

Ship Stability

By:
Subramaniam

Produced By :

Mohsen Baghery

E-Mail : ZMohsenbaghery@yahoo.com

Summer 1385

Autumn 2006

First edition Sept. 1981

Reprinted

September 1989

July 1991



*Copyright
All rights reserved*

Price Rs. 100/-

PRINTED AND PUBLISHED BY MRS. VIJAYA HARRY FOR VIJAYA PUBLICATIONS
OF 2 CHAITRA, 550 ELEVENTH ROAD, CHEMBUR, BOMBAY-400 071 AT THE
BOOK CENTRE LTD., SIXTH ROAD, SION EAST, BOMBAY-400 022.



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

Capt. R.D. Kohli
Extra Master,

13th September 1981.

Executive Director, Shipping Corporation of India Ltd.,
Chairman of the Council,
The Institution of Marine Technologists,
Master of the Company of Master Mariners of India,
President, Dufferin - Rajendra Old Cadets Association,
Vice Chairman, Narottam Morarjee Institute of Shipping.

FOREWORD

I have known Capt. Subramaniam for over ten years — a young enthusiastic mercantile marine officer with a dynamic personality, always giving the impression that he wants to accomplish more.

When he suddenly appeared at my office, I was surprised — a professor wanting to see me! After presenting me with a copy of his latest book 'Shipborne Radar' he said 'Sir, would you please write the foreword to my book on stability?' I was taken aback by this unusual request, more so when he went on to say that he had particularly decided, five years ago, to request me to write the foreword to his book on stability, even before he wrote the books on Navigation, Meteorology and Radar.

This set me thinking about my first voyage. I was a cadet fresh out of the training ship 'Dufferin' and the passage, trans-atlantic in winter. The ship rolled very heavily, often as much as 35°, creaking and moaning. Crashing sounds were frequently heard as various objects in the cabins broke loose, answering the call of gravity along the highly

inclined plane. I thoroughly enjoyed myself in blissful ignorance of terms in stability such as stiff and tender ships, free surface effect, angle of vanishing stability and progressive flooding. I shudder to think what I would feel, if I was in the same circumstances today, realising the implications of such a situation.

Capt. Subramaniam has attempted, and I would say succeeded, in combining the theory and practical application of stability. The book closely follows the best approach. Starting from the very basics, or 'beginning at the very beginning,' the book brings the student steadily up to the required level in such a manner that he can study it by himself, whilst out at sea, hardly needing any other assistance.

I have specifically avoided indulging in paraphrasing about the biography of the author. He has by now become well established by his "Nutshell Series".

I understand that Capt. Subramaniam plans to include the more complex topics on this subject in his next book 'Ship Stability II' in the near future. I wish him all success.



(R.D. Kohli)

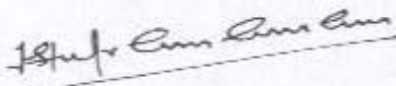
P R E F A C E

Like the earlier books in the Nutshell Series, this book is intended for study whilst out at sea.

Part I, this book, adequately covers the syllabuses for Second Mate (FG) and the recently proposed grade of WKO (Watch-Keeping Officer).

Part II, Nutshell Series Book 5, will contain additional topics. Master (FG) and First Mate (FG) will find that they require both the books to cover their syllabuses.

Marine Engineers also may find these two books useful.



(H. SUBRAMANIAM)

Bombay
13th September 1981.

C O N T E N T S

1	Density and relative density; Exercise 1.	1
2	Water pressure; Exercise 2.	8
3	Flotation; Exercise 3.	16
4	Some important terms — displacement; deadweight; form coefficients; reserve buoyancy; tonnes per centimetre; Exercise 4.	25
5	Effect of density on draft and displacement — FWA; DWA; loadlines of ships; Exercise 5.	33
6	Centre of gravity — definition; factors affecting its position; shift of COG of a ship; splitting into three components.	50
7	Final KG — GG_1 formula and its limitation to one weight at a time; moments by keel; Exercises 6 & 7.	56
8	Centre of buoyancy — definition; indication of its position by KB, AB or HB; KB of ships of various shapes; Exercise 8.	66
9	Transverse statical stability — list, heel; their relation to COG and COB; transverse shift of B; metacentre, metacentric height; righting lever; righting moment for both, small and large angles of heel; Exercise 9.	70

