwd & 14.8 m aft. From what location must 2500 tonnes cargo be discharged if the draft aft is to remain constant? State the final drafts fwd & aft.

Fwd 14 m aft 14.8 m, trim 0.8 m by stern
For mean draft 14.4 m, HF = 1.44 m aft.

$$\text{Corrctn} = \frac{HF}{L}(\text{trim}) = \frac{1.44(0.8)}{236} = 0.005 \text{ m}$$

Trim by stern & HF aft so correction (+)

Initial hydraft =14.4 + 0.005= 14.405 m.

Draft	W (t)	MCTC	HB fwd
14.405	94782.7	1203.448	4.038

$$\text{Trim in cm} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim x MCTC}}{W}$$

$$\overline{BG} = \frac{80(1203.448)}{94782.7} = 1.106 \text{ m}$$

Initial trim by stern:- COG is abaft COB
Initial HG = 4.038 - 1.106 = 3.022 m fwd

Final W = 94782.7 - 2500 = 92282.7 t

W (t)	draft	MCTC	HB fwd	HF aft
92282.7	14.053	1192.927	4.189	1.180

Ta = final draft aft - final hydraft
Ta = 14.800 - 14.053 = 0.747 metre

$$Ta = \frac{AF}{L}(Tc) \quad \text{or} \quad Tc = \frac{236(0.747)}{118 - 1.18} = 1.509 \text{ m}$$

Final draft fwd = 14.8 - 1.509 = 13.291m

$$\text{Trim in cm} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim x MCTC}}{W}$$

$$\overline{BG} = \frac{150.9(1192.927)}{92282.7} = 1.951 \text{ m}$$

Final trim by stern, so COG is abaft COB
Final HG = 4.189 - 1.951 = 2.238 m fwd.

Let HG of cargo to discharge = X m fwd.

Remarks	Weight	HG (m)	Moment abt H
Ship	94782.7	3.022 fwd	286433 fwd
Cargo	-2500	X fwd	2500X aft
Final	92282.7		286433-2500X fwd

(Since final HG is fwd final mom is fwd)

Final HG = final moment/final W = 2.238

$$\frac{286433-2500X}{92282.7} = 2.238 \text{ or } X = 31.962 \text{ m fwd}$$

HG of cargo to discharge = 31.962 m fwd.

Note: If the value of X was found to be negative, the assumed direction of COG, from H, would have to be changed. The value obtained would still hold good.

Rough check by method A

$$\text{Mean rise} = \text{Ta} \quad \text{or} \quad \frac{w}{TPC} = \frac{AF\ (dw)}{L(MCTC)}$$

Using initial hydrostatic particulars:

$$d = \frac{L(MCTC)}{AF(TPC)} = \frac{236 \times 1203.448}{(118-1.44)71.193} = 34.226 \text{ m}$$

HG of cargo = 34.226 - 1.440 = 32.786 m.

Example 8C

M.v. VICTORY is in SW drawing 11.8 m fwd and 12.2 m aft. 3000 t cargo is to be loaded. To effect some shipside repairs, the fwd draft has to be maintained at 11.8 m. Find where this cargo should be loaded and state the final draft aft.

Fwd 11.8 aft 12.2 m, trim 0.4 m by stern
For mean draft 12.0 m, HF = 0.74 m fwd.

$$\text{Corrctn} = \frac{HF(\text{trim})}{L} = \frac{0.74(0.4)}{236} = 0.001 \text{ m}$$

Trim by stern & HF fwd so correction (-)
Initial hydraft = 12 - 0.001 = 11.999 m.

Draft	W (t)	MCTC tm	HB fwd	HF fwd
11.999	77838.1	1123.960	5.020	0.741

$$\text{Trim in cm} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim x MCTC}}{W}$$

$$\overline{BG} = \frac{40(1123.96)}{77838.1} = 0.578 \text{ m}$$

Initial trim by stern:- COG is abaft COB
Initial HG = 5.020 - 0.578 = 4.442 m fwd

Final W = 77838.1 + 3000 = 80838.1 t

W (t)	draft	MCTC	HB fwd	HF fwd
80838.1	12.429	1139.441	4.858	0.291

Since final trim is by the stern,

Tf = final hydraft - final draft forward
= 12.429 - 11.800 = 0.629 metre.

$$\frac{\text{Fwd length (Tc)}}{L} = \text{Tf} \quad \text{or} \quad \text{Tc} = \frac{236\ (0.629)}{118 - 0.291}$$

Tc = Final trim = 1.261 m by the stern

Final draft aft = 11.8 + 1.261 = 13.061m

$$\text{Trim in cm} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim x MCTC}}{W}$$

$$\overline{BG} = \frac{126.1(1139.441)}{80838.1} = 1.777 \text{ m}$$

Final trim by stern, so COG is abaft COB
Final HG = 4.858 - 1.777 = 3.081 m fwd.

Let HG of cargo to be loaded be X m fwd.

Remarks	Weight	HG (m)	Moment abt H
Ship	77838.1	4.442 fwd	345757 fwd
Cargo	+3000	X fwd	3000X fwd
Final	80838.1		345757+3000X fwd

Final HG = final moment/final W = 3.081

$$\frac{345757+3000X}{80838.1} = 3.081, \quad X = -32.232 \text{ m fwd}$$

HG of cargo to be loaded = 32.232 m aft.

Note: HG of the cargo was intentionally assumed to be X m **fwd**, just to illustrate the meaning of the negative sign obtained at the end of the calculation.

Rough check by method A

$$\text{Mean sinkage} = \text{Ta or } \frac{w}{TPC} = \frac{\text{fwd length (dw)}}{L \times MCTC}$$

$$\frac{3000}{69.4} = \frac{(118-0.74)3000d}{236 \times 1123.296} \text{ or } d = 32.595 \text{ aft}$$

HG of cargo = 32.595 - 0.74 = 31.855 aft

Example 9C

M.v.VICTORY is alongside a loading berth with a conveyor chute loading into No:2 LH, HG 72 m fwd. The present drafts are

10 m fwd & 13 m aft. Find how much cargo to put in No:2 in order to bring the aft draft to 12 m. State the final draft fwd

Note: Because w is not given, the final W is not directly known and neither is the final hydraft given. Hence the final hydrostatic particulars are not readily available. Using the initial hydrostatic data, an approximate value of w is obtained by method A. This value is assumed to be loaded and the precise results calculated. Then minor changes are effected, as necessary, to obtain the precise quantity to load.

Fwd 10 m aft 13 m, trim 3 m by the stern
For mean draft 11.5 m, HF = 1.345 m fwd

$$\text{Corrctn} = \frac{HF}{L}(\text{trim}) = \frac{1.345(3)}{236} = 0.017 \text{ m}$$

Trim by stern & HF fwd so correction (-)
Initial hydraft =11.5 - 0.017 = 11.483 m

Draft	W (t)	MCTC	HB fwd	HF fwd
11.483	74266.1	1102.945	5.201	1.366

$$\text{Trim in cm} = \frac{W.\overline{BG}}{MCTC} \quad \text{or} \quad \overline{BG} = \frac{\text{trim x MCTC}}{W}$$

$$\overline{BG} = \frac{300(1102.945)}{74266.1} = 4.455 \text{ m}$$

Initial trim by stern:- COG is abaft COB
Initial HG = 5.201 - 4.455 = 0.746 m fwd

To find approximate w by method A:

Old draft + sinkage - Ta = new draft aft

$$1300 + \frac{w}{TPC} - \frac{AF(dw)}{L(MCTC)} = 1200$$

$$\frac{w}{69} - \frac{(118 + 1.366)(72 - 1.366)}{236 \times 1102.945}w = -100$$

w = 5587 tonnes (approximately).

Assuming that exactly 5587 t is loaded:-

Remarks	Weight	HG (m)	Moment abt H
Ship	74266.1	0.746 fwd	55403 fwd
Cargo	+5587	72 fwd	402264 fwd
Final	79853.1		457667 fwd

Final HG = 457667 ÷ 79853.1 = 5.731 fwd.

W (t)	draft	MCTC	HB fwd	HF fwd
79853.1	12.288	1134.433	4.909	0.437

Since COG is fwd of COB, trim is by head and final $\overline{BG}$ = 5.731 - 4.909 = 0.822 m.

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{79853.1 \times 0.822}{1134.433} = 57.9 \text{ cm.}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{(118 + 0.437)0.579}{236} = 0.291$$

Tf = Tc - Ta = 0.579 - 0.291 = 0.288 m

	Fwd	Aft
New hydraft	12.288 m	12.288 m
Tf or Ta	+0.288 m	-0.291 m
New drafts	12.576 m	11.997 m

Note: It is found that after loading 5587 t in No:2, the draft aft is calculated to be 11.997 m instead of 12.000 m. This is acceptable in practice because

(a) 0.003 m difference is not noticeable at the draft marks and
(b) the HG of cargo loaded cannot be made exactly 72 m fwd.

However, for the sake of theory, a minor adjustment, using the final hydrostatic data, would give an accurate result. To create a difference of 0.003 m in draft, method A will suffice.

Draft aft - mean rise + Ta = final draft

$$1199.7 - \frac{w}{TPC} + \frac{AF \times dw}{L(MCTC)} = 1200$$

$$-\frac{w}{69.63} + \frac{(118 - 0.437)(72 - 0.437)w}{236 \times 1134.433} = -0.3$$

w = 17.3 t to discharge.

Cargo to load = 5587 - 17.3 = 5569.7 t

Since 17.3 t is a very small quantity, the hydrostatic particulars would not change appreciably. So a simple calculation by method A would suffice to get the final draft fwd & also verify that the final draft aft is 12.000 m exactly.

$$\text{Mean rise} = \frac{w}{TPC} = \frac{17.3}{69.63} = 0.2 \text{ cm} = 0.002 \text{ m}$$

$$Tc = \frac{dw}{MCTC} = \frac{(72 - 0.437)\ 17.3}{1134.433} = 1.1 \text{ cm.}$$

$$Ta = \frac{AF}{L}(Tc) = \frac{(118+0.437)0.011}{236} = 0.005 \text{ m}$$

$$Tf = Tc - Ta = 0.011 - 0.005 = 0.006 \text{ m}$$

	Fwd	Aft
New draft	12.576 m	11.997 m
Mean rise	0.002 m	0.002 m
	12.574 m	11.995 m
Tf or Ta	-0.006 m	+0.005 m
Final drafts	12.568 m	12.000 m

Example 10C

M.v. Victory in FW draws 11.4 m fwd & 11 m aft. Find the final FW drafts if 8000t cargo is loaded in No:7 LH, HG 32 m aft.

Fwd 11.4 m aft 11 m, trim 0.4 m by head. For mean draft 11.2 m, HF = 1.172 m fwd.

$$\text{Corrn.} = \frac{HF(\text{trim})}{L} = \frac{1.172(0.4)}{236} = 0.003 \text{ m}$$

Trim by head & HF fwd so correction (+)
Initial hydraft =11.2 + 0.003 = 11.203 m

	Draft	W (t)	MCTC	HB fwd	HF fwd
SW	11.203	72335.7	1091.423	5.299	1.716
FW	11.203	70571.4	1064.803	5.299	1.716

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

$\overline{BG}$ = [40 x 1064.803] ÷ 70571.4 = 0.604 m

Initial trim by head:- COG is fwd of COB
Initial HG = 5.299 + 0.604 = 5.903 m fwd

Remarks	Weight	HG (m)	Moment abt H
Ship	70571.4	5.093 fwd	416583 fwd
Cargo	+8000	32 aft	256000 aft
Final	78571.4		160583 fwd

Final HG = 160583 ÷ 78571.4 = 2.044m fwd

	W (t)	draft	MCTC	HB fwd	HF fwd
SW	80535.7	12.386	1137.905	4.875	0.335
FW	78571.4	12.386	1110.151	4.875	0.335

Final COG is abaft COB so Tc is by stern and final $\bar{BG}$ = 4.875 - 2.044 = 2.831 m.

$$Tc = \frac{W.\bar{BG}}{MCTC} = \frac{78571.4 \times 2.831}{1110.151} = 200.4 \text{ cm.}$$

$$Ta = \frac{AF(Tc)}{L} = \frac{(118+0.335)2.004}{236} = 1.005 \text{ m}$$

Tf = Tc - Ta = 2.004 - 1.005 = 0.999 m

	Fwd	Aft
Final hydraft	12.386 m	12.386 m
Tf or Ta	-0.999 m	+1.005 m
Final drafts	11.387 m	13.391 m

Example 11C

M.v.Victory is in DW of RD 1.012 drawing 13 m fwd and 13.6 m aft. Find the final drafts fwd & aft in the same dock if the following operations are carried out:

5000 t cargo loaded in No:4, HG 30 m fwd
1000 t HFO received in No:5, HG 60 m aft
500 t SW transferred from the FP tank HG 110 m fwd, to the AP tank, HG 114 m aft.

