

ADVANCED SHIP STABILITY FOR MARINE OFFICERS

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CHAPTER O

FORMULAE

1. (A) **Areas Of Common Figures :**

$$\text{Circle} = \pi r^2$$

$$\text{Rectangle} = ab$$

$$\text{Square} = a^2$$

$$\text{Trapezoid} = h/2 (a + b)$$

$$\text{Triangle} = \frac{bh}{2}$$

$$= \frac{ab \times \sin \theta}{2}$$

$$= \sqrt{s(s-a)(s-b)(s-c)}$$

(B) $D = \frac{M}{V} \left[\frac{t}{m^3} \right] = \frac{\text{Mass}}{\text{Volume}}$

$$RD = \frac{\text{Density of Substance}}{\text{Density of Fresh Water}}$$

$$\text{Volume of cylinder} = \pi r^2 h$$

$$\text{Pressure} = \frac{\text{Load (Force)}}{\text{Area}} \left[\frac{t}{m^2} \right] \text{ Or } \frac{KN}{m^2}$$

$$1 \text{ tm}^{-2} = 9.81 \text{ KN m}^{-2}$$

$$1 \text{ Bar} = 10.2 \text{ tm}^{-2}$$

2. **List**

$$\text{Tan List} = \frac{d \times w}{W \times GM} = \frac{GG_1}{GM} = \frac{FLM}{W \times GM}$$

3. **Angle Of Loll**

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

$$GM = \frac{2 \times \text{initial GM}}{\cos \text{loll}}$$

4. **Trim / Dry Docking**

$$\text{Trim caused} = \frac{d \times w}{MCTC} = \frac{\text{Trimming moment}}{MCTC} \text{ (Cm)}$$

$$t \times MCTC = P \times LCF (AF) \quad \text{Or} \quad P = \frac{t \times MCTC}{LCF}$$

$$Tt = \frac{\text{Trimming Moment}}{MCTC} = \frac{P \times LCF}{MCTC} \text{ (during critical period)}$$

$$Ta = \frac{Tt \times AF}{LBP}$$

$$Tf = \frac{Tt \times FF}{LBP} \text{ or } Tt - Ta$$

Change in trim = $\frac{P}{MCTC} + \frac{AF}{LBP} + \frac{P \times AF}{MCTC}$

P after critical period = Drop of water level after critical period X TPC

P at any time = $W_1 - W_2$

Where W_1 = displacement while entering

W_2 = at any time

$$FSC = \frac{F.S.M}{W - P}$$

5. **Mean Rise / Sinkage (in cm)** = $\frac{w}{TPC}$

6. **Areas Of Water Planes**

By Simpson's First Rule Area = $h/3 (a + 4b + 2c + 4d + 2e + 4f + g)$

By Simpson's Second Rule Area = $3h/8 (a + 3b + 3c + 2d + 3e + 3f + g)$

By Simpson's Third Rule or Five-Eight Rule Area = $h/12 (5a + 8b - c)$

By Trapezoidal Rule (For very small h) area = $h \left[\begin{array}{l} \text{Sum of Intermediate ordinates} \\ \text{and } \frac{1}{2} \text{ sum of end ordinates} \end{array} \right]$

Moment of area by third rule = $(3a + 10b - c) \frac{h^2}{24}$

7. **Shift Of COB**

$$BB_1 = \frac{v \times gg_1}{V}$$

8. **Bilging**

Mean sinkage due to bilging of empty compartment = $\frac{v}{A - a}$

$$= \frac{\text{Volume of lost buoyancy}}{\text{Initial area} - \text{Lost area}}$$

Mean sinkage due to compartment with cargo of permeability 'p' = $\frac{vp}{A - ap}$

$$\text{Permeability} = \frac{\text{Stowage factor} - (1 \div \text{R.D.}) \times 100}{\text{Stowage factor}} = \frac{\text{Broken Stowage}}{\text{Stowage Factor}} \times 100$$

9. $KB = \frac{1}{2}$ draft for box shaped vessels.

$$KM_{\min} = B / \sqrt{6}$$

$$KB \text{ of } \nabla = \frac{2}{3}d \text{ from apex}$$

10. **Grounding**

$$\text{Fall in tide in cm} \approx \frac{P}{TPC} + \frac{P \times RF \times RF}{MCTC \times LBP}$$

$$\text{Virtual loss of GM} = \frac{P \times KM}{W} \text{ or } \frac{P \times KG}{W - P}$$

11. **BM :**

$$\text{For all shapes } BM = \frac{I}{V} = \left[\frac{m^4}{m^2} \right]$$

$$\text{For box shaped vessels } BM = \frac{b^2}{12d}$$

$$\text{For } \Delta \text{ar shaped vessels } BM = \frac{LB^3 \times 2}{12 \times L \times B \times d} = \frac{B^2}{6d}$$

$$\text{Approximate for ship shapes } BM = \frac{ab^2}{d}$$

$$\text{For triangular prisms } BM = B^2 / 6d$$

$$KB = \frac{2d}{3}$$

$$BM_L \text{ for all shapes } BML = \frac{I_L}{V}$$

$$\text{For box shaped vessels } BML = \frac{l^2}{12d}$$

12. **Loading To Keep Aft Draft Constant, $d = \frac{MCTC \times L}{TPC \times \ell}$**

13. **Dynamical Stability At Some Angle Of Heel :**

$$= W \times \text{Area under the statical stability curve up to that angle of heel.}$$

$$= W \left\{ \frac{v(gh + g_1 h_1)}{v} - BG \times \text{Versine } \theta \right\}$$

14. **GM By Inclining Experiment = $\frac{d \times w}{W} \times \frac{\text{cf (length of pendulum)}}{FL \text{ (Deflection)}}$**

15. **GZ At Small Angles Of Heel**

$$GZ = GM \sin \theta$$

$$\text{By ATWOOD's Formula } GZ = \frac{v \times GG_1}{V} - BG \times \sin \theta$$

$$\text{By Wall Sided formula } GZ = \sin \theta [GM + \frac{1}{2} BM \tan^2 \theta]$$

16. **Free Surface Of Liquids**

$$FSC = \frac{id_i}{V_{do}} = \frac{id_i}{W} = \frac{FSM}{W}$$

$$FSC \text{ total with slack tanks} = 1/n^2 \text{ (FSC Undivided tank)}$$

(Provided watertight divisions are identical)

$$17. \quad MCTC = \frac{W \times GM_L}{100 L} \approx \frac{W \times BM_L}{100 L}$$

Shift of G

$$GG_1 = \frac{d \times w}{W}$$

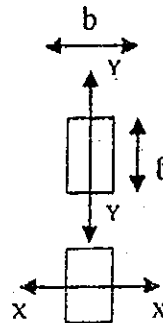
18. **Moment Of Inertia**

$$\text{Transversely for rectangular water plans } I_{YY} = \frac{\ell b^3}{12}$$

$$\text{Longitudinally for rectangular water plans } I_{XX} = \frac{b \ell^3}{12}$$

$$I_{XX} \times \nabla \times = BD^3/36$$

$$I_D \ominus = \pi D^4/64 = \pi r^4/4$$



$$19. \quad TPC = \frac{1.025 A}{100} \text{ in sea water}$$

$$= \frac{\delta A}{100} \text{ in water of density } \delta$$

$$20. \quad \text{FWA} = \frac{W}{4 \text{ TPC}}$$

(in mm)

$$DWA = \frac{\text{FWA} \times (1.025 - \delta)}{0.025}$$

21. Statical Stability

At small angle of heel, moment of statical stability = $W \times GM \sin \theta$

At any angle, moment of statical stability = $W \times GZ$

By Atwood's Formula, Moment of statical stability = $W \left[\frac{v \times gg_1}{V} - BG \times \sin \theta \right]$

For large angles of heel, moment of statical stability = $W \sin \theta (GM + \frac{1}{2} BM \tan^2 \theta)$

21. Form - Coefficients

$$C_w = \frac{\text{Area of water plane}}{L \times B}$$

$$C_m = \frac{\text{Area of A mid ship}}{B \times d}$$

$$C_b = \frac{\text{Volume of displacement}}{L \times B \times d}$$

$$C_b = C_m \times C_p$$

$$22. \frac{\text{New Draft}}{\text{Old Draft}} = \frac{\text{Old density}}{\text{New density}}$$

$$\frac{\text{New Displacement}}{\text{Old displacement}} = \frac{\text{New density}}{\text{Old density}}$$

Hydrostatic Draft = Draft measured at C.O.F.

$$\text{Correction to mean Draft} = HF \times \frac{\text{Trim}}{\text{LBP}}$$

(+ve for stern trim)

$$\text{Correction to Aft draft} = AF \times \frac{\text{Trim}}{\text{LBP}}$$

(-ve for stern Trim)

23. Increase In Draft Due To List

$$\text{New draft} = \frac{1}{2} b \sin \theta + d \cos \theta$$

$$\text{New draft} = \frac{1}{2} b \sin \theta + (d - r) \cos \theta$$

Where r is rise of floor

b is beam

θ is the list

d is draft

24. **Thrust** = $A \delta \text{ Head}$

$$\text{COP}_{\text{WL}} = \frac{I_{\text{WL}}}{A \times \text{head}}$$

25. **Ship's Squat**

$$\text{Blockage factor} = \frac{b \times T}{B \times H}$$

$$\text{Squat}_{(\text{max})} = \frac{C_B \times S^{0.81} \times V_k^{2.08}}{20}$$

26. **Heel Due To Turning**

$$\text{Tan heel} = \frac{v^2 \times BG}{g \cdot r \cdot GM}$$

27. **Rolling Period**

$$T = 2\pi \frac{K}{\sqrt{g \cdot GM}} = \frac{2k}{\sqrt{GM}} \quad (\text{approx})$$

28. **Zero GM**

$$\text{Tan list} = \sqrt[3]{\frac{2 \cdot w \times d}{W \times BM}}$$

29. **Theorem of parallel axes**

$$I_{CG} = I_{OZ} - Ay^2 \quad \text{OR}$$

$$I_{NA} = I_{XX} - Ay^2$$

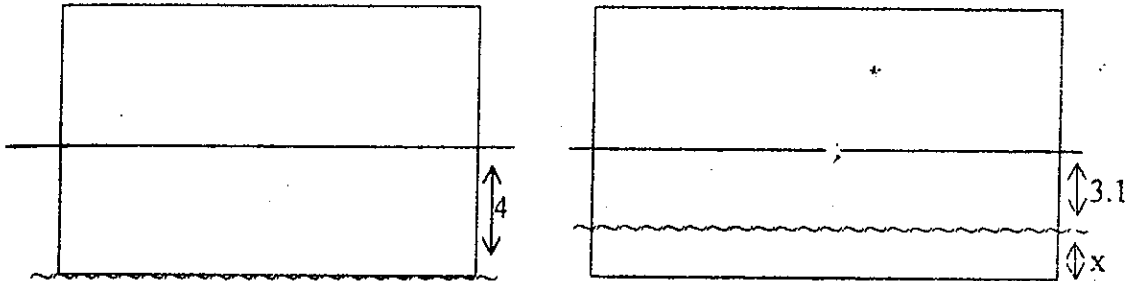
30. **Reserve buoyancy** = Total volume - u/w volume

$$\text{Reserve buoyancy \%} = \frac{\text{Above water volume}}{\text{Total volume}} \times 100$$

CHAPTER I

BASIC PROBLEMS

- Q. 1.** A box shaped vessel floats at a draft of 4m in SW with her keel just clear of the Sea bed which is of soft mud of RD 2.8. The tide then falls by 90cms. Calculate her draft.



$$\begin{aligned}
 \text{Gravitation force} &= \text{Buoyancy force} \\
 L \times B \times 4 \times 1.025 &= L \times B \times 3.1 \times 1.025 + L \times B \times x \times 2.8 \\
 LB (4 \times 1.025) &= LB (3.1 \times 1.025) + LB (2.8x) \\
 \cancel{LB} (4.1) &= \cancel{LB} (3.1775 + 2.8x) \\
 4.1 &= 3.1775 + 2.8x \\
 4.1 - 3.1775 &= 2.8x \\
 \therefore x &= \frac{0.9225}{2.8} \\
 \therefore x &= 0.329\text{m}
 \end{aligned}$$

Depth of water after the fall of tide by 0.9m = $4 - 0.9 = 3.1$ m.

the vsl with sink in the soft mud i.e. $x = 0.329$

$\therefore$ New draft = $3.1 + 0.329 = 3.429$ m.

- Q. 2. A vessel arrived at the river mouth in water of RD 1.027 with a free board of 2.50m. She proceeded up river consuming 56t of fuel & FW and is again at a free board of 2.50m. in water of RD 1.020. Calculate her displacement in salt water.

At a f 'board of 2.50m let her u/w vol = V

Then displacement in S 1.027 = 1.027 V

& displacement in RD 1.020 = 1.020 V

As per given conditions :

$$1.027 V - 56 = 1.020 V$$

$$\therefore V = 56/007 = 8000\text{m}^3$$

Since her underwater volume in δ

$$1.027 = 8000\text{m}^3$$

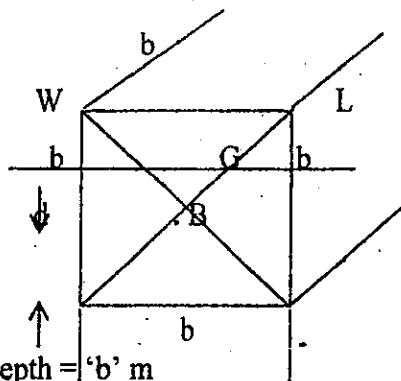
$$\text{Displacement in } \delta \text{ 1.027} = 8000 \times 1.027$$

$$= 8216\text{t}$$

$$\therefore \text{Displacement in S.W.} = \frac{8216 \times 1.025}{1.027}$$

$$= 8200\text{t}$$

- Q. 3. A uniform log of wood of square cross section of density 800 kg/m^3 floats in salt water. Show by calculation whether the log will float with one side of the square parallel to the water line or not? If not, what will be angle of loll.



Breadth = Depth = 'b' m

Length = 'l' m

Draft = 'd' m

Weight of barge = Displacement of barge
when sunk in salt water

$$\begin{aligned} \text{wt. of bg} &= b \times b \times l \times 0.8 \\ &= b^2 \times l \times 0.8 \end{aligned}$$

$$b^2 \times l \times 0.8 = b \times d \times l \times 1.025$$

(Where d is the draft in S.W.)

$$\therefore d = 0.8b / 1.025 = 0.78b$$

$$KB = \frac{1}{2} \text{ draft} = \frac{1}{2} \times 0.78b = 0.39b$$

$$BM = I/V = \frac{lb^3/12}{L \times b \times d}$$

$$= b^2/12d = b^2/12 \times 0.78b$$

$$BM = 0.107b$$

$$\therefore KM = KB + BM = 0.39b + 0.107b = 0.497b$$

$$GM = KM - KG = 0.497b - 0.5b \text{ (KG)}$$

$$= -0.003b$$

Since she has negative GM, she will not float with one side parallel to water line.

$$\begin{aligned} \tan \text{ loll} &= \sqrt{\frac{2GM}{BM}} \\ &= \sqrt{\frac{2 \times 0.003b}{0.107b}} \\ &= \sqrt{\frac{0.006}{0.107}} \end{aligned}$$

$$\therefore \text{Angle of loll} = 13.3^\circ$$

Exercise 1

1. What should be the R.D of a homogenous log of square cross section so that it just floats in fresh water with one face parallel to the water line.

(Hint : The solution of a quadratic equation $ax^2 + bx + c = 0$ will be

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Answer :

Less than 0.2113 or more than 0.7887.

CHAPTER II

SIMPSON'S RULES

Simpson's Rules are used to find areas / volumes and centroids of ship shaped bodies.

There are three rules which are used as follows :

1ST RULE :

$$\text{Area} = (h/3) \times (\text{Sum of Products})$$

& Simpson's multipliers are 1, 4, 1. It holds good for odd number of ordinates like 3, 5, 7, 9 etc. whose general expression is $(3 + 2n)$.

Ordinate	X	S.M.	=	Product for Area
a		1		1a
b		4		4b
c		2		2c
d		4		4d
e		1		1e

$$\text{Sum of Products} = 1a + 4b + 2c + 4d + 1e$$

$$\text{Area} = (h/3) (1a + 4b + 2c + 4d + 1e)$$

* Same holds good for volumes also.

2ND RULE :

$$\text{Area} = (3h/8) \times (\text{Sum of Products})$$

& Simpson's Multipliers are 1, 3, 3, 1. It can be used for $(4 + 3n)$ ordinates / areas where n is the number of ordinate or multiples of $4 + 3n$ eg. 4, 7, 10, 13, 16, 19, 22, 25.....etc.

Ordinates	X	S.M.	=	Product for Area
a		1		1a
b		3		3b
c		3		3c
d		2		2d
e		3		3e
f		3		3f
g		1		1g

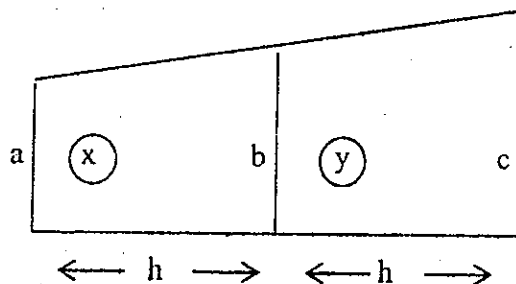
$$\text{Sum of Products} = 1a + 3b + 3c + 2d + 3e + 3f + 1g$$

$$\text{Area} = (3h/8) (1a + 3b + 3c + 2d + 3e + 3f + 1g)$$

* Same holds good for volumes.

3RD RULE :

[5, 8, -1 Rule]



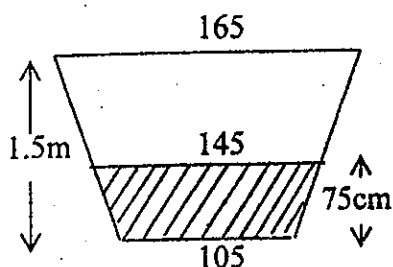
$$\text{Area X} = (h/12) (5a + 8b - c)$$

$$\text{Area Y} = (h/12) (5c + 8b - a)$$

- * (General) :
- * Where both rules are applicable always use the 1st rule and not the 2nd rule because it is more accurate.
- * When not fitting any rule use 1st and 2nd rule together.
- * When semi or half ordinates are given Multiply the area obtained by 2 to get full area.
- * For the 3rd rule, always note carefully from which end the area is required.
- * When working with two different rules, always work fully and separately and then add the two areas / volumes.

EXAMPLES :

- Q. 1. A DB Tank 1.5m deep has the following equally spaced horizontal areas. Commencing from the tank top : 165, 145, 105 m² respectively. The tank contains oil of RD 0.90 to a sounding of 0.75 m. Calculate the weight of the oil?



Ordinate	X	S.M.	=	Product for vol
105		5		525
145		8		1160
165		-1		-165
Sum of product vol.				1520

$$\therefore \text{vol} = \frac{h}{12} \times (\text{Sum of Products of vol.})$$

$$\text{vol} = \frac{0.75}{12} \times 1520 \quad * h = 0.75\text{m draft}$$

$$= 95 \text{ m}^3$$

$$\therefore 95 \times 0.90 = 85.5 \text{ t of oil}$$

- Q. 2. The Semi ordinates of a ship's water plane area, 126m in length are 0.9, 2.5, 4.8, 6.0, 5.5, 3.5 & 2.0m at equal intervals. Calculate her TPC & FWA if her displacement at that draft is 6800t.

$$h = \frac{126}{6} = 21 = h$$

Ordinates X SM = Product for Area

0.9	1	0.9
2.5	4	10.0
4.8	2	9.6
6.0	4	24.0
5.5	2	11.0
3.5	4	14.0
2.0	1	2.0

Half Area = $\frac{h}{3} \times \text{Sum of Product}$
 $= \frac{21}{3} \times 71.5$

Half Area = 500.5m^2

Full Area = 1001.0m^2

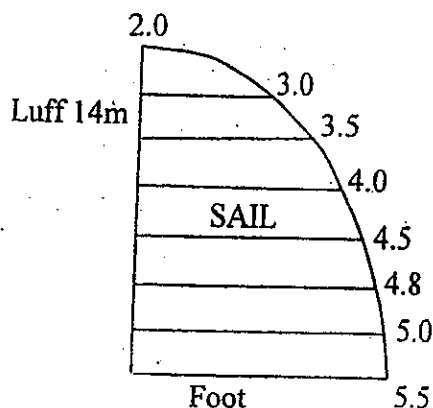
Sum of Products 71.5

$$\text{Now TPC} = \frac{1.025 \times \text{Area}}{100} = \frac{1.025 \times 1001.0}{100}$$

$$\text{TPC} = 10.26 \text{ t/cm}$$

$$\text{FWA} = \frac{W}{40 \text{ TPC}} = \frac{6800}{40 \times 10.26} = 16.57 \text{ cm.}$$

Q. 3. The fore Sail of the yacht has a luff 14m, the width of the sail at equal intervals commencing from foot are 5.5, 5.0, 4.8, 4.5, 4.0, 3.5, 3.0, and 2.0 mt. Calculate the area of the sail when stretched?



Note : Since the number of ordinates are 8, this problem will be solved by 1st and 2nd rule together

Here $h = 2\text{m}$

For Area X the ordinates are :

1ST RULE

Ordinate	X	SM	=	Products for Area
5.5		1		5.5
5.0		4		20.0
4.8		2		9.6
4.5		4		18.0
4.0		1		4.0
		Sum	=	<u>57.1</u>

$$\begin{aligned}
 \text{Area} &= \frac{h}{3} \times \text{Sum of Products} \\
 &= \frac{2}{3} \times 57.1 \\
 &= 38.067 \text{m}^2 \text{ Area X}
 \end{aligned}$$

For Area Y the ordinates are

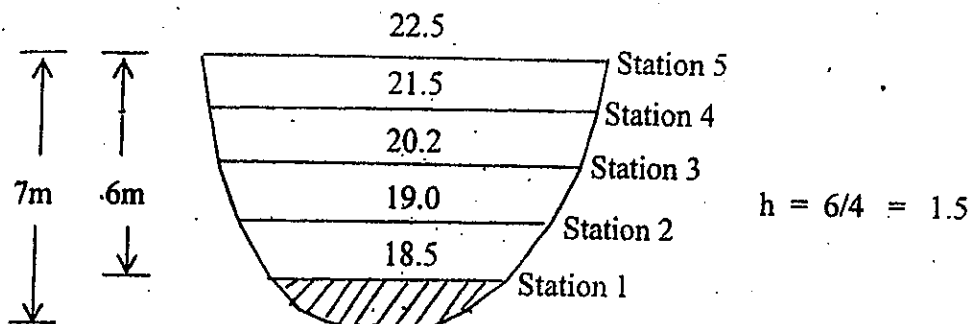
2ND RULE

Ordinate	X	SM	=	Products for Area
4.0		1		4.0
3.5		3		10.5
3.0		3		9.0
2.0		1		2.0
		Sum	=	<u>25.5</u>

$$\begin{aligned}
 \text{Area} &= \frac{3h}{8} \times \text{Sum of Products} \\
 &= \frac{3}{8} \times 25.5 \times 2 \\
 &= 19.125 \text{m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Thus the total area when the sail is stretched} &= \text{Area X} + \text{Area Y} \\
 &= 38.067 + 19.125 \\
 &= 57.192 \text{ m}^2
 \end{aligned}$$

Q.4. The load draft of a ship is 7 mts, her TPC's at equal intervals commencing from 1m water line are 18.5, 19.0, 20.2, 21.5 and 22.5. Below the 1m draft the volume of the appendage is 1800m^3 . Calculate her displacement and FWA?



6m because, vol. below 1m draft is already given and difference between 1 to 5 = 4 hence $h = 6/4 = 1.5\text{m}$

Ordinates (TPC)	Areas	SM	
18.5	1804.88	1	1804.88
19.0	1853.66	4	7414.64
20.2	1970.73	2	3941.46
21.5	2097.56	4	8390.24
22.5	2195.12	1	2195.12
			<u>23746.34</u>

$$\text{Volume} = 1.5/3 \times 23746.34$$

$$= 11873.17$$

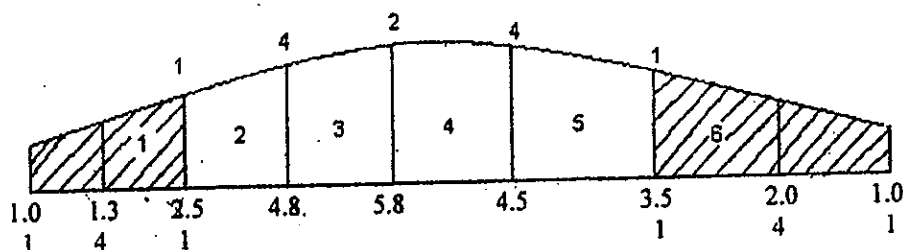
$$+ 1800$$

$$\underline{13673.17 \text{ m}^3}$$

$$\text{DISP} = 14015.0\text{t}$$

$$\text{FWA} = \frac{14015.0}{40 \times 22.5} = 15.57 \text{ Cm.}$$

- Q. 5.** A ship's water plane 96m in length has the following half ordinates 1.0, 1.3, 2.5, 4.8, 5.8, 4.5, 3.5, 2.0 and 1.0. The intervals between the 1st three and last three half ordinates is half that between the others. Calculate her TPC.



$$h = 96/6 = 16\text{m}$$

* Note : Here the first 3 ordinate and the last 3 ordinates are $\frac{1}{2} h$

$\therefore$ Total number of equally spaced ordinates are 6

SM	X	Ordinates	=	Product
0.5		1.0		0.50
2.0		1.3		2.60
1.5		2.5		3.75
4.0		4.8		19.20
2.0		5.8		11.60
4.0		4.5		18.00
1.5		3.5		5.25
2.0		2.0		4.00
0.5		1.0		0.50
Sum =				<u>65.40</u>

$$\text{Half Area} = 16/3 \times 65.40$$

$$= 348.80 \text{ m}^2$$

$$\text{Thus full Area} = 697.60 \text{ m}^2$$

$$\text{TPC} = \frac{1.025 \times A}{100} = \frac{1.025 \times 697.60}{100} = 7.15 \text{ t/cm}$$

Q. 6. The water plane areas of a ship at draft of 12 meters are as follows:

Draft	0	1	2	3	4	6	8	10	12
WPA	1100	1750	1800	1850	1950	1980	2000	2150	2200
S.M.	$\frac{1}{2}$	2	1	2	$1\frac{1}{2}$	4	2	4	1

Calculate her displacement?

$$h = 12/6$$

$$h = 2$$

* Note : There are only 6 ordinates as keel to 4m are considered $\frac{1}{2}$ ordinates.

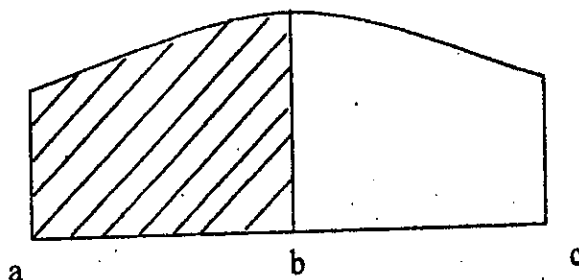
Ordinates	X	S.M. =	Product
1100		0.5	550
1750		2.0	3500
1800		1.0	1800
1850		2.0	3700
1950		1.5	2925
1980		4.0	7920
2000		2.0	4000
2150		4.0	8600
2200		1.0	2200
	Sum	=	<u>35195</u>

$$\begin{aligned} \therefore \text{Vol.} &= h/3 \times \text{Sum of Products} \\ &= 2/3 \times 35195 \\ &= 23463.33 \end{aligned}$$

$$\begin{aligned} \therefore \text{Displacement} &= \text{Vol.} \times 1.025 \\ &= 23463.33 \times 1.025 \\ W &= 24049.92 \text{ t} \end{aligned}$$

CENTER OF GRAVITY OF AREA / VOL

$$\text{Centroid of Area} = \frac{\text{Moment of Area}}{\text{Total Area}}$$



Area Calculation : By Rule No. 3

Ordinate	X	S.M.	=	Product of Area
a		5		5a
b		8		8b
c		-1		-c
				S.O.A

$$\text{Area} = \text{S.O.A} \times h/12$$

Moment Calculation : By Rule No. 3

Ordinate	X	Levers	=	Product of moment
a		3		3a
b		10		10b
c		-1		-c
				S.O. Moment

$$\text{Moment of Area} = \text{S.O.Moment} \times \frac{h^2}{24}$$

❖ EXERCISE :

1. The half ordinates of a ships water plane 210m in length commencing from fore end are : 0.0, 2.5, 4.5, 6.0, 5.2, 3.5 and 1.0m at equal intervals. Calculate her water plane area and the position of her C.O.F. with respect of her midship.

$$h = 210/6 = 35 = h$$

Half Ordinates X S.M. = Product of Area X lever = Product of Moment					
F	0.0	1	0.0	6h	0.0h
	2.5	4	10.0	5h	50.0h
	4.5	2	09.0	4h	36.0h
	6.0	4	24.0	3h	72.0h
	5.2	2	10.4	2h	20.8h
	3.5	4	14.0	1h	14.0h
A	1.0	1	1.0	0h	0.0h
		S.O.A	<u>68.4</u>	S.O.M.	<u>192.8h</u>

(i) $\text{Area} = \frac{35}{3} \times \text{S.O.A}$
 $= \frac{35}{3} \times 68.4 \times 2$
 $= 1596.0 \text{ m}^2$

C.O.F from A = $\frac{\text{Prod of Moment}}{\text{Product of Area}}$ = 98.65

(ii) $\text{Moment of Area} = 192.8 \times (35/3) \times 35 \times 2 = 157453.33$
 $\therefore \text{C.O.F} = \frac{157453.33}{1596} = 98.65 \text{ m from Aft}$

Now C.O.F with respect to mid ship = $210/2 = 105$ is mid ship.

$\therefore 105 - 98.65 = 6.35 \text{ m} = \text{C.O.F. from midship}$

C.O.F. = 6.35 m Aft of mid ship

$= \frac{1}{3} \times 35 \times 192.8 \times 35 \times 2$

2. A vessel of $W = 7500$ T, $KG = 6.2$ has a DB Tank 2.0 m deep, the horizontal areas of which commencing from tank top are 225, 190, 172 m^2 at equal spacing. The tank is run up with salt water to a sdg. of 1.0m. Calculate her KG?
- $h = 2.0/2 = 1.0$

➤ 3rd Rule

Ordinate	X	S.M. =	Product
172		5	860
190		8	1520
225		-1	-225
		S.O.P.	<u>2155</u>

$$\begin{aligned}\therefore \text{Vol} &= \frac{h}{12} \times 2155 \\ &= \frac{1.0}{12} \times 2155 \\ &= 179.58 \text{ m}^3\end{aligned}$$

$$\begin{aligned}W &= \text{Vol} \times 1.025 \\ &= 179.58 \times 1.025\end{aligned}$$

$$W = 184.069 \text{ t}$$

Ordinate	X	S.M. =	Product of Mom
172		3	516
190		10	1900
225		-1	-225
		S.O.P.	<u>2191</u>

$$\begin{aligned}\text{Mom of vol.} &= \frac{\text{S.O.M.} \times h^2}{24} \\ &= \frac{2191 \times 1^2}{24} \\ &= 91.29\end{aligned}$$

$$\therefore \text{C.O.G} = \frac{\text{Moment of Vol}}{\text{Total Vol}} = \frac{91.29}{179.58} = 0.508 \text{ m}$$

	Weight	Kg.	Moments
Ship	7500	6.2	46500
Weight	184.069	0.508	93.507
	<u>7684.069</u>		<u>46593.507</u>

$$\therefore \text{New KG} = \frac{46593.507}{7684.069} = 6.064 \text{ m.}$$

$$\therefore \text{New KG} = 6.064 \text{ m.}$$

The half ordinates of a ship's water plane area 210 m in length at equal intervals, commencing from after end are 2.0, 3.5, 5.8, 7.5, 9.0, 6.0, 3.0, & 0.0 m. Calculate her TPC & LCF.

> Area A1

$$h = 210/7 = 30\text{m}$$

Half Ordinate	X	S.M.	=	Product for Area
2.0		1		2.0
3.5		4		14.0
5.8		2		11.6
7.5		4		30.0
9.0		1		9.0
		S.O.A.		<u>66.6</u>

$$A1 = 66.6 \times 30/3$$

$$A1 = 66.6 \times 2$$

$$A1 = 1332 \text{ m}^2$$

> Area A2

Half Ordinate	X	S.M.	=	Product for Area
9.0		1		9.0
6.0		3		18.0
3.0		3		9.0
0.0		1		0.0
		S.O.A.		<u>36.0</u>

$$A2 = 36 \times 30/8 \times 3$$

$$A2 = 405 \times 2$$

$$A2 = 810 \text{ m}^2$$

$$\text{Total Area} = 1332 + 810 = 2142 \text{ m}^2$$

➤ **Moment 1**

Product of Ordinate	X	Lever =	Product for Moment
2.0		0h	0.0h
14.0		1h	14.0h
11.6		2h	23.2h
30.0		3h	90.0h
9.0		4h	36.0h
		S.O.P. 1	= <u>163.20h</u>

$$\therefore M_1 = \text{S.O.P.} \times \frac{h}{3} \times h = 163.2 \times \frac{30}{3} \times 30$$

$$= 48960 \times 2 = 97920 = M_1$$

➤ **Moment 2**

Product of Ordinate	X	Lever =	Product for Moment
9.0		4h	36.0h
18.0		5h	90.0h
9.0		6h	54.0h
0.0		7h	0.0h
		S.O.P. 2	= <u>180.0h</u>

$$M_2 = \text{S.O.P.} \times 3 \frac{h}{8} \times h = \frac{180 \times 30 \times 30 \times 3}{8}$$

$$= 60750 \times 2 = 121500 = M_2$$

$$\therefore \text{Total Moment} = M_1 + M_2 = 219420$$

$$\therefore \text{LCF} = \frac{219420}{2142} = \frac{\text{Total Moment}}{\text{Total Area}}$$

$$\text{LCF} = 102.437 \text{ m}$$

$$\text{TPC} = \frac{1.025 \times A}{100} = \frac{1.025 \times 2142}{100}$$

$$\text{TPC} = 21.955 \text{ t/cm}$$

4. The water plane areas of a ship are as follows:

Draft = 0.0 1.0 2.0 4.0 6.0 8.0 10.0

w/p = 2200 2315 2400 2512 2600 2650 2700

Calculate her W, KB and FWA at the draft of 10 m?

Ordinates	X	S.M	= Product for Vol	X	Lever	= Product for Moment
2200		0.5	1100		0.0h	0.00h
2315		2.0	4630		0.5h	2315h
2400		1.5	3600		1.0h	3600h
2512		4	10048		2h	20096h
2600		2	5200		3h	15600h
2650		4	10600		4h	42400h
2700		1	2700		5h	13500h
		S.O. Vol	<u>37878</u>		S.O.P.	<u>97511h</u>

$$h = 10/5 = 2$$

$$\text{Vol} = \text{S.O.Vol} \times \frac{h}{3}$$

$$= 37878 \times \frac{2}{3}$$

$$\text{Vol} = 25252 \text{ m}^3$$

$$\therefore W = 25252 \times 1.025$$

$$W = 25883.3 \text{ t}$$

$$\therefore \text{KB} = \frac{\text{Total Moment}}{\text{Total Vol}} = \frac{130014.667}{25252} = 5.148 \text{ m.}$$

$$\text{FWA} = \frac{W}{40 \times \text{TPC}}$$

$$\text{Now TPC at 10m draft} = \frac{1.025 \times A}{100}$$

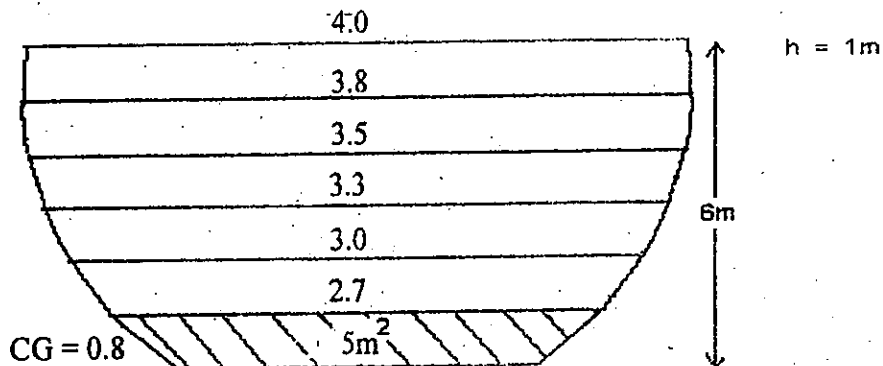
$$= \frac{1.025 \times 2700}{100}$$

$$\text{TPC} = 27.675 \text{ t/cm}$$

$$\therefore \text{FWA} = \frac{25883.3}{40 \times 27.675}$$

$$\therefore \text{FWA} = 23.38 \text{ cm.}$$

5. The semi ordinates of a b' head 6m in height at 1m interval commencing from the top of the b' head are 4.0, 3.8, 3.5, 3.3, 3.0 and 2.7 m. Below the last ordinate the area of the b' head is 5.0m^2 with its C.G. = 0.8m from the bottom of b' head. Calculate the area of b' head and the distance of its CG from the bottom of b' head?



➤ A1 S/O X S.M = Product for area

4.0	1	4.0
3.8	4	15.2
3.5	1	3.5
S.O.A. ₁		<u>22.7</u>

$$\text{Area} = \text{S.O.A.}_1 \times \frac{h}{3} \times 2 = 22.7 \times \frac{1}{3} \times 2$$

$$\underline{A_1 = 15.133 \text{ m}^2}$$

➤ A2 S/O X S.M. = Product for area

3.5	1	3.5
3.3	3	9.9
3.0	3	9.0
2.7	1	2.7
S.O.A. ₂		<u>25.1</u>

$$\text{Area} = \text{S.O.A.}_2 \times \frac{3h}{8} \times 2 = 25.1 \times \frac{3}{8} \times 2$$

$$\underline{A_2 = 18.825 \text{ m}^2}$$

$$\text{Total Area} = A1 + A2 = 15.133 + 18.825 = 33.958 \text{ m}^2$$

$$\text{Grand Total Area} = 33.958 + 5 = 38.958 \text{ m}^2$$

M1	Product for Area	X	Lever =	Product for Mom	M2	Product for Area	X	Lever =	Product for Mom
	4.0		0h	0.0h		3.5		2h	7.0h
	15.2		1h	15.2h		9.9		3h	29.7h
	3.5		2h	7.0h		9.0		4h	36.0h
			S.O.P.	<u>22.2h</u>		2.7		5h	13.5h
								S.O.P.	<u>86.2h</u>

$$\begin{aligned} \text{Moment} &= \text{S.O.P.} \times \frac{h}{3} \times 2 \times h \\ &= 22.2 \times \frac{1}{3} \times 2 \end{aligned}$$

$$M1 = 14.8$$

$$\begin{aligned} \text{Moment} &= \text{S.O.P.} \times \frac{3h}{8} \times 2 \times h \\ &= 86.2 \times \frac{3}{8} \times 2 \end{aligned}$$

$$M2 = 64.65$$

$$\therefore \text{Total Moment} = M1 + M2 = 14.8 + 64.65 = 79.45$$

$$\text{CG (A1 + A2) from 'top'} = \frac{79.45}{33.958} = 2.339$$

$$\text{CG from bottom} = 6.000 - 2.339 = 3.661 \text{ m}$$

$$\begin{aligned} \therefore \text{Total moment from bottom} &= \text{Area} \times \text{CG} + \text{Area} \times \text{CG} \\ &= (33.958 \times 3.661) + (5.0 \times 0.8) \end{aligned}$$

$$\text{Total Moment from bottom} = 128.32$$

$$\therefore \text{CG from bottom} = \frac{\text{Total Moment from bottom}}{\text{Total Area}}$$

$$= \frac{128.32}{38.958}$$

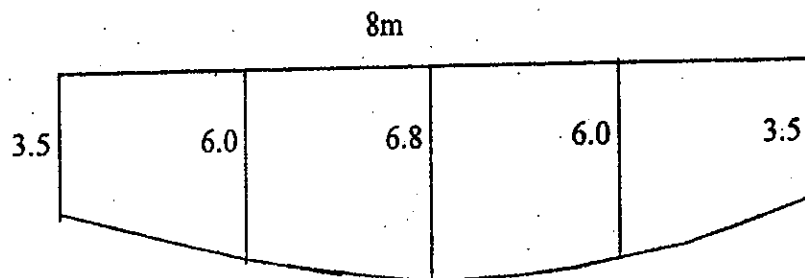
$$\therefore \text{CG} = 3.294 \text{ m from the bottom.}$$

CG when ordinates are parallel to KG

- Ordinates X SM = P.O.A X Ordinate = Product for Moment
- Area = S.O.A X $h/3$
- Moment of area = S.O.M. X $h/3$ X $\frac{1}{2}$ (important).

6. A b' head 12m broad at the top has the following equally spaced vertical ordinates 3.5, 6.0, 6.8, 6.0 and 3.5 m. Calculate the area of b' head and the distance of its CG from the bottom of the b' head?

Ordinate	X	S.M.	=	P.O.A X	Ordinate	=	P. for Mom
3.5		1		3.5	3.5		12.25
6.0		4		24.0	6.0		144.00
6.8		2		13.6	6.8		92.48
6.0		4		24.0	6.0		144.0
3.5		1		3.5	3.5		12.25
		S.O.A	=	<u>68.6</u>			S.O.M. = <u>404.98</u>



$$h = 12/4 = 3\text{m}$$

$$\text{Area} = 68.6 \times \frac{3}{3} = 68.6\text{m}^2$$

$$\text{Moment of Area} = 404.98 \times \frac{3}{3} \times \frac{1}{2} = 202.49$$

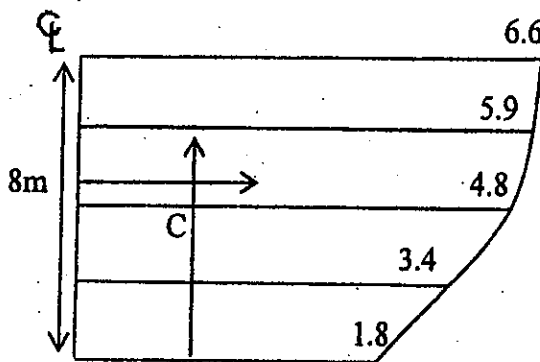
$$\therefore \text{CG} = \frac{\text{Total Moment}}{\text{Total Area}} = \frac{202.49}{68.6} = 2.95\text{m}$$

$$\text{CG from bottom} = 6.8 - 2.95 = 3.85\text{ m}$$

(* here 6.8 is the centre ordinate)

❖ PROBLEMS :

7. The end b' head of a port deep tank 8m in height which is bounded on the inboard side by the ship's centre line longitudinal bulkhead and on the outboard side by the ship side, has the following equally spaced horizontal ordinates, commencing from the top of the bulkhead. 6.6, 5.9, 4.8, 3.4 and 1.8 m. Calculate the area of the bulkhead and the position of it's centroid (a) from the bottom of b' head (b) from the ship's center line bulkhead.



$$h = 8/4 = 2.0 \text{ m}$$

Ordinate	X	S.M	=	Product for Area	X	lever	=	Product for Mom
1.8		1		1.8		0h		0.0h
3.4		4		13.6		1h		13.6h
4.8		2		9.6		2h		19.2h
5.9		4		23.6		3h		70.8h
6.6		1		6.6		4h		26.4h
		S.O.A		<u>55.2</u>		S.O.M.		<u>130.0h</u>

$$\text{Area} = \text{S.O.A.} \times \frac{h}{3}$$

$$= 55.2 \times \frac{2}{3}$$

$$\text{Area} = 36.8 \text{ m}^2$$

$$\text{Total Moment from bottom} = \text{S.O.M.} \times \frac{h}{3} \times h$$

$$= 130 \times \frac{2}{3} \times 2$$

$$= 173.33 \text{ m}$$

$$\therefore \text{CG from the bottom} = \frac{\text{Total Moment}}{\text{Total Area}} = \frac{173.33 \text{ m}^3}{36.8 \text{ m}^2}$$

$$\therefore \text{CG from the bottom} = 4.71 \text{ m.}$$

➤ Moments from the $\bar{C}$:

Product of Area $\times$ Ordinates = Product for Moment by area

1.8	1.8	3.24
13.6	3.4	46.24
09.6	4.8	46.08
23.6	5.9	139.24
06.6	6.6	43.56
S.O.P		<u>278.36</u>

$$\begin{aligned}\therefore \text{Moments from } \bar{C} &= \text{S.O.P.} \times \frac{h}{3} \times \frac{1}{2} \\ &= 278.36 \times \frac{2}{3} \times \frac{1}{2} \\ &= 92.787 \text{ m}\end{aligned}$$

$$\begin{aligned}\therefore \text{CG from the } \bar{C} &= \frac{\text{Total Moments along } \bar{C}}{\text{Total Area}} \\ &= \frac{92.787 \text{ m}}{36.8 \text{ m}^2}\end{aligned}$$

$$\text{CG from } \bar{C} = 2.521 \text{ m}$$

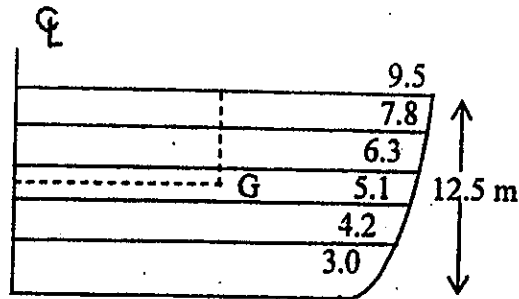
8. A stbd deep tank is bounded by the ship's $\bar{C}$ bulkhead on one side and the ship's hull on the other side. The end bulkhead of the tank is 12.5m in height and has the following equally spaced horizontal ordinates commencing from bottom 3.0, 4.2, 5.1, 6.3, 7.8 and 9.5 m . Calculate the area of the bulkhead and the position of centroid

(a) with respect to top of bulkhead

(b) from the $\bar{C}$ of b' head?

Since the No. of ordinate is 6, two rules will be applied 1st rule for the 1st 3 ordinates and 2nd rule for the rest.

$$h = 12.5/5 = 2.5 = h$$



❖ WORKING FROM TOP :-

Ordinate	X	S.M.	= P.O.A.	X	Lever	= Product for Mom.
9.5		1	9.5		0h	0.0h
7.8		4	31.2		1h	31.2h
6.3		1	6.3		2h	12.6h
		S.O.A.	<u>47.0</u>			S.O.P. <u>43.8h</u>

$$\therefore \text{Area A1} = \text{S.O.A.} \times h/3 = 47 \times 2.5/3 = 39.166 \text{ m}^2 = \text{A1}$$

$$\text{Moment M1} = \text{S.O.P.} \times h/3 \times h = 43.8 \times 2.5/3 \times 2.5 = 91.25 \text{ m}$$

Ordinate	X	S.M.	= P.O.A.	X	Lever	= Product for Mom.
6.3		1	6.3		2h	12.6h
5.1		3	15.3		3h	45.9h
4.2		3	12.6		4h	50.4h
3.0		1	3.0		5h	15.0h
		S.O.A.	<u>37.2</u>			S.O.P. <u>123.9h</u>

$$\therefore \text{Area A2} = \text{S.O.A.} \times 3/8 h = 37.2 \times 3/8 \times 2.5 = 34.875 \text{ m}^2 = \text{A2}$$

$$\therefore \text{Moment M2} = \text{S.O.P.} \times 3/8 \times h \times h = 123.9 \times 3/8 \times 2.5 \times 2.5 = 290.39 \text{ m}$$

$$\therefore \text{Total Area} = \text{A1} + \text{A2} = 34.875 + 39.166 = 74.04 \text{ m}^2$$

$$\text{Total Mom} = \text{M1} + \text{M2} = 91.25 + 290.39 = 381.64 \text{ m}$$

$$\begin{aligned} \therefore \text{CG from the top} &= \text{Total Moment from the top} / \text{Total Area} \\ &= \frac{381.64 \text{ m}}{74.04 \text{ m}^2} = 5.155 \text{ m} \end{aligned}$$

$$\therefore \text{CG from Top} = 5.155 \text{ m}$$

Working from $\bar{C}$:

P.O.A. $\times$ Ordinate = Product for Mom

9.5	9.5	90.25
31.2	7.8	243.36
6.3	6.3	39.69
	S.O.P.	<u>373.30</u>

$$\therefore \text{Moment } \bar{C}_1 = \text{S.O.P.} \times h/3 \times \frac{1}{2}$$

$$= 373.3 \times 2.5/3 \times \frac{1}{2} = 155.54 = \bar{C}_1 \text{ Mom}$$

P.O.A. $\times$ Ordinate = Product for Mom

6.3	6.3	39.69
15.3	5.1	78.03
12.6	4.2	52.92
3.0	3.0	09.00
	S.O.P	<u>179.64</u>

$$\therefore \text{Moment } \bar{C}_2 = \text{S.O.P.} \times \frac{3h}{8} \times \frac{1}{2}$$

$$= 179.64 \times \frac{3 \times 2.5}{8} \times \frac{1}{2} = 84.206 = \bar{C}_2 \text{ Mom}$$

$$\therefore \text{Total Moments about } \bar{C} = \bar{C}_1 + \bar{C}_2$$

$$= 155.54 + 84.206$$

$$\text{Total Mom } \bar{C} = 239.746 \text{ m}$$

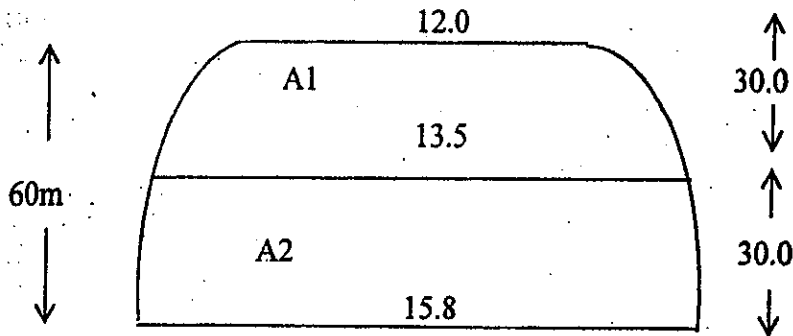
$$\therefore \text{CG from } \bar{C} = \text{Total Mom } \bar{C} / \text{Total Area}$$

$$= \frac{239.746 \text{ m}}{74.04 \text{ m}^2}$$

$$\text{CG from } \bar{C} = 3.238 \text{ m}$$

The fore deck of a vessel is 60m in length. The width of the deck @ equal intervals commencing from its fore end are 12.0, 13.5 and 15.8m. Calculate the area and the CG of the area from the fore end of :

- Fwd half of the deck
- Aft half of deck?



$$\therefore h = 60/2 = 30.0$$

❖ WORKING WITH FWD HALF OF THE DECK :

Ordinate X S.M. = P.O.A

12.0	5	60.0
13.5	8	108.0
15.8	-1	-15.8
S.O.A		<u>152.2</u>

$$\begin{aligned} \therefore \text{Area A1} &= \text{S.O.A.} \times h/12 \\ &= 152.2 \times 30/12 \\ \text{A1} &= 380.50 \text{ m}^2 \end{aligned}$$

Ordinate X S.M. = P.O.M

12.0	3	36.0
13.5	10	135.0
15.8	-1	-15.8
S.O.P		<u>155.2</u>

$$\begin{aligned} \therefore \text{Mom M1} &= \text{S.O.P} \times h^2/24 \\ &= 155.2 \times 30 \times 30/24 \\ \text{M1} &= 5820 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \therefore \text{CG from fwd half} &= \frac{\text{Total Moment}}{\text{Total Area}} \\ &= \frac{5820 \text{ m}}{380.5 \text{ m}^2} \\ &= 15.296 \text{ m} \\ \therefore \text{CG from FWD end} &= 15.296 \text{ m} \end{aligned}$$



❖ WORKING WITH AFTER HALF OF DECK :

Ordinate X S.M. = P.O.A

15.8 5 79

13.5 8 108

12.0 -1 -12

S.O.A 175

Ordinate X S.M. = P.O.M

15.8 3 47.4

13.5 10 135.0

12.0 -1 -12.0

S.O.P 170.4

$$\therefore A2 = \text{S.O.A.} \times \frac{h}{12}$$

$$= 175 \times \frac{30}{12}$$

$$A2 = 437.5 \text{ m}^2$$

$$\therefore M2 = \text{S.O.P.} \times \frac{h^2}{24}$$

$$= 170.4 \times \frac{30 \times 30}{24}$$

$$M2 = 6390 \text{ m}$$

$$\therefore \text{CG from after end} = \frac{\text{Total Moment}}{\text{Total Area}}$$

$$= \frac{6390}{437.5}$$

$$= 14.60 \text{ m}$$

$$\therefore \text{CG from fore end with respect to after half of deck}$$

$$= 60 - 14.60 \text{ m} = 45.39 \text{ m.}$$

is floating upright in S.W. on an even keel at 7m draft F and A. The

are as follows :

h (M)	1	2	3	4	5	6	7
(tonnes)	60	60.3	60.5	60.5	60.5	60.5	60.5

The volume between the outer bottom and 1m draft is 3044. M³, and its centre of

gravity is 0.5m above the keel. Find the ship's KB.

	TPC	AREA	SM	VOLUME	LEVERS	MOMENTS
1	60	60A	1	60 A	0h	0
2	60.3	60.3A	4	241.2A	1h	241.2 Ah
3	60.5	60.5A	2	121 A	2h	242 Ah
4	60.5	60.5A	4	242 A	3h	726 Ah
5	60.5	60.5A	2	121 A	4h	484 Ah
6	60.5	60.5A	4	242 A	5h	1210 Ah
7	60.5	60.5A	1	60.5A	6h	363 Ah
				<u>1087.7A</u>		<u>3266.2 Ah</u>

$$\text{Let } A = \frac{100}{1.025}$$

$$\begin{aligned} \text{Total Volume} &= \frac{h}{3} \times \frac{1087.7 \times 100}{1.025} \\ &= 35372.35 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Total Moments} &= \frac{h}{3} \times 3266.2 \times \frac{100}{1.025} \times h \\ &= \frac{1}{3} \times 3266.2 \times \frac{100}{1.025} \times 1 \\ &= 106217.8862 \end{aligned}$$

$$\begin{aligned} \text{Total Volume} &= 35372.35 + 3044 \\ &= 38416.35 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \therefore \text{KB of Area } A_1 &= \frac{106217.8862}{35372.35} \\ &= 3.0028 \text{ m} + 1 \\ &= 4.0028 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Final KB} &= \frac{\text{Volume of appendage} \times \text{KB} + \text{Volume of area} \times \text{KB}}{\text{Total Volume}} \\ &= \frac{3044 \times 0.5 + 35372.35 \times 4.0028}{38416.35} \\ &= 3.72 \text{ m} \end{aligned}$$

11. The waterplane areas of a ship at 1 m intervals, commencing from the keel are as follows:

Draft (m)	0	1	2	3	4	5	6
Areas (sq. m)	5850	5885	5900	5915	5943	5975	5995

Calculate her KB and FWA at a draft of 6m.

Solution:

$$h = 1\text{m}$$

Ordinates (Areas)	Simpson Mult.	Prod. For Vol.	Levers	Moments
5850	1	5850	0	0
5885	4	23540	h	23540h
5900	2	11800	2h	23600h
5915	4	23660	3h	70980h
5943	2	11886	4h	47544h
5975	4	23900	5h	119500h
5995	1	5995	6h	35970h
		<u>106631</u>		<u>321134h</u>

$$\therefore \text{Total Volume} = \frac{h}{3} \times 106631 = 35543.67 \text{ m}^3$$

$$\therefore \text{Total Moments} = \frac{h}{3} \times 321134 h = 107044.67$$

$$\therefore \text{KB} = \frac{\text{Total Moments}}{\text{Total Area}} = 3.012 \text{ m}$$

$$\text{TPC} = \frac{A}{100} \times \text{R.D.} = 61.45 \text{ t cm}^{-1}$$

$$\therefore \text{FWA} = \frac{10}{40 \text{ TPC}} = 14.82 \text{ cm} = 148.2 \text{ mm.}$$

Ans. **KB** = 3.012 m

FWA = 148.2 mm.

SIMPSON'S RULES

Exercise 2

The TPC of a ship are as follows:

Draft (m)	6.0	5.0	4.0	3.0	2.0
TPC	22.45	22.04	21.53	20.91	19.68

The displacement and KB at 2m draft are 3280t and 1.2m respectively Find the displacement and KB at 6m draft in SW.

The breadths of a ship's water-plane 120m long, measured 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 and 0.0m respectively. Find:

- The water plane area;
- TPC in sea water;
- FWA if displacement is 6690t.

A ship of length 300m floating at a draft of 20m has half ordinates of water plane as follows, commencing from the after perpendicular.

Station	0	$\frac{1}{2}$	1	2	3	4	5	$5\frac{1}{2}$	6
$\frac{1}{2}$ Ordinates	0.1	7.5	10	12	12.3	11.4	8	5.2	1.0

There is an appendage forward with an area of 2.8 m².

- Find : (a) The area of the water plane. (b) The TPC in SW and
(c) The FWA at 20m draft.

4. The area of a ship's water-planes, commencing from the load water-plane and spaced 1m apart, are 800, 760, 700, 600, 450 and 10 sq.m respectively. Midway between the lowest two water-planes, the area is 180 sq.m. Find the load displacement in salt water and the height of centre of buoyancy above the keel.

5. A wall-sided vessel of constant water-plane area of length 105m has the following equally spaced half-ordinates of water plane:
1.7, 3.4, 5.6, 6.7, 6.7, 5.6, 3.4 and 1.7 mtrs. When floating at an even keel draft of 4.5m, an empty compartment with transverse end bulkheads at the 6.7m ordinates is bilged. Calculate the end drafts at which she would settle.

6. A wall sided double bottom tank of depth 1.5m has half ordinates of breadth as follows at 4m intervals commencing at the after bulkhead:

Station	0	1	2	3	4	5	6
$\frac{1}{2}$ ord mtr	6.1	6.0	5.9	5.7	5.4	4.9	4.3

The after bulkhead is 65m forward of the centre of floatation. Calculate the change of trim if the tank is filled with fuel oil density 0.95, MCTC 200 tm.

7. The water plane areas of a ship at 1m intervals, commencing from the keel are as follows:

Draft (m)	0	1	2	3	4	5	6
Areas (sq. m)	5850	5885	5900	5915	5943	5975	5995

Calculate her KB and FWA at a draft of 6m.

8. The breadths of a bulkhead, at 3.0m intervals from the top, are : 19.2, 18.0, 17.1, 16.2, 14.4, 12.0, 9.3 and 6.0 m. Find the distance of its geometric centre from the top. (Use Simpson's I Rule for first five ordinates and II Rule for remaining ordinates).
9. A ship's water plane is 216m in length. The half ordinates of the waterplane commencing from forward are as follows:
0.4, 4.4, 8.8, 11.0, 11.6, 11.8, 11.8, 11.6, 9.6, 7.0, 0.4 respectively.
The spacing between the first three and last three ordinates is half of the spacing between the other half ordinates. Calculate her waterplane area and the position of the CF with respect to the midlength.
10. A double bottom tank is 1.5m deep. The horizontal areas of the tank at equal intervals, commencing from the tank top are 192, 186 and 158 sq.m. respectively. The tank is ballasted to a sounding of 0.75m with water of R.D. 1.012. Calculate the weight of ballast and its KG.
11. A wall sided vessel, 150m in length of constant waterplane, the semiordinates of which at equal intervals are : 0, 5, 9, 10, 9, 5 and 0m, has a double bottom 1m deep extending from side to side between the 9m and 9m half ordinates given. Calculate the thrust on the tanktop if the tank is run up by opening the sea valve, if her original evenkeel draft was 5.2m.
12. The half breadths of a ship's water-plane at 12m intervals from aft are: 0.0, 3.3, 4.5, 4.8, 4.5, 3.6, 2.7 and 1.5m. The half-breadth, midway between the first two from aft is 2m. At the fore end is an appendage by way of a bulbous bow 4.5m long. Its area is 24m^2 and its GC 2m from forward extremity. Find the area of the water-plane and the position of the COF.
13. Three semi-ordinate spaced at equal distance of 20m are 7.5, 11.8 and 15.8m. Calculate
(a) Geometric center of the area between first two and last two ordinates.
(b) Amount of cargo that can be loaded on the deck area between first two ordinates, if the load density of the deck is 10t/m^2 .
14. The TPC values for a ship at 1.2 meters intervals of draught commencing at the keel, are 8.2, 16.5, 18.7, 19.4, 20.0, 20.5, 21.1 respectively. Calculate her displacement at 7.2 metres draught.

-oOo-

Answers

1. Displacement = $8566.33\text{t} + 3280 = 11846.33\text{ t}$, Final KB = 3.253m
2. Water plan area = 1483.2m^2 TPC = 15.2t FWA = 11 cm
3. (a) 5706 m^2 (b) 27.32t (c) 50 mm
4. Load displacement = 2965.63 t, KB = 2.99m
5. 5.3961 m
(a) Area = 43.5m^2 COG = 1.638m
6. Change in trim = 144.2 cm by head.
7. KB = 3.012m FWA = 148.2 mm
8. 8.97m
9. Area = 4233.6 m^2 COF = 104.9m from A or 3.1m from midship.
10. Weight = 131.94t KG = 0.385 m
11. Thrust = 4656.83 tonnes (4.6999 X 1.025 X 966.67)
12. Area = 616.4 m^2 COF 43.09m from aft
13. (a) 10.74m / 9.518m (b) 3870t
14. 13291.954t

-oOo-

CHAPTER III

RIGHTING LEVER AND MOMENTS

K = keel

θ = Angle of heel

B_1 = COB after heeling

M = Transverse Metacentre

GZ = Righting lever

G = COG

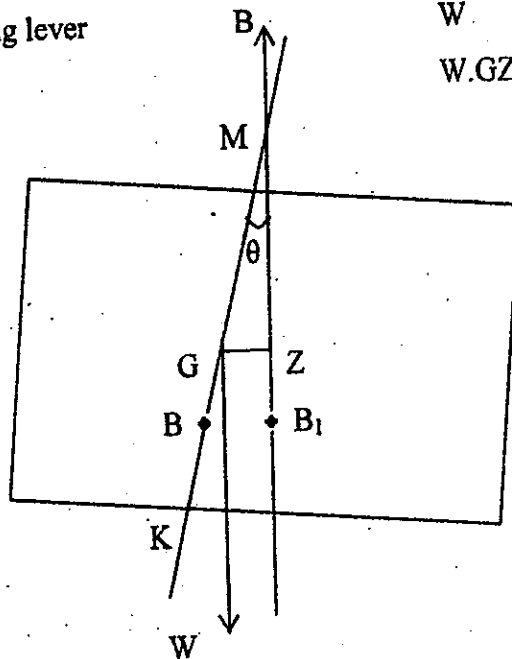
B = COB before heeling

BB_1 = Shift of COB due to heel

GM = Metacentric height

W = Displacement

W.GZ = Righting Moment



❖ THE POINT OF METACENTRIC 'M' :

As shown in the figure above, the intersection of centre-line and vertical through the centre of buoyancy is point of Meta centre.

For small angle of heel, up to about 15° , the shift of the centre of buoyancy is very small, and 'M' which is direct out come of this shift, changes negligible and can be termed as a fixed point. For large angle of heel, the centre of buoyancy moves out very quickly and there is appreciable change in position of M which can no more be considered as constant :

✓ RIGHTING LEVER (GZ) :

When a vessel is heeled, the force of buoyancy, acting vertically upwards through the new position of COB, becomes separated from the force of gravity, acting vertically downwards through the COG, by a horizontal distance called the righting lever (GZ).

GZ normally increases as angle of heel increases until it reaches a maximum value at some large angle of heel. Thereafter, GZ decreases as angle of heel increases.

For small angles of heel (up to about 15°) where in KM, & hence GM, may be considered constant,

$$GZ = GM \times \sin \theta$$

Where θ is the angle of heel and GM is the initial GM.

For large angles of heel, GZ can be calculated by the wall sided formula

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

This formula can be used whenever the ship's sides within the immersed wedge and the emerged wedge are parallel i.e. until the deck edge goes under water. For ship's that are not wall-sided, the sides are parallel only in the parallel middle body, and using the formula for large heel angles will give wrong results. θ is the angle of heel, GM the initial GM and BM is the height of the initial metacentre above the COB before heeling.

✓ RIGHTING MOMENT :

When a vessel is heeled, the forces of gravity and buoyancy, being equal and opposite, become separated by a horizontal distance called the righting lever and form a couple which tends to return the vessel to upright. The moment of this couple is a measure of the tendency of the vessel to return to upright and is hence called the righting moment or "Moment of statical stability".

$$RM = W.GZ$$

For all angles of heel.

For small angles of heel, where GM may be considered constant,

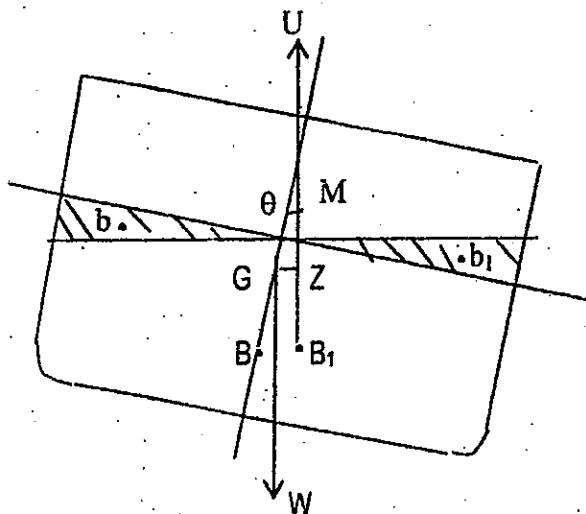
$GZ = GM \sin \theta$ and hence

$$RM = W.GM \sin \theta$$

Sketch (A) shows a ship heeled to a small angle by an external force. The center of buoyancy has moved from B to B_1 . BB_1 is parallel to bb_1 where b and b_1 are the centroids of the wedges (hatched). The line of upthrust through B_1 cuts the centerline at M which is the initial transverse metacentre. For small angles of heel, preferably less than 6° , it can be assumed that the movement of B of the low side follows an arc of a circle. BM is the radius of the arc.

where I is the second moment of area (or the moment of inertia) of the waterplane. For small angles of heel BM can be assumed constant because there is no significant change in the waterplane size or shape, i.e. I is assumed constant.

Conditions at a small angle of heel, but exaggerated.



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M is

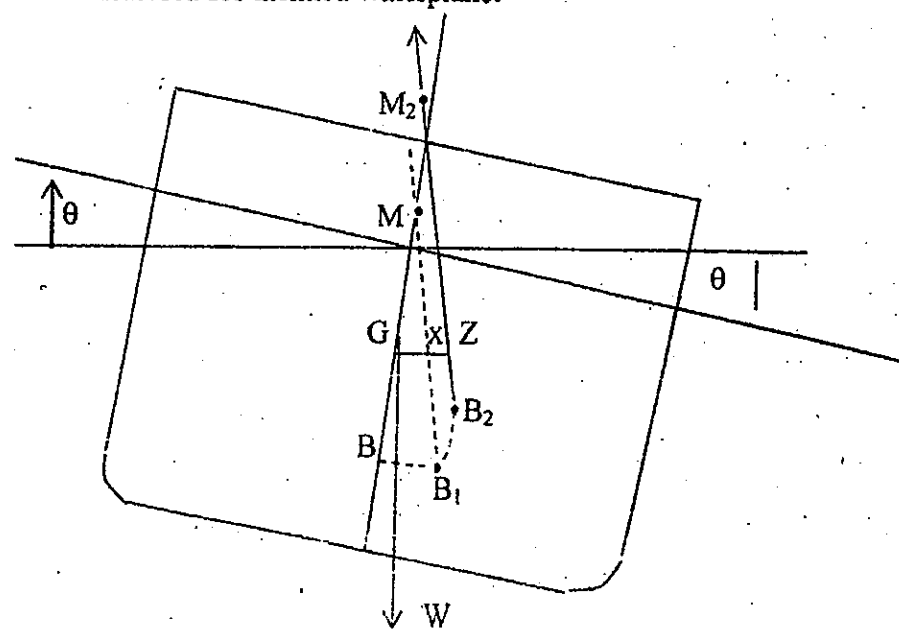
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Sketch (B) shows the vessel heeled to a large angle. When heeled bey
no longer acceptable to assume that B is moving in an arc of a circ
buoyancy from wedge to wedge is such that there is an increasing vert
the vertical component of transfer of buoyancy increases at a fas
horizontal component and B adopts a position B_2 rather than some posi
which it would have had if traveling in a constant arc. The waterplane at the larger angle
heel is larger; consequently I is larger and $BM (= I/V)$ is greater. This gives rise to
new metacentre (the prometacentre) at M_2 .

Sketch (B)

Conditions at a large angle of heel

$B_2M_2 = I/V$ where I is measured for inclined waterplane.



The righting lever arising from this higher position of the center of buoyancy (B_2) the upthrust had been applied at B_1 and passed through M . A formula for this new GZ , which applies for wall-sided inclinations only, is $GZ = GX + XZ = GM \sin \theta + \frac{1}{2} BM \tan^2 \theta \sin \theta$.

i.e. $GZ = (GM + \frac{1}{2} BM \tan^2 \theta) \sin \theta$

The values of GM and BM used in the formula are the readily calculated upright (centerline) values.

PROBLEMS :

1. A boxed shape vessel length 90m, breadth 20m and 6.5m deep is at an even keel draught of 4.0m. Calculate her Righting Moment at:

(a) a heel of @ 7°

(b) the angle of heel at which her deck edge immerses.

$$KG = 4.5 \text{ m.}$$

(a) $KM = KB + BM$

Now KB for box shaped vessel = draft / 2

$$\therefore KB = 4.0 / 2 = 2.0$$

$$BM \text{ for box shaped vessel} = \frac{B^2}{12d} = \frac{20 \times 20}{12 \times 4} = 8.33 \text{ m}$$

$$\therefore KM = 2.0 + 8.33$$

$$KM = 10.33 \text{ m ; Now } KG = 4.5 \text{ m (Given)}$$

$$\therefore GM = KM - KG = 10.33 - 4.5$$

$$\therefore GM = 5.83 \text{ m}$$

$$\therefore GZ = GM \cdot \sin \theta$$

$$= 5.83 \times \sin 7^\circ$$

$$\text{Now } RM = GZ \times W$$

$$\therefore W = L \times B \times \text{draft} \times \text{density}$$

$$= 90 \times 20 \times 4.0 \times 1.025$$

$$W = 7380 \text{ t}$$

$$\text{Thus } RM = W \cdot GZ$$

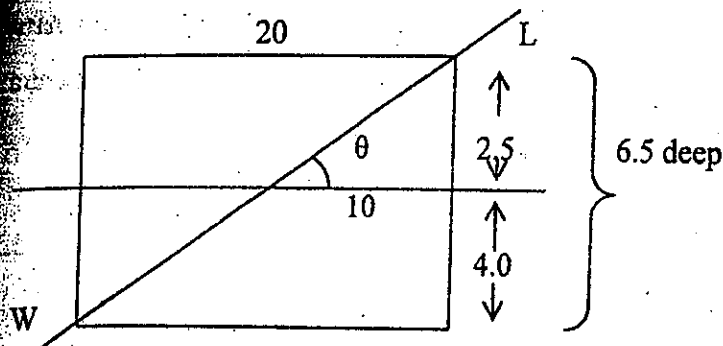
$$= 7380 \times 5.83 \times \sin 7^\circ$$

$$RM = 5243.477 \text{ tm}$$

ven keel

When deck edge immerses in water :

ting of a
ight



$$\begin{aligned}\therefore GZ &= (GM + \frac{1}{2} BM \times \tan^2 \theta) \sin \theta \\ &= (5.83 + 8.33/2 \tan^2 14.04^\circ) \sin 14.04^\circ\end{aligned}$$

$$\begin{aligned}\text{Now RM} &= W \times GZ \\ &= 7380 \times \sin 14.04^\circ [5.83 + 8.33/2 \tan^2 14.04^\circ] \\ \text{RM} &= 10904.2 \text{ tm}\end{aligned}$$

A vessel of $W = 7000 \text{ t}$, $KM = 6.0$, $FSM = 750 \text{ mt}$. has a righting moment 300 mt at a heel of 3° . Calculate her KG ?

$$\begin{aligned}\text{RM} &= W \times GZ & GZ &= GM \times \sin \theta \\ 300 &= 7000 \times GZ & 0.04285 &= GM \times \sin 3^\circ \\ \therefore GZ &= \frac{300}{7000} & GM &= \frac{0.04285}{0.05233}\end{aligned}$$

$$GZ = 0.0429 \text{ m} \quad (F) GM = 0.8188$$

$$\text{GM (S)} = \frac{FSC + 0.107}{0.9258}$$

$$FSC = \frac{FSM}{W} = \frac{750}{7000} = 0.107 \text{ m}$$

$$\therefore GM = KM - KG$$

$$0.9258 = 6.0 - KG$$

$$\therefore KG = 6.0 - 0.9258$$

$$KG = 5.0742 \text{ m,}$$

3. A vessel of $W = 6550$ t, $KG = 6.0$ m has to load further 1500t. At what KG should it be loaded if the ship is to have a Righting Moment of 350 mt at a heel of 3° . KM in final condition is 7.0 m.

$$\text{initial } W = 6550$$

$$\text{Wt. load} = 1500$$

$$\text{Final } W = 8050$$

$$RM = GZ \times W$$

$$350 = GZ \times 8050$$

$$\therefore GZ = 350/8050$$

$$= 0.0435$$

$$\therefore GZ = GM(f) \times \sin \theta$$

$$350/8050 = GM(f) \times \sin 3^\circ$$

$$GM(f) = \frac{0.0435}{\sin 3^\circ} = \frac{0.0435}{0.0523} = 0.8317$$

$$\therefore GM(f) = 0.8317 \text{ m}$$

$$\text{New KM} = 7.0 \text{ m}$$

$$\therefore \text{New KG} = 7 - 0.8317$$

$$= 6.1683 \text{ m}$$

$$\text{Taking Moments, new KG} = \frac{W \times KG + w \times kg}{\text{Final } W}$$

$$\text{i.e. } 6.1683 = \frac{(6550) 6.0 + (1500) X}{8050}$$

$$6550 \times 6.0 + 1500 X = 8050 \times 6.1683$$

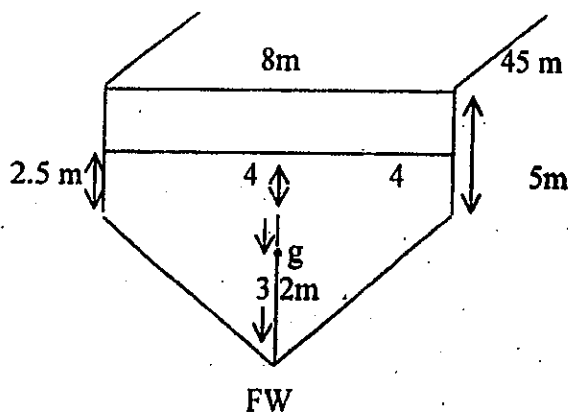
$$\therefore \frac{49654.81 - 39300}{1500} = X$$

$$\text{New KG} = 6.90 \text{ m}$$

$$\therefore X = 6.90 = \text{KG of the cargo to be loaded.}$$

at KG
eel of

A water barge 45m in length has a uniform cross sectional area consisting of a rectangle 8m broad, 5m deep above a triangle of base 8m and height 3m. Light displacement 900t, light kg = 4.5m. Find the GM (fl) if the barge is floating in F.W. and triangular portion is ballasted with F.W.



GM when floating in FW and triangle portion full of GW.

Light boye KG = 4.5m Area of Δ 'ar portion

Light Disp = 900t $\frac{1}{2} \times 8 \times 3 = 12 \text{ m}^2$

$\therefore$ Value of Δ 'ar or portion = $12 \times 45 = 540 \text{ m}^3$

$\therefore$ Ballast = 540 t

When filled with FW, weight added = 540t, Kg = 2 m

Final KG = $\frac{900 \times 4.5 + 540 \times 2}{1440} = \frac{4050 + 1080}{1440} = 3.5625$

Total Disp = 1440t, Total underwater volume (UWV) = 1440 m^3

Length = 45 m

$\therefore$ Total Area = $1440 / 45 = 32 \text{ m}^2$

Triangle Area = 12 m^2

$\therefore$ Rectangular area = $32 - 12 = 20 \text{ m}^2 = 8 \times x$

$\therefore x = 2.5 \text{ m}$

KM = KB + BM

$$KB = \frac{540 \times 2 + 20 \times 45 \times 4.25}{1440} = \frac{1080 + 3825}{1440} = 3.406$$

$$BM = \frac{I}{V} = \frac{45 \times 8^3}{12 \times 1440} = 1.333$$

$$\therefore KM = 4.3758$$

$$KG = -3.5625$$

$$GM(S) = 1.1767 \text{ m}$$

$$FSC = \frac{I\delta}{W} = \frac{45 \times 8^3 \times 1}{12 \times 1440} = 1.333$$

$$GMS = KM - KG$$

$$= KB + BM - KG$$

$$= 3.406 + 1.333 - 3.5625$$

$$GM(fl) = 3.406 + 1.333 - 3.5625 - 1.333$$

$$= -0.1565$$

$$\text{Ans : } -0.1565 \text{ m}$$

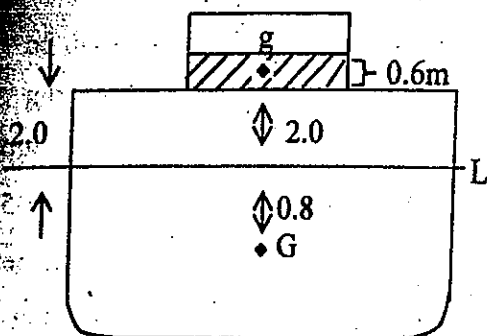
5. A vessel of $W = 7100\text{t}$ has a free board of 2.0m , her CG is 0.8m below the W/L. Due to shipping heavy seas, a swimming pool on deck. $L = 20\text{m}$, $B = 10\text{m}$ fills with water to a depth of 0.6m . Calculate her change in Righting Moment at a heel of 4° .

$$GG_1 = \frac{w \times d}{W}$$

$$\text{Where } w = L \times B \times d \times \delta$$

$$= 20 \times 10 \times 0.6 \times 1.025$$

$$= 123 \text{ t}$$



$$d = 0.8 + 2.0 + 0.3 = 3.1 \text{ m}$$

$$GG_1 = \frac{123 \times 3.1}{7223} = 0.0528$$

$$FSC = \frac{lb^3}{12 W} \times \delta = \frac{20 \times 10^3 \times 1.025}{12 \times 7223} = \frac{20000 \times 1.025}{86676} = 0.2307$$

$$GG_1 \uparrow = 0.0528$$

$$FSC = 0.2365$$

$$\text{Total upward } GG_1 = \frac{0.2893}{}$$

$$\therefore \text{Reduction in GZ} = GG_1 \sin \theta$$

$$= 0.2893 \times \sin 4^\circ$$

$$\text{Reduction in GZ} = 0.0202$$

$$\begin{aligned} \text{New disp} &= 7100 + 123 \\ &= 7223 \text{ t} \end{aligned}$$

$$\therefore \text{Reduction in RM} = W \times GZ$$

$$= 7223 \times 0.0202$$

$$= 145.76 \text{ mt}$$

the W/L.

0m fills

at a heel

MISCELLANEOUS – PHASE I

Exercise 3

1. A water barge 45m long has a uniform transverse cross-section throughout, consisting of a rectangle above a triangle. The rectangle is 8m broad & 5m high. The triangle is apex downwards 8m broad & 3m deep. KG & displacement when empty are 4.5m & 900 tons respectively. Find the GM when floating in F.W. with the triangular portion full of F.W.?
2. (a) A water-barge 50m long has a uniform transverse cross-section throughout, consisting of a rectangle above a semi-circle. The rectangle is 10m broad and 2m high. The semi-circle has a diameter of 10m. Find the KM at 6m draft. (The Geometric Centre of the semi-circle of radius R is $\frac{4R}{3\pi}$ below its centre of curvature. ($\pi = 22/7$))
 (b) If the KG of the empty barge is 4.5m, find the initial transverse GM when the semi-circular portion is filled with fresh water, the draft being 6m.
3. A box shaped vessel 120m X 18m X 12m floating in fresh water on even keel draft of 8m with $K_g = 7.278$ meters loads a weight of 432 tonnes on the centerline at a KG of 11.981 meters. Calculate her KG and KM to the nearest of 0.1 of a cm and hence her righting moment at the angle of heel at which her deck edges is immersed.
4. A water barge 50m in length has a uniform cross sectional area consisting of a rectangle 10m broad, 6m deep above a semicircle of diameter 10m. Light displacement 450t $K_g = 5$ m. Calculate her GM (f) if the semicircle part is filled with SW? (CG of semi circle = $\frac{4r}{3\pi}$)
5. A box vessel $L = 120$ m, $B = 18$ m, $d = 8$ m in SW has $K_g = 6.4$ m. Calculate the length of the righting lever GZ when heeled by an external force.
 - (i) to 5°
 - (ii) to 30°

6. A ship displacing 10000 tonnes SW has $KG = 7.0\text{m}$. The second moment of area of the waterplane (with respect to a centerline longitudinal axis) is 39000 m^4 . $KB = 4.40\text{m}$. Calculate GZ .

(iii) at 4°

(iv) at 24°

7. A box vessel, length 116m , breadth 16m , depth 9.8m is upright on an even keel at a draught 5.7m in SW. $KG = 6.0\text{m}$. Calculate the moment of statical stability when heeled to the angle of deck edge immersion.

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Answers :

1. $GM = -0.1565\text{ m}$
2. (a) $KM = 5.101\text{ m}$
(b) $GM(S) = 1.862\text{ m}$ $GM(f) = 0.212\text{ m}$
3. Deck edge immersion at 22° $53.4'$ heel, $R.M. = 2022.2\text{ tm}$
4. $GM(FI) = 0.080\text{ m}$
5. i. 0.085 m ii. 0.769m
6. i. 0.098m ii. 0.730 m
7. $5361\text{ tonne - metre}$

-oOo-

CHAPTER IV

LIST

List is the transverse inclination caused when the COG of the ship is off the centre line.

$$\tan \theta = \frac{GG_1}{GM}$$

Where θ = is the angle of list

GG_1 = is the transverse shift of COG

GM = is the final fluid GM before listing.

Since $GG_1 = \frac{\overleftrightarrow{dw}}{W}$, the formula becomes.

$$\tan \theta = \frac{\overleftrightarrow{dw}}{W.GM}$$

Where θ is the angle of list $\overleftrightarrow{dw}$ is the final listing moment in tonne metres.

W is the final displacement in tones

GM is the final fluid GM in metres.

In order to calculate the angle of list systematically the following order of work is suggested.

- (i) Find the final listing moment ($\overleftrightarrow{dw}$)
- (ii) Find the final displacement (w)
- (iii) Find the final fluid GM
- (iv) Apply the list formula $\tan \theta = \overleftrightarrow{dw} / GM.W$

❖ PROBLEMS

1. A ship of W 6000 t KG 6.0, KM = 6.5, shifts a weight of 100t transversely to port through a distance of 5m. Calculate the resultant list.

$$GG_1 = \frac{\overleftarrow{dw}}{w} = \frac{5 \times 100}{6000} = \frac{500}{6000} = 0.0833$$

$$KM = 6.5 \text{ m}$$

$$KG = 6.0 \text{ m}$$

$$GM = 0.5 \text{ m}$$

$$GG_1 = \frac{100 \times 5}{6000} = 0.0833 \text{ m}$$

$$\tan \theta = \frac{GG_1}{GM} = \frac{0.0833}{0.5}$$

$$\therefore \tan \theta = 0.1666$$

$$\therefore \theta = 9.46^\circ \text{ List port}$$

2. A vessel of W = 6800 t KG = 5.50 m KM = 6.10 FSM = 700 m.t, discharged 50 t from kg. 9.0m and 3m to port of centre line. Calculate her resultant list.

Ship	6800	5.5	=	37400
Weight	-50	9.0	=	-450.0
	<u>6750</u>			<u>36950</u>

$$\therefore \text{Final KG} = \frac{36950}{6750} = 5.474 \text{ m}$$

$$FSC = \frac{FSM}{W} = \frac{700}{6750} = 0.104 \text{ m}$$

KM	=	6.100
New KG	=	5.474
GM (S)	=	<u>0.626</u>
FSC	=	<u>0.104</u>
GM (f)	=	0.522 m

$$GG_1 = \frac{w \times d}{W} = \frac{50 \times 3}{6750} = \frac{150}{6750} = 0.022\text{m}$$

$$\therefore \tan \theta = \frac{GG_1}{GM(f)} = \frac{0.022}{0.522}$$

$$\therefore \tan \theta = 0.042$$

$$\therefore \theta = 2.44^\circ \text{ stbd.}$$

3. A ship of W 9000 t, kg 6.15 m KM = 6.80m, carried out the following operations loaded 115 t, kg 3.8 and 2m to port of centre line, discharged 250 t kg 9.5 and 3m to port of centre line. A wt. of 90 t is shifted from kg. 6.5m and 6.2 m port of ϕ to a position kg. 3.5m and 2.2m port of centre line. Calculate the resultant list.

To find ILM :

Remarks	Load	Disch.	Shift	dist. Off ϕ	Listing Mom	
					Port	Stbd
	115	-	-	2 (p)	230	-
	-	250	-	3 (p)	-	750
	-	-	90	4 (p)	-	360
					230	1110
						- 230
					FLM = 880 to st	

Ship	Load	Disch.	Shift	KG	Load	Disch.
	9000	-	-	6.15	55350	-
	115	-	-	3.80	437	-
	-	250	-	9.50	-	2375
	-	-	90↓	3.00	-	270
	9115	250			55787	2645
	-250				-2645	
	8865				53142.0	

$$\text{Initial KG} = \frac{53142}{8865} = 5.995\text{m}$$

$$\text{Now KM} = 6.80$$

$$\text{Now KG} = 5.995$$

$$\text{GM (f)} = 0.805$$

$$\text{Now FLM} = 880$$

$$\therefore GG_1 = \frac{dw}{W}$$

$$GG_1 = 880 / 8865$$

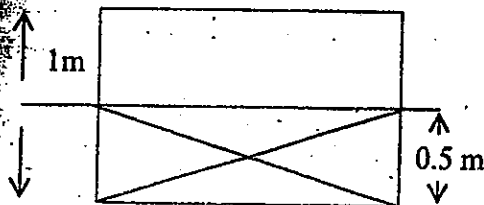
$$= 0.099$$

$$\tan \theta = \frac{GG_1}{GM} = \frac{0.099}{0.805} = 0.1233$$

$$\tan \theta = 0.1233$$

$$\theta = 7.02^\circ \text{ STBD}$$

A ship of $W = 12000 \text{ t}$, $\text{kg. } 6.5\text{m}$ $\text{km } 7.5\text{m}$ $\text{FSM} = 700\text{m.t.}$, has a rectangular stbd D.B. Tank, $15 \times 7 \times 1\text{m}$ with its $\text{CG} = 3\text{m}$ from the ships centre line. Calculate the list if that tank is run up with SW to half its depth?



$$\text{Weight added} = 15 \times 7 \times 0.5 \times 1.025$$

$$= 53.81 \text{ t}$$

$$\text{KG} = \frac{1}{2} \text{ draft} = \frac{0.5}{2} = 0.25 \text{ (m)}$$

12000	6.5	78000
53.81	0.25	13.45
12053.81		78013.45

$$\therefore \text{KG} = \frac{78013.45}{12053.81}$$

$$\text{KG} = 6.472 \text{ m}$$

$$\text{KM} = 7.50$$

$$\text{GM (S)} = 1.028 \text{ m}$$

$$\text{FSC} = 0.095$$

$$\text{GM (f)} = 0.933 \text{ m}$$

$$FSM = I \delta t$$

$$= \frac{L \times b^3 \times \delta t}{12}$$

$$= \frac{15 \times 7^3}{12} \times 1.025$$

$$FSM = 439.47$$

$$\text{Initial FSM} = 700.0$$

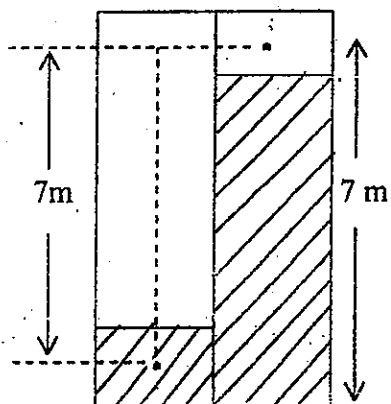
$$\text{Final FSM} = 1139.47$$

$$GG_1 = \frac{3 \times 53.81}{12053.81} = 0.013 \text{ m}$$

$$\therefore \tan \theta = \frac{GG_1}{GM(f)} = \frac{0.013}{0.933}$$

$$\therefore \tan \theta = 0.0144 \quad \therefore \theta = 0.83^\circ \text{ (STBD),}$$

5. A vessel of $W = 16000 \text{ t}$ KG 6.5 m KM $= 8.0 \text{ m}$ has two identical rectangular deep tanks each 5 m long. 8 m wide 7 m deep. The stbd tank is full with FW and port tank is empty. The transverse distance between their C.O.G is 7.5 m . Calculate the list produced if 40 t of FW is transferred from the full to the empty tank.



$$\text{Wt. of the full tank} = 5 \times 8 \times 7 \times 1$$

$$= 280 \text{ t}$$

$$\text{Out of which } 40 \text{ t} \quad \left. \begin{array}{l} -40 \text{ t} \\ 240 \text{ t} \end{array} \right\} \text{Transferred to port}$$

$$240 \text{ t remaining in stbd tank}$$

$$\therefore \text{Port tank } W = L \times B \times d \times \delta$$

$$40 = 5 \times 8 \times d \times 1$$

$$\therefore d = 1 \text{ m.}$$

Now taking the C.G. of 1 m i.e. 0.5 on each tank.

$$\therefore \text{Vertical distance between the two C.O.G. of P \& S tank} = 6 \text{ m}$$

$$16000 \quad \times \quad 6.5 \quad = \quad 104000$$

$$40 \quad \times \quad 6.0 \downarrow \quad = \quad - 240$$

$$\hline 16000 \quad \quad \quad 103760$$

$$\therefore KG = \frac{103760}{16000} = 6.485 \text{ m}$$

$$\therefore KM = 8.000$$

$$KG = 6.485$$

$$GM(S) = 1.5150 \text{ m}$$

$$FSC = 0.0266 \text{ m}$$

$$GM(f) = 1.4884 \text{ m}$$

$$\text{Now to find } FSC = \frac{FSM}{W}$$

$$\text{but } FSM = \frac{lb^3}{12} \times \delta t$$

$$= \left[\frac{5 \times 8^3}{12} \times 1 \right] \times 2$$

$$FSM = 426.66$$

$$\therefore FSC = \frac{426.66}{16000} = 0.0266$$

$$GG_1 = dw/w = \frac{40 \times 7.5}{16000}$$

$$\therefore GG_1 = 0.01875$$

$$\therefore \tan \theta = \frac{GG_1}{GM(f)} = \frac{0.01875}{1.4884} = 0.01259$$

$$\therefore \theta = 0.72^\circ \text{ Port}$$

A vessel of W 8700t KG 6.20 m, KM 6.75 m, a weight of 50 t lying on the Q at a KG 3.5 is discharged using her derrick, the head of which is 21m above the keel.

If the derrick head has an out reach of 10m from the ships Q . Calculate the maximum list during discharging.

The maximum list will be when the derrick has picked up the weight and swung out maximum. When a weight is picked up by a derrick / crane, the centre of gravity of the body is transferred directly to the head of the derrick and the KG of the ship increases. To find out the new KG :-

(W) Initial Displacement X initial KG = Initial vertical moment	
+ W_1 (weight loaded) X Height of the derrick head from Keel (KG_1) =	+ Moment
W_2 (weight discharged) X (Derrickhead height - Present KG of weight W_2) =	- Moment
Final Displacement	Final moment

The initial displacement multiplied by the initial KG gives initial vertical moment. If the weight is being loaded, the KG of this weight immediately shifts to the head of the derrick and KG of the weight being loaded is basically the height of the derrick head above the keel. In case of weight being discharged, as soon as it is picked up by the derrick, the KG of this weight shifts from the present location to the derrick head. Thus the distance shifted = Derrick head – the present location of the weight W_2 .

$$\text{The final KG} = \frac{\text{Final Moment}}{\text{Final Displacement}}$$

$$\begin{array}{rclcl} 8700 & \times & 6.20 & = & 53940 & \therefore \text{KG} = \frac{54815}{8700} \\ -50 & \times & 17.5 & = & +875 & \\ \hline 8700 & & & & 54815 & = 6.300 \text{ m} \end{array}$$

$$\text{KM} = 6.75 \text{ m}$$

$$\text{KG} = 6.30 \text{ m}$$

$$\text{GM (S)} = 0.45 \text{ m}$$

$$\therefore \tan \theta = \frac{\text{GG}_1}{\text{GM (f)}} = \frac{0.0575}{0.45} = 0.1277$$

$$\therefore \theta = 7.28^\circ$$

$$\text{Now } \text{GG}_1 = d \times w / W$$

$$\text{GG}_1 = (10 \times 50) / 8700$$

$$\text{GG}_1 = 0.0575$$

7. A vessel of $W = 9200 \text{ t}$ $\text{KG} = 6.5 \text{ m}$; $\text{KM} = 7.5 \text{ m}$, loads a wt. of 75 t using her own derrick the head of which is 25 m above keel with an outreach of 11 m . Calculate

(1) Maximum list during operation.