10	Equilibrium of ships — stable equilibrium; unstable equilibrium; neutral equilibrium.	76
11	More about unstable equilibrium — angle of loll; behaviour of vessel at angle of loll.	79
12	Free surface effect — general explanation; free surface correction (FSC); solid GM; fluid GM; calculation of FSC; effect of tank-breadth on FSC; Exercise 10.	81
13	List — explanation of factors causing list; problems based on same; Exercise 11.	97
14	Stiff and tender vessels.	117
15	Stability of vessels with deck cargo of timber.	119
16	Hydrostatic curves — curves of displacement, deadweight, TPC, KB, KM _T , KM _L , AB, AF & MCTC; Exercise 12.	121
17	Hydrostatic tables — problems based on the same; Exercise 13.	131
18	Hydrostatic draft — what it is; problems based on same; Exercise 14.	144
	Answers	155
	Appendix I - Hydrostatic particulars of M.V. 'VIJAY'	160

1

DENSITY & RELATIVE DENSITY

Density of a substance is its mass per unit volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

where mass is in tonnes (t), volume is in cubic metres (m^3) and density is in tonnes per cubic metre (tm^{-3}).

Though mass may be expressed in kilogrammes (kg) and density in kilogrammes per cubic metre (kgm^{-3}), the use of tonnes is more convenient in stability. The density of fresh water is 1 tm^{-3} .

Relative density of a substance is the number of times the substance is heavier than fresh water. Being a ratio, RD has no units.

$$\text{RD} = \frac{\text{Mass of any volume of substance}}{\text{Mass of an equal volume of FW}}$$

Considering a volume of 1m^3 ,

$$\text{RD of substance} = \frac{\text{Density of substance}}{\text{Density of fresh water}}$$

Since the density of fresh water is 1 tm^{-3} , RD of a substance is numerically equal to its density, if density is expressed in tm^{-3} .

Some typical values are given below:

	<u>Density</u>	<u>RD</u>
Fresh water	1.0 tm^{-3}	1.0
Salt water	1.025 tm^{-3}	1.025
Fuel oil	0.95 tm^{-3}	0.95
Diesel oil	0.88 tm^{-3}	0.88
Dock water	1.015 tm^{-3}	1.015

Example 1

A tank has a volume of 400 m^3 . Find how many tonnes of SW (density 1.025 tm^{-3}) it can hold.

$$\begin{aligned}
 \text{Mass of SW} &= \text{Volume} \times \text{density} \\
 &= 400 \times 1.025 \\
 &= 410 \text{ t}
 \end{aligned}$$

Answer: The tank can hold 410 t of SW.

Example 2

A tank can hold 320 tonnes of SW. Find how many tonnes of oil of RD 0.8 it can hold.

$$\begin{aligned}
 \text{Mass of SW} &= \text{Volume of SW} \times \text{density of SW} \\
 320 &= V \times 1.025 \\
 V &= \frac{320}{1.025}
 \end{aligned}$$

$$\text{Volume of tank} = \frac{320}{1.025} \text{ m}^3$$

$$\begin{aligned}
 \text{Mass of oil} &= \text{Volume of oil} \times \text{density of oil} \\
 &= \frac{320}{1.025} \times 0.8 \\
 &= 249.8 \text{ t}
 \end{aligned}$$

Answer: The tank can hold 249.8 tonnes of oil.

Example 3

A cylindrical tank is 10 metres high and has a radius of 3 metres. If it is filled to an ullage of 2 metres, with oil of RD 0.7, find the mass of oil.

$$\begin{aligned}
 \text{Mass of oil} &= \text{Volume of oil} \times \text{density of oil} \\
 &= \frac{22}{7} \times 3 \times 3 \times 8 \times 0.7 \\
 &= 158.4 \text{ t}
 \end{aligned}$$

Answer : Mass of oil is 158.4 tonnes.

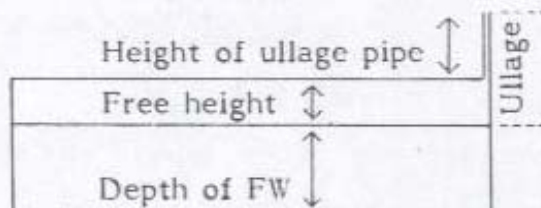
Example 4

A rectangular tank measuring 20 m x 10 m x 10 m has an ullage pipe extending to 0.5 m above the tank top. If the tank is 98% full of FW, find the mass of FW and state the ullage.

$$\text{Volume of FW} = \frac{98}{100} (20 \times 10 \times 10) \text{ m}^3$$

$$\begin{aligned}
 \text{Mass of FW} &= \text{Volume of FW} \times \text{density of FW} \\
 &= \frac{98}{100} (20 \times 10 \times 10) \times 1 \\
 &= 1960 \text{ t.}
 \end{aligned}$$

$$\begin{aligned}
 \text{Depth of FW} &= \frac{98}{100} \times \text{depth of tank} \\
 &= \frac{98}{100} \times 10 = 9.8 \text{ m}
 \end{aligned}$$



$$\text{Free height inside tank} = 10 - 9.8 = 0.2 \text{ m}$$

$$\begin{aligned} \text{Height of ullage} \\ \text{pipe above tank top} &= \underline{0.5 \text{ m}} \end{aligned}$$

$$\text{Ullage} = 0.7 \text{ m}$$

Answer : Mass of FW 1960 tonnes, ullage 0.7 metres.