Fwd 13 m aft 13.6 m, trim 0.6 m by stern
For mean draft 13.3 m, HF = 0.55 m aft.

$$\text{Corrctn} = \frac{HF(trim)}{L} = \frac{0.55(0.6)}{236} = 0.001 \text{ m}$$

Trim by stern & HF aft so correction (+)
Initial hydraft =13.3 + 0.001 = 13.301 m

	Draft	W (t)	MCTC	HB fwd
SW	13.301	86958.6	1169.083	4.500
DW	13.301	85855.7	1154.255	4.500

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

BG = [60 x 1154.255] ÷ 85855.7 = 0.807 m

Initial trim by stern:- COG is abaft COB
Initial HG = 4.500 - 0.807 = 3.693 m fwd

Remarks	Weight	HG (m)	Moment abt H
Ship	85855.7	3.693 fwd	317065 fwd
Cargo	+5000	30 fwd	15000 fwd
HFO	+1000	60 m aft	60000 aft
SW transferred	500 x 224 aft		112000 aft
Final	91855.7		160065 fwd

Final HG = 160065 ÷ 91855.7 = 1.743m fwd

	W (t)	draft	MCTC	HB fwd	HF aft
SW	93035.7	14.159	1196.162	4.146	1.260
DW	91855.7	14.159	1180.991	4.146	1.260

Final COG is abaft COB so Tc is by stern and final $\overline{BG}$ = 4.146 - 1.743 = 2.403 m.

$$Tc = \frac{W.\overline{BG}}{MCTC} = \frac{91855.7 \times 2.403}{1180.991} = 186.9 \text{ cm.}$$

$$Ta = \frac{AF}{L}(Tc) = \frac{(118-1.260)1.869}{236} = 0.925 \text{ m}$$

Tf = Tc - Ta = 1.869 - 0.925 = 0.944 m

	Fwd	Aft
Final hydraft	14.159 m	14.159 m
Tf or Ta	-0.944 m	+0.925 m
Final drafts	13.215 m	15.084 m

Exercise 24
Trim problems, type C

1 M.v.VICTORY draws 12.5 m fwd & 14.5 m aft in SW. Find the new drafts fwd & aft if 500 t ballast is transferred from the AP tank, HG 114 m aft, to the FP tank, HG 110 m fwd.

2 M.v.VICTORY draws 13.8 m fwd and 16 m aft in DW of RD 1.010. Find the new drafts if 1500 t HFO is shifted from No:5 hopper tank, HG 58 m aft, to the fwd deep tank, HG 104 m fwd.

3 M.v.VICTORY is in SW, drawing 12.2 m fwd & 14.6 m aft. HG is 1.248 m fwd. Find the drafts fwd and aft if 4820 t cargo is loaded in No:3, HG 52 m fwd.

4 M.v.VICTORY draws 13.7 m fwd and 13 m aft in SW. HG is 5.42 m fwd. Find the drafts after the following:-
8000 t disch from No:3 LH HG 52 m fwd
5000 t disch from No:5 LH HG 10 m fwd
2000 t disch from No:9 LH HG 72 m aft
1000 t SW taken into FPT HG 110 m fwd

5 The drafts of m.v. VICTORY in SW are 11 m fwd & 11.5 m aft. HG of ship is 4.531 m fwd. Find the new drafts fwd and aft after loading the following:
6000 t in No:2 hold, HG 72 m fwd
5000 t in No:4 hold, HG 30 m fwd
5000 t in No:6 hold, HG 10 m aft
10000 t in No:8 hold, HG 52 m aft.

6 M.v. VICTORY is in SW drawing 11.45 m fwd & aft. Find the drafts if 11000 t cargo is loaded in No:6, HG 10 m aft.

7 The drafts of m.v. VICTORY are 13 m & 14.8 m fwd & aft in SW. Find the new drafts if 9500 t cargo is discharged from No:7 hold, HG 32 m aft.

8 M.v.VICTORY arrives port drawing 12 m fwd & 12.4 m aft in SW. Find the new drafts if 4200 t cargo is discharged from No:3 hold, HG 52 m fwd.

9 M.v.VICTORY draws 13 m fwd & 14 m aft in SW. 7000 t is yet to be loaded. Conveyors are ready to load in No:3, HG 52 m fwd, & in No:7, HG 32 m aft. Find how much ore to load in each of these two holds to finish with a trim of 0.40 m by the stern. State the final drafts fwd and aft.

10 M.v. VICTORY is in FW, drawing 14.8 m fwd & 14 m aft. 6000 t of cargo is to be discharged, part from No:3 HG 52 m fwd and part from No:8 HG 52 m aft. Calculate the quantities to discharge & the final FW drafts if the trim on completion is to be 1 m by the stern.

11 The drafts of m.v. VICTORY in SW are 12 m fwd & 13.2 m aft. How much cargo may be put in No:1 hold, HG 92 m fwd, and in No:9 hold, HG 72 m aft, in order to complete loading on an even keel draft of 14.8 m?

12 M.v. VICTORY is in DW RD 1.012 at an even keel draft of 14.6 m. How much cargo may be discharged from No:3 LH, HG 52 m fwd, & from No:7 HG 31 m aft, in order to finish at 13.6 m draft, even keel, in the same dock?

13 M.v. VICTORY is in SW drawing 11.1 m fwd and 13.6 m aft. At what location may 1000 t of cargo be loaded if the draft aft is to remain at 13.6 m? State the final draft fwd.

14 M.v.VICTORY is in DW RD 1.018 drawing 12.5 m fwd and 11.9 m aft. Where may 4000 t cargo be loaded if the draft fwd is to remain at 12.5 m? State the final draft aft.

15 M.v.VICTORY is in FW at 12.9 m draft, even keel. Find the location from which 3000 t cargo may be discharged in order to finish with 12.9 m draft aft. State the final draft fwd.

16 M.v.VICTORY is in DW RD 1.010 drawing 12.4 m fwd and 12.6 m aft. Find where 2800 t may be loaded if the ship is to sail with 12.4 m draft fwd. State the final draft aft.

17 M.v. VICTORY is in SW with drafts of 11.8 m fwd & 12 m aft. How much cargo may be loaded into No:7, HG 32 m aft, in order to finish at 13 m draft aft? State the final draft fwd.

18 M.v.VICTORY is afloat in DW RD 1.017 at drafts of 13.7 m fwd and 14 m aft. How much ore is to be discharged from No:2, HG 72 m fwd, if the final draft fwd is to be 12 m? What would be the final draft aft?

19 M.v. VICTORY arrives at a SW port at 14.6 m even keel. Cargo is to be discharged in stream to lighten the ship

sufficiently to enter the docks at an even keel draft of 11.6 m. The master decides to discharge 4500 t of cargo from each of hold Nos:3 (HG 52 m fwd) 5 (HG 10 m fwd) and 7 (HG 31 m aft). Find the quantities to discharge from Nos:1 (HG 92 m fwd) & 9 (HG 72 m aft)

20 M.v.VICTORY arrives in DW of RD 1.009 drawing 14.6 m fwd & 14.8 m aft. Ore is to be discharged as follows:

6000 t from No:4, HG 30 m fwd,
8000 t from No:6, HG 10 m aft.

A further 6000 t is to be discharged, part from No:2 (HG 72 m fwd) and part from No:8 (HG 52 m aft). Find how much to discharge from each of these two spaces if the final trim is to be one metre by the stern. State the final DW drafts fwd and aft.

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CHAPTER 29

COMBINED

LIST AND TRIM

Sometimes, it may become necessary to cause a change of both, list and trim, by shifting fuel oil, FW, SW ballast or, as a last resort, by shifting cargo. In such cases, the problem could be split into two parts and each part may then be calculated separately, and in any order. In this book, change of list has been tackled first and then, change of trim. Having studied the earlier chapters on list and trim, the student should find the calculations here, quite simple.

Example 1

A ship of W 8000 t, KM 8 m, KG 7.2 m and MCTC 150 tm, is listed 6° to port and trimmed 0.2 m by the head. It is desired to bring the ship upright & trimmed 1 m by the stern by shifting heavy fuel oil between No:2 DB tanks port and starboard and No:6 DB tanks port & starboard. The COG of each tank is 8 m off the centre line of the ship. The distance between the centres of Nos:2 & 6 tanks is 80 m. No:2 DBT port and starboard have 300 t HFO each while No:6 DBT port & starboard are empty. Find how much transfer of HFO should take place between the tanks and the final distribution.
(Neglect free surface correction).

To correct list

$\tan\theta = \text{ILM} \div \text{W.GM}$ or $\text{ILM} = \text{W.GM.}\tan\theta$

ILM = 8000(0.8)tan 6° = 672.667 tm port.

To upright the vessel it is necessary to cause LM of similar value to starboard.

dw = 672.667 or w = 672.667 ÷ 16 = 42 t.

Required to shift 42 t HFO to starboard.

To change trim

Present: 0.2 m by head. Desired: 1 m by stern. So Tc = 1.2 m = 120 cm by stern.

$$Tc = \frac{dw}{MCTC} \quad \text{or} \quad w = \frac{MCTC(Tc)}{d}$$

w = 150(120) ÷ 80 = 225 t HFO to go aft.

Distribution in tonnes
Initial: 2P 300, 2S 300, 6P Nil, 6S Nil.
Final : 2P 75, 2S 300, 6P 183, 6S 42.

Example 2

M.v.VIJAY, in SW drawing 4 m fwd & 6.6 m aft, is listed 7° to port. KG = 8 m. How much HFO must be transferred between tank Nos:2 P & S and 7 P & S to bring the ship upright and trimmed 1.2 m by the stern? The COG of the tanks are transversely 11 m apart & longitudinally 92 m. (Neglect free surface correction.)

Fwd 4 m, aft 6.6 m, trim 2.6 m by stern. Mean draft 5.3 m for which AF = 71.800 m

$$Corr = \frac{AF}{L}(trim) = \frac{71.800(2.6)}{140} = 1.333 \text{ m}$$

Initial hydraft = 6.6 - 1.333 = 5.267 m.

Draft	W (t)	MCTC tm	KMT m
5.267	10481.7	167.569	8.530

To correct list

$\tan \theta = ILM \div W.GM$ or $ILM = W.GM.\tan \theta$

$ILM = 10481.7\ (0.53) \tan 7° = 682.105$ tm

To upright the vessel it is necessary to cause LM of similar value to starboard.

$dw = 682.105$ or $w = 682.105 \div 11 = 62$ t.

Required to shift 62 t HFO to starboard.

To change trim

Present: 2.6 m by stern. Desired: 1.2 m by stern. So Tc = 1.4 m = 140 cm by head

$$Tc = \frac{dw}{MCTC} \text{ or } w = \frac{MCTC(Tc)}{d} = \frac{167.569(140)}{92}$$

Required to shift 255 t HFO aft to fwd.

Example 3

M.v. VICTORY is in DW, RD 1.015, drawing 12 m fwd & 14 m aft. KG is 12.6 m. The ship is listed 5° to starboard. Find how much oil transfer is required between the following tanks to bring the ship upright and trimmed 1 m by the stern: No:2 P and S (HG 61 m fwd) and No:5 P and S (HG 59 m aft). The COG of each tank is 16 m off the centre line of the ship. (Neglect free surface correction.)

Fwd 12 m, aft 14 m, trim 2 m by stern. For mean draft 13.0 m, HF = 0.270 m aft.

$$\text{Corr} = \frac{HF}{L} \times \text{trim} = \frac{0.270 \times 2}{236} = 0.002 \text{ m}$$

Hydraft = 13 + 0.002 = 13.002 m.

	Draft	W (t)	MCTC tm	KMT m
SW	13.002	84853.1	1159.167	13.180
DW	13.002	84025.2	1147.858	13.180

GM = 13.180 - 12.600 = 0.580 metre.

To correct list

$\tan\theta = ILM \div W.GM$ or $ILM = W.GM.\tan\theta$

ILM = 84025.2 (0.58) tan 5° = 4263.7 tm.

To upright the vessel it is necessary to cause LM of similar value to port.

dw = 4263.7 or w = 4263.7 ÷ 32 = 133.2 t

Required to shift 133.2 t HFO to port.

To change trim

Present: 2.0 m by stern. Desired: 1.0 m by stern. So Tc = 1.0 m = 100 cm by head

$$Tc = \frac{dw}{MCTC} \text{ or } w = \frac{MCTC(Tc)}{d} = \frac{100(1147.858)}{120}$$

Required to shift 956.5 t HFO forwards.

Exercise 25
Combined list & trim

1 A ship of W 15000 t, KM 9 m, KG 8 m, MCTC 200 tm, is listed 6° to port and trimmed 3 m by the stern. What oil transfer must take place between Nos:3 P & S and Nos:8 P & S to bring the V/L upright & trimmed 2 m by the stern? The COG of the tanks are transversely 10 m apart and longitudinally, 100 m. (Neglect free surface correction.)

2 A tanker of W 50000 t, MCTC 650 tm, KM 11 m, KG 10.1 m, is listed 7° to port and trimmed 5 m by the stern. Find the transfer of oil that must take place between Nos:10 P & S and Nos:2 P & S to bring the ship upright and trimmed 3 m by the stern. The COG of the tanks are transversely 14 m apart and longitudinally 140 m apart. (Neglect FSC.)

3 M.v.VIJAY is upright in SW drawing 5.6 m fwd & 6.8 m aft. KG 7.16 m. Find how much oil transfer must take place between Nos:2 P & S and Nos:7 P & S, in order to list the ship 5° to port and bring her on an even keel. The COG of the tanks are transversely 10 m apart and longitudinally, 90 m. (Neglect free surface correction.)

4 M.v.VICTORY is in DW RD 1.009, drawing 13.6 m fwd & 12.6 m aft. KG 12.647 m. The ship is listed 8° to starboard. Find the oil transfer to be made between the following tanks to bring the ship upright and trimmed 0.5 m by the stern: Nos:2 P & S (HG 61 m fwd) &

Nos:5 P & S (HG 59 m aft). The COG of each tank is 16 m off the centre line. (Neglect free surface correction.)

5 M.v. VIJAY is in DW, RD 1.017, drawing 7 m fwd & 6 m aft, listing 5° to port. KG is 7.4 m. How much FW must be transferred between the peak tanks (COG 132 m apart) and HFO between Nos: 2 P and S (COG 10 m apart) to upright the ship and trim her one metre by the stern? (Ignore FSC.)