(2) The list when the wt. has been placed on deck $\text{KG} 12 \text{ m}$ and 3 m to port of C ?

$$\begin{array}{rclcl} \text{(a) } 9200 & \times & 6.5 & = & 59800 & \therefore \text{New KG} = \frac{61675}{9275} \\ + 75 & \times & 25.0 & = & +1875 & \\ \hline 9275 & & & & 61675 & \text{KG} = 6.649 \end{array}$$

$$\therefore \text{KM} = 7.500$$

$$\text{KG} = 6.649$$

$$\text{GM} = 0.851$$

$$\text{Now } \text{GG}_1 = d \times w / W$$

$$= 75 \times 11 / 9275$$

$$\text{GG}_1 = 0.089$$

If the
of the
k head
by the
d. Thus

$$\therefore \tan \theta = \frac{0.089}{0.851} = 0.1045$$

$$\therefore \theta = 5.95^\circ$$

$$\begin{array}{rclcl} \text{(b)} & 9200 & \times & 6.5 & = & 59800 \\ & 75 & \times & 12 \downarrow & = & +900 \\ \hline & 9275 & & & & 60700 \end{array}$$

$$\therefore KG = \frac{6.700}{9275} = 6.544 \text{ m}$$

$$KM = 7.500$$

$$KG = 6.544$$

$$GM = 0.956$$

$$GG_1 = \frac{d \times w}{W} = \frac{75 \times 3}{9275} = 0.0243$$

$$\therefore \tan \theta = \frac{0.0243}{0.956} = 0.0254$$

$$\therefore \theta = 1.45^\circ \text{ Port}$$

8700

75t using her
reach of 11m.

n to port of ϕ ?

$$\begin{array}{r} = 61675 \\ \hline 9275 \\ = 6.649 \end{array}$$

$$\begin{array}{r} w/W \\ 11/9275 \end{array}$$

A vessel of $W = 11000 \text{ t}$ kg. 7.0m GM 0.8m has a wt. of 75t, lying in the lower hold at a kg. of 3.5m and 2.5m to port of ϕ . The wt. is shifted to upper deck kg. 11.6m and 3.5m stbd of ϕ using her derrick, the head of which is 20m above the keel. Calculate the list:

- When the weight is picked up by the derrick plumped over the ships ϕ .
- When the weight has been placed on deck.
- Maximum list if the wt. is then discharged over the port side with the derrick swung out 10m from the ϕ .
- The list after the wt. has been discharged.

$$\begin{array}{rclcl} \text{(a)} & 11000 & \times & 7.0 & = & 77000 \\ & 75 \uparrow & \times & 16.5 & = & +1237.5 \\ \hline & 11000 & & & & 78237.5 \end{array}$$

$$GG_1 = \frac{2.5 \times 75}{11000} = \frac{150}{11000} = 0.017$$

$$\therefore \text{kg.} = \frac{78237.5}{11000} \quad \therefore \tan \theta = \frac{GG_1}{GM} = \frac{0.017}{0.6875}$$

$$\text{kg.} = 7.1125$$

$$\tan \theta = 0.0249$$

$$KM = 7.8 \quad (7 + 0.8)$$

$$\theta = 1.43^\circ (\text{S})$$

$$GM = 0.6875$$

$$(b) \begin{array}{r} 11000 \times 7.0 = 77000 \\ 75 \times 8.1 = +607.5 \\ \hline 11000 \quad \quad 77607.5 \end{array}$$

$$\text{Kg.} = \frac{77607.5}{11000}$$

$$\text{Kg.} = 7.055$$

$$KM = 7.800$$

$$GM = 0.745$$

$$GG_1 = \frac{d \times w}{W} = \frac{6 \times 75}{11000}$$

$$GG_1 = \frac{450}{11000} = 0.0409$$

$$\therefore \tan \theta = \frac{GG_1}{GM} = \frac{0.0409}{0.745}$$

$$\tan \theta = 0.0549$$

$$\therefore \theta = 3.14^\circ (\text{Stbd})$$

$$(c) \begin{array}{r} 11000 \times 7.0 = 77000 \\ 75 \times 16.5 = 1237.5 \\ \hline 11000 \quad \quad 78237.5 \end{array}$$

$$\therefore \text{Kg.} = \frac{78237.5}{11000}$$

$$\text{Kg.} = 7.1125$$

$$KM = 7.800$$

$$GM = 0.6875$$

$$GG_1 = \frac{d \times w}{W} = \frac{7.5 \times 75}{11000}$$

$$GG_1 = \frac{562.5}{11000} = 0.0511$$

$$\therefore \tan \theta = \frac{GG_1}{GM} = \frac{0.0511}{0.6875}$$

$$\therefore \tan \theta = 0.0743$$

$$\theta = 4.25^\circ (\text{P})$$

$$(d) \begin{array}{r} 11000 \times 7.0 = 77000 \\ - 75 \times 3.5 = -262.5 \\ \hline 10925 \quad \quad 76737.5 \end{array}$$

$$GG = \frac{2.5 \times 75}{10925} = \frac{187.50}{10925} = 0.0172$$

Contd.

$$\therefore Kg. = \frac{76737.5}{10925}$$

$$\therefore \tan \theta = \frac{GG_1}{GM} = \frac{0.0172}{0.776}$$

$$\therefore Kg. = 7.024$$

$$\therefore \tan \theta = 0.0221$$

$$KM = 7.800$$

$$\theta = 1.26^\circ \text{ (Stbd)}$$

$$GM = 0.776$$

Contd.

9.

A ship displacing 8500t; GM = 1.0m, is listed 2.5° port. A weight of 60t on deck kg. 11.5m and 3.5m to port of $\bar{C}$ is to be discharged over the stbd side, using her derrick, the head of which is 21m above the keel, with an out reach of 10m from $\bar{C}$. Calculate the list

- When the weight is picked up by the derrick plumped over the weight.
- When the derrick is swung out.

Vertical GG

Transverse GG

$$(a) \tan \theta = \frac{dw}{W \cdot GM}$$

$$\text{Now } GG_1 = \frac{dw}{W}$$

$$\therefore \tan 2.5^\circ = \frac{dw}{8500 \times 1}$$

$$GG_1 = \frac{60 \times 9.5 (21-11.5)}{8500} = 0.067$$

$$\text{i.e. } \tan 2.5^\circ \times 8500 \times 1.0 = dw$$

$$GM = 1.000$$

$$371.118 = dw$$

$$GG_1 = -0.067$$

$$\text{New GM} = 0.933$$

$$\therefore \tan \theta = \frac{dw}{W \cdot GM} = \frac{371.118}{8500 \times 0.933} = \frac{371.118}{7930.5} = 0.04679$$

$$\tan \theta = 0.04679 \therefore \theta = 2.68^\circ (P)$$

$$(b) \text{ Listing Mom} = W \times d = 60 \times (3.5 + 10) = 810$$

$$810 \quad \text{L.M.}$$

$$-371.118 \quad \text{I.L.M}$$

$$438.882 \quad \text{F.L.M}$$

$$\tan \theta = \frac{438.882}{8500 \times 0.933} = 0.0513$$

$$\theta = 3.16^\circ \text{ stbd.}$$

10. A ship wt = 7000t Kg 7.0, has to load a 1600t parcel of cargo and there after a heavy lift of 95t using her own derrick the head of which is 25m above the keel with an outreach of 15m from the G . If her KM @ a W = 8695t is 8.0m at what max kg should be 1600t loaded, so that when the heavy lift is being loaded, list will not exceed 9° .

*Some Type
Excess m. y
Pg 65*

$$\text{Transverse GG} = \frac{95 \times 15}{8695} = \frac{1425}{8695} = 0.16388$$

$$\text{Now } \tan \theta = \frac{GG_1}{GM}$$

$$\tan 9^\circ = \frac{0.16388}{GM}$$

$$GM = \frac{0.16388}{\tan 9^\circ}$$

$$GM = \frac{0.16388}{0.15838}$$

$$GM = 1.0349$$

$$KM = 8.0000$$

$$KG = 6.9651 \text{ Ship}$$

Now taking Moments :

$$7000 \times 7.0 = 49000$$

$$1600 \times x = 1600x$$

$$95 \times 25 = 2375$$

$$\frac{8695}{51375 + 1600x}$$

$$\therefore KG = \frac{\text{Final Mom}}{\text{Final W}}$$

$$6.9651 = \frac{51375 + 1600x}{8695}$$

$$\therefore (6.9651 \times 8695) = 51375 + 1600x$$

$$60561.54 = 51375 + 1600x$$

$$60561.54 - 51375 = 1600x$$

$$9186.544 = 1600x$$

$$8196.544 = x$$

$$1600$$

$$x = 5.74$$

$\therefore$ The Max kg is 5.74 m.

11. A ship of $W = 7400t$ $Km = 8.5$, $KG = 8.0$, lost some deck cargo kg . $11m$ & $3.5m$ from Q . If the resultant list was 3.5° , calculate the amount of cargo lost.

Vertical Moment

$$7400 \times 8.0 = 59200$$

$$\frac{x}{7400 - x} \times 11 = \frac{11x}{59200 - 11x}$$

Transverse Mom.

$$GG_1 = dw / W$$

$$GG_1 = 3.5x / 7400 - x$$

$$\therefore KG = \frac{59200 - 11x}{7400 - x}$$

$$\therefore KM - KG = GM$$

$$8.5 - \left[\frac{59200 - 11x}{7400 - x} \right] = GM$$

$$\therefore \tan \theta = \frac{GG_1}{GM} = \tan 3.5^\circ = \frac{3.5x / 7400 - x}{8.5 - \left[\frac{59200 - 11x}{7400 - x} \right]}$$

$$\tan 3.5^\circ = \frac{3.5x / 7400 - x}{8.5 (7400 - x) - (59200 - 11x) / 7400 - x}$$

$$\tan 3.5^\circ = \frac{3.5x / 7400 - x}{(62900 - 8.5x - 59200 + 11x) / 7400 - x}$$

$$0.06116 = \frac{3.5x}{3700 + 2.5x}$$

$$0.06116 (3700 + 2.5x) = 3.5x$$

$$227.92 + 0.1529x = 3.5x$$

$$227.92 = 3.348x$$

$$\therefore x = \frac{227.92}{3.348} = 67.61 t$$

12. A vessel of $W = 7250t$, $GM = 1.0m$ is listed 3.5° stbd. She has to discharge $450t$ which may be discharged $6.0m$ & $2.5m$ to port of ☞ & from $9.0m$ & $6.2m$ to stbd of ☞ . Calculate the amount to be discharged from each space to finish discharging up right?

$$\tan \theta = \frac{GG_1}{W.GM}$$

$$\tan 3.5^\circ = \frac{GG_1}{7250 \times 1.0}$$

$$\therefore ILM = \tan 3.5^\circ \times 7250 \times 1.0$$

$$ILM = 443.429t \text{ stbd}$$

Now suppose x tonnes is discharged

from $6.0m$ & $(450 - x)$ discharged from $9.0m$ kg.

for the final condition is

$$ILM = FLM = \text{upright}$$

$$\therefore 6.2(450 - x) - 2.5x = 443.429$$

$$2790 - 6.2x - 2.5x = 443.429$$

$$2790 - 8.7x = 443.429$$

$$8.7x = 2346.571$$

$$\therefore x = 269.72t \text{ from } 6.0m \text{ Kg}$$

$$\therefore (450 - 269.72) = 180.28t \text{ from } 9.0m \text{ KG}$$

13. A vessel of $w = 9900t$ $km = 8.0$, $KG = 6.9$ is listed 3.5° (P). Where with respect to ☞ should $60t$ be loaded at a kg of $3.5m$ to bring the ship upright.

$$\tan \theta = \frac{GG_1}{W.GM} = \frac{dw}{W.GM}$$

$$KM = 8.0$$

$$KG = 6.9$$

$$GM = 1.1$$

$$\tan 3.5^\circ = \frac{d \cdot 60}{9900 \times 1.1}$$

$$\therefore 60d = \tan 3.5^\circ \times 9900 \times 1.1$$

$$d = \frac{666.06}{60}$$

$$\therefore d = 11.101m \text{ from } \text{☞} \text{ to stbd.}$$

ge 450t

0.0m &

pace to

arged

ect to

A vessel of $W = 9200t$ kg 6.0, km 7.1 is listed 3° port. She fills up a stbd DB tank, kg 0.5 & 9m from ship's ∇ with 125t sw. Calculate her final list.

$$FLM = \tan \theta = \frac{dw}{W \cdot GM}$$

$$KM = 7.1$$

$$KG = 6.0$$

$$GM = 1.1$$

$$\tan 3^\circ = \frac{dw}{9200 \times 1.1}$$

$$FLM = \tan 3^\circ \times 9200 \times 1.1$$

$$FLM = 530.366 \text{ port}$$

$$LM \text{ caused due to stbd DB tank} = 125 \times 9 = 1125 \text{ stbd}$$

$$\therefore FLM = 1125 \text{ stbd} - 530.366 \text{ port}$$

$$FLM = 594.634 \text{ stbd}$$

$$\text{Now } 9200 \times 6.0 = 55200$$

$$KM = 7.100$$

$$+ 125 \times 0.5 = +62.5$$

$$KG = 5.926$$

$$\underline{9325}$$

$$\underline{55262.5}$$

$$GM = 1.174$$

$$\therefore KG = \frac{55262.5}{9325} = 5.926$$

$$\therefore \tan \theta = \frac{FLM}{W \cdot GM} = \frac{594.634}{9325 \times 1.174}$$

$$\tan \theta = 0.0543$$

$$\theta = 3.11^\circ \text{ stbd.}$$

15. A ship of $W = 11000$ kg. 7.5, $KM = 8.0$, is listed 3° stbd, the following operations carried out :

1. Loaded 135t kg. 6.0m, 3.5m to port of ∇

2. Discharged 125t kg. 9.0m, 4.5m to stbd of ∇

3. Pumped out 75t ballast kg. 0.6m, 5m to port of ∇

Calculate the final list.

$$GM = 8.0 - 7.5 = 0.5 \text{ m}$$

11000 X 7.5 = 82500	∴ Final KG = <u>82140</u>
135 X 6.0 = + 810	10935
- 125 X 9.0 = - 1125	KG = 7.512
- 75 X 0.6 = - 45	KM = <u>8.000</u>
10935	GM = 0.488
82140	

$$\tan 3^\circ = \frac{dw}{11000 \times 0.5}$$

$$\therefore \text{ILM} = \tan 3^\circ \times 11000 \times 0.5 = dw$$

$$\text{ILM} = 288.243 \text{ stbd}$$

LM caused due to operation :	P	S
+ 135 X 3.5m (P) =	472.5	-
- 125 X 4.5m (S) =	562.5	-
- 75 X 5m (P) =	-	<u>375</u>
	<u>1035</u>	<u>375</u>
	- 375	

$$\text{FLM} = 660 \text{ Port}$$

$$\therefore \text{FLM} = 660 \text{ port} - 288.243 \text{ stbd}$$

$$\text{FLM} = 371.757 \text{ t port}$$

$$\text{Now listing moment} = \tan \theta = \frac{\text{FLM}}{\text{W. GM.}}$$

$$\tan \theta = \frac{371.757}{10935 \times 0.488} = 0.0697$$

$$\therefore \theta = 3.985^\circ \text{ Port}$$

LIST

Exercise 4

1. A ship of displacement 8000 tonnes, KM 8.7m, KG 8.0m lost a quantity of her deck cargo (Kg 11.5m, 5m to port of the centerline). The resulting stbd. list was 3.5° , calculate the quantity of the cargo lost.
2. A ship of displacement 1400 tonnes has 2 metres freeboard with her centre of gravity of 0.2 metre above the waterline. A rectangular deck area 20 metres long and 10 metres wide is filled to a depth of 0.5 metre when the vessel ships seas in heavy weather. Find the change in vessel's righting lever at 5° angle of heel.
3. A ship of 13750 tons displacement, KM = 7.2m, KG = 6.4m is listed 2.5° to starboard. She has to load a further 300 tons. Space is available in No. 4 tween deck KG = 8.4m on the port side 7m from the centre line and on the starboard side 5m from the centre line. How much cargo should be loaded on each side to complete loading upright.
4. A ship of displacement 8600t, KG 7.3m has to load a 2200t parcel of cargo and then a heavy lift of 100t using her Jumbo derrick, the head of which is 26m above the keel with an outreach of 16m from the centerline. If her KM at a displacement of 10900t is 8.2m, at what maximum KG can the 2200t parcel be loaded so that the list when loading the heavy lift will not exceed 8 degrees.
5. A ship of 12500 tonnes displacement, KM 7m, KG 6.4m, has a 3 degree list to starboard and has yet to load 500 tonnes of cargo. There is space available in the tween decks, centres of gravity 6m each side of the centre line. Find how much cargo to load on each side if the ship is to complete loading upright.
6. A ship of displacement 7500 ts, KM 8.6m, KG 7.8m, lost a quantity of deck cargo of KG 12m, from 4m to stbd of the centerline. If the resulting list was $3^\circ 20'$ to port, calculate the weight of deck cargo lost.

Answers :

1. 70.93t
2. 0.111m.
3. 165.05 t on port side 134.95 t on stbd side
4. $KG = 4,09\text{ m}$
5. 282.75t to port, 217.25 tonnes to stbd
6. 91.95 tonnes.

-oOo-

CHAPTER V

TRIM

The following is to be noted :

- For shift of wt. already on board :

$$\begin{aligned}\text{Trimming Moment} &= \text{Wt. Shifted} \times \text{distance shifted} \\ &= d \times w\end{aligned}$$

- For weight loaded or discharged :

$$\begin{aligned}\text{Trimming Moment} &= \text{Wt. loaded / discharged} \times \text{distance from COF} \\ &= d \times w\end{aligned}$$

$$\begin{aligned}\text{➤ Total trim caused} &= \frac{\text{trimming Moment}}{\text{MCTC} \times 100} \\ (\text{in meter, } T_t) &\end{aligned}$$

$$\begin{aligned}\text{➤ Sinkage / Rise} &= \frac{\text{Final Wt. Loaded / discharged (w)}}{\text{TPC} \times 100} \\ (\text{in meter}) &\end{aligned}$$

$$\begin{aligned}\text{➤ Change of trim Aft} &= \frac{\text{Total trim} \times \text{After length}}{\text{Total Length}} \\ (T_a) &\end{aligned}$$

$$\begin{aligned}\text{➤ Change of trim Fwd} &= \frac{\text{Total trim} \times \text{Fwd. length}}{\text{Total length}} \\ (T_f) & \\ &= T_t - T_a\end{aligned}$$

1. A vessel of length 140 mt, CF 4m aft of midship, MCTC 145 M.T. at a draft of Fwd 4.75m, Aft = 5.60m shifted a wt. of 95t from 65m. aft of midship to 10m abaft the midship. Calculate her drafts F & A.

$$\begin{aligned}\text{Trimming Moment} &= 95 \times (65 - 10) \\ &= 95 \times 55 \\ &= 5225 \text{ mt}\end{aligned}$$

$$\text{Total trim caused (in m)} = \frac{\text{trim Moment}}{\text{MCTC} \times 100} = \frac{5225}{145 \times 100}$$

$$\text{Total trim} = 0.36 \text{ m.}$$

➤ Shift Fwd $\longrightarrow$ So trim by head.

$$\text{Change of trim Aft} = \frac{\text{Total trim} \times \text{Aft length}}{\text{Total length}} = \frac{0.36 \times 66}{140}$$

$$\text{Change of trim Aft} = 0.1697 \text{ m}$$

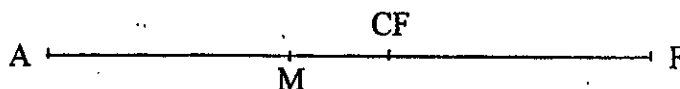
$$\text{Change of trim Fwd} = \frac{\text{Total trim} \times \text{Fwd length}}{\text{Total length}} = \frac{0.36 \times 74}{140}$$

$$\text{Change of trim fwd} = 0.1903 \text{ m}$$

Draft	Fwd	AFT
	4.75m	5.60m
Change in trim	+ 0.1903m	- 0.1697m
Final draft	4.9403m	5.4303m

draft of
to 10m

A vessel of length 150mt CF 3mt fwd of midship TPC = 20 t/cm ,
MCTC = 175mt, draft Fwd = 5.90m Aft = 6.30m loads 135t, 15m fwd of midship
length. Calculate her F & A draft.



$$\text{Trimming Moment} = 135 \times 12 = 1620 \text{ mt}$$

$$\text{Wt. loaded } \therefore \text{ sinkage} = \frac{135}{20 \times 100} = 0.0675 \text{ m}$$

$$\text{Total trim (m)} = \frac{1620}{175 \times 100} = 0.0926 \text{ m}$$

$$\begin{aligned} \text{Change of trim Aft} &= \text{Total trim} \times \text{Aft length} / \text{Total length} \\ &= 0.0926 \times 78 / 150 \\ &= 0.0482 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Change of trim fwd} &= \text{Total trim} \times \text{Fwd length} / \text{Total length} \\ &= 0.0926 \times 72 / 150 \\ &= 0.0444 \text{ m} \end{aligned}$$

	Fwd	Aft
Draft	5.90	6.300
Sinkage	0.0675	0.0675
	<u>5.9675</u>	<u>6.3675</u>
Change of trim	+ 0.0444	- 0.0482
Final draft	<u>= 6.0119 m</u>	<u>6.3193 m</u>

3. A vessel of length 160 m CF 2m fwd of midlength. TPC 22 t/cm, MCTC = 170mt, draft Fwd = 5.70, Aft = 6.80 following operations carried out.
- Loads 150t, 35m fwd of midlength
 - Disch 275t, 35m fwd of midlength
 - Shifted 75t, from 35m abaft midship to 10m fwd of midship
- Find the draft for'd and Aft.

➤ Trimming Moment : $d \times w$ where d is the distance between COF and position of weight loaded / discharged.

$$\begin{array}{rcl}
 + 150 \times 33 & = & + 4950 \text{ F} \\
 - 275 \times 33 & = & - 9075 \text{ A} \\
 \hline
 75 \times 45 & = & + 3375 \text{ F} \\
 \hline
 275 - 150 & & 750 \text{ Aft}
 \end{array}$$

= 125t Final disch.

∴ Since the final cargo is 125 t disch. the ship will rise.

$$\therefore \text{Rise} = 125 / 22 \times 100 = 0.0568 \text{ m} \uparrow$$

$$\text{Total Trim} = \frac{750}{170 \times 100} = 0.044 \text{ m}$$

$$\begin{aligned}
 \text{Change in trim Aft} &= \text{Total Trim} \times \text{Aft. Length} / \text{Total length} \\
 &= 0.044 \times 82 / 160 \\
 &= 0.023 \text{ m}
 \end{aligned}$$

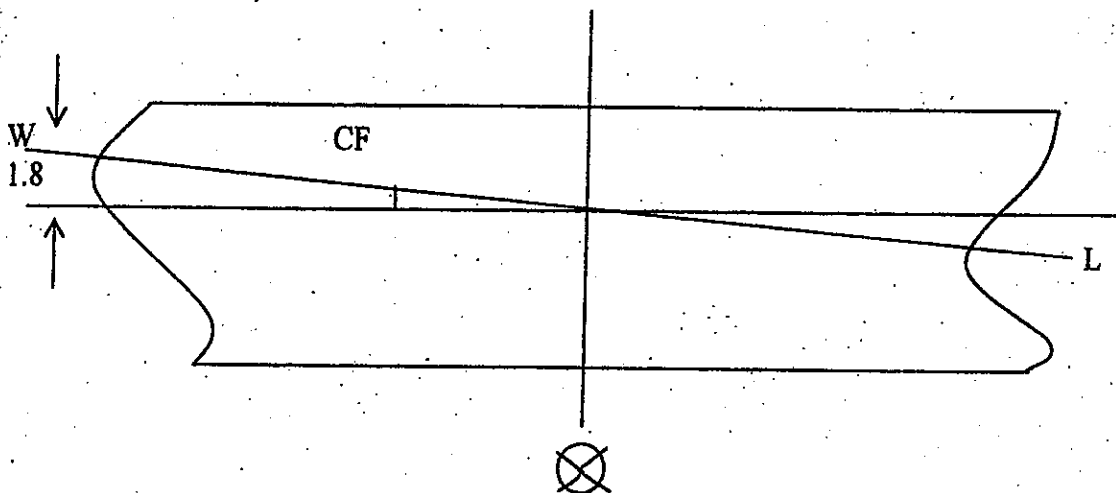
$$\begin{aligned}
 \text{Change in trim Fwd} &= \text{Total Trim} \times \text{Fwd length} / \text{Total length} \\
 &= 0.044 \times 78 / 160 \\
 &= 0.021 \text{ m}
 \end{aligned}$$

2 t/cm,
ed out.

	Fwd	Aft
Draft	5.700	6.800
M. Rise	- 0.0568	- 0.0568
Draft	<u>5.681</u>	<u>6.761</u>
Change in trim	+ 0.021	- 0.023
Final draft	<u>= 5.664 m</u>	<u>6.720 m</u>
	5.622	6.766

tion of

A vessel of length 175m CF = 3m aft of midship is trimmed 2.0m by stern at a mean draft of 8.25m. Calculate her hydrostatic draft.



$$\text{Correction to Aft draft} = \frac{\text{trim} \times \text{LCF}}{\text{LBP}}$$

$$\frac{F + \text{Aft draft} = 8.25}{2}$$

For a length of 175m, trim = 2.0

∴ for 3m trim = ?

$$\therefore \frac{3 \times 2}{175} = 0.034 \text{ m}$$

$$\text{M draft} = 8.25$$

$$\text{Corr} = + 0.034$$

$$\text{Hydro draft} = 8.284 \text{ m}$$

$$\text{Aft draft} - F = 2 \text{ m}$$

solving simultaneous eqn.

$$A + F = 8.25$$

$$A - F = 2$$

get drafts

apply Hyd. draft correction

5. A box shaped vessel 125m X 20m is in SW at an E.K. draft of 3mt, KG = 4.5m, calculate the draft F and A if a weight of 125t on board is shifted aft through 50m.

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

Where GM_L is obtained as follows :

$$KM_L = KB + BM_L$$

$$\therefore KM_L - KG = GM_L$$

$$\text{Now } BM_L = \frac{I_{CF}}{V} = \frac{BL^3}{12V}$$

Note : If GM_L can not be calculated then BM_L can be used. Since GM_L & BM_L are very large the difference is insignificant.

But in place of GM (f), BM cannot be taken since the values are quite small & hence significant changes are quite viable.

$$\begin{aligned} W &= L \times B \times \text{draft} \times \delta \\ &= 125 \times 20 \times 3 \times 1.025 \end{aligned}$$

$$W = 7687.5t$$

$$KM_L = KB + BM_L$$

$$\text{Where } KB = 3/2 = 1.5 \text{ m}$$

$$BM_L = \frac{BL^3}{12 \cdot V}$$

$$BM_L = \frac{20 \times 125^3}{12 \times 125 \times 20 \times 3}$$

$$= 434.028$$

4.5m,
50m.

434.028 m
1.5 m
435.528 m
-4.5 m

= 431.028 m

$$\therefore \text{MCTC} = \frac{W \times GM_L}{100 \times L}$$

$$= \frac{7687.5 \times 431.028}{100 \times 125}$$

$$\text{MCTC} = 265.08 \text{ cms.}$$

$$\text{Trimming Moment} = 125 \times 50 = 6250 \text{ mt}$$

$$\text{Trim caused} = \frac{6250}{265.08 \times 100} = 0.236 \text{ m}$$

$$\text{Change of trim aft} = \frac{\text{Trim} \times \text{AF}}{\text{LBP}}$$

$$= \frac{0.236 \times 62.5}{125}$$

$$= 0.118 \text{ m}$$

$$\text{Change of Trim for'd} = 0.118 \text{ m}$$

E.K. draft

Fwd

Aft

3.00

3.00

- 0.118

+

0.118

Fwd 2.882 m

3.118 m Aft

6. A ship 140m in length, MCTC = 150, CF 3.0 mts aft of mid length is trimmed 40 cms. by stern. From where with respect to midship should 245t be discharged to bring her on even keel.

➤ Trim Moment = Wt. disch. X dist from COF

➤ Total trim caused = $\frac{\text{Trim Moment}}{\text{MCTC}}$

$$\therefore 40 \text{ cms} = \frac{\text{trim moment}}{150 \text{ cms}}$$

$$\therefore \text{Trim Moment} = 40 \times 150 = 6000$$

$$\text{Now } 6000 = 245 \times x$$

$$\therefore x = \frac{6000}{245} = x = 24.49 \text{ m}$$

Since the vessel has to be even keel, the wt. discharged has to be from 24.49m aft of C.O.F.

$$\text{Or } 24.49 + 3.0 = 27.49 \text{ m aft of midship.}$$

7. A vessel of length 130mt, CF = 2m aft of midship. TPC = 12mt MCTC = 145 tm. is at a draft of 5.20m fwd & 6.60m aft. She is to sail on E.K. draft of 6.48m. Space is available in No. 1# 50m fwd of the midship & No. 4#, 25m aft of midship. Calculate the amount to be loaded in each space.

Draft

Fwd 5.20 m

Aft 6.60 m

Trim 1.40 m

$$\therefore \text{Cor}^n \text{ to aft draft} = \frac{\text{Trim} \times \text{CF}}{\text{MCTC}} = \frac{1.40 \times 63}{130}$$

$$\text{Aft draft} = 6.600\text{m} \quad \text{TPC} = 12\text{t/cm}$$

$$\text{corr}^n = -0.678\text{m}$$

$$\text{initial hydro. draft} = 5.922\text{m} \quad \text{i.e. } 0.558 \times 12 \times 100 = 669.6\text{t}$$

$$\text{Req. Final hydro draft} = 6.480\text{m}$$

$$\therefore \text{Sinkage} = 0.558\text{m}$$

$$\therefore \text{Cargo to be loaded for the sinkage} = 669.6\text{t}$$

Now suppose No. 1# loads x t

Then No. 4# loads $(669.6 - x)$ t

Now taking moments

Initial trim = 140 cms.

MCTC = 145cm

$\therefore$ to finish her at even keel draft

$$\text{Total trim} = \frac{\text{Trimming Moment}}{\text{MCTC} \times 100}$$

$$1.40 = \frac{52x - 23(669.6 - x)}{145 \times 100}$$

$$\therefore 140 \times 145 = 52x - 15400.8 + 23x$$

$$35700.8 = 75x$$

$$\therefore x = 476.01$$

No. 1#

$$669.6 - 476.01 = 193.59$$

No. 4#

8. A ship of length 165m CF 3m fwd of midship $TPC = 15t$, $MCTC = 170mt$ is at a draft of fwd 6.00m aft = 7.20m. She receives 135t of Fw, 45m fwd of midship. She has to discharge 1820t of cargo of which 420t is to be discharged from No. 2 #, 36m fwd of midship and 480t fm No. 4 #, 30m aft of midship. The remaining cargo is to be discharged from No. 1 # 65m fwd of midship and No. 5 #, 50m aft of midship. Calculate the wt. to be discharged from No. 1 and No. 5 # to finish on EK. Also find the EK draft then.

Draft

Fwd = 6.00	Total cargo 1820t
Aft = 7.20	of which 420 No. 2 #
Trim = 1.20m by stern	480 No. 4 #
	900t

remaining cargo $(1820 - 900) = 920t$

to be discharged from No. 1 and No. 5 #.

So let 'x' t be discharged from No. 1 #, then $(920 - x)$ t from No. 5 #

So taking moments :

		TRIMMING	MOMENTS
		Head	Stern
Rec'd FW	135 X 42 (F)	5670	-
Disch No. 2 #	420 X 33 (F)	-	13860
Disch No. 4 #	480 X 33 (A)	15840	-
Disch No. 1 #	x X 62 (F)	-	62 x
Disch No. 5 #	$(920 - x) \times 53$ (A)	$48760 - 53x$	-
		$79270 - 53x$	$13860 + 62x$

$$\text{Now Total Trim} = \frac{\text{Trimming Moment}}{\text{MCTC}}$$

$$120 = \frac{70270 - 53x - (13860 + 62x)}{170}$$

$$120 \times 170 = 70270 - 53x - 13860 - 62x$$

$$20400 = 56410 - 115x$$

$$115x = 56410 - 20400$$

$$115x = 36010$$

$$\therefore x = \frac{36010}{115} = 313.13 \text{ t No. 1 \#}$$

$$(920 - 337.13) = 606.87 \text{ t No. 5 \#}$$

To find EK draft

Final displacement i.e. $1820 - 135 = 1685 \text{ t}$

i.e. total cargo discharged = 1685

$$\therefore \text{Mean rise} = \frac{1685}{15 \times 100} = \frac{\text{Wt. discharged}}{\text{TPC} \times 100} = 1.123 \text{ m}$$

Change of trim aft = Aft length $\times$ trim / LBP

$$= 85.5 \times 120 / 165 = 62.182 \text{ Cm} = 0.622 \text{ m}$$

Change of trim fwd = Fwd length $\times$ trim / LBP

$$= 79.5 \times 120 / 165 = 57.81 = 0.578 \text{ m}$$

	Fwd	Aft
Initial draft	6.000	7.200
M. Rise	1.123	1.123
Uncorrected draft	4.877	6.077
Change in trim	+ 0.578m	- 0.622
Final EK draft	5.455 m	5.455 m

9. A vessel of length 158m, CF = 2m fwd of midship, MCTC = 155m.t., TPC 20t, is at a draft of Fwd 6.35m, 7.85m aft, she is to sail with a trim of 1.11m by stern. Calculate:

- The wt. to be shifted through 25m & the drafts Fwd and aft then.
- If the required trim is to be achieved by loading 165t, find the position with respect to midship, where to load & the drafts Fwd & Aft then.
- If the required trim is to be achieved by pumping out ballast from 30m aft of midship, find the amount to be pumped out and the drafts F & A then.

(a) draft fwd	6.35m
aft	<u>7.85m</u>
trim	1.50m
Req. trim	<u>1.11m</u>
T_t	0.39 m

$$T_t = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC}$$

$$\therefore T_t = \frac{w \times d}{MCTC}$$

$$39 = \frac{w \times 25}{155}$$

$$\therefore w = \frac{39 \times 155}{25}$$

$$w = 241.8 \text{ t}$$

Since the final trim required 1.11m, the wt. 241.8 t has to be shifted fwd.

Hence the fwd will sink and aft will rise.

TPC 20t,
by stern.

Since the wt. on board is shifted

$$\text{Change of trim aft} = \frac{T_t \times AF(P)}{LBP} = \frac{0.39 \times 81}{158} = 0.20 \text{ m}$$

with

$$\text{Change of trim fwd} = \frac{T_t \times FF}{LBP} = \frac{0.39 \times 77}{158} = 0.19 \text{ m}$$

aft of

Initial draft	6.35	7.85
Change in trim	+ 0.19	- 0.20
Final draft	<u>6.54 m</u>	<u>7.65 m</u>

- (b) In this case the supposition is loading of 165t and thus sinkage is to be considered.

$$\text{Thus mean sinkage} = \frac{W}{TPC} = \frac{165t}{20 \times 100} = 0.082 \text{ m}$$

Draft	6.54	7.65
Sinkage	+ 0.082	+ 0.082
New draft	<u>6.622 m</u>	<u>7.732 m</u>

$$T_t = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC} = \frac{165 \times d}{155 \times 100} = 0.39$$

$$\therefore d = \frac{0.39 \times 155 \times 100}{165} = 36.64 \text{ from COF}$$

So with respect to midship $36.64 + 2 = 38.64 \text{ m fwd of midship.}$

(c) In this case the supposition is to pump out (deballast) from 30m aft of midship.

$$\therefore T_1 = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC} = \frac{x \times 32}{155 \times 100} = 0.39$$

$$\therefore x = \frac{0.39 \times 155 \times 100}{32} = 188.91 \text{ t of water ballast to pump out.}$$

Now since the ballast is pumped out there is going to be a rise in the draft.

Thus

$$\text{Mean rise} = \frac{W}{TPC \times 100} = \frac{188.91}{20 \times 100} = 0.094 \text{ m rise}$$

	Fwd	Aft
Drafts	6.54	7.65
M. rise	- 0.094	- 0.094
Final draft	<u>6.446 m</u>	<u>7.556 m</u>

10. A ship of length 160m, LCF 78 m, MCTC = 168, TPC 15t is at a draft Fwd 7.40 m, aft 8.65 m. To carry out the repairs at fore end it is necessary to reduce the fwd draft to 6.40m. If the maximum permissible draft at the repair berth is 8.10m and cargo may be discharged from No. 2 #, 33m fwd of midship and No. 5 # 60m, aft of midship, calculate the minimum amount of cargo to be discharged from each space?

Initial drafts	Fwd	7.40
	Aft	8.65
	<u>Trim</u>	<u>1.25m by stern</u>

To find the hydrostatic draft

$$\text{Corr}^n \text{ to aft. Draft} = \frac{\text{Trim} \times \text{LCF}}{\text{LBP}}$$

$$\text{Corr}^n \text{ to aft draft} = \frac{1.25 \times 78}{160} = 0.609$$

$$\therefore \text{Aft draft} = 8.65$$

$$\text{Corr}^n = - 0.609$$

$$\text{Initial hydro draft} = 8.041$$

$$\text{Final draft fwd} = 6.4 \text{ m}$$

$$\text{Aft} = 8.1 \text{ m}$$

$$\text{Trim} = 1.7 \text{ m}$$

$$\left\{ \begin{array}{l} \text{hence to get hydro draft} \\ \text{corr}^n \text{ to aft draft} \\ = \text{trim} \times \text{LCF} / \text{LBP} \end{array} \right.$$

$$\therefore \text{Corr}^n \text{ to aft draft} = \frac{1.7 \times 78}{160} = 0.829 \text{ m}$$

$$\therefore \text{Aft draft} = 8.10 \text{ m}$$

$$\text{corr}^n = 0.829 \text{ m}$$

$$\text{Final hydro draft} = 7.271 \text{ m}$$

$$\text{Thus initial hydro draft} = 8.041$$

$$\text{Final hydro draft} = 7.271$$

$$\text{Rise in draft} = 0.77 \text{ m}$$

$$\text{Now mean rise} = W / \text{TPC} \times 100$$

$$0.77 = \frac{W}{15 \times 100}$$

$$\therefore W = 0.77 \times 15 \times 100$$

$$W = 1155 \text{ t}$$

Thus total minimum cargo to discharge to achieve the required drafts is 1155 t.

Now since this cargo is to be discharged from No. 2 # and No. 5 #.

Suppose x t is discharged fm No. 2 # then $(1155 - x)$ t from No. 5 #.

Final trim = 1.70 m

Initial trim = 1.25 m

Total trim = 0.45 m

$$T_t = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC}$$

$$45 = \frac{35x - 58(1155 - x)}{168}$$

$$45 \times 168 = 35x - 66990 + 58x$$

$$7560 = 93x - 68817$$

$$7560 + 68817 = 93x$$

$$93x = 74550$$

$$\therefore x = 801.61 \text{ t}$$

$$\therefore x = 801.61 \text{ t fm No. 2 \#}$$

$$\therefore 1155 - 821.26$$

$$= 353.39 \text{ t fm No. 5 \#}$$

11. A vessel of length 144m, CF 3m aft of midship, MCTC 155, TPC 15t is trimmed 1.65m by the stern. Calculate the wt. to be loaded and its position with respect to midship to finish with the trim 1.05m by stern without change in the aft draft.

Initial trim 1.65m by stern

Final trim 1.05m by stern

$$T_t = 0.60 \text{ m}$$

$$\text{Now } T_t = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC}$$

$$\text{Meansinkage} = T_a$$

$$\therefore \frac{w}{TPC} = \frac{T_t \times LCF}{LBP}$$

$$\frac{TPC}{LBP}$$

$$\text{But } T_t = \frac{w \times d}{MCTC}$$

So substituting the value of T_t we get

$$\frac{W}{TPC} = \frac{w \times d}{MCTC} \times \frac{LCF}{LBP}$$

$$\frac{1}{15} = \frac{d}{155} \times \frac{69}{144}$$

$$\frac{1}{15} = \frac{69d}{22320}$$

$$\therefore \frac{22320}{15 \times 69} = d = 21.56 \text{ m for } d \text{ of COF}$$

$$\therefore 21.56 - 3 = 18.56 \text{ from midship}$$

Since d is known w can be found out by

$$T_t = \frac{T_m}{MCTC} = \frac{w \times d}{MCTC}$$

$$0.60 = \frac{w \times 21.56}{155 \times 100} \quad \therefore \frac{0.6 \times 155 \times 100}{21.56} = 431.35 \text{ t} = w$$

12. A vessel of length 140 mt LCF = 68 m, MCTC = 150, TPC = 20 is at a draft of 6.82 mt fwd, 7.67 mt aft. Calculate
- Amount of ballast to be pumped out from A.P.T. 62 m aft of midship to reduce the aft draft to 7.47 m. Also find the fwd draft then.
 - If the aft draft of 7.47 m is to be achieved by running up the E.P. Tank 65 m fwd of midship, calculate the amount of ballast to be run up and the fwd draft then.

- (a) The amount of ballast to pump out should be such that the aft draft from 7.67m should arrive at 7.47 m i.e. a rise of 0.20m aft, which will also sink the fwd draft.

$$\text{i.e. } 7.67 - 7.47 = 0.20\text{m} = 20\text{cm.}$$

$$\text{Now } T_t = \frac{T_m}{\text{MCTC}} = \frac{w \times d}{\text{MCTC}}$$

This T_m will change the T_a .

$$\therefore 20 = T_a + \text{Mean sinkage}$$

$$20 = T_a + \frac{w}{\text{TPC}} \text{ i.e. } \frac{w \times d}{\text{MCTC}} \times \frac{\text{LCF}}{\text{LBP}} + \frac{w}{\text{TPC}}$$

$$20 = \frac{w \times 60}{150} \times \frac{68}{140} + \frac{w}{20}$$

$$20 = (0.1943)w + \frac{w}{20}$$

$$20 = 0.2443 w$$

$$\therefore w = 20 / 0.2443 = 81.87\text{t}$$

$$T_t = \frac{d \times w}{\text{MCTC}} = \frac{81.87 \times 60}{150 \times 100} = 0.327 \text{ m}$$

$$\therefore T_f = \frac{0.327 \times 72}{140} = 0.168 \text{ m}$$

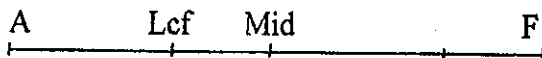
$$\text{Mean sinkage} = \frac{81.87}{20 \times 100} = 0.0409 \text{ m}$$

$$\text{Final fwd Draft} = 6.82 + 0.168 - 0.0409$$

$$\text{Final draft} = 6.947 \text{ m}$$

$$(b) \quad 20 = \frac{w}{20} + \frac{w \times 67}{150} \times \frac{58}{140}$$

20 150 140



$$20 = w(-0.05 + 0.2169)$$

$$w = 20 / 0.16695$$

$$w = 119.8$$

$$T_t = \frac{119.8 \times 67}{150} = 0.535 \text{ m}$$

$$T_f = \frac{0.535 \times 72}{140} = 0.275 \text{ m}$$

$$F = 6.82 + 0.06 + 0.275 = 7.154 \text{ m}$$

13. A vessel of length 200m CF = amidship, MCTC = 215 TPC = 20t, is at a draft of fwd 6.90m, aft = 8.13m loads 230t, 18mt fwd of midship. Calculate where with respect to midship should the remaining cargo of 470t be loaded, so that the final aft draft will be 8.10m, also calculate fwd draft then?

$$\text{Here LCF} = \frac{200}{2} = 100 \text{ m} = \text{midship}$$

$$\text{Total cargo to be loaded} = 230 + 470 = 700\text{t}$$

$$\therefore \text{The mean sinkage} = \frac{w}{\text{TPC}} = \frac{700}{20} = 35\text{cms}$$

$$T_t = \frac{(230 \times 18 - 470x)}{215}$$

$$\therefore T_a = \frac{(230 \times 18 - 470x)}{215} \times \frac{100}{200} - \frac{700}{20}$$

$$3 = \frac{(4140 - 470x)}{215} \times 0.5 - 35$$

$$215 \times 3 = 2070 - 235x - 35 \times 215$$

$$645 = -235x - 5455$$

$$235x = -5455 - 645$$

$$x = \frac{-6100}{235} = -25.957 \text{ m}$$

i.e. 25.957 = m fwd of midship

$$T_1 = \frac{4140 + 470 \times 25.957}{215} = \frac{16339.79}{215} = 0.76\text{m}$$

$$T_a = \frac{0.76 \times 100}{200} = 0.38$$

$$\begin{array}{r} 6.90 \\ + 0.38 (T_a) \\ \hline 7.28 \text{ m} \\ + .35 (M.S.) \\ \hline 7.63 \text{ m} \end{array}$$

14. A vessel of length 210m MCTC 255mt required 1230t to complete loading and is presently at a draft of Fwd 5.60m aft = 6.30m. She loads 615t, 3m fwd of midship, the drafts then are fwd 5.75 and aft 6.45m. The remaining cargo is to be loaded in No. 2 # 40m fwd of midship and No. 4 # 38m aft of midship. Calculate the amount to be loaded in each space so that the final aft draft will be 6.50m

	F	A	M
Initial	5.60	6.30	5.95
Later	5.75	6.45	6.10

Total Cargo required to load = 1230t
Of which 615t already loaded 3m fwd of midship.
∴ Remaining 615t to be loaded.

Since sinkage 0.15m is uniform for'd, aft and midship

$$TPC = \frac{615}{15} = 41\text{t}$$

Now after loading 615t the trim still remains the same i.e. at new draft fwd 5.75 & aft 6.45 the trim is still 0.70m

It means when 615t was loaded 3m fwd of the midship the trim remains the same.
 So the CF is 3m fwd of the midship.

Now after loading 615t more the mean sinkage will be 15cm i.e.

$$\begin{array}{rcl}
 & 6.45 \text{ m Draft aft} & \\
 + & 0.15 \text{ Sinkage} & \\
 \hline
 & 6.60 \text{ final draft} & \\
 & 6.50 \text{ Draft required} & \\
 \hline
 & 0.10 \text{ Total} = T_a &
 \end{array}$$

Now suppose load No. 2 # = x

Than No. 4 # = (615 - x)

$$T_t = \frac{T_m}{\text{MCTC}} = \therefore T_m = 37x - 41(615 - x)$$

$$\therefore 10 = \frac{37x - 41(615 - x)}{255} \times \frac{108}{210}$$

$$= \frac{(37x - 25215 + 41x)}{255} \times \frac{108}{210}$$

$$10 = \frac{(37x - 25215 + 41x) \times 108}{53550}$$

$$535500 = 78x \times 108 - 25215 \times 108$$

$$\therefore x = \frac{3258720}{8424} = 386.84$$

$$\therefore x = 386.84 \text{ in No. 2 \#}$$

$$615 - 386.84 = 228.16 \text{ in No. 4 \#}$$

15. A vessel of $L = 140\text{m}$, CF 3m aft of midship, MCTC = 150 TPC 20t has to load a further 125t. Where with respect to midship should it be loaded to keep the after draft unchanged. Also calculate the change in draft fwd then.

$T_a = \text{Meansinkage}$

$$\frac{TM}{MCTC} \times \frac{LCF}{LBP} = \frac{w}{TPC}$$

$$\frac{w \times d}{MCTC} \times \frac{LCF}{LBP} = \frac{w}{TPC}$$

$$\frac{125 \times d}{150} \times \frac{67}{140} = \frac{125}{20}$$

$$d \times \frac{8375}{21000} = \frac{125}{20}$$

$$\text{Now } T_t = \frac{w \times d}{MCTC}$$

$$= \frac{125 \times 15.67}{150 \times 100} = 0.1306 \text{ m}$$

$T_t = 0.1306 \text{ m change of trim fwd (Because Aft draft is not changing)}$

16. A ship of length 160m CF 2m aft of midship, MCTC 175, TPC 18t has to discharge a further amount of cargo. From where with respect to midship should it be discharged to keep the fwd draft unchanged.

Meanrise = Change of trim fwd.

$$\frac{w}{TPC} = T_f$$

$$\frac{w}{TPC} = \frac{w \times d}{MCTC} \times \frac{\text{For'd length}}{LBP}$$

$$\frac{x}{18} = \frac{x \times y}{175} \times \frac{82}{160}$$

$$\frac{1}{18} = \frac{y \times 82}{28000}$$

What about the component

$$28000 = 82 \times 18 \times y$$

$$\therefore y = 18.97 \text{ m Aft of COF}$$

or 20.97 m Aft of midship

A ship 124 m in length maximum beam 18m is in SW at a draft of fwd 6.0, aft 6.6m, her block co-efficient 0.85 and water plane co-efficient 0.74, CF 3m fwd of mid length. Longitudinal metacentric height (GM_L) 140m. Calculate the amount of cargo to discharge and its position with respect to midship to enable her to cross a bar of depth 7.0m with a clearance of 1.0 mt.

$$\begin{aligned} \text{draft fwd} &= 6.0 \\ \text{aft} &= 6.6 \\ \text{Trim aft} &= 0.60 \end{aligned} \qquad \begin{aligned} \text{Corr}^n \text{ to aft draft} &= \frac{\text{Trim} \times A. \text{ Length}}{\text{LBP}} \\ &= \frac{0.60 \times 65}{124} \\ &= 0.315 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Aft draft} &= 6.60 \\ \text{Corr}^n &= 0.315 \\ \text{Hydro draft} &= 6.285 \text{ m} \\ \text{Final hydro draft} &= 6.00 \text{ m} \\ \text{Rise} &= 0.285 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{bar Depth} &= 7.0 \text{ m} \\ \text{UK C} &= -1.0 \text{ m} \\ \therefore \text{Final hyd. draft} &= 6.0 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Now TPC} &= \frac{A \times 1.025}{100} \\ &= \frac{L \times B \times C_w \times 1.025}{100} \\ \text{TPC} &= \frac{124 \times 18 \times 0.74 \times 1.025}{100} \\ \text{TPC} &= 16.93 \text{ t} \end{aligned}$$

$$\begin{aligned} \text{Now Meanrise} &= \frac{w}{\text{TPC}} \\ 28.5 &= \frac{w}{16.93} \\ \therefore w &= 28.5 \times 16.93 \\ w &= 482.5 \text{ t} \end{aligned}$$

$$\begin{aligned} \text{To find MCTC} &= \frac{W \times GM_L}{100 \times L} = \frac{L \times B \times \text{draft} \times C_B \times 1.025 \times GM_L}{100 \times L} \\ \text{MCTC} &= 124 \times 18 \times 6.0 \times 1.025 \times 0.85 \times 140 / 100 \times 124 \\ \text{MCTC} &= 131.733 \text{ t} \end{aligned}$$

$$T_t = \frac{T_m}{MCTC}$$

$$T_t = \frac{w \times d}{MCTC}$$

$$60 = \frac{482.5 \times d}{131.733}$$

$$\therefore d = \frac{131.733 \times 60}{482.5}$$

$$d = 16.38 \text{ Aft of COF}$$

$$\underline{-3.00}$$

13.38 m fm aft of mid ship.

$$\text{Notes : TPC} = \frac{A \times 1.025}{100} \quad A = L \times B \times C_w \text{ (Water plane co-efficient)}$$

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

$$W = L \times B \times d \times \delta \times C_b$$

$$\text{Mean rise / sinkage} = \frac{w}{TPC}$$

$$T_m = \frac{w \times d}{MCTC}$$

$$\therefore MCTC = \frac{w \times d}{T_m}$$

18. A ship of $W = 6000$ t is 132 m in length. When a wt of 60t on board is shifted 25 m, her trim changes by 26 cms. Calculate her long metacentric height GM_L .

$$W = 6000$$

$$LBP = 132$$

$$w = 60$$

$$d = 25$$

$$\text{Change in trim} = 26 \text{ cms.}$$

$$GM_L = ?$$

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

$$\text{But } T_t = \frac{w \times d}{MCTC}$$

$$\therefore MCTC = \frac{w \times d}{T_t}$$

$$= \frac{60 \times 25}{26}$$

$$MCTC = 57.69 \text{ tm}$$

$$57.69 = \frac{6000 \times GM_L}{100 \times 132}$$

$$\frac{57.69 \times 100 \times 132}{6000} = GM_L$$

$$126.92 \text{ m} = GM_L$$

TRIM

Exercise 5

1. A ship 128m in length and 20m in breadth is trimmed 0.70m by stern and floating in dock water of relative density 1.017. She is required to sail on an even keel keeping the aft draft constant. Calculate the quantity of cargo to load and its location w.r.t. amidships if the co-efficient of fineness of waterplane is 0.82 [LCF 61m, MCTC 130tm].
2. A ship of length 120m, MCTC 180t, TPC 25t, CF 2m for'd of mid-length is at a draft of for'd 6.60m Aft 7.80m. 300t of cargo is to be discharged keeping her for'd draft unchanged. Calculate the position w.r.t. mid-length from where the cargo should be discharged. Also calculate her drafts fore and aft after discharging.
3. A vessel of length 140m, C of F 2m abaft midlength, MCTC 200mt, TPC 15t, is at a draft of 7.7m for'd and 7.9m aft. It is necessary to reduce the for'd draft to 6.7m with out changer in the after draft. Calculate the weight to be discharged and the position with respect to midlength from where it should be discharged.
4. A vessel of length 160m, C of F 3m abaft the mid-length, TPC 18t, MCTC 200mt is at a draft of F 7.8m, A 8.1m. To effect repairs at the bow, it is necessary to reduce the forward draft to 6.5m. The maximum permissible draft where the ship is to be berthed for effecting repairs is 7.0m, and cargo can be discharged from No. 1, 70m forward of mid-length and No. 4, 30m abaft mid-length. Calculate the minimum cargo to be discharged from each hold.

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Answers :

1. Cargo = 712.189t, $d = 9.778\text{m}$ for'd of midhsip
2. $d = 11.94\text{ m}$ aft of midship, Final draft = 6.60m, Final Aft = 7.552
3. $d = 25.43\text{m}$ for'd of COF, cargo to discharge 729 t
4. To discharge 621.7t from No. 1 cargo hold
To discharge 1532.9t from No. 4 cargo hold

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CHAPTER VI

COMBINED LIST AND TRIM PROBLEMS

A ship of $W = 13000t$ $MCTC = 180mt$. $KG = 7.2m$ $KM = 7.48m$ is trimmed $1.3m$ by stern and listed 7° port. No. 1 D.B. tanks (P & S) $35m$ fwd of COF with $Cgs = 3.6m$ each side of $\bar{C}$ are empty. No. 4 D.B. tanks (P & S) $13m$ abaft COF with their Cgs $3.7m$ each side of $\bar{C}$ are full of Do. Calculate the quantities to be transferred into each of No. 1 tanks using equal quantities from No. 4 tank to bring the vessel upright and on even keel.

First transfer fwd to bring it on even keel then transfer P to S to correct the list.

$$\text{Distance shift fwd} = 13 + 35 = 48 \text{ m}$$

$$Cg = 3.6$$

$$+ 3.7$$

$$7.3 \text{ m}$$

$$Tt = Tm / MCTC$$

$$KM = 7.48$$

$$Tt = \frac{w \times d}{MCTC}$$

$$KG = 7.20$$

$$MCTC$$

$$GM = 0.28$$

$$1.3 = \frac{w \times 48}{180}$$

$$180$$

$$ILM = FLM$$

$$\therefore w = \frac{130 \times 180}{48}$$

$$48$$

$$ILM = \tan 7^\circ \times 13000 \times 0.28 = 7.3x \text{ FLM}$$

$$w = 487.5$$

$$= 446.94 = 7.3x$$

$$\text{No. 4 P} = 243.75$$

$$\therefore x = \frac{446.94}{7.3} = 61.22$$

$$S = 243.75$$

$$\therefore 243.75 + \left[\frac{61.22}{2} \right] = 274.36t \text{ will go to No. 1 (Stbd)}$$

$$243.75 - \left[\frac{61.22}{2} \right] = 213.36t \text{ will go to No. 1 (Port)}$$

NB there can be more than one possibility to achieve the desired result. Thus the final distribution can differ.

COMBINED LIST & TRIM PROBLEMS

Exercise 6

1. A ship of 6000 tonnes displacement has $KM = 7\text{m}$, $KG = 6.4\text{m}$, and $MCT 1\text{cm} = 120\text{ tonnes m}$. The ship is listed 5 degrees to starboard and trimmed 0.15m by the head. The ship is to be brought upright and trimmed 0.3m by the stern by transferring oil from No. 2 double bottom tank to No. 5 double bottom tank. Both tanks are divided at the centre line and their centres of gravity are 6m out from the centre line. No. 2 holds 200 tonnes of oil on each side and is full. No. 5 holds 120 tonnes on each side and is empty. The centre of gravity of No. 2 is 23.5m forward of amidships and No. 5 is 21.5m aft of amidships. Find what transfer of oil must take place and give the final distribution of the oil. (Neglect the effect of free surface on the GM.) Assume that LCF is at amidships.
2. A ship of 10000 tonnes displacement is listed 5 degrees to port and trimmed 0.2m by the head. $KM = 7.5\text{m}$, $KG 6.8\text{m}$, and $MCT 1\text{cm} = 150\text{ tonnes m}$. Centre of flotation is amidships. No. 1 double bottom tank is divided at the centre line, each side holds 200 tonnes of oil and the tank is full. No. 4 double bottom tank is similarly divided each side having a capacity of 150 tonnes, but the tank is empty. The centre of gravity of No. 1 tank is 45m forward of amidships and the centre of gravity of No. 4 tank is 15m aft of amidships. The centre of gravity of all tanks is 5m out from the centre line. It is desired to bring the ship upright and trimmed 0.3m by the stern by transferring oil. If the free surface effect on GM be neglected, find what transfer of oil must take place and also the final distribution of the oil.
3. A ship displaces 12500 tonnes, is trimmed 0.6m by the stern and listed 6 degrees to starboard. $MCT 1\text{ cm} 120\text{ tonnes m}$, $KG 7.2\text{m}$, $KM 7.3\text{m}$. No. 2 and No. 5 double bottom tanks are divided at the centre line. Centre of gravity of No. 2 is 15m forward of the centre of flotation and centre of gravity of No. 5 is 12 m abaft centre of flotation. Centre of gravity of all tanks is 4 m out from the centre line.

The ship is to be brought upright and on to an even keel by transferring oil from aft to forward, taking equal quantities from each side of No. 5. Find the amounts of oil to transfer.

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Answers :

120 tonnes of oil to be transferred from for'd to aft. 26.25 tonnes to be transferred from stbd to port to bring vessel upright.

Final distribution :

Original		Final					
	P S	P S					
No 2	<table> <tr> <td>200</td> <td>200</td> </tr> </table>	200	200	<table> <tr> <td>200</td> <td>80</td> </tr> </table>	200	80	
200	200						
200	80						
	$\xleftarrow{26.25t}$ $\downarrow 120t$						
No 5	<table> <tr> <td>0</td> <td>0</td> </tr> </table>	0	0	<table> <tr> <td>26.25</td> <td>93.75</td> </tr> </table>	26.25	93.75	
0	0						
26.25	93.75						

- Transfer 125 tonnes from for'd to aft and 61.25 tonnes from port to stbd. Final distribution : No. 1 port 75t, No.1 stbd 200t, No. 4 port 63.75 t, No. 4 Stbd 61.25t.
- Transfer 133.33t from each side of No. 5. Put 149.8 t in No. 2 port and 116.9t in No. 2 stbd.

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CHAPTER VII

CHANGE IN TRIM DUE TO CHANGE IN DENSITY

Effect Of Addition Of Weight At The Centre Of Floatation :

Suppose a ship is floating at water line WL (Figure 1). Let a weight w be loaded vertically above centre of floatation F . Let centre of gravity (G), centre of buoyancy (B) be in same vertical line below F . When the weight w is added, G will move vertically upwards towards the centre of gravity of the weight w . The ship then sinks to water line $W_1 L_1$, so that the weight of the added layer WL $\frac{1}{2} W_1 L_1$ will be equal to that of the added weight w . Now the new centre of floatation is at F_1 and if the added weight is not too large, it will be directly above the old C.O.F. (F). Therefore B will move vertically upwards towards the centre of gravity of added layer which is somewhere between F and F_1 . In this case the G and B have vertically moved upwards and still are in the same vertical line and there is no couple formation. Thus there is no change of trim taking place.

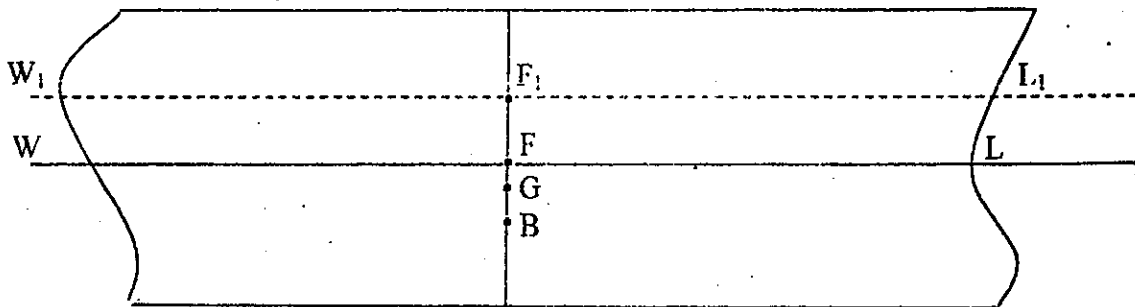


Figure 1.

Now imagine a case where the centre of floatation 'F' is not in the same vertical line as G and B . (Figure 2). The vessel is floating at water line WL in density δ_1 with certain trim. Now the vessel goes to another lesser density δ_2 . She will sink to another water line $W_1 L_1$.

$$TPC = \frac{A}{100} \times \text{density}$$

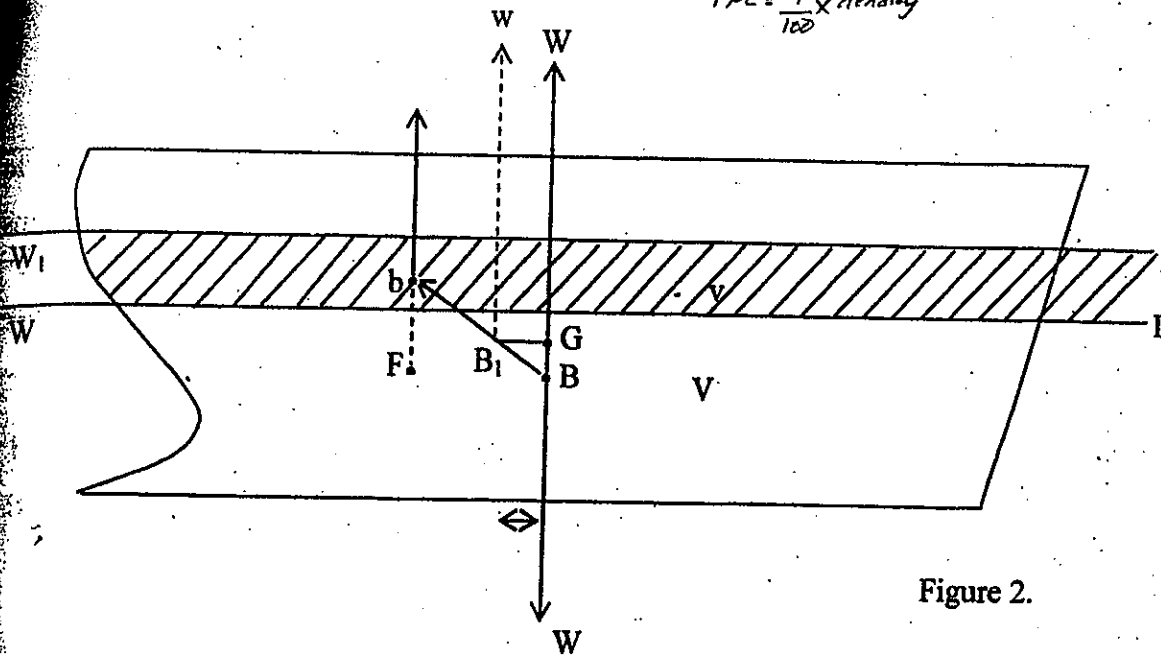


Figure 2.

The added layer is shown with shaded area. Let the centre of buoyancy of the added area be at 'b'. The maximum sinkage a vessel can have when she goes from S.W. ($\delta = 1.025$) to F.W. ($\delta = 1.0$) is equal to its fresh water allowance. From any one density to another density between S.W. and F.W. the sinkage will be equal to dock water allowance (DWA). Since the FWA (or DWA) is not very large quantity, the sinkage is not very large, the centre of buoyancy of added layer 'b' will be vertically above F. Because of added volume 'v', the centre of buoyancy B will move towards 'b' to some point B_1 , the new centre of buoyancy.

If the horizontal shift of the centre of buoyancy is BB_1 and original underwater volume in density δ_1 , is V then

$$BB_1 = \frac{v \times (LCB - LCF)}{\text{Final } V (V + v)}$$

$$\text{Final } V (V + v)$$

When the centre of buoyancy shifts to B_1 , the force of buoyancy will act vertically upwards from B_1 . Whereas the weight of ship acts downwards from G. A couple is formed which tends to trim the vessel towards head. The moment changing trim = $W \times BB_1$

The change in trim $Tt = \frac{BB_1 \times W}{MCTC}$ and

She will trim by head.

In different situations the trim will be as follows :

Position of COE \ Change in density	Vessel goes from higher density to lower density	Vessel goes from low density to higher density
COF Aft of COB (LCB - LCF = +ve)	Trim by head	Trim by Stern
COF For'd of COB (LCB - LCF = -ve)	Trim by stern	Trim by head

While solving the numericals, the mean sinkage / rise is also to be calculated and applied. In these cases the mean sinkage / rise is worked out by calculation, $FWA = W / 40 \text{ TPC}$ and then $DWA = \frac{FWA (1.025 - \delta)}{0.025}$

❖ Problems :

- Paet 0.122 TPC Pg 256-10.1*
1. A ship of $w = 7500t$, $L = 120m$ is at a draft of fwd $6.00m$ and aft $6.60m$. in SW. MCTC $136 t.m$. LCF $58m$. LCB $63m$. TPC $12t$. Calculate her drafts F and A if she proceeds to FW ?

$$u/w \text{ vol. in SW} = \frac{W}{\delta} = \frac{7500}{1.025} = 7317.07m^3$$

$$u/w \text{ vol. in FW} = \frac{W}{\delta} = \frac{7500}{1.000} = 7500.00m^3$$

$$v = 7500 - 7317.07 = 182.93 m^3$$

$$\text{Now } BB_1 = v (LCB - LCF) / \text{Final V.}$$

Imp

Note : Final V is the final volume when proceeding to the new density and not

$$(V + v) \text{ or } (V - v)$$

$$BB_1 = \frac{182.93 (63 - 58)}{7500} \\ = \frac{182.93 (5)}{7500} = 0.12195$$

Note : The amount of BB_1 is quite small, but when shifted through a large distance the amount is quite large and hence better to take BB_1 upto 5 places of decimals.

Now mean sinkage = FWA

$$= \frac{W}{40 \text{ TPC}} = \frac{7500}{40 \times 12} = 15.625 \text{ Cm} = \text{mean sinkage}$$

MCTC given in SW and hence change to FW.

$$\therefore \frac{136 \times 1.000}{1.025} = 132.683 \text{ t.m}$$

Hence now

$$\text{Total change in trim} = \frac{BB_1 \times W}{\text{MCTC (FW)}} = \frac{0.12195 \times 7500}{132.683} \\ = 6.89 \text{ cms.}$$

$$T_f = \frac{\text{Trim} \times \text{Fwd Length}}{\text{LBP}}$$

$$= \frac{6.89 \times 62}{120 \times 100}$$

$$= 0.0355 \text{ m}$$

$$T_a = \frac{\text{trim} \times \text{LCF}}{\text{LBP}}$$

$$= \frac{6.89 \times 58}{120 \times 100}$$

$$= 0.0333 \text{ m}$$

Fwd draft	6.000m	Aft	6.600m
Sinkage	= + 0.156m		+ 0.156m
draft	= 6.156m		6.756m
change in trim	= + 0.0355m		- 0.0333
final draft	= 6.1915m		6.7227m

2. A vessel of length 230mt. $W = 19000t$, $MCTC = 250tm$ $TPC = 30t$, $CF = 3m$ aft of midship. CB 4m fwd of midship is at a draft of fwd 9.40m, Aft = 10.85 in water of RD 1.005. Calculate her draft F and A on proceeding to water of RD 1.021.

$$u/w \text{ volume @ } 1.005 = \frac{19000}{1.005} = 18905.47 \text{ m}^3$$

$$u/w \text{ volume @ } 1.021 = \frac{19000}{1.021} = 18609.21 \text{ m}^3$$

$$\therefore v = 18905.47 - 18609.21 = 296.26 \text{ m}^3$$

$$\text{Now } BB_1 = \frac{v(LCB - LCF)}{\text{Final } V_{(1.021)}} = \frac{296.26(119 - 112)}{18609.21}$$

$$BB_1 = 0.11144m$$

$$MCTC \text{ for SW} = 250$$

$$\therefore \text{ for RD } 1.02 = ?$$

$$\frac{250 \times 1.021}{1.025} = 249.024 \text{ tm}$$

$$\text{Total change in trim} = \frac{BB_1 \times W}{MCTC} = \frac{0.11144 \times 19000}{249.024}$$

Total change in trim : 8.503 cm

$$\text{Now mean rise} = \frac{w}{TPC} = DWA$$

$$\therefore FWA = \frac{W}{40 \text{ TPC}} = \frac{19000}{40 \times 30} = 15.83 \text{ cms.}$$

$$DWA = \text{Change in } \delta \times \frac{FWA}{0.025}$$

$$= 0.016 \times \frac{15.83}{0.025} = 10.13 \text{ cm} = 0.101 \text{ m}$$

$$\text{Change in trim fwd} = \frac{\text{trim} \times LCB}{LBP} = \frac{0.08503 \times 118}{230}$$

$$= 0.0436 \text{ m}$$

$$\text{Change in trim Aft} = \frac{\text{trim} \times LCF}{LBP} = \frac{0.08503 \times 112}{230}$$

$$= 0.0414 \text{ m}$$

draft = Fwd	9.40m	Aft	10.85m
rise	- 0.101m	-	0.101m
	9.299m		10.749m
Change in trim	- 0.0436m	+	0.0414m
Final draft	9.2554m		10.7904m

3. A vessel at even keel draft of 9.3m in RD 1.005 has the following particulars:

$$W = 19500t$$

$$LBP = 145m$$

$$LCF = 70m$$

$$LCB = 72mt$$

$$MCTC = 215tm$$

$$TPC = 25t$$

Find her draft F and A when she goes to sea?

$$u/w \text{ volume in RD } 1.005 = \frac{19500}{1.005} = 19402.985 \text{ m}^3$$

$$u/w \text{ volume in RD } 1.025 = \frac{19500}{1.025} = 19024.39 \text{ m}^3$$

$$v = 19402.985 - 19024.39 = 378.595 \text{ m}^3$$

$$BB_1 = \frac{v (LCB - LCF)}{\text{Final } V} = \frac{378.595 (72 - 70)}{19024.39} = 0.0398 \text{ mt}$$

$$\text{Total change in trim} = \frac{BB_1 \times W}{MCTC (SW)} = \frac{0.0398 \times 19500}{215}$$

$$T_1 = 3.61m$$

$$\text{Mean rise} = FWA = \frac{W}{40 \text{ TPC}} = \frac{19500}{40 \times 25} = 19.5m$$

$$DWA = \text{Change in } \delta \times \frac{FWA}{0.025}$$

$$= 0.020 \times \frac{19.5}{0.025}$$

$$= 15.6 \text{ Cm}$$

$$= 0.156 \text{ m mean rise..}$$

lars:

Distance from CF to for'd
LBP

$$T_a = \frac{T_t \times LCF}{LBP}$$

75

$$T_a = \frac{3.61 \times 70}{145}$$

mm

$$= 0.0174 \text{ m}$$

Draft Fwd	9.30m
Rise	- 0.156m
	9.144m
Change in trim	- 0.0186
	9.1254m
Final draft	

Aft	9.30m
	- 0.156m
	9.144m
	+ 0.0174
	9.1614m

CHANGE IN TRIM DUE TO CHANGE IN DENSITY

Exercise 7

1. A ship 90 metres long displaces 5200 tonnes and floats at draughts of 4.95m forward & 5.35m aft when in seawater of R.D. 1.023. The waterplane area is 1100m^2 , GM_L 95m, LCB 0.60m forward of midships and LCF 2.2m aft of midships. Calculate the new draughts fore & aft when the vessel moves into water of RD 1.002. (Assume given hydrostatic particulars remain constant throughout).
2. A vessel of length 120m, displacement 8200 M/T, TPC 13 M/T, LCB 55 mts, LCF 59 mts, is in salt water at a draft of 4.35m forward and 4.80m aft. Calculate her draft Forward and Aft on proceeding to water of density 1.005 if MCTC in that water is 80 tons-mt.
3. A vessel on an even keel draft of 9.35m in RD 1.004 has the following particulars : Displacement 19494.5t, LBP 143.2m, LCF 69.63m, LCB 72.73m, KB 4.97m, MCTC 214.26tm, TPC 24.3t. Find her drafts fore and aft when she goes to sea.

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Answers :

1.	F = 5.0757m	A = 5.4212m
2.	F = 4.436m	A = 4.887m
3.	F = 9.156m	A = 9.2059m

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CHAPTER VIII

DRY-DOCKING

There are two possible dangers during the docking, or undocking, of any ship :

- (i) Structural damage to the ship (especially the rudder and stern frame) or to the blocks, or, but less likely, collapsing of the ground in way of the blocks.
- (ii) The ship may become unstable and fall off the blocks at some stage if, at that time, it is inadequately supported.

A ship is normally docked trimmed by the stern. In the early stages of the pumping out of the dock the ship sinks bodily, maintaining constant draughts fore and aft. After sufficient water has been pumped out to allow the ship to touch the blocks aft, the after draught reduces steadily, at the same rate as the water is lowered in the dock. The forward draught now increases, but at a slower rate than the after draught decreases; consequently the mean draught (strictly the true mean draught) decreases. The ship's trim decreases steadily and in due course the ship takes the blocks overall. If the blocks are set horizontally (i.e. they do not have a run down towards the gate – known as declivity) the ship's trim will then be zero; the ship will have suffered a change of trim equal to the original (free-floating) trim. The changes of draught between the docking condition and the 'all-flat' condition follow this pattern.

	Aft	Fwd	Mean
Docking	9.00 m	5.00 m	7.00 m
	8.00 m	5.60 m	6.80 m
	7.00 m	6.20 m	6.60 m
Flat on blocks	6.50 m	6.50 m	6.50 m

At the instant the vessel's stern first touches the blocks a vertical force P arises and this force increases steadily as the water is lowered. This reaction from the blocks measured the increasing load being imposed on the blocks and equals the reduction of the ship's displacement in the water. It can be determined at any stage by considering the reduction of the ship's (true) mean draught.

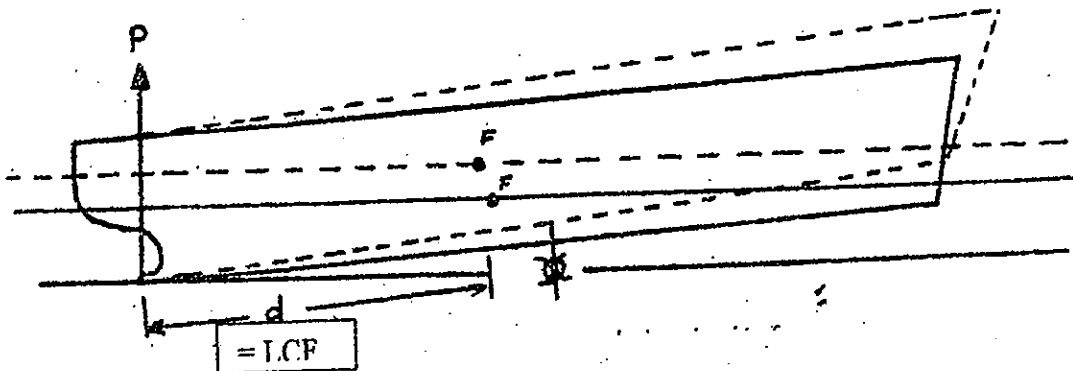
$$P = \text{Reduction of (true) mean draught} \times \text{TPC}$$

For example, if the TPC is assumed to be 22, and the ship's displacement is (originally) 10000 tonnes, the draught figures quoted previously lead to the following conclusions :

	Aft	Fwd	Mean	P	Displ.
in water					
Docking	9.00	5.00	7.00	0 tonnes	10000
tonnes					
	8.00	5.60	6.80	$(20 \times 22) = 440$	9560
	7.00	6.20	6.60	$(40 \times 22) = 880$	9120
On blocks overall	6.50	6.50	6.50	$(50 \times 22) = 1100$	8900

This ship's structure aft and the block on which the ship has been pivoting must (in this case) be able to withstand a force P amounting to 1,100 tonnes just before the ship grounds overall. After the ship has landed overall and the water is lowered further the force P continues to increase but is spread throughout the ship's length. When the ship is 'dry' the force P must equal the ship's original displacement (10000 tonnes in this case).

During the interval between first touching the blocks aft and grounding overall, the force P may also be calculated by considering the change of trim.



The broken lines show the ship's position and the water level when the ship first touches the blocks aft. The full lines show the ship and the water level at a later stage.

P is causing a trimming moment = $(P \times d)$ tonnes-metres where d is the distance between the 'aft block' and the LCF.

(originally)
 Displacements :
 Displ.
 10000
 9560
 9120
 8900
 Just (in this
 the ship
 further the
 the ship is
 this case).

$$\text{Change of trim (cms)} = \frac{(P \times d)}{MCTC}$$

This can be written :

$$P \text{ (tonnes)} = \frac{\text{Change of trim} \times MCTC}{d}$$

For example, consider the instant at which the draught became A 7.00 m F 6.20 m – a trim of 80 cm by the stern, assuming MCTC to be 198 tonnes-metres and d (the distance of the aft block from the center of flotation) to be 72m. The change of trim is 320 cm.

Hence :

$$P = \frac{320 \times 198}{72} = 880 \text{ tonnes}$$

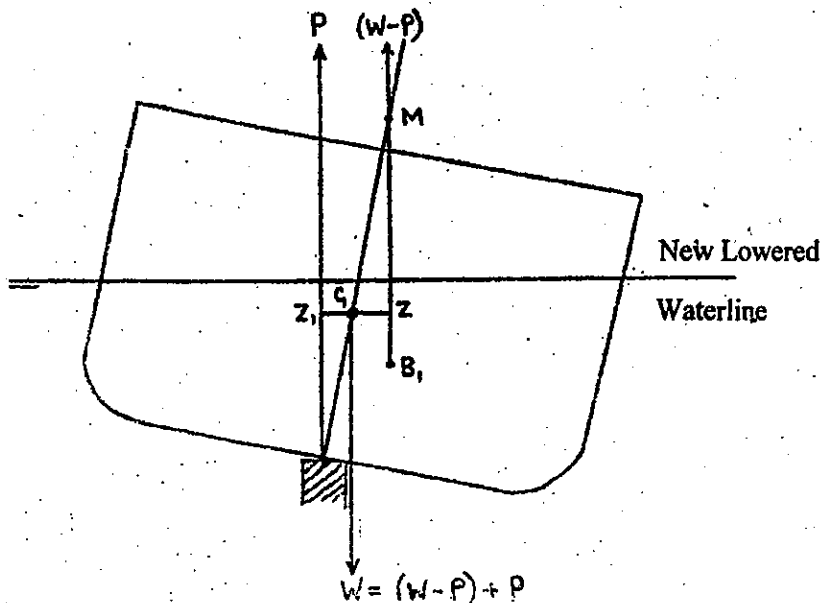
This is the same value as was found by considering the reduction of mean draught. When the ship is 'all-flat' the change of trim is 400 cm and :

$$P = \frac{400 \times 198}{72} = 1100 \text{ tonnes}$$

This method of finding P cannot, however, be used after the ship has landed flat.

THE LOSS OF STABILITY

The loss of stability during dry-docking varies directly with the value of P. The loss of stability arises because the force P introduced a capsizing moment should the vessel for any reason be slightly heeled whilst on the blocks. The sketch below shows this condition. The total weight is W tonnes acting through G. The upthrust is made up of two parts, P tonnes at K and (W – P) tonnes from the water, acting at B₁ through the metacentre M. This is the metacentre appropriate to the waterline at this time.



t touches
 between

The weight W can be considered in two parts, $(W - P)$ and (P) tonnes. The component of weight $(W - P)$ through G along with the upthrust $(W - P) \times GZ$ tonnes metres. The component of weight P through G along with the upthrust P from the blocks at K constitute a capsizing couple the moment of which is $(P \times GZ_1)$ tonnes metres. Hence the net righting moment is $[(W - P) \times GZ] - [P \times GZ_1]$ and this is less than the righting moment $(W \times GZ)$ which would have existed if the whole of the upthrust $(W$ tonnes) was provided by the water.

The loss of stability is conveniently calculated as a virtual (or effective) loss of GM i.e. the reduced righting moment can be deemed to arise from a reduction of GM . There are two ways in which the effective loss of GM may be measured :

- (i) As a virtual rise of G . In this case, loss of $GM = \frac{(P \times KG)}{(W - P)}$ metres where :

P = Force from the blocks (tonnes);

KG = The ship's real KG (metres);

W = Displacement free-floating (tonnes).

- (ii) As a virtual drop of M . In this case, loss of $GM = \frac{(P \times KM)}{W}$ metres where :

P = Force from the blocks (tonnes);

KM = Metacentre appropriate to the waterline at this time (metres);

W = Displacement free-floating (tonnes).

The two formulae will not give exactly equal results for the loss of GM , or for the effective remaining GM . Formula (i) is more accurate.

Example

1. A ship displacing 9000 tonnes is being docked at draughts F 6.60m A 7.80m, KG 8.10m. Calculate the effective GM when flat on the blocks if KM then is 8.80m and assuming LBP 140m, LCF 4m abaft amidships. MCTC 140 tonnes-metres.

$$P = \frac{\text{Change of trim} \times \text{MCTC}}{\text{Distance from aft block of LCF}}$$

When flat, change of trim = 120 cm

$$P = \frac{120 \times 140}{66} = 254.6 \text{ tonnes}$$

Using the formula, loss of GM = $\frac{(P \times KG)}{(W - P)}$ we get

$$\text{loss of GM (or virtual rise of G)} = \frac{254.6 \times 8.10}{(9000 - 254.6)} = 0.236 \text{ m}$$

$$\text{Virtual KG} = 8.10 + 0.236 = 8.336$$

$$\text{KM} = 8.800$$

$$\text{Virtual (Effective) GM} = \underline{0.464 \text{ m}}$$

Alternatively, using the formula loss of GM = $\frac{P \times KM}{W}$ gives :

$$\text{Loss of GM (virtual drop of M)} = \frac{254.6 \times 8.80}{9000} = 0.249 \text{ m}$$

$$\text{Virtual KM} = 8.800 - 0.249 = 8.551$$

$$\text{KG} = 8.100$$

$$\text{Effective GM} = \underline{0.451 \text{ m}}$$

Although the two methods give different values for the loss of GM and for the effective GM when on the blocks, each is correct. The proper measure of a ship's stability is the righting moment i.e. (displacement X GM X Sinθ) tonnes-metres. If the GM had been calculated by the first method it has to be related to a displacement (W - P) and the righting moment is (9000 - 254.6) X 0.464 X Sin θ which is (4058 X Sinθ) tonnes-metres. If the GM had been found by the second method it has to be related to a displacement W and the righting moment is (9000 X 0.451 X Sinθ) which is also (4058 X Sinθ) tonnes-metres. Both are equal.

THE REASONS FOR THE DESIRABILITY OF DOCKING WITH A SMALL STERN TRIM

The rate at which the dock is being pumped out is temporarily reduced when the keel aft nears the blocks in order that the ship can be properly aligned on the blocks. After the ship has landed aft, side shores can be shipped progressively, starting aft and working forward, although they cannot be hardened up i.e. wedged tight, at this stage. Pumping is

again slowed up as the ship approaches the 'all-flat' condition to ensure that the ship is correctly centred along the blocks. Once on the blocks along the whole length the side shores can be quickly wedged up. Alternatively the vessel will now be supported along each bilge by bilge blocks or shores. Any possibility of capsizing is eliminated and pumping out can proceed at maximum rate. By having only a small docking trim the force P which builds up at the aft block (during the interval between touching aft and grounding overall) is never great; there is no risk of structural damage; the loss of GM is small and the ship should still have a positive GM even if the original GM was not great. An excessive trim leads to a large value of P in way of the aft block and the likelihood of structural damage; the aft block may be tripped (upset) – if this happens the ship dips aft and surges aft, possibly causing damage to other blocks or to the ship's structure; the loss of GM will be considerable and the stability may become negative – again with the possibility of damage to ship or dock.

Although stability considerations alone would permit a ship to be docked with a very heavy trim when it is known that the original GM is also very large, the possibility of structural damage aft, or tripping of the blocks, means that a heavy trim must be avoided if it is possible to do so. Otherwise it is essential to ensure that the dock staffs are forewarned of the intention to dock with a heavy trim; they may then take precautions to ensure a safe docking.

Although docking on an even keel would eliminate the troubles due to force P at the aft block, the ship is then more difficult to land centrally on the blocks. Pumping must be reduced to a minimum while the ship is nearing and taking the blocks and can only be speeded up after it has been ensured that all shores or bilge blocks are tight.

DRY DOCKING A LOADED SHIP

If a ship sustains propeller / rudder or bottom, side or other damage below the waterline, dry-docking the ship in it's loaded condition might be considered. In such a situation the following points should be noted:

- The dry-dock manager must be provided with plans showing clearly the position of bulkheads and other key structural features, rise of floor (if any), plug positions for all tanks and a cargo plan showing the weights in each space/hold/tank.
- With the aid of the information provided above extra support for the ship will be planned which may incorporate bilge beds built up to the level of the bottom plating.
- The ship should be docked as close to even keel as possible (or trimmed equivalent to the declivity of the dock) to reduce the thrust at the aft keel block to a minimum during the critical period. Consider the formula.

$$P. (\text{tonnes}) = \frac{T_t \times MCTC}{d}$$

- Immediately the dock is emptied inspection should be undertaken to identify any hull deformation and additional side and bilge shores may be added.
- The dock should be flooded on completion of work to float the ship at the earliest opportunity.
- In the event of side shell damage, it may only be necessary to partly empty the dock once the ship is on the blocks fore and aft. Once the site of the damage is exposed the remaining water may be left in the dock. Thus, the remaining volume of displacement will assist in providing support to the ship and will reduce the effects of sagging or otherwise that might have arisen had the dry-dock been completely emptied.
- In any event, serious consideration should be given to the risk of structural damage which might occur while docking the ship in the loaded condition. Consequently, discharge of cargo might be the most appropriate action prior to dry-docking.

Problems :

2. A ship of $W = 6600t$, $KM = 6.8m$, $KG = 6.3m$ is trimmed $0.5m$ by stern, $MCTC = 115mt.$, $LCF = 57.5m$. Calculate her virtual GM and the RM at a heel of 3° @ the critical instant.

$$t \times MCTC = P \times a$$

$$50 \times 115 = P \times 57.5$$

$$\therefore P = \frac{50 \times 115}{57.5}$$

$$P = 100t$$

$$GG_1 = \frac{P \times KG}{W - P}$$

$$= \frac{100 \times 6.3}{6600 - 100}$$

$$= \frac{630}{6500}$$

$$= 0.0969$$

$$\text{OR } \frac{P \times KM}{W}$$

$$\frac{100 \times 6.8}{6600}$$

$$\frac{680}{6600}$$

$$0.1030$$

$$KM = 6.8$$

$$KG = 6.3$$

$$GM = 0.50$$

$$\therefore GM = 0.5000m$$

$$- GG_1 = 0.0969m$$

$$\text{Virtual } GM = 0.4031m$$

$$0.5000m$$

$$- 0.1030m$$

$$0.397m$$

$$R.M. = (W - P) \cdot GM \cdot \sin \theta$$

$$= 6500 \times 0.4031 \times \sin 3^\circ$$

$$RM = 137.13 \text{ mt}$$

$$RM = W \cdot GM \cdot \sin \theta$$

$$= 6600 \times 0.397 \times \sin 3^\circ$$

$$RM = 137.13 \text{ mt}$$

3. A vessel of length $142m$, $CF = 3m$. aft of midship, $MCTC = 148$, $KM = 7.0$, $KG = 6.3$, is at a draft of fwd 5.24 , Aft 6.30 . $FSM = 700mt$ $W = 7200t$ is dry docked. Calculate her GM (f) on taking blocks all over.

$$t \times MCTC = P \times LCF$$

$$106 \times 148 = P \times 68$$

$$\therefore P = \frac{106 \times 148}{68} = 230.706t$$

$$\text{Drafts Fwd } 5.24$$

$$\text{Aft } 6.30$$

$$\text{Trim } 1.06m \text{ by stern}$$

stem,
at a

$$GG_1 = \frac{P \times KG}{W - P}$$

$$= \frac{230.706 \times 6.3}{7200 - 230.706}$$

$$= \frac{1453.448}{6969.294}$$

$$= 0.2086$$

$$\frac{P \times KM}{W}$$

$$\frac{230.706 \times 7.0}{7200}$$

$$\frac{1614.942}{7200}$$

$$0.224$$

$$FSC = \frac{FSM}{W - P} = \frac{700}{7200 - 230.706} = \frac{700}{6969.294} = 0.100$$

$$KM = 7.000$$

$$KG = 6.300$$

$$GM(s) = 0.700$$

$$FSC = -0.100$$

$$GM(f) = 0.600$$

$$GM(f) = 0.6000$$

$$GG_1 = 0.2086$$

$$GM(f) = 0.3914m$$

$$0.600$$

$$-0.224$$

$$0.376m$$

4. A ship of $L = 150m$, $W = 6800t$, $KM = 7.4$, $KG = 6.8$, $MCTC = 164mt$ CF = 2m fwd of midship, drafts fwd = 5.15, Aft = 6.05, is dry docked. If at the critical instant the M has risen by 0.20m. Calculate her virtual GM on taking blocks.

$$Fwd \quad 5.15m$$

$$Aft \quad 6.05m$$

$$Trim \quad 0.90m$$

$$\therefore t \times MCTC = P \times LCF$$

$$90 \times 164 = P \times 77$$

$$\therefore P = 90 \times 164 / 77$$

$$P = 191.688t$$

$$KM = 7.40$$

$$KM = +0.20$$

$$KM = 7.60$$

$$KG = 6.80$$

$$GM = 0.80$$

$$\begin{aligned}
 GG_1 &= \frac{P \times KM}{W} \\
 &= \frac{191.688 \times 7.6}{6800} \\
 &= \frac{1456.8288}{6800} \\
 &= 0.2143m
 \end{aligned}$$

$$\begin{aligned}
 GM &= 0.80m \\
 GG_1 &= -0.2143m \\
 \hline
 GM &= 0.5857m
 \end{aligned}$$

OR

$$\begin{aligned}
 &\frac{P \times KG}{W - P} \\
 &\frac{191.688 \times 6.80}{6800 - 191.688} \\
 &\frac{1303.478}{6608.312} \\
 &0.197m
 \end{aligned}$$

$$\begin{aligned}
 GM &= 0.80m \\
 GG &= -0.197m \\
 \hline
 GM &= 0.603m
 \end{aligned}$$

5. A vessel of $W = 5500t$, $L = 130m$, $CF = 3m$ aft of midship $MCTC = 135$, $KM = 6.80$, $GM(f) = 0.80m$. $FSC = 0.12$ at drafts fwd = 4.80, aft = 5.70 is dry docked. Calculate her $GM(f)$ on taking blocks all over.

$$\begin{aligned}
 \text{Fwd} &4.80 \\
 \text{Aft} &5.70 \\
 \hline
 \text{Trim} &0.90
 \end{aligned}$$

$$\begin{aligned}
 t \times MCTC &= P \times LCF \\
 90 \times 135 &= P \times 62 \\
 P &= 90 \times 135 / 62 = 195.968
 \end{aligned}$$

$$\begin{aligned}
 GM(f) &= 0.80m \\
 FSC &= +0.12m \\
 \hline
 GM(s) &= 0.92m \\
 KM &= 6.80m \\
 \hline
 KG &= 5.88m
 \end{aligned}$$

$$\begin{aligned}
 GG_1 &= \frac{P \times KM}{W} \quad \text{OR} \quad \frac{P \times KG}{W - P} \\
 &= \frac{195.968 \times 6.8}{5500} \quad \text{OR} \quad \frac{195.968 \times 5.88}{5500 - 195.968} \\
 &= \frac{1332.582}{5500} \quad \text{OR} \quad \frac{1152.292}{5304.032} \\
 &= 0.2423m \quad \quad \quad 0.2172
 \end{aligned}$$

$$FSC = \frac{FSM}{W}$$

$$0.12 = \frac{FSM}{5500}$$

$$FSM = 660$$

$$\therefore FSC = \frac{FSM}{5304.032} = \frac{660}{5304.032}$$

$$FSC = 0.1244$$

$$GM(s) = 0.92$$

$$FSC = -0.1244$$

$$GM(f) = 0.7956$$

$$GG_1 = 0.2423$$

$$GM(f) = 0.5533m$$

$$GM(s) = 0.92$$

$$FSC = -0.1244$$

$$GM(f) = 0.7956$$

$$GG_1 = -0.2172$$

$$GM(f) = 0.5784m$$

6. A vessel of $W = 19000t$, $L = 200m$, $CF = 2m$ fwd of midship $MCTC = 215tm$, $KM = 7.5$, $KG = 7.0$ is to be dry docked. Calculate the maximum permissible trim by stern, if her GM should be at least 40 cms on taking the blocks F & A .

$$KM = 7.5$$

$$KG = 7.0$$

$$GM = 0.50$$

$$GM = 0.40 \text{ Required}$$

$$GG_1 = 0.10$$

$$\therefore GG_1 = \frac{P \times KM}{W}$$

$$0.10 = \frac{P \times 7.5}{19000}$$

$$\therefore P = \frac{0.10 \times 19000}{7.5} = 253.33t$$

$$\therefore t \times MCTC = P \times a(LCF)$$

$$t \times 215 = 253.333 \times 102$$

$$\therefore t = \frac{253.333 \times 102}{215}$$

$$t = 120.18 \text{ cm}$$

$$\therefore t = 1.202 \text{ m}$$

7. A vessel of $L = 82\text{m}$, $CF = 3\text{m}$ aft of midship $MCTC = 78\text{m}$, $TPC = 16\text{t}$
 $KM = 4.6$, $KG = 4.10$, $W = 3200\text{t}$ drafts for'd = 3.8m , Aft = 4.3m is dry
 docked. Calculate

- (i) Vertical GM on taking blocks all over
 (ii) The drafts F and A then
 (iii) Her draft F and A, when she becomes unstable.

$$\begin{array}{r} \text{(i) Fwd } 3.80 \\ \text{Aft } 4.30 \\ \hline \text{Trim } 0.50 \end{array}$$

$$\begin{array}{r} KM = 4.60 \\ KG = 4.10 \\ \hline GM(s) = 0.50\text{m} \end{array}$$

$$\begin{array}{l} t \times MCTC = P \times a \\ 50 \times 78 = P \times 38 \end{array}$$

$$\begin{array}{l} GG_1 = \frac{P \times KM}{W} \\ = \frac{102.63 \times 4.60}{3200} \end{array}$$

$$\therefore P = \frac{50 \times 78}{38}$$

$$P = 102.63\text{t}$$

$$GG_1 = 0.148$$

$$GM(s) = 0.50\text{m}$$

$$GG_1 = -0.148\text{m}$$

$$GM(s) = 0.352\text{m}$$

$$\text{(ii) Initial hydro draft : } \text{Corr}^n \text{ to aft draft} = \frac{\text{Trim} \times A.L.}{L}$$

$$\text{Corr}^n = \frac{0.50 \times 38}{82} = 0.232\text{ m}$$

$$\text{Aft draft} = 4.300$$

$$\text{Corr}^n = -0.232$$

$$\text{Hydro draft} = 4.068\text{ m}$$

$$\text{Mean rise} = \frac{P}{TPC \times 100} = \frac{102.63}{16 \times 100}$$

$$\text{Mean rise} = 0.064\text{ m}$$

16t
dry

$$\text{Hydro draft} = 4.068$$

$$\text{Mean rise} = \underline{-0.064}$$

$$\text{Draft F \& A} = 4.004 \text{ m}$$

This is because after taking the blocks the vessel is on even keel and hence the draft F and A will be same.