Example 5

A rectangular tank is 20 m x 20 m x 12 m. Find how many tonnes of oil of RD 0.8 it can hold, if 2% of the volume of the tank is to be left for expansion. State also, the ullage on loading.

$$\text{Volume of tank} = 20 \times 20 \times 12 = 4800 \text{ m}^3$$

$$\text{Volume of tank} = \text{Volume of oil} + \text{Free space}$$

$$4800 = V + \frac{(2 \times 4800)}{100}$$

$$\begin{aligned} 4800 &= V + 96 \\ V &= 4704 \text{ m}^3 \end{aligned}$$

$$\text{Mass of oil} = \text{Volume of oil} \times \text{density of oil}$$

$$\begin{aligned} &= 4704 \times 0.8 \\ &= 3763.2 \text{ t} \end{aligned}$$

$$\begin{aligned} \text{Depth of oil} &= \frac{98}{100} \times \text{depth of tank} \\ &= \frac{98}{100} \times 12 = 11.76 \text{ m} \end{aligned}$$

$$\text{Ullage} = 12 - 11.76 = 0.24 \text{ m}$$

Answer : Mass of oil = 3763.2 t, ullage = 0.24 m.

Example 6

In worked example 5, if it was required to leave 2% of the volume of oil loaded for expansion, find the mass of oil and the ullage on loading.

$$\begin{aligned}
 \text{Volume of tank} &= \text{Volume of oil} + \text{Free space} \\
 4800 &= V + \left(\frac{2}{100} \times V \right) \\
 4800 &= 1.02V \\
 V &= 4705.88 \text{ m}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Mass of oil} &= \text{Volume of oil} \times \text{density of oil} \\
 &= 4705.88 \times 0.8 \\
 &= 3764.7 \text{ t}
 \end{aligned}$$

$$\begin{aligned}
 \text{Depth of oil} &= \frac{\text{Volume of oil}}{\text{Area of tank surface}} \\
 &= \frac{4705.88}{20 \times 20} = 11.765 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 \text{Ullage} &= \text{Depth of tank} - \text{depth of oil} \\
 &= 12 - 11.765 = 0.235 \text{ m}
 \end{aligned}$$

Answer: Mass of oil 3764.7 t, ullage 0.235 m.

Exercise 1Density and relative density

- 1 A rectangular tank measures 16 m x 15 m x 6 m. How many tonnes of oil of RD 0.78 can it hold?
- 2 A cylindrical tank of diameter 8 m is 10 m high. 400 t of oil of RD 0.9 is poured into it. Find the ullage, assuming π to be 3.1416.

- 3 A tank of 2400 m^3 volume and 12 m depth, has vertical sides and horizontal bottom. Find how many tonnes of oil of RD 0.7 it can hold, allowing 2% of the volume of the tank for expansion. State the ullage on loading.
- 4 A tank 10 m deep has vertical sides. Its bottom consists of a triangle measuring 12 m x 12 m x 10 m. Find the mass of oil (of RD 0.8) to be loaded, allowing 3% of the volume of oil loaded for expansion. State the ullage on completion of loading.
- 5 A rectangular tank measuring 25 m x 12 m x 8 m has an ullage pipe projecting 0.3 m above the tank top. Find the mass of SW in the tank when the ullage is 3.3 m.
- 6 A rectangular tank measures 30 m x 16 m x 14 m. It has an ullage pipe projecting .5 m above its top. Oil of RD 0.78 is to be loaded. The pipeline leading from the refinery to the ship is 10 km long and 40 cm in diameter. At the time of completion, all the oil in the pipeline has to be taken. Find at what ullage the valve at the refinery end must be shut so that the final ullage in the ship's tank would be 0.78 m. State also, the mass of oil loaded finally. (Assume π to be 3.1416).
- 7 A tank with a horizontal base and vertical sides is 10 m deep and has a rectangular trunkway 1 m high. The volume of the tank alone is 8000 m^3 and that of the trunkway 500 m^3 . Find the ullage when 5320 t of vegetable oil of RD 0.7 is loaded.
- 8 A rectangular tank has a total depth of 21 m and a volume of $10\,600 \text{ m}^3$, which includes a trunkway of depth 1 m and volume 600 m^3 . Find the ullage when 8320 t of oil of RD 0.8

is loaded.