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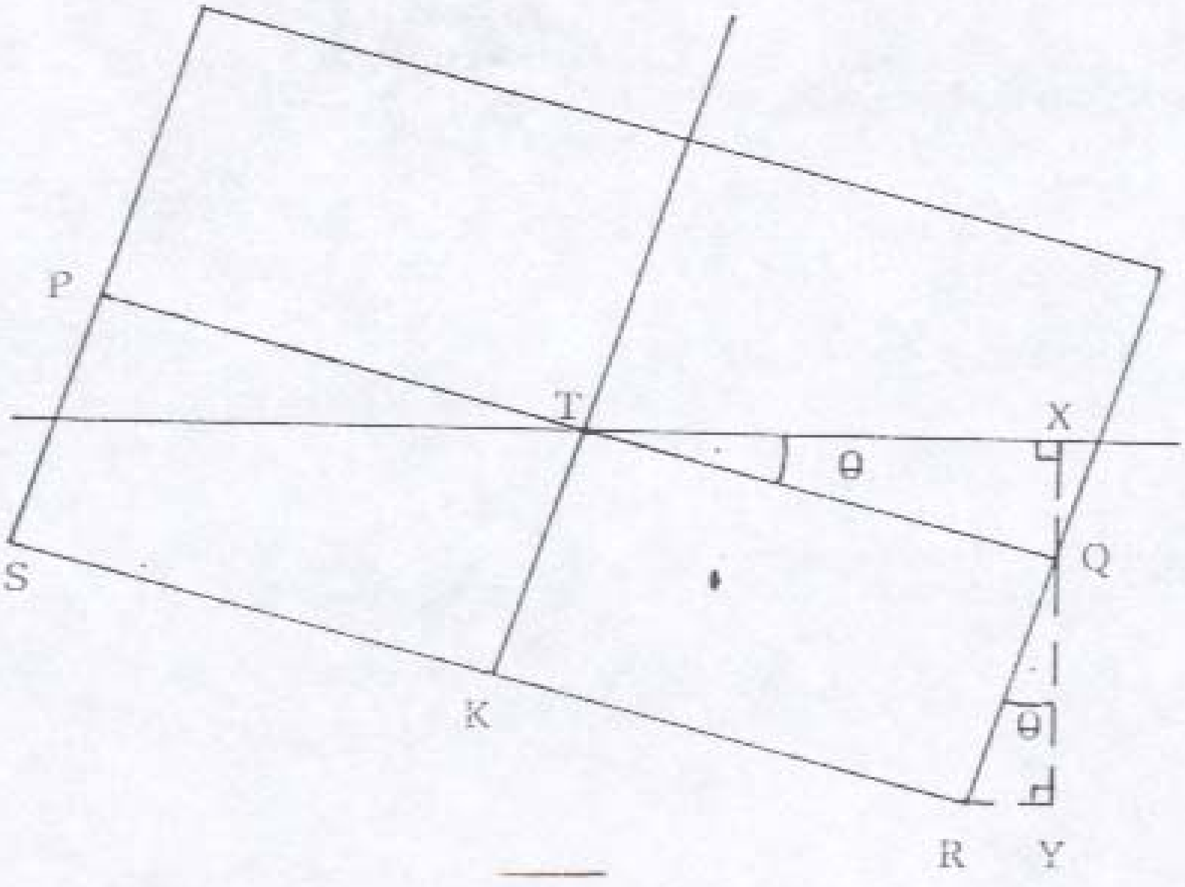
CHAPTER 30

DRAFT INCREASE

DUE TO LIST

Draft is the depth of the lowest part of the ship below the waterline. When the vessel lists, the draft increases. Calculation of this increase can be done by simple trigonometry.

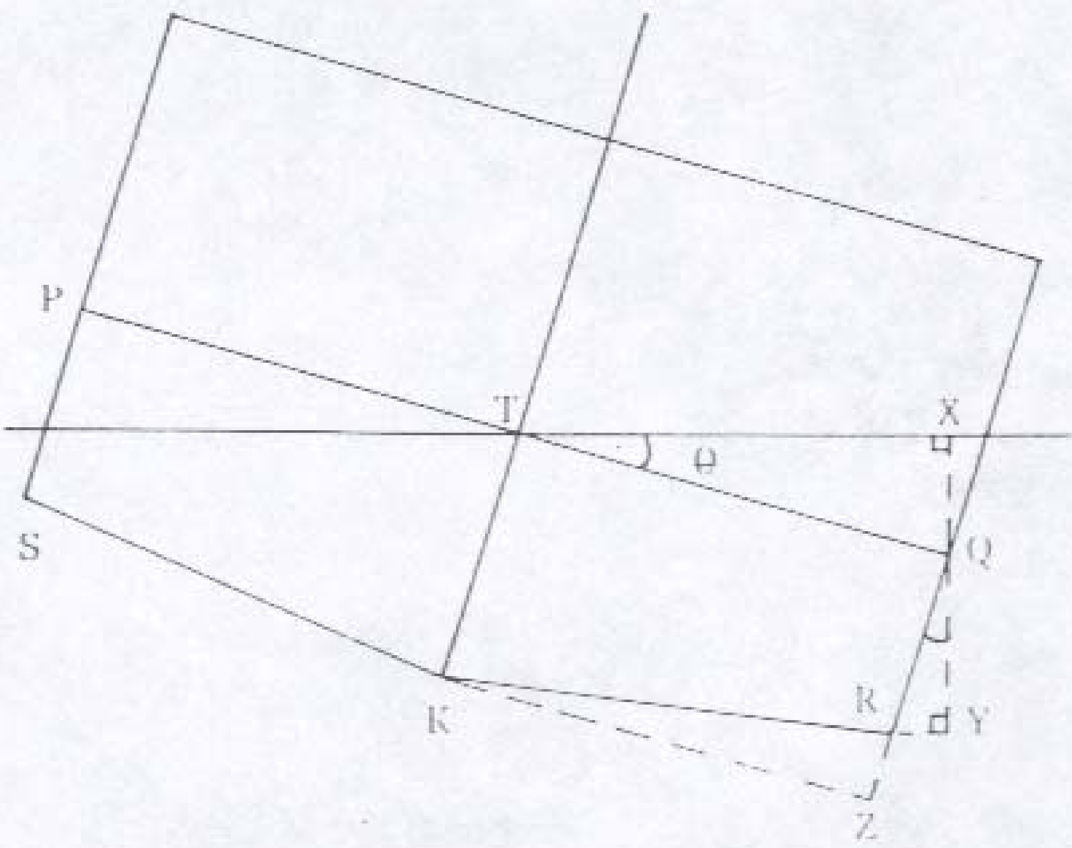
Box-shaped vessel



New d = XY = XQ+QY = TQ Sin θ + QR Cos θ
= ½beam Sin θ + old draft Cos θ

Ship-shapes

The midship section of a ship resembles that of a box-shaped vessel except that the ship usually has a rise of floor. Rise of floor is the vertical distance between the keel and the bilge when the ship is upright. When pumping out a tank rise of floor helps drain the liquid towards the suction pipe which is situated near the centre line of the ship.



New d = XY = XQ+QY = TQ Sin θ + QR Cos θ
= TQ Sin θ + (QZ − RZ) Cos θ

New d = $\frac{1}{2}$beam Sin θ + (old d − R) Cos θ
(where R = rise of floor of ship).

Note: Where there is no rise of floor, zero may be substituted in the foregoing formula which then becomes the same as the earlier formula.

Example 1

A box-shaped vessel 10 m broad floats upright & on an even keel draft of 6 m. Find the increase in draft if the vessel lists 15°.

New draft = ($\frac{1}{2}$beam Sin θ) + old d.Cos θ

= $\frac{1}{2}$ x 10 Sin 15° + 6 Cos 15° = 7.09 m

Increase of draft = 7.09 - 6.0 = 1.090 m

Example 2

A ship, 18 m broad at the waterline, is upright & floats at 8 m draft even keel. Rise of floor is 0.310 m. Find the new draft if the ship lists 12°.

New d = $\frac{1}{2}$beam Sin θ + (old d - R) Cos θ

= $\frac{1}{2}$(18Sin 12°) + (8 - 0.31)Cos 12°

= 9.393 metres.

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Exercise 26

Draft increase due to list

1 A box shaped vessel, 100 x 20 x 8 m, floats upright at 5 m draft. Find the new draft if the vessel lists 16°.

2 A ship, 32 m broad at the waterline, is upright and draws 12.3 m. The rise of floor is 0.34 m. Find the new draft at 15° list.

3 A box-shaped vessel, 27 m broad, is upright at 9.00 m draft, in DW of RD 1.016. Find the increase in draft when listed 12°.

4 A ship 18 m broad is upright and draws 8.6 m in FW. The rise of floor is 0.15 m. Find the new draft when listed 18°.

5 A flat bottomed barge is 12 m broad at the waterline and is upright. The draft is 5 m in SW. Find the increase in draft when listed 13°.

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CHAPTER 31

DRYDOCKING

AND GROUNDING

When a ship enters a graving type dry dock, she should be in stable equilibrium, upright and trimmed slightly by the stern. As far as possible, all tanks should be either empty or pressed up so as to reduce FSE to the barest minimum possible under the circumstances.

When the gate is closed and pumping out commences, the water level in the dock will drop gradually. Side shores consisting of large baulks of timber will be positioned loosely between the ship's sides and the sides of the dock, by shore personnel, at intervals of about five metres.

As the lower end of the stern frame nears the blocks, the rate of pumping will be reduced suitably while the ship is correctly positioned and aligned over the keel blocks. After the stern takes to the blocks, pumping out is continued. As the forward end near the blocks, the side shores are wedged up tight, working from the after end towards forward, so that, by the time the bow also takes to the blocks, all the side shores would be tight thereby aligning the ship correctly over the keel blocks and preventing her from capsizing.

Until the stern has taken to the blocks, the ship is floating freely. Whatever trim, GM, etc. that she had while entering the dock will be unaffected until the stern touches the keel blocks. After the stern has taken to the blocks, part of the weight of the ship gets transferred to the blocks, say 'P' tonnes. This is equivalent to the discharge of weight from the location of the stern frame - both KG and AG of the discharged weight are zero metres. This results in:

(a) Decrease in the hydraft of the ship.
(b) Decrease in the trim by the stern.
(c) Virtual rise of COG of the ship and consequent virtual loss of GM.

The value of 'P' at the stern frame increases as the water level drops, until the bow also takes to the blocks. Thereafter, P acts along the entire keel and not only at the stern frame.

The interval, from the instant the stern takes to the blocks till the instant the bow also takes to the blocks, is called the critical period. This is because, during this period, the ship suffers steadily increasing virtual loss of GM, without the benefit of the side shores. The most dangerous time is at the end of the critical period, called the critical instant, when P, acting at the stern frame only, is maximum while the side shores are all not yet wedged tight.

Calculation of P

(1) During the critical period:
During the critical period, the force P

acts only at the after perpendicular of the ship. So its distance from the COF is the AF of the ship.

$$\text{Trim (cm)} = \frac{TM}{MCTC} = \frac{P.AF}{MCTC} \quad \text{or} \quad P = \frac{\text{trim} \times MCTC}{AF}$$

(2) After the critical period:
After the ship has taken to the blocks at both ends, further drop in the level of water would cause further transfer of weight to the keel blocks but this would act all along the ship's length and not only at the stern frame. This increase of P, after the critical period, may be calculated by multiplying the drop in water level after the critical period by the TPC. The results obtained by this method are approximate as TPC of a ship is not constant but changes with draft.

(3) At any time:
Obtain the ship's displacement while entering the drydock - W1. At any time during the drydocking process, whether during the critical period or afterwards, obtain the hydraft and thence the displacement - W2. Then, at that time, P = W1 - W2 tonnes. The results obtained by this method are fairly accurate.

Virtual loss of GM

The virtual loss of GM, at any time during the process of drydocking, may be calculated by either of two formulae:

Formula................. A...or... B

$$\text{Virtual loss of GM (in metres)} = \frac{P.KG}{W - P} \qquad \frac{P.KM}{W}$$

In both these formulae, the values of W and Ft. are those that the ship had while entering the drydock. Whenever sufficient data is available, the KM used should be that for the reduced displacement, (W - P). If sufficient data is not available, then the value of KM in formula B may be taken to be that with which the ship entered the drydock. Both formulae give fairly close results.

Formula A assumes that P is a transfer of weight to the keel blocks equivalent to the discharge of weight from the keel resulting in a virtual increase of KG. It is derived from the $GG_1\uparrow$ formula.

Formula B assumes that P is a transfer of buoyancy to the keel blocks resulting in a decrease of KM while the weight and KG remain constant.

While calculating the moment of statical stability (righting moment), at small angles of inclination during the drydocking process, by multiplying by GM.Sin θ, the displacement used after formula A should be (W - P) and after formula B, the original W. The GM used in both cases should be the virtual GM.

The virtual loss of GM, as calculated by the foregoing formulae, is approximate only. Therefore, the only practical solution, available to the Master/Chief Officer, is to ensure that the residual virtual GM at the critical instant, arrived at by using these formulae, is sufficiently large to accommodate the possible inaccuracy.

The calculation need only be done using either formula A or formula B. For illustration purposes, each example has been worked twice in this book, once with formula A and again with formula B.

Free surface correction

During the critical period FSC increases and may be calculated by the formula: FSC = FSM ÷ (W – P), where FSM is in tm.

Once the ship is wedged up tight in drydock, without any possibility of roll, FSE ceases to exist. Hence, after the critical period is over, FSE may be ignored. However, if the ship is aground she may roll due to wave action even though she may be sitting overall on the sea-bed. In such a case, FSE cannot be ignored - FSC must be applied.

Example 1

M.v. VIJAY enters a SW drydock drawing 3 m fwd & 5.2 m aft. KG 9 m, FSM 1200 tm. Calculate the virtual GM & the moment of statical stability at 0.5° heel, when she is just about to take to blocks fwd.