(iii) For the vessel to be unstable the final GM should be zero (0) i.e.

$GG_1 = GM$ and hence the difference is equal to zero.

$$\text{Hence } GG_1 = GM = 0.50$$

$$GG_1 = \frac{P \times KM}{W}$$

$$0.50 = \frac{P \times 4.6}{3200}$$

$$\therefore P = \frac{0.50 \times 3200}{4.6}$$

$$= 347.83t$$

Now here $347.83t = P$ is required to bring the GM to zero.

$$\text{So mean rise} = \frac{P}{TPC} = \frac{347.83}{16} = 0.217m$$

$$\text{Initial hydro draft} = 4.068$$

$$\text{Mean rise} = -0.217$$

$$\text{Drafts (unstable)} = \underline{3.851m}$$

8. A ship of $L = 130\text{m}$, $W = 5200\text{t}$, $CF = 2\text{m}$ aft of midship $MCTC = 140\text{mt}$, $KM = 6.5$, $KG = 6.0\text{m}$, $TPC = 20\text{t}$, draft Fwd = 4.35m , Aft = 5.41m is dry docked. Calculate her residual GM and the drafts F and A

(i) When the trim has reduced to 35 cms.

(ii) When the water level has been lowered 1.2 m after she has taken the blocks all over.

$$\begin{array}{rcl}
 \text{Drafts Fwd} & = & 4.35\text{m} \\
 \text{Aft} & = & 5.41\text{m} \\
 \hline
 \text{Trim} & = & 1.06\text{m} \\
 \text{Present trim} & = & 0.35\text{m} \\
 \hline
 \text{Reduction in trim} & = & 0.71\text{m}
 \end{array}$$

$$\begin{aligned}
 t \times MCTC &= P \times a \\
 71 \times 140 &= P \times 63
 \end{aligned}$$

$$\begin{aligned}
 \therefore P &= \frac{71 \times 140}{63} \\
 &= 157.78\text{t}
 \end{aligned}$$

$$\begin{aligned}
 GG_1 &= \frac{P \times KM}{W} \\
 &= \frac{157.78 \times 6.5}{5200} \\
 &= 0.197\text{m}
 \end{aligned}$$

$$KM = 6.50\text{m}$$

$$KG = 6.00\text{m}$$

$$GM = 0.500\text{m}$$

$$GG_1 = 0.197\text{m}$$

$$V.GM = 0.303\text{m}$$

$$\text{Mean rise} = \frac{P}{TPC \times 100} = \frac{157.78}{2000} = 0.007889$$

$$\text{Initial hydro draft : Corr}^n \text{ to Aft draft} = \frac{\text{Trim} \times A.L.}{L}$$

$$\text{Aft draft} = 5.410\text{m}$$

$$\text{Corr}^n = 0.514\text{m}$$

$$\text{Hydro draft} = 4.896\text{m}$$

$$\text{Corr}^n \text{ of aft draft} = \frac{1.060 \times 63}{130}$$

$$\text{Cor}^n = 0.514\text{m}$$

$$T_f = \frac{\text{Trim} \times \text{F.L.}}{L}$$

$$= \frac{1.060 \times 67}{130}$$

$$= 0.546$$

$$T_a = \frac{\text{Trim} \times \text{A.L.}}{L}$$

$$= \frac{1.060 \times 63}{130}$$

$$= 0.514 \text{ m}$$

$$\text{Hydro draft} =$$

$$\text{Mean rise} =$$

Fwd	Aft
4.896	4.896
- 0.079	- 0.079
<u>4.817</u>	<u>4.817</u>

$$T_f = \frac{0.71 \times 67}{130}$$

$$= 0.366 \text{ m}$$

$$T_a = \frac{0.71 \times 63}{130}$$

$$= 0.344 \text{ m}$$

$$\text{Draft} =$$

$$\text{Mean rise} =$$

Fwd	Aft
4.350	5.410
- 0.079	- 0.079
<u>4.271</u>	<u>5.331</u>
+ 0.366	Ta - 0.344
<u>4.637m</u>	<u>4.987m</u>

(i)

$$t \times \text{MCTC} = P \times a$$

$$106 \times 140 = P \times 63$$

$$\therefore P = \frac{106 \times 140}{63} = 235.55 \text{ t}$$

$$\text{Mean rise} = \frac{w}{\text{TPC} \times 100}$$

Mean rise = drop of 1.2m of water.

$$1.20 = \frac{w}{20 \times 100}$$

This means in addition to $P = 235.55 \text{ t}$
another wt. = 2400t has to be discharged
i.e. $235.55 + 2400 = 2635.55$

$$w = 20 \times 100 \times 120$$

$$w = 2400$$

$$\text{Now } GG_1 = \frac{P \times KM}{W}$$

$$= \frac{2635.55 \times 6.5}{5200}$$

$$= 3.294 \text{ m}$$

$$GM = 0.500$$

$$GG_1 = 3.294$$

$$\underline{GM = - 2.794 \text{ m}}$$

Note the negative GM; the vessel is unstable but since she is sitting on the blocks and wooden shoring is kept on ship sides, she will be well secured.

$$\text{Mean rise} = \frac{W}{TPC} = \frac{2635.55}{20 \times 100} = 1.318 \text{ m mean rise}$$

Now hydro draft

Mean rise

Fwd

4.896

- 1.318

3.578m

Aft

4.896

- 1.318

3.578m

DRY DOCKING

Exercise 8

1. A ship of 19200 M.T. displacement, 235m long has KM 10.2m, KG 9.4m, TPC 32 MCTC 254tm is floating at draft forward of 9.42m and aft 10.88m in water of RD 1.005. The centre of floatation is 5m abaft amidships, centre of buoyancy is 3m forward of amidships. Vessel is drydocked in water of density 1.020. Calculate her virtual GM on taking blocks all over.
2. A vessel of displacement 6220t, length 144m, CF 2m abaft midships, KM 6.9m, MCTC = 150, TPC = 17t, KG 6.2m at a draft of F 4.10m, A 6.20m, is floating in a dry dock where the depth of water is 7.0m above the top of the blocks. Calculate her virtual GM (i) when the level is lowered by 1.5m, (ii) when the water level is lowered a further 1m.
3. A vessel is to be dry docked in a damaged condition. She is floating at F 12.60m and A 9.00m. It is estimated that she will take the blocks 15m aft of the forward perpendicular.
Estimated data: KG 8.9m, KM 9.4m. TPC 21.3 t/cm, MCTC 290 tm/cm, AF 76m, LBP 165m displacement 19500 tonnes.
(a) Is it safe to dry dock the vessel in this condition? Support your answer with calculations.
(b) Estimate the drafts at the perpendiculars on taking to the blocks fore and aft.
4. A vessel, displacement 9013t, KG 8.0m, TPC 21.89, MCTC 162.7 tm, AF 72.013m, FSM 900 tm, enters a SW drydock drawing 3.4m fwd and 5.8m Aft. Find the virtual GM when the level of water has fallen one metre after the ship has taken to the blocks overall the KM then being 9.151m. LBP = 145 m.
5. A vessel of length 140m, displacement 5210t, KG 5.8m, KM 6.1m, MCTC 130tm, TPC 14t, CF 2m abaft midlength is afloat in a drydock at a draft of Forward 3.9m and Aft 5.2m. The water level in the dock is 6m above the top of the blocks. Calculate the virtual GM and drafts F & A, when the water level is lowered by 1.5m.

6. A ship of displacement 8487t, LBP 140m, draft For'd 3.0m and Aft 5.8m, KG 8.6m, FSM 800 tm, LCF 72.1m from AP, MCTC 161 tm enters a salt water drydock. Calculate the GM (fluid) and the Moment of Statical Stability at 1° heel at the critical instant of taking the blocks all over, given the KM at this instant is 9.57 m.
7. A vessel, with following particulars, enters a seawater drydock:
 Length B.P = 140m, Draft Fwd : 3.4m, Aft : 5.8 m, KG = 8.0m, KM = 9.02m,
 Displacement = 8930 t, TPC = 21.9, LCF = 72.2m from A.P.,
 MCTC = 162.5 tm.
 Find the virtual GM and the drafts F & A, when the level of water has fallen one metre after the stern has taken to the blocks, given the KM at this displacement = 9.18m.
8. A vessel of length 180m, displacement : 11000t, LCF : 80m, TPC : 22t, MCTC : 155tm, KM : 7.2m, KG: 6.8m, at a draft of F : 6.10m, A : 6.70m, is drydocked. Calculate her residual GM and the drafts F & A at the critical instant.
9. A vessel of displacement 4740t, mean draft 4.22m, length 120m, KM 6.0m, KG 5.5m, CF amidships, TPC 10t, MCTC 79tm, is to be dry docked. If the GM on taking the blocks F and A is to be not less than 0.3m, what is the maximum permissible trim by the stern? At what drafts F and A would she become unstable?
10. A vessel about to dry dock is in the following condition :
 Draft : For'd 6.10m, Aft 6.70m
 $KM_0 = 7.20m$, $KG_0 = 6.8m$
 MCTC = 155 tm, TPC = 22t, LCF = 80m for'd of AP
 Length = 180m, Disp = 11000 tonnes
 Find : (a) GM of the vessel at critical instant
 (b) The righting moment of 1° heel
 (c) The draft for'd and at the critical instant.

- A vessel with length of 185m, displacement of 29000 is floating in a graving dock with a depth of 10m at drafts F 8.00 and A 9.38m. $KM = 11.50m$, $KG = 10.95m$, $MCTC = 410 \text{ t/m}$, $TPC = 29.6$, $LCF = 89.5m$. Find the effective GM and draft fore and aft of the vessel after the water level has dropped by 1.25m.
12. A vessel of $W = 6500 \text{ T}$, $L = 120m$, $CF = 2m$ fwd of midship, $MCTC = 110mt$, $TPC = 15T$, $KM = 6.7m$, $KG = 6.1m$ at a draft of $F = 4.00m$ $A = 6.2m$ is floating in a drydock where the W/L is 6.5 mtrs above the top of the blocks. Calculate the residual GM of the vessel when (a) W/L is lowered by 1m. (b) It is lowered a further 1m.
 13. A vessel of $L = 145m$, $CF = 3 \text{ mts}$ fwd of $\odot$, $MCTC = 150 \text{ mt}$ $TPC = 18 \text{ t}$, $KM = 7.5m$, $KG = 6.9$, $w = 11200$ at a draft of $F = 3.72m$, $A = 5.70m$ is floating in a dry dock where depth of water is 6.5m above the top of the blocks. Calculate the vessel's residual GM and her draft's F & A, when the W/L is lowered by 1.5m.
 14. A box shaped vessel $80 \times 16m$ at draft of 3m (F), 4m (A) $KG = 4.2m$ is dry docked. Calculate the residual GM on taking blocks F & Aft. $KG = 4.2 \text{ m}$
 15. A vessel of length 140m, $W = 19200t$, $KM = 6.7m$, $KG = 6.2m$, $CF = 4m$ fwd of midship, $MCTC = 145 \text{ Tm}$ is to be dry docked. Calculate the max. permissible tm. by the stern to ensure that she would have a positive GM of 30 cm on taking blocks F & A.
 16. A vessel of length 84m, displacement 3000t, $TPC = 12t$, $KM = 4.5m$, $KG = 4.05m$, $MCTC = 80 \text{ Tm}$, $CF = 2m$ abaft midship at a draft of 4m (F) 4.5m (A) is dry docked. Calculate (1) The residual GM in taking blocks all over. (2) Her drafts F & A then (3) Her draft F & A when she becomes unstable.
 17. A ship LBP 240m, W 20000 tonnes, KG 9.0m, TPC 30, LCF 5m abaft of amidships is being dry-docked drawing 6m forward 8m aft. When just landing flat on the blocks the draught is 6.2m. Calculate the loss of GM at this time.

18. A ship length 200m LCF 5m forward of amidships is being docked at draughts F 7.35m A 9.15m. W 38700 tonnes, TPC 48, MCTC 360, KG 7.46m.
Find : (i) The GM when flat on the blocks if KM then is 8.20m.
(ii) The draught when flat on the blocks.
(iii) The GM when the draught is 7.8m if KM is then 8.30m.
(iv) The draught at which the ship becomes unstable.
19. A ship is being docked at a displacement 26240 tonnes. LBP 184m, LCF 4m abaft of amidships. KG 7.4m, KM 7.8m, TPC 38, MCTC 300. Calculate the maximum allowable stern trim to ensure GM is at least 0.1m when landing overall.
20. A ship LBP 170m, displacement 21480 tonnes, KG 6.96m, KM 7.12m is being dry-docked. Calculate the maximum allowable stern trim to ensure stability is not negative when landing flat overall. TPC 30, MCTC 260, LCF 2m abaft of amidships.
21. A ship length 200m, W 1400 tonnes is being docked at draughts 6.30m forward 7.60m aft LCF is 4m abaft of amidships. TPC 18, KM 8.80m. When just landing flat on the blocks the draught is 6.80m. Calculate the loss of GM.
22. Calculate the GM taking the blocks overall when drydocking a (damaged) vessel, given W 43200 tonnes, LBP 210m, LCF 5m abaft of amidships and draughts F 13.14m A 9.84m. KG 8.60m, KM 9.00m, TPC 36, MCTC 350 t-m.
23. A ship LBP 180m, W 18000 tonnes is damaged forward and trimmed by the head. Calculate the maximum allowable trim by the head to ensure that there is a positive GM of 0.15m when taking the blocks overall given that the blocks have a run down (towards the gate) of 10 cm per 100m and that the ship is being docked bow in. KG 7.20, KM 7.56m, MCTC 210 t-m and LCF 8m abaft of amidships.

-oOo-

Answers :

- GM = 0.615m
- (i) GM = 0.428 m (ii) GM = - 0.536 m
- (a) GM = -0.18m, Not safe (b) 10.013m F & A (9.996)
- Virtual GM = 0.698m, 0.665 m
- Virtual GM = 0.048m, F = 4.325m A = 4.50m
- Virtual GM = 0.163m, Moment of statical stability = 24.14 tm
- (a) Virtual GM = 0.806m (b) Draft F = 4.017m A = 4.80m
- Residual GM = 0.324m, Draft F & A = 6.38m
- Max Permissible trim = 1.2m by stern,
- Draft when she becomes unstable F = 2.325m A = 5.325m
10. (a) P = 116.25 Virtual GM = 0.324m
- (b) 62.2 tm
- (c) 6.38m
11. GM = 0.371m, Draft F = 8.355m A = 8.750m
12. When W/L is lowered 1m virtual GM = 0.398m, when W/L is lowered a further 1m virtual GM = - 0.271 m
13. P = 220.43t, Virtual GM = 0.452m, F = 4.129m, A = 5.000
14. P = 215.15t. Residual GM = 3.278 m
15. Trim = 2.92 m
16. Residual GM on taking blocks F & A = 0.30m, Original hydro draft = 4.262m
- Hydro draft on taking blocks F & A = 4.179m,
- Draft F & A when unstable = 4.012m
17. 1.301m
18. 0.61m, 8.076m, 0.42m, 7.389m assuming loss is $\frac{P \times KM}{W}$
19. 2.99m by stern assuming loss is $\frac{P \times KG}{W - P}$ $\left[2.96 \text{ m, by } \frac{P \times KM}{W} \right]$
20. Assuming loss = $\frac{P \times KM}{W}$, 1.54 m by stern.

21. Original TMD 6.976m, P 317t, Loss of GM 1.991m

22. Assuming loss = $\frac{P \times KG}{W - P}$, GM 0.186m $\left[\frac{P \times KM}{W} (0.182) \right]$

23. Assuming loss = $\frac{P \times KM}{W}$, 2.153 m by head.

-oOo-

$$TLC = \frac{PRF}{100 \times MCTC \times LBP}$$

$$+ \frac{P}{TPC \times 100}$$

CHAPTER IX (6) FOR TRGS

GROUNDING

involved 4 to find

$$\left. \begin{array}{l} TR_a \\ TR_f \end{array} \right\} \frac{TLC = T_{ex} LCF}{LBP}$$

When a ship grounds at a single point it is possible to make an estimate of the upthrust at the grounding point and changes in mean draft and trim if the fall in tide is known.

The method used is an extension of the relationship used to calculate change in draft aft. In the case of grounding we know the change in draft at the point of contact, if we know the fall in tide. In Figure 9.7 the vessel length L_m grounds at a point C, x m forward of the centre of flotation. The tide falls a distance y cm and the waterline changes from W_0L_0 to W_1L_1 . The change in draft at the point of contact is the same as the fall of tide y cm.

Then

Change of draft at C = bodily rise + change of trim at C

$$y = \frac{P}{TPC} + \frac{x}{L} + \frac{P \times x}{MCTC}$$

From which P can be found.

From which P can be found.

Once P is found it is possible to calculate the new drafts of the vessel by treating P as a weight discharged from C. Similarly the effect on stability can be calculated. The method must be regarded as approximate as the change in water level may be large and the value of TPC, MCTC and X will change considerably.

$$\text{Virtual loss of GM} = \frac{P \times KM}{W} \quad \text{or} \quad \frac{P \times KG}{W - P}$$

$$\text{Mean rise} = \frac{P}{TPC}$$

Whenever float is existing there are two to four formulas

$$1) \text{ Trim change} = \frac{P \times x}{100 \times TPC} + \frac{P \times 100 \times RF^2}{100 \times MCTC \times LBP}$$

2)

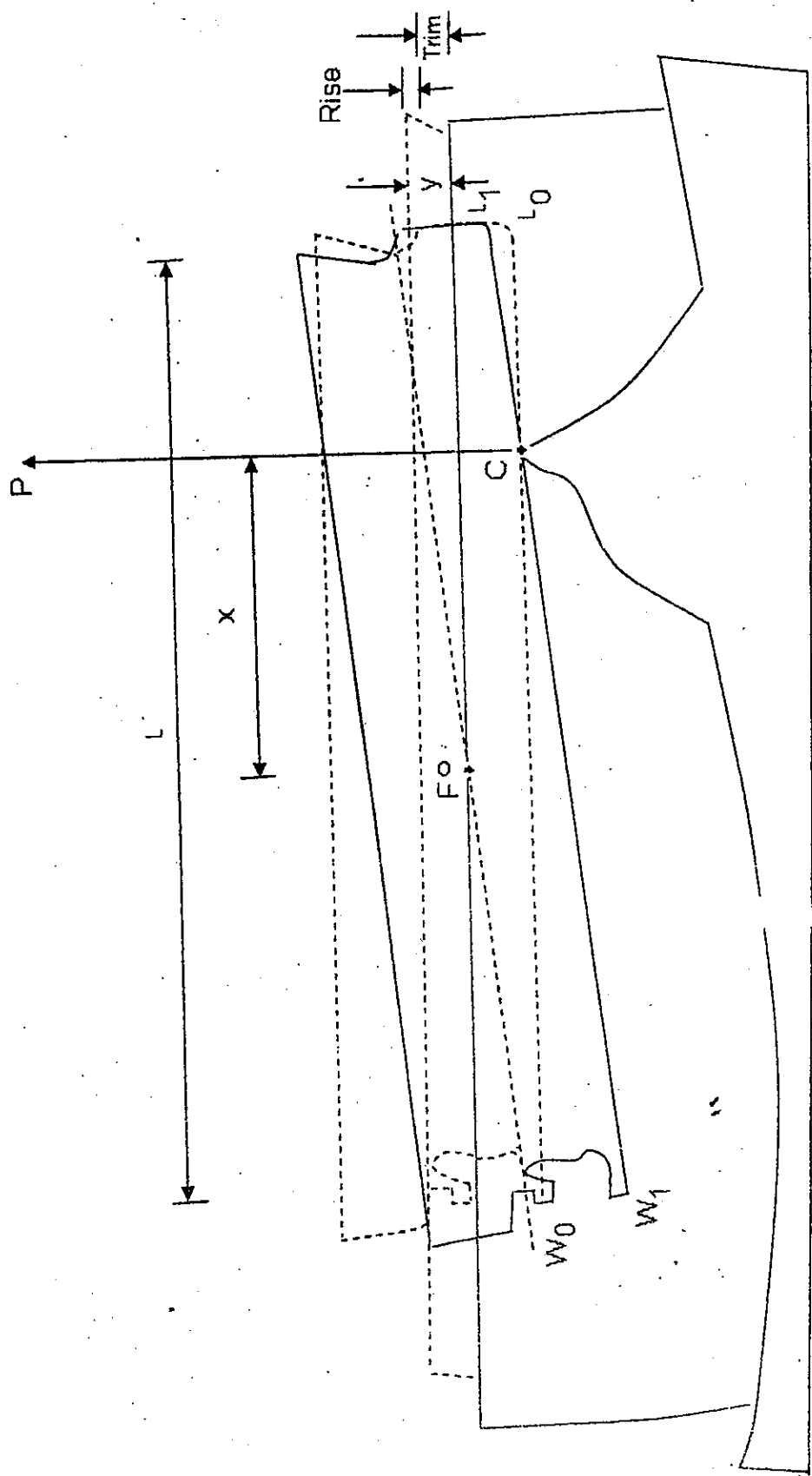
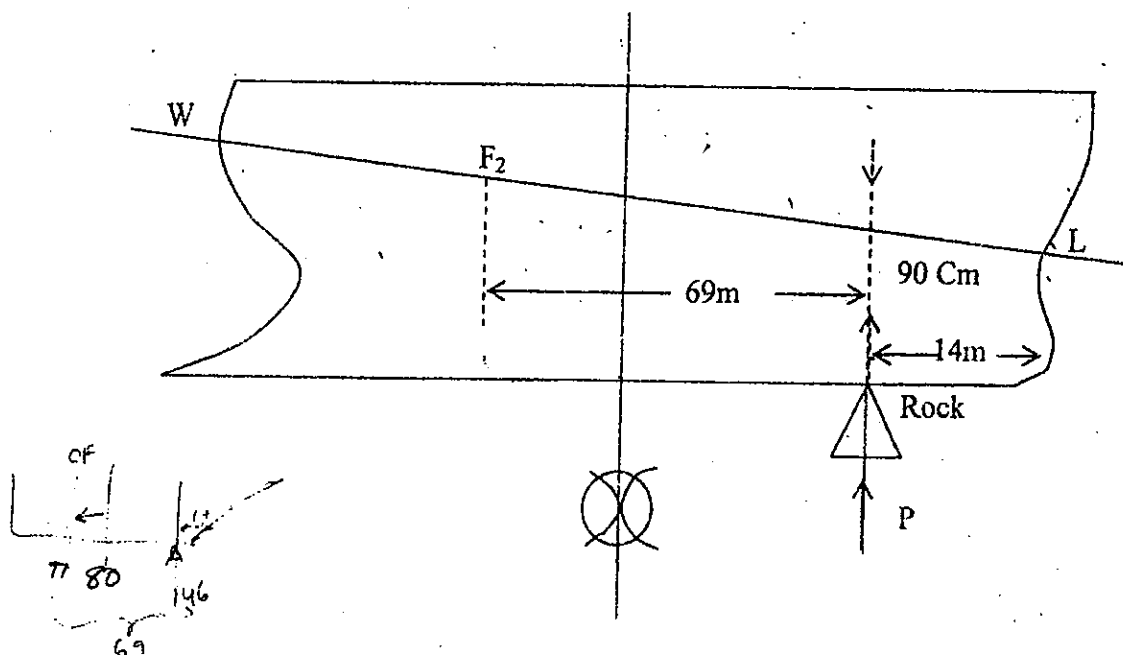


Figure Grounding at a single point

Problems:

1. A ship of length 160m, disp $W = 10500t$, $CF = 3m$ abaft the midship, $MCTC = 160mt.$, $TPC = 18t$, $KM = 7.0m$, $Kg = 6.6m$ at a draft of 6.9m fwd, 7.3m aft, grounds lightly on a rock 14m abaft the fore end. The tide then falls by 90cm. Calculate her virtual GM and drafts fwd and aft then.



Mean Rise + Change in trim at the point P = Fall of tide

$$\frac{P}{TPC} + \frac{\text{Trim Moment} \times \frac{69}{LBP}}{MCTC} = 90 \text{ cm}$$

$$\frac{P}{18} + \frac{P \times 69}{160} \times \frac{69}{160} = 90 \text{ cm}$$

$$\frac{P}{18} + \frac{P \times 69}{160} \times \frac{69}{160} = 90$$

$$\frac{P}{18} + 0.186P = 90$$

$$P + 18(0.186P) = 90 \times 18$$

$$P + 3.348(P) = 1620$$

$$4.66(P) = 1620$$

$$\therefore P = \frac{1620}{4.66}$$

$$P = 372.585$$

$$GG_1 = P \times KM / W$$

$$= 372.585 \times 7.0 / 10500$$

$$GG_1 = 0.248 \text{ m} \downarrow$$

$$KM = 7.0m$$

$$KG = 6.6m$$

$$GM = 0.40m$$

$$GG_1 = 0.248m$$

$$GM \text{ Virtual} = 0.152 \text{ m}$$

$$\text{Now Mean rise} = \frac{P}{\text{TPC}} = \frac{372.585}{18 \times 100} = 0.207\text{m}$$

$$\text{Total change in trim} = \frac{P \times 69}{\text{MCTC}} = \frac{372.585 \times 69}{160}$$

$$T_t = 160.677$$

$$t_f = \frac{T_t \times \text{F.L.}}{L}$$

$$= \frac{160.677 \times 83}{160 \times 100}$$

$$t_f = 0.833\text{m}$$

$$t_a = \frac{T_t \times \text{A.L.}}{L}$$

$$= \frac{160.677 \times 77}{160 \times 100}$$

$$t_a = 0.773\text{m}$$

	Fwd	Aft
Draft	6.900m	7.300m
Mean rise	- 0.207m	- 0.207m
	6.693m	7.093
t_f	- 0.833m	t_a + 0.773
New draft	5.860m	7.866m

Note : Point 'P' where the vessel is grounded, is the only spot, where it can be deduced that the tide has fallen or risen and hence the total change in trim is calculated (i.e. trimming moment $P \times 69$) from that point.

vessel of $L = 150\text{m}$, $CF = 2\text{m}$ fwd of midship $W = 8000\text{t}$, $KM = 7.5\text{m}$,
 $KG = 6.8\text{m}$, $TPC = 20\text{t}$, $MCTC = 160\text{ m.t}$ at a draft of 5.20m , fwd and 6.89m
 aft, is floating in a dry dock, where the water level is 7.4m above the top of the
 blocks. Calculate her virtual GM and draft Fwd and Aft when the water level is
 lowered by 1.4m .

Original W/L in the dry dock = 7.4m above the top of the block

Then lowered by = -1.4m

$\therefore$ Present W/L = 6.0m

The after draft of the vessel was 6.89m and the present W / L dropped to 6.0m , it means that the stern has already taken to the blocks and hence the mean rise at that point is $6.89 - 6.00 = 0.89\text{m}$ ✓

Mean Rise + Total change in trim X Change in trim at point 'P' = Fall of W.L. at stern

$$\frac{P}{TPC} + \frac{P \times AL}{MCTC} \times \frac{AL}{L}$$

$$\frac{P}{20} + \frac{P \times 77}{160} \times \frac{77}{150} = 89$$

$$\frac{P}{20} + \frac{77P}{160} \times 0.5133 = 89$$

$$\frac{P}{20} + 0.247(P) = 89$$

$$P + 4.94(P) = 89 \times 20$$

$$5.94(P) = 89 \times 20$$

$$\therefore P = \frac{89 \times 20}{5.94} = 299.66\text{t}$$

$$KM = 7.5m$$

$$KG = 6.8m$$

$$GM = 0.70m$$

$$Fwd = 5.20m$$

$$Aft = 6.89m$$

$$Trim = 1.69m$$

$$\begin{aligned} \text{To find virtual loss } GG_1 &= P \times KM / W \\ &= 299.66 \times 7.5 / 8000 \\ &= 0.2809 \end{aligned}$$

$$\text{Original GM} = 0.7000$$

$$GG_1 = -0.2809$$

$$\text{Virtual GM} = \underline{0.4191 m}$$

$$\text{Mean Rise} = \frac{P}{TPC} = \frac{299.66}{20 \times 100} = 0.1498m$$

$$\begin{aligned} \text{Total Change in trim} &= \text{Trimming Mom} / \text{MCTC} \\ &= P \times A.L. / \text{MCTC} \\ &= \frac{299.66 \times 77}{160} \\ &= 144.21cm \end{aligned}$$

$$\begin{aligned} T_{fwd} &= \frac{T_t \times FL}{L} \\ &= \frac{144.21 \times 73}{150 \times 100} \\ &= 0.7018m \end{aligned}$$

$$\begin{aligned} T_{aft} &= \frac{T_t \times A.L.}{L} \\ &= \frac{144.21 \times 77}{150 \times 100} \\ &= 0.7403m \end{aligned}$$

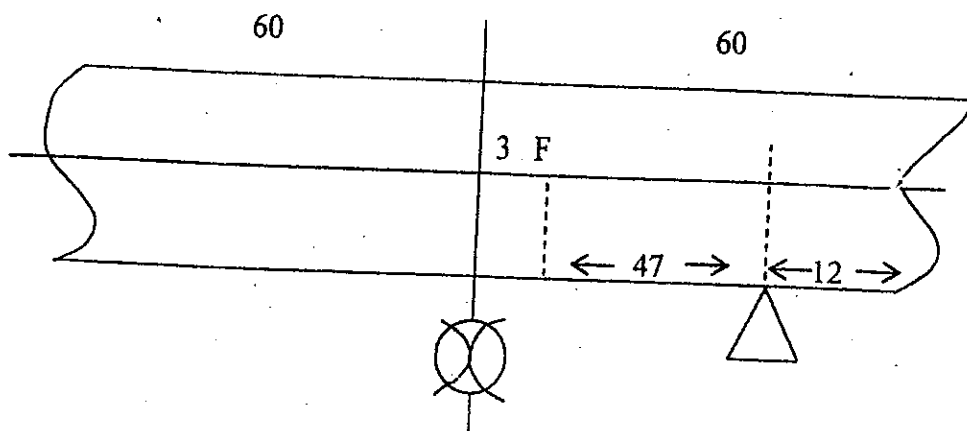
Draft	Fwd	5.20
M' Rise		- 0.1498
		5.0502
Ch. in trim	T _{fwd}	+0.7018
		<u>5.752m</u>

Aft	6.890
	- 0.1498
	6.7402
T _{aft}	- 0.7403
	<u>6.000m</u>

❖ Check the after draft which is 6.00m which confirms the problem.

A vessel of length 124m $W = 7100t$, $CF = 3m$, fwd of midship, $MCTC = 120$ mt, $TPC = 20t$, $KM = 6.2m$, $KG = 5.8m$, at a draft of 4.0m fwd and 4.9m aft, grounds lightly on a rock 12m abaft her fore end.

- Calculate (a) The fall of tide that will make the vessel unstable
(b) her draft F and A then.



$$KM = 6.2$$

$$KG = 5.8$$

$$GM = 0.4$$

$$\text{Fwd} = 4.0m$$

$$\text{Aft} = 4.9m$$

$$\text{Trim} = 0.9m$$

When the vessel is unstable, virtual loss of GM, $GG_1 = \text{Initial GM}$

$$GG_1 = \frac{P \times KM}{W}$$

$$0.4 = \frac{P \times 6.2}{7100}$$

(Virtual loss)

$$\frac{7100 \times 0.4}{6.2} = P$$

$$458.06t = P$$

$$\text{Diff in level} = \text{Mean rise} + \text{Total change in trim} \times \text{Change in trim @ P}$$

$$= \frac{P}{TPC} + \frac{P \times A.L.}{MCTC} \times \frac{A.L.}{LBP}$$

$$= \frac{458.06}{20} + \frac{458.06 \times 47}{120} \times \frac{47}{124}$$

$$= 22.903 + 179.41 \times 68.0$$

$$= 90.904 \text{ cms. Fall of tide.}$$

$$\text{Now total change in trim} = \frac{P \times A.L.}{MCTC} = \frac{458.06 \times 47}{120} = 179.407cm$$

$$T_{\text{fwd}} = \frac{T_{\text{trim}} \times \text{F.L.}}{\text{LBP}}$$

$$= \frac{179.407 \times 59}{124}$$

$$= 0.8536\text{m}$$

$$T_{\text{aft}} = \frac{T_{\text{trim}} \times \text{A.L.}}{\text{LBP}}$$

$$= \frac{179.407 \times 65}{124}$$

$$= 0.9404\text{m}$$

$$\text{Mean rise} = \frac{P}{\text{TPC}} = \frac{458.06}{20} = 22.903 \text{ cm} = 0.229\text{m}$$

Draft	Fwd	Aft
	4.0000	4.9000
Mean rise	- 0.2290	- 0.2290
	3.7710	4.6710
T_{fwd}	- 0.8536	$T_{\text{aft}} + 0.9404$
Final draft	2.9174m	5.6114m

4. A vessel of $L = 140\text{m}$, $W = 16000\text{t}$, $\text{MCTC} = 190$, $\text{TPC} = 24\text{t}$, $\text{LCF} = 72\text{m}$, $\text{KM} = 8.20\text{m}$, $\text{KG} = 7.20\text{m}$, $\text{FSM} = 1370\text{mt}$. draft = Fwd = 6.68m , Aft = 8.84m grounds on an isolated rock, the draft then are fwd 5.88 and aft 9.28m . Calculate following.

- The up thrust provided by the rock.
- The position with respect to after perpendicular, where the grounding occurred.
- The virtual GM (f) of the vessel then.
- The angle of heel if she had grounded 3m to stbd of ϕ .
- The rise in tide required for the vessel to refloat?

Original draft

Fwd	6.68m
Aft	<u>8.84m</u>
Trim	2.16m

draft after grounding

Fwd	5.88m
Aft	<u>9.28m</u>
Trim	3.40m

Hydrostatic draft original

$$\begin{aligned}\text{Corr}^n \text{ to aft draft} &= \frac{\text{trim} \times \text{LCF}}{\text{LBP}} \\ &= \frac{2.16 \times 72}{140} \\ &= 1.11 \text{ m}\end{aligned}$$

Hydro draft after grounding.

$$\begin{aligned}\text{Corr}^n \text{ to after draft} &= \frac{\text{trim} \times \text{LCF}}{\text{LBP}} \\ &= \frac{3.40 \times 72}{140} \\ &= 1.749\end{aligned}$$

Aft draft	=	8.840
Corr ⁿ	=	-1.11 m
Hydro draft	=	<u>7.73 m</u>

Aft draft	=	9.280
Corr ⁿ	=	- 1.749
Hydro draft	=	<u>7.531 m</u>

Difference in hydro draft is the change / fall of tide.

Hydro draft @ grounding	=	7.531 mm
Hydro draft @ origin	=	<u>7.73 mm</u>
Fall in tide	=	0.199m

$$\therefore \text{Up thrust} = 0.199 \times \text{TPC} = 0.199 \times 24 \times 100$$

(i) $P = 477.6 \text{ t}$

$$(ii) \quad T_c = \frac{P \times x}{MCTC}$$

$$124 = \frac{477.6 \times x}{190}$$

$$\frac{124 \times 190}{477.6} = x = 49.33$$

$$\text{Trim} = 3.40 \text{ @ ground}$$

$$\text{Trim} = 2.16 \text{ @ origin}$$

$$T_c = \frac{1.24 \text{ m}}{124 \text{ cm}}$$

$$\text{LBP} = 140$$

$$\text{Mid length} = 72 + x$$

$$= 72 + 49.33 \text{ from A.P.}$$

$$= \underline{121.33 \text{ m fwd of A.P.}}$$

$$(iii) \quad GG_1 = \frac{P \times d}{W - P} = \frac{477.6 \times 3}{16000 - 477.6} = \frac{1432.8}{15522.4} = 0.0923$$

$$\text{KM} - \text{KG} = \text{GM (S)}$$

$$8.20 - 7.20 = 1.00 \text{ GM (S)}$$

$$\therefore \text{GM (S)} = 1.00$$

$$\therefore \text{Tan } \theta = GG_1 / \text{GM (f)}$$

$$GG_1 = \frac{P \times \text{KM}}{W} = \frac{477.6 \times 8.20}{16000} = 0.245 \text{ m}$$

$$\text{FSM} = 1370$$

$$\therefore \text{FSC} = \frac{1370}{W - P} = \frac{1370}{15522.4} = 0.088$$

$$\text{GM} = 1.000 \text{ m}$$

$$GG_1 = 0.245 \text{ m}$$

$$\text{GM (S)} = 0.755 \text{ m}$$

$$\text{FSC} = -0.088 \text{ m}$$

$$\text{GM (f)} = 0.667 \text{ m}$$

$$(ii) \quad \tan \theta = \frac{GG_1}{GM} = \frac{0.0923}{0.667} = 0.13838$$

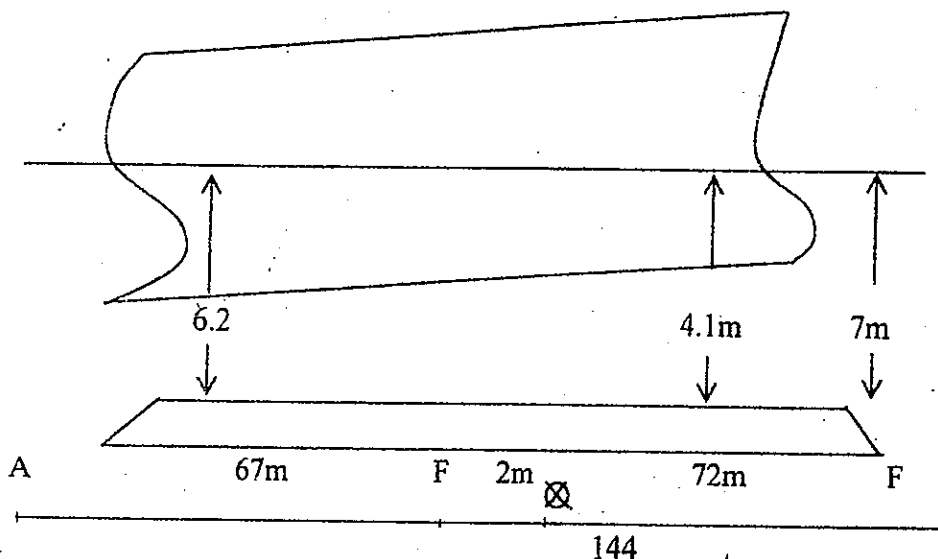
$$\therefore \theta = (\text{Port}) 7.88^\circ$$

$$(v) \quad \frac{P}{TPC} + \frac{P \times A.L.}{MCTC} \times \frac{A.L.}{LBP} = x$$

$$\frac{477.6}{24} + \frac{477.6 \times 49.33}{190} \times \frac{49.33}{140}$$

$$= 19.9 + 43.69 = 63.59 \text{ Cms.}$$

5. A vessel of disp. 6200t, $L = 140$, $CF = 3\text{m}$, abaft midship $MCTC = 148$, $TPC = 18\text{t}$, $KM = 6.8$, $KG = 6.1$, at a draft of 4.0m fwd, 6.1m aft is floating in a dry dock where the depth of water is 7.5m above the top of the blocks. Calculate her virtual GM and draft F and A when (i) the w/L is lowered by 1.6m (ii) the W/L is lowered further by 0.9m.



$$P \times a = \text{trim} \times MCTC$$

$$P \times 67 = 210 \times 148$$

$$P = \frac{210 \times 148}{67}$$

$$P = 463.88 \text{ t}$$

draft

Fwd 4.0

Aft 6.1

Trim 2.10

i.e. the thrust $P = 463.88\text{t}$ when the stern is just touching the blocks, but the fwd end is still afloat

$\therefore$ find hydro static draft then :-

$$\text{Corr}^n \text{ to aft draft} = \frac{\text{trim} \times \text{A.L.}}{\text{LBP}} = \frac{2.10 \times 67}{140}$$

$$\therefore \text{Corr}^n \text{ to aft draft} = 1.005\text{m}$$

$$\text{Aft draft} = 6.100\text{mt}$$

$$\text{Corr}^n = - 1.005\text{mt}$$

$$\text{Hydro draft} = \underline{5.095\text{m}}$$

$$\text{Now mean rise} = \frac{P}{\text{TPC}} = \frac{463.88}{18 \times 100} = 0.2577$$

$$\therefore \text{Original hydro draft} = 5.0950 \text{ m}$$

$$\text{Mean rise} = - 0.2577$$

$$\left. \begin{array}{l} \text{Drafts F and Aft} \\ \text{at critical instance} \end{array} \right\} 4.8373$$

$$\text{Now when W/L is dropped by 1.6m i.e. } 7.5\text{m} - 1.6\text{m} = 5.9\text{m}$$

$$\text{Original aft draft} = 6.1\text{mt}$$

$$\therefore 6.1 - 5.9 \text{ m} = 0.20\text{m change in trim.}$$

$$\therefore \frac{P}{\text{TPC}} + \frac{P \times \text{A.L.}}{\text{MCTC}} \times \frac{\text{A.L.}}{\text{LBP}} = \text{Change in trim}$$

$$\frac{P}{18} + \frac{P \times 67}{148} \times \frac{67}{140} = 20$$

$$P = 73.5 \text{ t}$$

$$\text{Low virtual loss of GM i.e. } GG_1 = \frac{P \times KM}{W}$$

$$= \frac{73.5 \times 6.8}{6200}$$

$$= 0.0806\text{mt}$$

$$KM = 6.8$$

$$KG = 6.1$$

$$GM = 0.7$$

$$\text{V. Loss } GG_1 = 0.0806$$

$$\text{Virtual GM} = 0.6194\text{m}$$

$$\text{Mean Rise} = \frac{P}{TPC} = \frac{73.5}{18 \times 100} = 0.0408\text{m}$$

$$T_c = \frac{P \times A.L.}{MCTC} = \frac{73.5 \times 67}{148} = 33.27 \text{ cm}$$

$$\therefore T_{\text{fwd}} = \frac{T_c \times F.L.}{LBP}$$

$$= \frac{33.27 \times 73}{140 \times 100}$$

$$T_{\text{fwd}} = 0.173 \text{ m}$$

$$T_{\text{aft}} = \frac{T_c \times A.L.}{LBP}$$

$$= \frac{33.27 \times 67}{140 \times 100}$$

$$T_{\text{aft}} = 0.159 \text{ m}$$

Draft	Fwd	Aft
Original	4.000	6.100
M. Rise	- 0.0408	- 0.0408
Draft	3.9592	6.0592
T_{fwd}	+ 0.173	T_{aft} - 0.159
	<u>4.1322</u>	<u>5.90 m</u>

Dry dock W/L	= 7.50m
W/L drop initially	= 1.60m
W/L drop further	= 0.90m
Dry dock W/L	= 5.00m

i.e. with dry dock W/L up to 5.0m and vessel's hydro draft of 5.095m, means the vessel is sitting all over the blocks.

i.e. initial hydro draft = 5.095

Present dock W = 5.000

Change of hydro draft = 0.095m

Now the thrust at this instance $\frac{P}{TPC} = \text{Mean rise}$

$P = \text{Mean rise} \times TPC$
 $= 0.095 \times 18 \times 100$

$P = 171 \text{ t}$

Now virtual loss of GM then $= GG_1 = \frac{P \times KM}{W} = \frac{171 \times 6.8}{6200}$

Virtual loss $GG_1 = 0.1875\text{m}$

Initial GM = 0.7000m

Virtual GM = 0.5125m

The drafts F and A then will be 5.0m as she is sitting all over the blocks.

A tanker displacing 6000m^3 floats at drafts F 5.1m, A 5.8m. The vessel grounds on a
 side, on a rock, at a position 28m forward of amidship. Calculate the up thrust
 on the ship's bottom and the F & A drafts after the tide has fallen by 25 cms. The
 static curves of the vessel for the above drafts show the following data:
 = 166m, Centre of Floatation 6m abaft amidship. Water Plane Area = 1850 m^2 ,
 = 550m.

$$\text{m}^3 = UWV$$

$$\begin{aligned} F &= \underline{5.1\text{ m}} \\ A &= \underline{5.8\text{ m}} \end{aligned}$$

$$6000 \times 1.025 = \underline{6150\text{ t}}$$

$$= \frac{P}{\text{TPC}} + \frac{P \times Rf^2}{\text{MCTC} \times \text{LBP}}$$

$$\text{MCTC} = \frac{\text{WGM}_L}{100\text{ L}}$$

$$= \frac{P}{18.9625} + \frac{P \times 34 \times 34}{203.765 \times 166}$$

$$= \frac{6150 \times 550}{100 \times 166}$$

$$25 = 0.05273 P + 0.03418 P$$

$$= 203.765$$

$$25 = 0.0869 P$$

$$\therefore P = \frac{25}{0.0869} = \underline{287.687\text{ t}}$$

$$\text{TPC} = \frac{1.025 A}{100}$$

$$\text{Rise} = \frac{287.687}{18.9625} = 15.17\text{ Cm}$$

$$= \frac{1.025 \times 1850}{100}$$

$$= 0.1517\text{m}$$

$$= 18.9625\text{ t}$$

$$\text{Total Trim} = T_t = \frac{P \times Rf}{\text{MCTC}} = \frac{287.687 \times 34}{203.765}$$

$$T_a = \frac{287.687 \times 34}{203.765} \times \frac{77}{166} = 0.223\text{ m (+)}$$

$$T_f = \frac{287.687 \times 34 \times 89}{203.765 \times 166} = 0.257\text{ m (-)}$$

	F	A
	5.100	5.800
-	0.157	0.157
-	0.257	0.223
Answer:	<u>4.686 m</u>	<u>5.866 m</u>

GROUNDING

Exercise 9

1. A vessel of length 142m, displacement 16130t, KM 8.24m, KG 7.26m, MCTC 192 mt, TPC 23.4t, LCF 71m, FSM 1372 mt, at a draft of F 6.70m, A 8.86m. grounds on a rock. The drafts then are F 5.90m, A 9.30m.
Calculate :
 a) The upthrust provided by the rock.
 b) The position with respect to AP where the grounding occurred.
 c) Her virtual GM (Fl.) then
 d) The rise of tide required for her to refloat.
2. A vessel of length 140m is floating at drafts Forward 5.23m Aft 5.74m runs aground lightly on a rock 12m abaft the stem. The tide falls by 80cms. Given the following data estimate the virtual GM of the vessel and her drafts forward and aft after the fall of tide. KG 5.80m, KM 6.40m, MCTC 130tm, TPC 18t, AF 73m, Displacement 18500t.
3. A vessel of displacement 7200 tonnes. Length 120m, MCTC 110tm, KG 6.0m, TPC 16 tonnes, center of floatation 2 mts forward of midship, grounds on a rock 10 mts. Aft her forward perpendicular. Given initial draft F: 4.2m, A: 5.1m.
 a) Find the fall in tide in cm, that will make the vessel unstable, given KM at that moment equal to 6.4 mts.
 b) What will be the drafts forward and aft at that moment.
4. A vessel of length 120m, Displacement 6400 tonnes, TPC 15 tonnes, MCTC 110tm, KM 6.4m, KG 5.1m, CF 2m for'd of the midlength grounds on a rock 45m for'd of midlength the tide then falls by 80 cm. Calculate the residual GM then.
5. A vessel of L = 140m, CF = 2m fwd of midship, KM = 6.1m, KG = 5.5m, MCTC = 130 mt, w = 5700t at a draft of F = 4.15m, A = 4.851m grounds on a rock 10 mts for'd of her stern. The tide then falls 80cm. Calculate her virtual GM then and her drafts f & A, TPC = 16T.
6. Vessel of length 120m, LCF = 2m, Aft of midship, Draft = 4.70m. For'd = 5.20 m, Aft TPC = 15 t, MCTC = 110 tm, KM = 5.9, KG = 5.1 m. Grounds on a rock 10 meters abaft her stern. The tide then falls 80 cm. Calculate the drafts F & A then and state whether she would remain upright.

DATA - ?)

A vessel of displacement 12200 t, MCTC = 200 tm, COF = 3 m, for'd of midship, length 152 m, KG = 7.2 m, KM = 8.1 m has draft for'd 5.1m, A 5.2 m. This vessel runs aground on an isolated rock 11.5 m aft of for'd perpendicular. Find the virtual GM and Draft for'd and Aft. Given TPC = 25t, fall in tide 1 meter.

A vessel of displacement 15185t, MCTC = 378 tm, TPC = 36.9t; Draft for'd 4.4m, AFT = 4.7 m, Length 180m, runs lightly aground on an isolated wok 7.5m, abaft for'd end. Find the virtual GM and draft for'd and aft COF 4.06m for'd of midship. Given KG = 8.0m, KM = 8.5m, fall in tide 80 cm.

-oOo-

Answers :

(a) 421.2 t

(b) 127.52 m

(c) 0.678 m

(d) 67.36 cm

Virtual GM = 0.475 m

For'd = 4.299 m,

Aft = 6.336 m

(a) 1.067 m

(b) F = 2.969 m

A = 5.83 m

Residual GM = 0.91 m

P = 292.28 t,

V. L of GM = 0.313 m,

GM = 0.6 m

Res. GM = 0.287 m,

Draft F = 4.644 m,

A = 3.951 m

0.495 m

Draft For'd = 3.78 m

Aft = 5.67 m

Virtual GM = 0.496 m

Draft For'd = 3.959 m

Aft = 5.929 m

P = 680.67

Virtual GM = 0.119 m

F = 3.5416

A = 5.2541

-oOo-

CURVES OF STABILITY

$$K_P = K_G \sin \theta$$

$$\therefore GZ = KN - (KG \sin \theta)$$

Cross Curves of stability are a set of curves of KN values plotted against a scale of displacement for various angles of heel. These curves facilitate obtaining of KN values, at any displacement, for the particular angles of heel for which the curves are drawn.

The main use of KN values is to obtain GZ for any KG, at any displacement, for different angle of heel. The GZ at any angle of heel may be obtained by the expression $GZ = KN - KG \sin \theta$

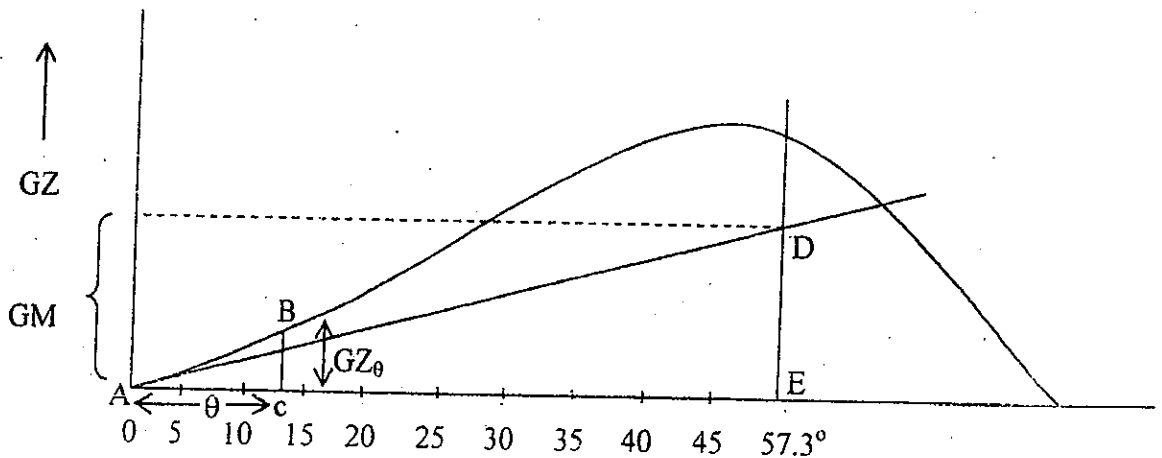
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❖ CURVE OF STATICAL STABILITY

This is a curve of GZ values plotted against a scale of heel for a particular displacement and a particular KG.

From a curve of statical stability, it is possible to ascertain the following.

- a) The Initial Metacentric height, (GM fluid). This is achieved by drawing a tangent to the curve and erecting a perpendicular on the heel scale @ 57.3° (i.e. 1 radian = 57.3°) where the two lines meet, read off GM value on the GZ scale.



Relationship between GM and GZ curve

As shown above, a vertical is drawn at 57.3° (1 radian) and a tangent is drawn at the origin on the GZ curve.

The two triangles ABC and ADE are similar.

$$\therefore \frac{DE}{AE} = \frac{BC}{AC}$$

$$\text{Or } \frac{DE}{57.3} = \frac{GZ_0}{AC}$$

If θ is small,

$$GZ = GM \sin \theta$$

And also $\sin \theta \approx \theta$ (where θ is θ measured in radian)

$$57.3^\circ = 1 \text{ radian}$$

$$\therefore \frac{DE}{1} = \frac{GM \cdot \theta_c}{\theta_c} = GM$$

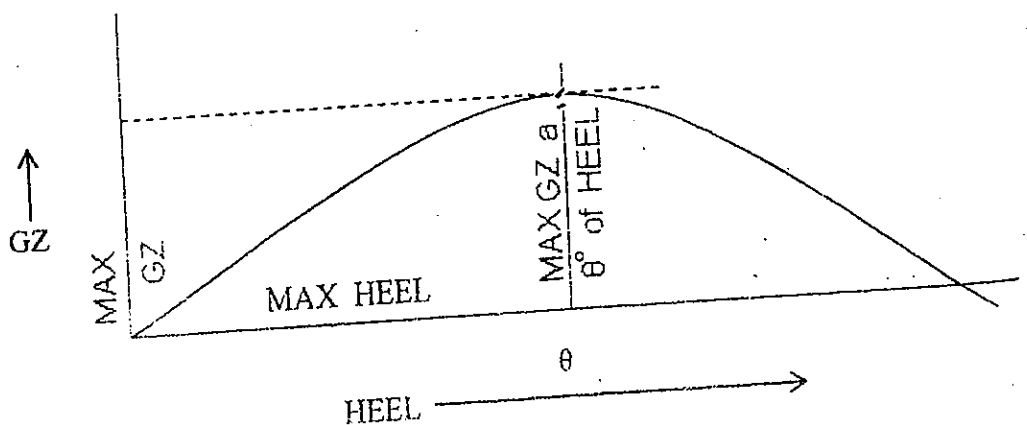
$$\therefore GM = DE$$

b) The angle of "Contra flexure"

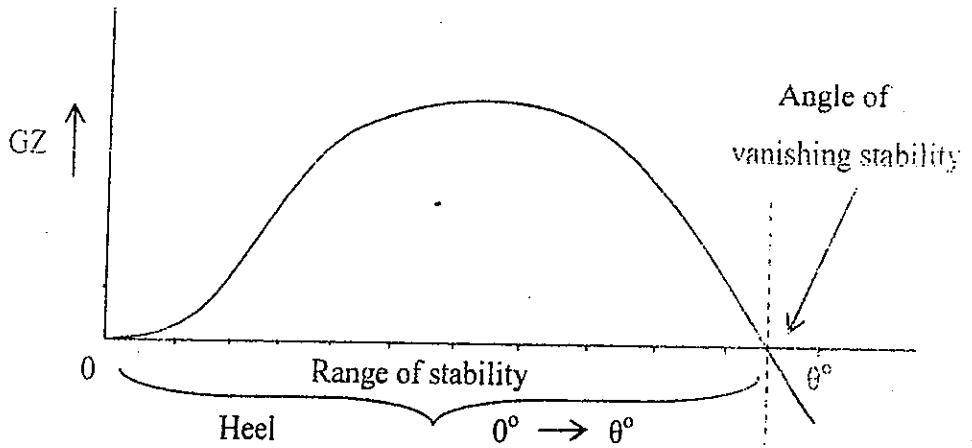
i.e. the angle of heel up to which the rate of increase of GZ with heel is increasing. Though the GZ may increase further, the rate of increase of GZ begins to decrease at this angle. The angle of contra flexure occurs at about the angle of heel at which the deck edge immerses.

(Angle of contra flexure : is the angle of heel at which the rate of increase of GZ with heel commences to decrease i.e. the point at which the curve changes its shape.)

c) The maximum GZ value of the vessel and the angle of heel at which it occurs.

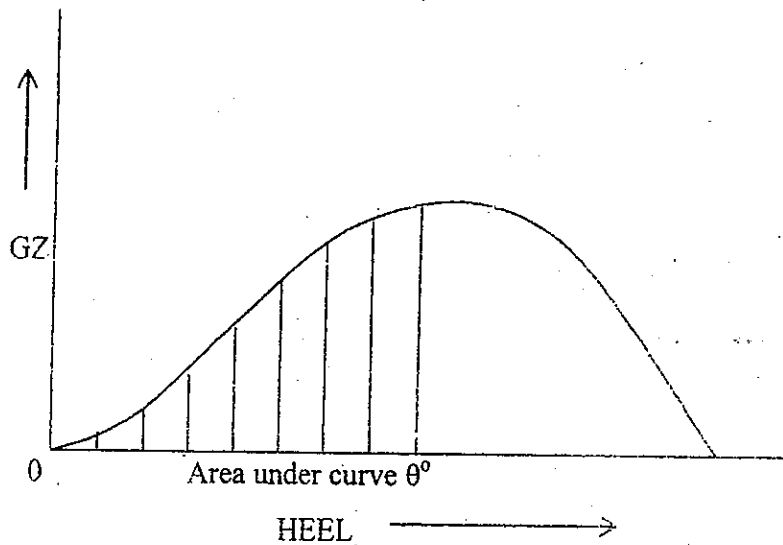


- d) The angle of vanishing stability and the range of stability.



- e) The dynamical stability of the vessel at any angle of heel i.e. the work done in inclining the vessel upto that angle.

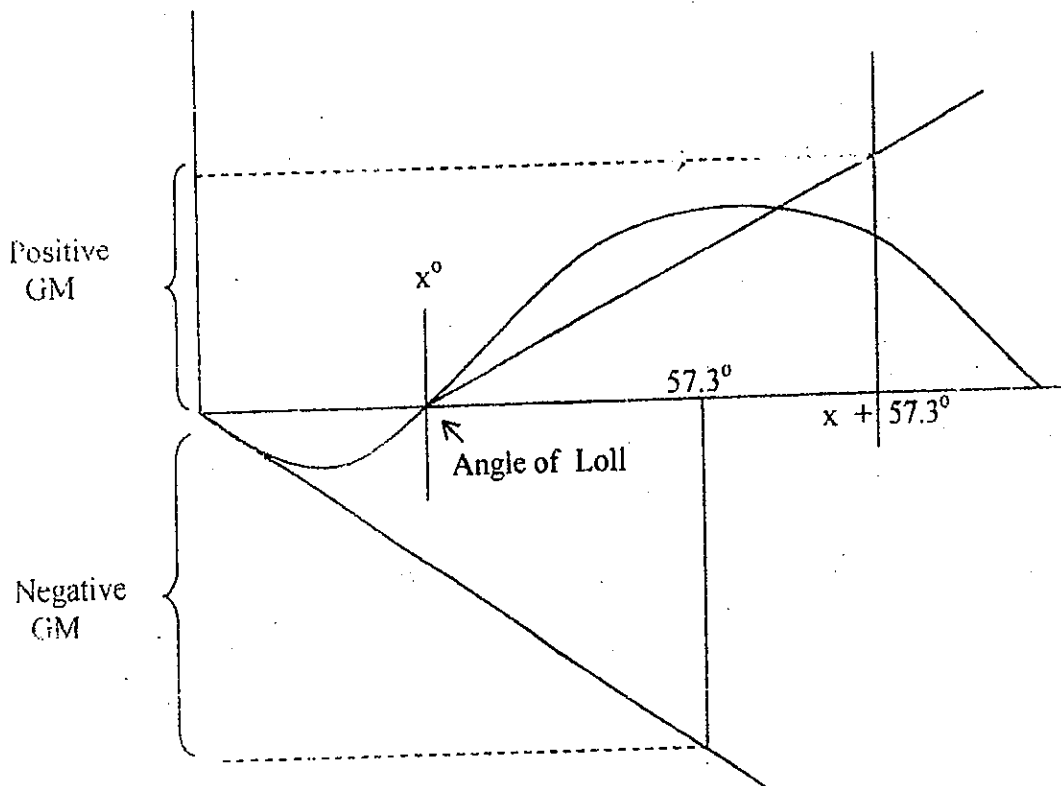
This can be found as the product of the displacement of the vessel and the area under the curve of statical stability upto that angle, in meter radians.



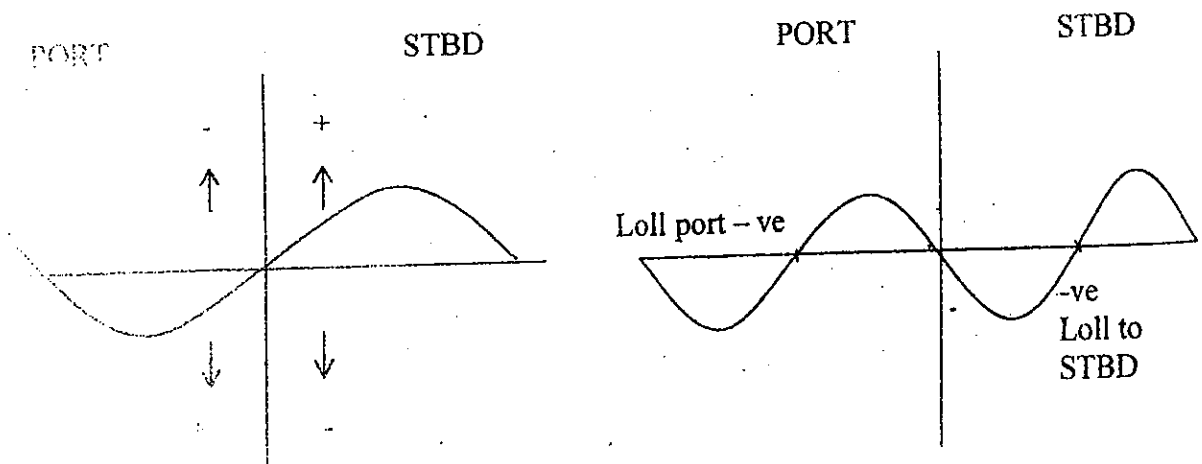
$$\text{Dynamical stability} = \text{Area (M. radian)} \times \text{disp. (tonne)}$$

- f) Whether the ship fulfills the various stability criteria specified in the International load line convention.

- g) Accurate determination of list produced due to transverse shift of ships centre of gravity.
- h) The angel of loll in a vessel with initial negative metacentric height.
The angle of loll of a vessel with an initial negative GM is the angle of heel at which she will develop positive stability.

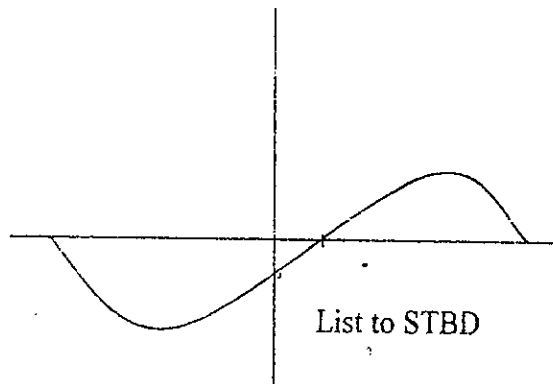


Curve for list :



hips

of



It must be stressed that the early part of the GZ curve say up to 40° , can be taken as a reasonable representative of the actual GZ because in practice at very large angles of heel it is possible that

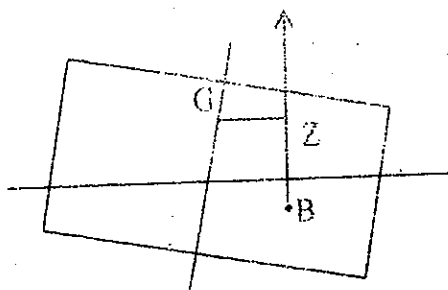
- (i) cargo may have shifted
- (ii) Water could have entered the vessel or
- (iii) Equipment would have broken loose.

This makes invalid the general consumption that COG does not shift.

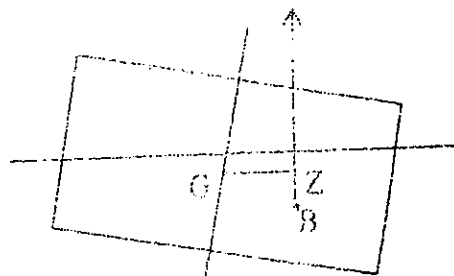
CROSS CURVES OF STABILITY : KN CURVES

When a ship is heeled by an external force the center of buoyancy (B) moves from the centerline to the geometric center of the new underwater volume. The position of B when heeled is therefore dependent on (i) the displacement and (ii) the angle of heel, because these are the two factors which control the shape of the volume of water displaced.

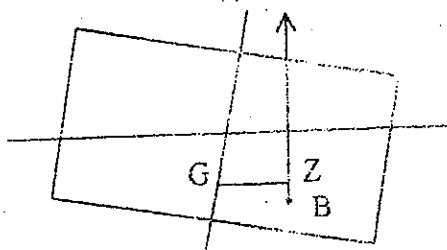
The line of upthrust passes vertically upwards through B. The length of the righting lever which arises depends on the height of the ship's centre of gravity (G). The four sketches below show the variations of lever GZ due to change of KG in a ship of a given displacement and at a given angle of heel.



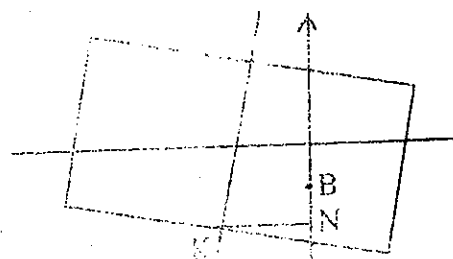
(i)



(ii)



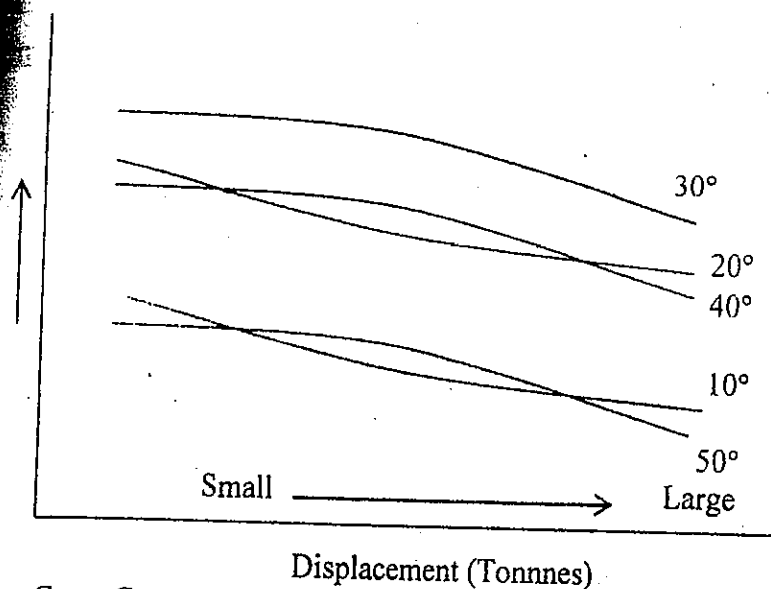
(iii)



(iv)

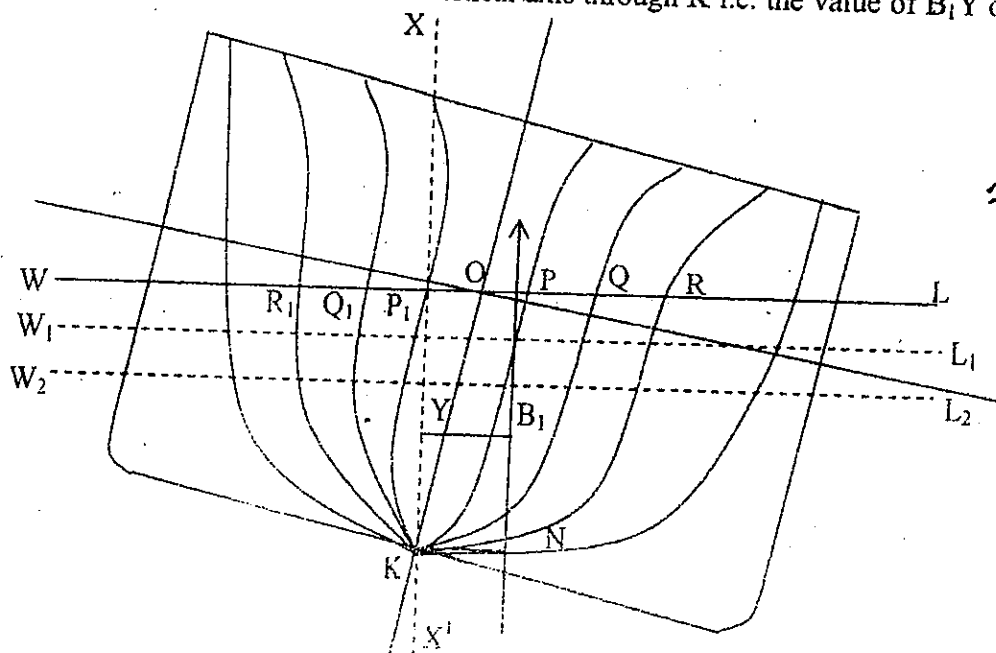
The extreme case (fig (iv)) is when G is at the keel (K). The lever is then denoted by the length KN and this is the maximum possible.

Cross curves of stability show the values of the righting levers KN, at all displacements between light and load conditions, at several specified angles of heel, e.g. 10° 20° 30° 90° . A set of cross curves is supplied by the builder amongst the stability information required for a certificate of assignment of load lines and the 1968 Load Line Rules.



Deriving Cross Curves

The method of deriving cross curves (KN curves) utilizes the ship's body plan and an integrator. The body plan for this purpose shows both sides of the ship. A waterline is drawn on the plan at any chosen height and angle of heel (say WL at 20° heel). The integrator is set up with the bar parallel to a vertical axis xx' through K. The pointer is then traced around each under water section in turn and readings obtained for (i) the area of the section, and (ii) the moment of area relative to the vertical axis through K. These two readings are obtained for all sections such as $OPKP_1$, $PQKQ_1$, $PRKR_1$ etc. possibly eleven in total. The eleven values are then put through Simpson's rule. The areas give the total volume displaced and hence displacement weight; the moments of area are used to find the distance of the centroid from the vertical axis through K i.e. the value of B_1Y or KN.



	<u>Area</u>	<u>SM</u>	<u>F (vol)</u>	<u>Moment of area</u>	<u>SM</u>	<u>f (moment) of</u>
<u>vol</u>						
OPKP ₁		1			1	
PQKQ ₁		4			4	
ORKR ₁		2			2	
Etc.		Etc.			Etc.	
		Σ	=		Σ	=

Displacement = $1/3 \times CI \times \Sigma f(\text{vol}) \times \text{density}$.

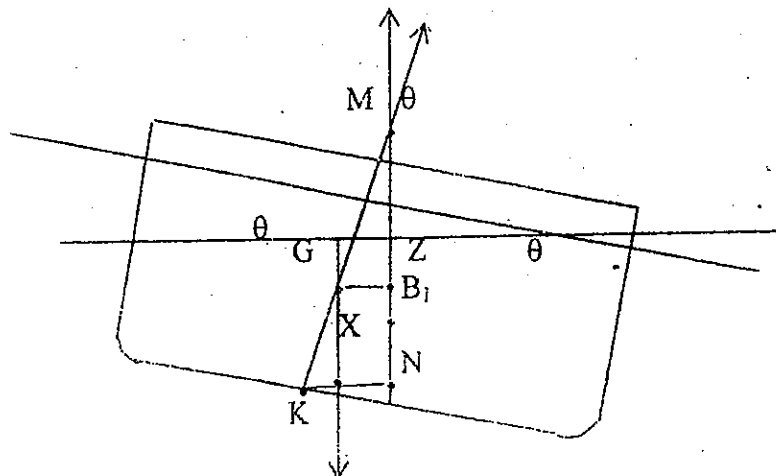
$$KN = B_1Y = \frac{\text{Moment of Volume}}{\text{Volume}} = \frac{\Sigma f(\text{Moment of Volume})}{\Sigma f(\text{vol})}$$

Having obtained the value of GZ appropriate to waterline WL at 20° heel, the whole calculation is repeated for several other displacements (W₁L₁ W₂L₂ etc.) at the same heel. This gives a series of GZ values which, when plotted, give the cross curve for 20° heel. This is repeated through out to obtain the cross curves at other selected angles of heel (30°, 40° etc.).

There is a simple relationship between the value of KN and the corresponding value of GZ for any given value of KG. As the diagram below shows :

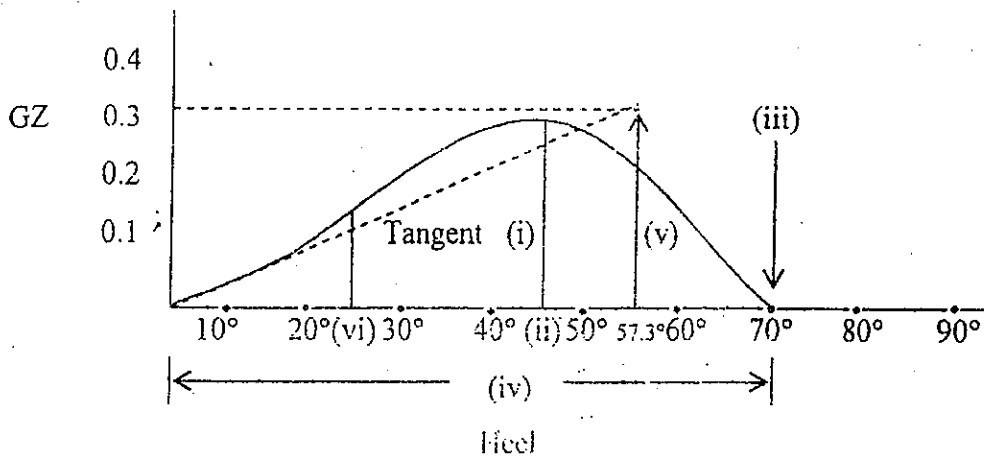
$$GZ = XN = KN - KX = KN - KG \sin \theta$$

The term $KG \sin \theta$ (always subtracted) is the correction to KN'



CURVES OF RIGHTING LEVERS

A curve of righting levers (a 'GZ curve') is one which shows the value of the righting lever GZ at different angles of heel. For a ship with a positive initial GM the curve will have the general form shown.



The specific information given by such a curve is :

- i. The maximum GZ.
- ii. The angle of maximum stability.
- iii. The angle of vanishing stability.
- iv. The range of positive stability.
- v. The (approximate) initial GM.
- vi. The (approximate) angle of deck edge immersion.

Because it shows the value of GZ at any angle, the righting MOMENT (moment of statical stability) at that angle can be calculated.

Moment of statical stability = $W \times GZ$ (tonne metre)

The dynamical stability for any angle can be calculated from the formula :

Dynamical stability = $W \cdot GZ$

(GZ is the area under the curve from 0° to θ°).

All of this information is only valid and reliable if the ship is in the condition and circumstances assumed by the person (s) doing the calculation of KN and GZ. To be valid the ship must:

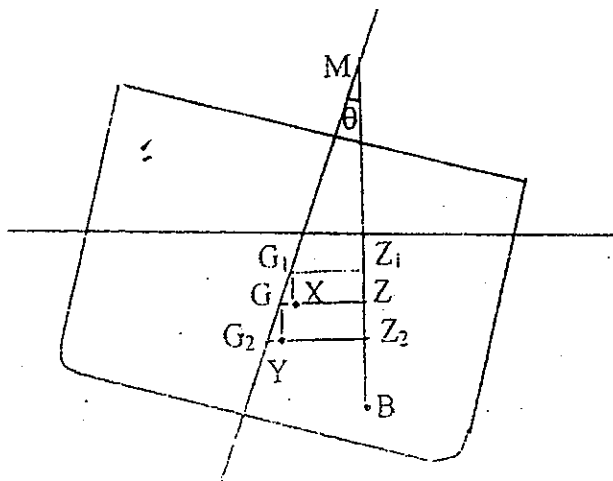
- Be at the assumed displacement and trim.
- Be loaded or ballasted to the assumed KG (or KG_{FLUID}).
- Have G stationary; any possible shift of cargo is ignored.
- Be in still water, and stopped.
- Be momentarily at rest at the angle(s) of heel concerned.
- Be intact, displacing water at all compartments which can be maintained 'watertight'.

(And the righting moment can only effectively be $(W \times GZ)$ if the heeling moment is no longer present)

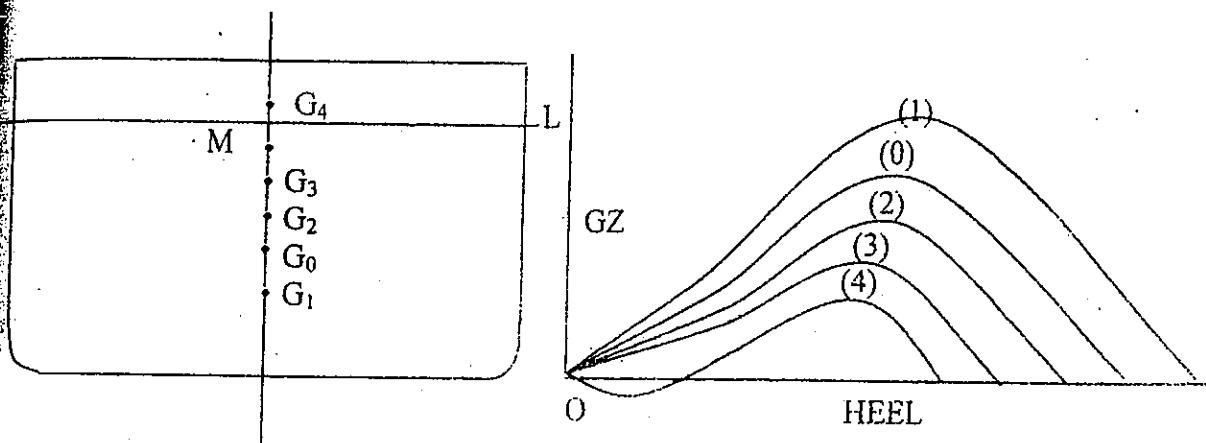
The data will be wrong if the ship is in a seaway, actively pitching, rolling or heaving etc, or if G moves for any reason, or if the ship is at a different trim etc.

EFFECT OF A CHANGE OF KG (i.e. a vertical shift of G)

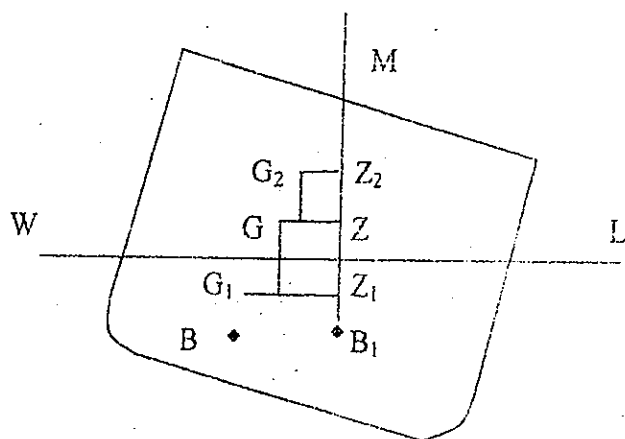
The diagram shows a ship heeled to any angle θ by an external force. When the center of gravity is at G the lever is GZ. If the centre of gravity is at some higher position G_1 the lever will be G_1Z_1 . The loss of lever due to raising G to G_1 is GX which is $GG_1 \sin \theta$.



Similarly, the GAIN of lever due to lowering G to a position G_2 is G_2Y which is $GG_2 \sin \theta$. In general, a vertical shift of G results in a change of lever given by (shift of G $\times \sin \theta$). A DROP of G improves stability in EVERY way. A RISE of G worsens stability in EVERY way. The diagram below shows representative GZ curves for different values of KG (not to scale) as numbered in the ship diagram.



Lowering G improves ALL aspects of stability and raising G worsens ALL aspects of stability.



$$\text{Correction to GZ} = GG_1 \sin \theta$$

Correction is positive $\rightarrow$ added if GG decreases

Correction is negative $\rightarrow$ subtracted if GG increases

i.e. for downward shift of G

$$G_1Z_1 = GZ + GG_1 \sin \theta$$

i.e. for upward shift of G

$$\longrightarrow G_2Z_2 = GZ - GG_2 \sin \theta$$

$$\text{New } G_1 Z_1 = GZ - GA$$

$$G_1 z_1 = GZ - GG_1 \cos \theta$$

This can be proved as follows :

$$\therefore \text{Angle BGW} = \theta^\circ = \text{List}$$

GG_1 is transverse shift of G , GG_1 is perpendicular to GB .

$\therefore (\theta) \text{ BGW} + \text{WGG}_1 = 90^\circ$ and GA (GZ) and
area also perpendicular

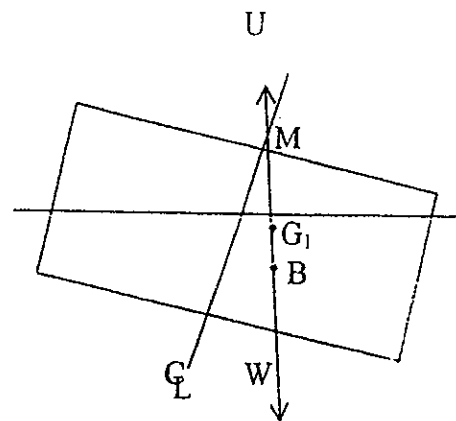
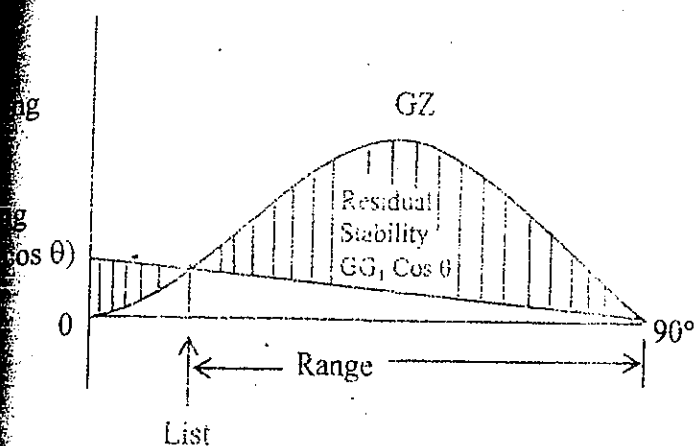
$$\therefore WGG_1 + G_1GA = 90^\circ = BGW + WGG_1$$

$$\therefore \text{BGW} = G_1GA = \theta = \text{List}$$

$$\cos \theta = \frac{GA}{GG_1}$$

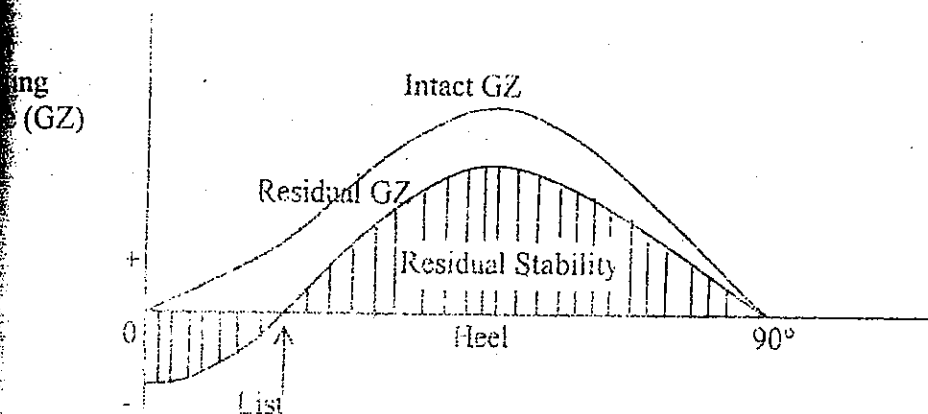
$$\therefore GA = GG_1 \cos \theta$$

The effect of this shift of G on the ships stability can be seen by superimposing a graph of $GG_1 \cos \theta$ on the GZ curve. The point of intersection is the list acquired in calm water. At this angle there is no righting lever (see diagram below). At any larger angle there is a righting lever shown by the excess of GZ over $GG_1 \cos \theta$. This quantity is termed the residual stability. At any smaller angle there is a capsizing lever shown by the excess of $GG_1 \cos \theta$ over GZ.



Showing the original curve as one having an angle of vanishing stability 90° is a (of convenience.)

Alternative method of showing the effect of a transverse shift of G is to subtract the stability $GG_1 \cos \theta$ from GZ and plot the residual below. The resulting diagram(s) are shown below.



residual stability (shaded) is the same area as shown on the previous diagram.

It should be noted that the transverse shift of G both creates a list and causes a reduction in all aspects of stability at angles greater than the list, other than the angle of vanishing stability (that too would be reduced if the original Angle of Vanishing Stability was less than 90°).

Example 1.

For M.V. MMTI, displacement 5000 tonnes draw the curve of righting levers for $KG = 6.1\text{m}$ and state :

- Range of positive stability.
- Angle of maximum stability.
- Approximate initial GM.
- Angle of contra flexure.
- The moment of statical stability at 30°

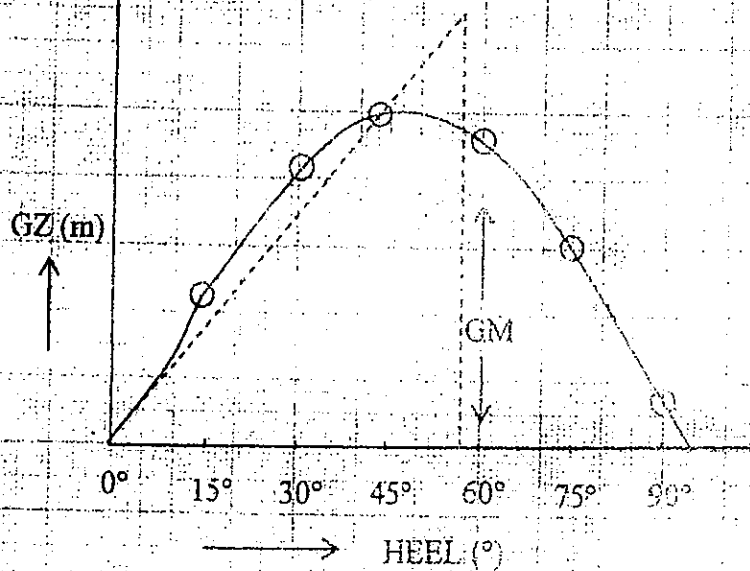
Solution :

Inspecting the KN curve for M.V. MMTI, given at the end of the book, the following KN values are obtained :

Heel	0°	15°	30°	45°	60°	75°	90°
KN (m)	0	2.65	5.15	6.90	7.55	7.35	6.4
KG	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Sin θ	0	0.2588	0.5	0.7071	0.866	0.9659	1.0
KG Sin θ	0	1.5787	3.05	4.3133	5.2826	5.892	6.1
KN - KG Sin $\theta = GZ$	0	1.0713	2.10	2.5867	2.2674	1.458	0.3

Plotting these values of GZ on the graph provided, the following results are obtained :

- $0 - 94^\circ$
- 45°
- 3.25 m (approximately)
- 15° (approximately)
- $W \times GZ = 5000 \times 2.10 = 10500\text{ mt.}$



GZ CURVES

Exercise 10

1. A vessel has the following GZ values :

Heel	15°	30°	45°	60°	75°	90°
GZ (m)	0.391	1.00	1.138	0.774	0.129	-0.584

Cargo is then redistributed causing the C.G. to rise by 0.25m. Draw her curve of statical stability for the final condition and from the curve, find the following:

- (a) An estimate of her GM. (b) Her range of stability.
 (c) Maximum GZ & the angle of heel at which it occurs.
2. A ship has a KG of 6.56 metres and a KM of 6.45 metres. Her KNs are as follows :

Heel	5°	10°	15°	30°	45°	60°
KN (m)	0.56	1.13	1.72	3.43	4.80	5.63

Find the righting levers, draw a curve of statical stability and find the range of stability, the approximate angle of loll and the amount and angle of maximum stability.

3. For a ship 5000 tonnes displacement the values of KN are as follows :

Heel	0°	15°	30°	45°	60°	75°	90°
KN (m)	0	1.73	3.43	5.01	5.95	5.89	5.41

Draw the curve of righting levers for KG = 6.1m and state :

1. Range of positive stability
 2. Angle of maximum stability
 3. Approximately initial GM
 4. The moment of statical stability at 30°.
4. A ship displacing 5000 tonnes has GZ values as follows when KG = 6m

Heel	0°	15°	30°	45°	60°	75°	90°
GZ (m)	0	0.14	0.36	0.73	0.67	0	-0.65

Draw the curves of righting levers for this condition and for KG = 5m. Discuss the effect on stability of lowering the C of G.

A ship at displacement 45000t has $GM = 0.67m$. The cross curves show constant values of GZ for any displacement from 43000t to 45000t inclusive, and for the ship's actual KG the values of GZ are as follows:

Angle of Heel	0°	15°	30°	45°	60°	75°	90°
GZ (m)	0	0.22	0.71	1.05	1.02	0.85	0.56

2000t of cargo are discharged from a position 17 metres below the centre of gravity.