- 9 A rectangular tank has a total depth of 10.5 m and volume 8200 m^3 , which includes a trunkway of depth 0.5 m and volume 200 m^3 . Find the mass of oil of RD 0.8 loaded and the ullage, if 2% of the volume of the tank is left for expansion.
- 10 A rectangular tank has a total depth of 21 m and volume 10250 m^3 which includes a trunkway of depth 1 m and volume 250 m^3 . Oil of RD 0.9 is to be loaded so as to leave 3% of the volume of oil loaded, for expansion. Find the mass of oil to be loaded and the final ullage.

2

WATER PRESSURE

Pressure is the load per unit area.

At any point in a liquid, pressure acts in all directions and is expressed in tonnes per square metre (tm^{-2}). It may, if desired, be expressed in kilo-Newtons per square metre (kN m^{-2}) where 1 tonne per square metre = 9.81 kilo-Newtons per square metre OR in bars where 1 bar = 10.2 tonnes per square metre.

At any point in a liquid,

$$\begin{aligned}\text{Pressure} &= \text{depth} \times \text{density} \\ \text{tm}^{-2} &= \text{m} \times \text{tm}^{-3}\end{aligned}$$

Thrust is the total pressure exerted on a given surface. Thrust is expressed in tonnes (t) but may, if desired, be expressed in kilo-Newtons (kN) where 1 tonne = 9.81 kilo-Newtons.

$$\begin{aligned}\text{Thrust} &= \text{pressure} \times \text{area} \\ t &= \text{tm}^{-2} \times \text{m}^2\end{aligned}$$

Example 1

Find the thrust on a keel plate 10 m x 2 m when the draft of the ship is 5 m in salt water.

$$\begin{aligned}
 \text{Pressure} &= \text{depth} \times \text{density} \\
 &= 5 \times 1.025 \\
 &= 5.125 \text{ tm}^{-2}
 \end{aligned}$$

$$\begin{aligned}
 \text{Thrust} &= \text{pressure} \times \text{area} \\
 &= 5.125 \times 10 \times 2 \\
 &= 102.5 \text{ t}
 \end{aligned}$$

Answer: Thrust on keel plate = 102.5 tonnes.

Example 2

A tank has a rectangular bulkhead 20 m wide and 10 m high. Find the thrust experienced by the bulkhead when the tank is full of oil of RD 0.9.

Note: For calculating the thrust on a vertical surface, the pressure is taken at the geometric centre of the immersed part of the surface and multiplied by the immersed area.

$$\begin{aligned}
 \text{Pressure} &= \text{depth} \times \text{density} \\
 &= 5 \times 0.9 \\
 &= 4.5 \text{ tm}^{-2}
 \end{aligned}$$

$$\begin{aligned}
 \text{Thrust} &= \text{pressure} \times \text{area} \\
 &= 4.5 \times 20 \times 10 \\
 &= 900 \text{ t}
 \end{aligned}$$

Answer : Thrust on bulkhead = 900 tonnes.

Example 3

A lock gate is 30 m wide and 10 m high. The water inside the lock is 7 m deep and of RD 1.005 and that

outside is 5 m deep and of RD 1.025. Find the resultant thrust and the direction in which it acts.

Considering the water inside,

$$\begin{aligned}\text{Pressure} &= \text{depth} \times \text{density} \\ &= \frac{7}{2} \times 1.005 \\ &= 3.5175 \text{ tm}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Thrust} &= \text{pressure} \times \text{area} \\ &= 3.5175 \times 30 \times 7 \\ &= 738.675 \text{ t}\end{aligned}$$

Considering the water outside

$$\begin{aligned}\text{Pressure} &= \text{depth} \times \text{density} \\ &= \frac{5}{2} \times 1.025 \\ &= 2.5625 \text{ tm}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Thrust} &= \text{pressure} \times \text{area} \\ &= 2.5625 \times 30 \times 5 \\ &= 384.375 \text{ t}\end{aligned}$$

$$\text{Thrust outwards} = 738.675 \text{ t}$$

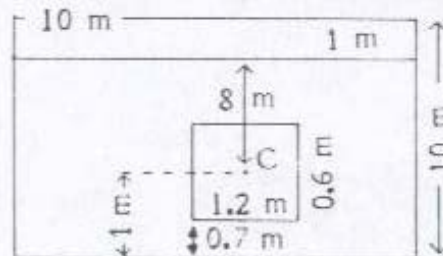
$$\text{Thrust inwards} = \underline{384.375 \text{ t}}$$

Answer : Resultant thrust = 354.3 t outwards.