Fwd 3.0 m aft 5.2 m, trim 2.2 m by stern
Mean draft 4.1 m for which AF = 72.113 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{72.113(2.2)}{140} = 1.133 \text{ m}$$

Initial hydraft = 5.20 – 1.133 = 4.067 m

Draft	W (t)	MCTC tm	AF (m)
4.067	7853.1	158.403	72.118

To find P & GM at critical instant:

$$\text{Trim (cm)} = \frac{TM}{MCTC} = \frac{P.AF}{MCTC} \quad \text{or} \quad P = \frac{\text{trim} \times MCTC}{AF}$$

P = 220(158.403) ÷ 72.118 = 483.2 tonnes

(W - P) = 7853.1 - 483.2 = 7369.9 t,
for which KM from hydro. table = 9.887 m

GM = KM - KG = 9.887 - 9.000 = 0.887 m
FSC = FSM/(W - P)=1200/7369.9 = 0.163 m
GM fluid .... = 0.724 m

	Formula A		Formula B
Virtual loss of GM =	$\frac{P.KG}{W - P}$		$\frac{P.KM}{W}$
	= $\frac{483.2(9)}{7369.9}$	or	$\frac{483.2(9.887)}{7853.1}$

Virtual loss of GM = 0.590 m or 0.608 m.
GM fluid .... = 0.724 m 0.724 m.
Virtual GM .... = 0.134 m or 0.116 m.

	Formula A		Formula B
RM @ 0.5° =	(W - P)GM.Sin θ	or	W.GM.Sin θ
	= 8.618 tm	or	7.950 tm

Example 2

M.v.VIJAY has W = 7277 t in SW, KG = 9.1 m. Find the maximum trim with which she may enter drydock, if the virtual GM at the critical instant is to be not less than 0.[illegible] metre.

W (t)	MCTC tm	AF (m)	KM (m)
7277	156.0	72.141	9.950

Initial GM solid = 9.95 - 9.10 = 0.850 m
Minimum desired virtual GM = 0.250 m
Permitted virtual loss of GM = 0.600 m

$$\text{Virtual loss of GM} = \underset{\text{Formula A}}{\frac{P.KG}{W - P}} \quad \text{or} \quad \underset{\text{Formula B}}{\frac{P.KM}{W}}$$

$$0.6 = \frac{P\,(9.1)}{W - P} \quad \text{or} \quad \frac{P\,(9.95)}{7277}$$

Maximum P = 450.1 t or 438.8 t.

$$\text{Maximum trim} = \frac{P.AF}{MCTC} \quad \text{or} \quad \frac{P.AF}{MCTC}$$

$$= \frac{450.1(72.141)}{156} \quad \text{or} \quad \frac{438.8(72.141)}{156}$$

Maximum trim = 208.1 cm or 202.9 cm.

Note: Due to the nature of the problem, the value of P is available only towards the end of the calculation. Hence the KM used is for the original displacement (W) not for the reduced displacement (W - P). In reality, the KM for (W - P) would be more than the KM used above and hence the maximum safe trim would be more than the value calculated above. The error is thus on the safer side.

Example 3

M.v.VIJAY is at anchor drawing 4.9 m fwd & 6.7 m aft in SW. KG 7 m, FSM 1100 tm. During low water, the depth of water around the ship is expected to drop to 5.5 m. Assuming that the sea-bed is horizontal, find the virtual GM at LW.

Fwd 4.9 m aft 6.7 m, trim 1.8 m by stern
Mean draft 5.8 m for which AF = 71.586 m

$$\text{Corr} = \frac{AF \times \text{trim}}{L} = \frac{71.586(1.8)}{140} = 0.920 \text{ m}$$

Initial hydraft = 6.70 - 0.920 = 5.780 m

Note: An interesting case develops here. At LW, when the depth of water becomes 5.5 m, if the ship is sitting overall on the sea-bed, then the hydraft of the ship would be 5.5 m, for which the displacement (W - P), and KM, can be obtained from the hydrostatic table. On the other hand, if at LW the ship is not sitting overall on the sea-bed, the aft draft would have reduced from 6.7 m to 5.5 m as a result of mean rise and the after proportion of trim (Ta). In such a case, the hydraft at LW would be <5.5 m. The correct situation can be assessed by a simple calculation.

Draft	W (t)	MCTC tm	AF (m)
5.780	11627.1	171.160	71.595

To sit overall, P = (trim x MCTC) ÷ AF

= 180(171.16) ÷ 71.595 = 430.3 t

(W - P) = (11627.1 - 430.3) = 11196.8 t, for which hydraft as per table = 5.588 m

The hydraft when sitting overall on the sea-bed will be 5.588 m. In other words, the depth of water at which the ship would sit overall on the sea-bed is 5.588 m. The depth at LW is 5.5 m. So at LW, the ship is sitting overall and the hydraft then is 5.5 m, for which the displacement = 11000 t and KM = 8.417 m.

At LW, P = 11627.1 - 11000 = 627.1 t
GM solid = 8.417 - 7.0 = 1.417 m
FSC = FSM ÷ (W - P) = 0.100 m
GM fluid .... = 1.317 m

$$\text{Virtual loss of GM} = \underset{\text{Formula A}}{\frac{P.KG}{W - P}} \qquad \underset{\text{Formula B}}{\frac{P.KM}{W}}$$

$$= \frac{627.1(7)}{11000} \text{ or } \frac{627.1(8.417)}{11627.1}$$

Virtual loss of GM = 0.399 m or 0.454 m.
GM fluid .... = 1.317 m   1.317 m.
Virtual GM .... = 0.918 m or 0.863 m.

Example 4

M.v. VIJAY enters a SW drydock drawing 3.6 m fwd and 5.8 m aft. KG 8.2 m, FSM 1000 tm. Find the virtual GM when the water level has dropped by 1 m after the stern has taken to the blocks.

Fwd 3.6 m aft 5.8 m, trim 2.2 m by stern
Mean draft 4.7 m for which AF = 71.992 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.992(2.2)}{140} = 1.131 \text{ m}$$

Initial hydraft = 5.80 - 1.131 = 4.669 m

Note: When the stern takes to the blocks the depth of water above the blocks will be 5.8 m. After a fall of 1 m in level, if the ship is sitting overall on the blocks, the hydraft will be 4.8 m. If, however, after the 1 m drop in level, the bow is still afloat, the hydraft will be <4.8 m. The actual situation can be ascertained by a simple calculation.

Draft	W (t)	TPC t	MCTC tm	AF (m)
4.669	9164.1	21.918	163.252	71.998

To sit overall, P = (trim x MCTC) ÷ AF

= 220(163.252) ÷ 71.998 = 498.8 t

(W - P) = (9164.1 - 498.8) = 8665.3 t, for which hydraft as per table = 4.441 m

The depth of water above the blocks, at the given time, is 4.8 m. Therefore, the ship is still in the critical period. The draft aft has reduced from 5.8 m to 4.8 m as a result of mean rise and the after proportion of trim (Ta).

Decrease of draft aft = mean rise + Ta

$$100 = \frac{P}{TPC} + \frac{AF \times Tc}{L}$$

$$100 = \frac{P}{21.918} + \frac{P(71.998)}{163.252}\,\frac{(71.998)}{(140)}$$

P = 367.1 t. (W - P) = 8797 t for which, from the hydrostatic table, KM = 9.086 m

GM solid = 9.086 - 8.200 ..... = 0.886 m
FSC = FSM ÷ (W - P) .... = 0.114 m
GM fluid at required time ..... = 0.772 m

	Formula A	Formula B
Virtual loss of GM =	$\frac{P.KG}{W - P}$	$\frac{P.KM}{W}$

$$= \frac{367.1(8.2)}{8797} \text{ or } \frac{367.1(9.086)}{9164.1}$$

Virtual loss of GM = 0.342 m or 0.364 m.
GM fluid .... = 0.772 m 0.772 m.
Virtual GM .... = 0.430 m or 0.408 m.

Example 5

M.v.VIJAY has W = 6849 t in SW, KG = 9.6 m, FSM = 900 tm. Find the maximum trim with which she may enter a drydock, if the GM at the critical instant is to be not less than 0.3 metre.

Note: This example is similar to example 2 but for one difference. Here, FSM has been given and has to be allowed for in the calculation.

W t	Draft	TPC t	MCTC	AF (m)	KM (m)
6849	3.60	21.36	154.1	72.141	10.274

Initial GM = 10.274 - 9.600 = 0.674 m
Virtual GM @ critical instant = 0.300 m
Permitted total loss of GM = 0.374 m

Total loss of GM = FSC + loss due to P

Therefore $0.374 = \frac{FSM}{W - P}$ + drydocking loss

By formula A: $0.374 = \frac{900}{6849-P} + \frac{P.KG}{W - P}$

$0.374 = \frac{900}{6849-P} + \frac{P(9.6)}{6849-P}$ so **P = 166.6 t**

Trim = 166.6(72.141) ÷ 154.1 = **78.0 cm**

By formula B: $0.374 = \frac{900}{6849-P} + \frac{P.KM}{W}$

$0.374 = \frac{900}{6849-P} + \frac{P(10.274)}{6849}$ so **P = 159.6 t**

Trim = 159.6(72.141) ÷ 154.1 = **74.7 cm**

Example 6

While drawing 3 m fwd and 7 m aft in SW, m.v. VIJAY runs aground lightly on a sandy coast. External soundings indicate that the depth of water near the after perpendicular is 2 m greater than near the fwd perpendicular. If KG is 8.1 m & FSM is 1200 tm, find (a) the drop in water level at which the ship would sit overall on the sea-bed; (b) the virtual GM when the ship sits overall on the sea-bed; (c) The drop in water level at which the ship would become unstable.

Note: When sitting overall on the sea-bed, the trim would be 2 m by the stern.

Fwd 3.0 m aft 7.0 m, trim 4.0 m by stern
Mean draft 5.0 m for which AF = 71.913 m

Corr = $\frac{AF}{L}$ x trim = $\frac{71.913(4.0)}{140}$ = 2.055 m

Initial hydraft = 7.00 - 2.055 = 4.945 m

Draft	W (t)	MCTC tm	AF (m)	KM (m)
4.945	9770.0	165.315	71.929	8.725

Initial trim 4 m by stern. Final trim 2 m by the stern. So Tc = 2 m by the head.

Tc = P.AF/MCTC or P = Tc (MCTC)/AF

P = 200(165.315) ÷ 71.929 = 459.7 tonnes

(W - P)	Draft	AF m	KM m
9310.3	4.736	71.984	8.881

Hydraft when sitting overall = 4.736 m
& trim = 2 m by the stern. Draft aft = ?

Ta = AF(Tc)/L = 71.984(2)/140 = 1.028 m.
Draft aft = 4.736 + 1.028 = 5.764 metres

Draft aft when sitting overall = 5.764 m
Draft aft when aground lightly = 7.000 m
Drop to sit overall = ans (a) = 1.236 m

Tabular verification of above:-

	Draft of ship aft (m)	fwd	Depth of water aft (m)	fwd
Initial:	7.000	3.000	7.000	5.000
Final :	5.764	3.764	5.764	3.764
Remarks:	Final trim by stern = 2 m		Rise of bottom 2m at fwd end.	

New GM solid = 8.881 - 8.100 = 0.781 m
FSC = FSM/(W-P) = 1200/9310.30 = 0.129 m
Fluid GM when sitting overall = 0.652 m

Virtual loss of GM = Formula A $\frac{P.KG}{W - P}$ Formula B $\frac{P.KM}{W}$

$$= \frac{459.7(8.1)}{9310.3} \text{ or } \frac{459.7(8.881)}{9770}$$

Virtual loss of GM = 0.400 m or 0.418 m.
GM fluid .... = 0.652 m 0.652 m.
Virtual GM **ans (b) = 0.252 m or 0.234 m.**

Initial GM = Initial KM - KG = 0.625 m, the loss of which will result in zero GM

Total loss of GM = FSC + loss due to P

Therefore $0.625 = \frac{FSM}{W - P}$ + drydocking loss

By formula A: $0.625 = \frac{1200}{9770-P} + \frac{P.KG}{W - P}$

$0.625 = \frac{1200}{9770-P} + \frac{P(8.1)}{9770-P}$ so P = 562.3 t

GM will be 0 when disp = W-P = 9207.7 t.

W (t)	Draft	AF (m)
9207.7	4.689	71.994

Ta = AF(Tc)/L = 71.994(2)/140 = 1.028 m.

Draft aft = 4.689 + 1.028 = 5.717 metres

Draft aft when GM becomes zero = 5.717 m
Draft aft when aground lightly = 7.000 m
Drop in level for 0 GM **ans** (c) = **1.283** m

By formula B: $0.625 = \frac{1200}{9770-P} + \frac{P.KM}{W}$

$0.625 = \frac{1200}{9770-P} + \frac{P(8.725)}{9770}$ so P = 554.1 t

GM will be 0 when disp = W-P = 9215.9 t.

W (t)	Draft	AF (m)
9215.9	4.693	71.993

Ta = AF(Tc)/L = 71.993(2)/140 = 1.028 m.
Draft aft = 4.693 + 1.028 = 5.721 metres

Draft aft when GM becomes zero = 5.721 m
Draft aft when aground lightly = 7.000 m
Drop in level for 0 GM **ans** (c) = 1.279 m

(See note at the end of example 2).

Example 7

M.v., VIJAY enters a SW drydock drawing 3 m fwd & 5.8 m aft. KG = 8.6 m, FSM = 800 tm. Find the new GM: (a) on taking to blocks overall and (b) after the water level drops by one metre thereafter.

Fwd 3.0 m aft 5.8 m, trim 2.8 m by stern
Mean draft 4.4 m for which AF = 72.056 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{72.056(2.8)}{140} = 1.441 \text{ m}$$

Initial hydraft = 5.80 - 1.441 = 4.359 m

Draft	W (t)	MCTC tm	AF (m)
4.359	8486.8	160.952	72.065

Tc = P.AF/MCTC or P = Tc (MCTC)/AF
P = 280(160.952) ÷ 72.065 = 625.4 tonnes

W - P = 7861.4 t, for which KM = 9.570 m

New GM = new KM-KG = 9.57-8.6 = 0.970 m
FSC = FSM/(W - P) = 800/7861.4 = 0.102 m
GM fluid when sitting overall = 0.868 m

$$\text{Virtual loss of GM} = \underset{\text{Formula A}}{\frac{P.KG}{W - P}} \qquad \underset{\text{Formula B}}{\frac{P.KM}{W}}$$

$$= \frac{625.4(8.60)}{7861.4} \text{ or } \frac{625.4(9.57)}{8486.8}$$

Virtual loss of GM = 0.684 m or 0.705 m.
GM fluid .... 0.868 m 0.868 m.
Virtual GM **ans** (a) = 0.184 m or 0.163 m.