Draw the curve of righting levers for the new condition and state the information obtainable from it.

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Answers :

- (a) Initial $GM = 1.28m$
 (b) $0^\circ - 73^\circ$ Range of stability
 (c) At 38° maximum $GZ = 1.0m$.
- 57° , 12° , $0.19m$ at 38° .
- (1) 0° to 75° (2) 52° (3) $0.45m$ (4) 1900 tonnes metres.
- Range improved 75° to 94° . Angle of vanishing stability equally improved : maximum GZ increased from $0.82m$ to $1.65m$: angle of maximum stability increased from 52° to 54° .
 GM increased by 1 metre (from approximately $0.5m$ to $1.5m$).
 Dynamical stability increased at all angles, and is, for example, roughly doubled at 50° heel.
- $GM = -0.120m$; Loll 14° ; Angle of vanishing stability 77° ;
 Range 14° to 77° ; Angle of maximum stability 48° ; Maximum $GZ = 0.51m$

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CHAPTER XI

GRAIN STABILITY

Prior to loading grain in bulk the ship shall have a "document of Authorization" issued by the administration, stating that the ship is capable of complying with the stability requirements as per the International Grain Code.

Together with these documents, the ship shall be provided with a grain loading manual, giving information, including the following.

- (i) The ship's particulars
- (ii) Light ship displacement, KG and LCG.
- (iii) A table of free surface correction for each tank in which liquids may be carried.
- (iv) Capacity, KG and LCG's of every compartment in the ship.
- (v) A curve or table of angle of flooding for various drafts.
- (vi) Curves or tables of hydrostatic properties for a range of drafts between light and load drafts.

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of
- (vii) Cross curves of stability at sufficiently close intervals of angles of heel, to accurately define her statical stability curve and this shall include KN curves at 12° and 40° angles of heel.
why 12° & 40° angles of heel?
- ain
(viii) Curves or tables of volumes, centers of volume, vertically and longitudinally and assumed volumetric heeling moment for every compartment, filled or partly filled or combinations thereof including the effects of temporary fittings.
- (ix) Tables or curves of maximum permissible heeling moments for varying displacements and for varying KG's to enable the master to demonstrate the compliance with the requirement of grain code.
- x) Details of scantlings of any temporary fittings where necessary to meet the requirements of the grain code.
- xi) Loading instructions in the form of notes, summarising the requirement of the grain code.
- xii) A worked example for the guidance of the master.
- xiii) Typical loaded service departure and arrival conditions and where necessary, intermediate worst service conditions.

INTACT STABILITY REQUIREMENTS FOR SHIPS CARRYING GRAIN IN BULK

Through out the voyage, she shall meet the following criteria taking into account the assumed heeling moments due to grain shift.

1. The angle of heel due to assumed shift of grain shall not be greater than 12° and in the case of ships constructed on or after 1st January 1994, the angle of heel shall not exceed 12° or the angle of deck edge immersion, which ever is less.
2. The net or Residual area between the heeling arm curve and the righting arm curve upto 40° or the angle of flooding or the angle of heel at which maximum difference occurs between the heeling arm curve and righting arm curve, which ever is least, shall not be less than 0.075 metre radian.
3. Her GM fluid shall not be less than 0.3 metres.
4. Before loading the grain, the master shall demonstrate, the ability of the vessel at all stages of the voyage to comply with the above stability criteria.
5. The ship shall be upright before proceeding to sea.

The angle of flooding is the angle of heel at which openings in hull, superstructures or Mast houses which can not be closed water tight immerse. Small openings through which progressive flooding can not take place can be neglected.

With respect to figure 1. the grain regulations assume that for filled compartment's there will be a void space beneath the top of the compartment, the depth of void being determined by the formulae involving the distance from the hatch to the compartment boundary and the depth of the hatch side girder. The grain in the filled compartment is then assumed to shift 15° to the horizontal. The volumetric heeling moment then can be calculated from the geometry of the compartments. In most of the cases the volume centroid of the compartment will be taken as the KG of the grain. However the KG is lowered by taking into account the void spaces then the vertical shift of grain must be taken into account and then .

The heeling moment = $1.06 \times$ Calculated heeling moment

For filled compartment untrimmed, the KG of the whole compartment is taken for calculation and thus no multiplication factor.

3. In case of partly filled compartments, the grain is assumed to shift no fall step 25° to the horizontal before the volumetric heeling movement is calculated then :-

Total heeling moment = $1.12 \times$ Calculated heeling moment.

4. The sum of all the values of volumetric heeling moment is then for a particular load condition and value of λ_0 can be worked out as follows :

$$\lambda_0 = \frac{\text{Assumed volumetric heeling moment}}{\text{S.F.} \times \text{Displacement}} = \frac{\text{vol. of grain shifted} \times \text{Distance shifted}}{\text{S.F.} \times \text{Displacement}}$$

λ_0 is equivalent to : $\frac{\text{Weight of grain shifted} \times \text{Distance shifted}}{\text{Displacement}}$

$$\lambda_{40} = 0.8 \lambda_0$$

5. The values of λ_0 and λ_{40} are plotted along GZ at 0° and 40° respectively and joining the two points thus obtained calling it heeling arm curve.

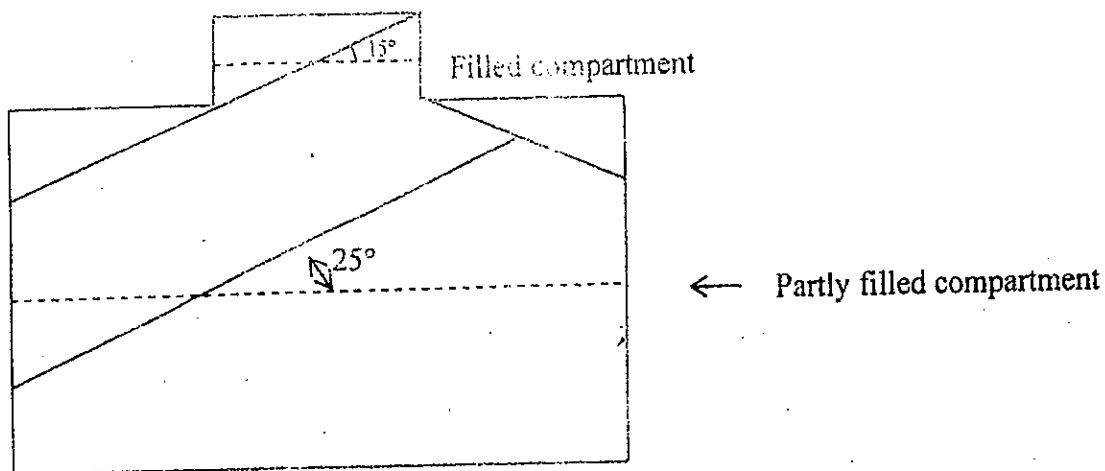
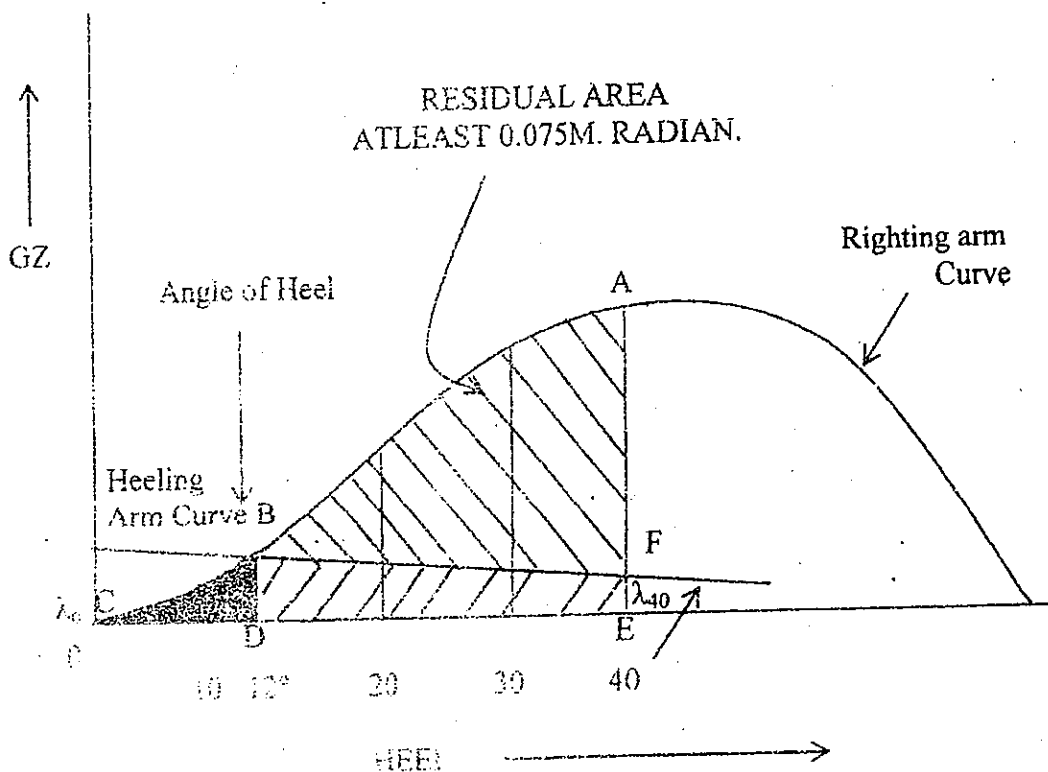


Figure 1

6. Volumetric heeling moment is very similar to free surface effect except that it is calculated for two particular angles of heel.



7. Upto about 40° cosine is nearly a linear sloping line and hence join λ_0 upto

$$\lambda_{40}. \text{ Cosine } 40^\circ = 0.77 = 0.8$$

$$\text{i.e. } \lambda_0 \times 0.8 = \lambda_{40}$$

8. To find the Residual Area :

Find the full area under the curve by Simpson rule.

i.e. Area A, B, C, D, E.

Subtract the area of the Δ upto 12° , where the curve is nearly a straight line and hence considered a Δ i.e. $\frac{1}{2} \text{ base} \times \text{height} \div 57.3^\circ = \text{M. radian}$.

i.e. area B, C, D.

Subtract the area of the Trapezium from 12° to upto 40° i.e.

$$\text{Area} = \frac{\frac{1}{2} \text{ Sum of the two sides} \times \text{Distance between them}}{57.3} \quad \text{M. radian}$$

i.e. area BDEF.

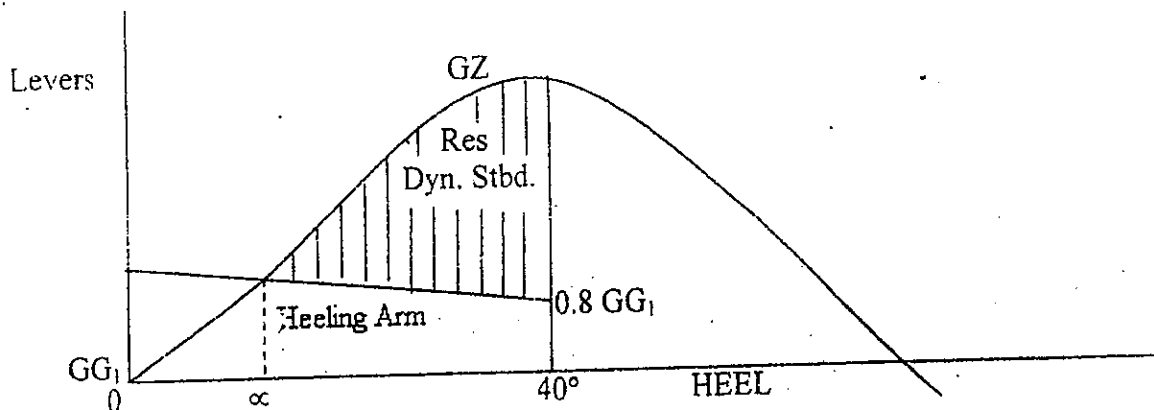
THE EFFECT OF AN ASSUMED SHIFT OF GRAIN IN TERMS OF IMO GRAIN RULES

The IMO Grain Rules (the only approved method of grain carriage for NEW ships under the Grain Rules) assumes that unsecured grain is able to move (i) through an angle of 15° in a space supposedly full (because of unavoidable voids), and (ii) through an angle of 25° in a space which is obviously slack (only partly filled). The grain loading data in the stability book makes it possible to calculate the total volumetric heeling moment (i.e. volume $\times$ distance, for any particular stowage). The corresponding weight moment is

$$\left\{ \frac{\text{Volumetric moment}}{\text{stowage factor (SF)}} \right\}$$

$$\text{Then } GG_1 = \frac{\text{Weight moment}}{W} = \frac{\text{volumetric moment}}{\text{SF} \times W}$$

The heeling lever (or loss of righting lever) $GG_1 \cos \theta$ is assumed to be a straight line of value GG_1 at 0° and $(0.8 GG_1)$ at 40° as shown below.



To be deemed satisfactory

- i. GM must be at least 300 mm
- ii. The list (α) shown by the above must not exceed 12°
- iii. The residual dynamic stability between α° and 40° (shown hatched) must be at least 0.075 metre radians.

THE EFFECT OF A STEADY BEAM WIND

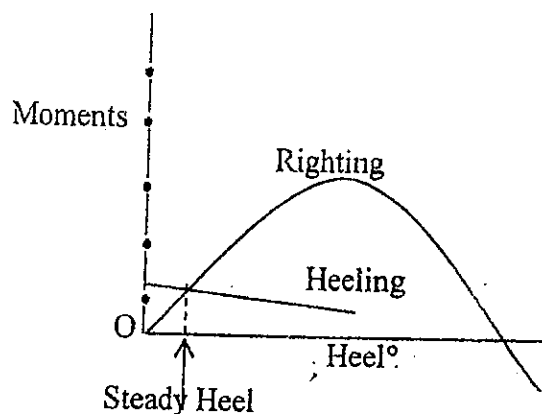
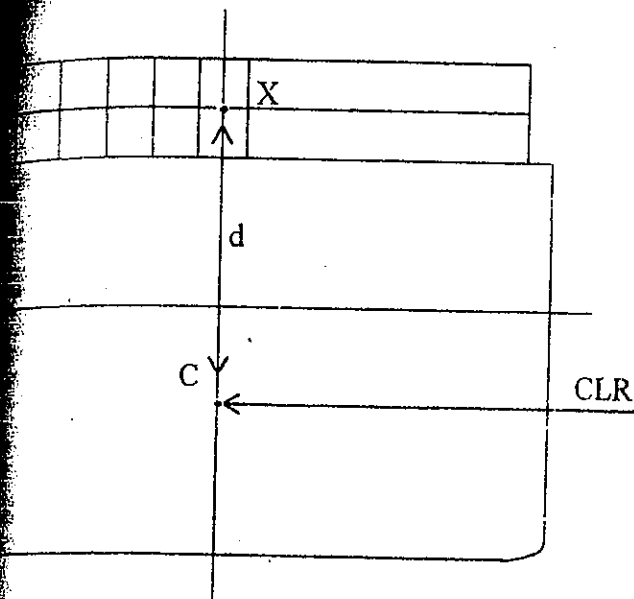
The HEELING MOMENT set up by a beam wind can be determined by calculating

- i. The thrust (T) imposed on the exposed side area.
- ii. The leverage (d) between the centroid of this area (X) and the centre of lateral resistance (CLR).— the distance CX in diagram.

Hence

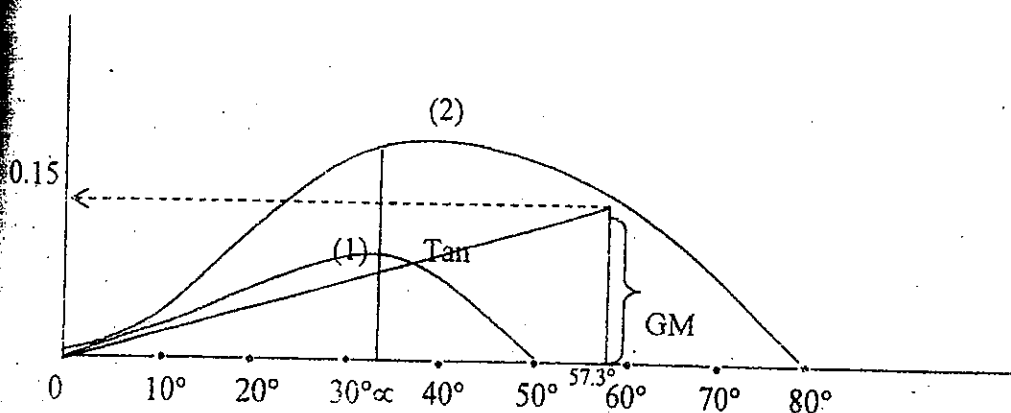
- iii. The wind heeling moment (T d) tonnes metres

If this moment is assumed to remain constant (even as the ship heels) the ship will heel to the angle at which heeling moment (T d) equals the righting moment (W X GZ). This angle can be established by drawing the two MOMENT curves to the same scale and finding the point of intersection.



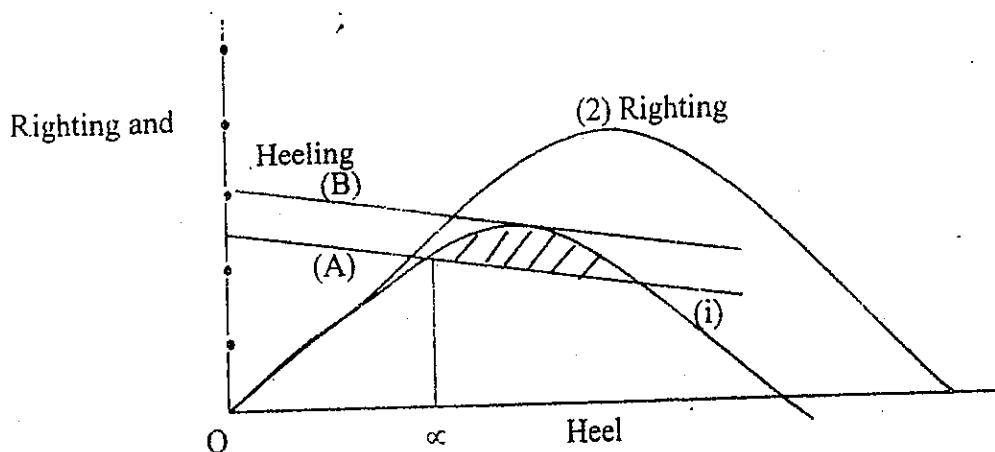
REASONS FOR GM ALONE NOT BEING AN ADEQUATE MEASURE OF STABILITY

Initial metacentric height (GM) is a measure of the (statical) stability possessed by a ship at small angle of heel. The two GZ curves in a diagram below are for ships having the same value of GM (say 150 mm, - the most common minimum requirement).



The vessels would behave similarly at small angles of heel but they differ greatly at large angles of heel in all other respects, e.g. angle of maximum stability, maximum GZ, range of positive stability and dynamical stability (the work done to heel ship (1) to capsize would

heel ship (2) only to α° (approximately). The lack of area under curve (1) means that it may be unable to cope with any effect which raises G (icing?) or which causes G to move athwartships (shift of cargo) or which imposes a significant heeling moment (such as a strong beam wind or turning at high speed, or indeed, any incident, mishap or accident which causes even a slight loss of stability. The outcome of any event which causes an athwartships shift of G (or which has an effect equivalent to that) can be illustrated by drawing the curve of heeling levers on the GZ curve.



Curve (A) shows ship (1) heeling to α° at which point there is very little dynamical stability remaining (see shaded area) and it would take little further effort or only a minor 'mishap', to capsize the ship. Ship (1) could not withstand the heeling implied by curve (B). Ship (2) on the other hand would heel less than (1) under the influence of A, and would still have a substantial residual dynamical stability – sufficient to cope adequately with the heeling moment set up by (B), or, indeed, by a much bigger 'effort' than (B). To ensure that every ship is more like (2) than (1) the Load Line Rules prescribe (in addition to the minimum GM 150 mm) several other minima for the GZ curve, viz, area 0° to 30° , area 0° to 40° , area 30° to 40° , the fact that the angle of maximum stability must exceed 30° , and GZ must be at least 0.2 at 30° or greater. These minimum criteria are to ensure that the vessel has adequate stability at moderate and large angles for normal heavy weather etc and withstand the heeling effects imposed by one, two or several adverse circumstances of the nature described above.

GRAIN STABILITY

PROBLEMS :

A vessel is loaded with grain in Bulk, of SF $2 \text{ m}^3/\text{t}$ and has a $W = 70000\text{t}$, $KM = 12.2$, $FSM = 4000\text{mt}$. Two holds are partly filled and their combined VHM as read off from curves is 2900 m^4 , all other holds are full and their total VHM is 19000 m^4 . The KG of the ship calculated assuming the CG of grain in the filled compartments are at the volumetric centroid of each of those compartment is 10.2 mt . The angle of flooding is 41° , the KN values for her W are as follows :

Heel	12°	15°	30°	40°	45°	60°
KN	2.75	3.50	7.0	9.40	10.20	11.30

Determine whether the ship satisfies the intact stability criteria for vessel loaded with grain in bulk.

$$FSM = 4000$$

$$\therefore FSC = \frac{FSM}{W}$$

$$= \frac{4000}{70000}$$

$$FSC = 0.057 \text{ m}$$

$$\text{Ship's KG} = 10.20$$

$$FSC = +0.057$$

$$\text{Corrected KG} = 10.257 \text{ m}$$

$$\therefore GM(f) = KM - \text{Corrected KG}$$

$$= 12.2 - 10.257$$

$$GM(f) = 1.943 \text{ m}$$

$$\therefore GM(f) = 1.943 \text{ m is } > 0.3 \text{ m GM as required.}$$

Thus the Residual Area =

Total area - Area of Δ - Area of $\square$

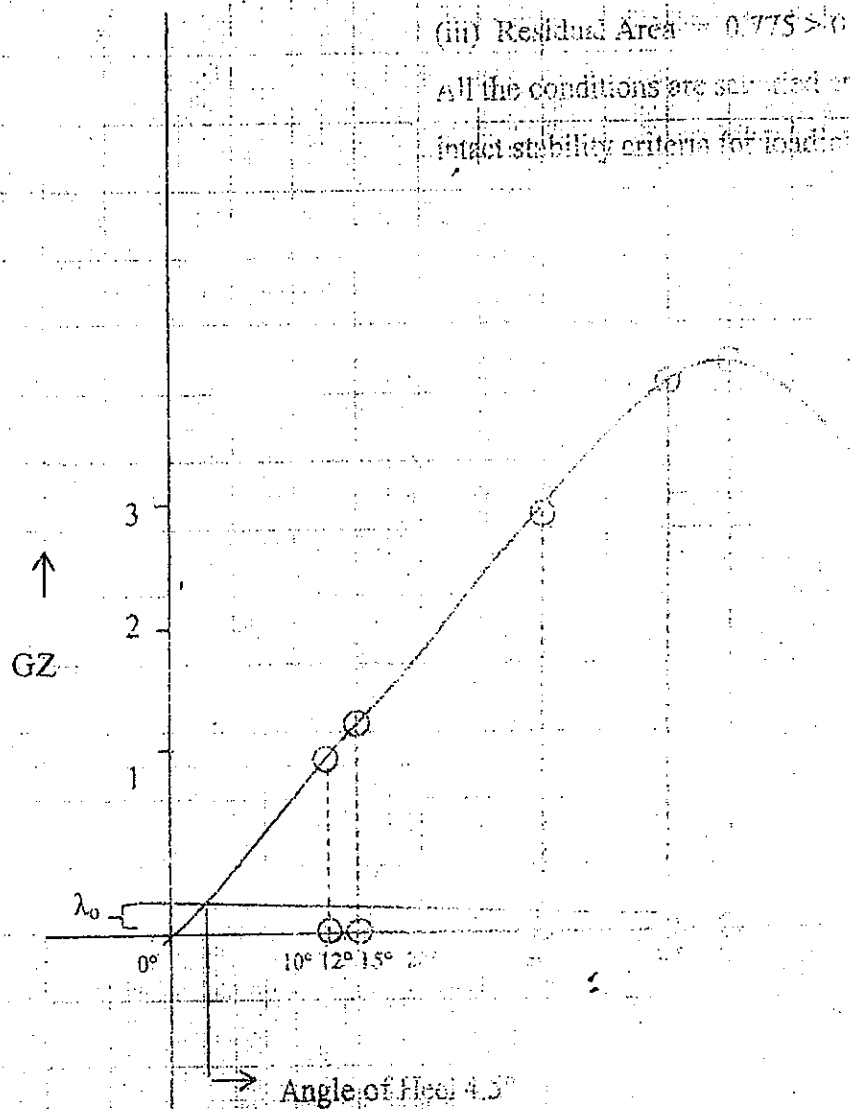
This Residual area should be at least 0.075

(i) $GM(0) = 1.943 > 0.3$ Satisfied

(ii) Angle of heel = $4.5^\circ < 12^\circ$ Satisfied

(iii) Residual Area = $0.775 > 0.075$ Satisfied

All the conditions are satisfied and hence one satisfies the intact stability criteria for loading with grain in bulk.



$$GZ = KN - KG \cdot \sin \theta$$

Heel	12°	15°	30°	40°	45°	60°
KN	2.75	3.70	7.0	9.40	10.20	11.30
KG	10.257	10.257	10.257	10.257	10.257	10.257
Sin θ	0.2079	0.2588	0.5	0.6428	0.7071	0.8660
KG. Sin θ	2.1324	2.6545	5.1285	6.5932	7.2527	8.8826
G.Z.	0.6176	0.8455	1.8716	2.8068	2.9473	2.4174

Please refer to the graph paper attached :

Now partly filled compartment VHM = 2900 m⁴

Factor X 1.12

3248

VHM for other holds full 19000

Total VHM 22248

$$\text{Heeling Moment} = \frac{\text{VHM Total}}{\text{S.F.}} \frac{\text{m}^4}{\text{m}^3/\text{t}} = \text{mt}$$

$$= \frac{22248}{2} = 11124 \text{ m.t.}$$

$$\text{Heeling Arm} = \frac{\text{Heeling Moment}}{W} = \frac{11124}{70000} = 0.1589\text{t}$$

$$\text{i.e. } \lambda_0 = 0.1589$$

$$\text{Now } \lambda_{40} = \lambda_0 \times 0.8 = 0.1589 \times 0.8$$

$$\lambda_{40} = 0.1271$$

	Ordinates	X	SM	=	Prod. Of Area
0°	0.0		1		0.0
10°	0.6		4		2.40
20°	1.10		2		2.20
30°	1.87		4		7.48
40°	2.80		1		2.80
				S.O.A.	<u>14.88</u>

$$\text{Area} = \frac{14.88 \times 1 \times 10}{3} = 49.6$$

Now convert the area into m. radian : $49.6 / 57.3 = 0.866 \text{ m. radian}$

∴ Total area under the curve upto 40° ⇒ 0.866 m. radian

(i) Area of Δ upto 4.5° of heel where the curve changes

$$\begin{aligned}
 &= \frac{1}{2} \times \text{base} \times \text{height} &= \frac{1}{2} \times 0.15 \times (4.5^\circ / 57.3) \\
 & &= \frac{1}{2} \times 0.15 \times 0.7853 \\
 & &= 0.0059 \text{ M.R.}
 \end{aligned}$$

(ii) Area of Tripesiam

$$\begin{aligned}
 &= \frac{1}{2} \times \text{Sum of parallel side} \times \text{Length} \\
 &= \frac{1}{2} (0.1271 + 0.15) \times (40^\circ - 4.5^\circ) / 57.3 \\
 &= \frac{1}{2} (0.2771) \times (0.6195) \\
 &= 0.085 \text{ m. radian}
 \end{aligned}$$

$$\begin{aligned}
 \therefore \text{Total Area} &= 0.866 \text{ mr} \\
 \text{Area of Triangle} &= - 0.0059 \text{ mr} \\
 \text{Area of } \triangle &= - 0.085 \text{ mr} \\
 \text{Residual Area} &= \underline{0.775 \text{ m. radian}}
 \end{aligned}$$

This is > 0.075 m. Radian

A vessel laden with grain in bulk of SF 1.2 m³/t has a W, 88000t, her KG, calculated assuming the CG's of the cargoes in the filled compartment to be at the volumetric centroid of those compartments = 10.30 mt. FSM = 2650 mt, KM = 13.0, the VHM of the filled holds is 5800 m⁴ and that of partly filled holds is 14500 m⁴, the angle of flooding is 38°. The KN values for that W are as follows:

Heel	12°	15°	30°	40°	45°
KN	2.75	3.45	6.86	8.59	9.30

Ascertain whether she satisfies the stability criteria for vessel's laden with grain in bulk.

KG	=	10.30
FSC = FSM / W = 2650 / 88000	=	+ 0.030
Corrected KG	=	10.33
KM	=	13.00
GM (f)	=	2.67 m

Heel	12°	15°	30°	40°	45°
KN	2.75	3.45	6.86	8.59	9.30
KG (Corr)	10.33	10.33	10.33	10.33	10.33
Sin θ	0.2079	0.2588	0.5	0.6428	0.7071
KG Sin θ	2.148	2.673	5.165	6.640	7.304
GZ	0.602	0.777	1.695	1.95	1.996

$$\text{VHM of partly filled comp} = 14500$$

$$\text{Factor} = \times 1.12$$

$$\text{VHM of partly filled comp} = 16240 \text{ m}^4$$

$$\text{VHM of filled comp} = 5800 \text{ m}^4$$

$$\text{Total VHM} = 22040 \text{ m}^4$$

$$\lambda_o = \frac{\text{VHM}}{\text{SF} \times \text{W}} = \frac{22040}{1.2 \times 88000} = 0.209$$

$$\lambda_{40} = \lambda_o \times 0.8 = 0.209 \times 0.8 = 0.167$$

Stations	X	Ordinates	X	S.M.	=	P.O.A
0°		0.00		1		0.0
9.5°		0.45		4		1.80
19.0°		1.10		2		2.20
28.5°		1.65		4		6.60
38°		1.90		1		1.90
				S.O.A		<u>12.50</u>

$$12.5 \times \frac{9.5}{3} \times \frac{1}{57.3} = 0.69 \text{ m. radian}$$

$$\therefore \text{Total Area under the curve} = 0.69 \text{ m. radian}$$

$$\begin{aligned} \text{Area of triangle} &= \frac{1}{2} \times \text{base} \times h = \frac{1}{2} \times 0.25 \times 4/57.3 \\ &= 0.0087 \text{ m. radian} \end{aligned}$$

$$\begin{aligned} \text{Area of } \triangle &= \frac{1}{2} (\text{Sum of parallel side}) \times (\text{Length}) \\ &= \frac{1}{2} (0.25 + 0.18) \times \frac{(38^\circ - 4^\circ)}{57.3} \\ &= \frac{1}{2} (0.43) \times 0.59 \\ &= 0.127 \text{ m. radian} \end{aligned}$$

∴ Total area = 0.69 m. radian

Area of Δ = -0.0087 m. radian

Area of ∇ = -0.127 m. radian

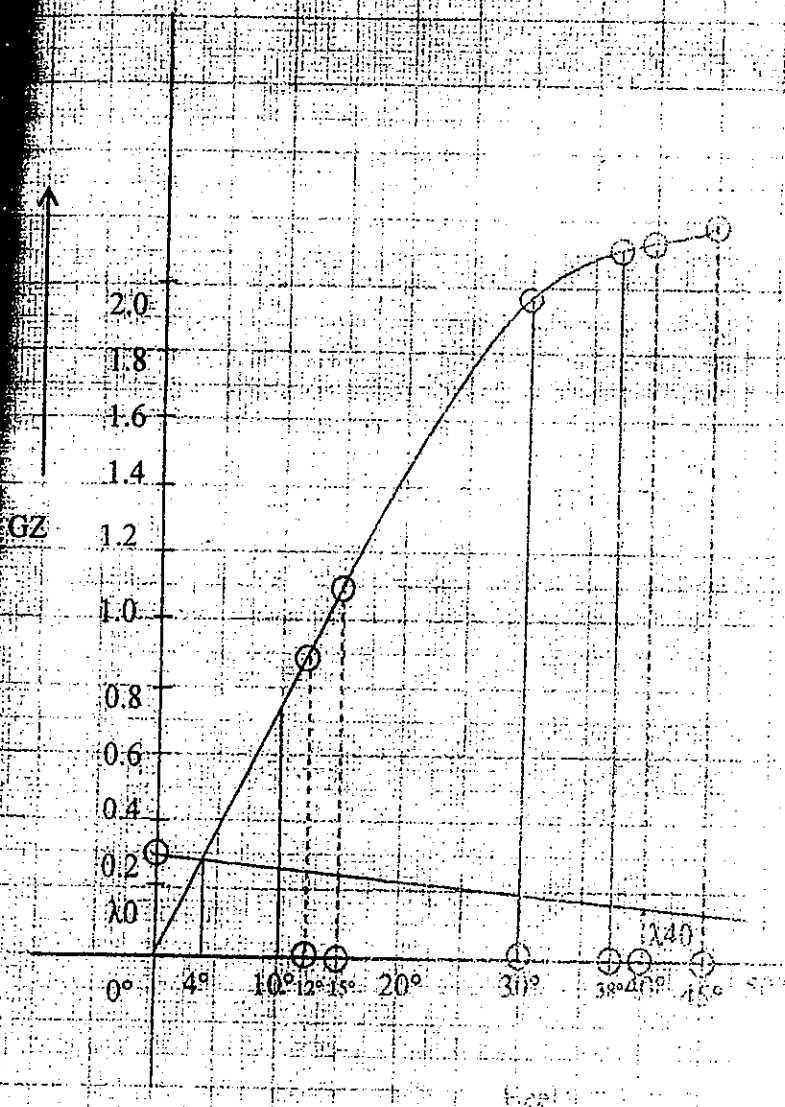
Residual area = 0.5543 m. radian > 0.075 m. radian

(i) $GM(t) = 2.67 \text{ m} > 0.3$ Satisfied

(ii) Angle of heel = $4^\circ < 12^\circ$ Satisfied

(iii) Residual Area = 0.5543 m. radian > 0.075 m. radian Satisfied

Thus the vessel satisfies the stability criteria for laden vessel with grain in bulk



GRAIN STABILITY

Exercise 11

1. A vessel displacing 16500 tonnes has KG, 7.50m. Calculations of grain shift give the following data.

$$\text{Volumetric heeling moment} = 3960\text{m}^4$$

$$\text{Stowage factor} = 1.2\text{m}^3/\text{tonne}$$

For the given displacement and KG the vessel has the following values of GZ at the angles of heel given.

Heel	0	15	30	45	60	75	90
GZ	0.00	0.267	0.645	0.571	0.163	-0.454	-1.104m

Verify whether the vessel satisfies intact stability requirements for grain cargo.

Angle of flooding is 40° .

2. The values of GZ of a vessel at different angles of heel are as follows:

Heel ($^\circ$)	0	5	12	20	30	40	60	75
GZ (m)	0.0	0.188	0.449	0.764	1.227	1.551	1.713	1.298

The heeling arm at $0^\circ = 0.275$ metres. The angle of flooding is 40° and maximum difference between the righting arm and heeling arm occurs at an angle greater than 40° . Verify whether the vessel satisfies the intact stability requirements for a cargo ship carrying grain in bulk.

3. A vessel's GZ values for various angles of heel are as follows:

Heel ($^\circ$)	00	05	12	20	30	40	60	75
GZ (m)	0.000	0.136	0.315	0.472	0.604	0.631	0.562	0.248

The heeling arm at $0^\circ = 0.18\text{m}$. The angle of flooding is 40° and maximum difference between the righting arm and heeling arm occurs at 43° . Verify whether the vessel satisfies the criteria of stability for a cargo ship carrying grain in bulk (Assume the deck edge immerses at 10° heel).

4. A vessel loaded with grain in bulk is at a displacement of 35186t, KG 7.809m, KM 11.30m. The stowage factor of the grain is $1.3\text{m}^3/\text{t}$ and the total volumetric Heeling Moments are 21321m^4 . At the displacement her KN values are as follows :

Heel ($^\circ$)	5	12	15	30	45	60
KN (m)	1.00	2.42	2.90	5.60	7.30	8.05

If her angle of flooding exceeds 40° , ascertain whether the vessel complies with the intact stability requirements for such vessels.

5. A vessel's GZ values for various angles of heel are as follows:

Heel ($^\circ$)	00	05	12	20	30	40	60	75
GZ (m)	0.000	0.136	0.135	0.472	0.604	0.631	0.562	0.248

The heeling arm at $0^\circ = 0.18\text{m}$. The angle of flooding is 40° and maximum difference between the righting arm and heeling arm occurs at 43° . Verify whether the vessel satisfies the criteria of stability for a cargo ship carrying grain in bulk. (Assume the deck edge immerses at 10° heel)

Answers :

1. Initial GM = 0.776m satisfactory
Heel = 12° Marginal
Residual Area = 0.168m radians satisfactory
2. (a) Initial GM 1.8m > 0.3 m
(b) Angle of heel due to shift of grain = $7^\circ < 12^\circ$
(c) Residual area = 0.500 mR > 0.075 mR
Thus the vessel satisfies the grain loading criteria.
3. (a) Initial GM 1.41m > 0.3 m
(b) Angle of heel due to shift of grain = $6.5^\circ < 12^\circ$
(c) Residual area 0.162mR > 0.075 mR.
4. Angle of heel due to shift of grain is $7^\circ < 12^\circ$
Initial GM is 3.491m > 0.3 m
Residual area is 0.422mR > 0.075 mR.
5. Heel due to shift of grain = 17°
GM = 0.52 m
Residual Area : 0.2647 mr
 - 0.024 mr
 - 0.0595 mr
 0.1811 mr

Thus the ship does not comply.

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CHAPTER XII

FORM CO-EFFICIENTS

1. Coefficient of fineness of the midship section or midship section coefficient (C_m)

This is the ratio between actual underwater area of a midship section and that of a rectangle of the similar depth and width. For example in Figure (1) given here :

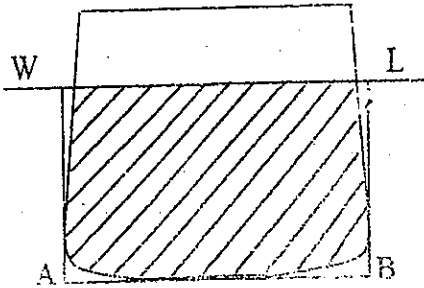


Figure 1.

$$\frac{\text{Shaded area}}{\text{Area of ABLW}} = \text{Midship coefficient}$$

2. Coefficient fineness of a water plane or water plane coefficient (C_w)

As given below in Figure (2), it is the ratio between area of water plane and that of a rectangle of similar length and breadth

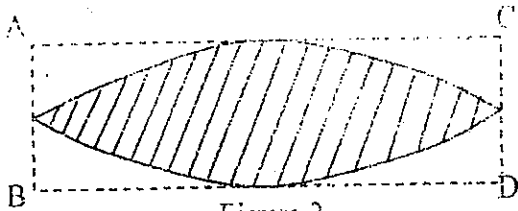


Figure 2.

$$\text{Water plane coefficient} = \frac{\text{Shaded area}}{\text{Area ABCD}}$$

3. Block coefficient of fineness of displacement or block co-efficient (C_b)

It is the ratio between the underwater volume of a ship and that of a box shaped vessel having same length, breadth and mean draft. It is shown in Figure (3) below.

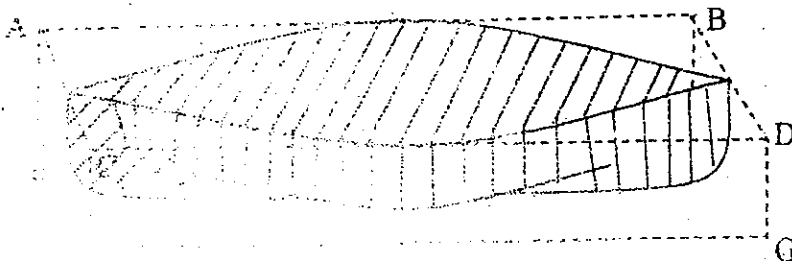


Figure 3.

$$\text{Block coefficient} = \frac{\text{Shaded value}}{\text{Value of ABCDEFG}}$$

4. Prismatic coefficient of fineness of displacement or prismatic coefficient (C_p)

As per Figure (4) below it is defined as the ratio between the underwater volume of a ship and that of a prismatic having the same length as the ship and same cross section as her midship section.

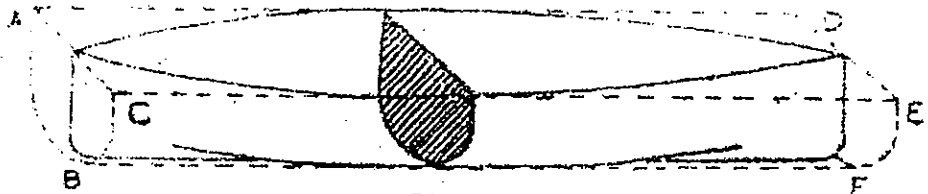


Figure 4.

$$\text{The prismatic coefficient} = \frac{\text{Under water volume of the ship}}{\text{Value of the prismatic ABCDEF}}$$

5. Wetted surface :

Wetted surface of the underwater part of the ship

$$= L \{1.7d + (C_b \times B)\}$$

Where L = Ship's length, d = Mean draft

B = Breadth of the ship C_b = Block coefficient

It can be used to calculate the paint requirement for a ship to paint the underwater areas.

FORMULAE

- Co-efficient of water plane = $\frac{\text{Area of water Plane}}{L \times B}$

$$C_w = \frac{A_w}{L \times B}$$

- Block Co-efficient = $\frac{\text{Volume of displacement}}{L \times B \times \text{Draft}}$

$$C_b = \frac{V}{L \times B \times d}$$

- Midship section Co-efficient = $\frac{\text{Area of Midship}}{B \times \text{Draft}}$

$$C_m = \frac{A_m}{B \times \text{draft}}$$

- Prismatic Co-efficient = $\frac{\text{Vol}}{A_m \times L}$

$$C_p = \frac{V}{A_m \times L}$$

$$C_p = \frac{V}{A_m \times L} = \frac{V}{A_m \times L} \times \frac{B \times d}{B \times d}$$

$$= \frac{V \times B \times d}{L B d \times A_m}$$

$$= \frac{V}{L B d} \div \frac{A_m}{B \times d}$$

$$C_p = \frac{C_b}{C_m}$$

$$\text{Where } C_b = V/L \times B \times d ;$$

$$C_m = A_m / B \times d$$

blems :

A vessel of length 120m, maximum breadth 17m, d = 7.2m has $C_b = 0.76$ and $C_m = 0.96$. The ship is jumboised by adding a parallel section 6m in length at midlength. Calculate here new displacement, C_b & C_p . ($W = 12164.6T$, $C_b = 0.769$, $C_p = 0.801$)

$$\text{Vol. added} = \text{Midship Area} \times \text{Length}$$

$$= 117.5 \times 6 = 705.024 \text{m}^3$$

$$\text{Total Vol.} = 705.024 + 11162.88 = 11867.9$$

$$\text{New } W = 12164.6 T$$

$$\text{New } C_b = \frac{11867.9}{126 \times 17 \times 7.2} = 0.769$$

$$C_p = \frac{C_b}{C_m} = \frac{0.769}{0.96} = 0.801$$

$$C_m = \frac{A_m}{B.d} = \frac{A_m}{17 \times 7.2} = 0.96$$

$$\therefore A_m = 17 \times 7.2 \times 0.96$$

$$= 117.5 \text{ m}^2$$

$$C_b = 0.76 = \frac{\text{Volume}}{120 \times 17 \times 7.2}$$

$$\therefore \text{Volume} = 0.76 \times 120 \times 17 \times 7.2$$

$$= 11162.88 \text{ m}^3$$

2. A vessel of length 135m, B = 20m, draft = 7.0m, $C_b = 0.70$, $C_m = 0.90$ is lengthened by adding a parallel section amidship 10m in length. Calculate her new displacement, C_b and C_p at the same draft?

$$C_b = \frac{V}{L \times B \times d}$$

$$V = 126 \times 10 = 1260$$

$$0.70 = \frac{V}{135 \times 20 \times 7.0}$$

$$\therefore \text{Total Volume} = 13230 + 1260 \text{ m}^3$$

$$= 14490 \text{ m}^3$$

$$V = 0.70 \times 135 \times 20 \times 7.0$$

$$\therefore W = 14490 \times 1.025 = 14852.25 \text{ t}$$

$$V = 13230 \text{ m}^3$$

$$C_b = \frac{V}{L \times b \times d} = \frac{14490}{145 \times 20 \times 7.0}$$

$$C_m = \frac{A_m}{B \times \text{draft}}$$

$$= \frac{14490}{20300} = 0.7138$$

$$0.90 = \frac{A_m}{20 \times 7.0}$$

$$C_p = \frac{C_b}{C_m} = \frac{0.7138}{0.90}$$

$$A_m = 0.90 \times 20 \times 7.0$$

$$C_p = 0.7931$$

$$A_m = 126 \text{ m}^2$$

FORM COEFFICIENTS

12

How many persons can be accommodated in a life boat whose particulars are as follows: Length = 7m, Breadth = 2m, Depth = 1m, $C_b = 0.6$, space required by one person as per rules is 0.283m^3 .

A ship is 150m long, has 20 m beam, load draft 9 and light draft is 4m. The C_b at the load draft = 0.766 and at light draft is 0.668. Find the ships dead weight.

A vessel of length 140 , Breadth 7.2m, $C_b = 0.75$, $C_m = 0.92$ is lengthened by adding a parallel section amidship 8 m in length. Calculate her new displacement, C_b and C_p at the same draft?

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Answers :

1. 29 Persons
2. 12982.65 tonnes
3. Disp - 14925.64t, $C_b = 0.7592$, $C_p = 0.8252$

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CHAPTER XIII
THEORETICAL SUBJECTS

IMO CODE ON INTACT STABILITY

INTACT STABILITY CRITERIA FOR ALL PASSENGER AND CARGO SHIPS

1. The area under the GZ curve should not be less than 0.055 meter radians upto an angle of heel of 30° .
2. The area under the curve upto an angle of 40° or the angle of flooding (Which ever is least) shall not be less than 0.09 meter radians.
3. The area under the curve between 30° and 40° or the angle of flooding (which ever is least) shall not be less than 0.03 meter-radians.
4. The righting lever GZ shall be at least 0.20m at an angle of heel equal to or greater than 30° .
5. The maximum righting lever should occur at an angle of heel preferably exceeding 30° but not less than 25° .
6. The initial metacentric height should not be less than 0.15m.

In addition for passenger ships, the angle of heel on account of crowding of passengers on one side should not exceed 10° .

In addition for passenger ships, the angle of heel on account of turning should not exceed 10° .

Provision shall be made for a safe margin of stability at all stages of the voyage, regard being given to addition of weight, such as due to absorption of water and icing and to loss of weight, such as those due to consumption of fuel and stores.

Ships carrying oil – based pollutants in bulk, should be able to satisfy the above criteria during all loading and ballasting operations.

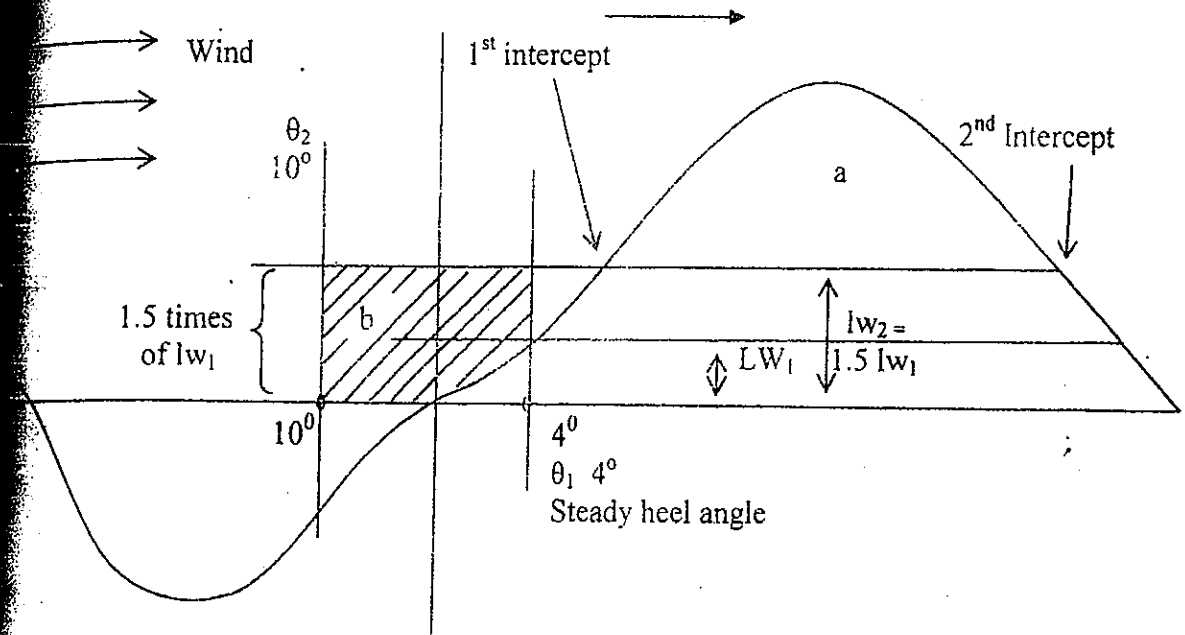
INTACT STABILITY CRITERIA FOR SHIPS CARRYING TIMBER DECK CARGO

For ships carrying timber deck cargoes and using timber load lines, provided that the cargo extends longitudinally between super structures (if there is no superstructure at the after end, the timber deck cargo should extend to the after end of the after most hatchway) and transversely for the full beam of the ship, the Administration may apply the following criteria instead of those mentioned for cargo ships.

1. The area under the GZ curve should not be less than 0.08 meter radians upto an angle of 40° or the angle of flooding (whichever is least).
2. The maximum righting lever should be at least 0.25m.
3. The initial Metacentric height corrected for free surface GM (f), should be at least 0.10m on departure.

At all times during the voyage, the metacentric height corrected for free surface and for absorption of water by deck cargo and ice accretion shall be positive.

HEEL DUE TO WIND



Factors used when calculating the angle at which she will roll into the wind are :

a, b, Roll period, distance of between G and the water line, Ratio of Breadth / draft, Area of bilge keel.

The roll period is calculated by formula.

Now suppose the Roll is say 14° i.e. $\theta_1 + \theta_2 = 14^\circ$

Assume that the gust of wind hitting the roll side (Gust of wind is taken as $1\frac{1}{2}$ times than that of wind).

Say $\theta_1 = 4^\circ$ is the angle at which she rolls steadily from here she rolls over the other side upto 10° i.e. θ_2 (thus $\theta_1 + \theta_2 = 14^\circ$ roll)

When angle of heel was 4° the heeling arm. i.e. the lever was lw_1 , and by 1.5 times at $10^\circ = \theta_2$, the lever is lw_2 i.e. $lw_2 = 1.5 lw_1$, due to Gust hitting the shipside of roll.

The residual area under the curve of statistical stability upto an angle of 40° or angle of flooding or angle of 2nd intercept (whichever is the least of the three should be equal to or greater than i.e. $a \geq b$

All ships must satisfy this condition.

- Ascertain why intact stability curve is more important than GM (i.e. area under the curve).

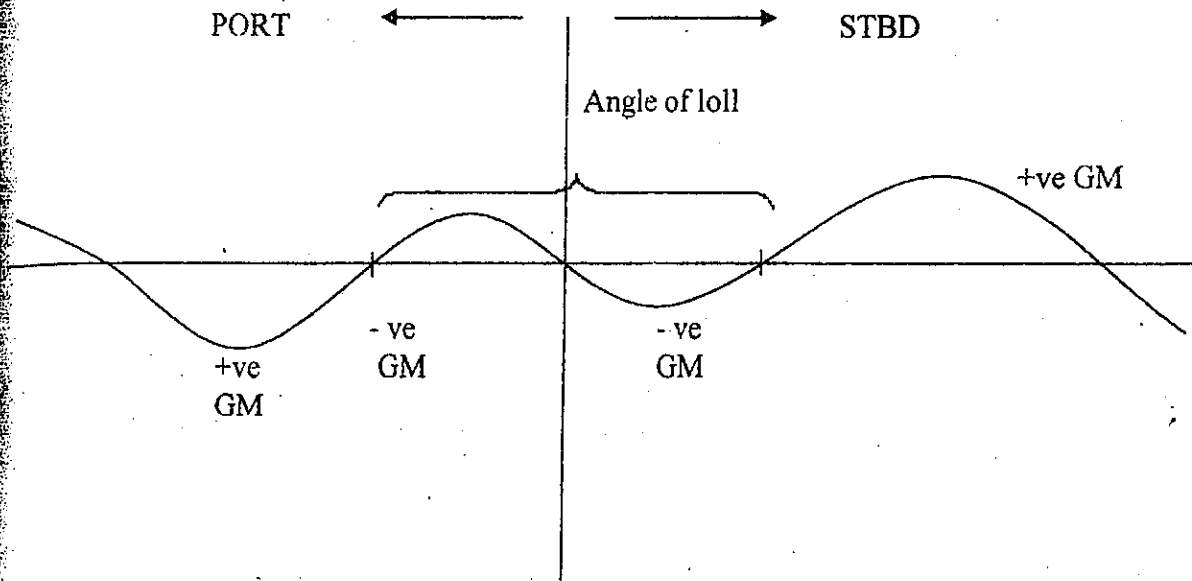
When a heeling moment is applied to a ship, she commences to heel over, for the vessel to stop the roll and then return upright two conditions have to be satisfied (1) Righting lever (GZ) should be greater than the heeling lever (2) her dynamical stability should be large enough to overcome the kinetic energy she develops when rolling.

The kinetic energy developed is $\frac{1}{2}mv^2$, where m = mass of the ship and v is the angle of velocity of the roll. The mass of the ship is extremely large therefore the kinetic energy she develops is also extremely large.

The dynamical stability at any angle of heel, is the area under the curve of statistical stability upto that angle multiplied by displacement.

Therefore the area under the curve of statistical stability upto any angle of heel is a function of a dynamical stability at that angle i.e. a measure of her potential energy at that angle. Since the dynamical stability has to be large enough to overcome the kinetic energy developed during the roll, her curve of statistical stability and the area under that curve upto various angles is a more important criteria than the GM alone in determining her stability and survival capacity in a seaway.

ANGLE OF LOLL



A vessel with an initial negative GM is unstable in the upright condition and therefore heels over as she has a capsizing lever when inclined slightly. On heeling, the centre of buoyancy moves out from the centre line till, at a particular angle of heel the centre of buoyancy and the centre of gravity, her G and M, are coincident. The angle of heel at which this occurs is called the angle of loll. In still water the vessel will remain heeled to that angle.

In vessel with a negative GM, there are no righting levers between the angle of loll on either side. The positive part of the curve on either side is also very shallow (small). Since there are no Righting levers between the angle of loll, a vessel going from angle of loll from one side to the angle of loll on the other side does so rapidly. Therefore the kinetic energy so built up is extremely large. This rolling motion will continue till her dynamical stability is large enough to overcome her large kinetic energy developed.

Due to the shallow positive statistical stability curve the area under the curve is fairly small and may not be large enough to provide sufficient dynamical stability to overcome the kinetic energy developed.

It is therefore likely that she will continue the roll beyond the angle of vanishing stability and thereafter capsize.

In a vessel with a good positive GM, statistical stability curve is quite steep at every instant of the roll, Righting levers are opposing the motion. Therefore the velocity of the roll is lesser and so the kinetic energy developed is also lesser. Due to the steep nature of her curve of statistical stability the area under the curve upto various angles is also large and therefore the dynamical stability is large enough to overcome the kinetic energy she develops.

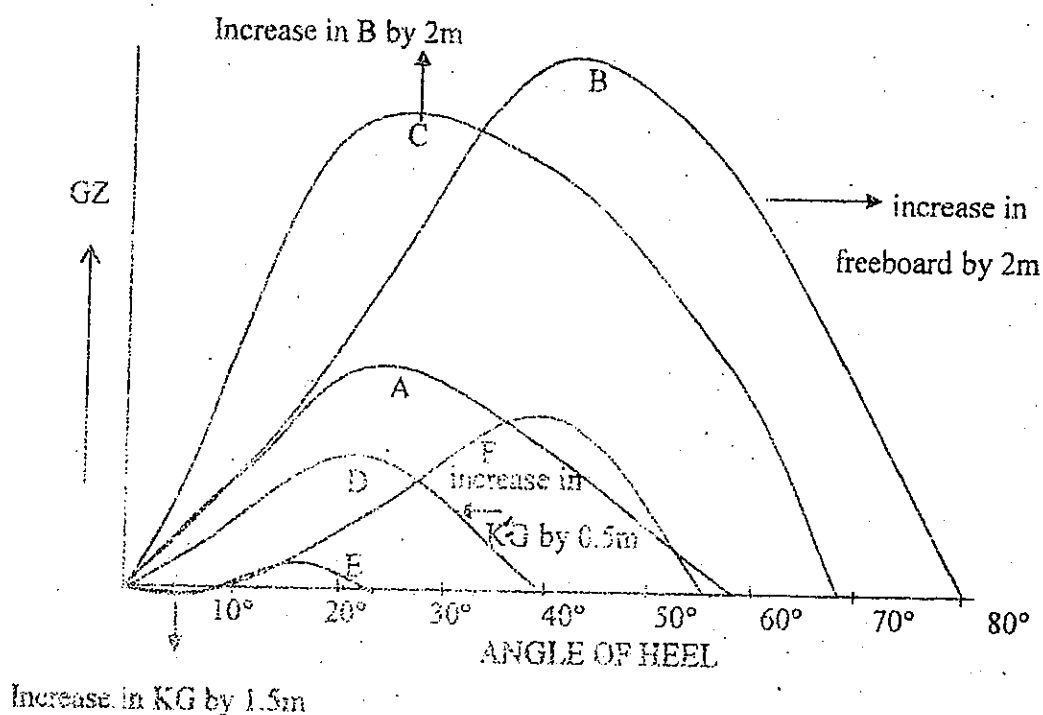
In such ships rolling to larger angles is therefore no cause of alarm.

Describe how the statical stability of a ship is governed by

a. The position of the ship's centre of gravity.

b. The form of the ship (under water volume)

- a. The position of the ship's centre of gravity depends upon the distribution of cargo and weights within the ship. The centre of gravity, in turn, affects the GM, the metacentric height, because $KM - KG = GM$. If KG changes, GM also changes. Also $GZ = GM \sin \theta$. Therefore with the change of centre of gravity, there is change in righting lever GZ which generates the statical stability curve.
- b. The form of the ship decides the under water volume of the ship, the emerged and immersed wedge of the vessel when heels. This change in emerged and immersed wedge decides the shift of the centre of buoyancy and thus the length of righting lever GZ or alternatively the position of metacentre and hence the metacentric height GM .



The curve A is for a vessel of length 150m, breadth 20m, moulded depth 12m and draft 8m. Curve B is the curve after increasing the free board of ship A (all other position remain same). The curves run together initially but B

continues to rise and thus increasing the maximum GZ and the range of stability and angle of vanishing stability.

Curve C is for the vessel where beam is increased by 2m compared to vessel A (all the particulars remaining same.) The maximum GZ is increased compared to A and thus increasing the angle of vanishing stability and range of stability.

The curve D is obtained when the center of gravity of the vessel is increased by half a meter. As can be seen there is considerable reduction in maximum GZ, angle of vanishing stability and range of stability.

When the centre of gravity of the vessel A is raised considerably by 1.5 meter and thereby making GM negative we have curve E. The negative stability makes the vessel loll to angle of about 8° but thereafter it has positive stability but the maximum GZ, angle of vanishing stability and range of stability are very small. In case the vessel E's freeboard is increased by 2m, we have the curve F. Since the vessel will have negative GM initially, the angle of loll will develop at about 8° but thereafter, due to increase in freeboard, she will have an improved stability as her maximum GZ, angle of vanishing stability and range of stability increases.

Conclusion :

- a. Increase in freeboard does not have any effect on initial stability but increases range of stability and angle of vanishing stability.
- b. Increase in beam increases initial stability but has very little effect on range of stability and angle of vanishing stability.
- c. When centre of gravity increases, both initial stability and range of stability decreases.
- d. A ship with initial negative GM will not necessarily capsize but may become stable at some small angle of heel and may have a reasonable range of stability before she will capsize if she had enough freeboard.

THE EFFECT OF BEAM ON STABILITY

increase of beam leads to an increase of initial GM and of GZ values generally.

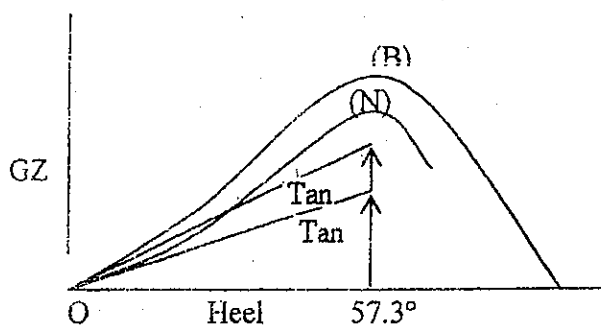
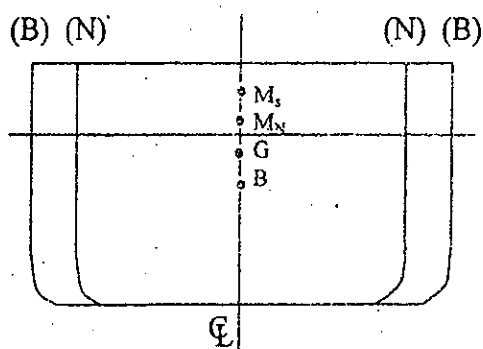
$$\text{Hence, } GM = KM - KG$$

$$KM = KB + BM$$

$$BM = \frac{I}{V} = \frac{LB^3}{12 \times L \times B \times d} = \frac{B^2}{12d} \text{ for a box shaped vessel.}$$

With the increase of Beam (draft remaining same), the B/M will increase in large amount, the KM will increase & consequently the GM will increase. Even in case of ship shaped vessel, it holds good.

The diagram below shows a narrower ship (N) and a broader ship (B). If the ships have similar underwater forms the value of KB will be the same in each. The value of BM ($= I/V$) is greater in the broader vessel. Consequently KM is greater in the broader vessel. If they are loaded similarly they will have the same KG. Hence GM is greater in the broader vessel and (B) has the better values of GZ at small angles.

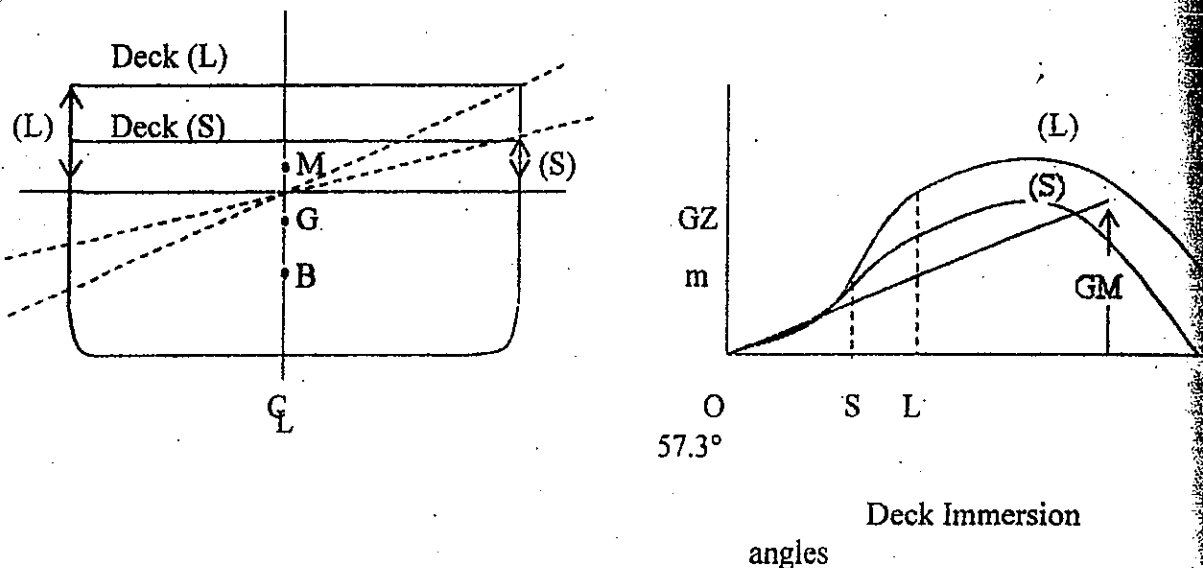


The wallsided formula, $GZ = (GM + \frac{1}{2} BM \tan^2 \theta) \sin \theta$ shows that GZ will be improved by reason of the increased GM and BM values. It is true that deck edge immersion occurs (a little) earlier in the broader ship, and the point of inflexion of the GZ curve occurs (a little) earlier but this only slightly diminishes the anticipated larger GZ's and the overall effect is, never-the-less, an increase of GZ at large angles. The two curves appear as (N) and (B) above. Curve (B) shows better values of GZ throughout, an improved range and increased dynamical stability at all stages.

THE EFFECT OF FREEBOARD ON STABILITY

Two vessels which have the same KG , the same draught but different depths, so that they have different freeboards will have the same initial stability i.e. the same GM and GZ^s at small angles but will have different values of GZ at moderate and large angles. The vessel with the larger freeboard will have the better stability overall.

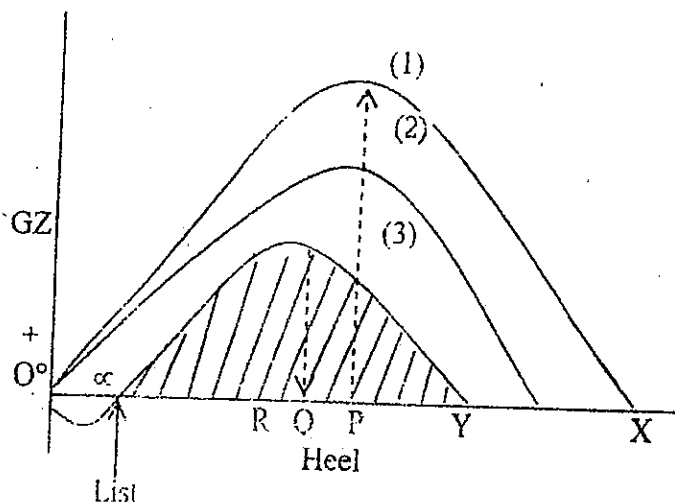
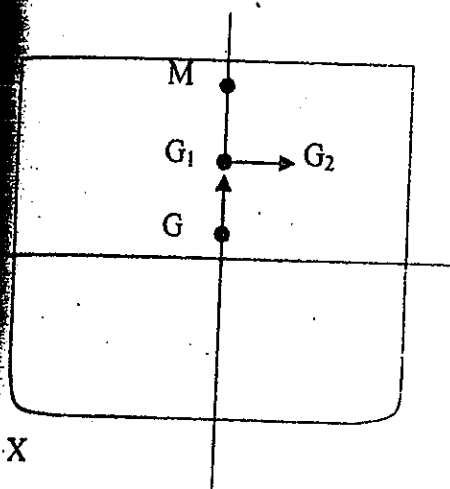
The diagram below shows two ships of the same draught and KG , but different depths. Ship (L) has a larger freeboard than ship (S).



The common underwater volume (V) and waterplane inertia (I) mean that KB and KM are identical for the two ships. Given the same KG , the ships have the same GM . The circumstances are identical in the two ships until the deck edge is immersed in ship (S), at which stage the GZ curve for ship (S) has a point of inflexion. The curve of ship (L) will have a later point of inflexion, a larger maximum GZ (at a larger angle of heel), and an improved range of stability. The dynamical stability for the ship (L) with a greater freeboard is identical at the smaller angles (where the GZ curve is common) but better at all other angles. (The benefit of larger freeboard becomes increasingly more important in ships which have little or no (or negative) initial stability.)

THE EFFECT OF A MOVEMENT OF WEIGHT, BOTH VERTICALLY (UP) AND TRANSVERSELY, ON STABILITY

A movement of weight vertically upwards causes a reduction of all GZ values. The reduction is $(\text{rise of } G) \sin \theta$ or $GG_1 \sin \theta$. This reduction is a maximum when θ is 90° . Curves (1) and (2) in the diagram below show representative curves for the two positions of the centre of gravity G and G_1 .



If the vessel also suffers an athwartships shift of G (from G_1 to G_2 in diagram) there is a further overall loss of GZ of amount $G_1G_2 \cos \theta$. This is a maximum when θ is 0° and nil when $\theta = 90^\circ$. The effect of this shift of G on curve (2) is shown by curve (3).

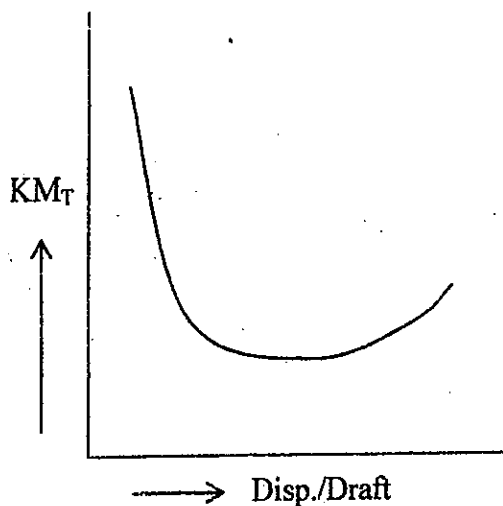
Comparison of curves (1) and (3) show that the two movements of G have caused :

- i. A reduction of ALL the GZ values.
- ii. A list (α°).
- iii. A reduction of the angle of vanishing stability (from X to Y).
- iv. A reduction of the range of stability.
- v. A reduction of the angle of maximum stability (from P to Q).
- vi. A reduction of GM (evident from the rise of G).
- vii. A reduction of dynamical stability at all angles. The dynamical stability for curve (3) is negative from 0° to α° (the list). The value of dynamical stability for condition (3) at its angle of vanishing stability Y (indicated by the area shown hatched) would appear to be about equal in value to that of condition (1) at R° .

❖ Explain how do the values of following parameters changes with change in vessel's draughts :

1. KM_T
2. LCB
3. MCTC
4. LCF
5. TPC

1. KM_T :



KM is the distance between the keel and the initial metacentric height which is a function of KB i.e. distance from keel to buoyance and BM i.e. buoyance to metacentre i.e.

$$KM = KB + BM$$

Where $BM = I/V$ where

I = Moment of inertia and

V = u/w volume of the vessel.

KB is always slightly greater than half the draft of the ship shape vessel.

Whereas BM is the function of two variables i.e.

I = Moment of inertia and V = u/w volume.

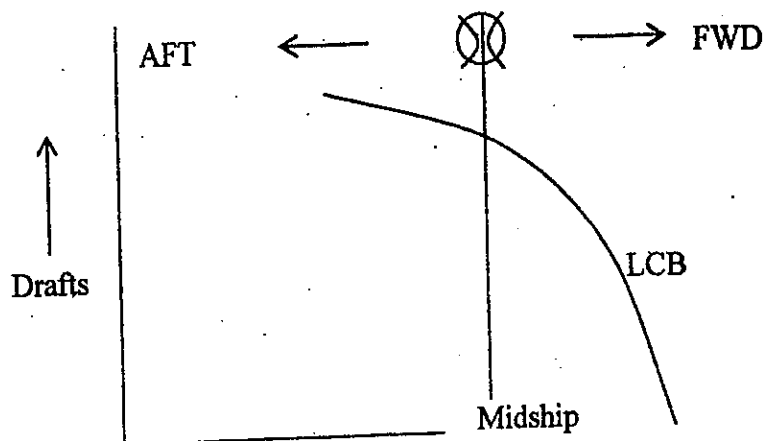
As the draft of the vessel increases i.e. as the displacement increases the u/w volume also increases.

So, when the vessel is at less draft the KM is very high i.e. less displacement more KM , as the draft increases the u/w volume increases and hence the BM decreases. This is a rapid decrease in BM and hence the graph is falling down, the KB does not increases appreciably, but at one stage when draft increases BM reduces rapidly and hence KM also reduces, but KB is slowly increasing and the two are just balancing each other and hence KM is almost unchanged. At still

large draft, KB increases slowly still and BM is steady and hence KM increases slowly at greater drafts.

2. LCB : Length of Centriod of Buoyance from the after perpendicular.

Centroid of Buoyance is the centroid of the u/w volume.



Initially when the draft is less, the u/w volume is less and hence the C.O.B. is fwd of the midship and so the graph is fwd of the midship. As the draft keeps on increasing, the u/w volume of the vessel also increases and hence the C.O.B. shifts itself to the after side and hence in the graph the curve also shifts aft of midship.

3. LCF : is the centre of floatation of the u/w plane area, measured from the after perpendicular.

The graph is similar to LCB. When the drafts are less LCF is fwd of midship

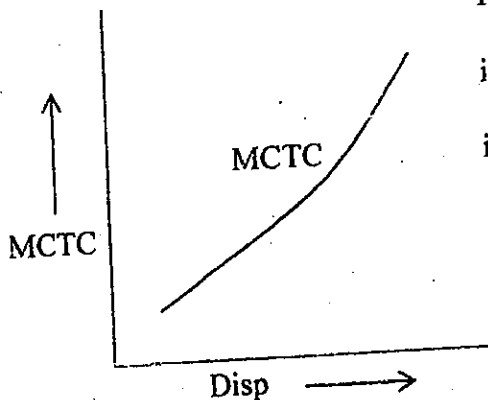
As the draft increases the LCF shifts aft. At small draft the vessel is more

submerged fwd than aft and hence the LCF is Fwd. As the draft increases the after part of the vessel is more full aft and hence the LCF shifts aft.

4. MCTC :

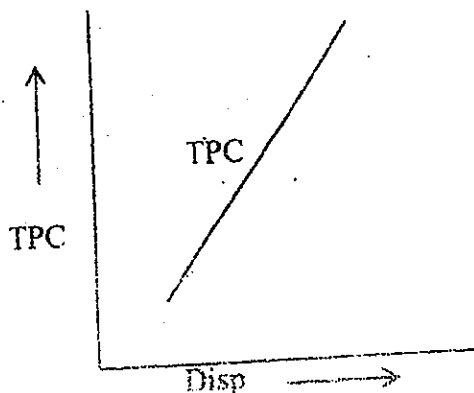
$$\text{MCTC} = \frac{W \times GM_L}{100 \times L}$$

Where W is the u/w displacement and is directly proportional to the draft, change in GM_L is a small quantity and thus GM_L is more of a steady value, and length remains constant.



Hence MCTC is directly proportional to W
i.e. as the draft increases MCTC also
increases and hence the increasing curve.

5. TPC : Tonnes per centimeter immersion = $\frac{A}{100} \times \delta$



TPC is directly proportional
to the area A and hence when
draft increases the u/w area
also increases i.e. u/w vol and
hence W also increases and
hence the curve.

STABILITY INFORMATION TO BE PROVIDED

The information relating to the stability of the vessel to be provided to the master may be briefly summarized as follows:

1. General Particulars of the ship, including dimensions tonnages, summer drafts displacement, dead weight etc.
2. Instruction on the use of the booklet.
3. General arrangement plans showing watertight compartments, closures, vent, down flooding angles, permanent ballast if any, allowable deck loadings and free board diagrams.
4. Hydrostatic curves or tables and cross curves of stability on a free trimming basis for a range of displacements between light and load draft and for a range of trim anticipated in normal operating conditions.
5. Capacity plan or tables showing capacities and centers of gravity (Both longitudinally and vertically) for each cargo space.
6. Tank sounding tables showing capacities, centre of gravity (both longitudinally and vertically) and free surface data for each tank.
7. Information on loading restrictions such as maximum KG or minimum GM value or that can be used to determine compliance with the applicable stability criteria.
8. Standard operating conditions and procedures for developing other essential loading and trim using the information provided in stability booklet.
9. Information on the use of the stability booklet and the importance of maintaining the stability of the vessel.

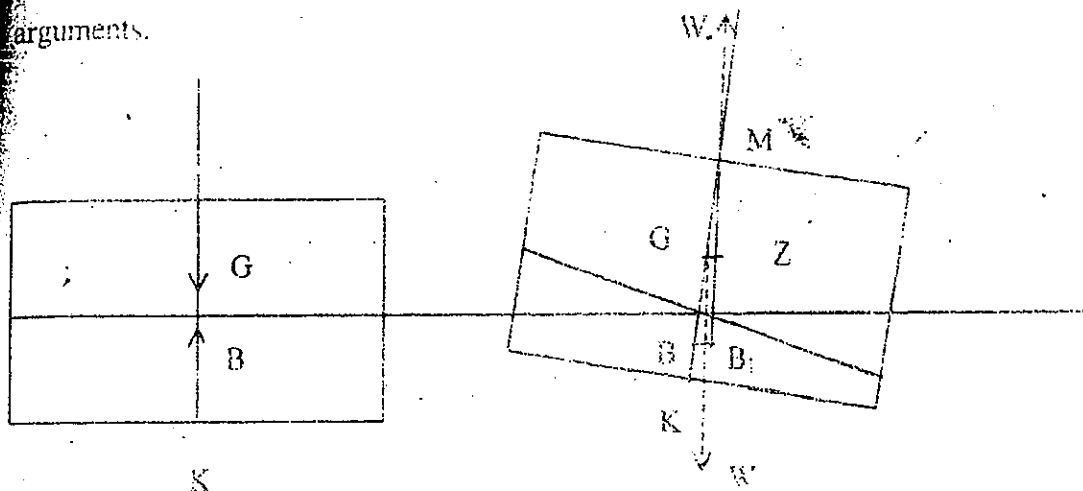
10. General Precautions for preventing unintentional flooding.
11. Information concerning the use of any special cross - flooding fittings, if provided with descriptions of damage which may be required cross flooding.
12. Any other guidance for the safe operation of the ship under normal and emergency conditions.
13. A table of content and index for the booklet.
14. Inclining test report for the ship. OR where the stability data is based on a sister ship, the inclining test report of the sister ship along with the Light Ship measurement report for the ship in question. OR where the light ship particulars are determined by other methods than the inclining of the ship or her sister, a summary of the method used to determine those particulars.
15. Recommendation for the determination of the ship's stability by means of an in-service inclining test.

The format of the booklet and the information included will vary depending on the type of ship and her operation.

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A well loaded ship may roll 20° to either side without cause for alarm. However, the same ship falling over from an angle of loll of 10° to the angle of loll on the opposite side is cause for great concern.

Justify the above statement, supporting your answer with well reasoned arguments.



The position of M is indicated by its height above the keel in metres (KM). KM increases as the angle of heel increases, until it reaches a maximum value at some large angle of heel. Thereafter it decreases as angle of heel increases. KM is calculated by adding KB and BM, the initial KM is therefore, a function of the draft of the vessel. Since the vessel is well loaded in the present case, her KM is going to be quite large, as compared to her GM. GM is the vertical distance between the centre of gravity and the metacentre. GM is termed positive when G is below M i.e. when KG is less than KM i.e. a vessel is considered to be stable when her GM is positive. A vessel with a flat deck also may be stable.

A vessel at angle of loll will keep rolling from one side to the other when subjected with external factors (swell / wind) and momentum of roll she may reverse. It is because there is not much of righting moment at small angle of loll. However a loaded ship with positive GM (without angle of loll) when heeling 20° will still have large restoring moment to bring her back to upright.

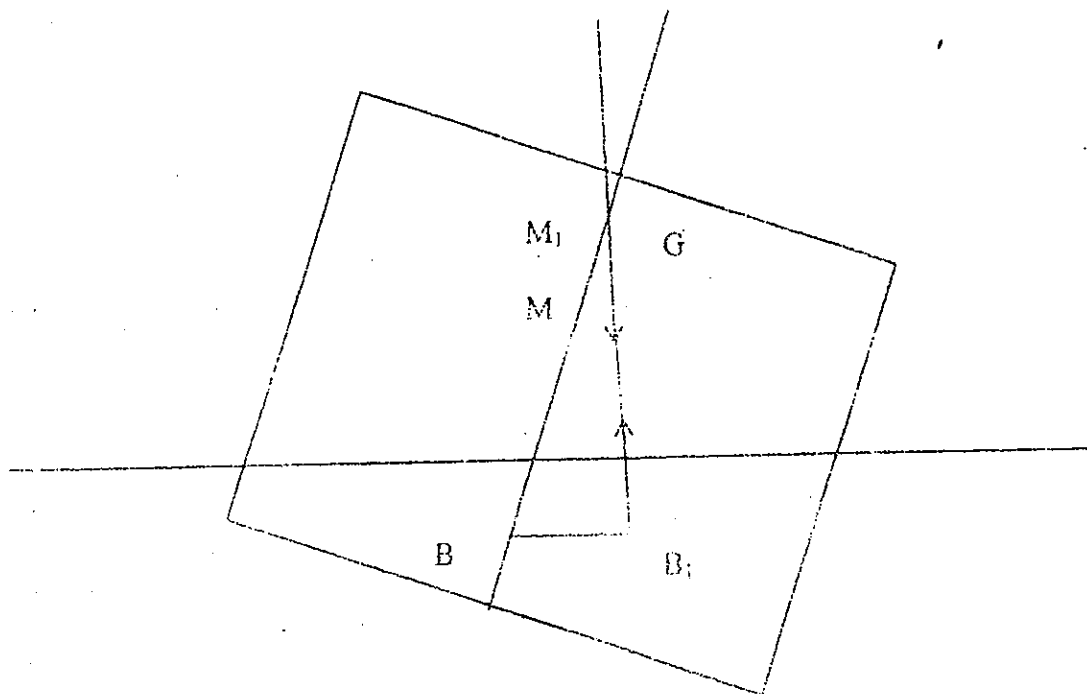
When a vessel is heeled to 20° to either side, the righting moment is still large enough to bring her back to upright.

separated from the force of gravity, acting vertically downwards through the COG by a horizontal distance GZ, called the righting lever. GZ normally increases as angle of heel increases until it reaches a maximum value at some large angle of heel thereafter, GZ decreases as angle of heel increases.

The forces of gravity and buoyancy, being equal and opposite, form a couple which tends to return the vessel to upright. The moment of this couple is a measure of the tendency of the vessel to return to upright and is called the righting moment or Moment of statical stability.

Thus even though the vessel rolls 20° , the righting moment will upright the vessel as long as the GM is less and KM is large and hence there is no cause of concern or alarm.

For a vessel to be at an angle of loll, her initial GM to be negative. (Refer to chapter XXVIII), for behaviour of a vessel with zero GM).



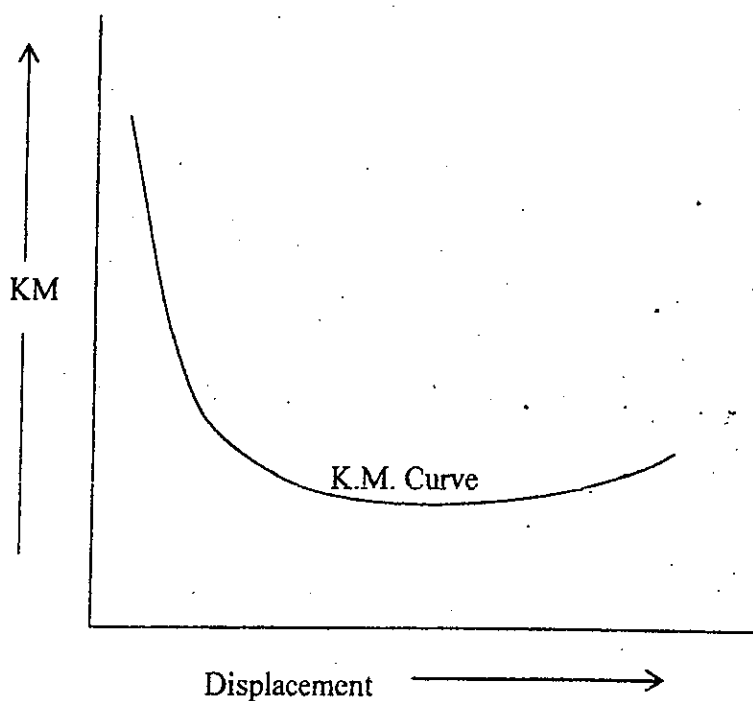
In this situation, KM increases as angle of heel increases until it reaches a maximum value at some large angle of heel, such that at some angle of heel, KM increases sufficiently to equal to KG and hence GM is zero, the B shifted to B_2 is directly under G, opposing each other in a vertical direction, thus forming no righting lever and hence no

ighting moment. The vessel thus has no tendency to continue heeling further or to return to her original condition. The angle at which this happens is called the angle of loll.

If any opening goes underwater, at this stage, or the cargo shifts, progressive flooding would take place and the vessel would capsize.

Thus, the vessel at an angle of loll, falling from one side to other is a great cause of concern.

- ❖ Sketch a normal curve of KM against a scale of displacement for a ship shaped vessel. Explain why the curve is shaped as you have sketched it.



KM is the distance between the keel and the initial point of metacentre. It is a function of KB i.e. distance from keel to the centre of buoyancy and BM i.e. from Buoyancy to Metacentre.

$$\text{i.e. } KM = KB + BM$$

where KB is half the draft of the box ship, for ship shaped vessel only slightly more than half.

i.e. $KB = \frac{1}{2}$ draft.

$BM = I/V$, where I = Moment of inertia i.e. $I = LB^3/12$ and

$V = u/w$ volume of the vessel. i.e. $BM = LB^3/12V$.

Thus BM is directly proportional to the cube of the breadth of the vessel and inversely proportional to the underwater volume of the vessel.

At lesser displacement the underwater volume is small and hence the KM is large, but as the displacement increases i.e. as the u/w volume increases which is at a very fast rate compared to the values of draft (KB) and the breadth ($LB^3/12$), the KM reduces rapidly until such stage when any further increase in the under water volume arrests the fall of KM. KM is then steady which is giving the smooth curve.

The change in KB during this stage is quite slow as compared to BM, but further as the displacement increases, the change in BM is quite slow as compared to KB, as KB is always gradually rising and then the curve after coming down recurves upward very slowly.

Thus the curve is shaped such.

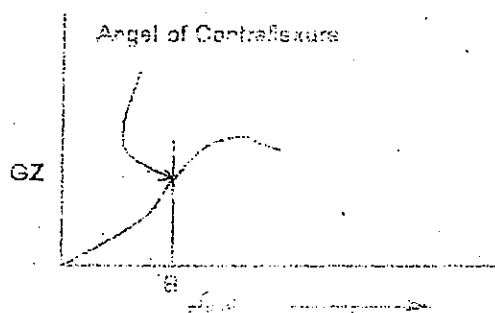
❖ State very briefly what you understand by the following :

1. Angle of loll
2. Angle of flooding
3. Angle of contra flexure
4. Dynamical stability
5. Grain heeling moment
6. Volumetric heeling moment.

1. ANGLE OF LOLL : The angle of inclination at which KM increases sufficiently to be equal to KG. i.e. the vertical distance between the COG and the metacentre is zero. This angle of heel at which $GM = \text{zero}$ is termed as angle of loll. Since G and M are coincident, no righting lever and hence no righting moment is formed

2. ANGLE OF FLOODING : The angle of inclination at which the openings on the deck cannot be closed water tight is termed as angle of flooding.

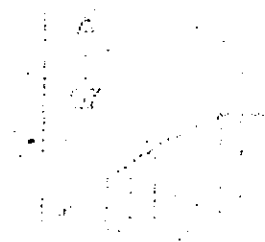
3. ANGLE OF CONTRAFLEXURE : is the angle of heel at which the rate of increase of GZ with heel commences to decrease. i.e. the point on curve at which the curve changes its shape from concave up to concave down. The angle of contra flexure occurs at about the angle of heel at which the deck edge immerses



4. DYNAMICAL STABILITY : the work done at any angle of heel is the work done in inclining the vessel up to that angle

$$\text{Dynamical stability} = \text{Area (M cos } \theta \text{ or } GZ \text{ curve) (area)} \times \text{Displacement}$$

Is the product of the displacement of the vessel and the area under the curve of statical stability up to that angle in the upright position.



5. GRAIN HEELING MOMENTS : A transverse shift of grain generates a grain heeling moment which is the product of the weight of the shifted grain multiplied by the horizontal distance between its initial and final cog's. Grain heeling moments are expressed in tonne meter.

6. VOLUMETRIC HEELING MOMENT : The magnitude of the grain heeling moment of cargo compartment varies directly with the unit weight and inversely with the stowage factor of grain loaded. Since there is wide variation in the weights of different types of grains, it is impractical to list heeling moments for various grains in the vessel's grain stability booklet. For this reason, it is common practice to calculate and tabulate the moment of a compartment in terms of volume times distance. This moment is designated a volumetric heeling moment (VHM) and is expressed m^4 ($m^3 \times m$).

Before departure from port, the grain in a ship has been loaded symmetrically and trimmed level. So the centre of gravity of the grain mass is on the center line and the ship is upright. In spite of the precautions which have been taken, the grain will shift. If this occurs the center of gravity of the grain mass will move off the centerline of the ship and the ship will list.

❖ Q. Discuss the differences as regards the stability of a vessel drydocking with no cargo on board as against the same vessel dry docking in the loaded condition, at the same trim.

Condition 1.

Stability of a vessel dry docking with no cargo on board.

While docking, 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. This results in

- a) Decrease in the hydrostatic part 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 ship suffers steadily increasing virtual loss of GM

The virtual loss of GM at any stage during the process can be calculated by the formula

$$\Delta GM = \frac{P \times KM}{W}$$

It is essential that the ship is stable at all stages from the moment the stern takes the block until the entire keel rest on the block. To ensure that she is stable at all stages of docking, she should have a sufficient large GM, which is only possible when she is light i.e. W is less. (because GM and W are inversely proportional) until the bow takes to the blocks the vessel should have sufficient residual virtual GM, to keep her stable and this can be made possible only when she is light

Condition 2.

Stability of the vessel dry docking in the loaded condition.

When the vessel entering the dock in the loaded condition, her GM is just sufficient to keep her statically stable i.e. the W is more GM is obviously less. When she touches the stern to the block, the weight is transferred to the stern frame and partly balanced by water buoyancy. As the water level drops the weight P keeps on increasing and the virtual GM gradually decreases. There is barely any GM to keep the vessel stable until she takes the block completely. At this stage, when only one end of the vessel is resting on the block and the other end is still in the water, she will heel over, damaging her bottom and keel.

Thus the condition of the vessel in the loaded condition with the trim of light condition is very critical. The weight on the vessel is so much that there is hardly any residual virtual GM to keep her stable.

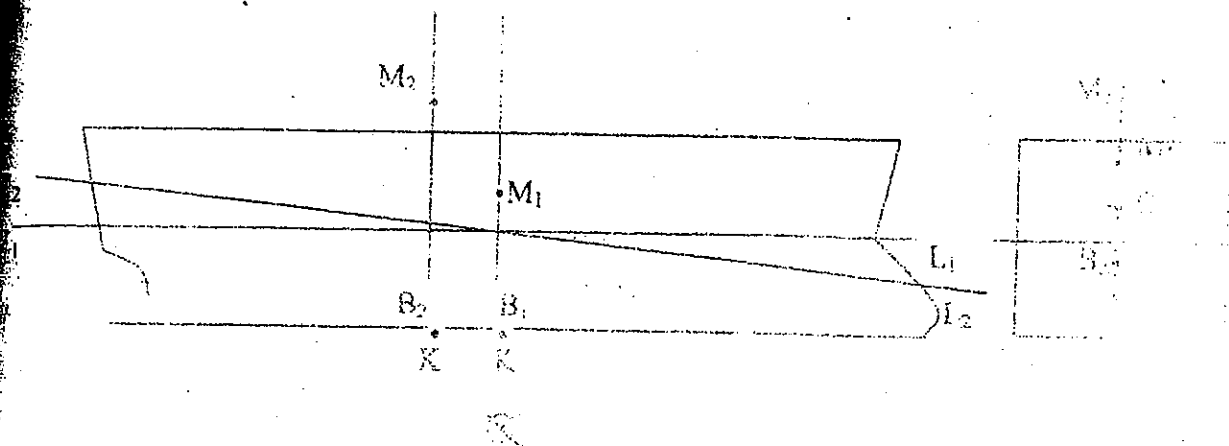
DRY DOCKING A LOADED SHIP :

If a ship sustains propeller, rudder or bottom, side or other damage below the waterline, dry-docking the ship in it's loaded condition might be considered. In such a situation the following points should be noted:

1. The dry dock manager must be provided with plans showing clearly the position of bulkheads and other key structural features, rise of floor (if any), plug position for all tanks and cargo plans showing the weights in each space hold / tanks.
2. With the aid of the information provided above, extra support for the ship will be planned which may incorporate bilge beds built up to the level of the bottom plating.
3. The ship should be docked as close to even keel as possible (or trimmed equivalent to the declivity of the dock) to reduce the thrust at the aft keel block to a minimum during the critical point.
4. Immediately after the dock is emptied inspection should be undertaken to identify any hull deformation and additional side & bilge shores may be added.
5. The dock should be flooded on completion of work to float the ship at the earliest opportunity.
6. In the event of side shell damage, it may only be necessary to partly empty the dock once the ship is on the blocks fore and aft. Once the site of the damage is exposed, the remaining water may be left in the dock. Thus the remaining volume of displacement will assist in providing support to the ship and will reduce the effects of sagging or otherwise that might have arisen had the dry dock been completely emptied.
7. In any event, serious considerations may be given to the risk of structural damage which might occur while docking the ship in the loaded condition. Consequently, the discharge of cargo might be the most appropriate action prior to dry-docking.
8. The double bottoms to be deballasted to withstand the weight of the cargo.