Example 4

A deep tank 10 m wide and 10 m deep has a rectangular manhole (1.2 m x 0.6 m) at its forward

end. The longer sides of the manhole are horizontal and its lower edge is 0.7 m from the bottom of the tank. Find the total pressure experienced by the manhole cover when the tank is full of oil of RD 0.8 to an ullage of 1 m.



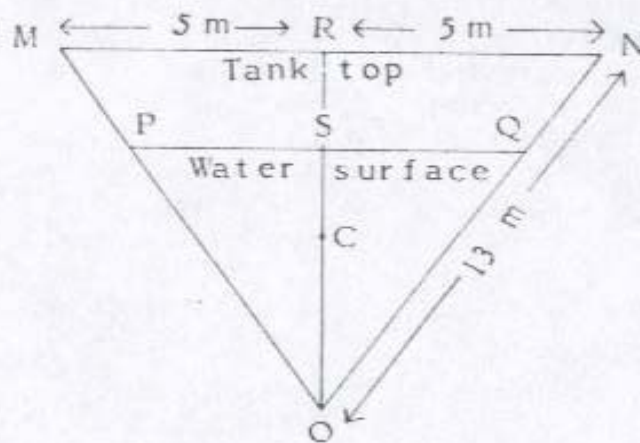
Depth of tank	= 10 m
Ullage	= <u>1 m</u>
Depth of oil	= 9 m
Height of C above bottom	= <u>1 m</u>
Depth of C below oil surface	= 8 m
Pressure at C	= Depth x density
	= 8×0.8
	= 6.4 tm^{-2}
Thrust	= Pressure x area
	= $6.4 \times 1.2 \times 0.6$
	= 4.608 t

Answer : Total pressure on manhole = 4.608 tonnes.

Example 5

A collision bulkhead is in the form of a triangle 10 m x 13 m x 13 m. Find the thrust experienced by it

when saltwater is run into the forepeak tank to a sounding of 9 m.



In triangle ORN,

$$\begin{aligned} OR^2 &= ON^2 - RN^2 \\ &= 13^2 - 5^2 \\ &= 144 \\ OR &= 12 \text{ m} \end{aligned}$$

$$\text{Depth of tank} = 12 \text{ m}$$

Triangles OSQ and ORN are similar.

$$\frac{SQ}{RN} = \frac{OS}{OR} \quad \text{or} \quad SQ = \frac{5 \times 9}{12} = 3.75 \text{ m}$$

$$\begin{aligned} \text{Area of triangle OPQ} &= \frac{1}{2} (PQ \cdot OS) = SQ \cdot OS \\ &= 3.75 \times 9 \\ &= 33.75 \text{ m}^2 \end{aligned}$$

$$\text{Area of immersed part of bulkhead} = 33.75 \text{ m}^2$$

$$\text{Depth of C below water line} = \frac{1}{3} \times 9 = 3 \text{ m}$$

13

$$\begin{aligned}\text{Pressure at C} &= \text{depth} \times \text{density} \\ &= 3 \times 1.025 \\ &= 3.075 \text{ tm}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Thrust} &= \text{pressure} \times \text{area} \\ &= 3.075 \times 33.75 \\ &= 103.781 \text{ t}\end{aligned}$$

Answer : Thrust on bulkhead = 103.781 tonnes.

Example 6

A double bottom tank measures 20 m x 20 m x 1 m. Its air pipe extends 12 m above its top. Find the thrust on the tank top when it is pressed up with salt water.

$$\begin{aligned}\text{Pressure at tank top} &= \text{depth} \times \text{density} \\ &= 12 \times 1.025 \\ &= 12.3 \text{ tm}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Thrust on tank top} &= \text{pressure} \times \text{area} \\ &= 12.3 \times 20 \times 20 \\ &= 4920 \text{ t}\end{aligned}$$

Answer : Thrust on tank top = 4920 tonnes.