Note: After the critical period is over, the side shores would be in position and there is no possibilty of roll. FSE can then be ignored.

On taking to blocks overall, the displacement is 7861.4 t, for which the hydraft is 4.071 m. After a further drop of 1 m in water level, hydraft = 3.071 m for which W = 5729.1 t & KM = 11.314 m. Then GM solid = 11.314 - 8.600 = 2.714 m and P = 8486.8 - 5729.1 = 2757.7 t.

	Formula A	Formula B
Virtual loss of GM =	$\frac{P.KG}{W - P}$	$\frac{P.KM}{W}$

$$= \frac{2757.7(8.6)}{5729.1} \text{ or } \frac{2757.7(11.314)}{8486.8}$$

Virtual loss of GM: 4.140 m or 3.676 m
GM solid ....: 2.714 m 2.714 m
Virtual GM **ans (b)**: -1.426 m or -0.962 m

Example 8

M.v. VIJAY, drawing 5 m fwd & 6 m aft in SW, has KG = 7.6 m and FSM = 950 tm. She runs aground lightly on a reef at the fwd perpendicular. Internal soundings indicate that the hull is still watertight. If the tide is expected to fall by 0.5 m, find at LW: (a) the upthrust exerted on the hull by the reef, (b) the drafts fwd & aft and (c) the virtual GM.

Fwd 5.0 m aft 6.0 m, trim 1.0 m by stern
Mean draft 5.5 m for which AF = 71.714 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.714(1.0)}{140} = 0.512 \text{ m}$$

Initial hydraft = 6.00 - 0.512 = 5.488 m

Draft	W (t)	TPC t	MCTC tm	AF (m)
5.488	10973.2	22.255	169.116	71.719

The draft fwd would decrease by 50 cm as a result of the upthrust P exerted by the reef at the fwd perpendicular.

Decrease of fwd draft = mean rise + Tf

50 = P/TPC + Tc(length forward of COF)/L

$$50 = \frac{P}{TPC} + \frac{P(L - AF)}{MCTC} \times \frac{(L - AF)}{L}$$

$$50 = \frac{P}{22.255} + \frac{P(68.281)(68.281)}{(169.116)(140)}$$

Upthrust P at LW = 206.7 t = **answer (a).**

$$Tc = \frac{P(L - AF)}{MCTC} = \frac{206.7(68.281)}{169.116} = 83.5 \text{ cm}$$

Trim @ LW = original trim + Tc = 1.835 m

Draft fwd = 5.000 - 0.5 = 4.500 m at LW
aft = 4.5 + 1.835 = 6.335 m **ans(b)**

W - P = 10766.5 t for which KM = 8.463 m
KG of ship .... = 7.600 m
GM solid at low water .... = 0.863 m
FSC = FSM/(W - P)= 950/10766.5 = 0.088 m
GM fluid at low water......... = 0.775 m

$$\text{Virtual loss of GM} = \frac{P.KG}{W - P} \quad \text{(Formula A)} \qquad \frac{P.KM}{W} \quad \text{(Formula B)}$$

$$= \frac{206.7(7.6)}{10766.5} \text{ or } \frac{206.7(8.463)}{10973.2}$$

Virtual loss of GM = 0.146 m or 0.159 m.
GM fluid at LW ... = 0.775 m   0.775 m.
Virtual GM **ans** (c) = 0.629 m or 0.616 m.

Example 9

M.v.VIJAY draws 6 m fwd & 8 m aft in SW. KG 7.04 m and FSM 1060 tm. She grounds lightly on a reef 30 m astern of the fwd perpendicular. The hull is still intact. The water level is expected to fall by 0.6 m. At LW, find: (a) the upthrust on the hull by the reef, (b) the drafts fwd and aft and (c) the virtual GM.

Note: This is similar to example 8 with the exception that the point of grounding is not at the forward perpendicular but 30 m astern of it.

Fwd 6.0 m aft 8.0 m, trim 2.0 m by stern
Mean draft 7.0 m for which AF = 70.602 m

Correction = 70.602(2.000)/140 = 1.009 m
Initial hydraft = 8.00 - 1.009 = 6.991 m

Draft	W (t)	TPC t	MCTC tm	AF (m)
6.991	14381.3	22.926	182.592	70.611

At R, the point of grounding, the decrease of draft, by tidal fall, = 60 cm. Let the distance of R from the COF = RF.
RF = AR - AF = 110 - 70.611 = 39.389 m.

Reduction of draft at R = mean rise + Tr where Tr is the proportion of Tc, the trim caused, at point R.

$$60 = \frac{P}{TPC} + \frac{P(RF)}{MCTC} \times \frac{(RF)}{L}$$

$$60 = \frac{P}{22.296} + \frac{P(39.389)^2}{182.592(140)} \text{ or } P = 575.2 \text{ t}$$

answer (a)

(W - P)	Draft	KM m
13806.1	6.740	8.083

$$Tc = \frac{P \times RF}{MCTC} = \frac{575.2(39.389)}{182.592} = 124.1 \text{ cm}$$

Trim @ LW = original trim + Tc = 3.241 m

$$Ta = \frac{AF}{L}(trim) = \frac{70.611\ (3.241)}{140} = 1.635 \text{ m}$$

Tf = trim - Ta = 3.241 - 1.635 = 1.606 m

Draft fwd = 6.74 - 1.606 = 5.134 m at LW
aft = 6.74 + 1.635 = 8.375 m **ans b**

GM solid at LW = 8.083 - 7.040 = 1.043 m
FSC = FSM/(W - P)=1060/13806.1 = 0.077 m
GM fluid at low water......... = 0.966 m

	Formula A	Formula B
Virtual loss of GM =	$\frac{P.KG}{W - P}$	$\frac{P.KM}{W}$
	$= \frac{575.2(7.04)}{13806.1}$ or	$\frac{575.2(8.083)}{14381.3}$

Virtual loss of GM = 0.293 m or 0.323 m.
GM fluid at LW ... = 0.966 m 0.966 m.
Virtual GM **ans** (c) = 0.673 m or 0.643 m.

Example 10

M.v.VIJAY is in a SW anchorage drawing 5.4 m fwd & 6 m aft. KG 7.2 m, FSM 1100 tm. At LW, the ship rests on an uncharted rock and it is found that the drafts are then 6 m fwd & 5 m aft. Find (a) the upthrust exerted on the hull by the rock; (b) the distance, to the nearest metre, of the rock from the after perpendicular (c) the virtual GM and (d) the rise of tide required for the ship to refloat, assuming that she is aground at only one point surrounded by deep water.

Fwd 5.4 m aft 6.0 m, trim 0.6 m by stern
Mean draft 5.7 m for which AF = 71.629 m

$$\text{Corr} = \frac{AF}{L} \times \text{trim} = \frac{71.629(0.6)}{140} = 0.307 \text{ m}$$

Initial hydraft = 6.00 - 0.307 = 5.693 m
for which the displacement W = 11431.8 t

Fwd 6.0 m aft 5.0 m, trim 1.0 m by head
Mean draft 5.5 m for which AF = 71.714 m

Correction = 71,714(1.000)/140 = 0.512 m

At LW, hydraft = 5.000 + 0.512 = 5.512 m

Draft	W - P	MCTC tm	AF (m)	KM m
5.512	11026.8	169.284	71.709	8.412

P = 11431.8 - 11026.8 = 405 t **answer** (a)

Original trim = 60 cm by stern. Trim at LW = 100 cm by head. Tc = 160 cm by head Hence rock is astern of COF. Let FR be the distance of the rock astern of COF.

Tc = P(FR)/MCTC or 160 = 405(FR)/169.284
FR = 66.878. AF = 71.709. So AR = 4.831

Distance of rock from the after perpendicular, to the nearest m, = 5 m **ans (b).**

GM solid at LW = 8.412 − 7.200 = 1.212 m
FSC = FSM/(W − P)=1100/11026.8 = 0.100 m
GM fluid at low water......... = 1.112 m

$$\text{Virtual loss of GM} = \underbrace{\frac{P.KG}{W - P}}_{\text{Formula A}} \qquad \underbrace{\frac{P.KM}{W}}_{\text{Formula B}}$$

$$= \frac{405(7.2)}{11026.8} \quad \text{or} \quad \frac{405(8.412)}{11431.8}$$

Virtual loss of GM = 0.264 m or 0.298 m.
GM fluid at LW ... = 1.112 m 1.112 m.
Virtual GM **ans** (c) = 0.848 m or 0.814 m.

Let Tr be the proportion of trim at R.

Before grounding:

$$Tr = \frac{FR(trim)}{L} = \frac{66.878(0.600)}{140} = 0.287 \text{ m.}$$

Since trim was by stern, draft at R was > initial hydraft of 5.693 m by 0.287 m.
Draft at R = 5.693 + 0.287 = 5.980 m.

After grounding

$$Tr = \frac{FR(trim)}{L} = \frac{66.878(1.000)}{140} = 0.478 \text{ m.}$$

Since trim is by head, draft at R is < the LW hydraft of 5.512 m by 0.478 metre
Draft at R = 5.512 − 0.478 = 5.034 m.

After grounding, draft at R = 5.034 m
To float freely, draft at R = 5.980 m
Required tidal rise **answer** (d) = 0.946 m

FLOATING DRYDOCKS

From the shipmaster's point of view, a floating drydock has one big advantage over a graving type drydock: the drydock itself can be made to have a trim in order to offset any adverse trim that the ship may have. Suppose the ship is trimmed one metre by the head. The dry-dock can be made to trim 2 m by the head so that, when the ship's stern takes to the keel blocks, the relative trim is one metre by the stern. Therefter, the ballast tanks of the drydock can be pumped out at a predetermined sequence to ensure that the stern frame of the ship always remains in contact with the keel blocks while the relative trim is gradually reduced. Once the bow also has taken to the blocks (relative trim zero) pumping out of the drydock can be completed, bringing the ship's keel above, & parallel to, the water surface.

If the ship is trimmed 3 m by the stern, the drydock can be made to trim 2 m by the stern so that the relative trim is only one metre by the stern, and so on.

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Exercise 27
Drydocking and grounding

1 M.v.VIJAY enters a SW drydock drawing 6 m fwd & 8 m aft. KG 6 m. When she is just about to take to the blocks fwd, calculate (a) the virtual GM and (b) the moment of statical stability at 0.5° heel.

2 Rework Q1 given that FSM = 1180 tm.

3 M.v.VIJAY has W = 10333 t, KG = 8 m. What is the maximum trim by the stern with which she may enter a SW drydock if the virtual GM at the critical instant is to be not less than 0.3 m?

4 Rework Q3 given that FSM = 970 tm.

5 M.v.VIJAY is at anchor in SW, drawing 7 m fwd & aft. KG 6.2 m. During low water, the depth of water around the ship is expected to drop to 6 m. Find the virtual GM at LW, assuming that the sea-bed is even and horizontal.

6 Rework Q5 given that FSM = 1400 tm.

7 While drawing 4.8 m fwd & 8 m aft in SW, m.v.VIJAY runs aground lightly on a sandy shoal, during a falling tide. Hand lead soundings indicate that the depth of water near the after perpendicular is one metre more than at the forward perpendicular. If KG = 7.5 m, calculate (a) the drop in water level at which the ship will sit overall on the sea-bed; (b) the virtual GM when just sitting overall and (c) the drop

in water level at which the ship would become unstable.

8 Rework Q7 given that FSM = 1300 tm.

9 M.v.VIJAY enters a SW drydock drawing 3.4 m fwd & 5.8 m aft. KG 8 m. Find the virtual GM when the level of water has fallen one metre after the stern has taken to the blocks.

10 Rework Q9 given that FSM = 880 tm. (If, during drydocking, the critical period is over, FSC may be ignored.)

11 M.v.VIJAY enters a SW drydock drawing 3.5 m fwd & 5.5 m aft. KG 7.1 m. Find the virtual GM after the water level has fallen to 4 m above the blocks.

12 Rework Q11 given that FSM = 820 tm. (If, during drydocking, the critical period is over, FSC may be ignored.)

13 M.v. VIJAY, drawing 5.6 m fwd & 8.4 m aft in SW, KG 7.2 m, runs aground lightly on a shoal during a falling tide. At low water, the drafts are found to be 6 m fwd & 7.4 m aft. Find the virtual GM at low water.

14 Rework Q13 given that FSM = 1400 tm.

15 M.v. VIJAY, floating at 5.2 m fwd & 7 m aft in SW, KG 7.4 m & FSM 1250 tm, runs aground lightly on a coral reef. Soon after grounding, the drafts are found to be 4.4 m fwd and 7.4 m aft. Find (a) the upthrust exerted on the hull by the reef and (b) the point,

to the nearest metre, where it acts. Find also (c) the virtual GM soon after grounding and (d) the rise of tide required for the ship to refloat assuming that the reef is acting only at one point surrounded by deep water.

16 M.v. VIJAY, afloat in SW at 4.6 m fwd & 5.4 m aft, KG 7.8 m, FSM 1180 tm, runs aground lightly at the foward perpendicular. The stern is in deep water. The tide is expected to fall by one metre. Find, at low water, (a) the upthrust exerted on the hull by the shoal; (b) the drafts fwd and aft and (c) the virtual GM.

17 M.v.VIJAY floats at drafts of 5 m fwd & 7 m aft, KG 7.64 m, FSM 1086 tm, in a SW anchorage. During ebb tide, she sits on an uncharted rock 20 m abaft the fwd perpendicular. The hull is still intact. The tide is expected to fall another 0.5 m. Find at low water (a) the force exerted on the hull by the rock; (b) the drafts fwd and aft and (c) the virtual GM.