EFFECT ON STABILITY OF A TRIM BY THE STERN

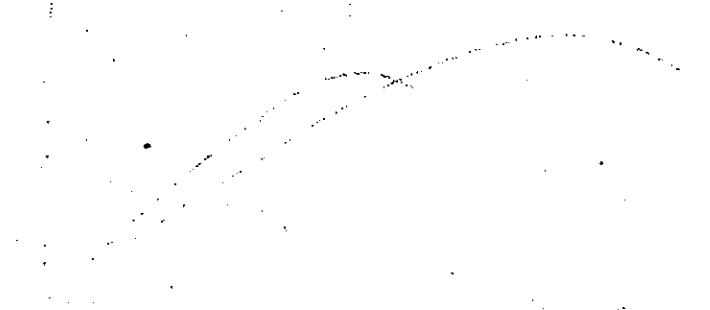
Other things equal, a ship trimmed by the stern in calm water can be expected to possess a greater GM than when on an even keel. This is because KM is normally greater when trimmed by the stern. This greater value of KM arises in part from a greater KB and in part from a greater BM.



For W.L.B. KB is higher because of the shape of the underwater volume and BM is higher because I is greater for the sloped waterline. Consequently KM must be greater, and for a given KC, the values of $\frac{GM}{L}$ and of $\frac{GM}{L}$ at small angles are correspondingly greater.

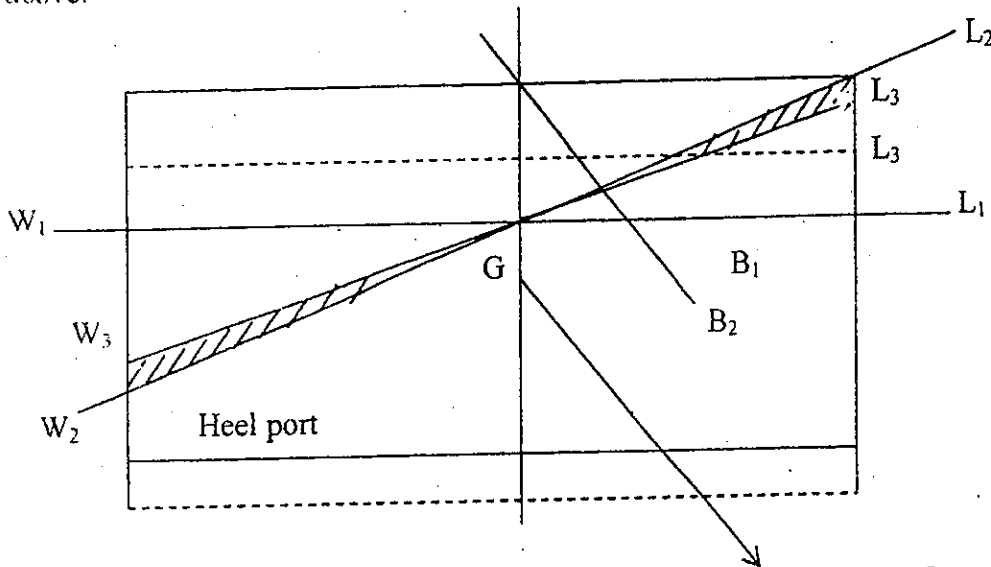
The factor of stability (infinity of small angles) is however more than eliminated by the adverse effect of the trim on the initial stability. When a ship is trimmed by the stern, the KEEL is forced to immerse the deck edge, the immersion occurs simultaneously in a certain length, thus making there is no shear and the section will not change. When the center of the deck is at the same level as the center of the keel, the ship will not change.

(GZ)



Heel

If the vessel has an initial trim by the stern and is then heeled, the after deck is immersed before the fore deck. The hull is providing more buoyancy forward than aft and the vessel is caused to trim by the stern. This trimming effect leads to a loss of buoyancy forward on the low side as the bow lifts and a gain of buoyancy aft on the high side as the stern drops. See diagram (2). Consequently the centre of buoyancy B_2 will not be so far to the low side as it was for the ship on an even keel and the result is a reduction of GZ values, as shown by curve (2) of the diagram above.



A similar effect may arise in a ship which has sheer forward but not aft, or more forward than aft, or in a ship which has a partial superstructure, even if it is on an even keel initially.

The GZ curves derived by a builder are normally for the even keel condition and assume 'fixed' trim i.e. any change of trim as the ship heels is disregarded. The curves will be different for a ship with an initial trim. If the effect of heel on the trim is taken into account – what is termed 'free' trim – the curves will be different again. A ship with sheer which is not symmetrical around amidships, or having intact superstructures which are not symmetrical around amidships can be expected to change trim as it heels (after the deck edge becomes immersed at some point). If this change of trim puts the vessel into a worse trim, the overall effect of the 'free trim' is adverse.

UNRELIABILITY IN PRACTICE OF STATICAL STABILITY DATA

Stability of a ship at sea will invariably be different from that shown in the ships stability data. The calculation of KM, KG and curves of stability (GZ) assume static conditions, with the ship in a hydrostatic environment, in a stationary attitude in calm water. It ignores the possibility of a shift of solid cargo or of the admission of water, (except in special cases) and all calculations are based on 'design' parameters, other than those quantities which are established by the inclining experiment.

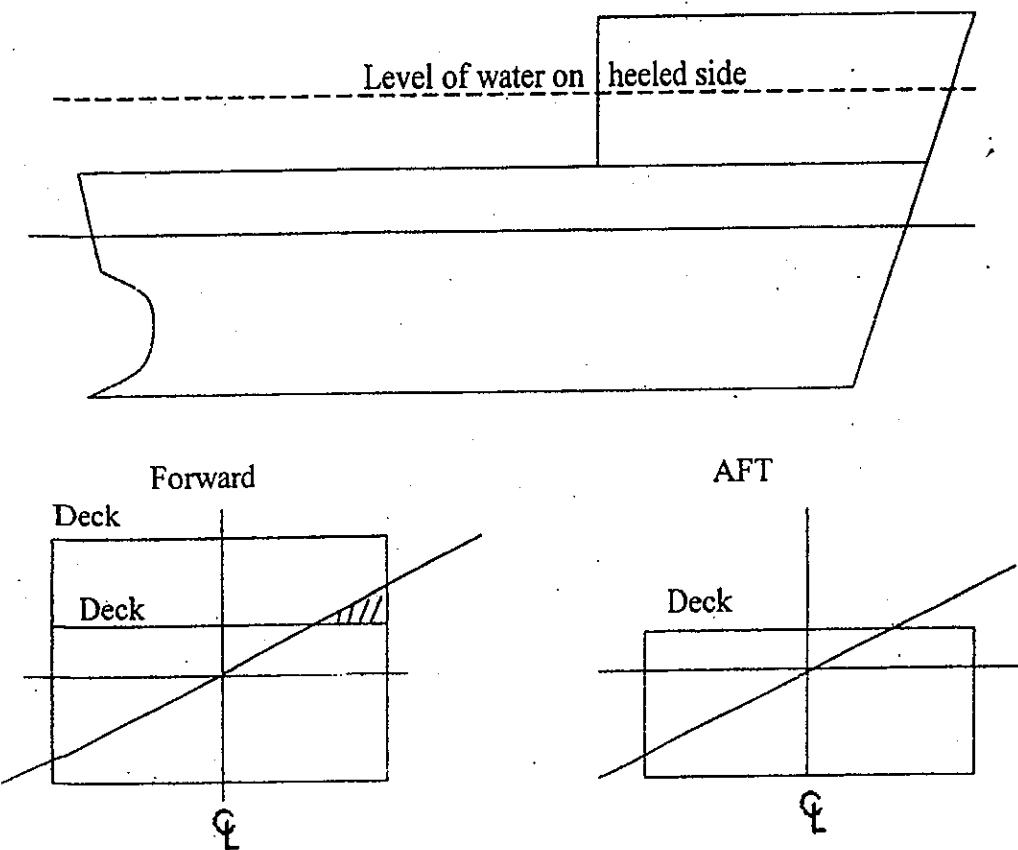
Service the light KG and displacement will alter with age by reason of changes of equipment, fittings, paint coatings, corrosion, accumulation of spares and the like. Furthermore the ship as built need not be exactly to design (drawing) dimensions, and data extracted from drawings may be in error.

Of greater importance is the fact that the ship will be subject to forces and moments not taken into account in 'static' calculations. Ship stability is being seen increasingly as a dynamic problem. The dynamic forces, either individually or cumulatively can be substantial and have been the cause of loss or near loss of ships which have had 'static' stability in excess of IMO, SOLAS or other statutory requirements.

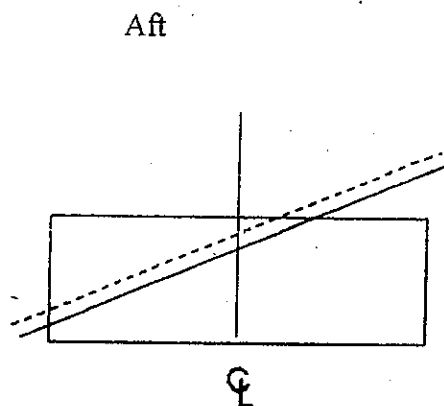
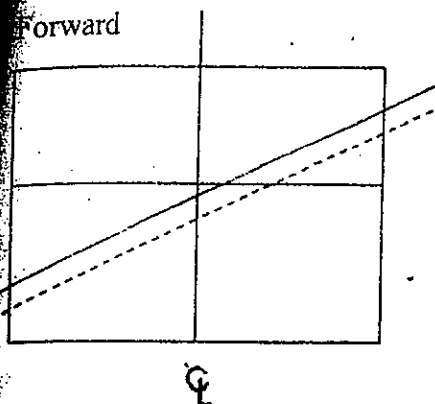
Mechanisms which will reduce stability and which can lead to capsize in waves of any heading to the vessel, - either in isolation or in combination - arise because of the ships motion and its (6) degrees of freedom, because water is disturbed by the ship's motion or by wind, and because motions of the water and ship give rise to hydrodynamic pressures which are different to hydrostatic pressures. The mechanisms include :

- (i) Change of stability by heaving or pitching - these motions cause changes in the magnitude and / or line of action of buoyancy forces.
- (ii) The effect of steady wind moments or asymmetric icing (for example). These create a steady heel and reduce the ships ability to cope with isolated sudden movements eg wind gusts, individual exceptional waves or the impact of a breaking wave.
- (iii) The effect of free trim i.e. the effect of the ship changing its trim in response to heeling to an angle such that the fore and aft distribution of buoyancy changes. In the normal 'static' investigation the ship is assumed to maintain the initial upright trim even when heeled - this is normally even keel. However, if the weather deck has sheer, or isolated

superstructures or deckhouses, buoyancy will be experienced in way of this element while water is coming on deck elsewhere. If the sheer/deckhouse/superstructure buoyancy is forward the ship will trim by the stern and so cause more water to come on deck aft than the 'fixed trim' assumption would indicate. Sinkage at the stern has the effect of giving a centre of buoyancy closer to the centreline than would otherwise be the case and this leads to a reduction of righting lever and of righting moment. The circumstances are illustrated for a vessel with a large forward superstructure :



The sketches above show the position of a waterline for the ship in the heeled condition at the original ('fixed') trim. The centre of buoyancy would be determined in relation to the volume of displacement shown below this waterline. However the 'pocket' of local buoyancy above the main deck forward (shown \\\\\\\\\\\\\) will trim the vessel by the stern, as shown by the broken line in the following sketches :

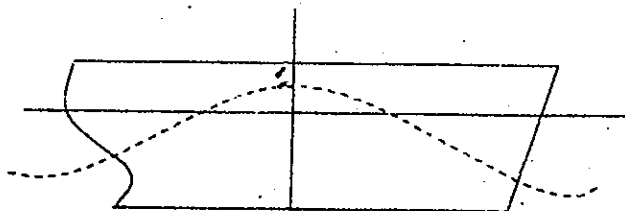


The vessel will lose buoyancy all across its width forward but the gain of buoyancy aft is mostly on the 'high' side (more water comes on deck on the low side aft). This means that in the 'free trim' condition the centre of buoyancy will be nearer the centerline and the righting lever is less than for the fixed trim. The loss of stability can be considerable and progressive. It is something which can apply to any type or size of vessel but is of greatest importance in small vessels with large superstructures which may in addition, be more prone to various other adverse effects on stability and for these reasons special instructions have been issued for supply vessels.

Pure stability loss on a wave crest. (Either in beam or longitudinal waves)

Stability is reduced when the ship is on a wave crest and increased when in a trough.

If an 'end-on' wave, equal in length to the ship, has its crest amidships (where wall-sided) and troughs at the ends (where fine) there will be a reduction of waterplane area compared with the calm water level. This gives a reduction in BM and loss of GM. (Because of end shapes, a drop of end waterlines will cause a lessened outward movement of B and GZ can be seen to be less for this reason).



The above diagrams show that the crest amidships does not affect the amount of buoyancy transferred across at amidships, but it is reduced in amount at the ends. A reduced movement of B implies a reduced value of BM. When the trough is amidships the opposite is true.

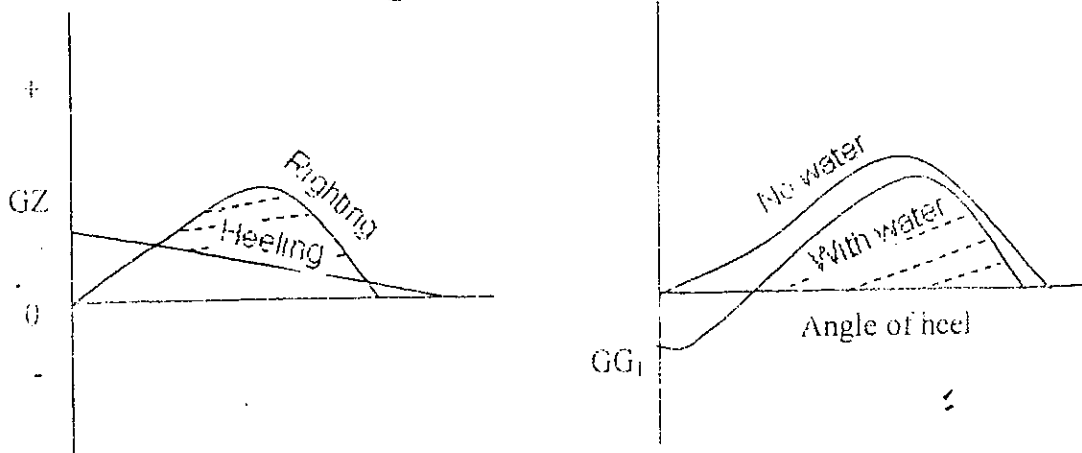
Apart from this change of BM/GM/GZ, when the ship is 'on' the crest there is a reduced buoyancy force because the pressure in the crest is less than hydrostatic (Smith correction). This causes a further reduction in stability.

When the ship is beam on to waves the crest / trough influence on the position of B is nil or insignificant but the loss of buoyancy (force) in the crest applies throughout the vessels length. There is a significant loss of stability due to this cause alone.

Parametric Resonance i.e. the increase of roll (or apparent loss of stability) due to the periodic passage of regular waves.

Dynamic movement of water on deck. This could at times be out of phase with the ships roll and then be acting like a passive (flume) stabilizing tank, (i.e. favourably) but must necessarily be assumed to be detrimental, moving in phase with ship and having the effect of reducing GZ by an athwartships movement of G (which is the true effect of a free surface). At the limit of its travel,

$$\text{Loss of GZ} = GG_1 \cos \theta = \left[\frac{\text{Wt of water} \times \text{Dist off } G}{\text{Displacement}} \right] \times \cos \theta$$



The residual stability is shown in hatched line.

The maximum static effect of the water on the GZ curve may be illustrated in either of the ways shown. Its real effect will be greater by reason of its momentum when surging across the deck.

CHAPTER XIV

BILGING

In this chapter the effect on draft and stability of flooding will be considered. The work will be restricted to simple box shapes and is intended to give an indication of the principles involved rather than a full description of the process of determining floodable length and the production of flooding curves.

OBJECTIVES

1. To determine the draft and stability condition of a box shape after a symmetrical midship compartment is bilged.
2. To determine the permeability of a compartment containing cargo.
3. To determine the list of a box vessel when a midship side compartment is bilged.
4. To determine the trim of a box vessel when an end compartment is bilged.
5. Description of the use of flooding curves.

FLOODING AND STABILITY

When a compartment is laid open to the sea and flooded it is said to be bilged. There are two possible ways of viewing the flood water. Firstly the water can be regarded as an addition to the displacement of the vessel. This approach has several disadvantages such as the difficulty in assessing the amount of water in the compartment, the need to take into account the change in KG and the effects of the free surface of the added water.

The second approach is to consider the bilged compartment as having been removed from the vessel so that it no longer contributes to the buoyancy of the vessel. This approach has several advantages, i.e. the displacement of the vessel does not change nor does the position of the centre of gravity, there is no need to consider free surface effects. The lost buoyancy, or constant displacement approach also lends to a very simple relationship between the condition of the vessel before and after bilging.

The stability of the vessel will be affected because the position of the centre of buoyancy will move and the inertia of the waterplane will be altered as a result of the changes in area of the waterplane.

The general relationship that:

$$KM = KB + BM = KB + \frac{I}{\nabla}$$

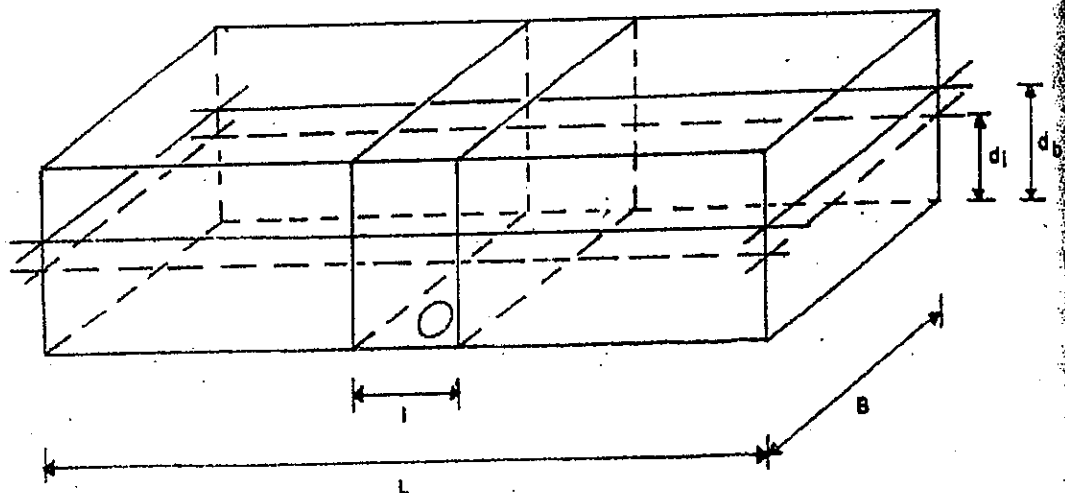


Figure 10.1 Bilging of midship compartment

holds good for the bilged condition. However, it is not possible to produce a general relationship for KM and each case must be examined individually, bearing in mind that the underwater volume ∇ remains constant, when compared with the intact condition.

Suppose a box shaped vessel is of length 'L' meters and breadth 'b' meter floating at a even keel draft of 'd' meters. There is a midship compartment of length 'l' meter which is extending from side to side and gets bilged. Because the vessel has lost buoyancy and displacement is considered constant, she will immerse in the water say by 'x' meter.

$$\text{So the lost buoyancy} = l \times b \times d$$

$$\text{Gained Buoyancy} = (L - l) b \times x$$

$$\text{Since lost buoyancy} = \text{Gained buoyancy}$$

$$l \times b \times d = (L - l) b \times x = Lbx - lbx = x(Lb - lb)$$

$$\therefore x = \frac{l \times b \times d}{Lb - lb} = \frac{\text{Lost buoyancy}}{\text{Initial water plane area} - \text{Lost water plane area}}$$

$$\text{Or sinkage} = \frac{\text{Lost buoyancy}}{\text{Intact water plane area}}$$

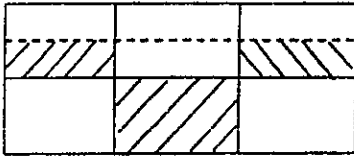
Flooding Curves :

Some ships are provided with flooding curves. The primary use of these curves is for design. For operational purpose these flooding curves can be used for finding out the state of the damaged ship given amount of damage. It can be seen whether ship will be safe or will founder after collision / agrounding.

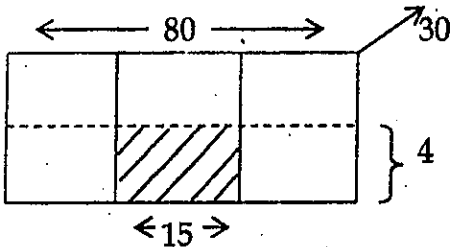
The length of the ship is placed as axis. The ordinates of the curve are the length of the vessel which if flooded could result in the vessel sinking. There are two criteria in general use:

1. Sinking to the margin line : A margin line is 76mm below the deck line on the ship side at the level of the bulkhead deck. This criteria is used for passenger vessels.
2. Sinking to the trim which would result in progressive flooding.

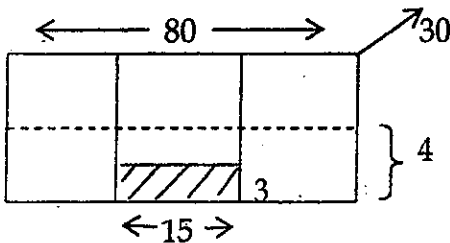
BILGING



$$\text{Mean Sinkage } (\delta) = \frac{\text{Vol. of lost buoyancy}}{\text{Intact water plane area}}$$

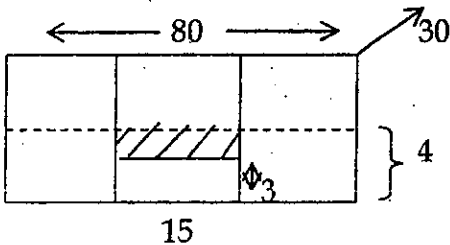


$$\delta = \frac{15 \times 30 \times 4}{65 \times 30} = 0.923 \text{ m}$$



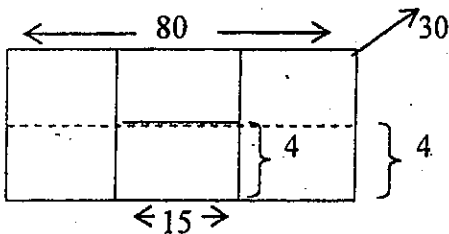
With W/T flat @ 3 mtr & getting bilged below it

$$\delta = \frac{15 \times 30 \times 3}{80 \times 30} = 0.5625 \text{ m}$$



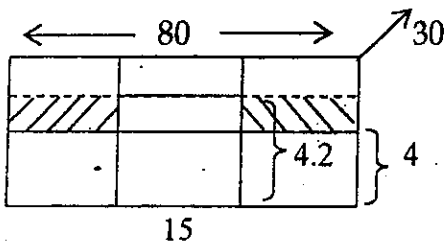
With W/T flat @ 3 mtr & getting bilged above it

$$\delta = \frac{15 \times 30 \times 1}{65 \times 30} = 0.2307 \text{ m}$$



Water tight flat at 4m.

$$\delta = \frac{15 \times 30 \times 4}{80 \times 30} = 0.750 \text{ m}$$

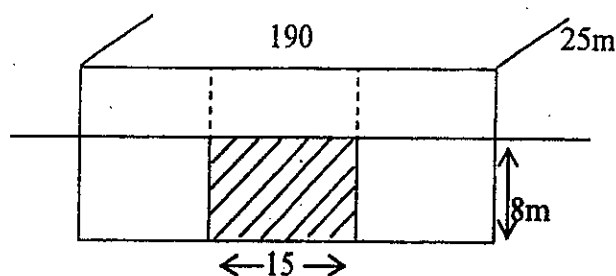


Water tight flat at 4.2 m

$$\begin{aligned} \delta &= \frac{(15 \times 30 \times 4) - (65 \times 30 \times 0.2)}{80 \times 30} \\ &= \frac{1800 - 390}{2400} = 0.5875 \end{aligned}$$

$$\text{Total sinkage} = 0.5875 + 0.2 = 0.7875 \text{ m}$$

A box shaped vessel 190m X 25m, floating at an even keel draft of 8m has a midship compartment 15m in length extending from side to side KG = 6.861m. Find the GM after this compartment gets bilged.



$$M.S. = \frac{\text{Volume lost}}{\text{Intact W.P. Area}}$$

$$M.S. = \frac{15 \times 25 \times 8}{175 \times 25} = \frac{3000}{4375} = 0.6857\text{m}$$

$$\text{New Draft} = 8 + 0.686 = 8.686\text{m}$$

$$KB = \frac{1}{2} \times 8.686 = 4.343$$

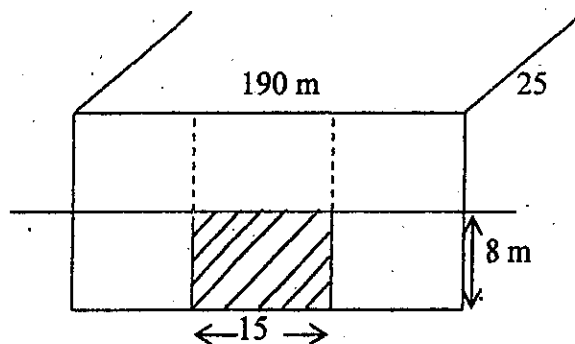
$$BM = \frac{LB^3}{12V} = \frac{175 \times 25^3}{12 \times 190 \times 25 \times 8} = 5.996\text{m}$$

$$KM = 4.343 + 5.996 = 10.339\text{m}$$

$$KG = \underline{6.861\text{m}}$$

$$GM = \underline{3.478\text{m}}$$

2. A box shaped vessel 190 m X 25m, floating at an even keel draft of 8 m has a midship compartment 15m in length extending from side to side. The compartment has a cargo of permeability 70%. Find the mean sinkage and new KB if that compartment gets bilged.



Permeability : It is the vacant / porous space in a cargo which can be filled up by the water when the compartment gets bilged. It is expressed as a percentage. When bilging

takes place, all the buoyancy is not lost. Only vacant / porous space gets lost, which is only a percentage of the total space.

To calculate permeability :

$$\text{Cargo Density} = 0.6 \text{ t/m}^3 \quad \text{or} \quad 1/0.6 = 1.67 \text{ m}^3/\text{t}$$

$$\text{SF} = \frac{2 \text{ m}^3}{1} \quad 2 - 1.67 = 0.33 \text{ m}^3 \text{ occupied by the water.}$$

$\therefore 0.33 \text{ m}^3$ is free for water to come in a volume of 2 m^3 .

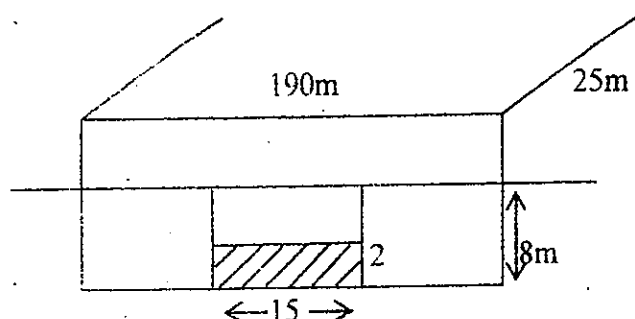
$$\therefore \text{Permeability} = \frac{0.33}{2} \times 100 = 16.5\%$$

Whenever the permeability is given, it may be introduced wherever that compartment with cargo is involved.

$$\begin{aligned} \text{M.S.} &= \frac{\text{Vol Lost}}{\text{Intact W/P area}} \\ &= \frac{15 \times 25 \times 8 \times 0.7}{(190 \times 25) - (15 \times 25 \times 0.7)} \\ &= \frac{2100}{4750 - 262.5} = \frac{2100}{4487.5} = 0.468 \text{ m} \end{aligned}$$

$$\text{M.S.} = 0.468 \text{ m} \quad \text{New Draft} = 8.468 \text{ m} \quad \text{New KB} = 4.234 \text{ m}$$

3. A box shaped vessel of length 190m breadth 25m is floating at an even keel draft of 8m. There is a 15m watertight flat at 2 mts draft at midship. Find the GM if this compartment is bilged below this W.T. flat. KG = 9.765m.



$$\text{M.S.} = \frac{15 \times 25 \times 2}{190 \times 25} = 0.158 \text{ m}$$

$$\text{New Draft} = 8.158$$

$$\text{New KB} = \frac{(190 \times 25 \times 8.158 \times 4.079) - (15 \times 25 \times 2 \times 1)}{190 \times 25 \times 8}$$

$$= \frac{158063.289 - 750}{38000} = 4.1398 \text{ m}$$

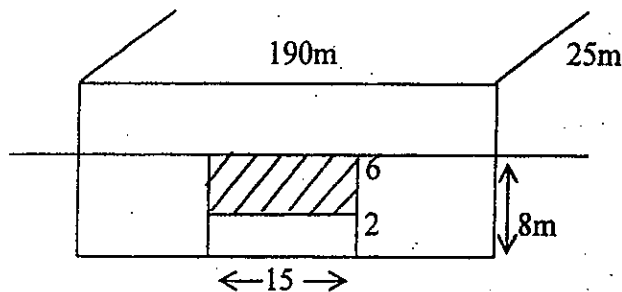
$$M = \frac{LB^3}{12V} = \frac{190 \times 25^3}{12 \times 190 \times 25 \times 8} = 6.510 \text{ m}$$

$$M = 4.140 + 6.510 = 10.65 \text{ m}$$

$$G = \frac{9.765 \text{ m}}{10.65 \text{ m}}$$

$$M = 0.885 \text{ m}$$

A box shaped vessel of length 190m breadth 25m is at an even keel draft of 8m. There is a watertight flat at 2m above the keel of length 15m. Find the GM if the compartment gets bilged above this W.T. flat. KG = 9.645 m



$$M.S. = \frac{15 \times 25 \times 6}{175 \times 25} = \frac{2250}{4375} = 0.514 \text{ m}$$

$$\text{New draft} = 8 + 0.514 = 8.514 \text{ m}$$

$$\text{New KB} = \frac{(190 \times 25 \times 8.514 \times 4.257) - (15 \times 25 \times 6.514 \times 5.257)}{190 \times 25 \times 8}$$

$$= \frac{172159.46 - 12841.54}{38000}$$

$$= 4.193 \text{ m}$$

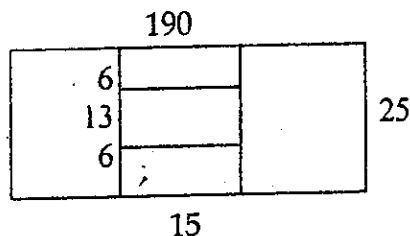
$$BM = \frac{LB^3}{12V} = \frac{175 \times 25^3}{12 \times 190 \times 25 \times 8} = 5.996 \text{ m}$$

$$KM = 4.193 + 5.996 = 10.189 \text{ m}$$

$$KG = \frac{9.645 \text{ m}}{10.189 \text{ m}}$$

$$GM = 0.544 \text{ m}$$

5. A box shaped V/L 190m X 25m @ an E.K. draft of 8 mtrs, KG = 6.823m has a midship compartment 15m in length divided in port, centre & Stbd compartments. Port & Stbd compartments are 6 mts wide each and centre 13 metre wide. Calculate GM of V/L.
- (a) If only centre compartment is bilged.
- (b) If only P & S compartments are bilged.



(a) Centre compartment is bilged.

$$MS = \frac{15 \times 13 \times 8}{(190 \times 25) - (15 \times 13)} = \frac{1560}{4750 - 195} = \frac{1560}{4555} = 0.342\text{m}$$

$$\text{New draft} = 8.342\text{m}$$

$$KB = \frac{1}{2} \times 8.342 = 4.171\text{m}$$

$$I_{CL} \text{ of whole area} = \frac{LB^3}{12} = \frac{190 \times 25^3}{12} = 247395.833$$

$$I_{CL} \text{ of bilged area} = \frac{LB^3}{12} = \frac{15 \times 13^3}{12} = 2746.25 (-)$$

$$I_{CL} \text{ of Intact area} = 244649.583$$

$$BM = \frac{I_{CL} \text{ of intact area}}{V} = \frac{244649.583}{190 \times 25 \times 8} = 6.438 \text{ m}$$

$$KM = 4.171 + 6.438 = 10.609\text{m}$$

$$KG = 6.823\text{m}$$

$$\therefore GM = 3.786 \text{ m}$$

When port and Stbd tanks are bilged.

$$MS = \frac{2 \times (15 \times 8 \times 6)}{(190 \times 25) - (15 \times 6 \times 2)} = \frac{1440}{4570} = 0.315\text{m}$$

$$\text{New draft} = 8 + 0.315\text{m} = 8.315\text{m}$$

$$\text{KB} = \frac{1}{2} \text{ Draft} = \frac{1}{2} \times 8.315 = 4.157\text{m}$$

$$\text{BM} = \frac{Z_{CL}}{V} \text{ (Intact)}$$

$$I_{CL} \text{ of Intact area} = \frac{LB^3}{12} = \frac{175 \times 25^3}{12} = 227864.58$$

$$I_{CL} \text{ of centre compartment} = \frac{\ell b^3}{12} = \frac{15 \times 13^3}{12} = 2746.25$$

$$\therefore I_C \text{ of Intact} = 227864.58 + 2746.25 = 230610.8$$

$$\therefore \text{BM} = \frac{230610.8}{190 \times 25 \times 8} = 6.069\text{m}$$

$$\text{KM} = 4.157 + 6.069\text{m} = 10.226\text{m}$$

$$\text{KG} = 6.823\text{m}$$

$$\text{GM} = 3.403\text{m}$$

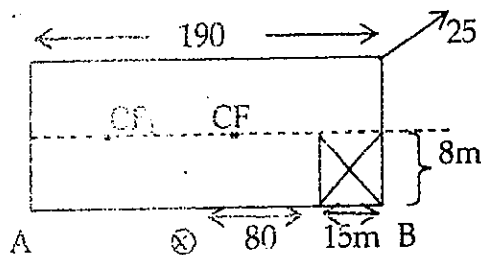
By other method also it can be found out.

$$I_{CL} \text{ of whole} = \frac{LB^3}{12} = \frac{100 \times 25^3}{12} = 247395.83$$

$$\begin{aligned} I_{CL} \text{ of side compartment} &= \left[\frac{\ell b^3}{12} + (\ell \times b \times h^2) \right] \times 2 \\ &= \frac{15 \times 6^3}{12} + (15 \times 6 \times 9.5^2) \times 2 \\ &= 16785 \end{aligned}$$

$$\therefore I_{CL} \text{ Intact} = 247395.83 - 16785 = 230610.8$$

6. A box shaped V/L 190m X 25m @ EK draft of 8m KG 4.343m has a compartment @ the fore end 15 mts in length extending full width of V/L. Calculate draft F/A after that compartment is bilged.



$$MS = \frac{15 \times 25 \times 8}{175 \times 25} = 0.686m$$

$$\text{New draft} = 8 + 0.686 = 8.686m$$

$$\text{New KB} = \frac{1}{2} \times 8.686 = 4.343m$$

To find new position of COF. taking moment w.r.t. midship, let it be x mts from midship.

$$175 \times 25 \times x = (190 \times 25 \times 0) - (15 \times 25 \times 87.5)$$

$$\therefore x = \frac{-32812.5}{4375} = -7.5$$

New COF will shift aft by a distance of $= 7.5m$

$$\therefore \text{Dist from aft (AI)} = 95 - 7.5 = 87.5m$$

$$BM_i = \frac{I_{ii} (\text{Intact})}{V}$$

$$\therefore I_{ii} (\text{Whole}) = \frac{BL^3}{12} + (L \times B \times h^2)$$

$$= \frac{25 \times 190^3}{12} + (190 \times 25 \times 7.5^2)$$

$$= 14289583.33 + 267187.5$$

$$= 14556770.83$$

$$I_{ii} (\text{lost}) = \frac{b\ell^3}{12} + (\ell b h^2)$$

$$= \frac{25 \times 15^3}{12} + (15 \times 25 \times 95^2) = 3391406.3 (7031.25 + 3384375)$$

$$= 3391406.25$$

$$\therefore I_{ii} (\text{Intact}) = 11165364.6$$

$$\therefore BM_i = \frac{I_{ii} (\text{Intact})}{V \times \text{New Draft}} = \frac{11165364.6}{175 \times 8.686} = 293.83m$$

$$\begin{aligned}
 GM_L &= KM_L - KG = KB + BM_L - KG \\
 &= 4.343 + 293.83 - 4.343 \\
 &= 293.83
 \end{aligned}$$

$$W = 190 \times 25 \times 8 \times 1.025 = 38950t$$

$$\begin{aligned}
 MCTC &= \frac{W \cdot GM_L}{100 \times L} \\
 &= \frac{(190 \times 25 \times 8 \times 1.025) \times 293.83}{100 \times 190} \\
 &= 602.35 \text{ t/m.}
 \end{aligned}$$

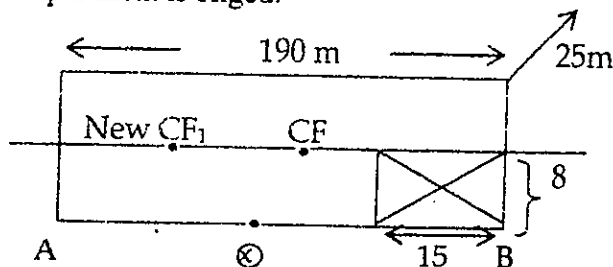
$$\begin{aligned}
 \text{Total trim caused } T_c &= \frac{dw}{MCTC \times 100} \\
 &= \frac{(15 \times 25 \times 8 \times 1.025) \times 95}{100 \times 602.35} \\
 &= 4.850 \text{ m.}
 \end{aligned}$$

$$\begin{aligned}
 \text{Change in trim aft } T_a &= \frac{T_c \times AF}{L} \\
 &= \frac{4.850 \times 87.5}{190} \\
 &= 2.233 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 T_f &= T_c - T_a \\
 &= 4.850 - 2.233 \\
 &= 2.617 \text{ m}
 \end{aligned}$$

∴ Original	F	A
	8.00 m	8.00 m
MS	(+) 0.686 m	(+) 0.686 m
	(+) 2.617 m	(-) 2.233 m
Final Draft,	F = 11.303	A = 6.453 m

7. A box shaped V/L 190 X 25 at E.K. draft of 8m KG 5.5m has a fwd compartment 15m in length with a permeability 70%. Calculate draft F & A if that compartment is bilged.



$$\begin{aligned} \text{KG} &= 5.5\text{m} \\ P &= 70\% = 0.7 \end{aligned}$$

$$\text{MS} = \frac{15 \times 25 \times 8 \times 0.7}{(190 \times 25) - (15 \times 25 \times 0.7)} = \frac{2100}{4487.5} = 0.468\text{m}$$

$$\text{New draft} = 8 + 0.468 = 8.468\text{m}$$

$$\therefore \text{New KB} = \frac{1}{2} \times 8.468 = 4.234\text{m}$$

To find new COF, taking moment w.r.t. midship,

Let it be x mts from midship

$$[(190 \times 25) - (15 \times 25 \times 0.7)]x = (190 \times 25 \times 0) - (15 \times 25 \times 0.7 \times 87.5)$$

$$\therefore x = \frac{-22968.75}{4487.5} = -5.118\text{m}$$

New COF will shift aft by a distance of 5.118m

$$\therefore \text{BM}_L = \frac{I_L (\text{Intact})}{V (\text{whole})}$$

$$I_L (\text{whole}) = \frac{BL^3}{12} + (LBh^2)$$

$$= \frac{25 \times 190^3}{12} + (190 \times 25 \times 5.118^2)$$

$$= 14289583.33 + 124421.139$$

$$= 14414004.5$$

$$Z_L (\text{lost}) = \frac{b\ell^3}{12} \times P + (\ell bh^2P)$$

$$= \frac{25 \times 15^3 \times 0.7}{12} + (15 \times 25 \times 92.618^2 \times 0.7)$$

$$= 4921.875 + 2251749.655$$

$$= 2256671.5$$

$$\therefore I_L (\text{Intact}) = 12157332.9$$

$$BM_L = \frac{I(\text{Intact})}{V(\text{whole})} = \frac{12157332.9}{190 \times 25 \times 8} = 319.930$$

$$KM_L = KB + BM_L$$

$$= 4.234 + 319.930$$

$$= 324.164\text{m}$$

$$GM_L = KM_L - KG$$

$$= 324.164 - 5.5$$

$$= 318.664\text{m}$$

$$W = 190 \times 25 \times 8 \times 1.025 = 38950\text{t}$$

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

$$= \frac{38950 \times 318.664}{100 \times 190} = 653.261$$

$$\text{Total trim caused } T_c = \frac{dw}{100 \times MCTC}$$

$$= \frac{(15 \times 25 \times 8 \times 0.7 \times 1.025) \times 92.618}{100 \times 653.261}$$

$$= 3.052\text{m}$$

$$\text{Trim aft } T_a = \frac{T_c \times AF}{L} = \frac{3.052 \times 89.882}{190}$$

$$= 1.444\text{m}$$

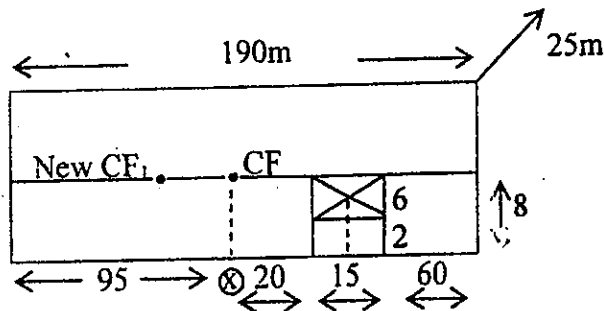
$$\text{Trim fwd } T_f = T_c - T_a$$

$$= 3.052 - 1.444$$

$$= 1.608\text{m}$$

	F	A
Original	8.000	8.000
M.S.	(+) 0.468	(+) 0.468
Tf E Ta	(+) 1.608	(-) 1.444
Final Draft	F = 10.076	A = 7.024

8. A box shaped vessel 190m X 25m is floating at a even keel draft of 8m. There is a water tight compartment 8m deep with watertight flat at 2m. The length of the compartment is 15m and it's aft bulkhead is 20 meters for'd of midship. Find the draft of the vessel if the watertight compartment gets bilged above the flat. The permeability of cargo in the watertight compartment is 70%.



$$MS = \frac{15 \times 25 \times 6 \times 0.7}{(190 \times 25) - (15 \times 25 \times 0.7)} = 0.351 \text{ mts}$$

$$\text{New draft} = 8 + 0.351 = 8.351 \text{ m}$$

To find new position of COF, taking moment of area w.r.t. midship, let it be x mt from midship.

$$[(190 \times 25) - (15 \times 25 \times 0.7)]x = (190 \times 25 \times 0) - (15 \times 25 \times 0.7 \times 27.5)$$

$$\therefore x = \frac{-7218.75}{4487.5} = -1.609$$

Now COF will shift aft by a distance of 1.609m

$$\therefore (\text{AF}) \text{ distance from aft} = 95 - 1.609 = 93.391 \text{ m}$$

Since KG is not given. Therefore

$$BM_L \simeq GM_L$$

$$\therefore BM_L = \frac{I(\text{Intact})}{V(\text{whole})}$$

$$I_L(\text{whole}) = \frac{BL^3}{12} + (LBh^2)$$

$$= \frac{25 \times 190^3}{12} + (190 \times 25 \times 1.609^2)$$

$$= 14289583.33 + 12297.185$$

$$= 14301880.5$$

$$\begin{aligned}
 I_L (\text{lost}) &= \frac{b\ell^3 \times P}{12} + (b\ell l^2 P) \\
 &= \frac{25 \times 15^3 \times 0.7}{12} + (15 \times 25 \times 0.7 \times 29.109^2) \\
 &= 4921.875 + 222425.144 \\
 &= 227347.019
 \end{aligned}$$

$$I_L (\text{intact}) = 14074533.48$$

$$\therefore BM_L = \frac{I_L (\text{intact})}{V (\text{whole})} = \frac{14074533.48}{190 \times 25 \times 8} = 370.383$$

$$W = 190 \times 25 \times 8 \times 1.025 = 38950t$$

$$\begin{aligned}
 MCTC &= \frac{W \cdot GM_L}{100 \times L} \\
 &= \frac{38950 \times 370.383}{100 \times 190} \\
 &= 759.285
 \end{aligned}$$

$$\begin{aligned}
 \text{Total trim caused (Tc)} &= \frac{dw}{100 \times MCTC} \\
 &= \frac{(15 \times 25 \times 6 \times 0.7 \times 1.025) \times 29.109}{100 \times 759.285} \\
 &= 0.619 \text{ mts.}
 \end{aligned}$$

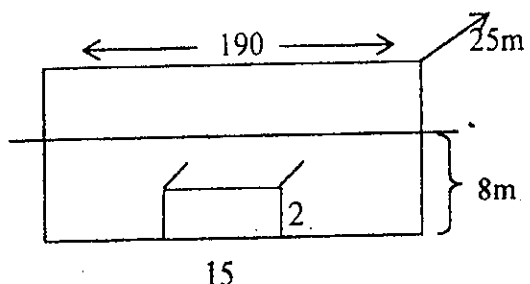
$$\text{Trim aft (Ta)} = \frac{Tc \times AF}{L} = \frac{0.619 \times 93.391}{190}$$

$$Ta = 0.304$$

$$\text{Trim fwd Tf} = Tc - Ta = 0.619 - 0.304 = 0.315m$$

	F	A
Original	8.000	8.000
M.S.	(+) 0.351	(+) 0.351
T(f) & Ta	(+) 0.315	(-) 0.304
Final Draft	F = 8.666m	A = 8.047m

9. Box shaped vessel 190m X 25m has a M'ship DB tank 2 mts deep 15m long which is full of salt water KG = 8.885m. Calculate vessel's GM after that tank is bilged if her initial even keel draft was 8.0m.



$$\text{Disp of V/L} = 190 \times 25 \times 8 \times 1.025 = 38950 \text{ t}$$

$$\text{Wt of water lost} = 15 \times 25 \times 2 \times 1.025 = 768.75 \text{ t}$$

$$\text{Disp. after bilged} = 38181.25 \text{ t}$$

$$\begin{aligned} \text{Buoyancy upto 2 mtr draft} &= 175 \times 25 \times 2 \times 1.025 \\ &= 8968.75 \text{ t} \end{aligned}$$

$$\begin{aligned} \text{Buoyancy above 2 mtr} &= 38181.25 - 8968.75 \\ &= 29212.5 \end{aligned}$$

$$\therefore \text{ draft above 2 mtr} =$$

$$29212.5 = 190 \times 25 \times x \times 1.025$$

$$\therefore \text{ above 2m} = \frac{29212.5}{190 \times 25 \times 1.025} = 6 \text{ mtr}$$

To find new KB

$$[(190 \times 25 \times 8) - (15 \times 25 \times 2)] \text{ KB} = (190 \times 25 \times 8 \times 4) - (15 \times 25 \times 2 \times 1)$$

$$\therefore \text{ KB} = \frac{151250}{37250} = 4.060 \text{ m}$$

$$\text{BM} = \frac{I_{CL}}{V} = \frac{190 \times 25^3}{12 [(190 \times 25 \times 8) - (15 \times 25 \times 2)]} = 6.641 \text{ m}$$

$$\therefore \text{ KM} = \text{KB} + \text{BM}$$

$$= 4.06 + 6.641$$

$$= 10.701 \text{ m}$$

$$\therefore \text{ New KG} = \frac{(190 \times 25 \times 8 \times 1.025 \times 8.885) - (15 \times 25 \times 2 \times 1.025 \times 1)}{38181.25}$$

$$= \frac{346070.75 - 768.75}{38181.25}$$

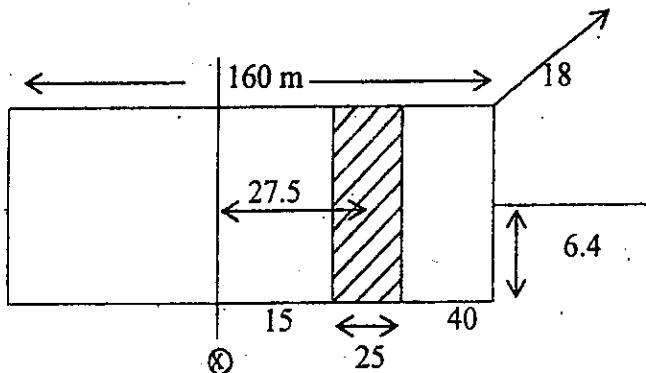
$$= 9.044\text{m}$$

$$\therefore KM = 10.701\text{ m}$$

$$KG = 9.044\text{ m}$$

$$GM = 1.657\text{ m}$$

A box shaped vessel 160 X 18 m floating at an even keel draft of 6.4m. A fore'd compartment 25m long is having cargo of permeability 80%. This compartment is extending from side to side and tank's c.o.g. is 27.5m fore'd of midship. $KG = 4.7\text{m}$. Find the draft F & A if this compartment gets bilged.



$$P = 80\%$$

$$KG = 4.7\text{ m}$$

$$\text{M.S.} = \frac{25 \times 18 \times 6.4 \times 0.8}{(160 \times 18) - (25 \times 18 \times 0.8)} = \frac{2304}{(2880 - 360)} = 0.914\text{ m}$$

$$\text{New draft} = 6.4 + 0.914 = 7.314\text{m}$$

$$\text{To find CF about midship} = \frac{160 \times 18 \times 0 - (25 \times 18 \times 0.8 \times 27.5)}{(160 \times 18) - (25 \times 18 \times 0.8)}$$

$$= \frac{0 - 8800}{2880 - 360} = \frac{9900}{2520} = -3.93\text{ m}$$

$$LCF = 80 - 3.93 = 76.07\text{m}$$

$$BM = \frac{I_{CF}}{V} \text{ of intact area}$$

$$I_{CF} \text{ of whole area} = \frac{BL^3}{12} \times Ah^2 = \frac{18 \times 160^3}{12} + Ah^2$$

$$= 6144000 + 160 \times 18 \times (3.93)^2$$

$$= 6144000 + 444813 = 6188481.3$$

$$I_{CF} \text{ of bilged area} = \frac{BL^3}{12} + Ah^2 = \frac{18 \times 25^3 \times 0.8}{12} + (25 \times 18 \times 0.8) \times (31.43)^2$$

$$= 18750 + 355624.15$$

$$= 374374.16 \text{ m}^4$$

$$\therefore I_{CF} \text{ of intact area} = 5814107.2 \text{ m}^4$$

$$BM_L = \frac{5814107.2}{160 \times 18 \times 6.4} = 315.4$$

$$KM = 3.657 + 315.4 = 319.057$$

$$KG = 4.700$$

$$GM_L = 314.357$$

$$MCTC = \frac{160 \times 18 \times 6.4 \times 1.025 \times 314.357}{100 \times 160}$$

$$= 371.23 \text{ tm}$$

$$T_t = \frac{TM}{MCTC} = \frac{25 \times 18 \times 0.8 \times 1.025 \times 6.4 \times 31.43}{371.23} = 2.0 \text{ m}$$

$$T_a = \frac{200 \times 76.07}{160} = 95 \text{ cm}$$

$$T_f = 105 \text{ cm}$$

F	A
6.4	6.4
+ 0.914	+ 0.914
+ 1.05	- 0.95
<u>8.364 m</u>	<u>6.364 m</u>

1. A box shaped vessel 75m X 10m X 6m deep is floating in S/W on an even keel draft of 4.5 mts. Find the new drafts F & A if a forward end compartment 5 mts long is bilged.

$$\text{Mean sinkage} = \frac{5 \times 10 \times 4.5}{70 \times 10} = 0.321\text{m}$$

∴ New draft = 4.821m F & A after considering the sinkage bodily.

Now consider the trim:

$$\begin{aligned} KB &= \frac{1}{2} \text{ draft} = \frac{1}{2} \times 4.821 \\ &= 2.4105\text{m} \end{aligned}$$

$$\begin{aligned} BML &= \frac{BL^3}{12 \times V} = \frac{10 \times 70^3}{12 \times 75 \times 10 \times 4.5} \\ &= 84.7\text{m} \end{aligned}$$

$$\begin{aligned} \therefore KML &= 2.4105 + 84.7 \\ &= 87.1105\text{m} \end{aligned}$$

$$\text{Initial KG} = \frac{1}{2} \times \text{depth} = 3 \text{ mts.}$$

$$\therefore GM_L = 84.1105\text{m} (KML - KG)$$

$$\begin{aligned} \text{MCTC} &= \frac{W \cdot GML}{100L} \\ &= \frac{75 \times 10 \times 4.5 \times 1.025 \times 84.1105}{100 \times 75} \\ &= 39.05 \end{aligned}$$

$$\begin{aligned} \text{Change of trim} &= \frac{d \times w}{\text{MCTC}} = \frac{5 \times 10 \times 4.5 \times 1.025 \times 37.5}{39.05} \\ &= 221.4 \text{ cm by head} \end{aligned}$$

$$\text{Change of trim aft} = \frac{221.4 \times 35}{75} = 103.3 \text{ cm}$$

$$\text{Change of trim for'd} = 118.1 \text{ cm}$$

F	A
4.821	4.821
+ 1.181	- 1.033
6.002 m	3.788 m

BILGING

Exercise 13

1. A box shaped vessel 120m X 20m at an even keel draft of 1.8m has a compartment 15m in length with its forward bulkhead 5m abaft the forward end. The compartment extending the full width of the vessel and having a permeability of 70% is bilged. If the vessel had a KG of 4m, calculate her final drafts F & A.
2. A box shaped vessel 80m X 10m floats at an even keel draft of 4.5m with KG 6.8m. She has a compartment 12m in length, extending from side to side with its after bulkhead 20m. for'd of mid-length. The compartment has a watertight flat 2.0m above the keel. Calculate the drafts for'd & aft if that compartment with permeability of 70% is bilged above the watertight flat.
3. A box shaped vessel 82m X 15m, at an even keel draft of 4.5m has a midship compartment 10m in length with a watertight flat at 4.7m above the keel. Her KG is 5.1m Calculate her drafts F & A and her GM if that compartment is bilged below the water level.
4. A box shaped vessel of length 80m and breadth 15m at an even keel draft of 4m has a midship compartment 12m in length with a water tight flat 3m above the keel. The midship compartment with a permeability of 70% is bilged below the water tight flat. Calculate her draft for'd & aft and GM after bilging if KG in initial condition is 5.1m.
5. A box shaped vessel of length 80m and breadth 15m floats in salt water at an even keel draft of 4.2m. KG = 5.1m. An amidships compartment of length 12m with a permeability of 70% gets bilged below a watertight flat located 3m above the keel. Find the GM and draft in this condition.
6. A box shaped vessel of length 80m, breadth 18m, at an even keel draft of 4m has a KG of 3.5m. A midship compartment extending the full width of the vessel and 10m long has a watertight flat at a height of 3m. above the keel. If this compartment of permeability 40% is bilged below the watertight flat, calculate the draft at which she will settle and her GM then.
7. A box shaped vessel 210m long and 25m wide floats in salt water at draft 10m F & A. KG = 10.6m. An empty amidships compartment 30m long and 25m wide has a water-tight flat 10.5m above the keel. Find the GM if this compartment is bilged below the water-tight flat.
8. A box shaped vessel, 80m X 15m at an even keel draft of 3.6m has a midship compartment 20m in length, extending from side to side, with a watertight flat 1.8m above the keel. The KG of the vessel is 5.8m. If that compartment is bilged calculate the draft at which she will settle and her GM after bilging.

A box-shaped vessel 80m X 16m at an even keel draft of 4.5m, KG 5.8m, has a midship compartment 22m in length with a water-tight flat 3m above the keel. If that compartment with permeability of 65% is bilged below the flat, calculate her drafts and GM.

A box shaped vessel 72m X 8m floats at on even keel draft of 4m. A Midship compartment 12m long has a watertight flat 4.5m above the keel. If that compartment is bilged below the watertight flat, find her KM.

1. A box shaped vessel 100m X 20m, KG = 5.2m, floats at an even keel draft of 5 mtrs Salt water. A end compartment forward, 10m long and covering the full breadth of the vessel is bilged. Calculate the new drafts forward and aft.

2. box-shaped vessel is 60 metres long, 10 metres wide and floats at a draft of 4.00 metres fore and aft. A compartment amidships is 15 metres long and contains cargo of permeability 40%. Find the new drafts if this compartment is bilged.

3. box-shaped vessel, 100 metres long and 20 metres beam, floats at drafts of 4.00 metres fore and aft. Find the new drafts after an empty end compartment, 10 metres long, is bilged forward.

4. box-shaped vessel, 120 metres long and 20 metres beam, floats at drafts of 4.00 metres fore and aft. An end compartment, 25 metres long, has a watertight flat 3.00 metres above the keel and contains cargo of permeability 60%. Find the new drafts if this compartment is bilged.

15. A box shaped vessel 100m X 20 mts floats at even keel draft of 5 mts, KG = 5.3 m has a forward compartment 10 mts in length with a cargo of permeability 60%. Calculate draft forward and aft if that compartment is bilged.

16. A box shaped vessel 80m X 16m at an even keel draft of 4.5m has a mid compartment 12m in length, extending from side to side, with a watertight flat 2m above the keel, KG = 4.72m. Calculate (a) her draft and (b) her GM after the compartment below the W/T flat with a permeability of 70% is bilged.

17. A box shaped vessel 100m long, 20m broad floats at an even keel draft of 6.0m in water of RD 1.005. A hold 10m long, 20m wide is full of cargo of RD 0.6 and SF $2.8\text{m}^3/\text{t}$. The forward bulkhead of this hold is 20m from the aft end of ship. Calculate the change in the KM_L of the ship if this compartment is bilged.

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ANSWERS

1. $F = 5.908 \text{ m}$ $A = 4.066 \text{ m}$ $MCTC = 216.14$
2. $F = 5.554 \text{ m}$ $A = 4.1398 \text{ m}$
3. $GM = 1.626 \text{ m}$ $Draft = 5.073 \text{ m}$
4. $GM = 1.798 \text{ m}$ $Draft = 4.315 \text{ m}$
5. $GM = 1.678 \text{ m}$ $Draft = 4.515 \text{ m}$
6. $GM = 3.746 \text{ m}$ $Draft = 4.15 \text{ m}$
7. $GM = 0.433 \text{ m}$ $Final Draft = 11.5 \text{ m}$
8. $Draft F \text{ \& } A = 4.20 \text{ m},$ $GM = 1.358 \text{ m}$
9. $Draft F \text{ \& } A = 5.036 \text{ m}$ $GM = 1.579 \text{ m}$
10. $Draft F \text{ \& } A 4.75 \text{ m}$ $KM = 3.731 \text{ m}$
11. $F = 7.865 \text{ m}$ $A = 3.666 \text{ m}$ $Hydrostatic draft = 5.555 \text{ m}$
12. 4.444 m
13. $New Draft F = 6.26 \text{ m},$ $A = 2.95 \text{ m}$
14. $New Draft F = 5.27 \text{ m}$ $A = 3.49 \text{ m}$
15. $[Mean Sinkage = 0.319 \text{ m}, C.O.F = 47.128,$
 $BM_L = 140.715$ $KM_L = 143.375$ $GM_L = 138.075$ $MCTC = 141.53$
 $Draft F = 6.419$ $A = 4.339]$
16. $Draft = 4.71 \text{ m}$ $GM = 2.438 \text{ m}$
17. $Final KM_L = 133.346 \text{ m},$ $Change in KM_L = 8.543 \text{ m}$

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CHAPTER XV

BILGING OF A MID SHIP SIDE COMPARTMENT

The following steps are to be followed to calculate the list where a midship side compartment is bilged.

1. Find the mean sinkage as usual. Get the bilged draft.
2. The list is given by the formula.

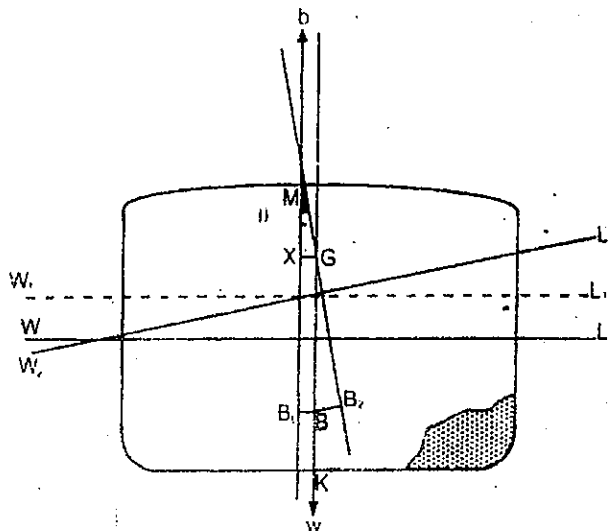
$$\tan \theta = \frac{BB_1}{GM}$$

When GM is the initial metacentric heights for the bilged condition. BB_1 is the transverse shift of ship's center of buoyancy.

When such a compartment is bilged, the buoyancy is lost and to make up for the fixed displacement, the vessel sinks further. Thus there is a mean sinkage. Since the compartment is on one side of center line and amidships, the original centre of buoyancy of the vessel B which was in line with center of gravity in upright condition shifts. The centre of buoyancy will move from B to B_1 directly away from the centre of gravity of the lost buoyancy.

$$BB_1 = \frac{d \times w}{W}$$

Where w represents the lost buoyancy, d represents the distance between the ship's centre of buoyancy and the centre of the lost buoyancy. The shift in the centre of buoyancy produces a listing moment which causes the list.



Example :

A box shaped vessel of length 60m, breadth 9m is floating at an even keel draft of 5m and has KG 3.0m. Find the list if empty midship side compartment of length 6m, breadth 6m is bilged.

$$1. \quad \text{Mean Sinkage} = \frac{\text{lost buoyancy}}{\text{Intact water area}} = \frac{6 \times 6 \times 5}{60 \times 9 - 6 \times 6} = \frac{180}{504} = 0.357\text{m}$$

$$\therefore \text{New draft} = 5.357\text{m}$$

$$\text{New KB} = 2.679\text{m}$$

2. To find h from side :

	Area	Centroid	Moment
L X B	540	4.5	2430
l X b	-36	3.0	-108
	<u>504</u>		<u>2322</u>

$$\therefore h = \frac{2322}{504} = 4.607\text{m from side}$$

$$\therefore \text{from centre line} = 4.607 - 4.5 = 0.107\text{m}$$

$$I_{\text{side}} = \frac{LB^3}{3} - \frac{lb^3}{3} = \frac{60 \times 9^3}{3} = 14148\text{m}^4$$

$$I_b = I_{\text{side}} - Ah^2$$

$$= 14148 - 504 \times 4.607^2 \text{ m}^4$$

$$= 3451 \text{ m}^4$$

$$\therefore BM_b = \frac{I_b}{V} = \frac{3451}{2700} = 1.278\text{m}$$

$$KB = 2.679$$

$$BM = 1.278$$

$$\therefore KM = 3.957\text{m}$$

$$KG = 3.0 \text{ m}$$

$$\therefore GM = 0.957\text{m}$$

$$\tan \theta = \frac{BB_1}{GM} = \frac{0.107}{0.957}$$

$$\therefore \theta = 6.38^\circ$$

BILGING SIDE COMPARTMENTS AMIDSHIPS

Exercise : 14

1. A box-shaped vessel, 120m long and 24m wide, floats on an even keel in salt water at a draft of 7m. $KG = 7m$. A compartment amidships is 12m long and is divided at the centre line by a full depth watertight bulkhead. Calculate the list if this compartment is bilged.
2. A box-shaped vessel is 50m long, 10m wide and is divided longitudinally at the centre line by a watertight bulkhead. The vessel floats on an even keel in salt water at a draft of 4m. $KG = 3m$. A compartment amidships is 12m long and contains cargo of permeability 30 per cent. Find the list if this compartment is bilged.
3. A box vessel has length, 180m; breadth, 16m is floating at draft 10m with $KG = 6.5m$. Find the list if a compartment midships length 10m with longitudinal bulkheads on the centerline and 4m to port of the centerline, is bilged.
4. A box vessel has length, 100m; breadth, 8m and is floating at draft 6m with $KG = 3.2m$. A midship side compartment length, 9m, breadth, 3m is bilged. Find the resulting list.
5. A box vessel has length, 180m; breadth, 16m is floating at draft, 10m with $KG = 6.5m$. Find the list if a compartment midships length 10m with longitudinal bulkheads on the centerline and 4m to port of the centerline, is bilged.

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Answers :

1. 5.7°
2. 4.9°
3. 2.32° Port
4. 6.58°
5. List = 2.32° Port

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CHAPTER XVI

INCLINING EXPERIMENT (TEST)

Purpose of the experiment :

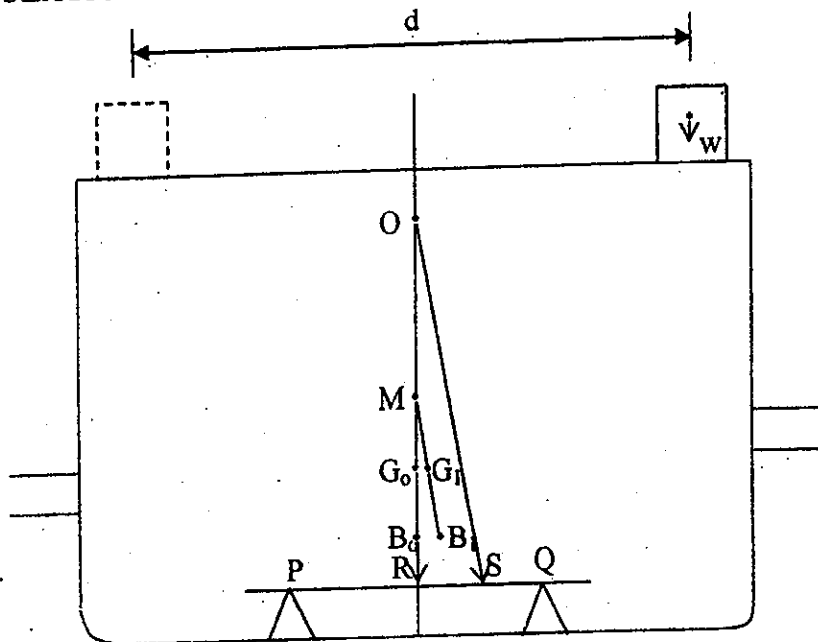
1. Unless the KG of the light ship is known, we can not work out the final KG in any loaded condition. Thus the GM can not be worked out which is used as a measure of stability of the ship.
2. It is in order to find the KG for the light condition that the inclining experiment is performed.
3. During currency of the commercial life of the ship, an inclining test may occasionally be used to give a quick check on the fluid GM of a loaded vessel. In this case a unit of cargo of known weight is loaded on one side of the deck, the list noted and the unit is then moved to the other side and change noted. An approximate GM (fluid) may then be worked out as given below.

Procedure of Conducting the experiment :

1. Three pendulums rigged one forward, one aft and one at midship. They may be suspended in the open hatchway at the centre line of the ship.
2. The pendulum bobs are immersed in horizontal trough of oil to damp their motion.
3. Graduated battens in cm are set up between each pendulum to measure their deflection when the vessel heels. The batten is adjusted to be horizontal, by use of a spirit level, when the ship is perfectly up right.
4. The pendulums may be replaced by an accurate inclinometer.
5. Four equal weights (Total 1/500 of the LWT) are placed on deck -- two on each side, of measured equal distances, at the centre line. Most ship yards use concrete blocks of known weights.
6. The pendulum positions are noted against each batten. One weight is shifted from port to starboard and the deflection of pendulums is noted.
7. Second weight on the portside is also, then shifted to starboard and the deflection of pendulum again noted.

8. The two weights are then returned to port side to check that the pendulums return to the initial position.
9. The entire procedure is then repeated with the two weights on the stbd side.
10. In modern ship yards, the heel procedure is measured by an instrument called, "STABILOGRAPH"

CALCULATION:



As shown in the figure above, a pendulum of known length is suspended on the centre line of the ship. It deflects on the graduated scale PQ. A known small weight w is moved through a distance d from one side of the vessel to the other across the deck.

The centre of gravity of the vessel G_0 will move athwartship to G_1 and the vessel will list until B_1 & G_1 are in the same vertical line. If the angle of heel is small, the vertical line will pass through M .

The hanging pendulum will move through a distance RS when the weight is shifted.

Now triangle MG_0G_1 & ORS are similar.

$$\therefore \frac{G_0M}{G_0G_1} = \frac{RO}{RS}$$

$$\text{Or } G_0M = \frac{G_0G_1 \times RO}{RS} \quad \text{----- (1)}$$

If the displacement of the vessel was 'W'

$$\text{From equation (1) } G_0G_1 = \frac{d \times w}{W}$$

$$\therefore G_0M = \frac{d \times w \times RO}{W \times RS} \quad \text{----- (2)}$$

The GM is calculated separately for each shifted weight, using the deflection of each pendulum. The average of GM is taken which gives GM (fluid) of the ship in that condition.

KM is obtained for that displacement from the vessels hydrostatic data. The corrected KG in that condition is then $KM - GM$ fluid.

The FSC is subtracted to obtain her KG in that condition.

By taking moments about the keel, allowance is made for any weights on board, including the inclining weights, which do not form a part of the light ship, to obtain KG in light condition.

Preparation / Precautions :

1. The vessel should be as close as possible to the light condition.
2. The ship must be up right at the commencement of the experiment.
3. A large trim is to be avoided.
4. Ship should not be inclined with a very small GM.
5. Ideally no wind or current other wise the ship should be moored head to wind or current.
6. All mooring lines to be slack, gangway lifted up to allow the vessel incline freely.
7. All derrick, boats etc. to be housed in sea going condition, loose weight to be secured well.
8. No other vessels to be moved along side.
9. The ship should be as near completion as possible.

An accurate list should be made of weights to be removed, those to go on board, and those to be shifted, together with their KG's so that proper allowances can be made for those weights, in the calculation of light KG.

All tanks should preferably be full or empty. All bilges to be dry.

A careful note should be made of all tank soundings, to allow for the weight of liquid in them, as well as any free surface effect. Ideally there should be no free surface.

The density of water and the drafts of the ship forward, aft and midship (port and starboard) should be noted carefully.

4. Least crew / officers to remain on board when conducting the inclining experiment.
5. This experiment may have to be performed again; during the life of the ship if any large structural alterations are made.
16. The inclining experiment performed on any ship may be acceptable for sister ships.
17. At periodical interval not exceeding 5 years a light ship survey must be carried out on all passenger ships to verify any changes in light ship displacement and new center of gravity.

EXTRACT FROM INCLINING TEST UNIFIED PROCEDURE (FOLLOWED BY CLASSIFICATION SOCIETIES)

1. Introduction

The purposed of this procedure is to achieve a satisfactory accuracy in the determination of the lightship weight and of the coordinates of its centre of gravity.

Where a surveyor of the Society is required to attend the inclining test, his responsibility is to verify that the test is conducted according to accepted procedures and that all basic measurements and data are correctly taken and recorded.

2. General Preparation for the Test

2.1 *Information to be submitted*

The Instruction, containing the information of date and location of the test, responsible person, stability, inclining weight, schemes of inclining weight positions etc., should be presented to the Classification Society before the inclining test.

The following information should be available at the time of the inclining test as necessary:

- General arrangement drawing;
- Tank capacity plan,
- Hydrostatic curves;
- Draft marks locations;

2.2 *The inclining test condition*

2.2.1 The ship should be as near to completion as possible. Equipment used by the yard on board should be limited to the utmost extent possible. Prior to the inclining test, lists of all items which are to be added, removed, or relocated should be prepared. These weights and their locations should be accurately recorded.

Normally, the total value of missing weights should not exceed 2 percent and surplus weights, excluding liquid ballast, not exceed 4 percent of the light ship displacement. For smaller vessels, higher percentages may be allowed.

2.2.2 All objects should be secured in their regular positions. All weights which may swing or shift must be secured in their known position. If more than one stowage position is possible, the actual stowage position used during the test should be recorded.

2.2.3 The ship should be cleared of residues of cargo, tools, debris, scaffolding and snow. Icing of the inner and outer surfaces, the underwater hull included, is not permitted.

2.2.4 All bilge water and other extraneous standing liquids must be removed. When draining individual tanks is impracticable, allowances for such liquids should be at the discretion of the Society.

2.2.5 All service tanks and machinery plant pipings are to be fitted as for the working condition.

2.2.6 In general, only the people participating in the inclining test should stay on board the ship.

2.2.7 All spaces should be safe for inspection.

2.3 Tank contents

2.3.1 Preferably, all tanks should be either full or empty. The number of tanks containing liquids should be kept to a minimum.

2.3.2 Soundings and density of liquids in tanks should be taken. Shapes of tanks which are partly filled are to be known in order to determine the free liquid surface effect.

2.3.3 Adequate measures are to be taken to preclude air pockets in completely full tanks. All connections between tanks are to be closed and all empty tanks are to be adequately dried.

2.4 Mooring Arrangements and Environmental Conditions

2.4.1 Mooring lines should be free of any tension in the transverse direction of the ship during the reading after each weight shift. No external moments should

be brought upon the ship (from mooring lines, quay, etc.). If possible, the ship should be located in a calm, protected area free from external forces.

2.4.2 The depth of water under the hull should be sufficient to ensure that the hull will be entirely free of the seabed. Prior to the test the depth of water should be measured in as many locations as necessary to positively satisfy this requirement, taking into account tide differences, if applicable.

2.4.3 An ideal mooring arrangement would involve bow and stern lines on both sides of the ship attached at or near the centre-line. Longitudinal mooring lines should be as long as practicable. More commonly, a ship may be moored by bow and stern lines on one side only and supplemented by spring lines. Where a single bow or stern line is proposed, the surveyor should be assured that the ship's freedom of movement does not adversely affect the conduct of the experiment.

2.4.4 The ship may be moored by means of other special arrangement approved by the Society.

2.4.5 When tidal currents are present the experiment should normally be conducted at or around slack tide.

2.4.6 The ship's gangway should be in the stowed position and any shore gangway removed during the inclining test. As few cables, hoses, etc., as possible should be connected to shore. Those which are needed shall be slack.

2.4.7 The test should not be conducted under adverse wind, wave and current conditions where the accuracy of the results cannot be assured.

2.5 Inclining Weights

2.5.1 For the inclining test, solid inclining weights normally should be used.

2.5.2 Use of water ballast transfer to incline the vessel may be permitted only in cases where it is impractical to incline the vessel using solid weights. If the transfer of water ballast is to be used, a detailed procedure, including calculation procedure, is to be submitted to the society for approval prior to the experiment.

2.5.3 The total weight used should be sufficient to provide a minimum inclination of one degree and a maximum of four degrees of heel to each side of the

initial position. However, in those cases where it is absolutely impractical to reach a minimum angle of 1 degree by use of solid weights or waterballast, a lesser inclination angle may be accepted, provided that the requirements on pendulum deflection or U-tube difference in length in 2.6.1 are complied with.

2.5.4 Each weight is to be compact, impervious to water and shaped so that its centre of gravity may be accurately determined. It is recommended that not fewer than four weights (or sets of weights) be used, each approximately equal in mass, and that the inclining weights (or sets of weights) be positioned as symmetrically as possible and parallel to the centre line in places convenient for the shifting of weights and measurement of the arms.

2.5.5 Each inclining weight should be marked with an identification number. The inclining weights should have been weighted with a calibrated instrument to the satisfaction of the Surveyor.

2.6 Pendulums and Instruments.

2.6.1 The use of three measuring devices is recommended to determine the vessel's inclination after each weight shift, however, a minimum of two devices should be used, one of which is to be a pendulum or U-tube arrangement. The length and arrangement of pendulum / U-tube are to be such as to ensure the accuracy of the readings of deflection / difference. The minimum deflection / difference, to each side of the initial position, corresponding to the total weight shift, should be 15cm.

2.6.2 The use of a stabilograph is also acceptable provided the calibration of the instrument has been verified to the Surveyor's satisfaction prior to the experiment. A trace of the recorded heel pattern is to be included in the test report.

2.7 Trim and Stability.

2.7.1 The vessel should be upright prior to the inclining. However, an initial list of the ship not exceeding 0.5° is permitted.

2.7.2 Excessive trim should be avoided. Excessive trim, or changes in waterplane shape, would cause the vessel to heel, and the effect on the ship is

heeled. Such features should be taken into account to select a suitable draught and trim for the test.

- 2.7.3 The persons conducted the test should be satisfied that the vessel has adequate, positive stability and acceptable stress levels during the test. The estimated initial metacentric height should be at least 0.20m.

3. Inclining Test and Record of Data.

3.1 *Person in Charge*

A competent person should be designated in charge of the preparation and execution of the inclining test.

3.2 *Accuracy of Data*

Measurement of Inclining Test data is to be as accurate as possible and to the satisfaction of the attending Surveyor.

3.3 *Draught and Water Density Measurements.*

- 3.3.1 Draught / freeboard should be measured immediately before and verified after the test, to ensure that no significant changes in vessel's condition have occurred during the test.
- 3.3.2 Draught / freeboards should be measured at fore and aft and midship draught marks at both sides. If the freeboards are not measured from the upper edge of deck line at side of freeboard deck or at the same frame locations as the draught marks, the locations and vertical datum must be stated.
- 3.3.3 A suitable boat with low freeboard should be available for the draught measurements.
- 3.3.4 To control the correctness of draught measurements, it is recommended to plot two waterlines by draught readings and by measured values of the freeboard when the latter is available. With correct measurement, both waterlines are to coincide. In case of non-coincidence of separate points, additional measurements should be taken.
- 3.3.5 Sufficient water samples are to be taken at suitable locations and depths to enable and accurate assessment of water density to be made.

3.4 Weight shifts and Inclination Measurements.

3.4.1 Two recommended procedures of shifting weights are shown in table 1.

Weight Shifts	Four		Six	
	PS	SB	PS	SB
No. 0	2, 4	1, 3	2, 4, 6	1, 3, 5
No. 1	4	1, <u>2</u> , 3	4, 6	1, <u>2</u> , 3, 5
No. 2		1, 2, 3, <u>4</u>		1, 2, 3, 4, <u>5</u> , 6
No. 3	<u>1</u>	2, 3, 4	<u>6</u>	1, 2, 3, 4, 5
No. 4	1, <u>3</u>	2, 4	<u>2</u> , <u>4</u> , 6	1, <u>3</u> , 5
No. 5	1, <u>2</u> , 3	4	<u>1</u> , <u>2</u> , <u>3</u> , 4, 6	5
No. 6	1, 2, 3, <u>4</u>		1, 2, 3, 4, <u>5</u> , 6	
No. 7	2, 3, 4	<u>1</u>	1, 2, 4, 6	<u>3</u> , <u>5</u>
No. 8	2, 4	1, <u>3</u>	2, 4, 6	<u>1</u> , 3, 5
PS and SB denotes port and starboard sides of ship respectively. The underlined numbers indicate the last weights or weight groups shifted.				

3.4.2 The inclining weight positions should be marked on the deck to ensure that consistency in placement is achieved. The transverse shift distance is to be as great as practicable and appreciable changes in longitudinal or vertical position when moving port to starboard and vice versa are to be avoided.

3.4.3 The pendulum length is to be measured from its point of suspension to the recording batten on which deflections are read.

3.4.4 Pendulum, or U-tube reading on the recording batten or scale can be registered by either of the following ways:

- on the final stable position of the pendulum or liquid column after stopping of ship motions due to shifting of the inclining weight;
- by making the mean value within the range of residual oscillation.

3.4.5 When using other devices, angles of inclination are to be recorded according to instructions supplied with each device.

3.4.6 Checks should be made in the process of the inclining test for each measuring device. These will, generally, be a progressive plot of angles of heel against heeling moments which should give a series of points lying about a straight line passing through (or close to) the origin.

If there is a deviation of points, either between the points for a particular weight movement, or from the straight line, the deflections and moments should be checked and corrected prior to the next weight movement.

- 3.4.7 Personnel should be instructed to remain on their assigned positions while inclination readings are being taken and a check should be made that all mooring lines, etc., remain slack following each weight shift until all deflections have been taken and recorded

3.5 *Other Relevant Data*

- 3.5.1 In the case where the inclinations are carried out by means of transfer of water, it has to be possible to evaluate accurately the weight and the centre of the shifted liquid in relation to the ship's heel and trim.

- 3.5.2 The weather conditions, i.e., wind speed and direction relative to the vessel, sea state, air and water temperatures, etc., during the test are to be recorded.

4. Postponement of the Test

If during the course of an inclining test circumstances arise such that the aforesaid requirements are not complied with, the attending Surveyor should advise the Person in Charge that the results may not be accepted.

5. Test Report and Analysis of Lightship Data

- 5.1 The Builder / Owner should incorporate the data gathered during the test into a comprehensive test report, which may be combined with the analysis of the lightship data. Test readings not used in the final analysis should still be recorded in the report.

- 5.2 The Surveyor is to ensure that the data given in the report is consistent with that gathered during the test and to sign the report.

- 5.3 The inclining test report and analysis combined with the report or separately, should be submitted to the Society for review and acceptance of results as the basis for approval of the stability information of the ship.

Example:

1. An inclining experiment is carried out on a vessel completing fitting out. The following data is noted.

Displacement as inclined	10000 tonnes
Mass of inclining weights	20 tonnes
Distance weights shifted transversely	15 m
Length of pendulum	10.0 m
Mean deflection of pendulum	12 Cm
Kg of inclining weights	12 m
KM of vessel from hydrostatic scales	8.50 m

Calculate the GM of the vessel as inclined. A tank containing 160 tonnes of fresh water is full at the time of the experiment. Kg of the water 1.5m. Calculate the light ship KG of the vessel.

$$\tan \theta = \frac{GG_1}{GM} = \frac{d \times w}{W \times GM}$$

$$\text{Or } \frac{\text{Deflection}}{\text{Length}} = \frac{d \times w}{W \times GM}$$

$$\text{Or } GM = \frac{\text{Length of pendulum} \times d \times w}{W \times \text{Deflection of pendulum}}$$

$$= \frac{10 \times 15 \times 20}{10000 \times 0.12}$$

$$= 2.50 \text{ m}$$

$$KG = KM - GM$$

$$= 8.50 - 2.50$$

$$= 6 \text{ m}$$

TO FIND LIGHT KG

Weight	KG	Moment	Weight	KG	Moment
10000	6	60000	20	12	240
-180		480	160	1.5	240
9820		59520	180		480

$$\text{Light ship KG} = \frac{59520}{9820} \text{ m}$$

$$= 6.06 \text{ m}$$

$$= 6.06 \text{ m}$$

INCLINING TEST

Exercise 15

1. A weight of 25 tonnes is shifted transversely for a distance of 10 metres across the deck of a ship. A plumb-line, which is suspended 4.0 metres above a horizontal batten moves out for a distance of 0.300 metres along the batten. If the ship's displacement is 4950 tonnes, what is her GM, assuming that she was upright at the beginning?

2. In an inclining experiment, a weight of 12.5 tonnes KG 15m, was moved 10 metres across the deck and caused a plumb-line, 12 metres long, to move out 32 centimetres. A double-bottom tank in the ship was full of water, which weighed 450 tonnes and had its centre of gravity 0.90 metres above the keel; otherwise the ship would have been in the light condition. If the ship's displacement at the time of the experiment was 3750 tonnes and her KM was 9.00 metres, find:-
 - (a) The KG at the time of the experiment.
 - (b) The light KG.

3. A box-shaped barge of length, 100m; breadth, 10m; depth 6m is floating at a draft of 2m in fresh water.
 A weight of 1 tonne is moved 8m transversely across the deck, deflecting a pendulum 5m long by 0.05m.
 What will be the GM of the vessel of loading a 200 tonne weight at a KG of 7m?

4. When a weight of 20 tonnes is moved 12m across the deck of the vessel to which the following data applies the vessel heels $0^{\circ} 24'$. Find the KG as inclined.
 Vessel floating at an even keel draft of 8m in salt water. Underwater volume 15000m^3 , KB, 4.7m. Length of 8m waterplane 120m. Half ordinates of the 8m waterplane are

Station	0	1	2	3	4	5	6
$\frac{1}{2}$ Ord.	0	7	8	9	9	6	0m

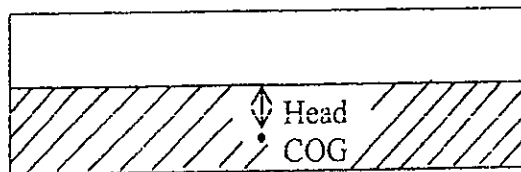
ANSWERS

1. 0.673 m
2. (a) 7.75 m (b) 8.66 m
3. KG as inclined 4.76 m
GM after loading weight = -0.08 m (unstable)
4. I_{cl} 33928.9 m⁴ KM = 6.962 m KG = 4.726 m

-oOo-

CHAPTER XVII

THRUST AND CENTRE OF PRESSURE



Water pressure : The water pressure at any depth is because of water above it. It increases uniformly as the depth of water / liquid increases. A point on the water surface will have zero pressure because there is no water above it. If we consider an area of water $1\text{ m} \times 1\text{ m}$ depth of which is 1 m below the top level of water, then there is $1 \times 1 \times 1 = 1\text{ m}^3$ of liquid above this area and if the density of water is δ tonnes/cub meter, the weight of the water above this area would be δ tonnes. Thus the pressure on this area will be δ tonnes per sq. meter. If the total area at this level (1 m below surface) is A then thrust will be total area $\times$ Pressure $= A \times \delta$ tonnes.

Similarly 2 meters below the top surface of water, pressure will be $= 2\delta$ tonnes/sq. meter & thrust will be $2A\delta$ tonnes.

Thus we can generalize the following expression:

$$\text{Pressure} = \delta \times h \text{ tonnes / sq. meter.}$$

$$\text{Thrust} = \delta \times h \times A \text{ tonnes}$$

Where

Head $= h =$ the depth of center of gravity of liquid below the surface

$\delta =$ The density of water in tonnes / m^3 &

$A =$ The area in sq. meter.

The centre of pressure is that point at which the resultant thrust on an immersed surface may be considered to act. The centre of pressure can be worked out as follows:

$$\text{C.O.P.} = \frac{I_{WL}}{A \cdot \text{head}}$$

$$I_{WL} = IG + Ah^2$$

where I_{WL} is the moment of inertia of water plane area about the top of water level and I_G is the moment about COG and h is the distance between top of water level and COG of the liquid.

1. A deep tank bulkhead 12m broad, 8m deep has S.W. water in tank. Calculate the thrust and posn of the cop with respect to top of bulkhead when the tank Sounding is (a) 6 mtrs (b) 8 mtrs (c) 11 mtrs

(a) **Thrust** = $A \times \delta \times \text{head}$

$$= 12 \times 6 \times 1.0 \times 3$$

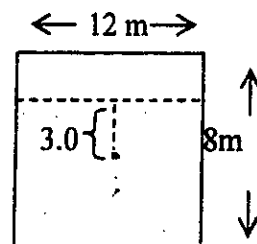
$$= 216 \text{ t}$$

$$I_{WL} = I_G + Ah^2$$

$$= \frac{12 \times 6^3}{12} + 12 \times 6 \times (3)^2$$

$$= 216 + 648$$

$$= 864$$



$$\text{COP below W/L} = \frac{I_{WL}}{A \times \text{hd}} = \frac{864}{12 \times 6 \times 3} = 4 \text{ mtrs}$$

CP from top of bulkhead = 6 mtrs.

(b) **Thrust** = $A \times \delta \times \text{hd}$

(8 mtrs)

$$= 12 \times 8 \times 1.0 \times 4.0 = 384 \text{ t}$$

$$I_{WL} = I_G + Ah^2$$

$$= \frac{12 \times 8^3}{12} + 12 \times 8 \times (4)^2$$

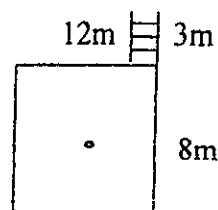
$$= 512 + 1536$$

$$= 2048$$

$$\therefore \text{COP below W/L} = \frac{I_{WL}}{A \times \text{hd}} = \frac{2048}{12 \times 8 \times 4} = 5.333 \text{ mtrs}$$

COP from top of bulkhead = 5.333 mtrs.

(c) **Thrust** = $A \times \delta \times hd$
 $= 12 \times 8 \times 1.0 \times 7.0$
 $= 672 \text{ t}$



$\therefore hd = 4 + 3 = 7 \text{ mtrs}$

$$I_{WL} = I_G + Ah^2$$

$$= \frac{12 \times 8^3}{12} + 12 \times 8 \times 7^2$$

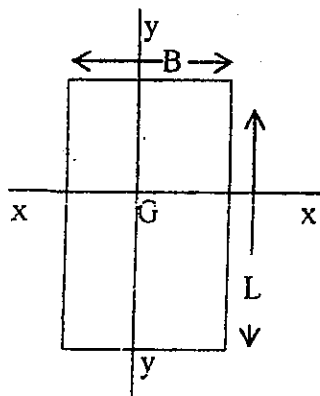
$$= 512 + 4704 = 5216$$

$$\text{COP below W/L} = \frac{I_{WL}}{A \times hd} = \frac{5216}{12 \times 8 \times 7.0} = 7.762 \text{ mtrs}$$

From top of bulkhead = 4.762 mtrs

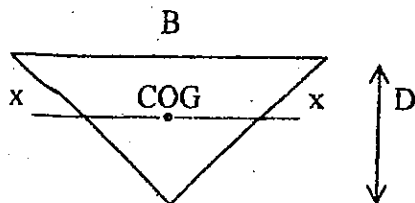
Analysis : For rectangular areas, provided water is below or at top of bulkhead COP is 2/3 its height below water line.

Moment of inertia of regular shapes.