Exercise 2

Water pressure

- 1 Find the thrust experienced by a flat keel plate 10 m x 2 m when the draft is 8 m in SW.
- 2 A box-shaped vessel 150 m x 20 m x 12 m is floating in a dock of RD 1.010 at an even

- keel draft of 10 m. Find the total water pressure experienced by the hull.
- 3 A submarine has a surface area of 650 m^2 and can withstand a total water pressure of 1332500 t. Find at what approximate depth in SW she would collapse.
- 4 A rectangular lock gate 40 m wide and 20 m high has water of RD 1.010 12 m deep on one side and water of RD 1.020 11 m deep on the other. Find the resultant thrust experienced and the direction in which it acts.
- 5 A rectangular lock gate 36 m wide and 20 m high has FW on one side to a depth of 16 m. Find what depth of SW on the other side will equalize the thrust.
- 6 A collision bulkhead is triangular in shape. Its maximum breadth is 12 m and its height 15 m. Find the thrust experienced by it if the forepeak tank is pressed up to a head of 3 m of SW.
- 7 A collision bulkhead is triangular shaped, having a breadth of 14 m at the tank top and a height of 12 m. As a result of a collision, the forepeak tank gets ruptured and SW enters the tank to a sounding of 9 m. Calculate the thrust on the bulkhead.
- 8 A tank has a triangular bulkhead, apex upwards. Its base is 14 m and its sides, 15 m each. It has a circular inspection hole of radius 0.5 m. The centre of the manhole is 0.8 m above the base and 1.6 from one corner. Find the thrust on the manhole cover when the tank contains oil of RD 0.95 to a sounding of 10 m. (Assume π to be 3.1416).

- 9 A rectangular deep tank is 22 m x 20 m x 10 m. Above the crown of the tank is a rectangular trunkway 0.2 m high, 5 m long and 4 m wide. Find the thrust on the tank lid when the tank is pressed up with SW to a head of 2.64 m above the crown of the tank.
- 10 A double bottom tank measures 25 m x 20 m x 2 m. Find the thrust on the tank top when pressed up to a head of 16 m of SW. Also find the resultant thrust on the tank bottom, and the direction that it acts, if the ship's draft in SW is 10 m.

FLOTATION

Archimedes' Principle states that when a body is wholly or partially immersed in a fluid, it suffers an apparent loss of weight which is equal to the weight of fluid displaced.

Since the word fluid includes both, liquids and gases, and the fact that merchant ships are only expected to be partially immersed in water, a modified version of Archimedes' Principle may be called the Principle of flotation.

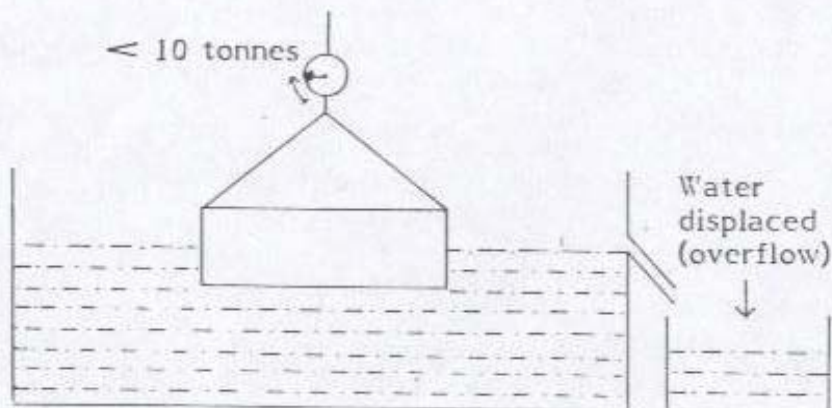
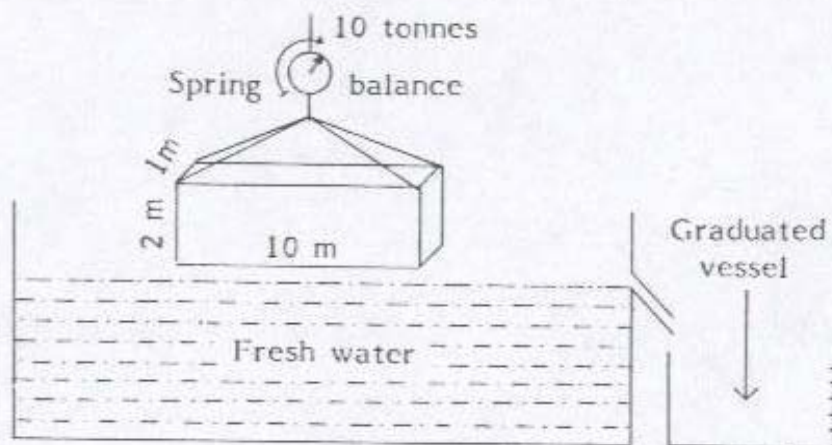
Principle of flotation: When a body is floating in a liquid, the weight of liquid displaced equals to the weight of the body.