18 M.v.VIJAY enters a FW drydock drawing 3.6 m fwd and 4.8 m aft. KG 8 m, FSM 960 tm. Find the virtual GM @ (a) the critical instant (b) after a further drop of one metre in water level.

19 M.v. VIJAY is in DW of RD 1.017. W is 9013 t, KG 8.02 m & FSM 810 tm. What is the maximum trim with which she may enter a drydock, of RD 1.017, if the virtual GM @ the critical instant is to be not less than 0.3 m?

20 M.v. VIJAY is to be refloated in a SW drydock after a prolonged stay for structural repairs. Her displacement, KG & AG after repairs are calculated to be 8576 t, 8.1 m and 68 m. FSM is 900 tm. Calculate the virtual GM and the depth of water, above the blocks, when the bow just lifts off the blocks.

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CHAPTER 32

BILGING OF AMIDSHIPS COMPARTMENTS

A compartment is said to be bilged when it is holed below the waterline, the hole being large enough for water to pass freely in and out. Minor leaks are excluded as they can be tackled by the ship's pumps.

Bilging causes a loss of buoyancy. A compartment, which was displacing water before, does not do so after bilging. So the ship's draft increases until the loss of buoyancy is regained by the extra sinkage of intact spaces. By this line of thought, the displacement and KG remain unaffected by bilging. Though the draft of the ship increases, resulting in change of hydrostatic particulars, the volume of displacement is the same because the volume of buoyancy lost equals the volume of buoyancy regained. The increase of draft, denoted by 'S' metres, may be calculated as follows:-

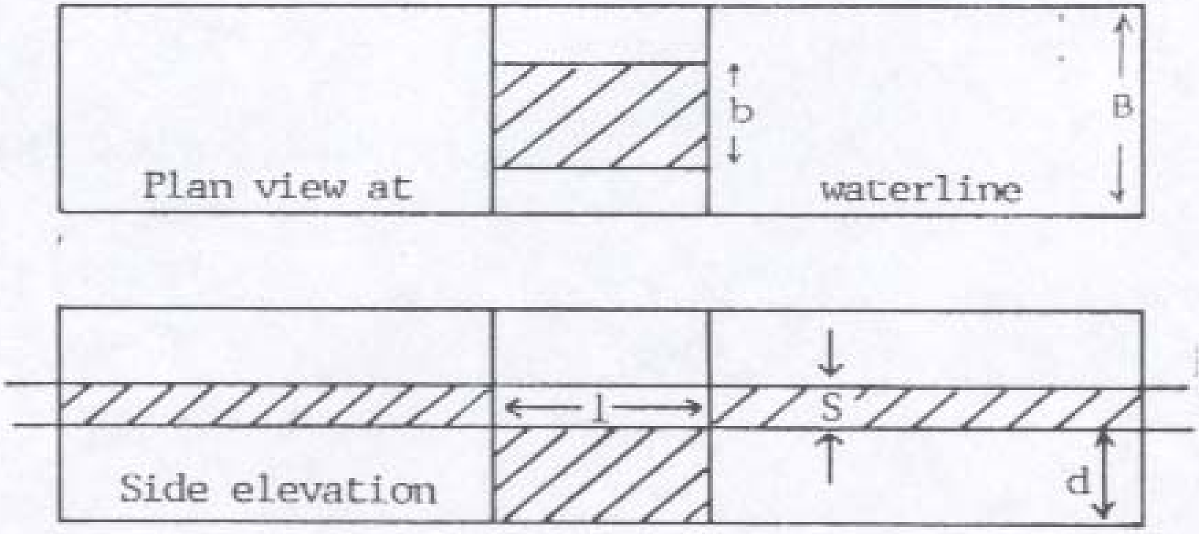
$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

This chapter deals only with bilging of the amidships compartment of box-shaped vessels, resulting in parallel sinkage without causing any trim or list.

Water-tight flats restrict the entry of water into a bilged compartment. The volume of lost buoyancy, and hence the resultant sinkage, is less when the bilged compartment has a water-tight flat below the waterline. A good example of a water-tight flat is the tank top of the double bottom tanks of a cargo ship. The following cases show the calculation of sinkage caused by bilging an amidships compartment. The advantage of having a WT flat is apparent by the limited amount of calculated sinkage.

Consider a box-shaped vessel 100 m long and 12 m wide, floating at an even keel draft of 6 m in SW. It has an empty amidships compartment 10 m long and 8 m wide, on the centre line of the ship.

Case 1A: The amidships compartment has a watertight flat far above the waterline. If this compartment is bilged, calculate the new draft.



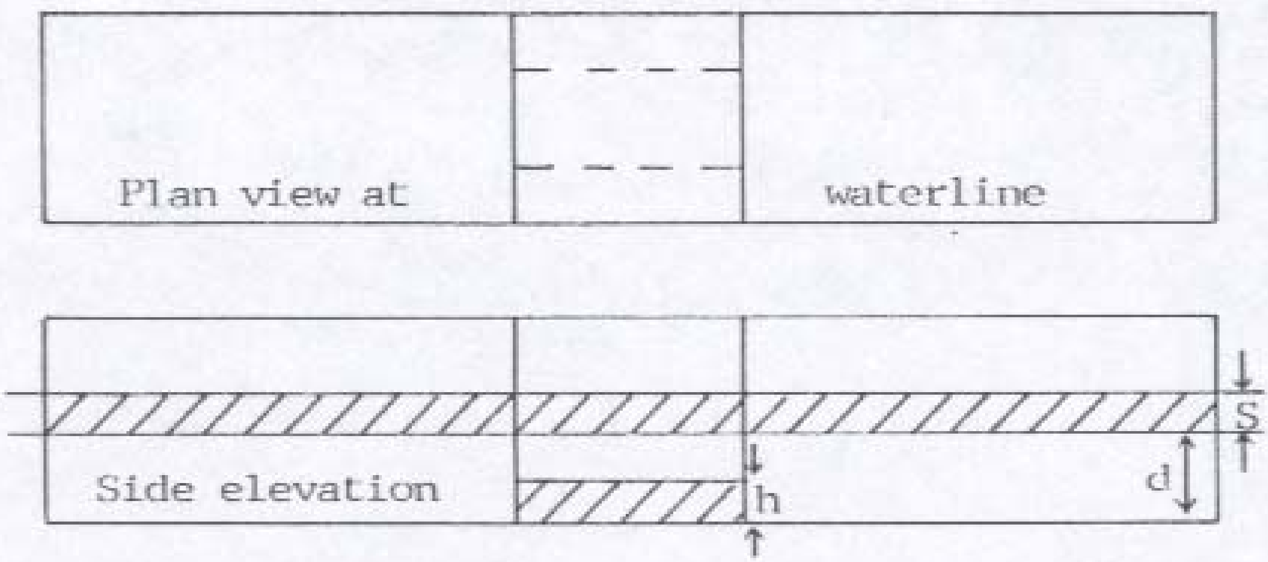
Note: Since the water-tight flat is far up, it will remain above the waterline after bilging. Its presence, therefore, makes no difference to the calculation.

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

Here, $S = \dfrac{lbd}{LB - lb} = \dfrac{10 \times 8 \times 6}{1200 - 80} = 0.429$ m

New draft = 6.000 + 0.429 = 6.429 metres

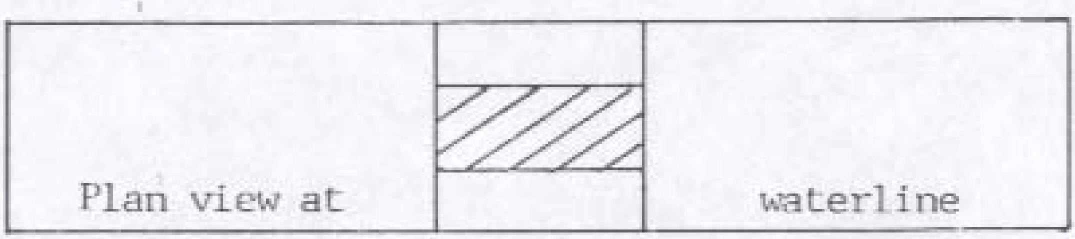
Case 2A: The amidships compartment has a WT flat 1 m above the keel. Find the new draft if the compartment is bilged below this flat. (Note: The bilged compartment is similar to the DB tank of a ship.)

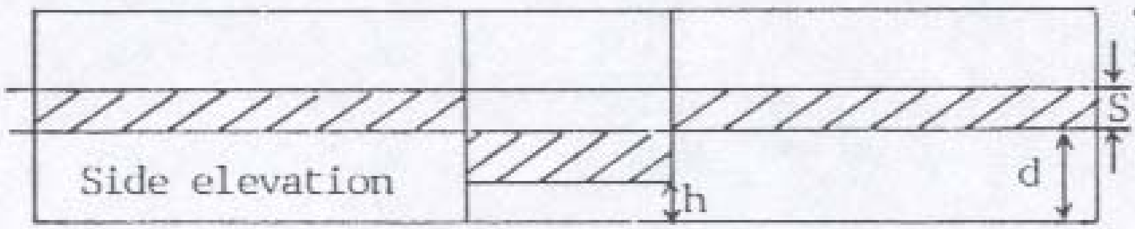


Here, $S = \dfrac{lbh}{LB} = \dfrac{10 \times 8 \times 1}{100 \times 12} = 0.067$ m

New draft = 6.000 + 0.067 = 6.067 metres

Case 3A: The amidships compartment has a WT flat 1 m above the keel. Find the new draft if the compartment is bilged above this flat.



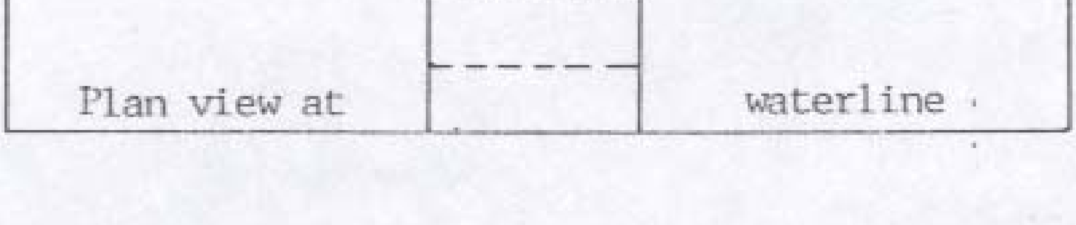


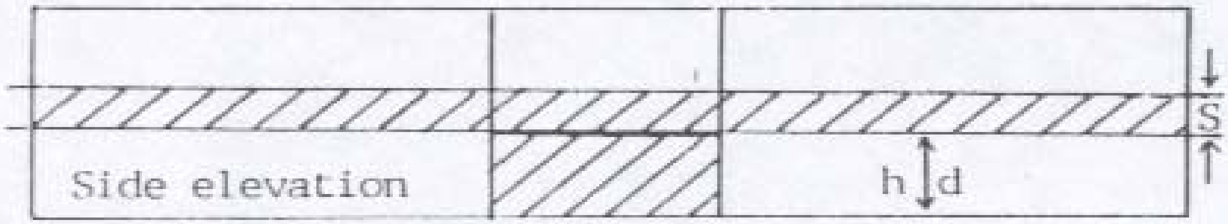
$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

Here, $S = \dfrac{lb(d-h)}{LB - lb} = \dfrac{10 \times 8 \times 5}{1200 - 80} = 0.357$ m

New draft = 6.000 + 0.357 = 6.357 metres

Case 4A: The amidships compartment has a WT flat 6 m above the keel. Find the new draft if the compartment is bilged.



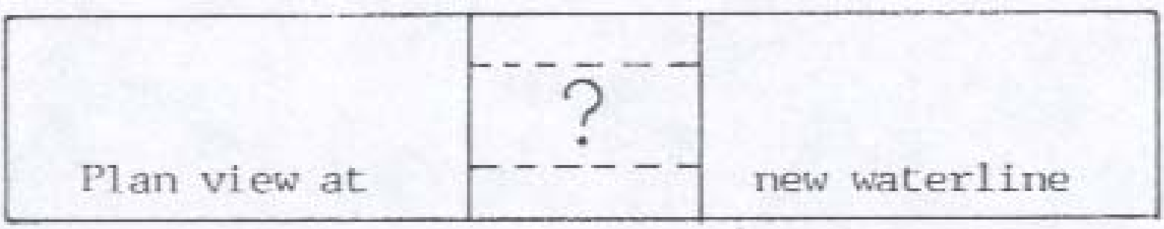


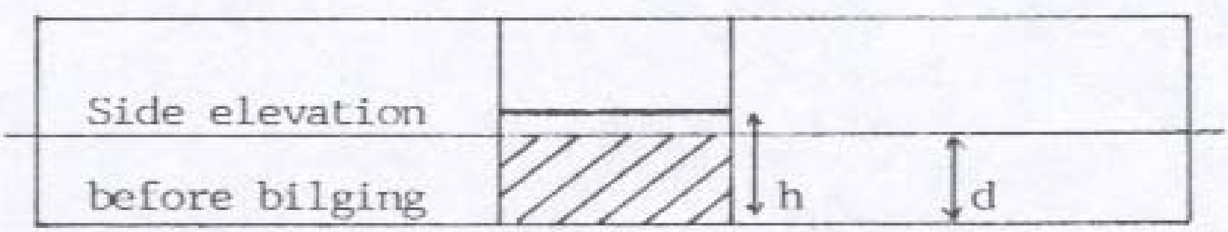
$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}}$$

Here, $S = \frac{lbd}{LB} = \frac{10 \times 8 \times 6}{1200} = 0.400$ m

New draft = 6.000 + 0.400 = 6.400 metres

Case 5A: The amidships compartment has a WT flat 6.5 m above the keel. Find the new draft if this compartment is bilged.





Note 1: This compartment is protectively located - it has a tank below and one on either side - making it impracticable to bilge without bilging any other tank!

For theoretical purposes, assume that a very large pipeline leading out to sea has burst inside the compartment.