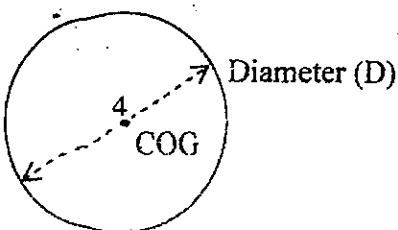


$$I_{yy} = \frac{LB^3}{12}$$

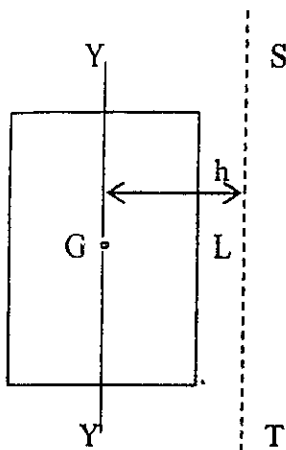
$$I_{xx} = \frac{BL^3}{12}$$



$$I_{xx} = \frac{BD^3}{36}$$

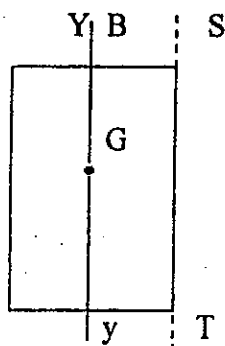


$$\left[\begin{array}{l} I_D \\ \text{Moment} \\ \text{about diameter} \end{array} \right] = \frac{\pi D^4}{64} = \frac{\pi r^4}{4}$$



$$I_{ST} = I_{yy} + Ah^2$$

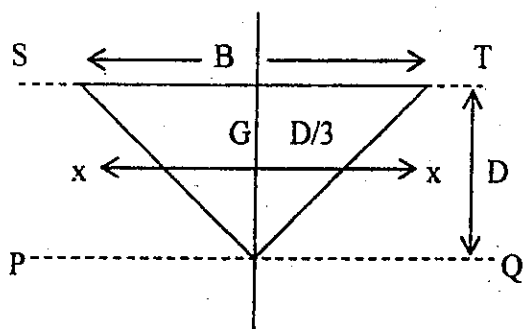
Theorem of parallel axes : The moment of inertia of an area about any axis parallel to an axis through its centroid is equal to the sum of moment of inertia of area about the axis through its centroid and product of the area and square of distance separating the axis.



$$I_{ST} = I_{yy} + Ah^2$$

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

$$= \frac{LB^3}{12} + \frac{LB^3}{4} = \frac{LB^3}{3}$$



$$I_{ST} = I^{xx} + Ah^2$$

$$= \frac{BD^3}{36} + \left[\frac{1}{2}BD \cdot \frac{D^2}{9} \right]$$

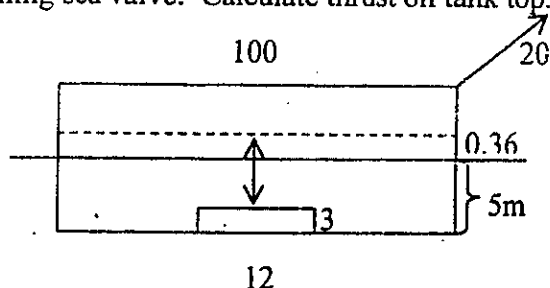
$$= \frac{BD^3}{36} + \frac{BD^3}{18} = \frac{BD^3}{12}$$

$$I_{PQ} = I_{xx} + Ah^2$$

$$= \frac{BD^3}{36} + \left[\frac{1}{2}BD \cdot \frac{4D^2}{9} \right]$$

$$= \frac{BD^3}{36} + \frac{2BD^3}{9} = \frac{BD^3}{4}$$

2. A box shaped vessel 100m X 20m at an E.K. draft of 5m has double bottom tank 3m deep, 12m long extending the full width of vessel at mid length. This tank is run up by opening sea valve. Calculate thrust on tank top.



$$\text{Thrust} = A \times \delta \times \text{head}$$

$$\text{TPC} = \frac{1.025 A}{100} = \frac{1.025 \times 100 \times 20}{100} = 20.5 \text{ t/cm}$$

$$\text{Mean Sinkage} = \frac{\text{Lost volume}}{\text{Intact Area}}$$

$$\text{Wt. of ballast} = 12 \times 20 \times 3 \times 1.025 = 738 \text{ t}$$

$$\text{Sinkage} = \frac{738}{20.5} = 36 \text{ cm}$$

$$= \frac{12 \times 20 \times 3}{100 \times 20}$$

$$\therefore \text{New draft} = 5.36 \text{ m}$$

$$= 0.36 \text{ m}$$

$$\text{hd} = 5.36 - 3 = 2.36 \text{ m}$$

$$\text{Mean Sinkage} = 36 \text{ cm}$$

$$\therefore \text{Thrust} = 12 \times 20 \times 1.025 \times 2.36 = 580.56 \text{ t}$$

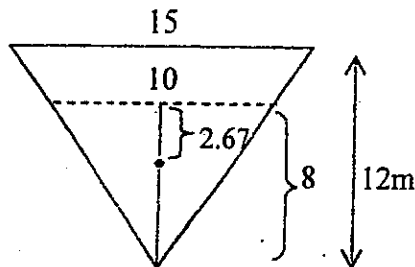
3. A triangular collision bulkhead is 15 m broad at top and 12 m deep. The F.P.K tank contains ballast of R.D. 1.015. Calculate thrust on bulkhead and posn. of COP below top of the bulkhead when sndg in tank is (a) 8 mtrs (b) 12 mtrs (c) 14 mtrs.

$$\text{for 12 mts } \xrightarrow{\text{Base is}} 15 \text{ mts}$$

$$\therefore 8 \text{ m} = 10 \text{ mts base}$$

$$\text{GC} = \frac{1}{3} \text{ draft} = \frac{8}{3} \text{ mts} = 2.67 \text{ mts}$$

$$A = \frac{1}{2} \times 10 \times 8 = 40 \text{ m}^2$$



$$\text{Thrust} = A \times \delta \times \text{head}$$

$$= 40 \times 1.015 \times 2.67 = 108.40$$

$$I_{WL} = I_G + Ah^2$$

$$= \frac{10 \times 8^3}{36} + 40 \times 2.67^2 \left[\frac{BD^3}{36} + Ah^2 \right]$$

$$= 142.22 + 285.16 = 427.38$$

$$\text{COP below WL} = \frac{I_{WL}}{A \times hd} = \frac{427.38}{40 \times 2.67} = 4.0 \text{ mtrs}$$

COP below top of bulkhead = 8.0 mtrs.

(b) **Thrust** = $A \times \delta \times hd$

Area = $\frac{1}{2} \times 11.25 \times 9$

$$= 50.625 \text{ m}^2$$

$$\therefore \text{thrust} = \frac{1}{2} \times 15 \times 12 \times 1.015 \times 4$$

$$= 365.4 \text{ t}$$

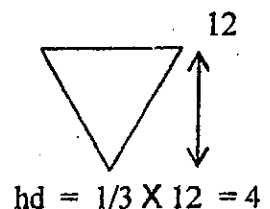
$$I_{WL} = I_G + A.h^2$$

$$= \frac{15 \times 12^3}{36} + \frac{1}{2} \times 15 \times 12 \times 4^2 = 2160$$

$$\therefore \text{COP below W/L} = \frac{I_{WL}}{A \times hd}$$

$$= \frac{2160}{\frac{1}{2} \times 15 \times 12 \times 4} = \frac{2160}{90 \times 4} = 6 \text{ m}$$

$\therefore$ COP below top of bulkhead = 6 m



(c) **Sndg** = 14 mts

Thrust = $A \times \delta \times hd$

Area = $\frac{1}{2} \times 12 \times 15 = 90 \text{ m}^2$

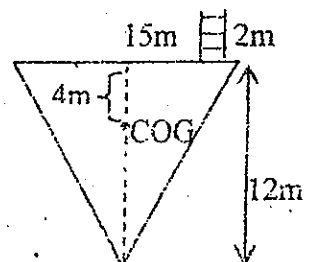
$$\therefore \text{Thurst} = 90 \times 1.015 \times 6 = 548.1 \text{ t}$$

$$I_{WL} = I_G + A.h^2$$

$$= \frac{15 \times 12^3}{36} + 90 \times 6^2$$

$$= 720 + 3240 = 3960$$

$$(\text{hd} = \frac{1}{3} \times 9 = 3 \text{ m} + 2 = 5 \text{ m})$$



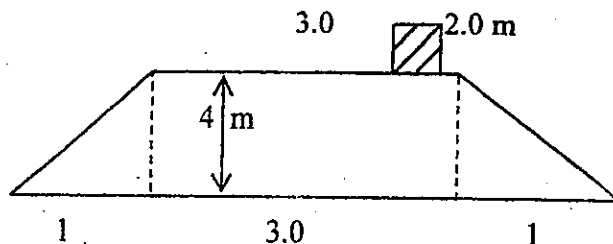
$$\text{COP from W/L} = \frac{I_{WL}}{A \cdot hd} = \frac{3960}{90 \times 6} = 7.333 \text{ mtrs.}$$

COP from top = 5.333 mtrs.

Analysis : For triangle apex down, for water level below or at top of bulkhead, the C.O.P. is $\frac{1}{2} \times$ depth below water level.

4. A vertical bulkhead is in form of a regular trapezium, width at top is 3 mts and bottom 5 mts. Bulkhead is 4m deep. Calculate thrust and posn. of COP with respect to bottom of bulkhead when tank contains oil of RD 0.90 to sounding of 6 mts.

$$\text{COP below W/L} = \frac{I_{WL}}{A \cdot hd}$$



$$I_{\square WL} = \frac{3 \times 4^3}{12} + 3 \times 4 \times 4^2$$

$$= 16 + 192 = 208$$

$$I_{\triangle WL} = \frac{BD^3}{36} + A \times h^2$$

$$= 2 \left[\frac{1 \times (4)^3}{36} + \frac{1}{2} \times 1 \times 4 \times 4.67^2 \right]$$

$$= 2 [1.78 + 43.62] = 90.8$$

$$A = \frac{1}{2} (3 + 5) \times 4 = 16 \text{ m}^2$$

$$\text{CG from top} = \frac{(3 \times 4 \times 2) + 2 \times (1/2 \times 1 \times 4) \times 2.67}{16}$$

$$= \frac{24 + 10.68}{16} = 2.17$$

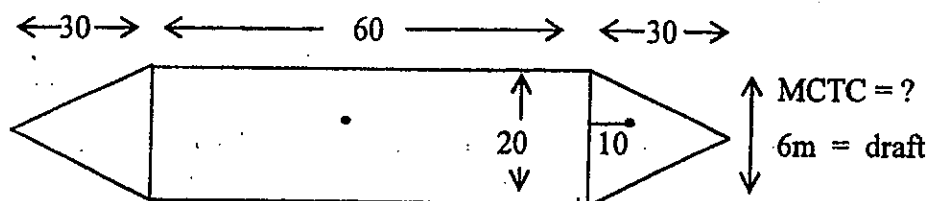
$$\text{COP} = \frac{208 + 90.8}{16 \times 4.17} = 4.48 \text{ mtrs}$$

$$\text{COP from bottom} = 1.52 \text{ m}$$

$$\text{Thrust} = 16 \times 0.90 \times 4.17$$

$$\text{Thrust} = 60.05 \text{ t}$$

5. A vessel of constant W/P as shown below has $KG = 4.8\text{m}$. Calculate her MCTC if she floats in SW at an even keel draft of 6.0m . Depth of the vessel is 6m .



$$KB = \frac{1}{2} \text{ draft} = 3.0\text{m}$$

$$BM_L = \frac{I}{V} = \frac{I_{\square}}{V} + 2 \frac{I_{\Delta}}{V}$$

$$I_{\square} = \frac{BL^3}{12} = \frac{20 \times 60^3}{12} = 36 \times 10^4$$

$$I_{\Delta} = \frac{BD^3}{36} + \left(\frac{1}{2} \times 20 \times 30 \times 40^2\right)$$

$$= \frac{20 \times 30^3}{36} + 10 \times 30 \times 40^2$$

$$= 15000 + 480000$$

$$= 495000 = 49.5 \times 10^4$$

$$\therefore I = I_{\square} + 2 I_{\Delta}$$

$$= 36 \times 10^4 + 2 \times 495000$$

$$= 36 \times 10^4 + 99 \times 10^4$$

$$= 135 \times 10^4$$

$$\text{Volume of } W = (60 \times 20 + 2 \times \frac{1}{2} \times 30 \times 20) \times 6$$

$$= 10800 \text{ m}^3$$

$$BM_L = \frac{I_{WP}}{V} = \frac{135 \times 10^4}{10800} = 125 \text{ m}$$

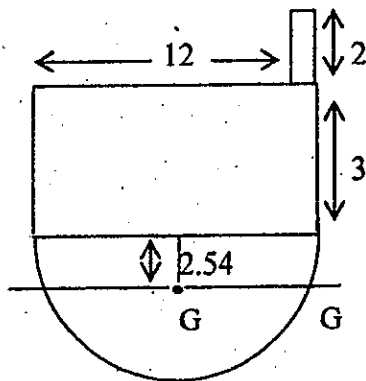
$$\therefore KM_L = KB + BM_L$$

$$= 3 + 125 = 128 \text{ m}$$

$$\therefore GM_L = KM_L - KG = 128 - 4.8 = 123.2 \text{ m}$$

$$\begin{aligned}
 \therefore \text{MCTC} &= \frac{W \times GM_L}{100 \times L} \\
 &= \frac{10800 \times 1.025 \times 123.2}{100 \times 120} \\
 &= \underline{113.652 \text{ tm}}
 \end{aligned}$$

6.



With respect to the adjacent figure,
calculate thrust and posn of COP with
respect to top of bulkhead,

Area of rectangle + Area of Semi Circle. =
Area of full body

$$\text{C.O.G. of semicircle} = \frac{4 \times 6}{3\pi} = 2.54 \text{ mts}$$

$$\text{Total area} = 12 \times 3 + \frac{\pi(6)^2}{2} = 92.571 \text{ m}^2$$

$$\text{COG} = \frac{36 \times 3.5 + 56.571 \times (5 + 2.54)}{92.571} = 5.969 \text{ mtrs}$$

Below W/L

$$\text{Thrust} = 92.571 \times 1.025 \times 5.969 = 566.37 \text{ T}$$

$$\text{COP} = \frac{I_{WL} \square + I_{WL} \ominus GG}{A \cdot hd}$$

Below WL

$$= \frac{I_{WL} \square + I_{\ominus} - Ah^2 + Ah^2}{A \times hd}$$

$$= \frac{\left\{ \frac{12 \times (3)^3}{12} + 12 \times 3 \times (3.5)^2 + \frac{\pi \times (6)^4}{4 \times 2} - \frac{\pi(6)^2 \times (2.54)^2}{2} + \frac{\pi(6)^2 \times (7.54)^2}{2} \right\}}{92.571 \times 5.969}$$

$$= \frac{27 + 441 + 509.14 - 364.976 + 3216.18}{552.556}$$

$$= \frac{3828.34}{552.556}$$

$$= 6.93 \text{ mtrs.}$$

$\therefore$ Cop below top of bulkhead = 4.93m

7. A rectangular bulkhead is 12m broad and 8m deep. The tank contains liquid and COP is 3.0 m above the bottom of bulkhead. Calculate sndg of tank.

Taking the tanks as just full of liquid, the COP = $8 \times 2 / 3 = 5.33$ below liquid level. Since it is only 5m below liquid level, the liquid is above the top of the tank. Let us say it is x mtrs.

$$\text{COP} = \frac{I_{WL}}{A \cdot \text{hd}}$$

$$(5 + x) = \frac{\left[\frac{12 \times 8^3}{12} \right] + 12 \times 8 \times (4 + x)^2}{(12 \times 8) (4 + x)}$$

$$(5 + x) = \frac{512 + 96(4 + x)^2}{96(4 + x)}$$

$$96[(5 + x)(4 + x)] = 512 + 96(4 + x)^2$$

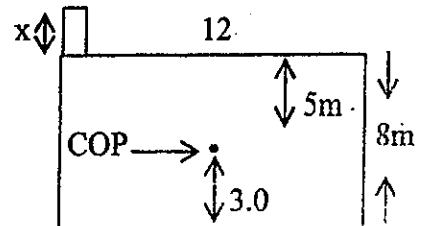
$$96[20 + 4x + 5x + x^2] = 512 + 96(16 + x^2 + 2 \times 4x)$$

$$1920 + 864x + 96x^2 = 512 + 1536 + 96x^2 + 768x$$

$$96x = 128$$

$$x = 1.33 \text{ mtrs}$$

$$\therefore \text{Sndg} = 8 + 1.33 = 9.33 \text{ mtrs.}$$



8. A deep tank bulkhead 10m deep has following equally spaced horizontal ordinates commencing from top. Tank contains SW to a Sndg of 12 mts. Calculat thrust and position of COP w.r.t. top of bulkhead.

Ordinates	SM	Product for area	Levers	Product for moment	Levers	Product for M.I.
8.0	1	8	0h	0h	0h	0h ²
7.5	4	30	1h	30h	1h	30 h ²
6.8	2	13.6	2h	27.2h	2h	54.4 h ²
5.8	4	23.2	3h	69.6h	3h	208.8 h ²
4.5	1	4.5	4h	18h	4h	72 h ²
		<u>79.3</u>		<u>144.8h</u>		<u>365.2 h²</u>

$$h = 10/4 = 2.5\text{m}$$

$$\text{Area} = \frac{79.3 \times 2.5}{3} = 66.08\text{m}^2$$

$$\text{Moment of Area} = \frac{2.5 \times 144.8 \times 2.5}{3} = 301.67$$

$$\text{Moment of Inertia from top} = \frac{2.5 \times 365.2 \times 2.5 \times 2.5}{3} = 1902.08\text{ m}^4$$

$$\text{CG} = \frac{301.67}{66.08} = 4.56\text{m}$$

$$\text{Thrust} = A \times \delta \times h_d$$

$$= 66.08 \times 1.025 \times 6.56 = 444.32\text{ t}$$

$$\text{M.I. about CG} = 1902.08 - 66.08 \times (4.56)^2 = 528.04$$

$$\text{Shift of inertia about CG} = \text{Moment of Inertia about top bulkhead} - Ah^2$$

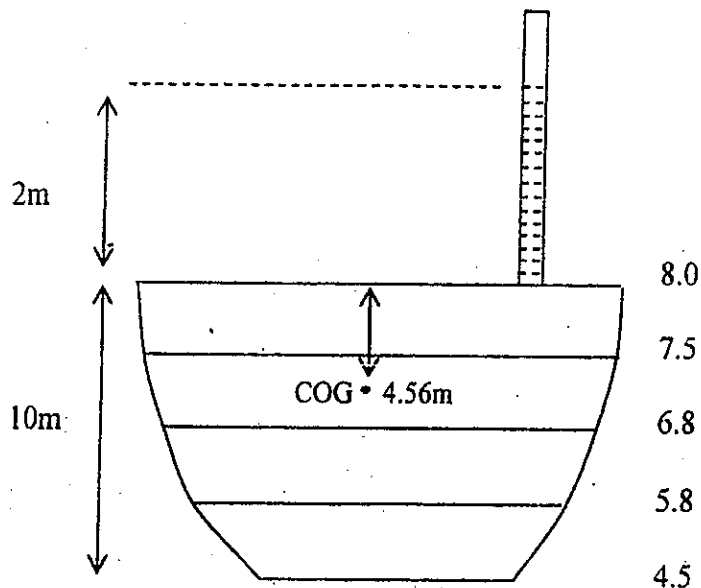
$$\text{M.I. about W/L} = 528.04 + 66.08 \times (6.56)^2$$

$$= \text{Moment of inertia about CG} + Ah^2$$

$$= 3371.7$$

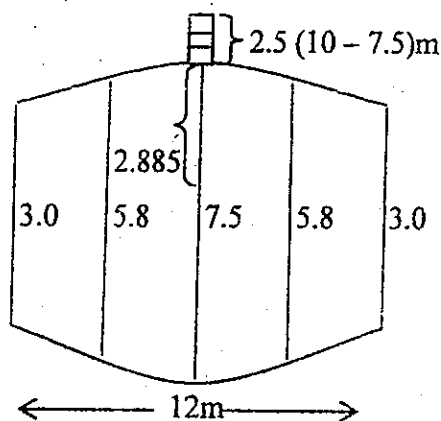
$$\text{COP} = \frac{3371.7}{66.08 \times 6.56} = 7.78\text{ mtrs below W.L.}$$

$$\therefore \text{COP below top of bulkhead} = 5.78\text{ m}$$



9. A deep tank bulkhead 12m broad has the following equally spaced vertical ordinates 3.5, 5.8, 7.5, 5.9 and 3.0. The tank contains SW to a sndg of 10m. Calculate thrust on bulkhead and COP w.r.t. top of bulkhead.

$$h = 12/4 = 3.0 \text{ m}$$



Ord	SM	Product for area	Ord ²	SM	Product for moment	Ord ³	SM	Product for M.I.
3.0	1	3.0	9.0	1	9.00	27.000	1	27.000
5.8	4	23.2	33.64	4	134.56	195.112	4	780.448
7.5	2	15	56.25	2	112.50	421.875	2	843.750
5.8	4	23.2	33.64	4	134.56	195.112	4	780.448
3.0	1	3.0	9	1	9.00	27.000	1	27.000
	S _A	67.4		S _{MA}	399.62		S _{MI} Top	2458.646

$$\text{Area of bulkhead} = \frac{1}{3} \times 3 \times 67.4 = 67.4 \text{ m}^2$$

$$\text{Moment of Area} = \frac{1}{3} \times \frac{1}{2} \times 3 \times 399.62 = 198.81$$

$$\text{M.I. top of bulkhead} = \frac{1}{3} \times \frac{1}{3} \times 3 \times 2458.646 = 819.548$$

$$\therefore \text{CG of bulkhead} = \frac{\text{Moment of area}}{\text{area}} = \frac{198.81}{67.4} = 2.95 \text{ m}$$

$$\therefore \text{hd} = 2.5 + 2.95 = 5.45 \text{ m}$$

$$\text{M.I. @ C.G.} = 819.548 - 67.4 \times (2.95)^2 = 232.999$$

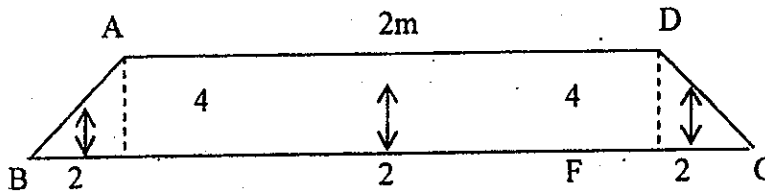
$$\text{M.I. @ W.L.} = 232.999 + 67.4 \times (5.45)^2 = 2234.95$$

$$\therefore \text{COP} = \frac{2234.950}{67.4 \times 5.45} = 6.08 \text{ m}$$

Below WL

$$\text{COP top of bulkhead} = 6.08 - 2.50 = 3.58 \text{ m}$$

$$\text{Thrust} = 67.4 \times 1.025 \times 5.45 = 376.51 \text{ T}$$



10. (a) Calculate the thrust on bulkhead and position of CP when ballast of R.D. 1.020 stands to one side of it, to its full depth.

(b) Also calculate the thrust if the bulkhead is inclined at 30° to vertical, with ballast standing on top of inclined bulkhead?

Solution :

$$\text{Thrust} = A \times \text{hd} \times \delta$$

$$\begin{aligned} \text{Area} &= \frac{1}{2} \times 2 \times 4 \times 2 + (2 \times 4) \\ &= 16 \text{ m}^2 \end{aligned}$$

$$\text{COG of } \square = 2 \text{ m.}$$

$$\text{COG of } \triangle = \frac{1}{3} \times 4 = 1.333$$

Taking moments about keel

$$\text{COG} = \frac{(4 \times 2 \times 2) + 2 \times (\frac{1}{2} \times 2 \times 4 \times 1.333)}{16}$$

$$= \frac{16 + 10.664}{16} = 1.667 \text{ m}$$

$$H_d = 4 - 1.667 = 2.333 \text{ m}$$

$$\text{Thrust} = 2.333 \times 16 \times 1.020 = 38.075$$

$$\text{COP} = \frac{I_{WL}}{A.h}$$

$$I_{WL} \text{ of } \square = \frac{2 \times 4^3}{12} + 2 \times 4 \times 2^2$$

$$= 10.67 + 32 = 42.67 \text{ m}^4$$

$$I_{WL} \text{ of } \triangle = 2 \left[\frac{2 \times 4^3}{36} + \frac{1}{2} \times 2 \times 4 \times (2.667)^2 \right]$$

$$= 2 [3.555 + 28.452]$$

$$= 2 \times 32.006$$

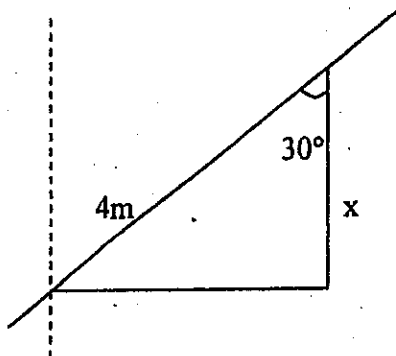
$$= 64.012 \text{ m}^4$$

$$\text{Total } I_{WL} = 42.67 + 64.012$$

$$= 106.682 \text{ m}^4$$

$$\text{COP} = \frac{106.682}{16 \times 2.333} = 2.858 \text{ m}$$

b)



$$\cos \theta = x/4$$

$$x = 4 \cos 30^\circ$$

$$= 3.464$$

$$\text{For height 4m COG} = 1.667 \text{ m}$$

$$\therefore \text{for height 3.464 COG} =$$

$$\frac{1.667 \times 3.464}{4} = 1.444 \text{ m from bottom}$$

$$\therefore H_d = 4 - 1.444 = 2.556 \text{ m}$$

$$\text{Thrust} = 2.55 \times 16 \times 1.020 = 41.616 \text{ t}$$

THRUST AND WATER PRESSURE

Exercise 16

1. A 12m high vertical bulkhead of a tank has the following equally spaced horizontal ordinates commencing from top:
8.8m 8.5m 8.2m 8.0m 7.6m 7.1m 6.0m
The tank is pressed up with seawater to a head of 2m above the top of the tank. Calculate the thrust on the bulkhead and the position of the COP above the tank's bottom.
2. A vertical bulkhead is in the form of a trapezium 2m broad on the top, 4m broad at the base and 3m deep. Calculate the thrust and center of pressure when the tank contains oil of RD 0.92 to a sounding of 4.5m.
3. A special tank has triangular bulkhead, apex upwards. The base of the triangle is 10 m and each of its sloping sides is 13m long. Calculate the distance of center of pressure from the base of bulkhead when the tank is filled with fuel oil of RD 0.95 to an ullage of 3.0m.
4. The vertical ordinates of a bulkhead measured downwards from the horizontal deck, at equal intervals are : 3, 5, 7, 8.5, 7, 5 and 3 meters. Find the position of the Centre of Pressure from the top of the bulkhead when liquid level is at the top of the bulkhead.
5. The height of the upper edge of deep tank bulkhead at equidistant intervals across it are 0, 3, 5, 6, 5, 3 and 0 meters respectively. Find the C.O.P. below W.L. if water is at the height of 2 meters above the top of the tank. Also find the thrust on the bulkhead if the tank is filled with salt water.
6. A 10 meter high vertical bulkhead of a tank has the following equally spaced horizontal ordinates commencing from top:
7.2m, 7.1m, 6.6m, 6.2m & 5.0m.
The tank is pressed up with seawater with a head of 1.5m above the top of the tank. Calculate the thrust on the bulkhead and the position of centre of pressure above the bottom of the tank.
7. A deep tank bulkhead is 6m in height. The horizontal half ordinates of the bulkhead at equal intervals, commencing from the top, are 2.82, 2.54 and 2.26m respectively. Calculate the thrust on the bulkhead when the tank contains salt water to a depth of 3m.
8. A vertical bulkhead is in the form of a trapezium with horizontal parallel edges of 2m at top and 6m at bottom. The bulkhead is 4m deep. Calculate the thrust on the bulkhead and the position of its CP when ballast of R.D. 1.016 stands to one side of it, to its full depth.

Also calculate the thrust if the bulkhead is inclined at 40° to the vertical. with the ballast standing to the top of the inclined bulkhead.

9. A vessel of constant water-plane of length 150m and maximum breadth 16m and water-plane coefficient 0.833 is at an even keel draft of 7.5m. She has a midship rectangular double bottom tank of length 19m, width 16m and depth 1.2m. Calculate the thrust on the tank top if that tank is run up by opening the sea valves.
10. A deep tank bulkhead 8 mts broad, 9 mts deep has saltwater in the tank. Calculate the thrust and position of C.O.P. with respect to top of the bulkhead when the tank sounding is (i) 6 mts (ii) 12 mts.
11. A square plate of side 'a' is vertical and is immersed in water with an edge of its length in the free surface. Prove that the distance between the centre of pressure of the two triangles into which the plate is divided by a diagonal, is $\frac{a\sqrt{13}}{8}$

-oOo-

ANSWERS

1. Thrust = 741.3 t C.O.P. = 4.779 m above the tank bottom.
2. Thrust = 26.22 t C.O.P. = 3.394 m below water level
3. C.O.P. from base of the bulkhead = 2.5 m
4. C.O.P. = 4.854 m
5. Thrust = 100.47 h where h is 1/6 of breadth of bulkhead at upper edge
C.O.P. below W.L. = 4.866 m
6. Thrust = 419.307 t, C.O.P. above bottom = 3.966 m
7. 21.71 t
8. Thrust = 37.925 t Centroid below W/L = 2.333 m
Portion of C.O.P. below W/L = 2.853 m
9. Thrust = 2207.06 t
10. (i) 7m (ii) 5.4 m

-oOo-

CHAPTER XVIII

THE DETERMINATION OF SHEAR FORCES AND BENDING MOMENTS IN SHIPS

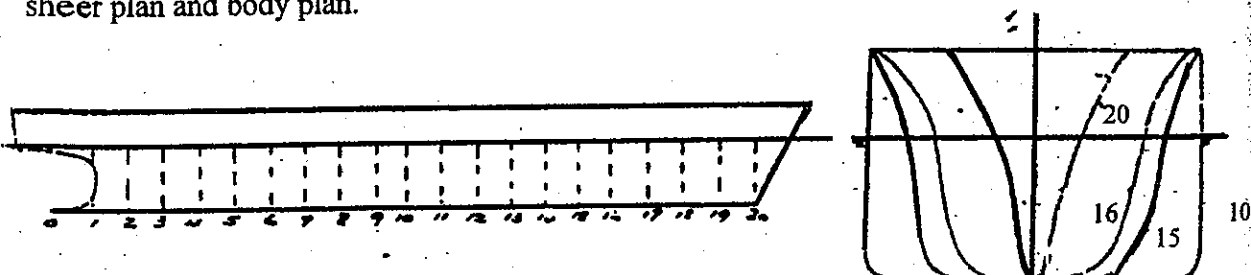
Two potentially serious effects to which a ship is subjected are shear forces and bending moments. It is obviously necessary to build the ship to a sufficiently standard of strength that it can withstand the shear forces and bending moments which may be imposed on it in all reasonable loaded conditions – not just in calm water but also in a seaway.

The builder / designer investigates a series of “reasonable loaded conditions” including ballast conditions, both in still water and (separately) in a seaway. Curves of shear force and bending moment which show the variation in value of these quantities along the hull are derived for each condition investigated. Because the shear forces and bending moments are the result of the ‘loads’ imposed on the ship, the builder must first derive the values of weight and buoyancy which give rise to these loads. Consequently five curves must be derived, namely the curves of buoyancy, weight, loads, shearing force and bending moment.

DERIVATION OF CURVES FOR STILL WATER

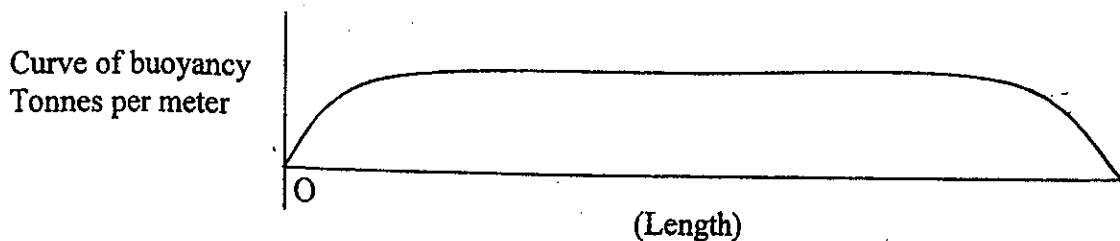
The ship is assumed to be laden or in ballast, with consumable stores, fuel etc. disposed in a way which accentuates the hog or sag which would arise from the cargo distribution.

The value of the force of buoyancy is derived from the lines drawings, in particular the sheer plan and body plan.

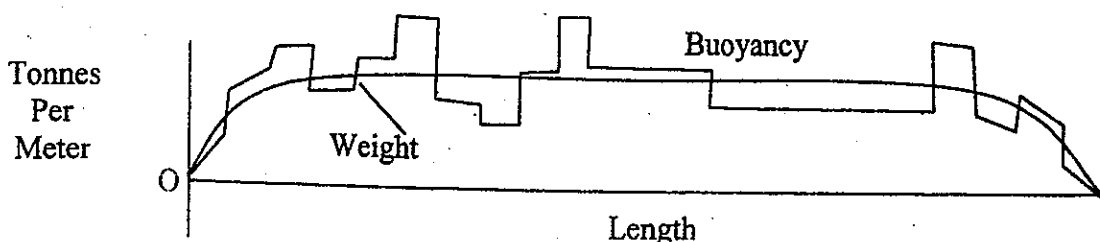


At each of a number of selected stations, possibly 21, the area of the immersed cross-section is found by Simpsons Rules. This area (m^2) is numerically the same as the

volume of water displaced (m^3) by a length of one metre at the station. The weight of water displaced, i.e. the upthrust, is (volume displaced $\times$ 1.025) tonnes. When this calculation is repeated for each of the sections a curve of buoyancy can be drawn, of this general nature.

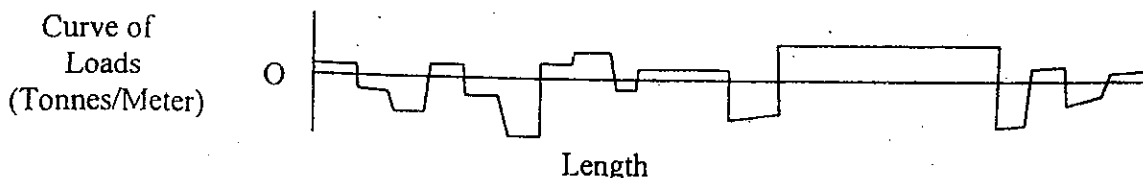


The ordinates of the curve of weight may be calculated by finding the total weight within one of the parts into which the ship is divided (possibly 20) and dividing this weight by the length of the part to obtain a 'mean weight per metre' for that part. Each of the values (possibly 20) is then plotted at the mid-point of the part to which it refers. The curve of the weight is drawn in portions, each portion approximately parallel to the curve of buoyancy in that vicinity as shown.

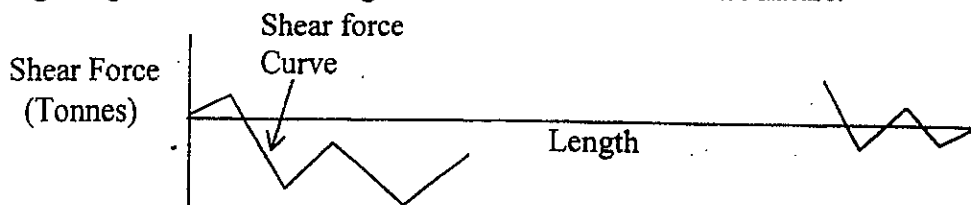


At this stage the builder will check that the area under each curve is the same (i.e. total weight equals total buoyancy) and that the centroids of the areas under the curves are in the same longitudinal positions (i.e. LCG is in line with LCB).

The ordinates of the curve of loads are the intercepts (differences) between the curves of weight and buoyancy. Because of the construction adopted earlier the load values give rise to a curve of loads, which appears as a series of level lines.

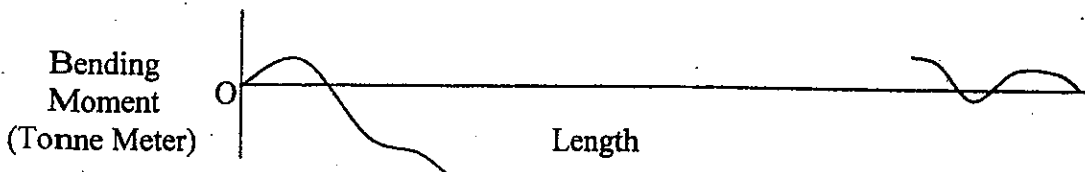


The shear force (tonnes) at any point is the algebraic sum of the loads to left or to right of the point. Integrating the curve of loads gives a shear force curve of this nature.



The shear force will obtain a maximum value (i.e. there will be a turning point on the shear force curve) where the load direction is reversed.

The bending moment (tonnes metre) at any point is the algebraic sum of the moments of the loads to left or to right but can be obtained by integrating the shear force curve with a result of this nature.

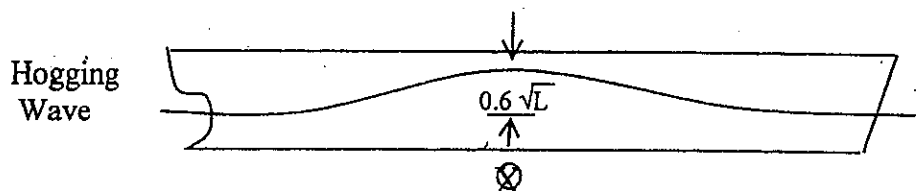


(If the algebraic sum of the moments of the loads to the left of the point is clockwise the ship will be sagging at that point.)

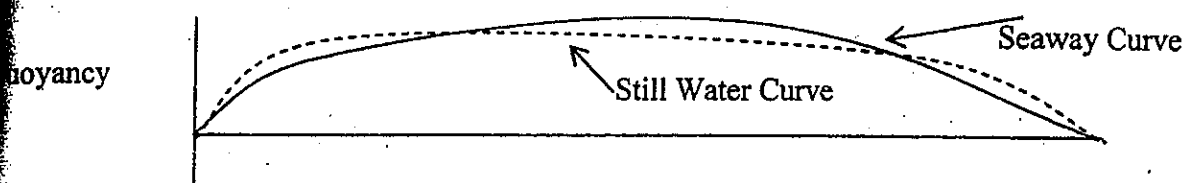
The SF and BM curves for still water naturally show the positions at which these effects attain their maximum values. The ship must (for a start, but see later) have adequate material, correctly disposed, to ensure that these values of SF and BM are well below the ultimate (failure) values of the structure.

DETERMINATION OF CURVES FOR A SEAWAY

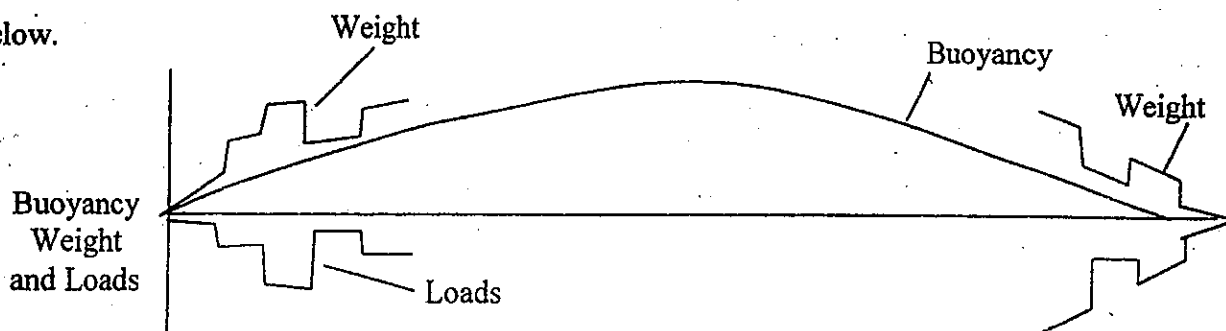
This ship is assumed to be laden (or ballasted) and poised momentarily on the crest, or in the trough of a trochoidal wave. The chosen wave has a length equal to the ships length and a wave height equal to $0.6 \sqrt{L}$ (M). Again the consumable stores, fuel etc are assumed disposed in a way which accentuates the hog, or sag (as the case may be), caused by the cargo deadweight and wave pattern.



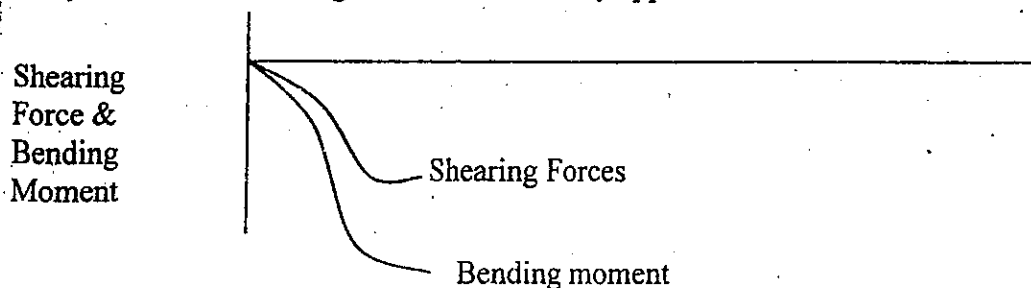
The value of the buoyancy at various points along the ship's length are again obtained from the lines drawings, - as outlined previously - and when plotted on a base of ship's length the curve of buoyancy will have the following representative shape shown for a hogging wave i.e. for a crest amidships. (For purposes of comparison the still water buoyancy curve is shown in broken line).



The curve of weight is obtained as previously described and comparison of the curves of weight and buoyancy gives the ordinates for the curve of loads. These curves are shown below.



Continuing as described earlier the builder obtains next the curve of shearing forces and lastly the curve of bending moments which may appear as shown.



It is to be expected that a ship which is subjected to a hogging bending moment in still water would be subjected to an even greater hogging bending moment in a seaway when

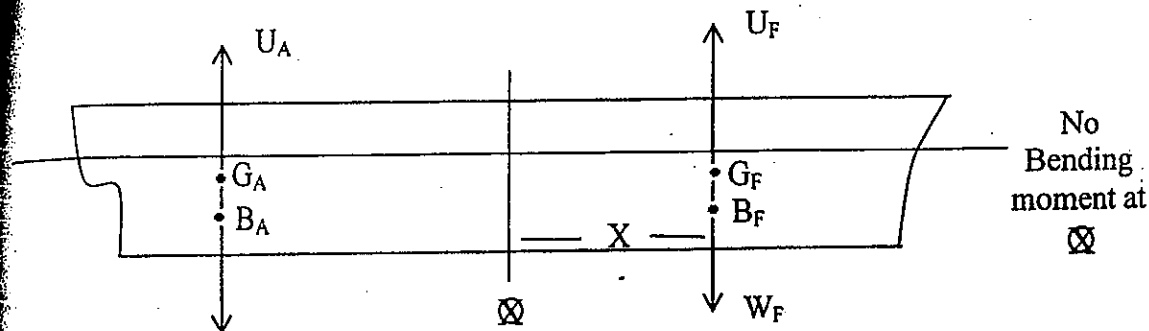
the wave crest was amidships, and the maximum shear forces would also be greater in a seaway than in still water. Similarly a ship which suffered a sagging bending moment in still water would suffer an even greater sagging moment when in a seaway with the wave trough amidships, - and again the shear forces would be greater than existed when in still water. The difference between the bending moments in a seaway and in still water is "the moment due to the wave"; the difference between still water and seaway shear forces is "the shear force due to the wave". The ship must of course be built to the standard of strength required to withstand, - with adequate safe margin, - these increased values of shear force and bending moment which are set up in a seaway.

Given that the ship has been completed to the strength standard required in the light of the previous calculations it means that when deciding on a safe distribution of deadweight for a SEA Voyage the values of shear force and bending moment which may be imposed are less than the values of shear force and bending moment which are acceptable as an "in-dock" condition. When it is known that the ship is not going to be subjected to the increase of shear force and bending moment which would arise from a wave form it is permissible to have a more extreme distribution of deadweight than would be allowable if the ship was to proceed to sea. When two sets of values of SF and BM are supplied to the ship, the lesser values are the limits being imposed for the still water condition if proceeding to sea and the GREATER values are acceptable if NOT proceeding to sea.

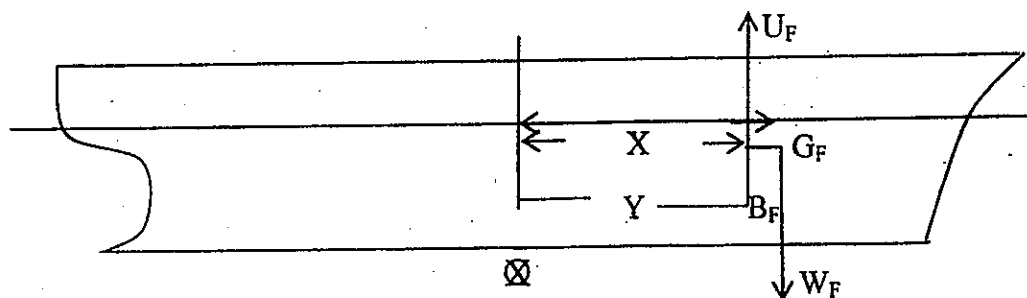
ALLOWABLE VALUES OF BENDING MOMENT

The bending moment which arises at amidships from any given condition of loading can be determined by finding :-

- (i) The weights and longitudinal centres of gravity (LCG) of the forward and aft halves of the ship, and
- (ii) The buoyancy and longitudinal centres of buoyancy (LCB) of each half. If the moments of weight and buoyancy in either half are equal there will be no bending moment amidships.



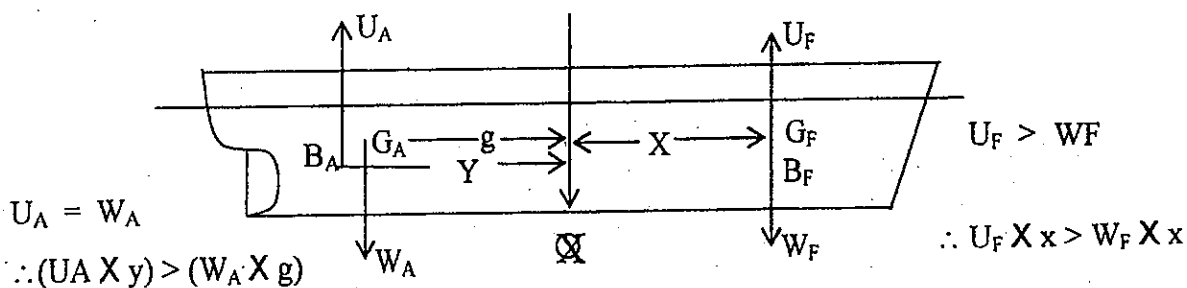
If, however, the moment of forward weight exceeds the moment of forward buoyancy (and the moment of aft weight exceeds the moment of aft buoyancy) the ship will hog. This condition would arise, for example, if weight and buoyancy were equal in the forward half but LCG was further forward than LCB – as shown.



$$\text{Bending moment (Hogging)} = (W_F X x) - (B_F X Y)$$

But hogging would also be caused by the forward weight being greater than the forward buoyancy when LCG and LCB were in the same longitudinal positions; and there are other possibilities.

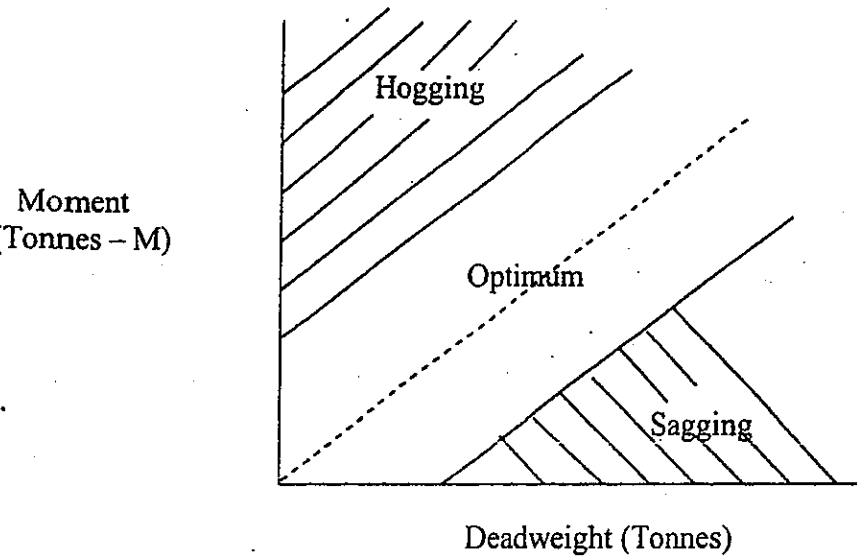
(When circumstances are reversed the ship will be sagged as shown below.)



However, if we consider only the hogging ships, - the builder can determine for any given even keel draught, the value of the forward moment of buoyancy (and, of course, the value of the aft moment of buoyancy). The sum of this moment and the permissible hogging bending moment for the ship (already known from a consideration of its

scantlings) determines the maximum allowable hogging weight moment. This is, in turn, made up of two parts, viz a known (fixed) value of hogging light weight moment and the variable hogging deadweight moment. By subtraction, therefore, the maximum allowable hogging deadweight moment is determined for the draught in question. A series of such calculations allows a curve of maximum allowable deadweight moments to be determined.

When a similar series of calculations is done for the sagging condition a second curve is obtained, a curve of minimum allowable deadweight moments. Both curves may be drawn against a scale of deadweight as shown.



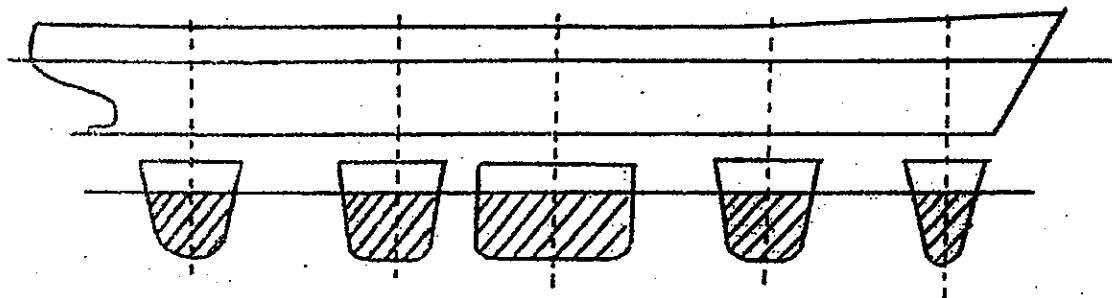
The optimum condition is on the central axis.

LONGITUDINAL BENDING

Hogging and sagging are caused by differences between the weight and buoyancy distributions along the ship's length. For a ship shape, on an even keel, the buoyancy varies throughout the length in accordance with the change in the volume of water displaced and this depends on the lines of the ship.

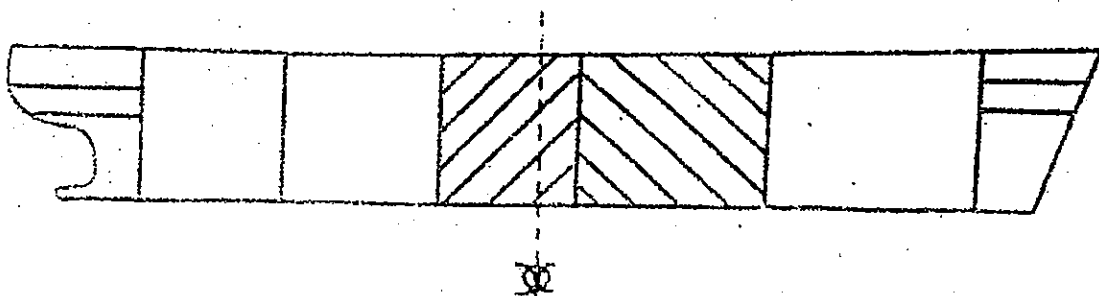
(Buoyancy = weight of water displaced = volume displaced X density; when volume displaced depends on the lines and draught of the ship).

To minimise bending (and shearing forces) the weight should be distributed to be as near equal to buoyancy at all points within the ship's length.

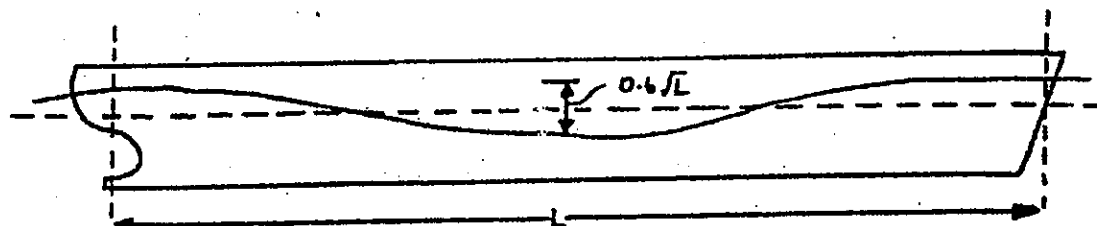


(To avoid bending, weight should be distributed to equal the buoyancy, depicted by the shaded cross sectional areas.)

Sagging will arise in calm water, if too great a proportion of the total deadweight is loaded at or near to amidships so that weight amidships exceeds buoyancy amidships. An extreme case would be where holds amidships were loaded before end holds.

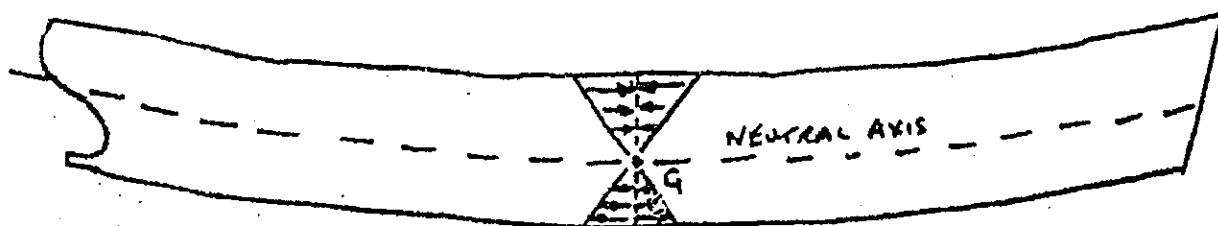


Longitudinal bending will also arise in another set of circumstances. In the case of a well-laden ship, being one which would not be subject to bending in still water, which then encounters waves. Sagging will occur when there is a trough at or near amidships and crests at or near the ends. The extreme case is when the wavelength equals the ship's length. The design staff assume this possibility and that the wave height is $0.6 \sqrt{L}$ m where L is the ship's length.



Unlike the bending which occurs in calm water because of a bad loading condition, the bending due to wave (alone) alternates in direction. Half a wave-length later than the circumstances shown above, the ship will have a wave crest amidships and will then hog if the ship is initially hogged (or sagged) in calm water and encounters a train of waves, the wave-bending will alternately cause the ship to bend more and then to bend less – possibly even become straight or bend a little the other way e.g. a ship sagged in still water will sag more on the wave depicted above.

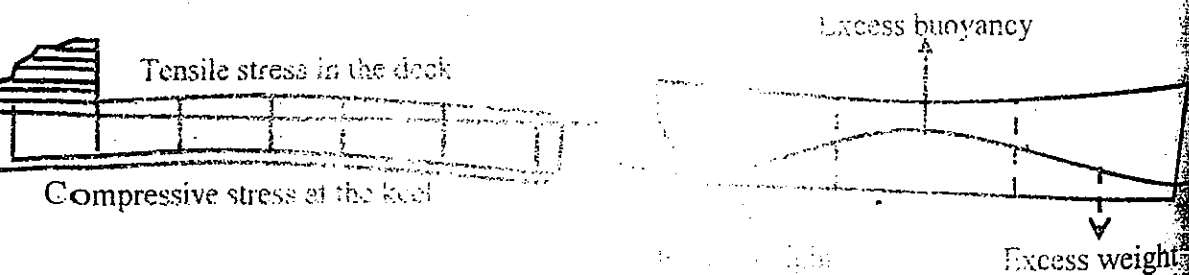
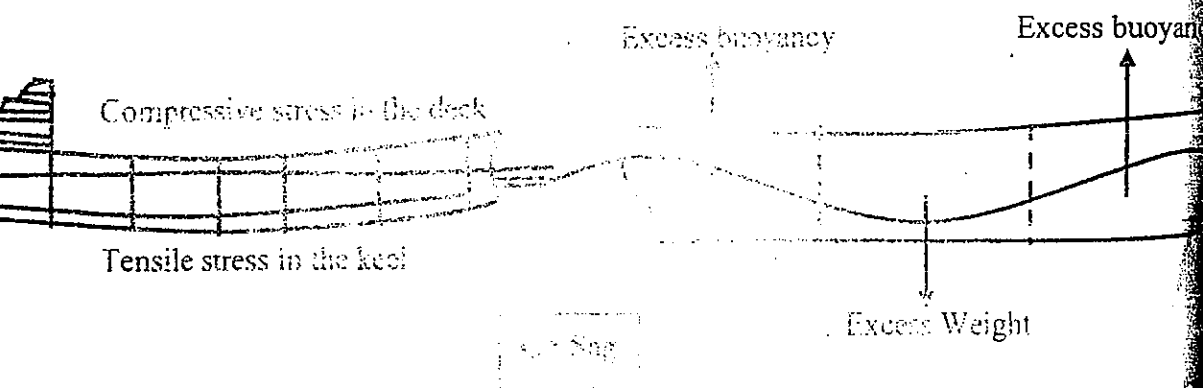
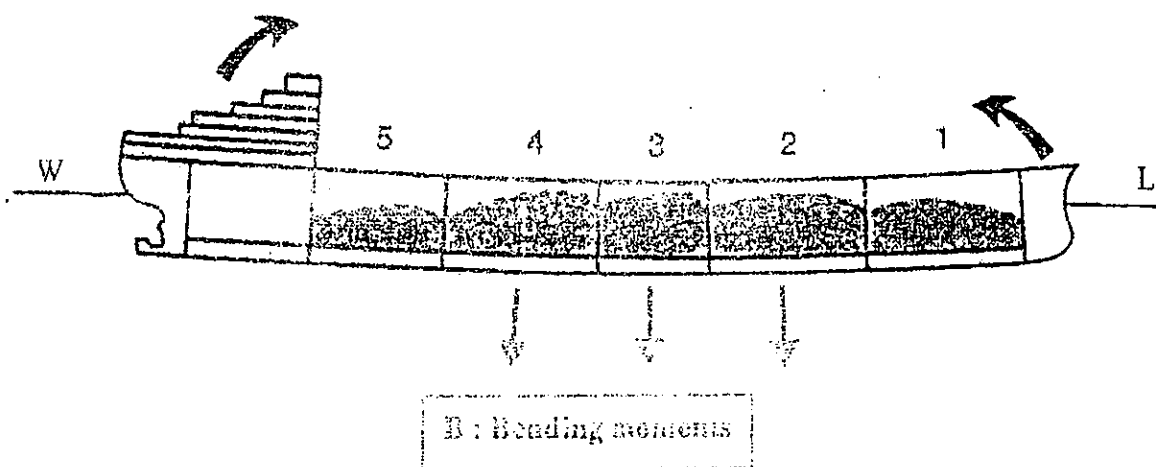
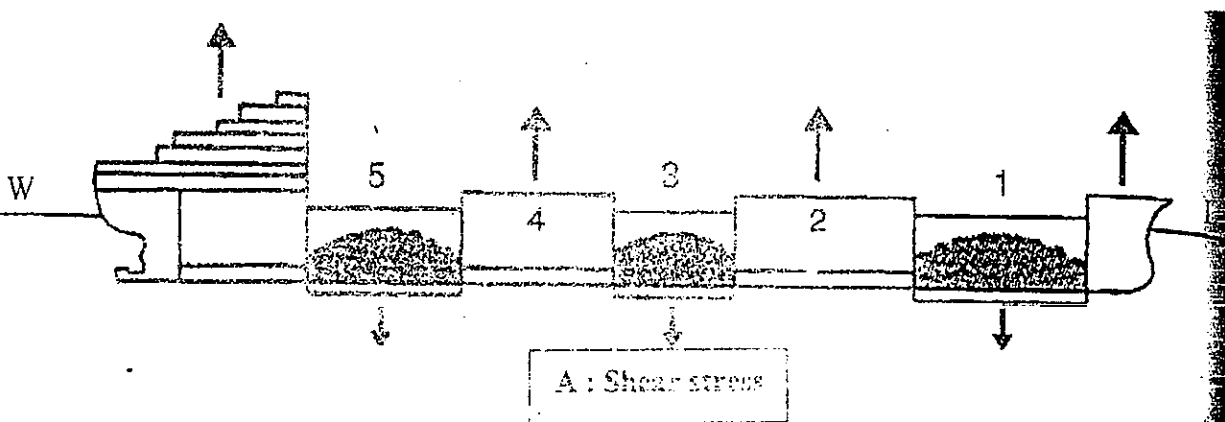
The stresses associated with bending are shown below.



The neutral axis is a layer of zero stress. When sagged, as shown, the material above the neutral axis is in compression, experiences a compressive stress and may fail due to buckling. The material below the neutral axis is in tension, is being subjected to tensile stress, and may fracture. (The greatest bending may not occur amidships but is generally at some position near to amidships, and decreases towards the ends of the ship.)

The design of any ship must be such that it can withstand both the bending due to a limited degree of improper loading plus the bending imposed by the appropriate wave i.e. there must be sufficient material of the correct type, in the right place, to ensure that the maximum tensile (or compressive) stresses that are set up will be within safe limits, well below the yield point of the material (which for mild steel is about 24 kg/mm^2): This requires an adequate amount of continuous longitudinal material because the most efficient girder (the one with the greatest strength for the least weight) has a large proportion of the material in its top and bottom flanges. The ship girder has relatively thick plating at the (continuous strakes of) upper deck, the sheerstrake, the bilge, bottom and keel.

The continuous longitudinal material which resists hogging / sagging, and keeps the bending stresses within acceptable limits, varies in different types of ship but is generally as shown in the following sketches. The point 'G' is the center of gravity of the continuous material shown and dictates the position of the neutral axis – the layer of zero stress. Whilst all the material resists bending stresses, the most valuable is that material which is farthest from the neutral axis. The contribution to overall longitudinal strength of an item of a given size varies (almost) directly as the square of its distance from the neutral axis, so it pays to fit heavy material at the top and bottom-most parts of the hull.

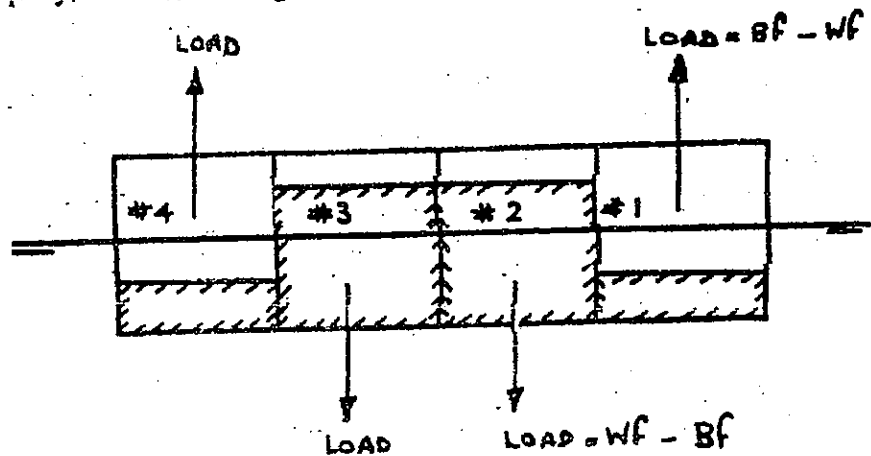


SHEARING STRESSES

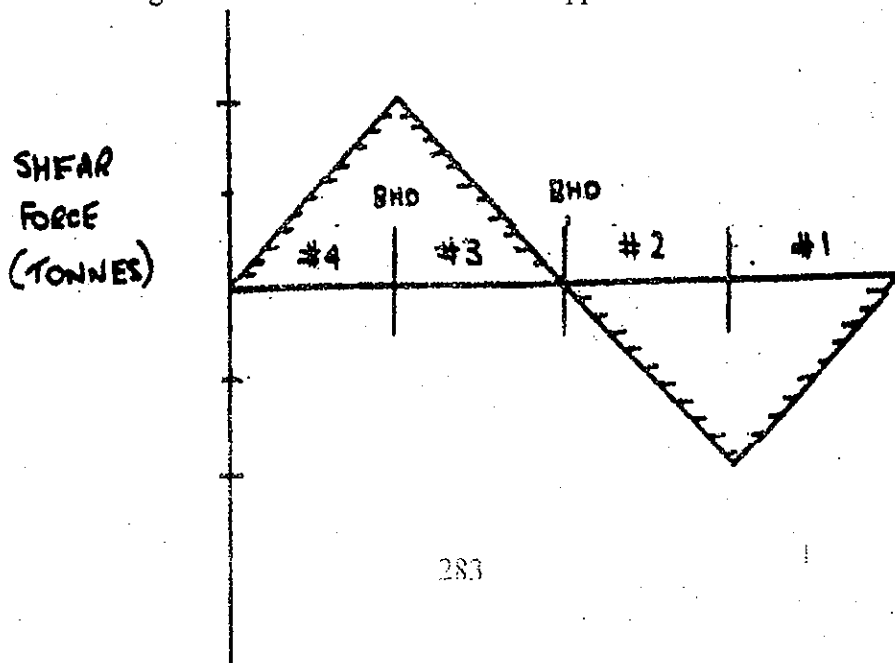
Shearing forces are vertical forces which tend to slice the ship into separate parts.

If the buoyancy experienced by any portion (a short length or compartment) differs from the weight at that part, the difference is termed the load at that position. Loads act vertically, downwards when weight exceeds buoyancy and upwards when buoyancy exceeds weight. It is the existence of these loads which cause a ship to bend (eg. loads acting upwards amidships and downwards at the ends cause hogging). At the same time these loads tend to slice the ship vertically i.e. they tend to shear the ship. The shearing force at any position is the algebraic sum of the loads acting to the left (or right) of the position and is measured in tonnes.

Shearing forces obviously arise in a box vessel, having four compartments laden unequally, as shown, floating on an even keel i.e. zero trim.



A graph of shearing forces for such a vessel would appear as shown below.

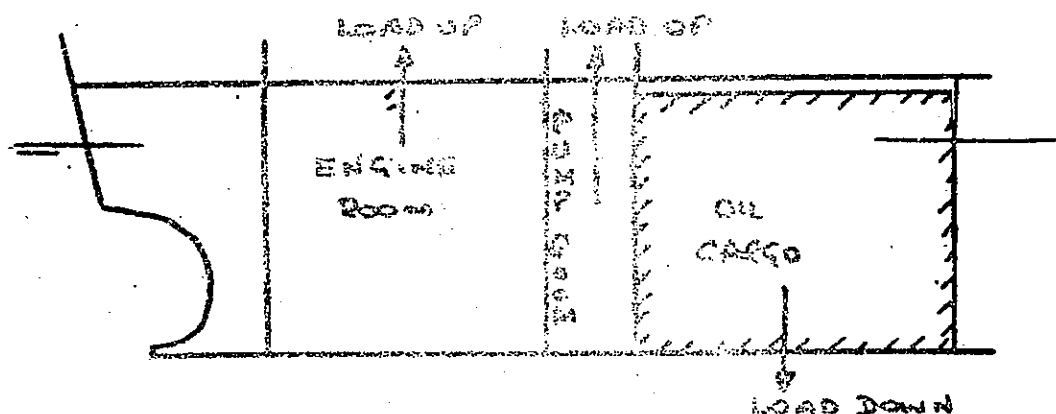


Some value of shearing force exists at all points other than amidships (and the ends) because of the 'load' acting to left (or right) of the point i.e. the imbalance between total weight and total buoyancy either to the left or to the right of the point. The maximum shearing forces arise where the direction of the load changes i.e. at the bulkhead separating holds 1 and 2, or 3 and 4, in the case illustrated.

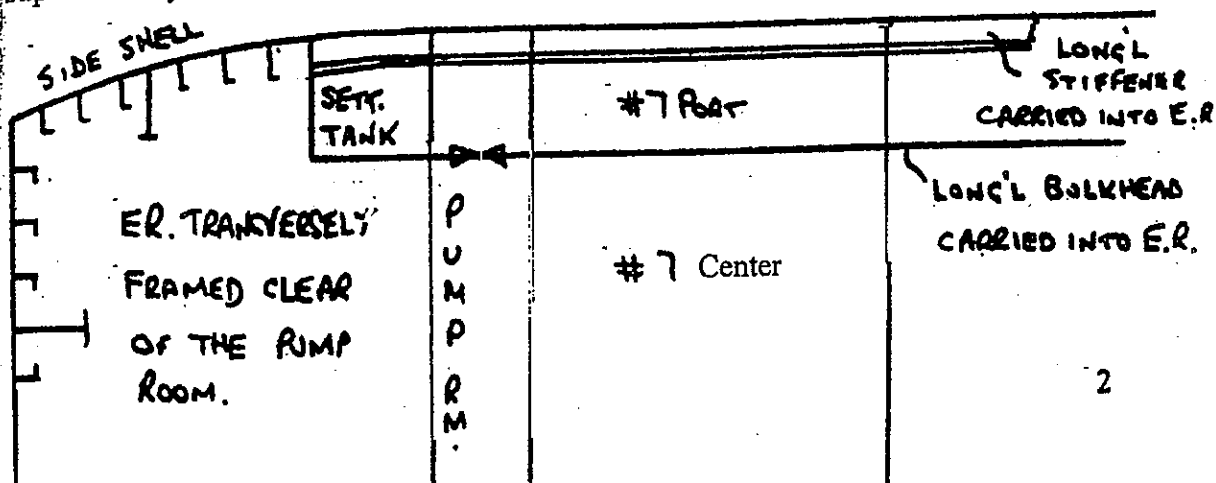
The material which resists shearing forces is the longitudinal material and most especially the vertically disposed longitudinal material, eg. the side shell plating, longitudinal bulkheads, bottom center girder, other deck and bottom longitudinals, (especially deep girders) etc. Transverse material such as web frames, floors etc. are of no help in this respect.

In many cases the continuous longitudinal material which resists hogging and sagging will be adequate to withstand the shearing forces. This is normally true of the general cargo ship or (dry) bulk carrier loaded in a reasonably uniform way throughout it's length. It is not true of ships which have an irregular loading (or ballasting) pattern such as 'alternate hatch loading' bulk carriers or OBO's in the ore condition. Additional material may have to be introduced, or the scantlings increased, in some positions to ensure adequate shear strength in these ships.

Tankers with pump room sited aft, will, in the loaded condition, have forces acting as shown.



The high shearing forces which exist in the area of the pump room would not be adequately resisted if the longitudinal bulkheads and members of the (normal) longitudinal framing system were stopped at the pump room/cargo tank bulkhead. These members are therefore continued into the engine room before being discontinued and superseded by a transverse framing system (see plan view of layout).



The values of the shearing forces being set up at any given time, like the degree of hogging or sagging, do not depend directly upon the total deadweight on board but upon its distribution. It is quite common for shearing stresses (and longitudinal bending) to be greater in the ballast or part loaded condition than when fully laden.

Bending Moment Curve :

Since the area under the curve of SF upto any point gives the BM at that point, the BM curve may be obtained by integrating the area under the curve of SF. The BM could be max whenever the SF curve crosses the baseline. Normally at about mid length. In newer design of vessels the max BM occurs normally slightly abaft midships.

$$F = M / I / y = M / Z$$

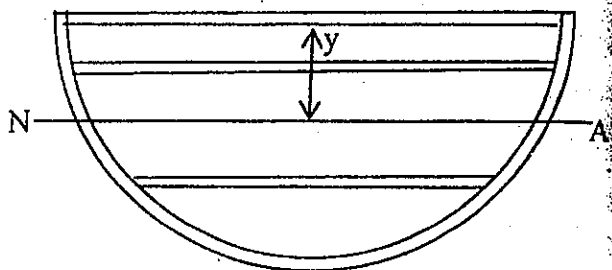
F = Force at a point (Stress)

I = Moment of inertia

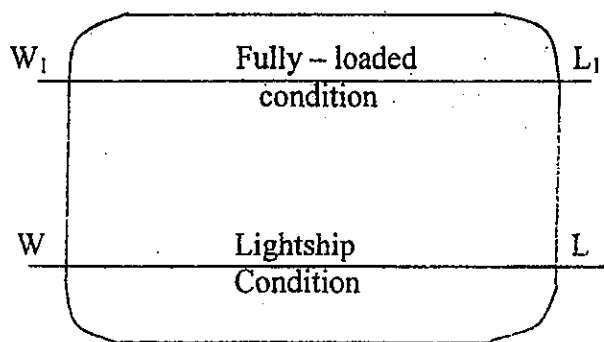
M = Bending moment

y = dist.

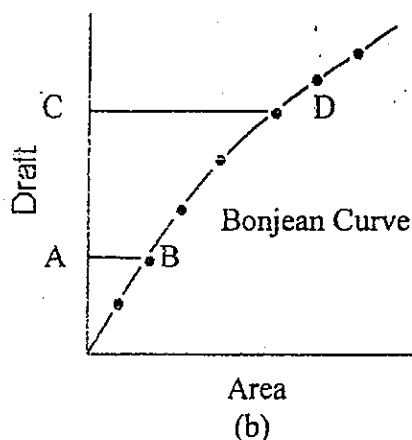
$I/y = Z$ - Section modulus of the vessel designated as Z



Mom. of inertia about vertical axis



(a)

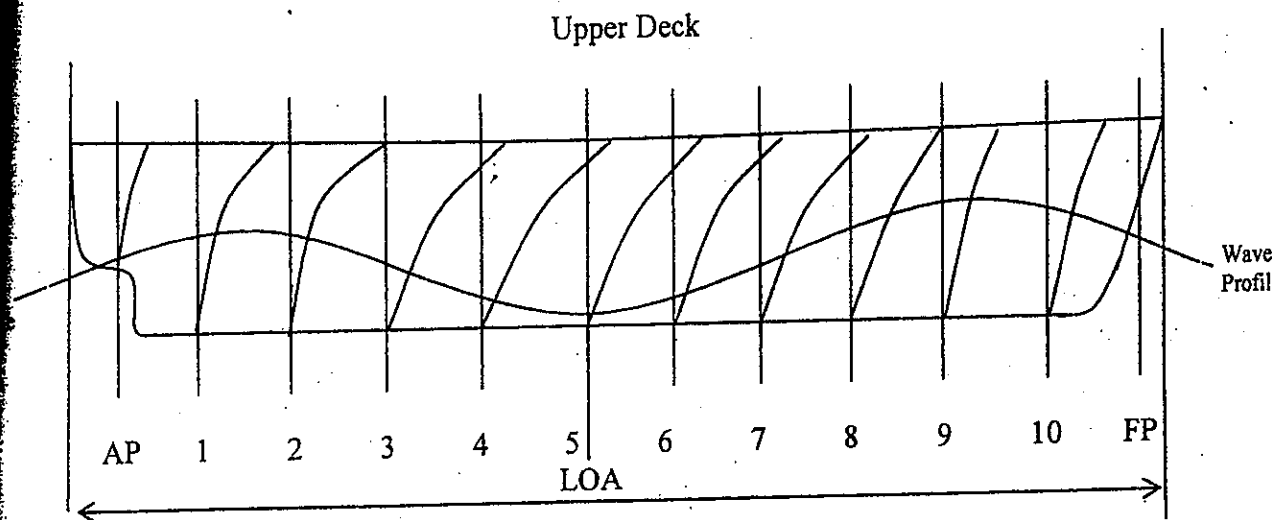


(b)

Bonjean Curves

Bonjean Curves are drawn to give the immersed area of transverse sections to any draft and may be used to determine the longitudinal distribution of buoyancy. For example, above figure (a) shows a transverse section of a ship and figure (b) shows the Bonjean Curve for the same section. The immersed area to the waterline WL is represented on the Bonjean Curve by ordinate AB, and the immersed area to waterline W_1L_1 is represented by ordinate CD.

In figure below the Bonjean Curves are shown for each section throughout the length of the ship. If a wave formation is superimposed on the Bonjean Curves and adjusted until the total buoyancy is equal to the total weight of the ship, the immersed transverse area at each section can then be found by inspection and the buoyancy in tones per metre run is equal to the immersed area multiplied by 1.025.



Example

1. A steel beam is 40 cm deep and 5 cm wide. The bending moment at the middle of its length is 15 tonnes metre. Find the maximum stress on the steel.

$$I = \frac{Ib^3}{12}$$

$$f = \frac{M}{I} \times y$$

$$= \frac{5 \times 40^3}{12}$$

$$y = \frac{d}{2} = \frac{40}{2} = 20 \text{ cm}$$

$$I = \frac{80000}{3} \text{ cm}^4$$

So

$$f = \frac{1500 \times 3 \times 20}{80000} \text{ tonnes per sq cm}$$

$$f = 1.125 \text{ tonnes per sq cm}$$

Ans. Maximum Stress = 1.125 tonnes per sq cm or 1125 Kg per sq cm.

BENDING MOMENTS AND SHEARING FORCES.

STRAIN: It is the lengthening or distortion of a member due to stress. Its units are expressed in elongation or distortion per unit length. The use of the term 'strain' here is quite different from its common use on board ship where such expression as 'take a strain on the line' means to tighten or stress the line already in tension.

SHEARING STRESS : It is result of two forces acting in opposite directions and along parallel lines. The tendency of shearing stress is to tear the material between the two forces. If, for example, the total shearing force or pull across the shank of a rivet in a lap joint is 4 tons and the shank has a diameter of 1m, the shear stress can be determined by dividing the total force by the cross sectional area of the rivet or $4 / 3.14 \times 0.5^2$ giving a shear stress of 5.1 tons per m^2 . It is the load / applied force per unit area.

Stress is proportional to strain below the elastic limit. It is called Hook's Law.

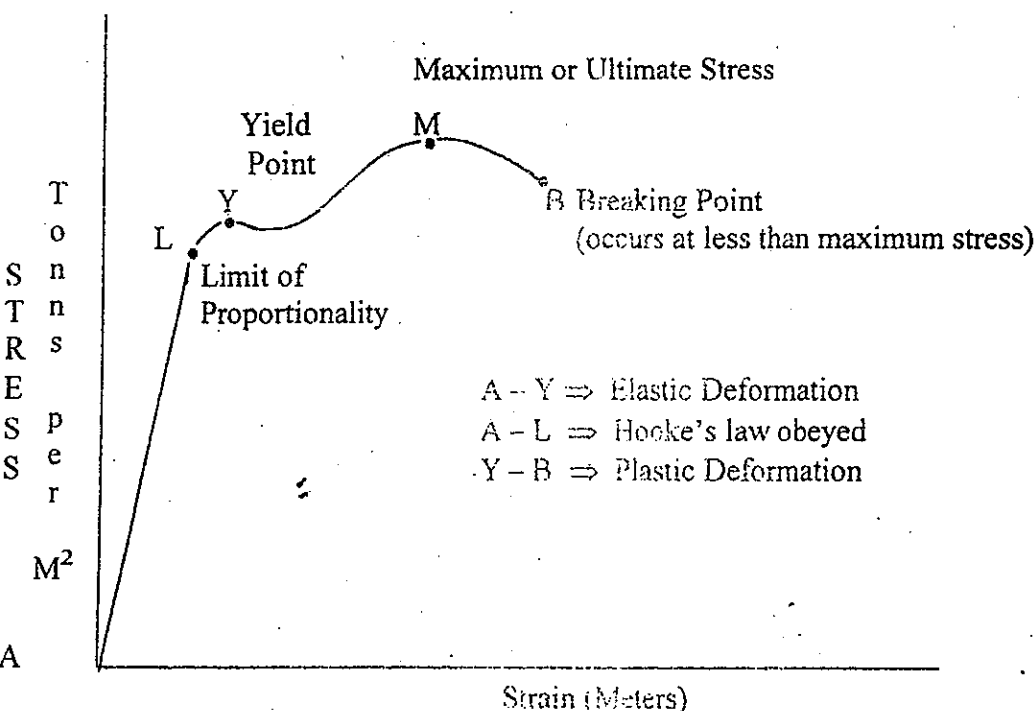


Fig. : Stress v/s strain relationship

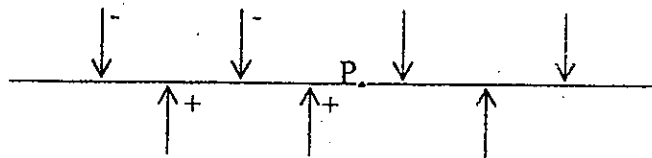
Upto elastic limit $Y = (E/e)$

When 'Y' is, young's modulus of elasticity for the material.

Stress may be classified as :

1. **Tensile Stress :** When a force is applied pulling the sample metal piece, it causes Tensile stress.
2. **Compressive Stress :** When a force is applied in such a way that it compresses the sample metal piece, it causes a compressive stress.
3. **Shearing Stress :** When one compartment is full with cargo and the adjacent compartment is empty, the full compartment wants shear off at the juncture. It causes shearing force.
4. **Tortional Stress :** It is also called twisting stress. When one of for'd D.B. Tank and diagonally opposite aft tank is full of ballast and other tanks are empty, it causes tortional stress.

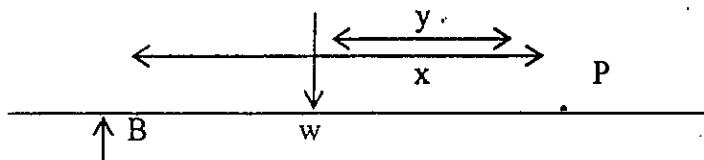
Shearing force : The shearing force at any point is defined as the algebraic sum of all the vertical forces acting on one side of that point. The unit is kg or tonne.



Sign Convention : If summing up forces left of point : upward forces are positive and down ward forces negative. If summing up forces right of point; upward forces will be negative and down ward will be positive.

Bending Moments : Bending moment at any point in a structure is the algebraic sum of all the moments on one side of that point. The moment is calculated by multiplying force and distance up to that point. The unit is tm (tonne metre).

Sign Convention : If summing up moments left of point : The clock wise moments left of point will be positive and anticlockwise moments will be negative. If summing up moments right of point : The clockwise moments right of point will be negative and anti dock wise moments will be positive.

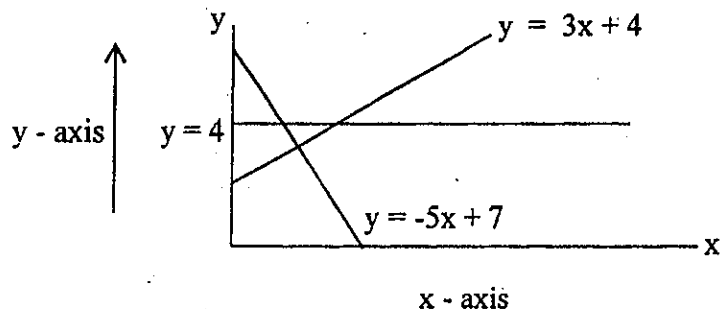


The BM at P will be $Bx - wy$

Mathematical Facts

As we have read in the co-ordinate geometry earlier the following facts are to be kept in mind when plotting the SF and BM curves for any structure.

1. When an equation does not contain X , the plot of it will be a straight line parallel to the base. E.g. $Y = 4$.

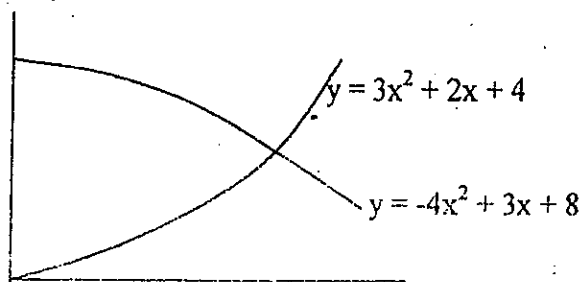


2. When an equation contains a positive term of x , the plot of it will be straight line making an angle with the base. It will rise to the right e.g. $y = 3x + 4$.

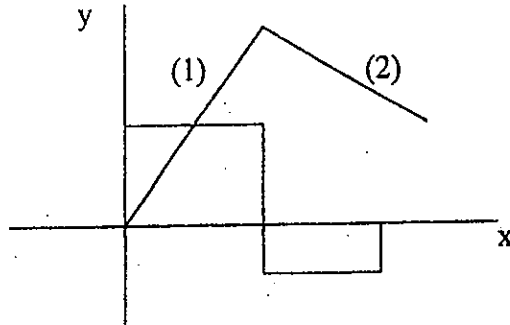
When an equation contains a negative term of x , the plot of it will be straight line making an angle with the base. It will fall to the right e.g. $y = -5x + 7$

3. When an equation contains a positive term of x^2 , the plot of it will be a curve which is concave up e.g. $y = 3x^2 + 2x + 4$

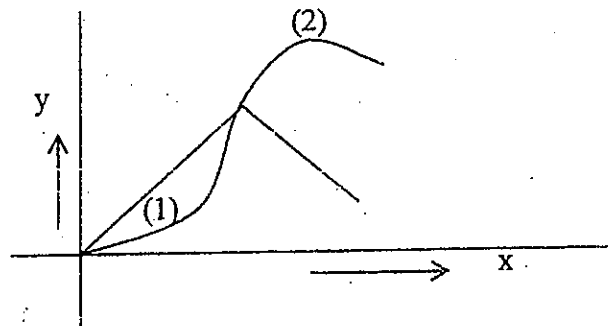
4. When an equation contains a negative term of x^2 , the plot of it will be a curve which is concave down e.g. $y = -4x^2 + 3x + 8$



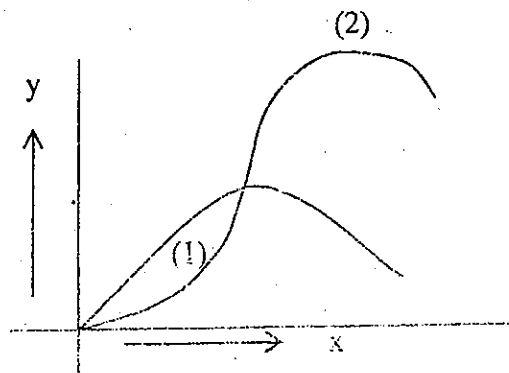
5. The plot of an area formed by a line parallel to the base, will be a straight line making an angle with the base. If the area is above the base line it is termed as positive. If the area is below the base line it is termed as negative. The plot of a positive area will be a straight line rising to the right e.g. (1) and the plot of a negative area will be a straight line falling to the right e.g. (2).



6. The plot of an area formed by a slanting straight line, will be a curve. If the straight line is rising to the right, its plot will be a curve concave up. E.g. (1). If the straight line is falling to the right, its plot will be concave down e.g. (2)

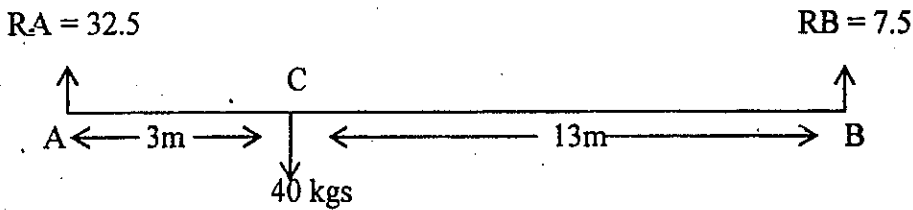


7. The plot of an area bound by a curve will be a curve. The plot will concave up if the original curve was rising to the right e.g. (1) and it will concave down if the original curve was falling to the right e.g. (2)



EXAMPLE:

2. A light beam AB 16 mtrs in length is supported at its ends and carries a load of 40 kgs at 3 mtrs from end A. Draw SF & BM diagram for beam.



To find R_B take moments about A

$$40 \times 3 = R_B \times 16$$

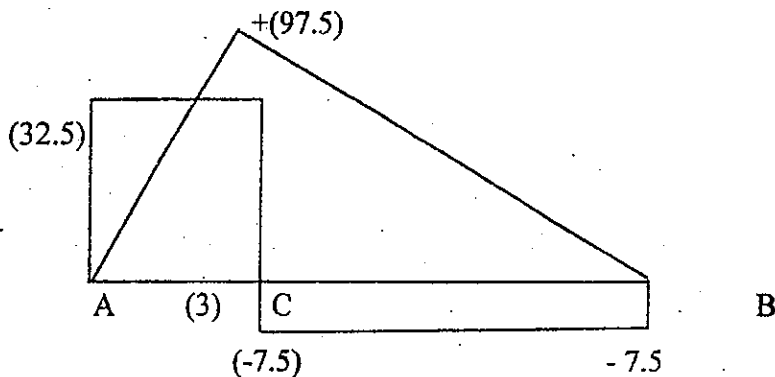
$$R_B = \frac{40 \times 3}{16} = 7.5$$

$$R_A + R_B = 40$$

$$\therefore R_A = 32.5$$

S.F. @ any pt between A & C = 32.5 kg

S.F. @ any pt between C & B = $+32.5 - 40 = -7.5$ kg.



Whenever there are concentrated forces at a point, there is a sudden discontinuity in SF dia. & amount of discontinuity will be equal to force at that point.

The area under the curve of shearing force above the base line must be equal to area under the curve below base line.

BM curve by equation Method :

BM at any point between A & C, x m from A

$$= 32.5 X x \text{ Kg.m} \quad \text{When } x = 0, \text{ BM} = 0$$

$$\text{When } x = 3, \text{ BM} = 97.5$$

BM at any point between C & B, x m from A

$$= 32.5x - 40(x - 3)$$

$$= -7.5x + 120$$

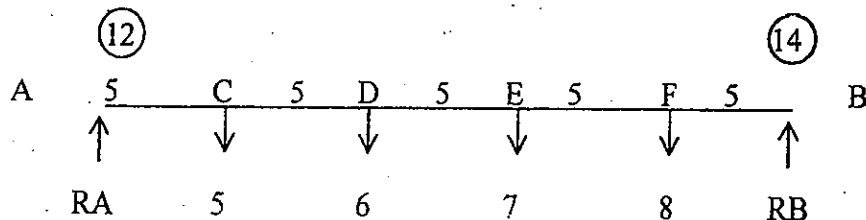
$$\text{When } x = 3, \text{ BM} = 97.5$$

$$\text{When } x = 16, \text{ BM} = 0$$

Notes:

- The end value of BM must be zero (must close at each end)
 - The BM curve will turn whenever the shearing force curve crosses the base line.
3. A light beam AB 25 mts in length is supported at its ends and carries loads of 5, 6, 7, 8 kgs at 5m intervals respectively end A. Draw SF & BM dia. for beam.

Ans.



To find RB take moments about A

$$5 \times 5 + 10 \times 6 + 15 \times 7 + 20 \times 8 = RB \times 25$$

$$\therefore RB = \frac{25 + 60 + 105 + 160}{25} = 14$$

$$\therefore RA + RB = 5 + 6 + 7 + 8 = 26$$

$$\therefore RA = 12$$

SF at any point between A & C = +12

SF at any point between C & D = 12 - 5 = +7

SF at any point between D & E = 12 - 5 - 6 = +1

SF at any point between E & F = 12 - 5 - 6 - 7 = -6

SF at any point between F & B = $12 - 5 - 6 - 7 - 8 = -14$

For light beam SF curves are all Straight line parallel to base

BM at any point between A & C = x m from A = $12x$

When $x = 0$, BM = 0

When $x = 5$, BM = 60

BM at any point between C & D = x m from A = $+12x - 5(x - 5)$

$$= 7x + 25$$

When $x = 5$, BM = 60

When $x = 10$, BM = 95

BM at any points between D & E = x m from A = $12x - 5(x - 5) - 6(x - 10)$

$$= x + 85$$

When $x = 10$, BM = 95

When $x = 15$, BM = 100

BM at any points between E & F = x m from A = $x + 85 - 7(x - 15)$

$$= -6x + 190$$

When $x = 15$, BM = 100

When $x = 20$, BM = 70

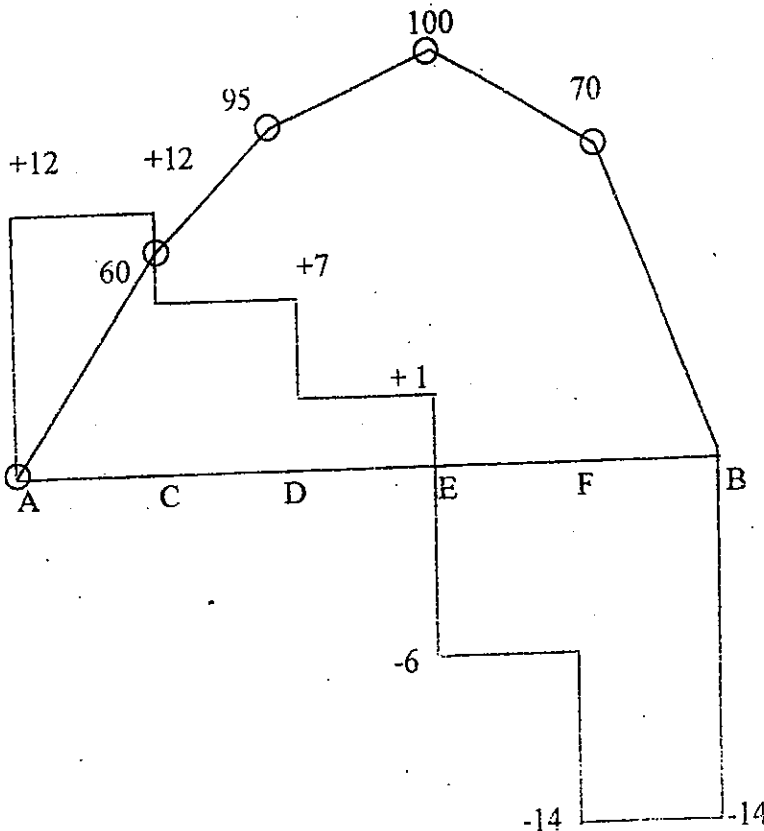
BM at any points between F & B = x m from A = $-6x + 190 - 8(x - 20)$

$$= -6x + 190 - 8x + 160$$

$$= -14x + 350$$

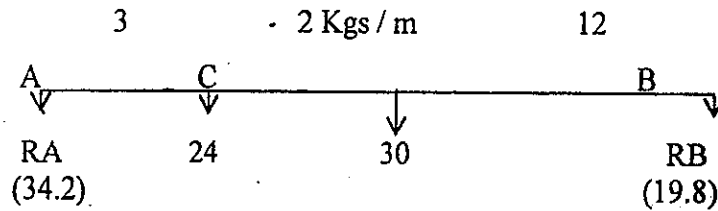
When $x = 20$, BM = 70

When $x = 25$, BM = 0



Heavy beams:

4. A uniform beam 15m in length weighting 30 kgs is supported at its ends and carries a load of 24 kgs at 3m from end A. Draw SF & BM diagram for the beam and state their values at 8m from end A.