Experimental explanation

Consider a rectangular watertight box $10\text{ m} \times 1\text{ m} \times 2\text{ m}$, weighing 10 t . If this was lifted by a crane and gradually lowered into a pool full of FW, the volume of water displaced can be collected and measured.

It will be noticed that as the box is lowered more and more into the water, the load registered by the spring balance becomes less and less. Consider the case when the draft becomes 0.1 m . The underwater volume of the box is then 1.0 m^3 i.e. the volume of water displaced (overflow) is 1.0 m^3 . The weight of water displaced or displacement is 1 t . So the apparent loss of weight or buoyancy experienced

by the box is 1 t. The spring balance now shows a reading of only 9 t whereas it showed 10 t before the box reached the water surface. Similarly when the draft becomes 0.2 m, the displacement (or buoyancy) is 2 t and the load registered by the spring balance is 8 t.



The following would be the results, expressed as a table :

Draft	Volume of displacement	Displacement or buoyancy	Load registered by spring balance
0.00 m	0.0 m ³	0.0 t	10 t
0.05	0.5	0.5	9.5
0.1	1	1	9
0.2	2	2	8
0.4	4	4	6
0.6	6	6	4
0.8	8	8	2
1.0	10	10	0

At a draft of 1.0 m, it is noted that the spring balance registers zero indicating that the buoyancy equals to the weight so that the body is now floating freely.

From the foregoing it is clear that:

- (i) The volume of water displaced is the under-water volume of the ship.
- (ii) Buoyancy or displacement is the upward thrust experienced by the ship. When the ship is floating freely, its displacement (or buoyancy) equals to its weight. The weight of the ship is therefore referred to as displacement (W).

$$W = \text{Volume of water displaced} \times \text{Density of water displaced}$$

OR

$$W = \text{Underwater volume of ship} \times \text{Density of water displaced}$$

While doing stability calculations, density should preferably be in tm^{-3} , volume in m^3 and displacement in t.

Example 1

A homogeneous rectangular log 6 m x 1 m x 0.8 m floats in SW at a draft of 0.5 m, with its largest face parallel to the water. Find its mass.

$$\begin{aligned} W &= \text{u/w volume} \times \text{density of water displaced} \\ W &= 6 \times 1 \times 0.5 \times 1.025 = 3.075 \text{ t} \end{aligned}$$

Since the log is floating freely, its displacement and mass are equal.

Answer : Mass of log = 3.075 tonnes.

Example 2

A homogeneous rectangular log 6 m x 1.5 m x 1 m has RD 0.7. Find its draft in FW. (Assume that the log will float with its largest face parallel to the water).

$$\begin{aligned} \text{Mass of log} &= \text{Volume} \times \text{density} \\ &= 6 \times 1.5 \times 1 \times 0.7 \\ &= 6.3 \text{ t} \end{aligned}$$

When floating freely, mass = displacement.

$$\begin{aligned} W &= \text{u/w volume} \times \text{density of water displaced} \\ 6.3 &= 6 \times 1.5 \times d \times 1 \\ d &= 0.7 \text{ m} \end{aligned}$$

Answer : Draft in FW = 0.7 metres.

Example 3

A homogeneous log of 0.5 m square section has RD 0.8. Find its draft in water of RD 1.02, assuming that it will float with one face horizontal.

Let the length of the log be L metres.

$$\begin{aligned}\text{Mass of log} &= \text{Volume} \times \text{density} \\ &= L \times 0.5 \times 0.5 \times 0.8 \text{ tonnes}\end{aligned}$$

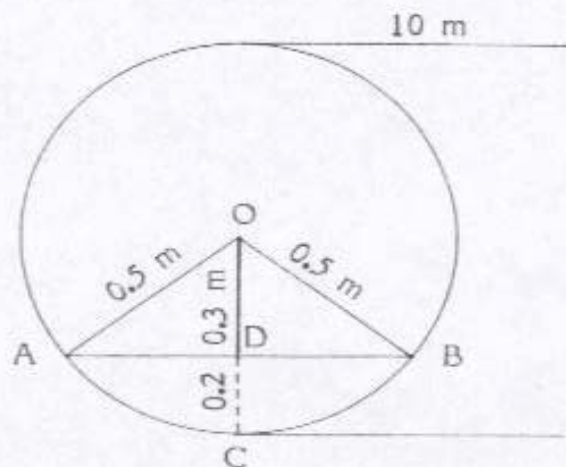
$$\begin{aligned}W &= \text{u/w volume} \times \text{density of water displaced} \\ W &= L \times B \times d \times 1.02 \\ &= L \times 0.5 \times d \times 1.02 \text{ tonnes}\end{aligned}$$

When floating freely, Displacement = Mass

$$\begin{aligned}L \times 0.5 \times d \times 1.02 &= L \times 0.5 \times 0.5 \times 0.8 \\ d &= \frac{0.5 \times 0.8}{1.02} = 0.392 \text{ m}\end{aligned}$$

Answer : Draft of log = 0.392 metres.