Note 2: Since the WT flat is very near the waterline before bilging, it is not possible to judge, at a glance, whether the new waterline will be above or below the WT flat. The intact water-plane area will be (LB - lb) until the waterline reaches the level of the WT flat: thereafter, it will be LB.

Vol of buoyancy lost = 10(8)6 = 480 m^3.

If S = (h - d) = 0.5 m, volume regained = 0.5(LB - lb) = 0.5(1200 - 80) = 560 m^3

Since the ship cannot regain more buoyancy than what she lost, S < 0.5 m. The WT flat remains above the waterline even after bilging. The calculation is now similar to that of case 1A.

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

$$\text{Here, } S = \frac{480}{LB - lb} = \frac{480}{1200 - 80} = 0.429 \text{ m}$$

New draft = 6.000 + 0.429 = 6.429 metres

Case 6A: The amidships compartment has a WT flat 6.2 m above the keel. Find the new draft if this compartment is bilged.

Reference is invited to the figures and the notes under the previous case - 5A.

Volume of lost buoyancy = 10(8)6 = 480 m^3

If $S = (h - d) = 0.2$ m, volume regained $= 0.2(LB - lb) = 0.2(1200 - 80) =$ **224 m^3**

Vol yet to regain $= 480 - 224 =$ **256 m^3** during which the intact WP area = **LB.**

Further sinkage $= 256 \div 1200 =$ **0.213 m.**

New draft $= 6.0 + 0.2 + 0.213 =$ **6.413 m.**

Exercise 28

Bilging amidships compartment (empty)

A box-shaped vessel, 120 m long and 14 m wide, is afloat at 8 m draft even keel. Find the new draft if a central compartment 12 m long is bilged as under:

(As b is not given, assume b = B = 14 m)

1 It has a WT flat 11 m above the keel.

2 It has a WT flat 1.2 m above the keel, & the compartment is bilged below it.

3 It has a WT flat 1.5 m above the keel, & the compartment is bilged above it.

4 It has a WT flat 1.0 m above the keel. The compartment is bilged above and below this flat.

5 It has a WT flat 8.0 m above the keel.

6 It has a WT flat 8.9 m above the keel.

7 It has a WT flat 8.5 m above the keel.

-oOo-

PERMEABILITY

So far, the compartments bilged in this chapter were empty. If, however, they had cargo in them, that cargo would occupy space and only the balance space would be available for occupation by water in the event of bilging. In other words, cargo would restrict the space available for water, thereby reducing the volume of buoyancy lost due to bilging.

Permeability is the percentage ratio of the space available for the entry of water into a compartment, to the total volume of the compartment. The letter 'p' is used here to denote permeability. For an empty compartment, p = 100% and for a compartment so full that water could not enter at all, if bilging occured, p = 0%. For any compartment, p may be calculated by the formula: p % = (BS ÷ SF)100, where SF is the stowage factor in cubic metres per tonne & BS is the broken stowage per tonne of cargo.

Example: A compartment is full of coal in bulk (SF 1.3 m^3/t). If RD of coal is 1.1, find p % of the compartment.

RD = 1.1 so density = 1.1 t/m^3, meaning that 1.1 t of coal should occupy 1 m^3, or 1 t of coal should occupy 1 ÷ 1.1 = 0.909 m^3. But SF = 1.3 m^3/t meaning that 1 t of coal actually occupies 1.3 m^3. So broken stowage per tonne = 1.3 - 0.909 = 0.391 m^3.

p% = (BS/SF)100 = (0.391/1.3)100 = 30.1%

Where the cargo in a compartment is heterogenous, it is not possible to calculate the permeability to any degree of accuracy. In such a case, it is suggested that 60% may be used as a rough approximation at sea.

Permeability, once known or estimated, can be put to practical use as follows:

Consider the same box-shaped vessel and the six cases referred to earlier in this chapter, where L = 100 m, B = 12 m, d = 6 m, l = 10 m and b = 8 m.

Case 1B: The amidships compartment has a WT flat far above the waterline. Find the new draft if this compartment is bilged, given that p = 35%.

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

Note: Only 35% of (lbd) is available for entry of water as a result of bilging. The area of cargo also contributes to the intact water-plane area. So the area of lost buoyancy = 35% of (lb).

$$S = \frac{lbd(p/100)}{LB-lb(p/100)} = \frac{10(8)6(35/100)}{1200-80(35/100)} = 0.143\text{m}$$

New draft = 6.000 + 0.143 = 6.143 metres

Case 2B: The amidships compartment has a WT flat 1 m above the keel. The space below the WT flat, full of SW ballast, gets bilged. Find the new draft.
(Note: The bilged compartment is similar to the DB tank of a cargo ship.)

Since the bilged compartment was full of SW, $p = 0\%$; S = zero; new draft = 6.0 m.

Note: This is a short cut method which cannot be used if the contents of the bilged compartment had an RD different from that of the water outside. For a solution suitable for all problems of this kind see example 5 few pages hence.

Case 3B: The amidships compartment has a WT flat 1 m above the keel. If the space above this flat, having $p = 40\%$, gets bilged, find the new draft.

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

$$= \frac{lb(d-h)(p/100)}{LB - lb(p/100)} = \frac{10(8)5(40/100)}{1200-80(40/100)} = 0.137$$

New draft = 6.000 + 0.137 = 6.137 metres

Case 4B: The amidships compartment has a WT flat 6 m above the keel. Find the new draft if this compartment gets bilged, given that permeability = 30%.

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

$$S = \frac{lbd(p/100)}{LB} = \frac{10(8)6(30/100)}{1200} = 0.120\text{m}$$

New draft = 6.000 + 0.120 = 6.120 metres

Case 5B: The amidships compartment has a WT flat 6.2 m above the keel. Find the new draft if this compartment is bilged, given that $p = 25\%$.

Volume of buoyancy lost = lbd (p ÷ 100)

$= 10(8)6(25/100) = 120\ m^3$.

If S = (h-d) = 0.2 m, volume regained = 0.2[LB-lb(p/100)] = 0.2[1200-80(25/100)]

If S = 0.2 m, volume regained = 236 m^3.

Since the ship cannot regain more buoyancy than what she lost, S < 0.2 m. The WT flat remains above the waterline even after bilging. The calculation is now similar to that of case 1B.

$$S = \frac{120}{LB-lb(p/100)} = \frac{120}{1200-80(25/100)} = 0.102\ m$$

New draft = 6.000 + 0.102 = 6.102 metres

Case 6B: The amidships compartment has a WT flat 6.1 m above the keel. Find the new draft if this compartment is bilged, given that p = 80%.

Volume of buoyancy lost = lbd (p ÷ 100)

$= 10(8)6(80/100) = 384\ m^3$.

If S = (h-d) = 0.1 m, volume regained = 0.1[LB-lb(p/100)] = 0.1[1200-80(80/100)]

If S = 0.1 m, volume regained = 113.6 m^3

Vol yet to regain = 384-113.6 = 270.4 m^3 during which the intact WP area = LB.

Further sinkage = 270.4 ÷ 1200 = 0.225 m

New draft = 6.0 + 0.10 + 0.225 = 6.325 m

Exercise 29

Bilging amidships compartment (loaded)

Rework exercise 28 given that the bilged amidships compartment has the permeability given against each question below:-

(1) p = 20% (2) Full of SW (3) p = 30%

(4) p = 50% (5) p = 40% (6) p = 65%

(7) p = 80%.

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EFFECT OF BILGING ON STABILITY

Since bilging causes a loss of buoyancy, resulting in an increase of draft, the KM of the ship would change. KG remains unaffected by bilging.

Example 1: A box-shaped vessel 150 x 18 m floats in SW at 5 m draft even keel. KG = 4 m. An empty amidships compartment 25 m long and 18 m broad gets bilged. Find the GM before and after bilging.

Before bilging

$$BM = \frac{I}{V} = \frac{LB^3}{12V} = \frac{150(18 \times 18 \times 18)}{12\ (150 \times 18 \times 5)} = 5.4 \text{ m}$$

KM = KB + BM = 2.500 + 5.400 = 7.900 m
GM = KM - KG = 7.900 - 4.000 = 3.900 m

After bilging

$$S = \frac{\text{vol of lost buoyancy}}{\text{intact WP area}} = \frac{25(18)5}{150(18)-25(18)}$$

$S = 2250 \div (2700-450) = 2250/2250 = 1$ m.

New draft = 5.000 + 1.000 = 6.000 metres

BM = I*CL intact WP area ÷ vol of displ.

$$BM = \frac{LB^3 - lb^3}{12V} = \frac{150(18^3)-25(18^3)}{12(150 \times 18 \times 5)} = 4.5 \text{ m}$$

Note: Volume of displacement is constant

$$V = 150 \times 18 \times 5 = 13500 \text{ m}^3.$$
$$\text{or } V = 125 \times 18 \times 6 = 13500 \text{ m}^3.$$

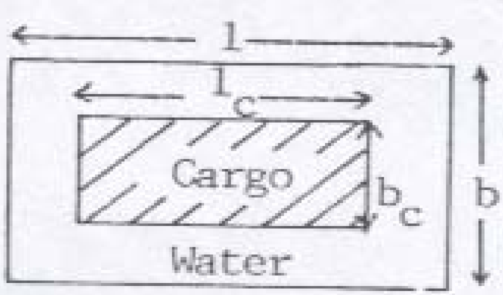
KM = KB + BM = 3.000 + 4.500 = 7.500 m
GM = KM − KG = 7.500 − 4.000 = 3.500 m

Example 2: Rework example 1 given that permeability = 30%.

The calculation of GM before bilging is the same as in example 1 & = 3.9 metres.

$$S = \frac{\text{buoyancy vol lost}}{\text{intact WP area}} = \frac{2250\ (30/100)}{2700-450(30/100)}$$

S = 0.263 m. After bilging, the area of the cargo contributes to the intact water-plane area. So the calculation of I of the intact WP area about the centre line should include the area of cargo in the compartment for which the following assumption is suggested:



The cargo is assumed to be centred over the compartment with its sides parallel to the boundaries, as shown in the figure.

Area of the bilged compartment = lb.
Area of water in compartment = lb(p/100)

$$\text{Area of cargo} = lb - \frac{lbp}{100} = \frac{lb(100 - p)}{100}$$

$$= l\sqrt{\frac{(100 - p)}{100}} \times b\sqrt{\frac{(100 - p)}{100}}$$

Length of cargo = lc = $l\sqrt{(100 - p)/100}$

Breadth of cargo = bc = $b\sqrt{(100 - p)/100}$

Here lc = $25\sqrt{0.7}$ and bc = $18\sqrt{0.7}$
So lc = 20.917 m and bc = 15.060 m

$$I^*CL \text{ intact WP area} = \frac{LB^3}{12} - \frac{lb^3}{12} + \frac{lc(bc^3)}{12}$$

$$= [150(18^3)-25(18^3)+20.917(15.06^3)]/12$$

I*CL intact WP area = 66703.784 m^4.

BM = I/V = 66703.784/13500 = 4.941 m
In this cse, KB = new draft/2 = 2.632 m
KM after bilging .... = 7.573 m
KG .... = 4.000 m
GM after bilging .... = 3.573 m

Example 3: A box-shaped vessel 220 x 36 m is afloat in SW at an even keel draft of 10 m. KG = 12 m. An empty DB tank 1.8 m high, 20 m long & 18 m wide, situated centrally, is bilged. Find the GM before and after bilging.

$$S = \frac{\text{buoyancy vol lost}}{\text{intact WP area}} = \frac{20(18)1.8}{220 \times 36} = \frac{648}{7920}$$

New draft = 10.0 + 0.082 = 10.082 metres

$$BM = \frac{I*CL}{V} = \frac{LB^3}{12V} = \frac{220\ (36^3)}{12(79200)} = 10.800 \text{ m}$$

Note: Here new KB is NOT half new draft.

Taking moments of volume about the keel:
Final V(final KB) = original V(its KB) - v lost (its KB) + v regained (its KB).

79200(KB) =79200(5)-648(0.9)+648(10.041)

Note: KB of vol regained = old draft + $\frac{S}{2}$

New KB = 5.075 metres.

KM = KB + BM = 5.075 + 10.800 = 15.875 m
GM = KM - KG = 15.875 - 12.000 = 3.875 m

Example 4: A box-shaped vessel 160 x 22 m floats at 6 m SW draft. Its DB tanks are 1 m high. A hold amidships 26 m long and 22 m wide gets bilged. Find the GM if permeability = 40% and KG = 9 m.

$$S = \frac{\text{volume lost}}{\text{intact WP area}} = \frac{26(22)5(40/100)}{160(22)-26(40/100)22}$$

Sinkage = 1144/3291.2 = 0.348 metres
New draft = 6.000 + 0.348 = 6.348 metres

$$lc = l\sqrt{(100 - p)/100} = 26\sqrt{0.6} = 20.140 \text{ m}$$

$$bc = b\sqrt{(100 - p)/100} = 22\sqrt{0.6} = 17.041 \text{ m}$$

$$I*CL \text{ intact WP area} = \frac{LB^3}{12} - \frac{lb^3}{12} + \frac{lc(bc^3)}{12}$$

$$= [160(22^3)-26(22^3)+20.14(17.041^3)]/12$$

I*CL intact WP area = 127208.122 m^4.

$$BM = \frac{I*CL}{V} = \frac{127208.122}{21120} = 6.023 \text{ metres.}$$

Note: Here new KB is NOT half new draft.

Taking moments of volume about the keel:
Final V(final KB) = original V(its KB) - v lost (its KB) + v regained (its KB).

21120(KB)=21120(3)-1144(3.5)+1144(6.174)

Note: KB of vol regained = old draft + $\frac{S}{2}$

New KB = 3.145 metres.

KM = KB + BM = 3.145 + 6.023 = 9.168 m
GM = KM - KG = 9.168 - 9.000 = 0.168 m

Example 5:

A box-shaped vessel 100 m long and 25 m wide floats at 5 m SW draft. KG = 10 m. A DB tank amidships 20 m long, 25 m wide and 1.8 m high, full of SW, gets bilged. Find the GM before and after bilging.