To find RB, take moments about A

$$24 \times 3 + 30 \times 7.5 = RB \times 15$$

$$\therefore 72 + 225 = RB \times 15$$

$$\therefore RB = 19.8$$

$$\therefore RA + RB = 30 + 24 = 54$$

$$\therefore RA = 34.2$$

To find SF

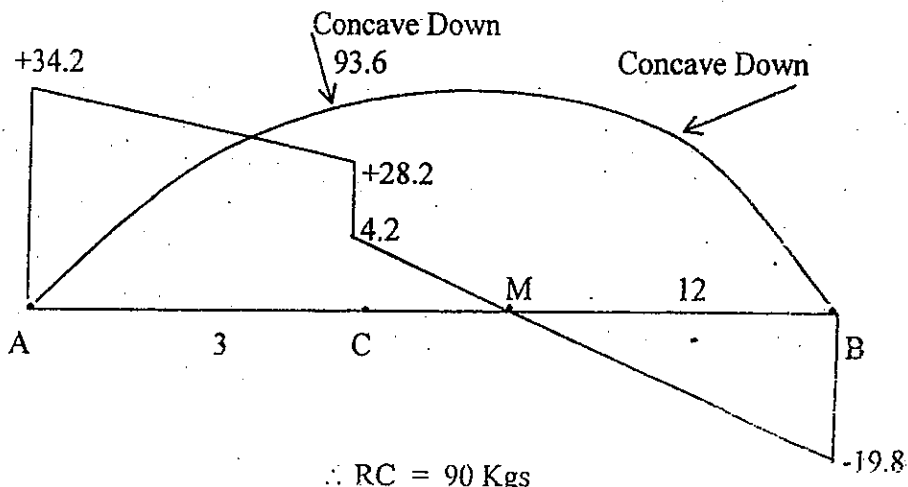
SF at any point between A and C – x meters from A = $34.2 - 2x$ when $x=0$, SF = 34.2

when $x=3$, SF = 28.2

SF at any point between C and B – x meters from A = $34.2 - 2x - 24$

= $10.2 - 2x$ when $x=3$, SF = 4.2

when $x=15$, SF = -19.8



To find BM

At any point between A & C x meters from A = $34.2x - 2x(x/2)$

$$= 34.2x - x^2 \quad \text{when } x = 0, \text{ BM} = 0$$

$$\text{when } x = 3, \text{ BM} = 93.6$$

At any point between C & B, x meters from A = $34.2x - x^2 - 24(x - 3)$

$$= 34.2x - x^2 - 24x + 72$$

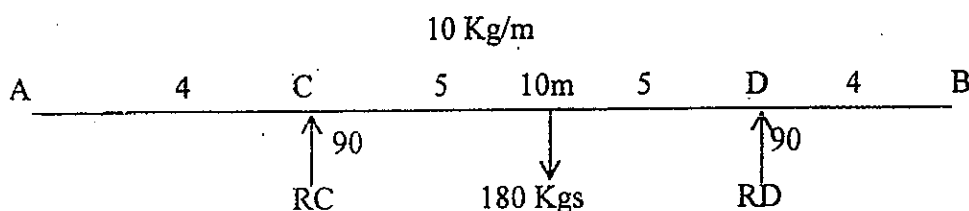
$$= -x^2 + 10.2x + 72 \quad \text{when } x = 3, \text{ BM} = 93.6$$

$$\text{when } x = 15, \text{ BM} = 0$$

$$\text{SF at 8m from A} = 10.2 - 2x = 10.2 - 2 \times 8 = -5.8$$

$$\text{BM at 8m from A} = 10.2 \times 8 - 8^2 + 72 = +89.6$$

5. A uniform beam of length 18 meters weighing 180 kgs & it is supported at points 4 meters from each end. Draw the SF & BM dia and state the points at which BM is nil?



To find RD, taking moments about 'C'

$$180 \times 5 = RD \times 10$$

$$\therefore RD = \frac{180 \times 5}{10} = 90 \text{ Kgs}$$

$$\therefore RC + RD = 180 \text{ Kgs}$$

$$\therefore RC = 90 \text{ Kgs}$$

F at any point between A & C; ' x ' meters from A = $-10x$

$$\text{when } x = 0, \text{ SF} = 0$$

$$\text{when } x = 4, \text{ SF} = -40$$

F at any point between C & D; ' x ' meters from A = $-10x + 90$

$$\text{when } x = 4, \text{ SF} = +50$$

$$\text{when } x = 14, \text{ SF} = -50$$

any point between D & B; 'x' meters from A = $-10x + 180$

when $x = 14$, $SF = +40$

when $x = 18$, $SF = 0$

any point between A & C; x meters from A = $-10x(x/2) = -5x^2$

when $x = 0$, $BM = 0$

when $x = 4$, $BM = -80$

any point between C & D, x meters from A = $-5x^2 + 90(x - 4)$

= $-5x^2 + 90x - 360$ when $x = 4$, $BM = -80$

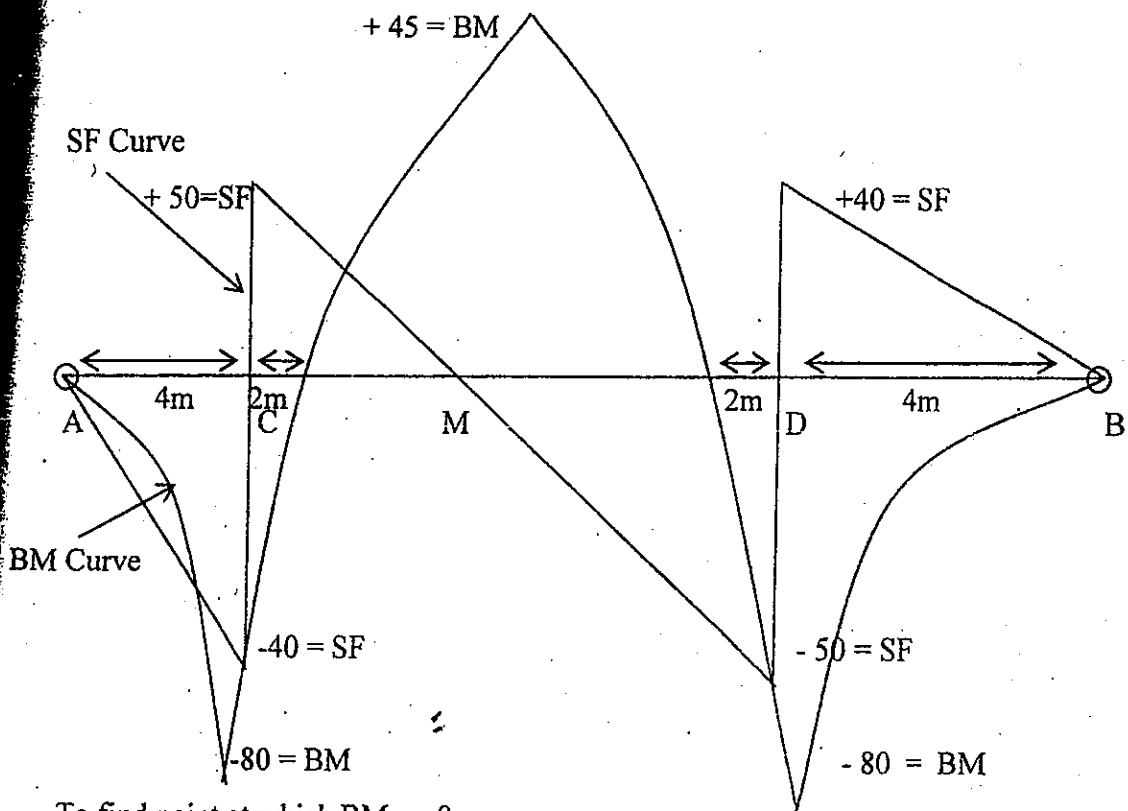
when $x = 9$, $BM = 45$

when $x = 14$, $BM = -80$

at any point between D & B, x meters from A = $-5x^2 + 90x - 360 + 90(x - 14)$

= $-5x^2 + 180x - 1620$ when $x = 14$, $BM = -80$

when $x = 18$, $BM = 0$



To find point at which $BM = 0$

$$-5x^2 + 90x - 360 = 0$$

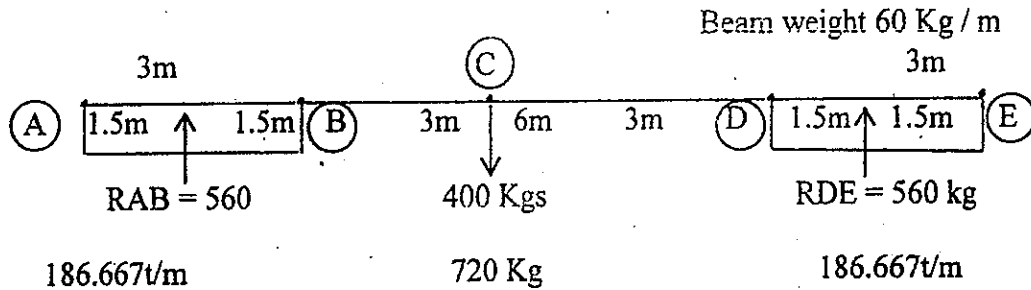
$$x^2 - 18x + 72 = 0$$

$$(x - 12)(x - 6) = 0$$

Either $x = 12$ at this point of $BM = 0$

Or $x = 6$

6. A uniform beam of length 12m weighting 720 kg is supported at 2 level platforms extending 3 meters from each end. A load of 400 kg is applied at mid length of the beam. Draw SF & BM diagram for the beam.



To find RDE, take moments about AB

$$720 \times 4.5 + 400 \times 4.5 = RDE \times 9$$

$$RDE = \frac{5040}{9} = 560$$

$$RAB = 560$$

$$\begin{aligned} \text{SF at any point between A \& B, } x \text{ m from A} &= 186.667x - 60x \\ &= 126.667x \end{aligned}$$

$$\text{When } x = 0, \text{ SF} = 0$$

$$\text{When } x = 3, \text{ SF} = +380$$

$$\text{SF at any point between B \& C, } x \text{ m from A} = 560 - 60x$$

$$\text{When } x = 3$$

$$\text{SF} = 380$$

$$x = 6, \text{ SF} = 200$$

$$\begin{aligned} \text{SF at any point between C \& D, } x \text{ m from A} &= 560 - 400 - 60x \\ &= 160 - 60x \end{aligned}$$

$$\text{When } x = 6$$

$$\text{SF} = -200$$

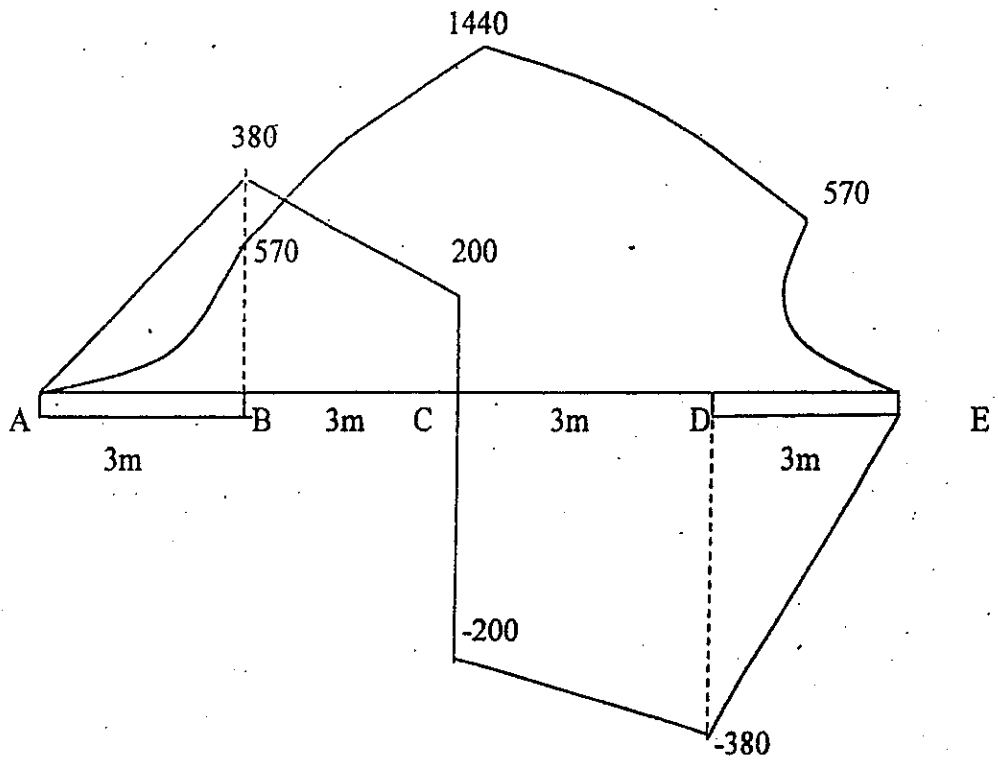
$$\text{When } x = 9, \text{ SF} = -380$$

$$\begin{aligned} \text{SF at any point between D \& E, } x \text{ m from A} &= 560 - 400 - 60x + 186.667(x - 9) \\ &= 126.667x - 1520.003 \end{aligned}$$

$$\text{When } x = 9$$

$$\text{SF} = -380$$

$$\text{When } x = 12, \text{ SF} = 0$$



$$B/M \text{ at } A = 0$$

$$B/M \text{ at 'B'} = \frac{1}{2} \times 380 \times 3 = 570$$

$$B/M \text{ at 'C'} = 570 + \frac{1}{2} \times 3 \times (380 + 200) = +1440$$

$$B/M \text{ at 'D'} = 1440 - (\frac{1}{2} \times 200 \times 3) - (380 \times 3) = +570$$

$$B/M \text{ at 'E'} = 570 - (\frac{1}{2} \times 3 \times 380) = 0$$

7. A uniform log of wood of square cross section 0.40 m each side and 25 mts in length floats in water of RD 1.015. When a load equally distributed over 3 mts of its mid length is placed on the log, the log just submerges uniformly. Density of log $800 \text{ kg/m}^3 = 0.8 \text{ t/m}^3$. Draw SF& BM diagram.

Sol. Total buoyancy = Total weight = $25 \times 0.4 \times 0.4 \times 1.015 = 4.06 \text{ t}$

Weight of log = $25 \times 0.4 \times 0.4 \times 0.8 = 3.2 \text{ t}$

$\therefore$ Weight of load = $0.86 \text{ t} (4.06 - 3.2 = 0.86)$

Buoyancy / m = $\frac{4.06}{25} = 0.1624 \text{ t}$

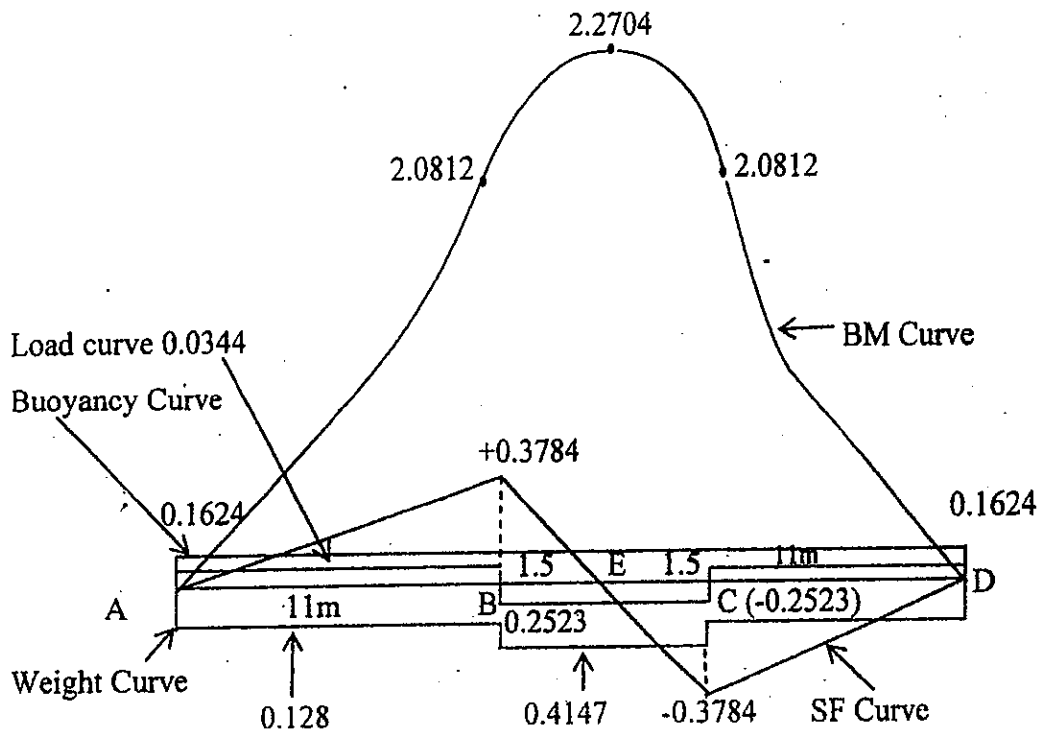
Weight of log / m = $\frac{3.2}{25} = 0.128 \text{ t}$

Weight of load / m = $\frac{0.86}{3} = 0.2867 \text{ t}$

load curve $0.1624 - 0.128 = 0.0344 \text{ t}$

Loads curve

1. Area under curve above baseline will be equal to area under curve below base line.
2. Since Buoyancy curve is a straight line, the loads curve will take (follow) shape of weight curve.
3. Shearing force is area under curve of loads.



SF

SF at A = 0

SF at B = $11 \times 0.0344 = 0.3784$

SF at E = $0.3784 + 0.37845 = 0.75685$

SF at C = 0.3784

SF at D = 0

BM

BM at A = 0

BM at B = $\frac{1}{2} \times 11 \times 0.3784 = 2.0812$

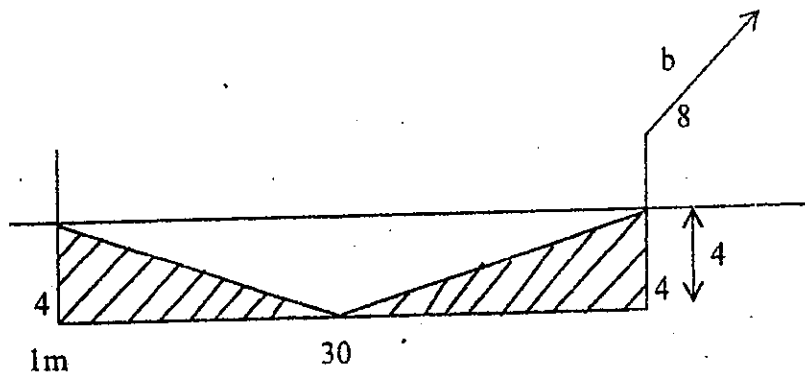
BM at E = $2.0812 + \frac{1}{2} \times 0.3784 \times 1.5 = 2.2704$

BM at C = $2.2704 - \frac{1}{2} \times 0.3784 \times 1.5 = 2.0812$

BM at D = $2.0812 - \frac{1}{2} \times 11 \times 0.3784 = 0$

8. A box shaped V/L 30m X 8m floats in SW with ore of S.F. $2/3 \text{ m}^3/\text{T}$ stored to a height of 4m at the ends sloping uniformly to nil at middle length. The vessel then floats in FW at an EK draft of 4m. Draw SF & BM diagram for the V/L.

Sol.



$$\text{Total buoyancy} = \text{Total weight} = 30 \times 8 \times 4 \times 1.0 = 960 \text{ t}$$

$$\begin{aligned} \text{Total of cargo} &= \frac{2 \times \frac{1}{2} \times 15 \times 4 \times 8}{2/3} \quad (2 \text{ wedges}) \\ &= 720 \text{ t} \end{aligned}$$

$$\text{Lt. weight of V/L} = 960 - 720 = 240 \text{ t}$$

$$\text{Buoyancy / m} = 960/30 = 32 \text{ t/m}$$

$$\text{Weight of V/L / m} = 240/30 = 8 \text{ t/m}$$

$$\text{Weight of cargo / m at mid length} = \text{Nil}$$

$$\text{Weight of cargo / m at end} = \frac{1 \times 4 \times 8}{2/3} = 48 \text{ t/m}$$

$$\text{BM at A} = 0$$

$$\begin{aligned} \text{BM at D} &= h/12 (5 \times 0 + 8 \times 90 - 1 \times 0) \\ &= 720 \times h/12 = 720 \times \frac{7.5}{12} = -450 \end{aligned}$$

$$\text{BM at B} = -450 - 450 = -900$$

$$\text{BM at E} = -900 + 450 = -450$$

$$\text{BM at C} = -450 + 450 = 0$$

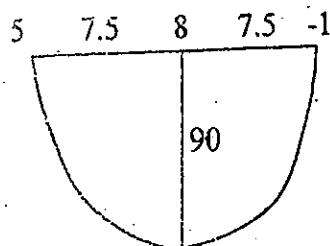
$$\text{SF at A} = 0$$

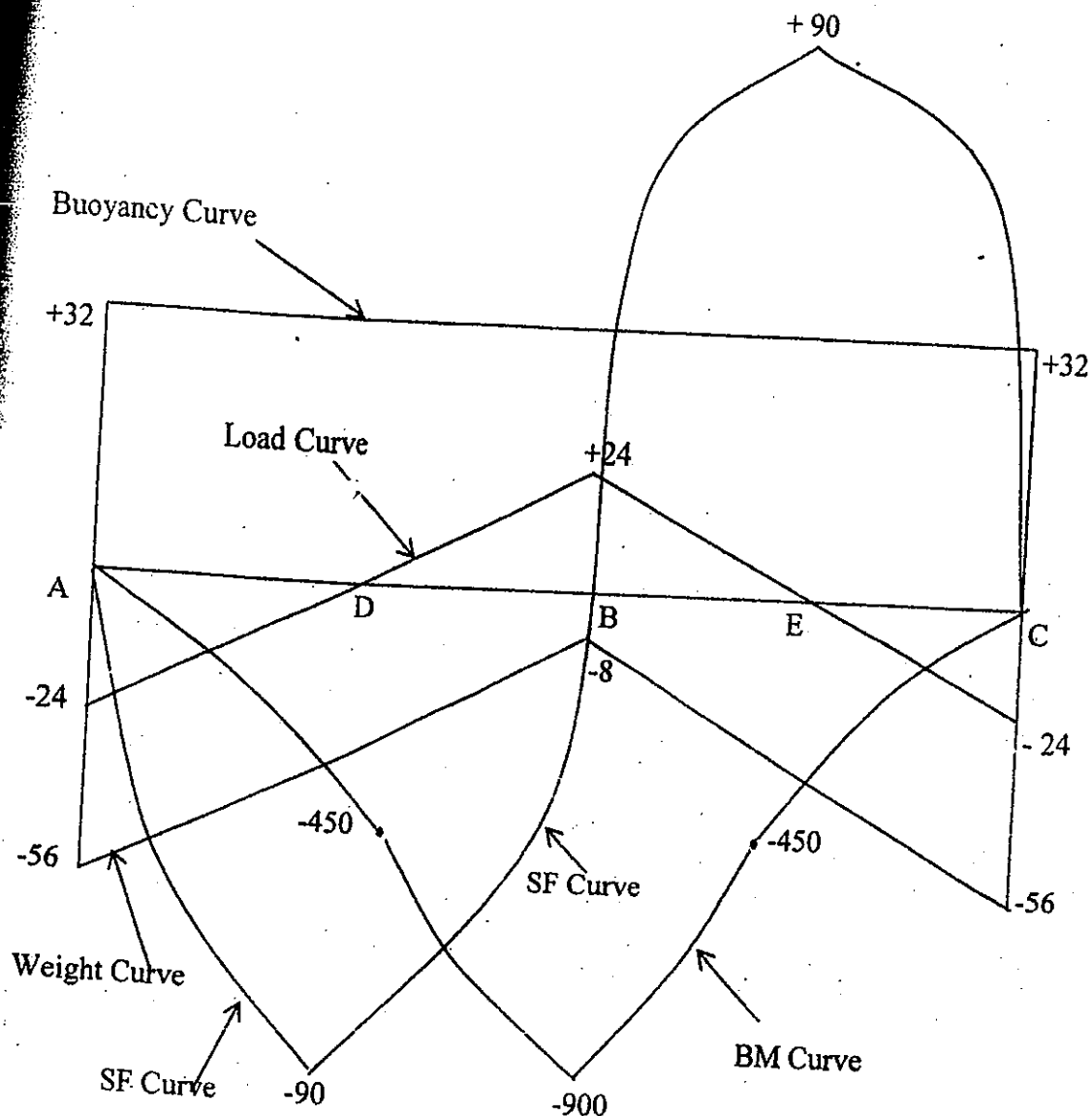
$$\text{SF at D} = \frac{1}{2} \times 7.5 \times (-24) = -90$$

$$\text{SF at B} = -90 + \frac{1}{2} \times 7.5 \times 24 = 0$$

$$\text{SF at E} = 0 + \frac{1}{2} \times 7.5 \times 24 = 90$$

$$\text{SF at C} = 90 + \frac{1}{2} \times 7.5 \times (-24) = 0$$





9. A box shaped barge length = 40m, light displacement = 160 t is loaded with 200 t of cargo peaking at mid length sloping uniformly till nil at the ends. Draw SF & BM dia. indicating their values at the appropriate position.

$$\text{Lt disp} = \begin{array}{r} 160 \text{ t} \end{array}$$

$$\text{Weight of cargo} = \begin{array}{r} 200 \text{ t} \end{array}$$

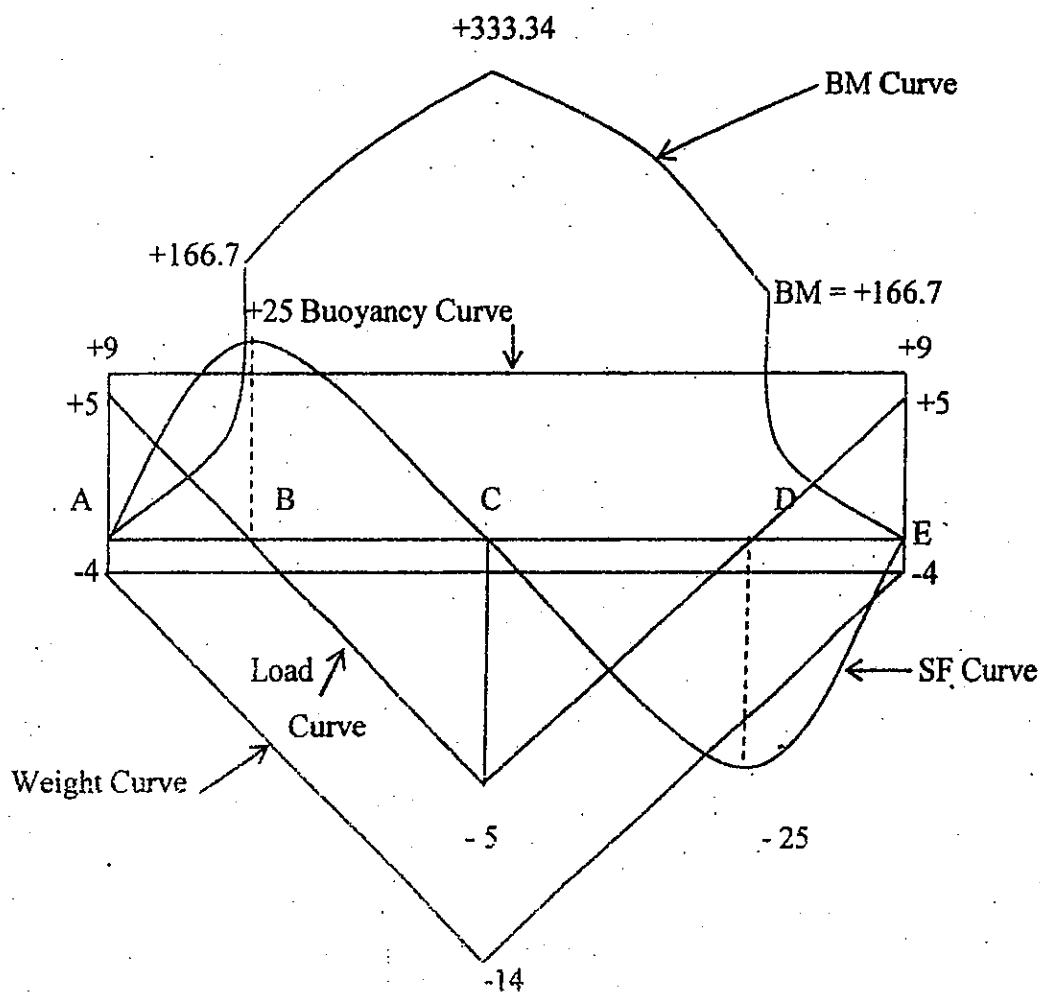
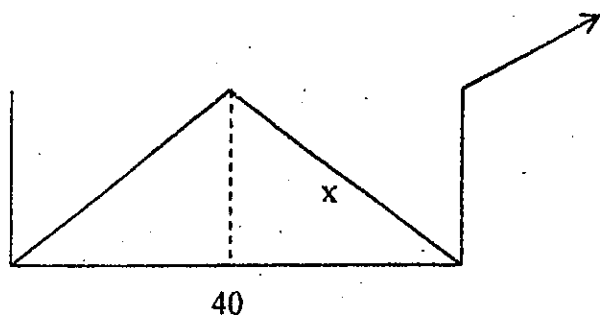
$$\text{Total weight} = \text{total buoyancy} = \begin{array}{r} 360 \text{ t} \end{array}$$

$$\text{Buoyancy / m} = \frac{360}{40} = 9 \text{ t/m}$$

$$\text{Lt. disp. / m} = \frac{160}{40} = 4 \text{ t/m}$$

Weight at ends = Nil

Weight at centre = 10t/m (See note)



$$\text{SF at A} = 0$$

$$\text{SF at B} = \frac{1}{2} \times 10 \times 5 = +25$$

$$\text{SF at C} = 0$$

$$\text{SF at D} = -25$$

$$\text{SF at E} = 0$$

$$\text{BM at A} = 0$$

$$\text{BM at B} = (5 \times 0 + 8 \times 25 - 1 \times 0) \times \frac{h}{12}$$

$$= 200 \times 10/12 = 166.67$$

$$\text{BM at C} = 333.34$$

$$\text{BM at D} = 166.67$$

$$\text{BM at E} = 0$$

Note :

Suppose the density of cargo is δ

$$\therefore \frac{1}{2} \times 20 \times h \times \frac{1}{2} \times 2 \times \delta = 200$$

$$\delta = \frac{200}{20 \times hb}$$

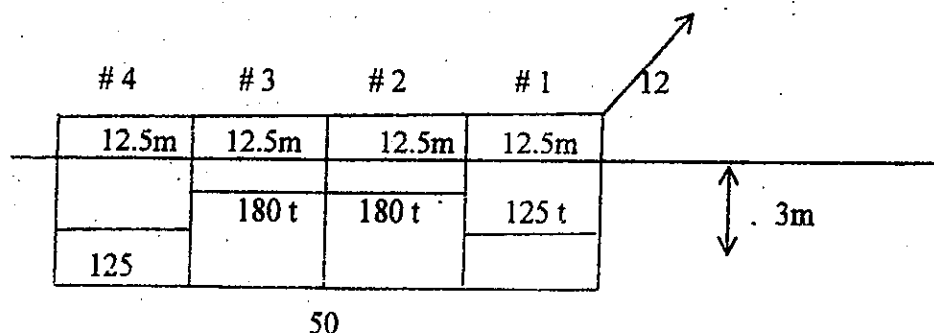
Per unit length weight

$$= h \times 1 \times b \times \delta$$

$$= \frac{hb \times 200}{20 \times hb} = 10 \text{ t/m at centre}$$

10. A box shaped vessel 50m X 12m is divided into four compartments of equal length. When loaded, with homogenous cargo level stowed as follows : No. 1 and No. 4 = 125t each, No. 2 & No. 3 = 180t each, the vessel floats in SW at EK draft of 3m.

Draw SF/BM diagram for the vessel.



$$\text{Total buoyancy} = \text{Total weight} = 50 \times 12 \times 3 \times 1.025 = 1845 \text{ t}$$

$$\text{Total weight of cargo} = 610 \text{ t}$$

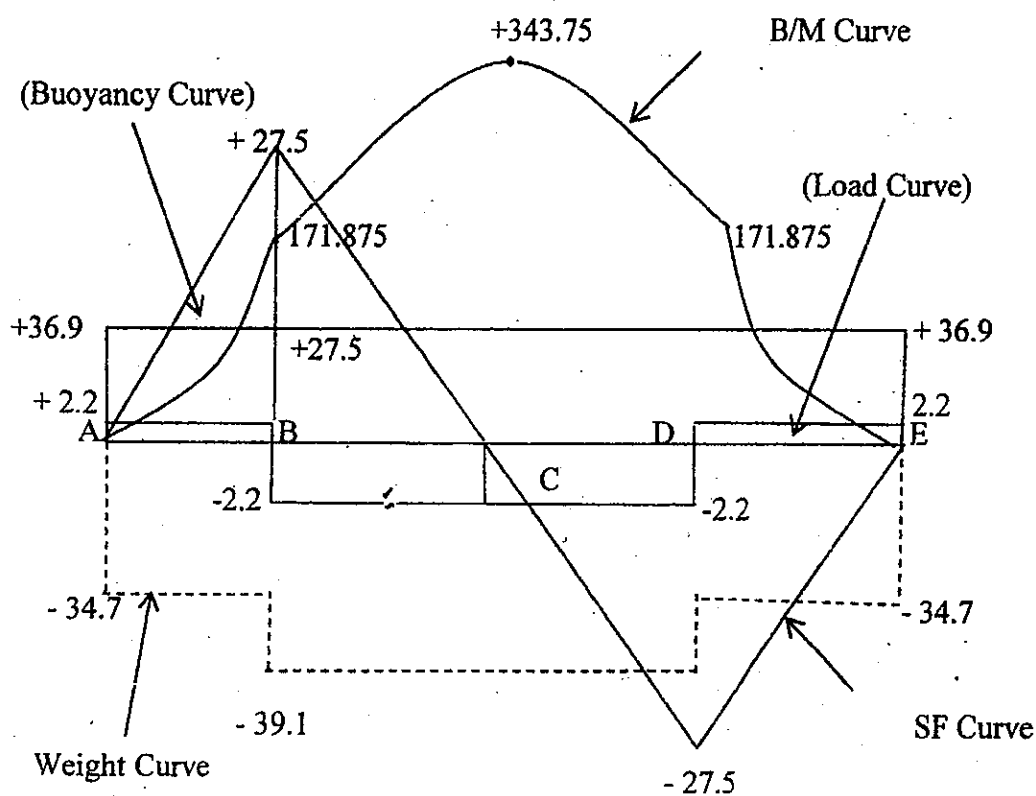
$$\text{Lt. weight of vessel} = \frac{1235}{1235 \text{ t}}$$

$$\text{Buoyancy / m} = \frac{1845}{50} = 36.9 \text{ t/m}$$

$$\text{Light weight of vessel / m} = \frac{1235}{50} = 24.7 \text{ t/m}$$

$$\text{Weight of cargo / mtr. No. 1 \& 4} = \frac{125}{12.5} = 10 \text{ t/m}$$

$$\text{Weight of cargo / mtr. No. 2 \& 3} = \frac{180}{12.5} = 14.4 \text{ t/m}$$



$$\text{SF at A} = 0$$

$$\text{SF at B} = 2.2 \times 12.5 = 27.5$$

$$\text{SF at C} = 0$$

$$\text{SF at D} = -27.5$$

$$\text{SF at E} = 0$$

$$\text{B/M at A \& E} = 0$$

$$\text{B/M at B} = \frac{1}{2} \times 12.5 \times 27.5 = 171.875$$

$$\text{B/M at C} = 343.75$$

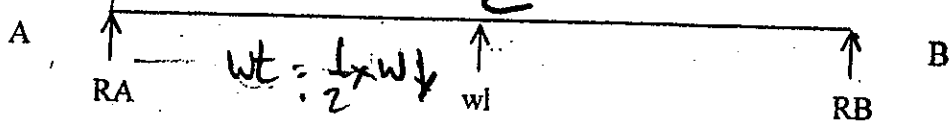
$$\text{B/M at D} = 171.875$$

V.Imp.

LOAD CURVE MUST TAKE SAME FORM AS WEIGHT CURVE.

11. A beam of length l and weight w per unit length is supported at its ends.

Draw SF and BM diagram of the beam

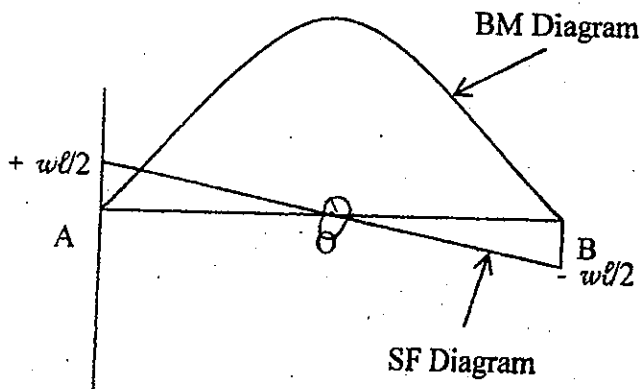


Taking moment about A

$$W \times \frac{l}{2} = R_B \times l$$

$$\frac{Wl}{2} = R_B$$

$$\therefore \frac{Wl}{2} = R_A$$



SF at any point between A & O, X mts for A

$$= \frac{w\ell}{2} - wx, \quad \text{if } x = 0, \quad SF = w\ell/2$$

$$\text{If } x = \ell/2, \quad SF = 0$$

$$\text{If } x = \ell, \quad SF = w\ell/2 - w\ell = -w\ell/2$$

BM at any point x mts from A

$$= \frac{W\ell}{2} \times x - wx \times \frac{x}{2} = \frac{W\ell x}{2} - \frac{wx^2}{2}$$

$$\text{If } x = 0, \quad B/M = 0$$

$$\text{If } x = \ell/2, \quad BM = \frac{w \times \ell \times \ell}{4} - \frac{w \times \ell^2}{8} = \frac{w\ell^2}{4} - \frac{w\ell^2}{8} = \frac{w\ell^2}{8}$$

$$\text{If } x = \ell, \quad BM = \frac{w\ell \times \ell}{2} - \frac{w\ell^2}{2} = \frac{w\ell^2}{2} - \frac{w\ell^2}{2} = 0$$

SHEARING FORCE AND BENDING MOMENTS

Exercise 17

1. A uniform beam 16 meters long, weighing 10 kg/m run is supported at points 3 meters from each end. Draw a SF and BM diagram and state the point at which the BM becomes nil.
2. A light beam, 24m in length, is supported at its ends. Weights are placed on it as follows:

5 Kg	4m from one end
6 Kg	8m from same end
7 Kg	12m from same end
8 Kg	16m from same end

Draw the SF and BM diagrams to scale. Calculate the maximum BM and state its location.
3. A uniform beam AB 16m long weighs 160 kg. It is supported at points two meters from each end. A load of 15 kg is applied at a point 6m from end A. Draw the SF and BM diagrams for the beam. What is the maximum value of BM and the position on the beam where it occurs? Calculate the point on the beam, between the load and end B, where the BM is nil.
4. A box shaped vessel of length 80m and light displacement 280 t is loaded with 640t of iron ore to equal heights at the ends and sloping uniformly to nil at mid length. Draw the SF and BM diagrams for the barge indicating their values at appropriate positions.
5. A box shaped barge of length 60m and light displacement 600t is loaded with iron ore level stowed as follows: - 150t each over a length of 15m at each end and 210t over a length of 15m at midlength. Draw the curves of Load, SF & BM for the barge.
6. A box shaped barge 40m X 5m has light SW draft of 0.8m fwd and aft. It has four identical holds, each 10m long. Cargo is loaded level as follows:

No. 1 hold: 200t,	No. 2 hold: 98t,
No. 3 hold: 98t,	No. 4 hold: 200t

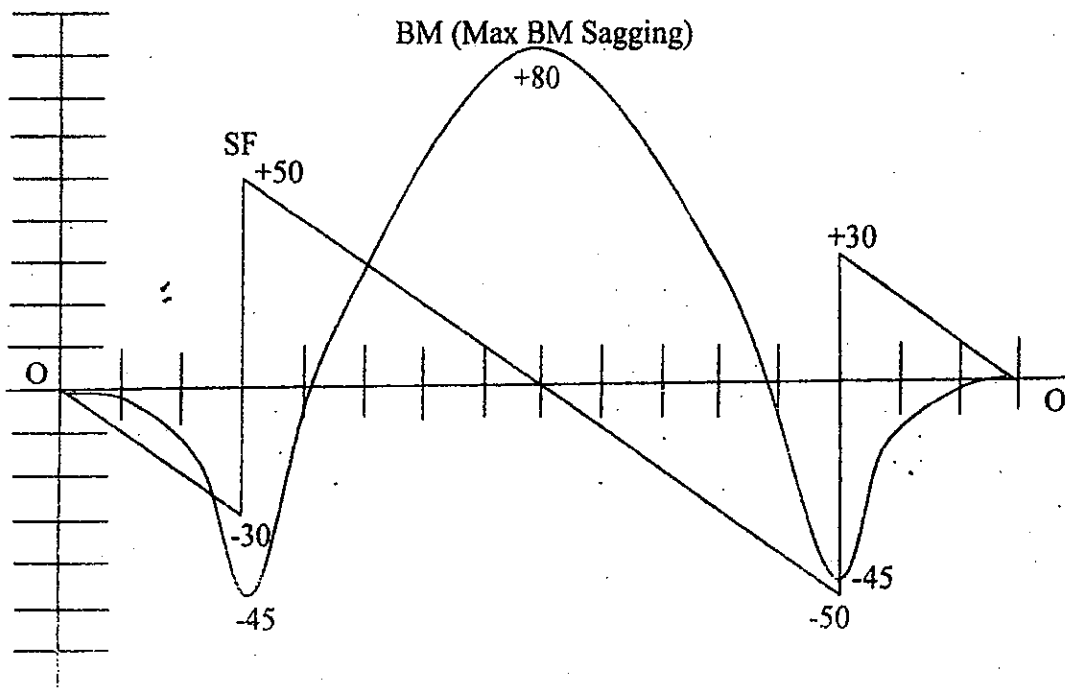
Draw the SF and BM curves to scale.
7. A box shaped vessel 24m long and 6m wide has light displacement of 120 tonnes. Iron ore (SF 0.6) is loaded, 3m high at the forward and after ends, sloping steadily to zero at the centre. Draw the SF and BM diagrams to scale. Note: The cargo has no slope in the athwart ships direction.

8. A box shaped vessel of length 120m, light displacement 1440t is divided into six compartments of equal lengths, the compartments are level stowed with cargo as follows:
- | | | |
|------|---------|-----------------|
| Nos. | 1 and 6 | 500 tonnes each |
| Nos. | 3 and 4 | 400 tonnes each |
| Nos. | 2 and 5 | Empty |
- Produce curves of Shearing Forces and Bending Moments for the vessel, indicating their values.
9. A box shaped barge of length 30m and light displacement 120 to be loaded with 180 t of ore, peaked at mid length and sloping uniformly to nil at ends. Draw the curves of weights, buoyancy, loads, SF and BM to scale, indicating their values.
10. A uniform beam 10-m in length weighting 1200 kg is supported on two level platforms extending 2m from each end of the beam. A load of 600 kg is applied at the mid length of the beam. Draw the SF and BM diagrams for the beam, showing the necessary calculations and indicating their values at appropriate positions on the diagrams.

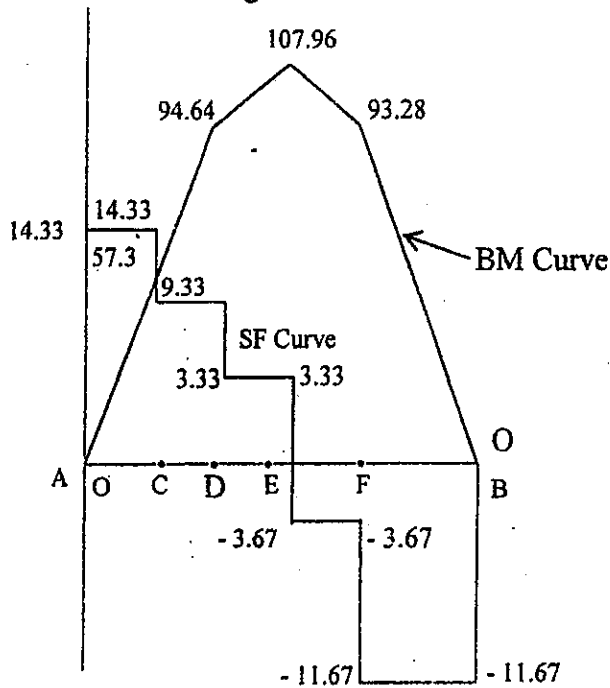
ANSWERS

1. The BM is nil at $X = 1$ or $X = 9$ m.

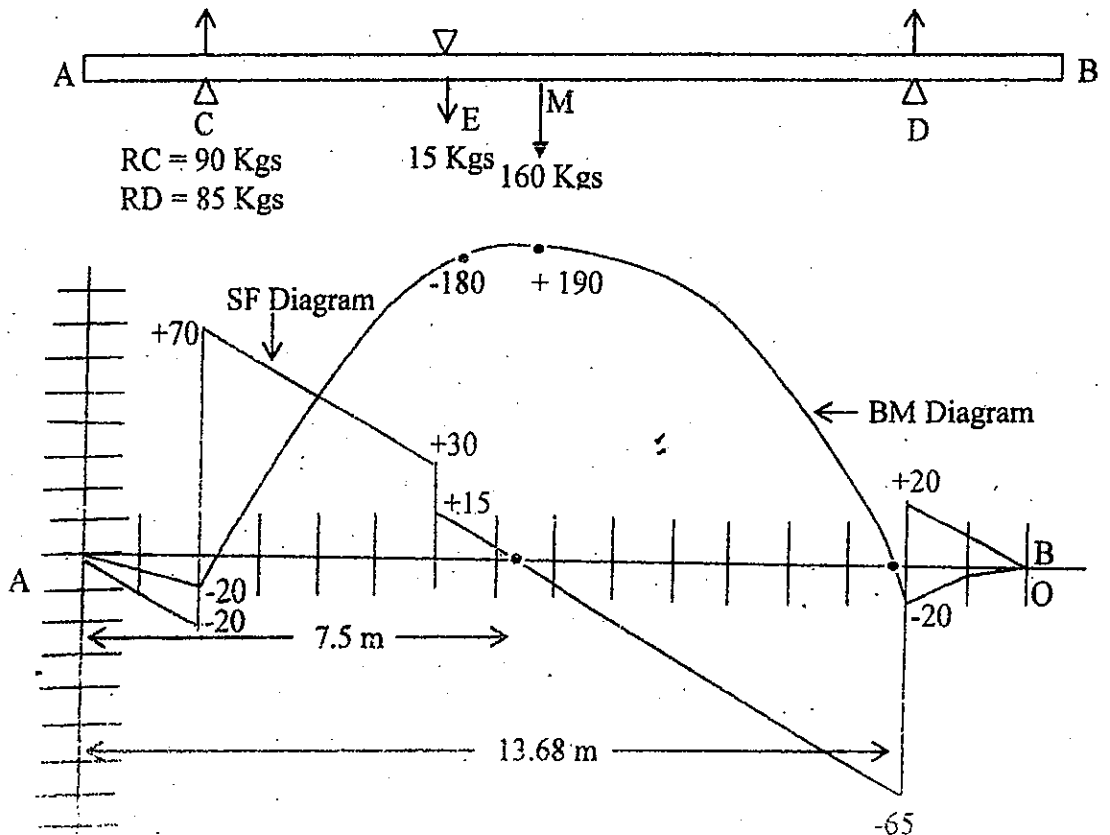
Scale SF Curve : 5 kg = 1 cm
 BM Curve : 10 kg. m. = 1 cm

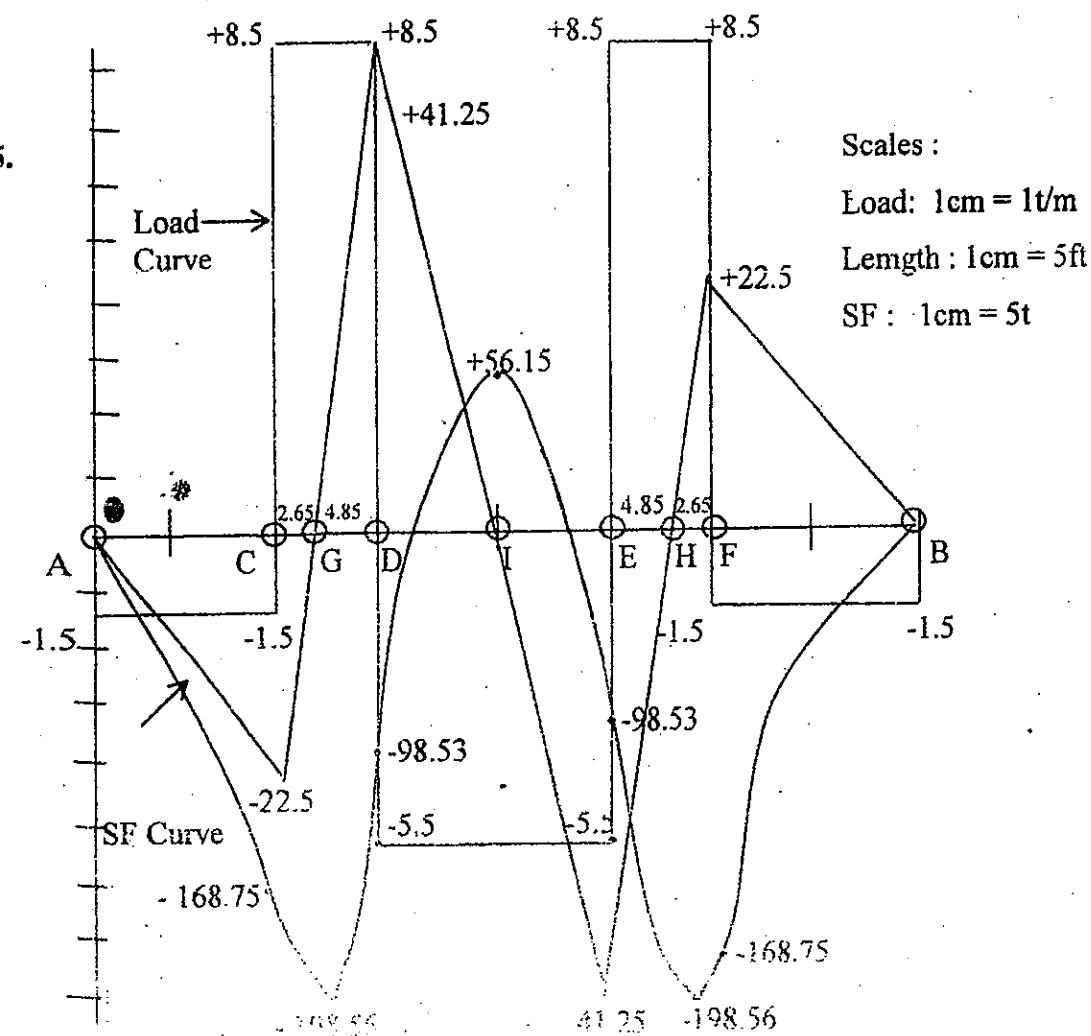
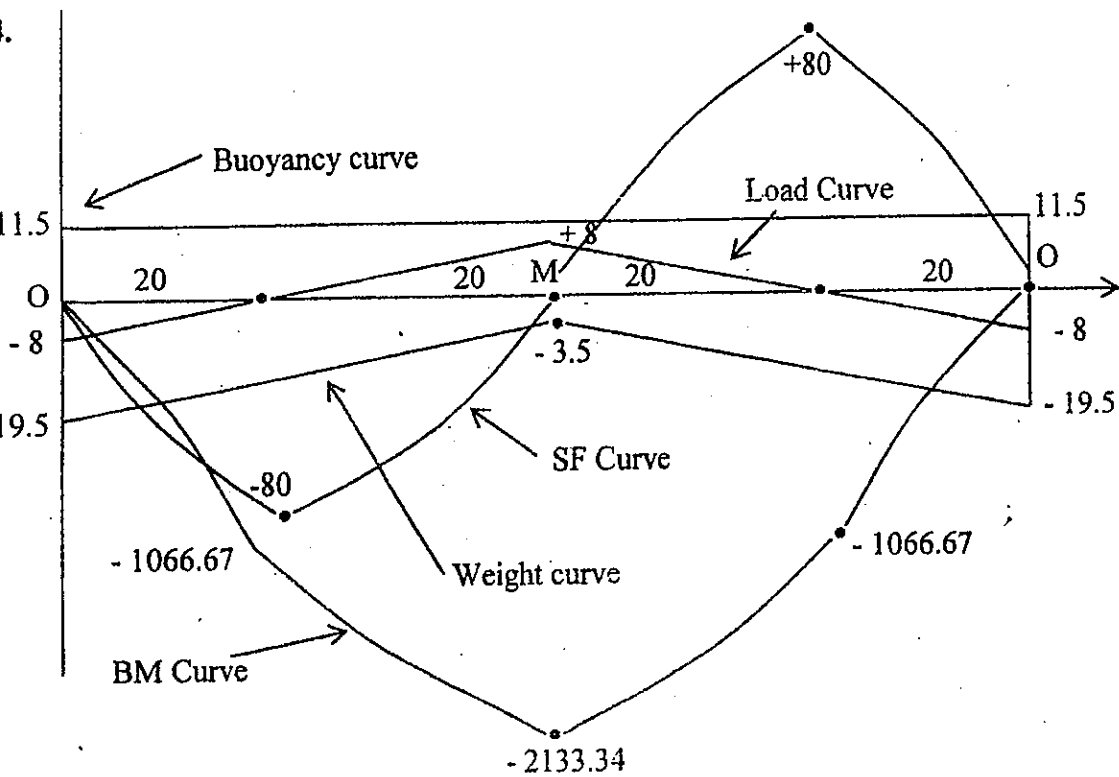


2. $R_A = 14.33 \text{ Kg}$ $R_B = 11.67 \text{ Kg}$ $SF = 0, 14.33, 9.33, 1.33, 18.35, 11.67, 0$ BM is maximum 107.96 Kg at middle of beam.



3. (i) Maximum BM 190.0 , 7.5m from A (ii) 13.68m .





Light displacement = 600t or 10 t/m

Iron ore = 510 t

Total weight = Total Buoyancy = 1110 t

$\therefore$ Buoyancy / m = $1110 / 60 = 18.5$ t

Weight / m between A & C = 20t

Weight / m between C & D = 10 t/m

Weight / m between D & E = 24 t/m

Weight / m between E & F = 10 t/m

$$\frac{CG(X)}{22.5} = \frac{GD(7.5 - X)}{41.25}$$

$$41.25X = 168.75 - 22.5X$$

$$\therefore X = \frac{168.75}{63.75} = 2.65 = CG$$

$$\therefore GD = 4.85m$$

B/M at A = 0, B/M at C = -168.75

BM at G = $-168.75 - \frac{1}{2} \times 22.5 \times 2.65 = -198.56$

B/M at D = $-\frac{1}{2} (17.65 \times 22.5) + \frac{1}{2} \times 4.85 \times 41.25 = 198.56 + 100.03 = -98.53$

B/M at E = $-98.53 + 154.69 - 154.9 = -98.53$

B/M at I = $-98.53 + 154.68 = +56.15$

B/M at E = $56.15 - \frac{1}{2} \times 7.5 \times 41.25 = -98.53$

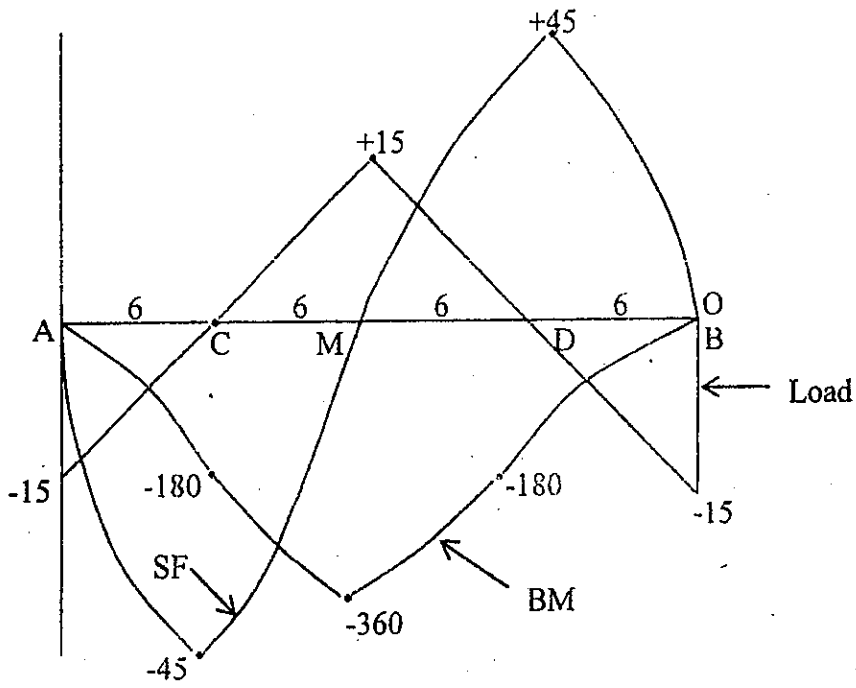
B/M at H = $-98.53 - \frac{1}{2} \times 4.85 \times 41.25 = -198.56$

B/M at F = $-98.53 - 100.03 + 29.81 = -168.75$

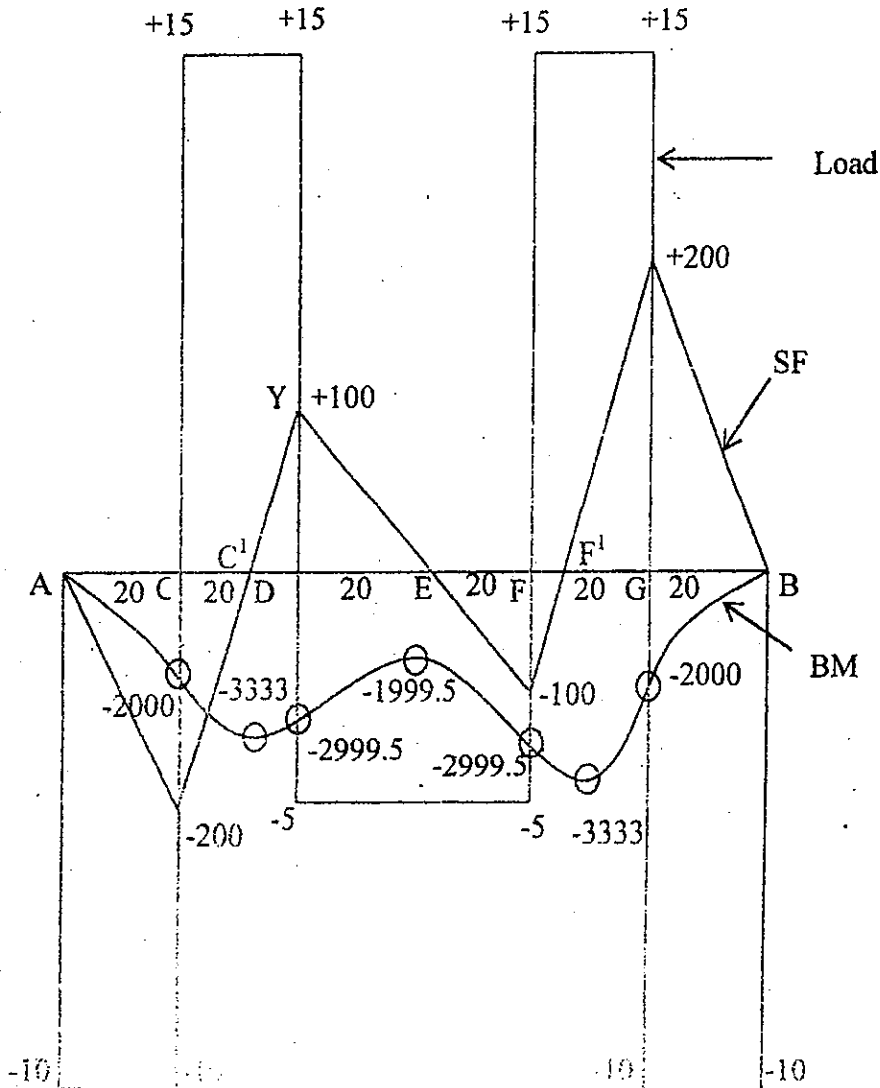
B/M at B = $-168.75 + 168.75 = 0$

6. SF = 0, -51, +51, 0, BM = 0, -255, -510, -255, 0 (Hogging)

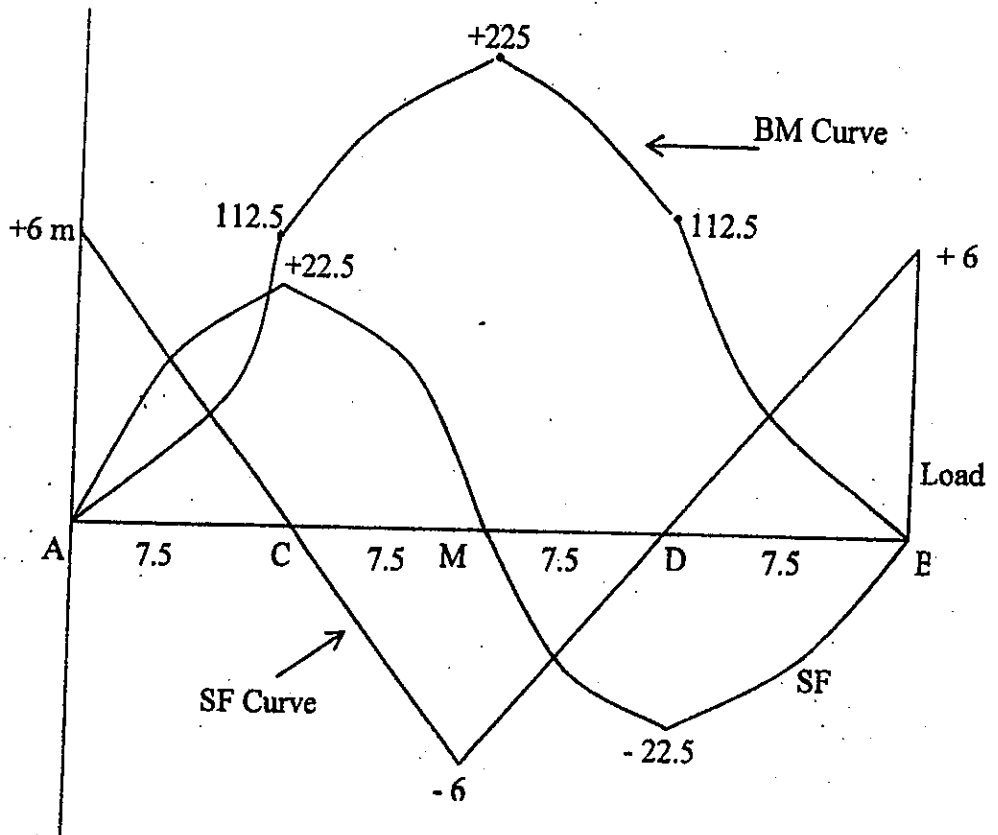
7.



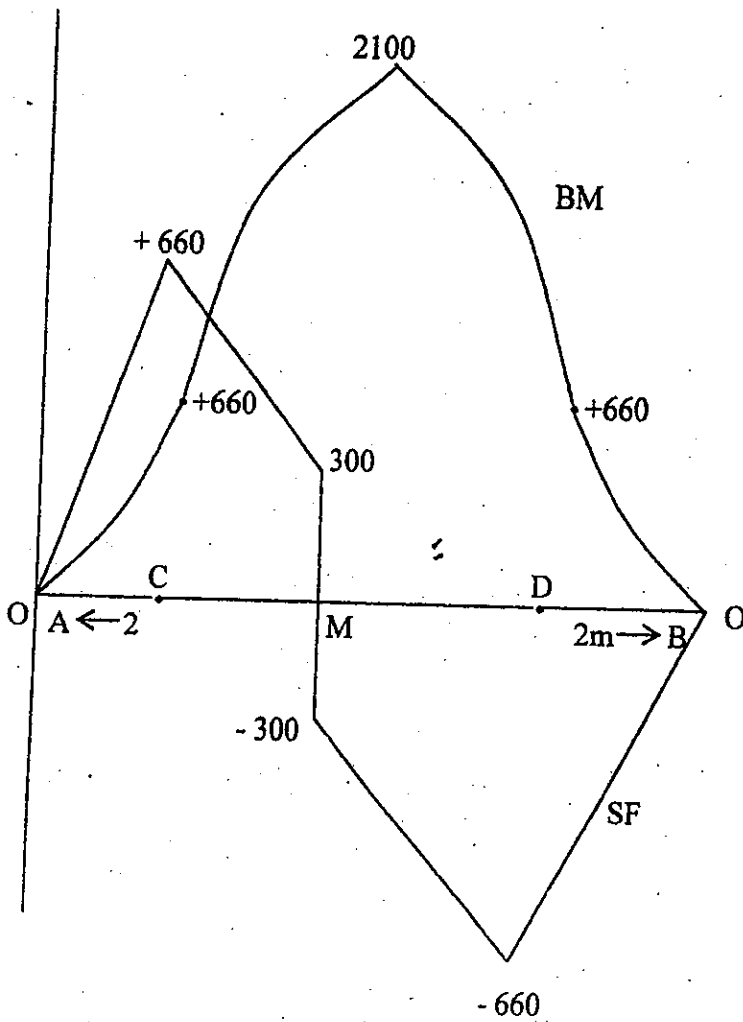
8.



9.



10.

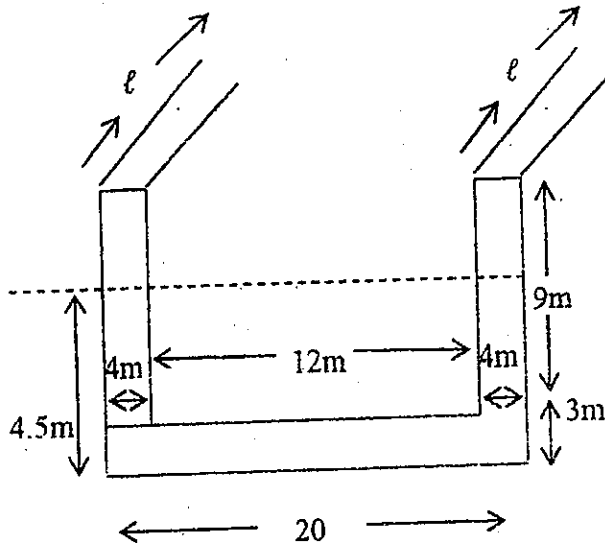


CHAPTER XIX

MISCELLANEOUS PROBLEMS – PHASE II

1. A floating drydock open at both ends has a rectangular D.B. tank with vertical side walls at each side mounted over DB. The DB is 20 mtr wide and 3.0m deep. Each side wall is 4 mtr wide 9 mtr deep. KG = 5.0 m. Calculate her GM when floating at the draft of 4.5 mtr.

Sol:



$$KG = 5.0$$

$$GM = KM - KG$$

$$KM = KB + BM$$

$$BM = \frac{I_{CL}}{V}$$

Centroid of u/w immersed volume will give KB

$$KB = \frac{\text{Moment of immersed u/w volume}}{\text{Immersed under water volume}}$$

$$KB = \frac{(\ell \times 20 \times 3 \times 1.5) + (\ell \times 2 \times 4 \times 1.5 \times 3.75)}{\ell (20 \times 3) + \ell (2 \times 4 \times 1.5)}$$

$$= \frac{90 + 45}{60 + 12} = \frac{135}{72}$$

$$= 1.875 \text{ m}$$

$$BM = \frac{I_{CL}}{V}$$

$$\therefore I_{CL} \text{ of whole vol} = \frac{LB^3}{12} = \frac{\ell \times 20^3}{12} = 666.67\ell$$

$$I_{CL} \text{ of centre volume} = \frac{\ell \times 12^3}{12} = 144\ell$$

$$I_{CL} \text{ of u/w vol} = (666.67 \ell - 144 \ell) = 522.67 \ell$$

$$\therefore BM = \frac{522.67 \ell}{\ell (20 \times 3 + 2 \times 4 \times 1.5)}$$

$$= 7.259 \text{ m}$$

$$BM = 7.259 \text{ m}$$

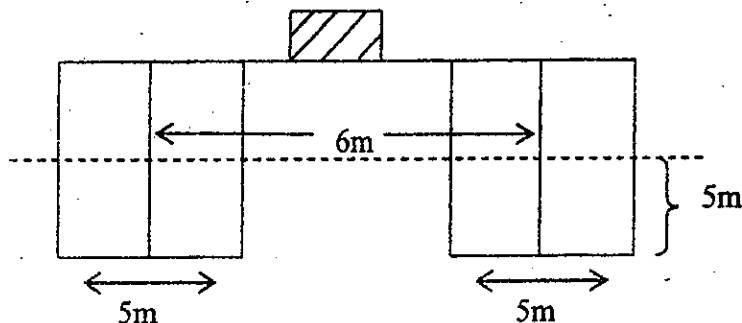
$$KM = 1.875 + 7.259 = 9.134 \text{ m}$$

$$\therefore GM = 9.134 - 5.0 = 4.134 \text{ m}$$

2. A raft is constructed of 2 identical box shaped barges each 5 mtrs wide parallel to each other, 6 mtrs apart centerline to centre line with a wooden deck over that. When a weight is placed on the centre line of wooden deck and barge is partially ballasted with SW to equal depth, the KG of raft is 6.05m and raft floats at an EK draft of 5 mtr. Calculate angle at which raft will incline.

Sol. Despite equal ballasting the raft is inclined which means there is angle of loll.

$$\tan \theta = \sqrt{\frac{2 GM}{BM}}$$



$$KB = 5/2 = 2.5 \text{ m}$$

$$BM = \frac{I_{CL}}{V}$$

$$\therefore I_{CL} \text{ of whole} = \frac{\ell \times 11^3}{12} = 110.916 \ell$$

$$I_{CL} \text{ of center} = \frac{\ell \times 1^3}{12} = 0.0833 \ell$$

$$I_{CL} = 110.916 \ell - 0.0833 \ell = 110.8327 \ell$$

$$BM = \frac{110.8327 \ell}{2 \times \ell \times 5 \times 5} = 2.2166 \text{ m}$$

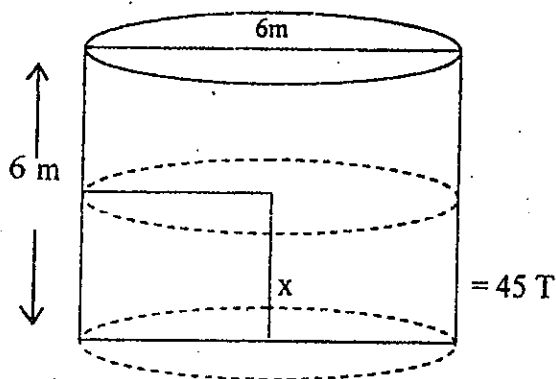
$$KM = 2.50 + 2.2166 = 4.7166 \text{ m}$$

$$FSC = \frac{idi}{W} = \frac{2 \times \ell \times 5^3 \times 1.025}{12 \times (\ell \times 5 \times 5 \times 1.025) \times 2} = 0.4166$$

$$GM(f) = KM - KG - FSC = 4.7166 - 6.05 - 0.4166 \\ = -1.75 \text{ m}$$

$$\tan \theta = \sqrt{\frac{2 \times 1.75}{2.2166}} \quad \text{or } 1.25658 \quad \theta = 51.48^\circ \text{ (Angle of loll)}$$

3. A circular pontoon of diameter 6m; depth 6m light ship displacement 250 t, KG 2.0m, is ballasted with 45t of S/W. A weight of 2 ton is placed 2m from the centre line. Find the resultant list.



$$\therefore \text{Initial } w = 250$$

$$SW = 45$$

$$Wt = 2 \text{ t}$$

$$\text{Total wt} = 297 \text{ t}$$

$$\text{Ballast} = \pi r^2 x \times 1.025 = 45$$

$$\therefore x = \frac{45}{3.14 \times 3 \times 3 \times 1.025} = 1.55 \text{ m}$$

$$\therefore \text{KG of Ballast} = 0.775 \text{ m}$$

$$\text{Also, } \pi r^2 h \times 1.025 = 297$$

$$\therefore h = \frac{297}{3.14 \times 3 \times 3 \times 1.025} = 10.25 \text{ m (Draft outside)}$$

$$\therefore KB = 5.125 \text{ m}$$

$$\text{To find BM, } I = \frac{\pi D^4}{64} = \frac{22 \times (6)^4}{7 \times 64} = 63.643$$

$$\therefore BM = \frac{I}{V} = \frac{63.643}{3.14 \times 3^2 \times 10.25} = 0.22 \text{ m}$$

$$KM = 0.22 + 5.125 = 5.345 \text{ m}$$

Weight	KG	Moment
250	2.0	500
45	0.775	34.875
2	6.000	12.000
297		546.875

$$\text{Final KG} = 1.841 \text{ m}$$

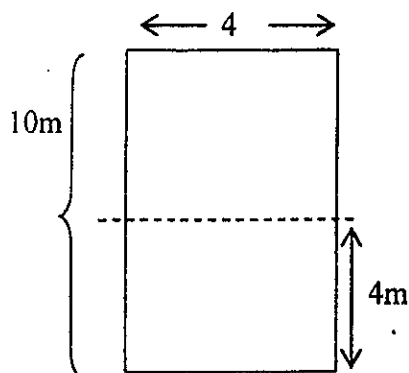
$$\begin{aligned} \text{FSC} &= \frac{63.643 \times 1.025}{3.14 \times 3 \times 3 \times 10.25 \times 1.025} \\ &= 0.22 \text{ m} \end{aligned}$$

$$GM(f) = 5.125 + 0.22 - 1.841 - 0.22 = 3.284 \text{ m}$$

$$\tan \theta = \frac{wd}{W \cdot GM(f)} = \frac{2 \times 2}{297 \times 3.284 \text{ m}} = 4.1011$$

$$\text{List} = 0.258^\circ = \theta^\circ = \underline{0.235^\circ}$$

4. A pontoon of circular cross section of diameter 4.0m, & depth 10m has KG = 3.0m, floating with its axis vertical at a draft of 4m. 60t of ballast is run into the pontoon and a weight of 2 ton is placed on deck 1.0m from centre line. Find list.



$$\tan \theta = \frac{wd}{W \cdot GM}$$

To find new GM? $KM - KG$

$$KM = KB + BM ?$$

$$KG = ?$$

$$FSC = ?$$

$$BM = \frac{\pi r^4}{4V}$$

$$BM = \frac{\pi \times 2^4}{4V}$$

$$\text{Initial } W = \pi r^2 h \times 1.025$$

$$= \pi \times 2^2 \times 4 \times 1.025 = 51.496 \text{ t}$$

$$\text{Final } W = 51.496 + 60 + 2 = 113.496 \text{ t}$$

Draft	W
4	51.496
?	113.496

$$\text{draft} = 8.816 \text{ m}$$

$$\therefore BM = \frac{\pi \times (2)^4}{4 \times \pi \times (2)^2 \times 8.816} = 0.113 \text{ m}$$

$$KB = \frac{1}{2} \times d = 4.408 \text{ m}$$

$$KM = 4.521 \text{ m} (4.408 + 0.113)$$

Let x be the depth of water inside:

$$60 = \frac{22}{7} \times 2^2 \times x \times 1.025$$

$$x = 4.656 \text{ m}$$

$$\therefore KG = \frac{1}{2} x$$

$$= 2.328 \text{ m}$$

(KG of ballast in the pontoon)

To find KG?

Wt	Load	Disch	KG	Moment
51.496		-	3.000	154.49
	60	-	2.328	139.68
	2	-	10.000	20.00
113.496				314.17

$$\therefore KG = \frac{314.17}{113.496} = 2.768 \text{ m}$$

$$\therefore GM(s) = 4.521 - 2.768$$

$$= 1.753 \text{ m}$$

$$FSC = \frac{id_l}{W} = \frac{3.14 \times 2^4}{4} \times \frac{1.025}{113.496}$$

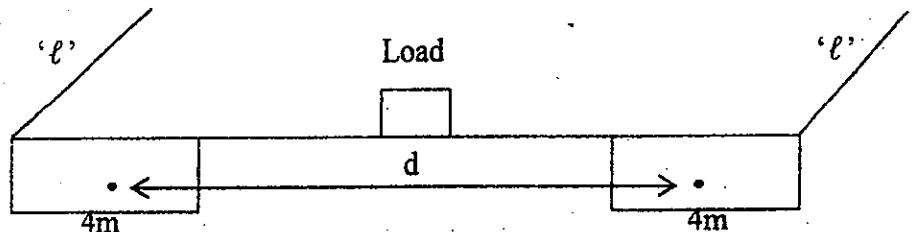
$$= 0.113 \text{ m}$$

$$\therefore GM_{\text{fluid}} = 1.753 - 0.113 = 1.64 \text{ m}$$

$$\therefore \tan \theta = \frac{2 \times 1}{113.496 \times 1.64} = 0.010$$

$$\therefore \text{List} = 0.615^\circ$$

5. A raft is constructed of two box shaped barges, each 4m wide, placed parallel to each other, with a wooden deck over them. When the raft is loaded, it floats at an even keel draft of 3m. with KG 4.544m. If the raft is to have a GM of 0.4m, what should be the distance between the center lines of the barges.



When loaded Draft = 3m

$$\therefore KB = \frac{1}{2} d = 1.5 \text{ m}$$

$$\text{Final GM} = 0.4 \text{ m}$$

$$KG = 4.544 \text{ m}$$

$$\therefore \text{Final KM} = 4.944 \text{ m}$$

$$KB + BM = 1.5 + BM$$

$$\therefore BM = 4.944 - 1.5 = \underline{3.444 \text{ m}}$$

$$I_{cl} \text{ of whole} = \frac{\ell(d+4)^3}{12}$$

$$I_{cl} \text{ of central portion} = \frac{\ell(d-4)^3}{12}$$

$$\therefore I_{cl} = \frac{\ell(d+4)^3}{12} - \frac{\ell(d-4)^3}{12}$$

$$\therefore BM = \frac{I_{cl}}{V} = \frac{[\ell(d+4)^3 - \ell(d-4)^3]}{12 \times 2 \times \ell \times 4 \times 3}$$

$$\text{Or } BM = \frac{(d^3 + 4 - d^3 + 4)(d^2 + 16 + 8d + d^2 + 16 - 8d + d^2 - 16)}{12 \times 2 \times 4 \times 3}$$

$$3.444 = \frac{8}{12 \times 12 \times 2} (3d^2 + 16)$$

$$\therefore 3d^2 + 16 = 3.444 \times 36 = 123.984$$

$$\therefore 3d^2 = 123.984 - 16 = 107.984$$

$$\therefore d^2 = 35.995$$

$$\therefore \underline{d = 6.0m}$$

$$\text{N.B. } a^3 - b^3 = (a-b)(a^2 + ab + b^2)$$

MISCELLANEOUS - PHASE II

Exercise 18

1. A pontoon of circular cross section 8m in dia and 8 metres deep floats in S.W. displacing 250 Tonnes, with its axis vertical. 50 Tonnes of S.W. ballast is run into the pontoon and weight of one tonne is placed on deck 1 m away from its center. Calculate resulting angle of list. KG of pontoon alone is 2.5m.
2. A pontoon of circular cross section diameter 4 meters floats with its axis vertical at a draft of 4m. The Kg is 2.5m, 50M/T of salt water is run into the pontoon and a weight of half a tonnes is placed on deck at a Kg of 9m and 0.5m away from the centerline. Calculate the angle of heel.
3. A pontoon of circular cross-section diameter 4 metres floats with its axis vertically at a draft of 4m. The KG is 2.5m. 50 M/T of salt water is run into the pontoon and a weight of half a tonne is placed on deck at a KG of 9m 2.05m. away from the centerline. Calculate the angle of heel.
4. A pontoon is constructed of two box shaped barges, each of width 4m, placed parallel to each other and 8m apart, centerline to centerline, with a deck placed over them. When the barges are ballasted with SW to a depth of 1m and a load placed on deck on the centerline of the pontoon, she floats at an even keel draft of 4m in SW. In this condition her KG (solid) is 5.7m. Calculate the angle to which she will incline. Show by calculation whether pumping out the entire ballast would improve or decrease her stability.
5. A vessel of constant triangular cross section has a depth of 12m and breadth at the deck of 15m. Calculate the draught at which the vessel will become unstable if the center of gravity is 6.675m above the keel.
6. The half ordinates of vessel's water plane area spaced 25m apart are :
0.4, 14.5, 26.6, 34.0, 37.0, 37.3, 37.1, 35.8, 28.8 & 6.0 meters respectively commencing from forward end.
If the SW displacement of the vessel up to that water plane is 150000t, calculate transverse BM, Longitudinal BM.

7. Find the distance between the centres of gravity and buoyancy of a rectangular log 1.2m wide, 0.6m deep, and of relative density 0.8 when floating in fresh water with two of its sides parallel to the waterline. If BM is equal to $\frac{b^2}{12d}$ determine if this log will float with two of its sides parallel to the waterline.
8. Will a homogeneous log 6m X 3m X 3m and relative density 0.4 float in fresh water with a side perpendicular to the waterline? If not, what will be the angle of loll?
9. A vessel of constant rectangular cross section has a breadth of 12m and metacentric height of one quarter of her draught. The vertical centre of gravity lies on the waterline. Calculate her draught.

-oOo-

ANSWERS

1. List = 0.258°
2. Draft = 7.921 m, FSC = 0.126 m, GM(FS) = 1.703 m,
List = $0^\circ 4.9'$
3. KG = 2.258 m, $BM_T = 0.126$ m, List = $0^\circ 20.3'$
4. No list at this condition as GM = +0.3m
List = 13.04° after pumping out all the water
5. 7.2 m
6. $BM_T = 32.609$ m $BM_L = 254.066$ m
7. BG = 0.06 m $GM = 0.19$ m, Since G is below M, the homogeneous log is in stable equilibrium and thereafter it will float with two of its sides parallel to waterline.
8. GM = -0.275 m, $\theta = 43^\circ 10' = \text{Angle of loll}$
4m

-oOo-

CHAPTER XX

DIRECTIONAL STABILITY

The directional stability of a ship is related with

- i. The steering characteristic of the vessel.
- ii. The degree to which she can be checked when swinging &
- iii. The change in her rate of turn when the rudder is put amidships.

There are 3 types of directional stability:

- a. A ship that tends to steady up when the rudder is put amidship said to have positive directional stability.
- b. If the ship tends to swing at increasing rate of turn when the rudder is amidships, she is said to have negative stability.
- c. A ship is said to have neutral directional stability, when she continues swinging at the present rate or continues along her current heading until external forces take charge.

When navigating in a river or narrow channel, the directional stability plays an important role. If a vessel is directionally unstable, more rudder will be needed for a longer time to check the swing.

A constant attention will be needed for these ships in narrow channels. Also while making course alterations at sea, we will require large rudder angles and concentration for directionally unstable ship.

The directional stability depends upon the draft and trim of the vessel. Even small increase in the trim by stern can give a vessel a positive directional stability. Normally when a ship is significantly down by head, she will have a negative directional stability and it will be quite difficult for the quarter master to steer. More time will be required to start ship's swing and large rudder angles will be needed to check it.

When handing over to pilot, the master must brief him up about the directional stability of the ship.

Apparently the following holds good in case of directional stability.

- i. The directional stability increases as the under keel clearance decreases.
- ii. It becomes more positive as the length increases.
- iii. It becomes more positive as the drag increases (trim changes)
- iv. It decreases as the block coefficient increases.
- v. It decreases as the beam increases for a given length. (Length / beam ratio decreases)
- vi. It decreases as the area of the for'd section increases relative to area of the after section. (as the pivot point shifts ahead)

CHAPTER XXI

HEEL WHILE TURNING

When a vessel is in a steady turn it can be assumed that the centrifugal force is acting at centre of gravity G and the equal and opposite centripetal force is acting at the centre of buoyancy B. The vessel will reach a steady heel when (Figure below).

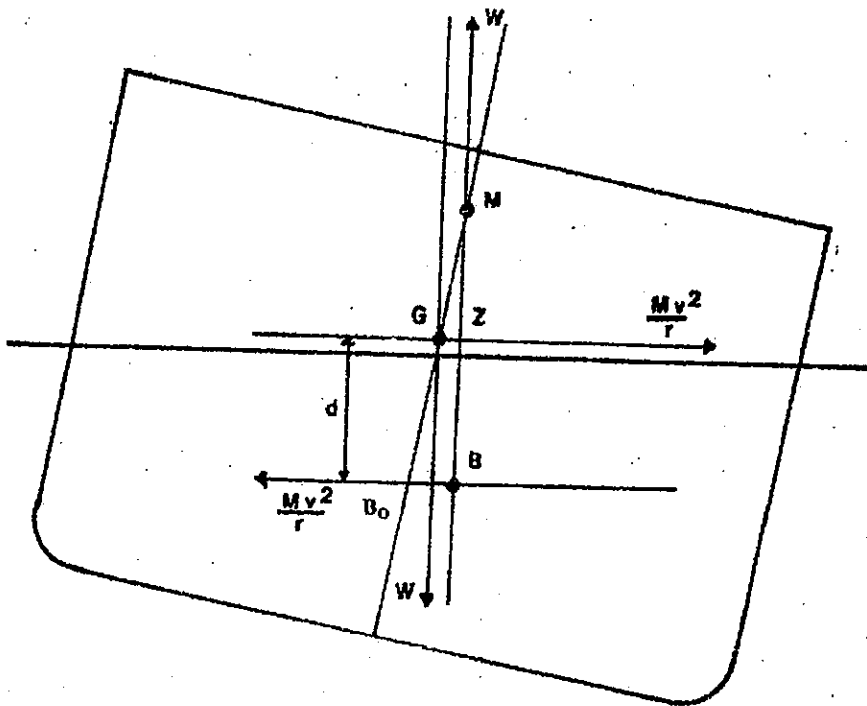


Figure Heel due to turning

$$\text{Righting moment} = d \times \text{centrifugal force}$$

Where d = vertical separation between G and B

$$\text{Centrifugal force} = \frac{Mv^2}{r}$$

M = Mass of vessel Kg

V = Velocity in m/s

r = Radius of turn m

Putting displacement = Mg

g = acceleration due to gravity

$$Mg \times GZ = \frac{Mv^2}{r} \times d$$

$$GZ = \frac{v^2 d}{rg}$$

For small angles

$$GZ = GM \sin \theta$$

$$d = B_0 G \cos \theta$$

$$\therefore GM \sin \theta = \frac{v^2 B_0 G \cos \theta}{rg}$$

$$\text{Or } \tan \theta = \frac{v^2 B_0 G}{GMrg} = \frac{v^2 \cdot B_0 G}{GM \cdot r \cdot g} = \frac{v^2 (KG - d/2)}{g \times GM \times r}$$

Example

A ship turns to port in a circle of radius 150 m at a speed of 16 knots. The GM is 0.8m and BG is 1.5m. If $g = 981 \text{ cm/sec}^2$ and 1 knot is equal to 1852 m/hour, find the heel due to turning.

$$\text{Ship speed in m/sec} = 16 \times \frac{1852}{3600}$$

$$v = 8.231 \text{ m/sec}$$

$$\tan \theta = \frac{v^2 \times BG}{g \cdot r \cdot GM}$$

$$= \frac{8.231^2 \times 1.5}{9.81 \times 150 \times 0.8}$$

$$\tan \theta = 0.12949$$

Ans. Heel = 4.93° to starboard, due to Centrifugal forces only.

In practice, this angle of heel will be slightly smaller. Forces on the rudder will have produced an angle of heel, say 2° to port. Consequently the overall angle of heel due to turning will be:

$$\text{Heel} = 7.38^\circ - 2^\circ = 5.38^\circ \text{ to starboard}$$

Exercise : 19

1. A vessel turns in a circle of radius 100 mts at a speed of 15 knots. Her KG, KB and GM (f) are 6m, 5m, 0.60m respectively. Find the heel to which the vessel will settle during the turn.

Ans : 5.78°

2. A ship turns in a circle of radius 100 metres at a speed of 15 knots. The GM is $\frac{2}{3}$ metres and BG is 1 metre. If $g = 981 \text{ cm/sec}^2$ and 1 knot is equal to 1.8532 Km/hour, find the heel due to turning.

Ans : 5.8°

CHAPTER XXII

HEEL DUE TO WIND LOADING

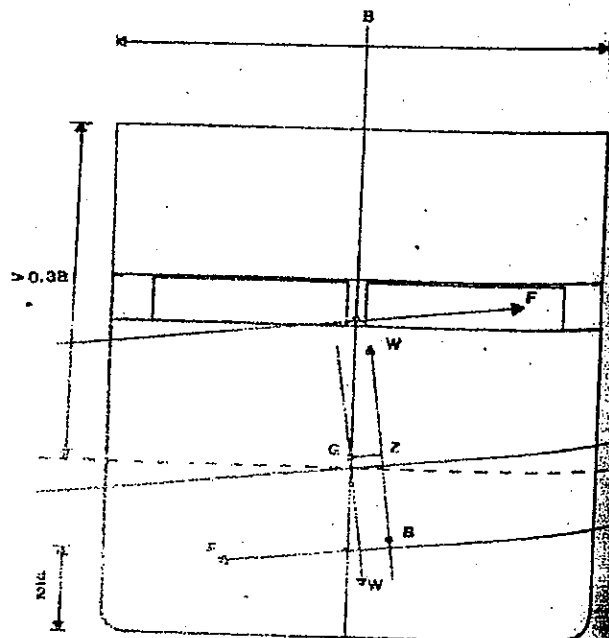
A vessel heeled due to wind (Figure 1 below) will be in equilibrium when the righting moment $W \times GZ$ is equal and opposite to the wind heeling moment $F \times l$, when l is the vertical distance between the mid draft and the centroid of the projected side area of the vessel.

There are no statutory regulations governing the stability of vessels subject to wind heeling. However, with reference to chapter XXVI later the recommendations are (see Figures 2 and 3):

- (a) The vessel is assumed to be in her worst condition.
- (b) The lateral windage area is assumed to be subjected to a steady wind loading of 48.5 kg/m^2 giving the Force F .
- (c) On a curve of righting moment the angle of heel due to steady wind loading is located at θ_1 , where
righting moment = $F \times l = \lambda_0$
- (d) It is then assumed that the vessel rolls 15° into the wind.
- (e) Taking λ_0 as being the righting moment at θ_1 , a line is drawn at $1.5 \lambda_0$ parallel to the heel axis.
- (f) The area S_1 between the righting moment curve and $1.5 \lambda_0$ is measured.
- (g) The angle θ_{dy} is found so that
area $S_1 = \text{area } S_2$

i.e. θ_{dy} represents the angle of heel to which the vessel would roll if the work represented by area S_1 were to be absorbed by area S_2 :

Figure 1
Heel due to wind loading.



The instructions recommend that θ_{dy} should not exceed the angle of flooding and that $\theta_1 < 0.65$ (angle of deck edge immersion)

Example (Figure 4)

A vessel has the following values of GZ at the angle of heel indicated

0° 5° 10° 25° 30° 40° = Heel

0 0.04 0.09 0.09 0.29 0.32 = GZ

The vessel is displacing 32000 tonnes, has KG, 10.3m and KM, 10.8m.