Before bilging KB = d/2 = 2.5 m

$$BM = \frac{I}{V} = \frac{LB^3}{12V} = \frac{100\ (25^3)}{12(12500)} = 10.417 \text{ m}$$

KM = KB + BM = 2.500 + 10.417 = 12.917 m
GM = KM - KG = 12.917 - 10.00 = 2.917 m

Note: After bilging, the SW in the DB is no longer part of the ship. First assume that the SW was pumped out and calculate the new draft, KG & W. Then, using this new data, the empty DB tank may be bilged and the usual calculation made.

W =LBd(1.025)=100(25)5(1.025)= 12812.5 t
w =lbh(1.025)=20(25)1.8(1.025) = 922.5 t

Remarks	Weight	KG	Moment
Ship	12812.5	10.0	128125.00
SW	- 922.5	00.9	830.25
Final	11890		127294.75

Final KG = 127294.75 ÷ 11890 = 10.706 m.

New draft = 11890/(100)25(1.025) = 4.640

After pumping out

W = 11890 t, V = 11600 m^3, d = 4.640 m
KB = 2.320 m, KG = 10.706 m.

After bilging

$$S = \frac{\text{volume of lost buoyancy}}{\text{intact water-plane area}} = \frac{900}{2500} = 0.36$$

New draft = 4.640 + 0.360 = 5.000 metres

Note: Here new KB is NOT half new draft.

Taking moments of volume about the keel:
Final V(final KB) = original V(its KB) - v lost (its KB) + v regained (its KB).

11600(KB)=11600(2.32)-900(0.9)+900(4.82)

Note: KB of vol regained = old draft+S/2

New KB = 2.624 metres. I*CL is unchanged

BM = I/V = 130208.333 ÷ 11600 = 11.225 m

KM = KB + BM = 2.624 + 11.225 = 13.849 m
GM = KM - KG = 13.849 - 10.706 = 3.143 m

Exercise 30
Bilging amidships compartment (KM)

1 A box-shaped vessel 110 m long & 16 m wide floats in SW at 4 m even keel draft. An empty central compartment 16 m long & 10 m wide is bilged. Find the KM before and after bilging.

2 A box-shaped vessel 140 m long & 20 m wide floats in FW at 7 m even keel draft. KG = 8 m. An empty central compartment, 24 m long and 20 m wide, gets bilged. Find the GM before and after bilging.

3 A box-shaped vessel 150 m long & 25 m wide floats in SW at 6 m even keel draft. KG = 10 m. An empty amidships compartment on the centre line, 25 m long & 18 m wide, has a WT flat 2 m high. Find the GM before and after it is bilged below this WT flat.

4 A box-shaped vessel 200 m long & 26 m wide floats in SW at 8 m even keel draft. KG = 9 m. An empty amidships compartment, 28 m long and 26 m wide, has a WT flat 1.6 m above the keel. Find the GM before and after it is bilged above this flat.

5 A box-shaped vessel 210 m long and 25 m wide floats in SW at 10 m draft fwd and aft. KG is 10.6 m. An empty amidships compartment 30 m long and 25 m wide has a watertight flat 10.5 m above the keel. Find the GM if this compartment is bilged.

6 Rework question 3 given that the compartment, before bilging, was half full of HFO of RD 0.95. No other tanks on the ship were slack.
(FSC to be allowed where applicable.)

7 Rework question 2 given that p = 40%.

8 Rework question 4 given that the compartment was full of coal of SF 1.25 & RD 1.3, other data unchanged.

9 Ship as in question 1. The bilged compartment originally had SW ballast in it to a sounding of 6 m. KG = 6 m. All other particulars as before. Find the GM before and after bilging.

10 Rework question 5, if p = 50%.

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A N S W E R S

Exercise 15 (page 8): (1) 11.681 m; 3.681 m (2) 3.333m (3) 8.167m (4) SW 10 m; FW 9.954 m (5) 0.71m (6) 2.375° or 2°22.5' (7) 4.899 m @ 5m draft (8) 10.666m (9)(a) 2.95 m (b) 5.60 m (10) 1.6m (11) 4.852m (12) 5.198m (13) 0.75 m & 3.5m (14) 0.583 & 1.5m (15) No! GM -0.024 m

Exercise 16 (page 18): (1) 20m^2 (2) 251.083m^2 (3) By Rule 1: 64.8 m^2 and by Rule 2: 64.65m^2 (4) By Rules 1 & 2: 149.75 m^2; by Rules 1 & 3 149.701 m^2 (5) (a) 1849.625 m^2 (b) 0.727 (c) 18.959 t/cm (6) By Rules 1 and 2: 299.438 m^2; by Rules 1 and 3: 299.2 m^2 (7) (i) 4 m^2 (ii) 6.28 litres (8) (a) 10.839 t/cm (b) 0.691 (9)(a) 1483.2 m^2 (b) 11.2cm (10) 1053.113 m^2.

Exercise 17 (page 22) (1)2324.583m^3 23.83t/cm (2) 2127.5m^3 (3) Rules 1 & 3: 7332.2t; Rules 1 & 2: 7317.6t (4) 58.4t (5) 35303.7t 58.55t/cm

Exercise 18 (page 33): (1) 1057.5 m^2; AF 40 m (2) (a) 62.8 m^2 (b) 3.227 m (c) 593.942 t. (3) By Rule 1: 198.533 m^2, 7.546 m; By Rule 2 198.550 m^2; 7.549 m (4) 2.322 m; 5227.5 t (5) 12113.3 t; KB 3.173 m (6) 299.288 m^2; GC 12.028 m from forward (7) 3.253 m; 11845.6 t (8) 31282.1 t; 2.552 m (9) COF 18.974 m from aft (10) 1886.667 m^2; AF 89.668 m (11) 1866m^2 HF 0.383 m aft (12) 616.4 m^2; AF 43.091 m (13) 2233.875 m^3; GC 11.179 m from aft (14) 4363.9 t; AB 47.255 m (15) By Rules 1 and 2: 12.983 m^2; GC 3.751 m from bottom and 1.308 m from port (16) 43.5 m^2; GC 1.638m from bottom (17) 30.5 t; GC 5.705 m from aft (18) Rules 1 & 3: 299.325 m^2; GC 12.028 m from fwd; Rules 1 & 2 as in Q6: 299.288 m^2; 12.028 m from fwd (19) 1820.438 m^2; as per Q5/Ex16: 1849.625 m^2 (20)(a) 1.181% low (b) 0.435% low.

Exercise 19 (page 42): (1) 19.11° or 19° 06' (2) -0.200 metre (3) 141 t (4) 5.158 metres (5) No! Angle of loll = 37.8° or 37° 48' (6) Less than 0.2113 or more than 0.7887.

Exercise 20 (page 57): (1) 1.440 m (2) 20° (3) 4.7m @ 31° (4) 0 - 86° (5) 190800tm @ 35°

Exercise 21 (page 65): (1) 2.53 metres at 40° (2) 0.95 metre at 49° (3) 6.17 metres @ 42.5° (4) 33° and 80° (5) 30°.

Exercise 22 (page 79): (1) F:4.104 A:5.104 m (2) 126.9 tonnes (3) F:8.304 A: 9.468m (4) F:10.126 A:10.426m (5) F:8.480 A:10.320m (6) F: 9.783 A:10.183m (7) F:8.262 A: 9.431m (8) 735.1 tonnes in No:1, 82.4 tonnes in No:4 (9) Hydrostatic draft 9.10 m; 943.2 t in No:1 806.8 tonnes in No:4 hold; F:8.550 A:10.550 m (10) HF 3 metres aft (11) HF 2 metres fwd (12) 12.630 m fwd of COF; F:7.704 m A:8.400 m (13) 13.85m fwd of COF (14) 24.82m abaft COF F:9.600 A:10.965 m (15) 161t; F:6.141 A:6.7m (16) 388.5t No:2, 331.5t No:4; F:7.793 A:9.0m (17) 506.3 t from No:2 and 743.70 t from No:4 (18) 62.50 tonnes; F:8.677 A:9.677 metres (19) 271.2 tonnes; F:8.142 A:8.600 metres (20) 199.9t from AP to FP; F:8.822 A:9.122 m.

Exercise 23 (page 105) (1) F:4.884 A:6.097 m (2) F:5.534 A:5.490 m (3) F:4.620 A:5.688 m (4) F:4.711 A:4.678 m (5) F:4.059 A:6.822 m (6) F:4.730 A:6.710 m (7) F:6.532 A:6.905 m (8) F:3.823 A:4.583 m (9) F:4.929 A:6.429 m 1183.4 t in No:2, 816.6t in No:4 (10) 760.4 t in No:2, 1039.6 t in No:5; F:4.764 A:5.764 m

(11) 1060.20 t in No:1, 2068.40 t in No:4
(12) 727.80 t from No:1, 616.20 t from No:5
(13) AG of cargo 85.553 m; F:3.543 A:5.600 m
(14) AG of cargo 56.817 m; F:4.300 A:4.765 m
(15) AG of cargo 56.883 m; F:4.900 A:3.742 m
(16) AG of cargo 86.211 m; F:3.103 A:4.000 m
(17) 1245.800 t of cargo; F:3.569 A:6.000 m
(18) AG of cargo 73.050 m; F:4.800 A:5.675 m
(19) 284.5 tonnes in No:1 hold, 715.5 tonnes in No:5 hold; Final drafts F:5.412 A:6.412 m
(20) 674.3 t from No:2, 825.7 t from No:4; Final drafts F:5.174 m A:5.974 m.

Exercise 24 (page 128) (1) F:12.979 A:14.026m (2) F:14.827 A:15.003m (3) **F:13.977 A:14.196m** (4) F:10.784 A:11.912m (5) F:14.797 A:15.086m (6) F:10.949 A:11.949m (7) F:12.930 A:12.189m (8) F:10.436 A:12.779m (9) F:14.286 A:14.686m No:3 3388.5t, No:7 3611.5t (10) 4934.3t from No:3, 1065.7 t from No:8; F:13.025 A:14.025 m
(11) 7589.4 t in No:1, 7985.6 t in No:9 hold
(12) 2508.9 t from No:3, 4504 t from No:7
(13) Cargo HG 31.333m fwd, F:11.382 A:13.600m
(14) Cargo HG 32.329m aft, F:12.500 A:13.054m
(15) Cargo HG 32.424m fwd, F:12.024 A:12.900m
(16) Cargo HG 33.071m aft, F:12.400 A:13.408m
(17) 3482 t; Final drafts F:11.801 A:13.000m
(18) 3706 t; Final drafts F:12.000 A:14.632m
(19) 2445.7 t from No:1, 5153.30 t from No:9
(20) 2328.40 t from No:2, 3671.6 t from No:8; Final drafts F:11.321 m A:12.321 m.

Exercise 25 (page 136): (1) 157.70 t to stbd, 200 t fwd (2) 394.7 t to stbd, 928.6 t fwd. (3) 112.3 t to port, 232.7 t fwd (4) 198.9 t to port, 1430.30 t aft (5) 82.60 t to stbd, 266.6 t fwd.

Exercise 26 (page 141): (1) 7.563 metres. (2) 15.964m (3) 2.610m (4) 10.818m (5) 1.222m

Exercise 27 (page 164):
Answers first by formula A then by formula B:

(1)(a) 1.856 or 1.789 m (b) 224.5 or 224.5 tm
(2)(a) 1.771 or 1.704 m (b) 214.3 or 213.9 tm
(3) 143 cm or 138 cm (4) 92.5 cm or 88.3 cm
(5) 0.868 or 0.730 m (6) 0.753 m or 0.615 m
(7)(a) 1.357 m (b) 0.369 or 0.354 m (c) 1.567 or more. (8)(a) 1.357 m (b) 0.264 or 0.249 m (c) 1.490 m or more (9) 0.844 m or 0.810 m
(10) 0.741 or 0.707 m (11) 1.618 or 1.428 m
(12) FSC 0.106 m - ignored: shores in place.
(13) 0.531 m or 0.506 m (14) 0.429 or 0.404 m
(15)(a) 484.9 t (b) 114 m fwd of A (c) 0.467 or 0.445 m (d) 0.579 m (16)(a) 407.7 tonnes (b) F:3.600 m A:6.076 m (c) 0.564 or 0.535 m
(17)(a) 352.4 tonnes (b) F:4.359 m A:7.349 m (c) 0.328 or 0.316 m (18)(a) 1.188 or 1.145 m (b) -0.023 m or -0.016 m after neglecting FSC
(19) 2.571 or 2.459m (20)(a) 0.742 or 0.694 m (b) 4.180m (hydraft at the critical instant).

Exercise 28 (page 174): (1) 8.889m (2) 8.120m (3) 8.722 m (4) 8.889m (5) 8.800m (6) 8.889 m (7) 8.850 m.

Exercise 29 (page 179): (1) 8.163m (2) 8.000m (3) 8.201 m (4) 8.421m (5) 8.320m (6) 8.556 m (7) 8.680 m.

Exercise 30 (page 185):
(1) (a) 7.333 metres (b) 7.344 metres
(2) (a) 0.262 metres (b) 0.170 metres
(3) (a) 1.681 metres (b) 1.886 metres
(4) (a) 2.042 m (b) 1.473m (5) 0.433 metres
(6) (a) 1.181 m fluid (b) 1.815 m (no FSC)
(7) (a) 0.262 metres (b) -0.003 metres
(8) (a) 2.042 metres (b) 1.575 metres
(9) (a) 1.144 m fluid (b) 1.382 m (no FSC)
(10) Final GM (after bilging) = -0.008 metre.

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
A after perpendicular
K keel
SW salt water of RD 1.025

Load W 19943 t
Light W 6000 t
DWT 13943 t

LOA 150.00 m
LBP 140.00 m
GRT 10,000 Tons
NRT 5576 Tons

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

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Subramaniam, H.

Ship stability