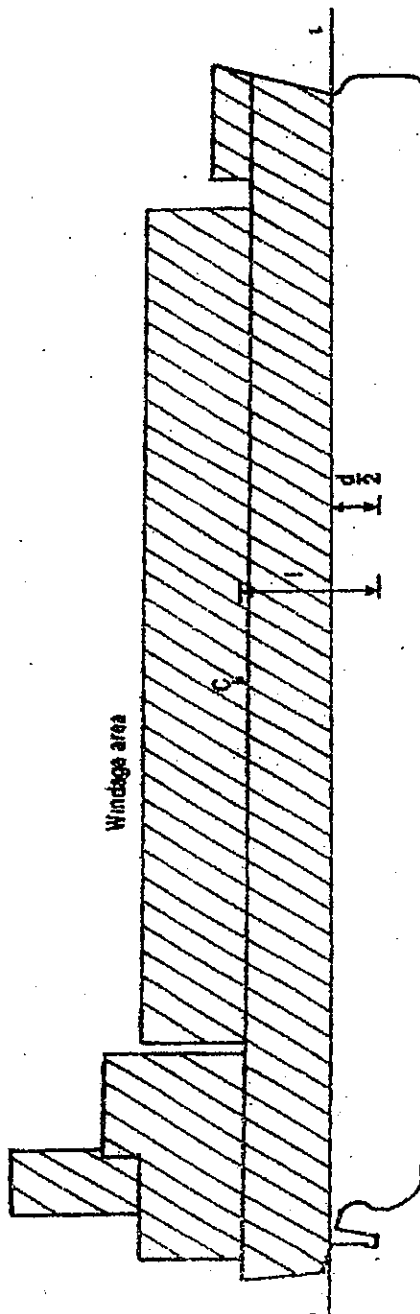


Figure 2 Windage area

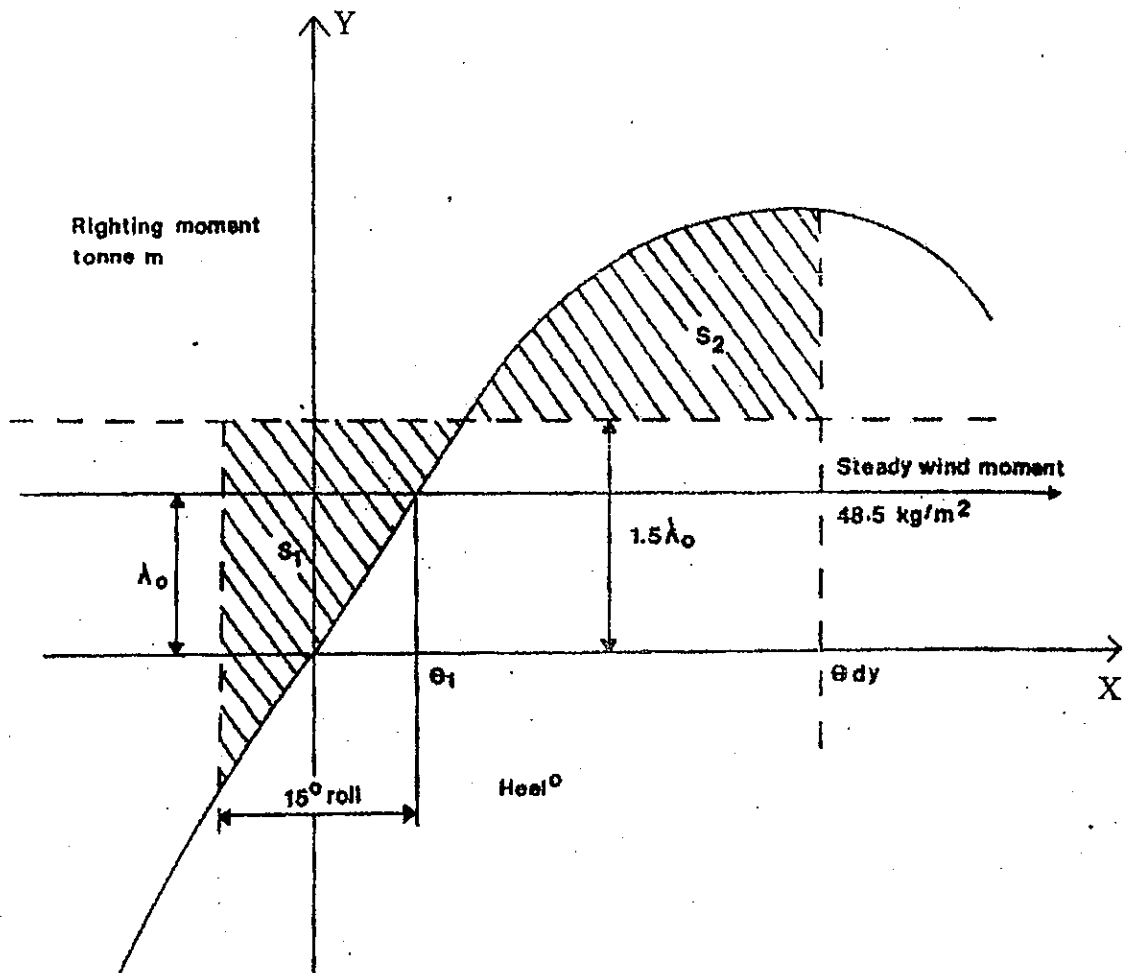


Figure 3 Stability recommendations for wind loading of container vessels

She is floating at draft 11m.

The windage area is 3800m^2 and the centroid of the area is 6m above the waterline.

The angle of deck edge immersion is 23° .

The angle of flooding is 34° .

Assess the ability of the vessel to withstand heeling due to wind (Figure 4).

Heel	GZ	Displacement	Righting moment
0°	0	32000	0
5°	0.04	32000	1280
10°	0.09	32000	2880
20°	0.19	32000	6080
30°	0.29	32000	9280
40°	0.32	32000	10240

$$= \frac{3800 \times 48.5 \times 11.5}{1000}$$

$$= 2119.45$$

$$1.5 \lambda_0 = 3179.18$$

From curve area S_1 extend of 18° . $h = 6^\circ$

Station	Ord.	SM	F (Area)
0	5300	1	5300
1	3450	3	10350
2	1890	3	5670
3	00	1	0
Sum =			21320

$$S_1 = \frac{3h}{8} \times \text{Sum} = \frac{3 \times 6}{8} \times \frac{21320}{57.3}$$

$$S_1 = 837.1 \text{ tonne m radians}$$

Taking 18° for S_2 as first approximation

Station	Ord.	SM	F (Area)
0	0	1	0
1	2100	3	6300
2	4050	3	12150
3	5690	1	5690
Sum =			24140

$$S_2 = \frac{3h}{8} \times \text{Sum} = \frac{3 \times 6}{8} \times \frac{24140}{57.3}$$

$$= 947.9 \text{ tonne m radians}$$

$$S_1 = 837.1$$

$$\text{Difference } 110.8$$

Reduction in θ assuming area approximately rectangular

$$5690 \times \theta_c = 110.8$$

$$\theta_c = \frac{110.8}{5690}$$

$$= \frac{110.8 \times 57.3}{5690}$$

$$= 1.12^\circ$$

$$\text{Range} = 18^\circ - 1.12^\circ$$

$$= 16.88^\circ$$

$$\text{New Interval} = 5.66^\circ \left[\frac{16.88}{3} = 5.66^\circ \right]$$

Stations	Ord.	SM	F (Area)
0	0	1	0
1	1900	3	5700
2	3800	3	11400
3	5400	1	5400
			22500

$$S_1 = \frac{3}{8} \times \frac{5.66}{57.3} \times 22500 \text{ tonne m radians}$$

$$= 833.4 \text{ tonne m radians}$$

Which is sufficiently close

$$\therefore \theta_{dy} = 10.8^\circ + 16.88^\circ$$

$$= 27.68^\circ$$

$$\theta_f = 34^\circ$$

θ_{dy} satisfactory because it does not exceed angle of flooding θ_f (34°)

$$\theta_1 = 8^\circ$$

$$0.65\theta_{dc} = 0.65 \times 23^\circ \quad (0.65 \times \text{angle of deck edge immersion})$$

$$= 14.95^\circ$$

$\therefore \theta_1$ satisfactory because $8^\circ (\theta_1)$ is $< 0.65 \times$ Angle of deck edge immersion.

CHAPTER XXIII

DYNAMICAL STABILITY

Explanation of Dynamical Stability

Before dealing with regulations about stability, it is necessary to be able to measure dynamical stability using the GZ curve.

In the case of a floating body the concept can be considered in terms of the separation between the centre of gravity G and the centre of buoyancy $B_0 - B_\theta$ as a vessel which is initially stable is heeled.

In Figure below a vessel which is initially stable is heeled through a small angle θ from the upright. If the initial separation between G_0 and B_0 is d_0 .

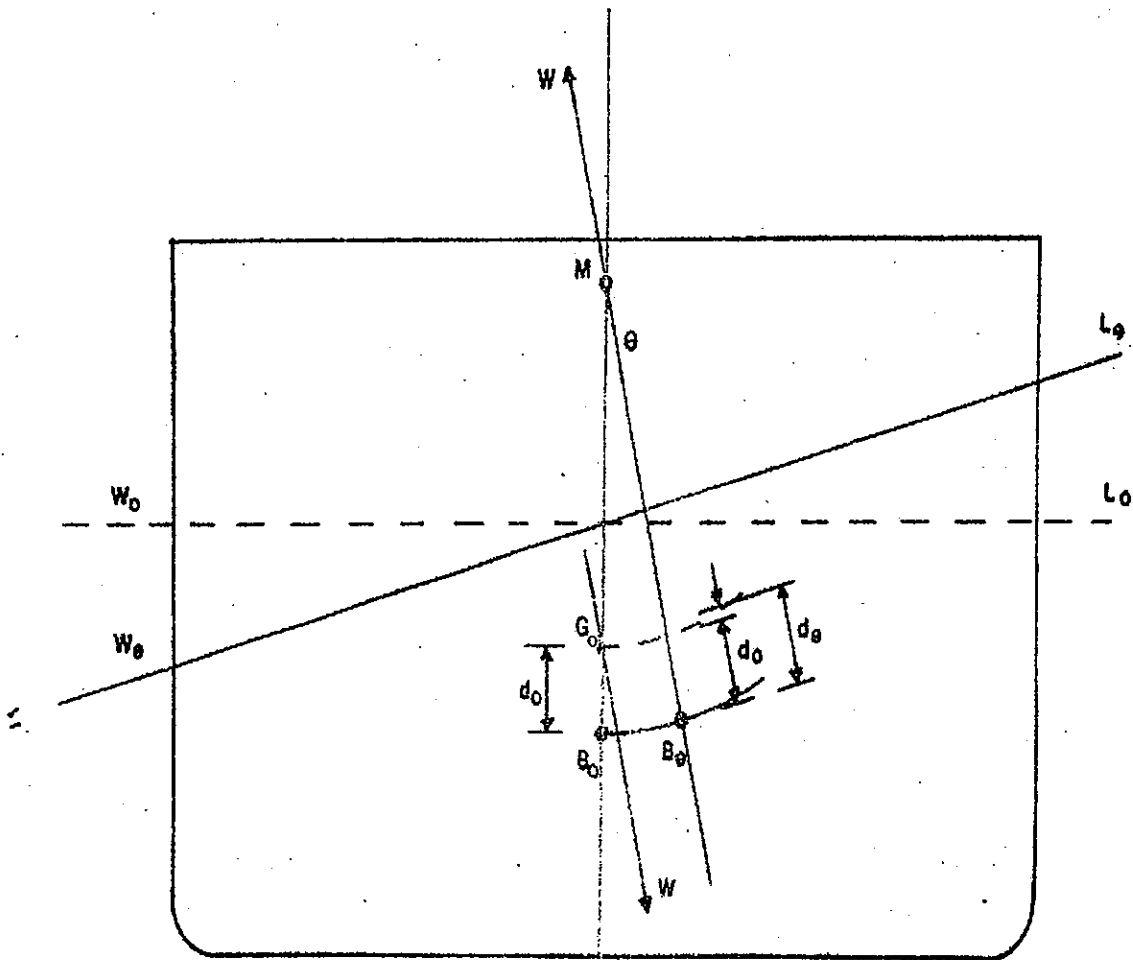


Figure Dynamical stability

Then if we assume that the metacentre M remains fixed on the centerline and centre of buoyancy will move in an arc, centre M, radius MB_0 . If the vertical separation between G_0 and B_0 is now measured and is d_θ , it can be seen that $d_\theta > d_0$. Hence work has been done separating G and B.

$$\text{Dynamical stability} = W (d_\theta - d_0)$$

The problem is to determine this value in general. If we consider a vessel heeled to some angle θ and then heeled through a further small angle $\delta\theta$. Then in Figure 2 and (b) the increase in separation of G and B_0 is $GZ_\theta \delta\theta$

$$\begin{aligned} & \text{GZ} = 0 \\ \therefore (d_0 - d_1) &= \sum_{\text{GZ} = 0}^{\text{GZ} = 0} \text{GZ} \delta\theta \end{aligned}$$

If on GZ curve (Figure 3) $\text{GZ}_\theta \delta\theta$ is plotted it can be seen that $\text{GZ}_\theta \delta\theta$ is an element of the GZ curve. Therefore in the limit

$$(d_0 - d_1) = \int_0^H \text{GZ} \delta\theta$$

which is the area beneath the GZ curve up to angle Φ

$$\therefore \text{Dynamical stability} = W (\text{Area beneath GZ curve})$$

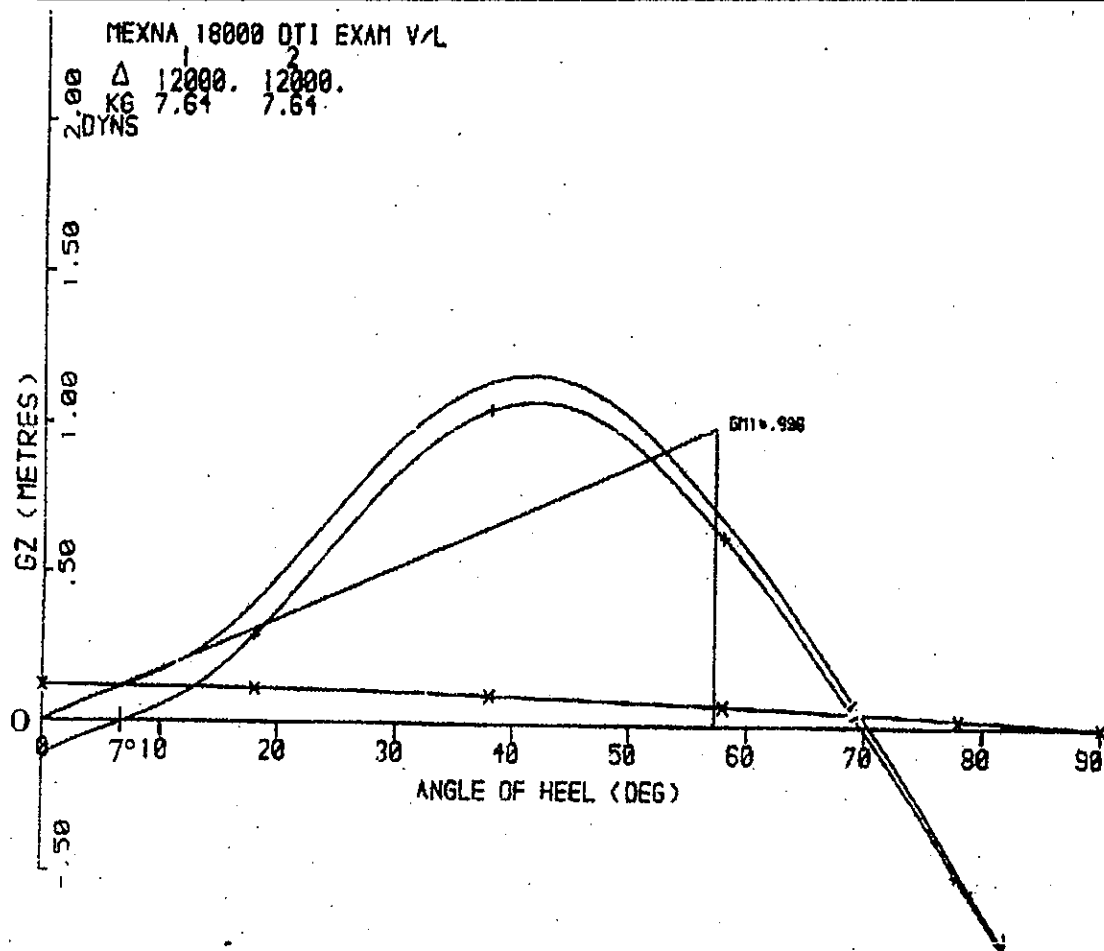
Example : 1

A vessel displacing 12000 tonnes has KG, 7.64 m. The values of GZ are as follows:

Heel	0	10	20	30	40	50	60	70	degrees
GZ	0	0.19	0.50	0.94	1.16	1.03	0.60	0.06	m

Cargo is redistributed so as to make the centre of gravity 0.13 m to port. Find the list and the dynamical stability from the list angle to 30°.

Heel	0	10	20	30	40	50	60	70
G_0Z_0	0	0.19	0.50	0.94	1.16	1.03	0.60	0.06
$G_0G_1 \cos$	0.13	0.13	0.12	0.11	0.10	0.08	0.07	0.05
G_1Z_1	-0.13	0.06	0.38	0.83	1.06	0.95	0.53	0.01



From Figure above

Heel 7°

Area 10° - 30°

Heel	GZ (m)	SM	F (Area)
10	0.06	1	0.06
20	0.38	4	1.52
30	0.83	1	<u>0.83</u>
			2.41

$$\begin{aligned}
 \text{Area } 10 - 30 &= \frac{1}{3} h \times \Sigma F (\text{Area}) \\
 &= \frac{1}{3} \times \frac{10}{57.3} \times 2.41 \text{ m radians} \\
 &= 0.140 \text{ m radians}
 \end{aligned}$$

Area 7 – 10 assuming that area is triangular

$$\begin{aligned}
 \text{Area} &= \frac{1}{3} \times \frac{3}{57.3} \times 0.06 \text{ m radians} \\
 &= 0.001 \text{ m radians}
 \end{aligned}$$

$$\text{Area } 7 - 30 = 0.141 \text{ m radians } (0.140 + 0.001 = 0.141)$$

$$\begin{aligned}
 \text{Dynamical stability} &= \text{Displacement} \times \text{area} \\
 &= 120000 \text{ tonnes} \times 0.141 \text{ m radians} \\
 &= 1692 \text{ tonne m.}
 \end{aligned}$$

Example : 2

A box shaped vessel has length 120m, breadth 18m, depth 12m is floating at draft 8m in fresh water with KG 7.278m. A weight of 432 tonnes is loaded on deck at Kg 12m. Find the dynamical stability of the vessel up to the angle of deck edge immersion.

$$\begin{aligned}
 \text{Displacement} &= L \times B \times d \times \rho \\
 &= 120 \times 18 \times 8 \times 1 \text{ tonne} \\
 &= 17280 \text{ tonne}
 \end{aligned}$$

Weight	KG	Moment
17280	7.278	125755.2
432	12000	5184.0
17712		130939.2

$$\begin{aligned}
 KG &= \frac{\text{moment}}{\text{Weight}} \\
 &= \frac{130939.2}{17712} = 7.393 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Draft} &= \frac{\text{displacement}}{L \times B \times \rho} \\
 &= \frac{17712}{120 \times 18 \times 1} = 8.2 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 KM &= \frac{d}{2} + \frac{B^2}{12d} \\
 &= \frac{8.2}{2} \text{ m} + \frac{18^2}{12 \times 8.2} \text{ m}
 \end{aligned}$$

$$KM = 7.393 \text{ m}$$

$$KG = 7.393 \text{ m}$$

$$GM = \underline{0.000 \text{ m}}$$

Angle of deck edge immersion

$$\begin{aligned}
 \tan \theta &= \frac{\text{freeboard}}{\text{Half breadth}} \\
 &= \frac{12 - 8.2}{9}
 \end{aligned}$$

$$\theta = 22.89^\circ$$

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

$$GZ = \frac{1}{2} BM \tan^2 \theta \sin \theta$$

$$BM = 3.293 \text{ m}$$

$$\frac{BM}{2} = 1.646 \text{ m}$$

$$GZ = 1.646 \tan^2 \theta \sin \theta$$

$$\text{Area 0} - 20$$

Heel	GZ	SM	F (Area)
0	0.000	1	0.000
5	0.001	4	0.004
10	0.009	2	0.018
15	0.031	4	0.124
20	0.075	1	<u>0.075</u>
			0.221

$$\text{Area}_{0-20} = \frac{1}{3} \times \frac{5}{57.3} \times 0.221$$

$$= 0.0064 \text{ m radians}$$

Area $20 - 22.89$

Heel	GZ
20	0.075
22.89	0.114
	<u>0.189</u>

Using trapezoid rule

$$\text{Area} = \frac{1}{2} \times \frac{2.89}{57.3} \times 0.189$$

$$= 0.0048 \text{ m radians}$$

$$\text{Area}_{0-20} = 0.0064 \text{ m radians}$$

$$\text{Area}_{0-22.9} = 0.0112 \text{ m radians}$$

$$\text{Dynamical stability} = \text{area} \times \text{displacement}$$

$$= 0.0112 \times 17712 \text{ tonne m}$$

$$= 198.4 \text{ tonne m}$$

DYNAMICAL STABILITY

Exercise 20

1. A ship displacing 20000 tonnes has the following values of GZ :

Heel	0	15°	30°	45°
GZ	0	0.325	0.775	0.860 metres

Calculate the values of statical and dynamical stability at 45°.

2. A box vessel, $L = 100\text{m}$, $B = 18\text{m}$, $D = 10\text{m}$ and $d = 4\text{m}$ on an even keel in SW has $KG = 5\text{m}$. Calculate the righting lever at a small angle of 10° and at a large angle of 20° . Hence calculate the dynamical stability at 20° heel.
3. A ship displacing 9000 tonnes, $KG = 5\text{m}$, loads 2000 tonnes, $Kg = 3\text{m}$ and 4000 tonnes $Kg = 9\text{m}$. Using cross curves of stability given (1) determine the statical stability and dynamical stability at 30° and discuss the difference in the values.
4. A ship displacing 15000 tonnes $KG = 7\text{m}$, $KM = 8.16\text{m}$ has the following values of GZ :

0	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
GZ	0	0.21	0.46	0.78	0.97	1.0	0.92	0.71	0.40	0.10m

Draw the curve of statical stability for displacement 15000 tonnes, $KG = 8\text{m}$. Determine the extent to which the ship complies with the minimum standard required by the Load Line Rules, viz:

1. GM not less than 150 mm.
 2. (a) Area up to $30^\circ = \nless 0.055$ metre radians.
 (b) Area up to $40^\circ = \nless 0.09$ metre radians.
 (c) Area between 30° and $40^\circ = \nless 0.03$ metre radians.
 3. GZ at least 0.20m at 30° or greater.
5. A ship displacing 14000 tonnes, $KG = 8.50\text{m}$, has the following values of GZ :

0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
0.0	0.10	0.35	0.70	1.08	1.18	1.10	0.92	0.67	0.30	-0.29

A mass of 200 tonnes moves athwartships through a distance of 7m. Plot the GZ curve for this condition and state :

- (i) Approximate list
- (ii) Angle of maximum stability
- (iii) Range of positive stability.

6. Ship displacing 10000 tonnes, $KG = 6m$, has the following GZ values :

0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
0	0.24	0.50	1.0	1.65	2.10	2.0	1.60	1.10	0.50	-0.10

A weight of 100 tonnes is shifted 15m across the deck.

By drawing the curves for both conditions discuss the effect on stability of the shift.

-oOo-

Answers :

1. Statical = 17200 tonnes metres. Dynamical = 8168 tonnes metres.

2. GZ at $10^\circ = 0.651m$. GZ at $20^\circ = 1.435m$.

Dynamical stability = 1734 tonnes metres.

3. Statical = 24000 tonnes metres Dynamical = 5655 tonnes metres.

4. Area to $30^\circ = 0.0525$ metre radians.

Area to $40^\circ = 0.1086$ metre radians.

Area to $30^\circ - 40^\circ = 0.0561$ metre radians.

Maximum GZ at 36° approx.

There are values of GZ in excess of 0.20m at 30° and above. GM is approx 2.00m.

Stability is therefore deficient, but only in terms of the area under the curve at 30° .

5. (i) 9° (ii) 52° (iii) 87°

6. Capsizing levers 0° to 7° ; Righting levers reduced at all angles between 7° and 90° ; Range reduced from approx. 98° to approx 91° .

-oOo-

CHAPTER XXIV

INCREASE IN DRAFT DUE TO HEEL

A vessel with draft d is heeled or listed to some angle θ . At angle θ the maximum draft of the vessel is $a + b$.

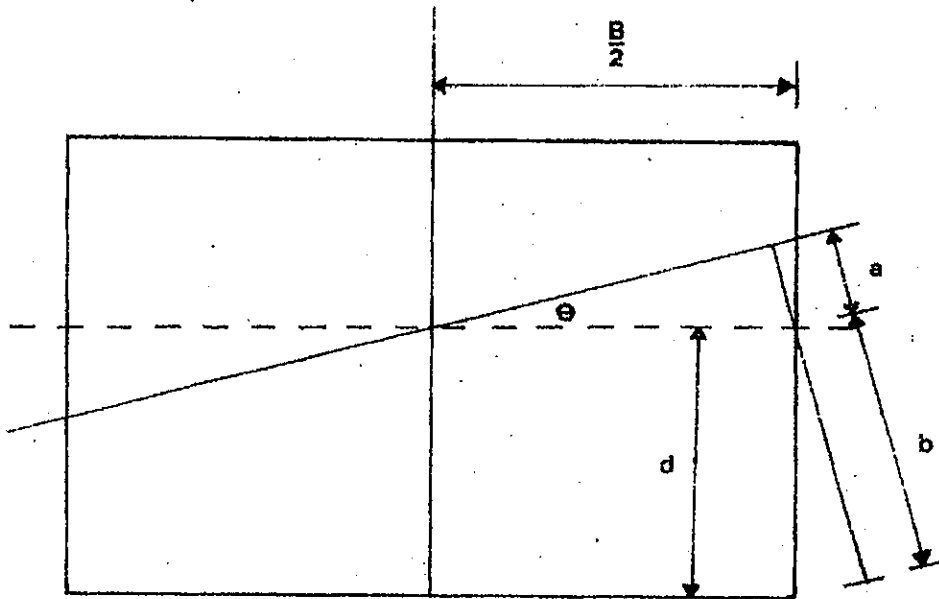


Figure Increase in draft due to heel

Then if the vessel has breadth B

$$a = \frac{B}{2} \sin \theta$$

$$b = d \cos \theta$$

$$\therefore \text{Draft heeled} = \frac{B}{2} \sin \theta + d \cos \theta$$

This relationship can be adapted to take into account rise of floor and turn of bilge. However, the indication of increased draft given by the equation will be sufficient for most practical purposes.

If the formula is to be used to find the new draft it must now be amended to allow for the rise of floor as follows :

$$\text{New draft} = \frac{1}{2} \text{ beam sin list} + (\text{Old draft} - \text{Rise of floor}) \cos \text{list}.$$

Note :

In practice, the shipbuilder's naval architect usually calculates the increase in draft for the ship at various angles of list and supplies the information to the ship's officer by means of a table on the plans of the ship.

The rise of floor, similar to tumblehome on merchant ships, has almost become obsolete on merchant ships of today.

Examples

1. A vessel's beam at waterline is 30m. She is floating upright at a draft of 8m. If the ship lists to 20° , find the new draft.

$$\begin{aligned} \text{New Draft} &= \frac{B}{2} \sin \theta + d \cos \theta \\ &= \frac{30}{2} \sin 20^\circ + 8 \cos 20^\circ \\ &= 5.13 + 7.51 \\ &= 12.64 \text{ m} \end{aligned}$$

2. A ship has 20m beam at the waterline and is floating upright at 6m draft. If the rise of floor is 0.25m, calculate the new draft if the ship is now listed 15 degrees

$$\begin{aligned}\text{Draft heeled} &= \frac{B}{2} \sin \theta + (d-r) \cos \theta \\&= \frac{20}{2} \sin 15^\circ + (6 - 0.25) \cos 15^\circ \\&= 10 \sin 15^\circ + 5.75 \cos 15^\circ \\&= 2.588 + 5.554 \\&= 8.142 \text{ m}\end{aligned}$$

CHAPTER XXV

SQUAT CALCULATION

Squat is the term used to describe the changes in draft and trim which occur when the depth of water beneath the vessel is less than one-and-a-half times the draft and the vessel is traveling at considerable speed. It may also be necessary to consider squat when reading drafts when there is little under keel clearance on a berth with a considerable tide running.

As the static under keel clearances have decreased and as the service speeds have increased, ship squats have gradually increased. They can now be of the order of 1.50 to 1.75m, which are of course by no means inconsequential.

Signs that a ship has entered shallow water conditions can be one or more of the following:

1. Wave-making increases, especially at the forward end of the ship.
2. Ship becomes more sluggish to manoeuvre. A pilot's quote, 'almost like being in porridge'.
3. Draught indicators on the bridge or echo-sounders will indicate changes in the end draughts.
4. Propeller rpm indicator will show a decrease. If the ship is in 'open water' conditions, i.e. without breadth the restrictions, this decrease may be up to 15 per cent of the service rpm in deep water. If the ship is in a confined channel, this decrease in rpm can be up to 20 per cent of the service rpm.
5. There will be a drop in speed. If the ship is in open water conditions this decrease may be up to 30 per cent. If the ship is in a confined channel such as a river or a canal then this decrease can be up to 60 per cent.
6. The ship may start to vibrate suddenly. This is because of the entrained water effects causing the natural hull frequency to become resonant with another frequency associated with the vessel.
7. Any rolling, pitching and heaving motions will all be reduced as the ship moves from deep water to shallow water conditions. This is because of the cushioning effects produced by the narrow layer of water under the bottom shell of the vessel.

8. The appearance of mud could suddenly show in the water around the ship's hull say in the event of passing over a raised shelf or a submerged wreck.
9. Turning circle diameter (TCD) increases. TCD in shallow water could increase 100 per cent.
10. Stopping distances and stopping times increase, compared to when a vessel is in deep waters.

CALCULATION OF SQUAT

Formulae have been developed that will be satisfactory for estimating maximum ship squats for vessels operating in confined channels and in open water conditions. These formulae are the results of analyzing about 600 results some measured on ships and some on ship models. Some of the empirical formulae developed are as follows:

Let

- b = breadth of ship
- B = breadth of river
- H = depth of water
- T = ship's even-keel static draft.
- C_b = block co-efficient
- V_k = ship speed relative to the water or current.
- CSA = Cross Sectional Area (See Fig.)

Let S = blockage factor = CSA of ship/CSA of river or canal.

If ship is in open water conditions, then the formula for B becomes

$$\text{Width influence, } B = \{7.7 + 20(1 - C_b)^2\} \times b,$$

$$\text{Blockage factor} = S = \frac{b \times T}{B \times H}$$

$$\text{Maximum squat} = \delta_{\max}$$

$$= \frac{C_b \times S^{0.81} \times V_k^{2.08}}{20}$$

metres, for open water
and confined channels

much cheaper.

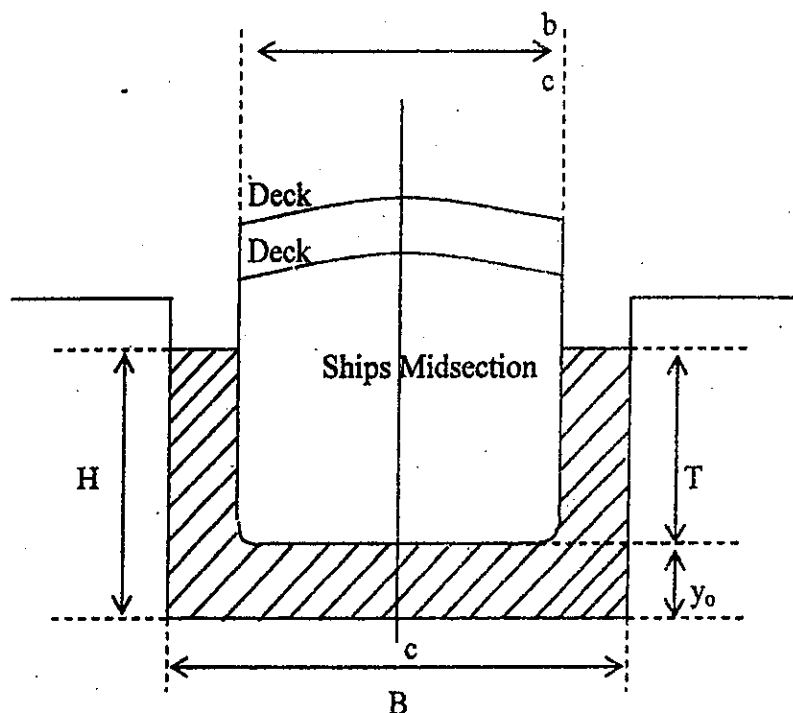


Fig.: Ship in a canal in static condition

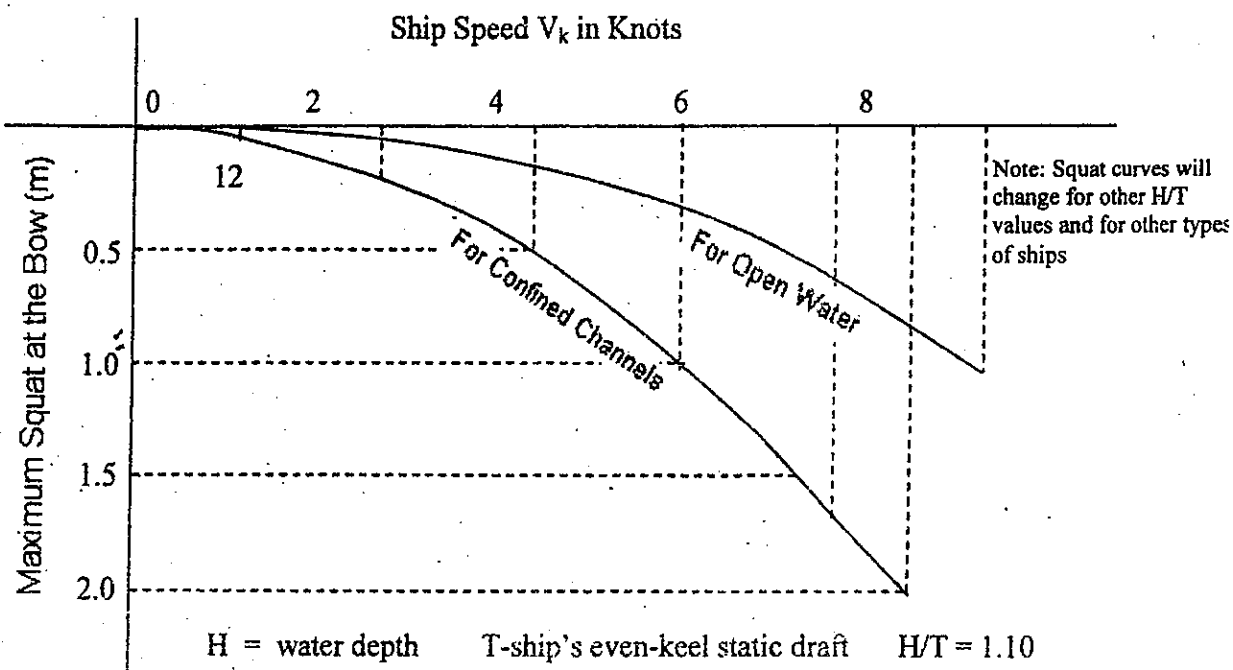


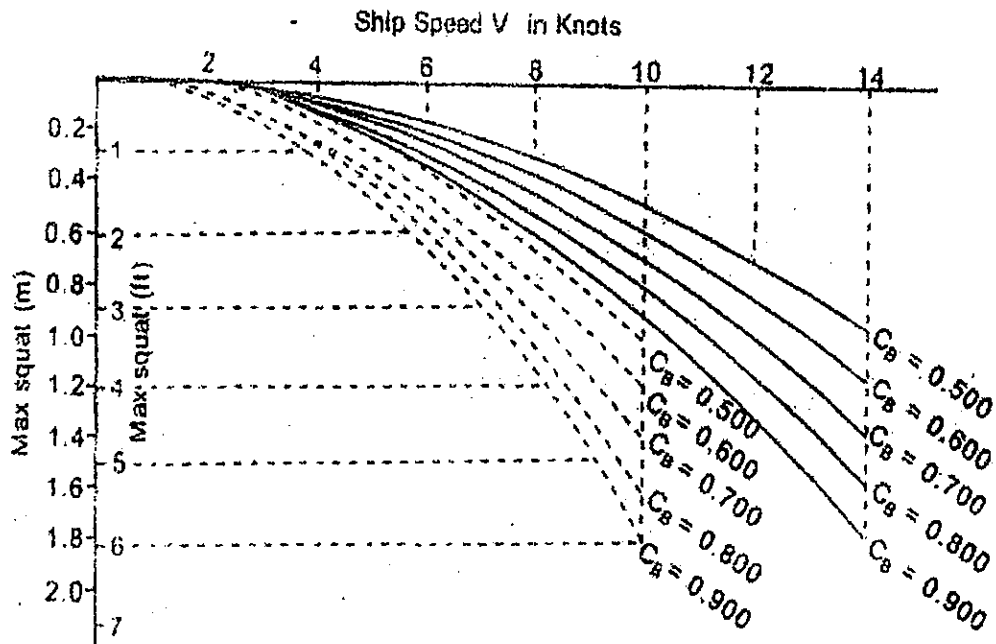
Fig. : Maximum squats against ship speed for 250 000t. dwt supertanker.

A_s = cross-section of ship at amidships = $b \times T$.

A_c = cross-section of canal = $B \times H$.

Blockage factor = $S = \frac{A_s}{A_c} = \frac{b \times T}{B \times H}$

γ_0 = static underkeel clearance.



----- Denotes ship is in a confined channel where $S = 0.100$ to 0.265

— Denotes ship is in open water, where $H/T = 1.10$ to 1.40

Ship type	Typical C_B , fully loaded	Ship type	Typical C_B , fully loaded
ULCC	0.850	General cargo	0.700
Supertanker	0.825	Passenger liner	0.625
Oil tanker	0.800	Container ship	0.575
Bulk carrier	0.750	Coastal tug	0.500

Fig: Maximum ship squats in confined channels and in open water conditions.

Worked example

A supertanker operating in open water conditions is proceeding at a speed of 15 knots. Her $C_B = 0.85$, static even-keep draft = 12 m with a static underkeel clearance of 2.0 m. Her breadth moulded is 60 m with LBP of 300 m.

Calculate the maximum squat for this vessel at the given speed and her remaining ukc (underkeel clearance) at V_k of 15 kts.

Answer:

$$\text{Width of influence} = \{7.7 + 20[1 - C_B]^2\} \times b = 'B'$$

$$\therefore 'B' = \{7.7 + 20[1 - 0.85]^2\} \times 60$$

$$\therefore 'B' = \underline{489 \text{ m.}}$$

i.e. artificial boundaries in open water

$$\text{Blockage factor, } S = \frac{b \times T}{'B' \times H} = \frac{60 \times 12}{489 \times [12 + 2]} = \underline{0.105}$$

(water depth)

$$\text{Maximum squat} = \frac{C_B \times S^{0.81} \times V_k^{2.08}}{20} = \delta_{\max}$$

$$\therefore \delta_{\max} = 0.85 \times 0.105^{0.81} \times 15^{2.08} \times \frac{1}{20}$$

$$\therefore \underline{\delta_{\max} = 1.91 \text{ m}}$$

at the bow, because $C_B > 0.700$.

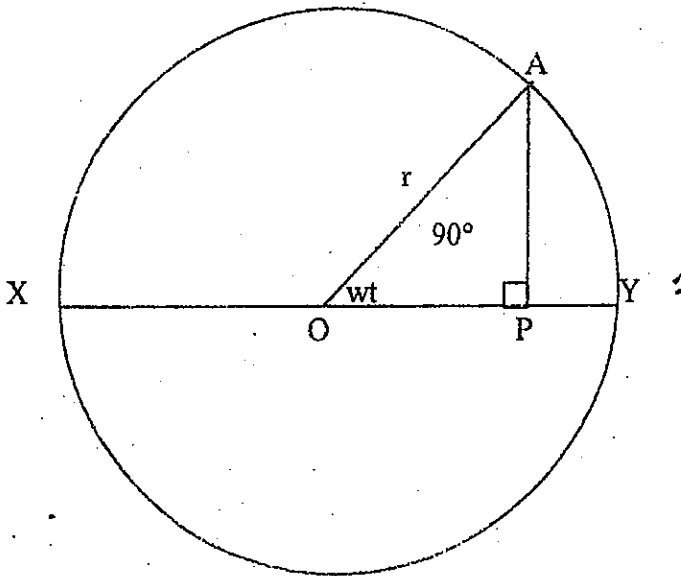
$$\text{Remaining UKC} = 2 - 1.91 = \underline{0.09 \text{ m}}$$

CHAPTER XXVI

UNRESISTED ROLLING IN STILL WATER

A ship will not normally roll in still water but if a study be made of such rolling some important conclusions may be reached. For this study it is assumed that the amplitude of the roll is small and that the ship has positive initial metacentric height. Under the conditions rolling is considered to be simple harmonic motion so it will be necessary to consider briefly the principle of such motion.

Let XOY in Figure be a diameter of the circle whose radius is ' r ' and let OA be a radius vector which rotates about O from position OY at a constant angular velocity of ' w ' radians per second. Let P be the projection of the point A on to the diameter XOY. Then, as the radius vector rotates, the point P will oscillate backwards and forwards between Y and X. The motion of the point P is called 'Simple Harmonic'.



Let the radius vector rotate from OY to OA in 't' seconds, then angle AOY is equal to 'wt'. Let the time taken for the radius vector to rotate through one complete revolution (2π radians) be equal to 'T' seconds, then :

$$2\pi = wT$$

or

$$T = 2\pi / w$$

Let

$$OP = x$$

then

$$x = r \cos wt$$

$$\frac{dx}{dt} = -rw \sin wt$$

$$\frac{d^2x}{dt^2} = -rw^2 \cos wt$$

but

$$r \cos wt = x$$

$$\therefore \frac{d^2x}{dt^2} = -w^2x$$

or

$$\frac{d^2x}{dt^2} + w^2x = 0$$

The latter equation is the type of differential equation for simple harmonic motion and since $T = 2\pi / w$ and 'w' is the square root of the coefficient of x in the above equation, then

$$T = \frac{2\pi}{\sqrt{\text{Coeff. of } x}}$$

When a ship rolls, the axis about which the oscillation takes place cannot be accurately determined but it would appear to be near to the longitudinal axis through the ship's centre of gravity. Hence the ship rotates or rolls about her 'G'.

The mass moment of inertia (I) of the ship about this axis is given by :

$$I = M \cdot K^2$$

Where

M = The ship's mass, and

K = The radius of gyration about this axis.

$$M = \frac{W}{g}$$

But

Where

W = the ship's weight, and

G = the acceleration due to gravity.

$$\therefore I = \frac{W}{g} K^2$$

When a ship is inclined to a small angle (θ) the righting moment is given by:

$$\text{Righting moment} = W \times GZ$$

Where

W = the ship's Weight, and

GZ = the righting lever.

But

$$GZ = GM \cdot \sin \theta$$

$$\therefore \text{Righting moment} = W \times GM \times \sin \theta$$

And since θ is a small angle, then:

$$\text{Righting moment} = W \times GM \times \theta$$

$$\text{The angular acceleration} = \frac{d^2 \theta}{dt^2}$$

$$\therefore I \times \frac{d^2 \theta}{dt^2} = -W \times GZ$$

or

$$\frac{W}{g} \cdot K^2 \times \frac{d^2 \theta}{dt^2} = -W \times GM \times \theta$$

$$\frac{W}{g} \cdot K^2 \times \frac{d^2 \theta}{dt^2} + W \times GM \times \theta = 0$$

$$\frac{d^2 \theta}{dt^2} + \frac{g \cdot GM}{K^2} \cdot \theta = 0$$

This is the equation for a simple harmonic motion having a period 'T' given by the equation:

$$T = \frac{2\pi}{\sqrt{\text{Coeff. of } \theta}}$$

or

$$T = \frac{2\pi K}{\sqrt{g \cdot GM}} = \frac{2\pi}{\sqrt{g}} \times \frac{K}{\sqrt{GM}} = \frac{2K}{\sqrt{GM}} \text{ approx}$$

From the above it can be seen that:

1. The time period of roll is completely independent of the actual amplitude of the roll so long as it is a small angle.
2. The time period of roll varies directly as K, the radius of gyration. Hence if the radius of gyration is increased, then the time period is also increased. K may be increased by moving weights away from the axis of oscillation. Average K value is about $0.35 \times \text{Br. Mid.}$
3. The time period of roll varies inversely as the square root of the initial metacentric height. Therefore ships with a large GM will have a short period and those with a small GM will have a long period.
4. The time period of roll will change when weights are loaded, discharged, or shifted within a ship, as this usually affects both the radius of gyration and the initial metacentric height.

Example 1

Find the still water period of roll for a ship when the radius of gyration is 8 m and the metacentric height is 0.8m.

$$T = \frac{2\pi K}{\sqrt{g \cdot GM}} = \frac{2K}{\sqrt{GM_T}} \quad \text{approx.}$$

$$T = \frac{2\pi K}{\sqrt{9.81 \times 0.8}} = \frac{2 \times 8}{\sqrt{0.8}} = \frac{16}{0.8944} \quad \text{approx.}$$

$$= 17.88^\circ \text{ s.}$$

(99.61 per cent correct giving only 0.39 per cent error!!)

Ans. $T = 17.95 \text{ s}$

Note: In the S.I. system of units the value of g to be used in problems is 9.81 m per second per second, unless another specific value is given.

Example 2

A ship of 12000 tonnes displacement has $GM = 0.8$ m. The period of roll in still water is 15 seconds. Find the new period of roll if a mass of 60 tonnes is discharged from a position 12 m above the centre of gravity. Assume $g = 9.81 \text{ m/sec}^2$

$$W_2 = W_0 - w = 12000 - 60 = 11940 \text{ tonnes}$$

$$T = \frac{2\pi K}{\sqrt{g \cdot GM}}$$

$$GG_1 = \frac{w \times d}{W_2}$$

$$T = \frac{2\pi K}{\sqrt{9.81 \times 0.8}}$$

$$= \frac{60 \times 12}{11940}$$

$$GG_1 = 0.06 \text{ m}$$

$$T^2 = \frac{4 \times \pi^2 \times K^2}{9.81 \times 0.8}$$

$$GM = 0.80 \text{ m}$$

$$\text{New GM} = 0.36 \text{ m}$$

$$K^2 = \frac{T^2 \times 9.81 \times 0.8}{4 \times \pi^2}$$

$$\text{OR } K^2 = \frac{15^2 \times 9.81 \times 0.8}{4 \times \pi^2}$$

$$= 44.69$$

$$\therefore K = 6.68$$

$$I (\text{Originally}) = M \cdot K^2$$

$$I_0 = 12000 \times 44.69$$

$$I_0 = 536280 \text{ tonnes} \cdot \text{m}^2$$

$$I \text{ of discharged mass about G} = 60 \times 12^2$$

$$= 8640 \text{ tonnes} \cdot \text{m}^2$$

$$\text{New I of ship about the original C of G} = \text{Original I} - I \text{ of discharged mass}$$

$$= 536280 - 8640$$

$$= 527640 \text{ tonnes} \cdot \text{m}^2$$

By the Theorem of parallel axes:

Let

$$\begin{aligned}
 I_2 &= \text{New I of ship about the new C of G} = \text{New I of ship about the original C of G} - W \times GG_1^2 \\
 I_2 &= 527640 - 11940 \times 0.06^2 \\
 I_2 &= 527640 - 43 \text{ (approx)} \\
 I_2 &= 527597 \text{ tonnes} \cdot \text{m}^2 \\
 I_2 &= M_2 \cdot K_2^2
 \end{aligned}$$

$$\therefore \text{New } K_2^2 = \frac{I_2}{M_2}$$

$$\therefore K_2^2 = \frac{527597}{11940}$$

Let

$$K_2 = \text{New } K = \sqrt{\frac{527597}{11940}}$$

$$K_2 = 6.65 \text{ m}$$

Let

$$T_2 = \text{New } T = \frac{2\pi K_2}{\sqrt{g \cdot GM_2}}$$

$$T_2 = \frac{2 \times 22/7 \times 6.65}{\sqrt{9.81 \times 0.86}}$$

$$= \frac{44/7 \times 6.65}{2.9045}$$

$$T_2 = 14.39 \text{ s}$$

CHAPTER XXVII

STABILITY OF A VESSEL WHEN $GM = 0$

$$\text{Since } \tan \theta = \frac{GG_1}{GM}$$

Where θ is the list, GG_1 is the transverse shift of 'G', GM is final GM (f)

When $GM = 0$, $\theta = 90^\circ$ which is not true. However the wall sided formula gives:

$$GZ = \sin \theta (GM + \frac{1}{2} BM \tan^2 \theta) \quad \text{----- (1)}$$

When $GM = 0$

$$GZ = \frac{1}{2} BM \tan^2 \theta \sin \theta$$

GZ is also $GG_1 \cos \theta$

$$\text{Or } GZ = \frac{d \times w}{W} \cos \theta \quad \text{----- (2)}$$

By equation (1) and (2)

$$\frac{d \times w}{W} \cos \theta = \frac{1}{2} BM \tan^2 \theta \sin \theta$$

$$\begin{aligned} \text{Or } \frac{d \times w}{W} &= \frac{1}{2} BM \tan^2 \theta \frac{\sin \theta}{\cos \theta} \\ &= \frac{1}{2} BM \tan^3 \theta \\ &= \frac{1}{2} BM \tan^3 \theta \end{aligned}$$

$$\therefore \tan^3 \theta = \frac{2 \times d \times w}{W \cdot BM}$$

$$\tan \theta = \sqrt[3]{\frac{2 \times d \times w}{W \times BM}}$$

This formula can be used to find the list when $GM = 0$ and holds good within the wall sided limits. Any case which falls outside those limits must be examined by constructing a GZ curve and plotting the $GG_1 \cos \theta$ curve on it.

Example

A vessel has displacement 22500 tonnes, KG 7.3 m, KM 7.4m, BM 3.6 m. A heavy lift of 150 tonnes at KG 2.5 m on the centerline is lifted using a derrick with head 17.5 m above the keel and swung 3 m to port. Determine list

Weight	KG	Moment	G from CL Centerline	Moment P
22500	7.3	164 250		
- 150	2.5	- 375		
<u>+ 150</u>	<u>17.5</u>	<u>2625</u>	3	<u>450</u>
22500		166 500		450

$$KG = \frac{\text{moment}}{\text{weight}}$$

$$= \frac{166\,500}{22\,500}$$

$$= 7.400\text{m}$$

$$KM = 7.400\text{m}$$

$$GM = 0.000\text{m}$$

$$G_0G_1 = \frac{\text{moment}}{\text{weight}}$$

$$= \frac{450}{22\,500}$$

$$= 0.02\text{m}$$

$$\tan \text{list} = \sqrt[3]{\frac{2G_0G_1}{BM}} = \sqrt[3]{\frac{2 \times 0.02}{3.6}}$$

$$\tan \text{list} = 0.223$$

$$\text{list} = 12.57^\circ \text{ port}$$

CHAPTER XXVIII

CODE OF INTACT STABILITY CRITERIA FOR ALL SHIPS (EXTRACTS)

1. Scope

The following criteria are recommended for passenger and cargo ships.

2. Recommended general criteria

- 2.1 The area under the righting lever curve (GZ curve) should not be less than 0.055 metre-radian up to $\theta = 30^\circ$ angle of heel and not less than 0.09 metre-radian up to $\theta = 40^\circ$ or the angle of flooding if this angle is less than 40° . Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30° and 40° or between 30° and angle of flooding if this angle is less than 40° , should not be less than 0.03 metre-radian.
- 2.2 The righting lever GZ should be at least 0.20 m at an angle of heel equal to or greater than 30° .
- 2.3 The maximum righting arm should occur at an angle of heel preferably exceeding 30° but not less than 25° .
- 2.4 The initial metacentric height GM, should not be less than 0.15m.
- 2.5 In addition, for passenger ships, the angle of heel on account of crowding of passengers to one side should not exceed 10° .
- 2.6 In addition, for passenger ships, the angle of heel on account of turning should not exceed 10° when calculated using the following formula:

$$M_R = 0.02 \frac{V_0}{L^2} \Delta (KG - \frac{d}{2})$$

Where:

M_R = Heeling moment (m-t)

V_0 = Service speed (m/s)

L = length of ship at waterline (m)

Δ = displacement (t)

$\bar{d}$ = mean draught (m)

KG = height of centre of gravity above keel (m)

- 2.7. Where anti-rolling devices are installed in a ship, the Administration should be satisfied that the above criteria can be maintained when the devices are in operation.
- 2.8. A number of influences, such as beam wind on ships with large windage area, icing of topsides, water trapped on deck, rolling characteristics, following seas, etc. adversely affect stability and the Administrations are advised to take these into account, so far as is deemed necessary.
- 2.9. Provisions should be made for a safe margin of stability at all stages of the voyage, regard being given to additions of weight, such as those due to absorption of water and icing (details regarding ice accretion are given in chapter 5) of code of intact stability, and to losses of weight, such as those due to consumption of fuel and stores.
- 2.10. For ships carrying oil-based pollutants in bulk, the Administration should be satisfied that the criteria given in 2 can be maintained during all loading and ballasting operation.

Severe wind and rolling criterion (weather criterion)

1. Scope

This criterion supplements the general intact stability criteria for all ships. The more stringent criteria given above and the weather criterion should govern the minimum requirements for passenger or cargo ships of 24m in length and over.

2. Recommended weather criterion

2.1 The ability of a ship to withstand the combined effects of beam wind and rolling should be demonstrated for each standard condition of loading with reference to figure given, as follows:

- 1) The ship is subjected to a steady wind pressure acting perpendicular to the ship's centerline which results in a steady wind heeling lever (l_w).
- 2) From the resultant angle of equilibrium (θ_0), the ship is assumed to roll owing to wave action to an angle of roll (θ_1) to windward. Attention should be paid to the effect of steady wind so that excessive resultant angles of heel are avoided;

- 3) The ship is then subjected to a gust wind pressure which results in a gust wind heeling lever (l_w);
- 4) Under these circumstances, area b should be equal to or greater than area a;
- 5) Free surface effects should be accounted for in the standard conditions of loading.

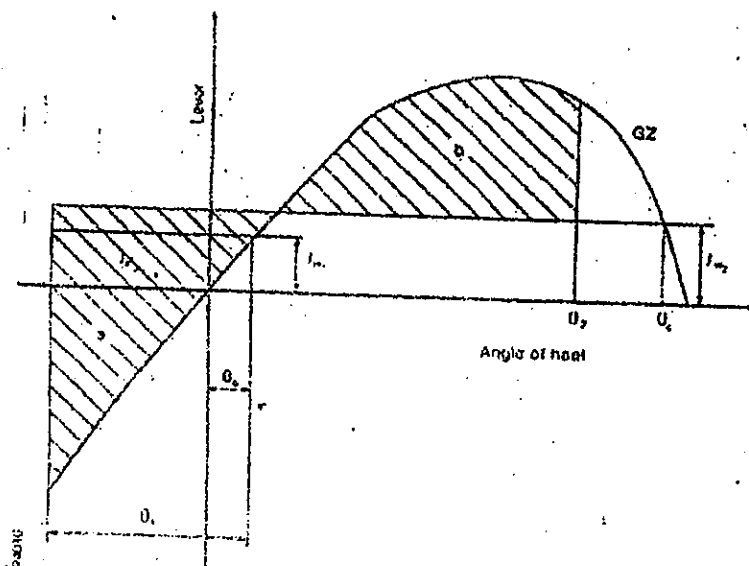


Figure - Severe wind and rolling

The angles in figure are defined as follows:

θ_0 = angle of heel under action of steady wind

θ_1 = angle of roll to windward due to wave action

θ_2 = angle of downflooding (θ_f) or 50° or θ_0 whichever is less,

where:

θ_f = angle of heel at which openings in the hull, super-structures or deck-houses which cannot be closed weathertight immerse. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open.

θ_c = angle of second intercept between wind heeling lever (l_{w2}) and GZ curves.

2.2 The wind heeling levers (l_{w1}) and (l_{w2}) are constant values at all angles of inclination and should be calculated as follows:

$$l_{w1} = \frac{PAZ}{1000g \Delta} \text{ (m) and}$$

$$l_{w2} = 1.5 l_{w1} \text{ (m)}$$

where:

$P = 504 \text{ N/m}^2$. The value of P used for ships in restricted service may be reduced, subject to the approval of the Administration;

$A =$ Projected lateral area of the portion of the ship and deck cargo above the waterline (m^2);

$Z =$ Vertical distance from the centre of A to the centre of the underwater lateral area or approximately to a point at one half the draught (m);

$\Delta =$ Displacement (t)

$g = 9.81 \text{ m/s}^2$

2.3 The angle of roll (θ_1) should be calculated as follows:

$$\theta_1 = 109k X_1 X_2 \sqrt{rs} \text{ (degrees)}$$

where :

$X_1 =$ factor as shown in table 1

$X_2 =$ factor as shown in table 2

$k =$ factor as follows:

$k = 1.0$ for a round-bilged ship having no bilge or bar keels

$k = 0.7$ for a ship having sharp bilges

$k =$ as shown in table 3 for a ship having bilge keels, a bar keel or both.

$$r = 0.73 \pm 0.6 \text{ OG/d}$$

With:

OG = distance between the centre of gravity and the waterline (m) (+ if the centre of gravity is above the waterline, - if it is below)

d = mean moulded draught of the ship (m)

s = factor as shown in table 4.

Table 1 – Values of factor X_1
 X_2

B/d	X_1
≤ 2.4	1.0
2.5	0.98
2.6	0.96
2.7	0.95
2.8	0.93
2.9	0.91
3.0	0.90
3.1	0.88
3.2	0.86
3.4	0.82
≥ 3.5	0.80

Table 2 – Values of factor

C_B	X_2
≤ 0.45	0.75
0.50	0.82
0.55	0.89
0.60	0.95
0.65	0.97
≥ 0.70	1.0

Table 3 – Values of factor k

$\frac{A_k \times 100}{L \times B}$	k
0	1.0
1.0	0.98
1.5	0.95
2.0	0.92
2.5	0.79
3.0	0.74
3.5	0.72
≥ 4.0	0.70

Table 4 – Values of factors

T	s
≤ 6	0.100
7	0.098
8	0.093
12	0.065
14	0.053
16	0.044
18	0.038
≥ 20	0.035

(Intermediate values in these tables should be obtained by linear interpolation)

Rolling period $T = \frac{2.08}{\sqrt{GM}}$ (s)

$\sqrt{GM}$

where $C = (0.573 + 0.00105 \cdot d) - 0.043 (1/100)$

The symbols in the above tables and formula for the rolling period are defined as follows:

L = waterline length of the ship (m)

B = moulded breadth of the ship (m)

d = mean moulded draught of the ship (m)

C_B = block coefficient

A_k = total overall area of bilge keels, or area of the lateral projection of the bar keel, or sum of these areas (m^2).

GM = metacentric height corrected for free surface effect (m).

Determination of ship's stability by means of rolling period tests

(for ships up to 70m in length)

1. Recognizing the desirability of supplying to masters of small ships instructions for a simplified determination of initial stability, attention was given to the rolling period tests. Studies on this matter showed that the rolling period test may be recommended as a useful means of approximately determining the initial stability of small ships when it is not practicable to give approved loading conditions or other stability information, or as a supplement to such information.

2. Investigations comprising the evaluation of a number of inclining and rolling tests according to various formulae showed that the following formula gave the best results and it has the advantage of being the simplest:

$$GM_0 = \left(\frac{fB}{T_r} \right)^2$$

Where :

f = factor for the rolling period (rolling coefficient).

B = breadth of the ship in metres;

T_r = time for a full rolling period in seconds (i.e. for one oscillation "to and fro" port – starboard – port, or vice versa).

The factor f is of the greatest importance and the data from the above tests were used for assessing the influence of the distribution of the various masses in the whole body of the loaded ship.

For coasters of normal size (excluding tankers) and fishing vessels, the following average values were observed:

	f values
Empty ship or ship carrying ballast	$f \approx 0.88$
Ship fully loaded and with liquids in tanks comprising the following percentage of the total load on board (i.e. cargo, liquids, stores, etc.):	
20% of total load	$f \approx 0.78$

10% of total load	$f \approx 0.75$
5% of total load	$f \approx 0.73$
Double-boom shrimp fishing boats	$f \approx 0.95$
Deep-sea fishing boats	$f \approx 0.80$
Boats with a live fish well	$f \approx 0.60$

The stated values are mean values. Generally, observed f values were within ± 0.05 of those given above.

The above f values were based upon a series of limited tests and therefore, Administrations should re-examine these in the light of any different circumstances applying to their own ships.

It should be noted that the greater the distance of masses from the rolling axis; the greater the rolling coefficient will be. Therefore it can be expected that:

- .1 The rolling coefficient for an unloaded ship, i.e. for a hollow body will be higher than that for a loaded ship; and
- .2 The rolling coefficient for a ship carrying a great amount of bunkers and ballast – both groups are usually located in the double bottom, i.e. far away from the rolling axis – will be higher than that of the same ship having an empty double bottom.

The above recommended rolling coefficients were determined by tests with ships in port and with their consumable liquids at normal working levels; thus the influences exerted by the vicinity of the quay, the limited depth of water and the free surfaces of liquids in service tanks are covered.

Experiments have shown that the results of the rolling test method get increasingly less reliable the nearer they approach GM values of 0.20m and below.

For the following reasons, it is not generally recommended that results be obtained from rolling oscillations taken in a seaway:

- .1 exact coefficients for tests in open waters are not available;
- .2 the rolling periods observed may not be free oscillations but forced oscillations due to seaway;
- .3 frequently, oscillations are either irregular or only regular for too short an interval of time to allow accurate measurements to be observed; and
- .4 specialized recording equipment is necessary.

However, sometimes it may be desirable to use the ship's period as a means of approximately judging the stability at sea. If this is done, care should be taken to discard readings which depart appreciably from the majority of other observations. Forced oscillations corresponding to the sea period and differing from the natural period at which the ship seems to move should be disregarded. In order to obtain satisfactory results, it may be necessary to select intervals when the sea action is least violent and it may be necessary to discard a considerable number of observations.

In view of the foregoing circumstances, it needs to be recognized that the determination of the stability by means of the rolling test in disturbed waters should only be regarded as a very approximate estimation.

The formula given in paragraph above can be reduced to:

$$GM_0 = \frac{F}{T_r^2}$$

And the Administration should determine the F value(s) for each ship.

The determination of the stability can be simplified by giving the master permissible rolling periods, in relation to the draughts for the appropriate value(s) of F considered necessary.

The initial stability may also be more easily determined graphically by using the sample nomogram as described below:

- .1 The values for B and f are marked in the relevant scales and connected by a straight line (1). This straight line intersects the vertical line mm at the point M.

- .2 A second straight line (2) which connects this point M and the point on the T_r scale corresponding with the determined rolling period intersects the GM scale at the requested value.

Test procedure

The rolling period required is the time for one complete oscillation of the ship and to ensure the most accurate results in obtaining this value the following precautions should be observed:

- .1 The test should be conducted with the ship in harbour, in smooth water with the minimum interference from the wind and tide.
- .2 Starting with the ship at the extreme end of a roll to one side (say port) and the ship about to move towards the upright, one complete oscillation will have been made when the ship has moved right across to the other extreme side (i.e. starboard) and returned to the original starting point and is about to commence the next roll.
- .3 By means of a stop-watch, the time should be taken for not less than about five of these complete oscillations; the counting of these oscillations should begin when the ship is at the extreme end of a roll. After allowing the roll to completely fade away, this operation should be repeated at least twice more. If possible, in every case the same number of complete oscillations should be timed to establish that the readings are consistent, i.e. repeating themselves within reasonable limits. Knowing the total time for the total number of oscillations made the mean time for one complete oscillation can be calculated.
- .4 The ship can be made to roll by rhythmically lifting up and putting down a weight as far off the middle-line as possible; by pulling on the mast with a rope; by people running athwart ships in unison; or by any other means. However, and this is most important, as soon as this forced rolling has commenced, the means by which it has been induced should be stopped and the ship allowed to roll freely and naturally. If rolling has been induced by lowering or raising a weight it is preferably that the weight is moved by a dockside crane. If the ship's own derrick is used, the weight should be placed on the deck, at the middle-line, as soon as the rolling is established.

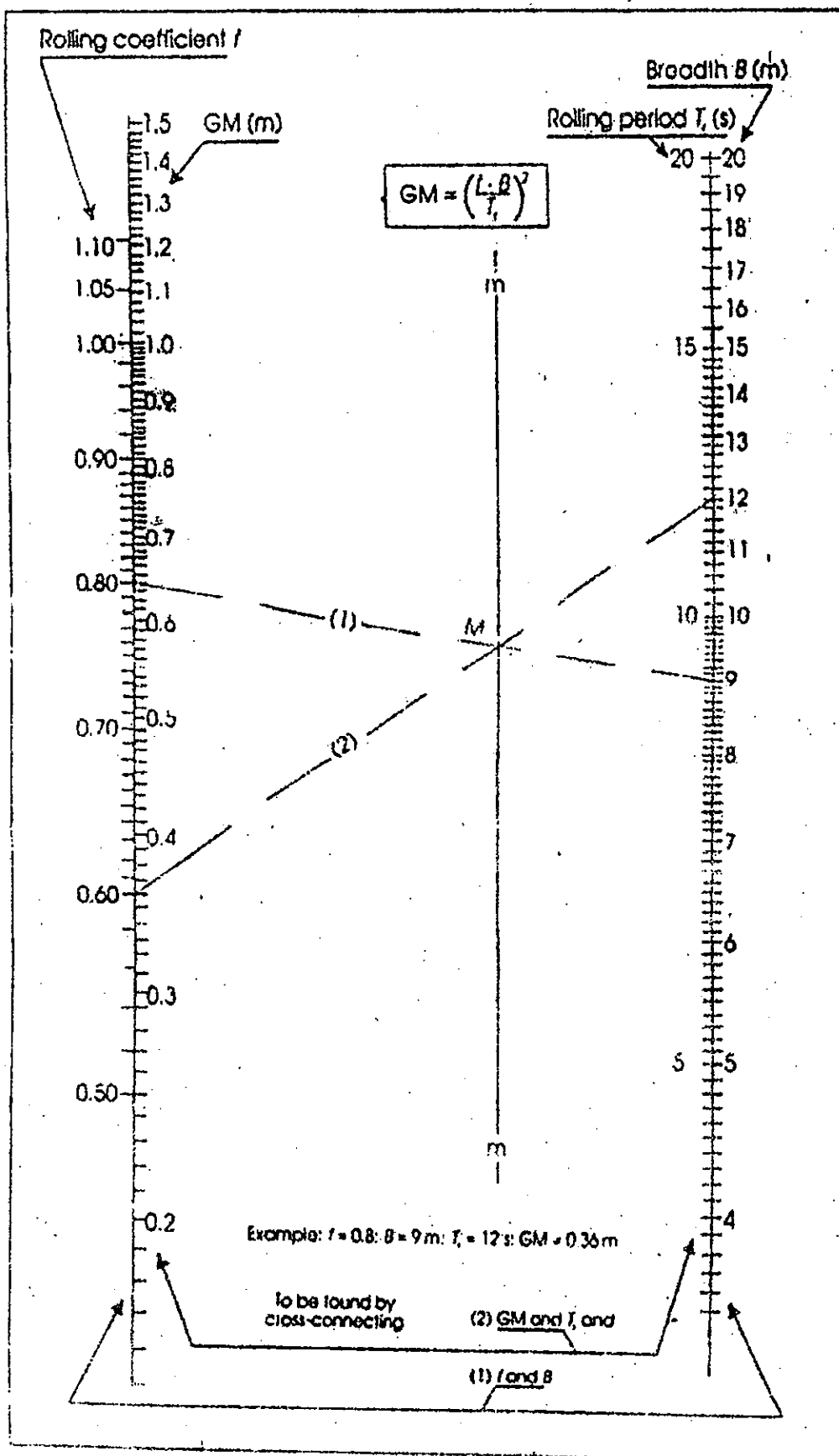
- 5 The timing and counting of the oscillations should only begin when it is judged that the ship is rolling freely and naturally, and only as much as is necessary to accurately count these oscillations.
- 6 The mooring should be slack and the ship "breasted off" to avoid making any contact during its rolling. To check this, and also to get some idea of the number of oscillations that can be reasonably counted and timed, a preliminary rolling test should be made before starting to record actual times.
- 7 Care should be taken to ensure that there is a reasonable clearance of water under the keel and at the sides of the ship.
- 8 Weights of reasonable size which are liable to swing (e.g. a lifeboat), or liable to move (e.g. a drum), should be secured against such movement. The free surface effects of stack tanks should be kept as small as is practicable during the test and the voyage.

Limitations to the use of this method.

A long period or roll, corresponding to a GM_0 of 0.20m or below, indicates a condition of low stability. However, under such circumstances, accuracy in determination of the actual value of GM_0 is reduced.

If, for some reason, these rolling tests are carried out in open, deep but smooth waters, inducing the oil, for example, by putting over the helm, then the GM_0 calculated by using the method and coefficient of paragraph above should be reduced by [figure to be estimated by the Administration] to obtain the final answer.

The determination of stability by means of the rolling test in disturbed waters should only be regarded as a very approximate estimation. If such a test is performed, care should be taken to discard readings which depart appreciably from the majority of other observations. Forced oscillations corresponding to the sea period and differing from the natural period at which the vessel seems to move should be disregarded. In order to obtain satisfactory results, it may be necessary to select intervals when the sea action is least violent and it may be necessary to discard a considerable number of observations.



CALCULATION OF STABILITY CURVES

1. General

1. Hydrostatic and stability curves should normally be prepared on a designed trim basis. However, where the operating trim or the form and arrangement of the ship are such that change in trim has an appreciable effect on righting arms, such change in trim should be taken into account.

2. The calculations should take into account the volume to the upper surface of the deck sheathing. In the case of wood ships, the dimensions should be taken to the outside of the hull planking.

2. Superstructures, deck-houses, etc. which may be taken into account.

1. Enclosed superstructures complying with regulation 3 (10) (b) of the 1966 Load Line Convention may be taken into account.

2. The second tier of similarly enclosed superstructures may also be taken into account.

3. Deck-houses on the freeboard deck may be taken into account, provided that they comply with the conditions for enclosed superstructures laid down in regulation 3 (10) (b) of the 1966 Load Line Convention.

4. Where deck-houses comply with the above conditions, except that no additional exit is provided to a deck above, such deck-houses should not be taken into account; however, any deck openings inside such deck-houses should be considered as closed even where no means of closure are provided.

5. Deck-houses the doors of which do not comply with the requirements of regulation 12 of the 1966 Load Line Convention should not be taken into account; however, any deck openings inside the deck-house are regarded as closed where their means

of closure comply with the requirements of regulations 15, 17 or 18 of the 1966 Load Line Convention.

6. Deck-houses on decks above the freeboard deck should not be taken into account, but openings within them may be regarded as closed.
7. Superstructures and deck-houses not regarded as enclosed can, however, be taken into account in stability calculations up to the angle at which their openings are flooded (at this angle, the static stability curve should show one or more steps, and in subsequent computations the flooded space should be considered non-existent).
8. In cases where the ship would sink due to flooding through any openings, the stability curve should be cut short at the corresponding angle of flooding and the ship should be considered to have entirely lost its stability.
9. Small openings such as those for passing wires or chains, tackle and anchors, and also holes of scuppers, discharge and sanitary pipes should not be considered as open if they submerge at an angle of inclination more than 30° . If they submerge at an angle of 30° or less, these opening should be assumed open if the Administration considers this to be a source of significant flooding.
10. Trunks may be taken into account. Hatchways may also be taken into account, having regard to the effectiveness of their closures.

Cargo ships carrying timber deck cargoes

1. Scope

The provisions given hereunder apply to all ships of 24m in length and over engaged in the carriage of timber deck cargoes. Ships that are provided with and make use of their timber load line should also comply with the requirements of regulations 41 to 45 of the Load Line Convention.

2. Definitions

The following definitions apply for the purposes of the present section :

1. Timber means sawn wood or lumber, can'ts, logs, poles, pulpwood and all other types of timber in loose or packaged forms. The term does not include wood pulp or similar cargo;
2. Timber deck cargo means a cargo of timber carried on an uncovered part of a freeboard or superstructure deck. The term does not include wood pulp or similar cargo;
3. Timber load line means a special load line assigned to ships complying with certain conditions related to their construction set out in the International Convention on Load Lines and used when the cargo complies with the stowage and securing conditions of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes, 1991 (resolution A, 715 (17)).

3. Recommended stability criteria

For ships loaded with timber deck cargoes and provided that the cargo extends longitudinally between superstructures (where there is no limiting superstructure at the after end, the timber deck cargo should extend at least to the after end of the aftermost hatchway) transversely for the full beam of ship, after due allowance for a rounded gunwale not exceeding 4% of the breadth of the ship and / or securing the supporting uprights and which remains securely fixed at large angles of heel, the Administration may apply the following criteria.

General

For any ship operating in areas where ice accretion is likely to occur, adversely affecting a ship's stability, icing allowances should be included in the analysis of conditions of loading.

Administrations are advised to take icing into account and are permitted to apply national standards where environmental conditions are considered to warrant a higher standard than those recommended in the following sections.

Cargo ships carrying timber deck cargoes

The master should establish or verify the stability of his ship for the worst service condition, having regard to the increased weight of deck cargo due to water absorption and / or ice accretion and to variations in consumables.

When timber deck cargoes are carried and it is anticipated that some formation of ice will take place, an allowance should be made in the arrival condition for the additional weight.

Allowance for ice accretion:

For vessels operating in areas where ice accretion is likely to occur, the following icing allowance should be made in the stability calculations:

- .1 30 kg per square metre on exposed weather decks and gangways;
- .2 7.5 kg per square metre for projected lateral area of each side of the vessel above the water plane;
- .3 the projected lateral area of discontinuous surfaces of rail sundry booms, spars (except-masts) and rigging of vessels having no sails and the projected lateral area of other small objects should be computed by increasing the total projected area of continuous surfaces by 5% and the static moments of this area by 10%.

Vessels intended for operation in areas where ice is known to occur should be:

- .4 designed to minimize the accretion of ice; and
- .5 equipped with such means for removing ice as the Administration may require; for example, electrical and pneumatic devices, and / or special tools such as axes or wooden clubs for removing ice from bulwarks, rails and erections.

Guidance relating to ice accretion

In the application of the above standards the following icing areas should apply:

- .1 the area north of latitude $65^{\circ} 30'N$, between longitude $28^{\circ} W$ and the west coast of Iceland; north of the north coast of Iceland; north of the rhumb line running from latitude $66^{\circ}N$, longitude $15^{\circ}W$ to latitude $73^{\circ} 30'N$, longitude $15^{\circ}E$, north of latitude $73^{\circ} 30'N$ between longitude $15^{\circ} E$ and $35^{\circ}E$ and east of longitude $35^{\circ}E$, as well as north of latitude $56^{\circ} N$ in the Baltic Sea;
- .2 the area north of latitude $43^{\circ}N$ bounding in the west by the North American coast and the east by the rhumb line running from latitude $43^{\circ}N$, longitude $48^{\circ}W$ to latitude $63^{\circ}N$, longitude $28^{\circ}W$ and thence along longitude $28^{\circ}W$;
- .3 all sea areas north of the North American Continent, west of the areas defined in .1 and .2;
- .4 the Bering and Okhotsk Seas and the Tartary Strait during the icing season; and
- .5 south of latitude $60^{\circ}S$.

For vessels operating in areas where ice accretion may be expected:

- .6 within the areas defined in .1, .3, .4 and .5 known to have icing conditions significantly different from those described in "allowance for ice accretion", ice accretion requirements of one half to twice the required allowance may be applied.
- .7 within the area defined in .2, where ice accretion in excess of twice the allowance required may be expected, more severe requirements may be applied.

STABILITY BOOKLET

1. Stability data and associated plans should be drawn up in the official language or languages of the issuing country and the language of the master. If the languages used are neither English nor French the text should include a translation into one of these languages.
2. Each ship should be provided with a stability booklet, approved by the Administration, which contains sufficient information to enable the master to operate the ship in compliance with the applicable requirements contained in the Code. On a mobile offshore drilling unit, the stability booklet is referred to as an operating manual.
3. The format of the stability booklet and the information included will vary dependent on the ship type and operation. In developing the stability booklet, consideration should be given to including the following information:
 1. a general description of the ship;
 2. instructions on the use of the booklet;
 3. general arrangement plans showing watertight compartments, closures, vents, downflooding angles, permanent ballast, allowable deck loadings and freeboard diagrams;
 4. hydrostatic curves or tables and cross-curves of stability calculated on a free-trimming basis, for the ranges of displacement and trim anticipated in normal operating conditions;
 5. capacity plan or tables showing capacities and centres of gravity for each cargo stowage space;
 6. tank sounding tables showing capacities, centres of gravity, and free surface data for each tank;
 7. information on loading restrictions, such as maximum KG or minimum GM curve or table that can be used to determine compliance with the applicable stability criteria;
 8. standard operation conditions and examples for developing other acceptable loading conditions using the information contained in the stability booklet;

4. As an alternative to the stability booklet mentioned in 2, a simplified booklet in an approved form containing sufficient information to enable the master to operate the ship in compliance with the applicable provisions of the Code may be provided at the discretion of the authority concerned.
5. As a supplement to the approved stability booklet, a loading computer may be used to facilitate the stability calculations.
6. It is desirable that the input/output form in the computer and graphical presentation be similar to the one in the stability booklet so that the operators will easily gain familiarity with the use of the stability booklet.
7. A simple and straightforward instruction manual, written as per sound marine practice and in a language common to all officers, should be provided with the loading computer.
8. In order to validate the proper functioning of the computer loadicator, four loading conditions taken from the stability booklet (final) should be run in the computer periodically and the print-outs should be removed on board as check conditions for future reference.

Operating booklets for certain ships

Special purpose ships, dynamically supported craft and naval craft should be provided with additional information in the stability booklet such as design limitations, maximum speed, worst intended weather conditions or other information regarding the handling of the craft that the master needs to operate the ship safely.

General precautions against capsizing

1. Compliance with the stability criteria does not ensure immunity against capsizing, regardless of the circumstances, or absolve the master from his responsibilities. Masters should therefore exercise prudence and good seamanship, having regard to the season of the year, weather forecasts and the navigational zone, and should take the appropriate action as to speed and course warranted by the prevailing circumstances.

2. Care should be taken that the cargo allocated to the ship is capable of being stowed so that compliance with the criteria can be achieved. If necessary, the amount should be limited to the extent that ballast weight may be required.
3. Before a voyage commences, care should be taken to ensure that the cargo and sizeable pieces of equipment have been properly stowed or lashed so as to minimize the possibility of both longitudinal and lateral shifting, while at sea, under the effect of acceleration caused by rolling and pitching.
4. A ship, when engaged in towing operations, should not carry deck cargo, except that a limited amount, properly secured, which would neither endanger the safe working of the crew on deck nor impede the proper functioning of the towing equipment, may be accepted.
5. The number of partially filled or slack tanks should be kept to a minimum because of their adverse effect on stability.
6. The stability criteria contained in chapter 3 of code of intact stability set minimum values, but no maximum values are recommended. It is advisable to avoid excessive values of metacentric height, since these might lead to acceleration forces which could be prejudicial to the ship, its complement, its equipment and to safe carriage of the cargo.
7. Regard should be paid to the possible adverse effects on stability where certain bulk cargoes are carried. In this connection, attention should be paid to the IMO Code of Safe Practice for Solid Bulk Cargoes.

Fixed ballast

If used, fixed ballast should be installed under the supervision of the Administration and in a manner that prevents shifting of position. Fixed ballast should not be removed from the ship or relocated within the ship without the approval of the Administration.

Operational procedures related to weather conditions

1. All doorways and other openings through which water can enter into the hull or deck-houses, forecastle, etc., should be suitably closed in adverse weather conditions and accordingly all appliances for this purpose should be maintained on board and in good condition.
2. Weathertight and watertight hatches, doors, etc., should be kept closed during navigation, except when necessarily opened for the working of the ship, and should always be ready for immediate closure and be clearly marked to indicate that these fittings are to be kept closed except for access. Hatch covers and flush deck scuttles in fishing vessels should be kept properly secured when not in use during fishing operations. All portable deadlights should be maintained in good condition and securely closed in bad weather.
3. Any closing devices provided for vent pipes to fuel tanks should be secured in bad weather.
4. Fish should never be carried in bulk without first being sure that the portable divisions in the holds are properly installed.
5. Reliance on automatic steering may be dangerous as this prevents ready changes to course which may be needed in bad weather.
6. In all conditions of loading, necessary care should be taken to maintain a seaworthy freeboard.
7. In severe weather, the speed of the ship should be reduced if excessive rolling, propeller emergence, shipping of water on deck or heavy slamming occurs. Six heavy slammings or 25 propeller emergences during 100 pitching motions should be considered dangerous.
8. Special attention should be paid when a ship is sailing in following or quartering seas because dangerous phenomena such as parametric resonance, broaching to,

reduction of stability on the wave crest, and excessive rolling may occur singularly, in sequence or simultaneously in a multiple combination, creating a threat of capsize. Particularly dangerous is the situation when the wave length is of the order of 1.0 to 1.5 ship's length. A ship's speed and / or course should be altered appropriately to avoid the above-mentioned phenomena.

9. Water trapping in deck wells should be avoided. If freeing ports are not sufficient for the drainage of the well, the speed of the ship should be reduced or the course changed, or both. Freeing ports provided with closing appliances should always be capable of functioning and are not to be locked.
10. Masters should be aware that steep or breaking waves may occur in certain areas, or in certain wind and current combinations (river estuaries, shallow water areas, funnel-shaped bays, etc.). These waves are particularly dangerous, especially for small ships.
11. Use of operational guidelines for avoiding dangerous situations in severe weather conditions or an on-board computer-based system is recommended. The method should be simple to use.
12. Dynamically supported craft should not be intentionally operated outside the worst intended conditions and limitations specified in the Dynamically Supported Craft Permit to Operate, in the Dynamically Supported Craft Construction and Equipment Certificate, or in documents referred to therein.

CHAPTER XXIX

QUESTIONS FOR EXTRA MASTERS

Exercise :

1. An all Tank bunkering barge has constant water plane areas the $\frac{1}{2}$ ord of which are 0.5, 6.9, 12.4, 17.0, 16.8, 15.4, 11.3, 6.2, 0.2m. Length of the barge is 160m. The barge is longitudinally divided on the centre line. When fully loaded with oil of RD 0.875 and tanks passed up, the GM is 0.5m. Loaded draft 7.5m. The depth of the tank is 8.0m. Find the GM of the vessel when the tank has an ullage of 0.8m
2. The half ordinates of a vessel's water plane spaced 13m apart are 0.25, 4.0, 8.0, 10.0, 11.0, 12.0, 12.0, 11.0, 9.0, 7.0, 0.7m respectively at a displacement of 12300 T in water of RD 1.020. If her C.G. is 2.5 meter above C.B. calculate her moment of statical stability when heeled 7° .
3. A vessel of displacement 4300 T has a special tank whose surface area is bounded by 2 radii at right angles to each other and a plane curve. The radial ordinates of the curve at equiangular intervals are 12, 11, 10, 9 and 8m respectively. The tank contains oil of RD 0.92. Calculate the loss of GM due to free surface effect in that tank. The 12m ordinate lies along the ship's centre line.
4. A ship heels to an angle of 20° . The immersed section area and distance of their centroids from the axis of rotation are as follows:

θ	0	5	10	15	20
A (m ²)	650	710	920	1030	1810
r (m)	3.5	3.2	3.8	4.8	6.0

The ships displacement 7175 T. Calculate

1. The volume of the immersed wedge.
 2. The shift in the CB of the ship, both vertically and horizontally.
5. A ship heels through an angle of 20° . The immersed areas and distances of their centroids from the axis of rotation are as follows:

θ	0	5	10	15	20
A (m ²)	700	790	1010	1340	1760
r (m)	3.1	3.3	3.8	4.8	6.1

Calculate the volume of the immersed wedge and horizontal and vertical shift in the ships CB, if her displacement was 8210 T

6. For the inputs to a computer program for hull fairing, the transverse sections of a ship are defined by ordinates spaced at 22.5° , radiating from a pole situated at the intersection of the centerline and the load waterline. The ordinates of one half of such a section are as follows : 8.2, 8.6, 9.2, 9.0 and 8.9m. The first ordinate is coincident with waterline. Calculate the :
1. Area of the section
 2. Its centroid relative to the waterline.
 3. The moment of inertia of the section about an axis through the keel and parallel to the waterline.
7. A wall sided car ferry of length 180m fitted with bow and stern doors has the following equally spaced half ordinates of water plane. 6, 10, 13, 15, 13, 10 & 6m. The car deck situated 6m above keel is symmetrical about the centre line and has an area of 3080 m^2 and moment of inertia of 82307 m^4 . After extinguishing a fire water remains on the car deck to a depth of 30 cm due to blocked scuppers. In this condition her displacement is 19926 tonnes, her KG is 10m and KB is 4m. With respect to her stability, show by calculation whether it would be advisable to open her bow and stern door thus keeping her car deck just awash.
8. A submarine of circular cross section floats in SW with its axis in the water plane. The semi ordinates of the water plane at 9m intervals are 0, 1.5, 3, 4, 3.5, 2 and 0m respectively. If COG of a semi circle is $\frac{4r}{3\pi}$ from the centre calculate her
1. TPC
 2. Displacement
 3. COF from Amidships
 4. BM_T
 5. COB from amidship
 6. COB below W/L
9. A cigar shaped vessel with circular cross section floats in SW with its axis in the water plane. The semi ordinates of water plane 9m apart commencing from forward are :
- 0, 1.5, 3, 4, 3.5, 2, 0.5 respectively C.G. of a semicircle is $\frac{4r}{3\pi}$ from the center.

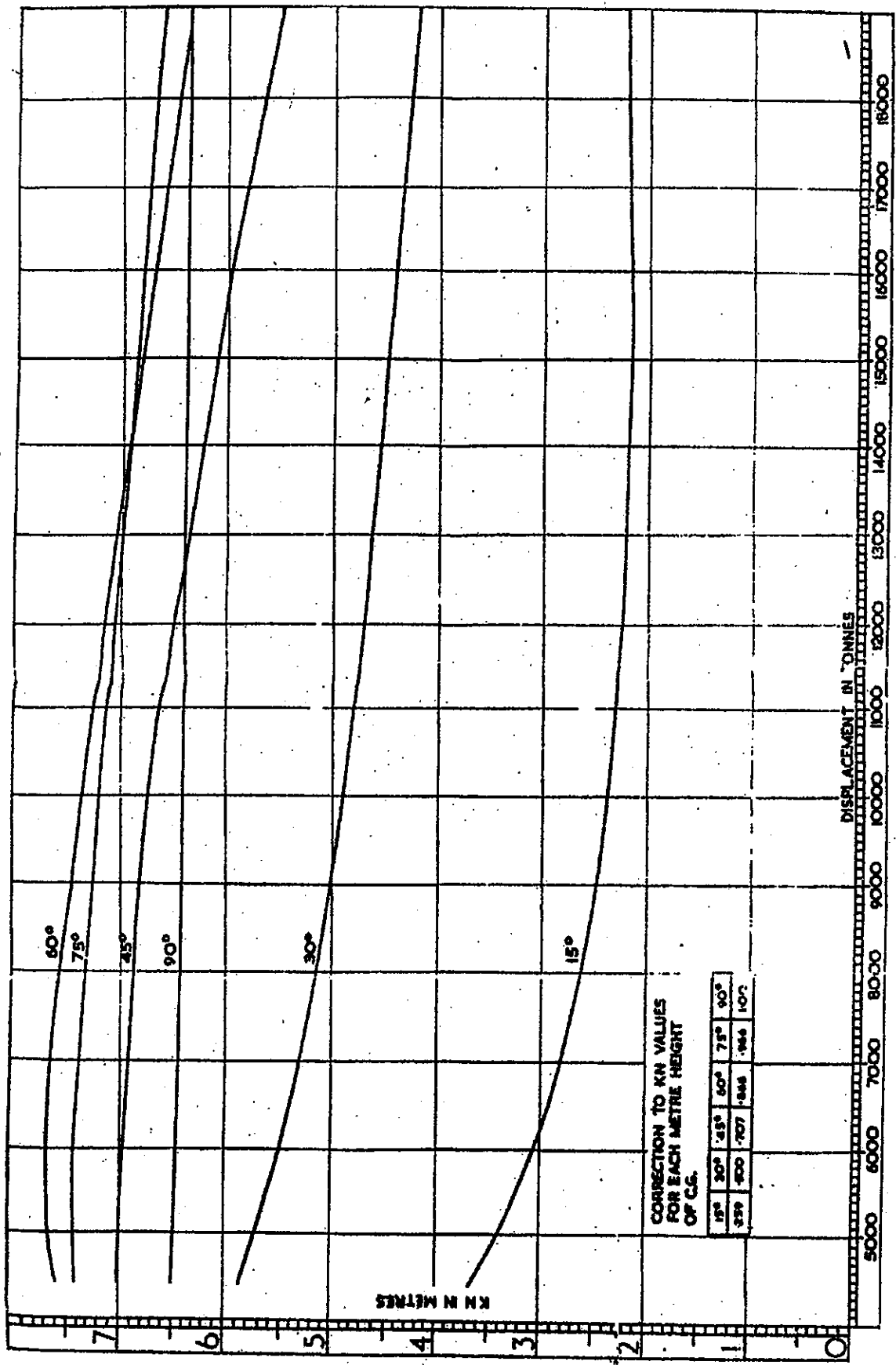
Find her TPC, displacement, CF from midships, CB from midships, BM (Transverse) CB below W/L.

10. The surface of a tank is bounded by a plane curve and two radii 90° apart. The length of the radii at equiangular intervals are 16, 14, 11, 9 and 8m respectively. The 16m ordinate is parallel to the centre line of the ship. The displacement of which is 5200t. Tank contains liquid of R.D. 0.92. Calculate the virtual loss of GM if tank is slack.
11. The radial ordinates of a special tank are 5, 6, 7, 8 & 9 meters. The 9m ordinate is parallel to ship's W/L and 3m away from it. The angle between first and last ordinates is 60° . Find the FSC if Tank contains oil of RD 0.92. Ship's displacement = 3000 t.
12. A vessel of 4500t displacement has a F/W tank where surface area is bounded by 2 radii at right angles to each other and a plane curve. The radial ordinates of the curve at equiangular intervals are 6, 7, 8, 9 & 10m. Find the FSC assuming that 10m ordinate is on F & A center line of the ship.
13. A vessel 180m long has the following equally spaced half ordinates along its water plane at an even keel draft of 10m in SW : 6, 10, 13, 15, 13, 10, 6. Calculate the draft F & A if the following particulars apply :
Displacement 33210, KG 12.27m, KB 5.6 m, LCG 2.9m abaft midship. The vessel has uniform section areas at distances equidistant from amidship.
14. A vehicle ferry with bow and stern doors has length 180m. At an even keel draft of 6 m in salt water, the car deck is in waterline. The ship's water plane has the following equally spaced half ordinates : 6, 10, 13, 15, 13, 10, 6 m. The car deck is as symmetrical about centre line and has equidistant half ordinates of 5, 8, 10, 10, 10, 8 & 5m. The following particulars apply in this condition draft 6m, KG 10m, KB 4m, Disp 19926t. The vessel is wall sided above this draft. After extinguishing a fire, water remains on the car deck to an overall depth of 25cm due to blocked scupper. Find (a) GM in this condition (b) The GM if the bow and stern doors were opened thus keeping the car deck just awash. What conclusions do you draw from results of your calculation?
15. A ship's water plane is defined by the following equally spaced half ordinates from bow to stern : 1.2, 2.4, 4.6, 6.7, 8.1, 9, 9.4, 9.2, 8.5, 6.3 and 0 m. If $L = 220$ m, Disp 19800t. Calculate BM, GM.

28. Area = 24.8m^2 CG from OX = 1.656m CG from OY = 6.20m
29. 0° 4.2°
30. 113.62tm
31. (i) $33.91\text{ tonnes of oil}$ (2) 2.895 m
32. 2.375 m
33. 4.42 m
34. 7.3°
35. 2.240 m

-oOo-

CROSS CURVES OF STABILITY (KN CURVES)



CORRECTION TO KN VALUES
FOR EACH METRE HEIGHT
OF C.G.

15°	30°	45°	60°	75°	90°
.239	.420	.707	.846	.966	1.07



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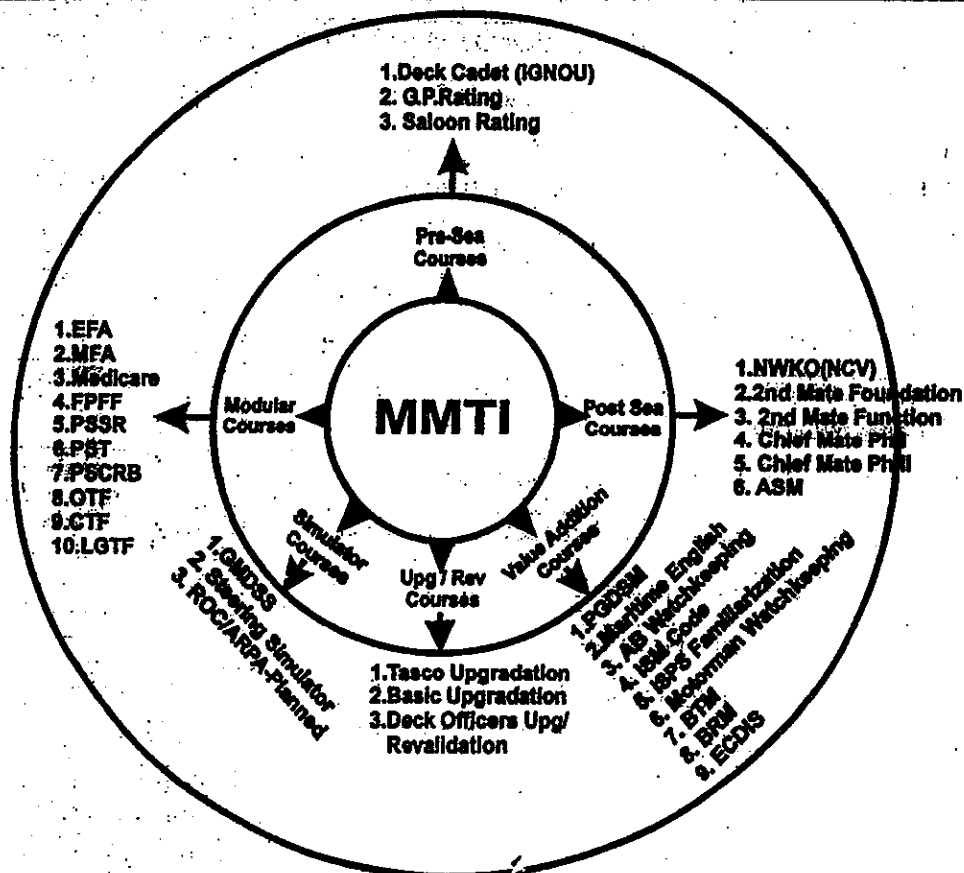
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