Figure for example 4



Example 4

A hollow, plastic cylinder of 1 m diameter and 10 m length floats in FW at a draft of 0.2 m, with its axis horizontal. Find its mass,

$$OA = OB = OC = 0.5 \text{ m radius}$$

$$CD = 0.2 \text{ m draft}$$

$$OD = OC - CD = 0.3 \text{ m}$$

In triangle ODB,

$$DB^2 = OB^2 - OD^2$$

$$= 0.5^2 - 0.3^2$$

$$= 0.16$$

$$DB = 0.4 \text{ m}$$

$$\sin BOD = \frac{.4}{.5} = 0.8$$

$$\text{Angle BOD} = 53.13^\circ$$

$$\text{Angle AOB} = 106.26^\circ$$

$$\frac{\text{Area of segment AOB}}{\text{Area of circle}} = \frac{\text{AOB}}{360^\circ}$$

$$\begin{aligned} \text{Area of segment AOB} &= \frac{\pi r^2 \times \text{AOB}}{360} \\ &= \frac{3.1416 \times 0.5^2 \times 106.26}{360} \end{aligned}$$

$$= 0.232 \text{ m}^2$$

$$\begin{aligned} \text{Area of triangle AOB} &= \frac{1}{2} \times 0.8 \times 0.3 \\ &= 0.120 \text{ m}^2 \end{aligned}$$

$$\begin{aligned}\text{Area of segment ABC} &= 0.232 - 0.120 \\ &= 0.112 \text{ m}^2\end{aligned}$$

$$\begin{aligned}\text{Underwater volume} &= 0.112 \times 10 \\ &= 1.12 \text{ m}^3\end{aligned}$$

$$W = \text{u/w volume} \times \text{density of water displaced}$$

$$\begin{aligned}W &= 1.12 \times 1 \\ &= 1.12 \text{ t}\end{aligned}$$

Answer : Mass of cylinder = 1.12 tonnes.

Example 5

A cylindrical drum of radius 40 cm and height 2 m weighs 200 kg. Lead pellets are put in it until it floats with its axis vertical, at a draft of 1.4 m in SW. Find the mass of lead pellets in it, in kilogrammes.

$$W = \text{u/w volume} \times \text{density of water displaced}$$

$$\begin{aligned}W &= \pi \cdot r^2 d \times 1.025 \\ &= 3.1416 \times .4 \times .4 \times 1.4 \times 1.025 \\ &= 0.7213 \text{ t}\end{aligned}$$

$$\text{Total mass of drum and lead} = 0.7213 \text{ t}$$

$$\text{Mass of drum} = 0.2 \text{ t}$$

$$\text{Mass of lead} = 0.5213 \text{ t}$$

Answer: Mass of lead pellets = 521.3 kilogrammes.

Example 6

A rectangular lidless box 6 m x 2 m x 1.5 m floats in water of RD 1.005 at a draft of 0.6 m. Find the

maximum mass of iron that can be put in it without sinking it, when it is floating in SW.

$$W = u/w \text{ volume} \times \text{density of water displaced}$$

$$\text{Maximum } W = 6 \times 2 \times 1.5 \times 1.025 = 18.450 \text{ t}$$

$$\text{Present } W = 6 \times 2 \times 0.6 \times 1.005 = \underline{7.236 \text{ t}}$$

$$\text{Difference of displacement} = \underline{11.214 \text{ t}}$$

Answer: In SW, it can hold 11.214 tonnes of iron.

Example 7

A rectangular barge 10 m x 5 m x 4 m, floating in SW at a draft of 2 m, is being lifted out of the water by a heavy-lift crane. Find the load taken by the crane when the draft becomes 1.2 m.

$$W = u/w \text{ volume} \times \text{density of water displaced}$$

$$W \text{ at } 2.0 \text{ m draft} = 10 \times 5 \times 2.0 \times 1.025 = 102.5 \text{ t}$$

$$W \text{ at } 1.2 \text{ m draft} = 10 \times 5 \times 1.2 \times 1.025 = \underline{61.5 \text{ t}}$$

$$\text{Load taken by crane} = \text{difference} = 41.0 \text{ t}$$

Exercise 3

Flotation

- 1 A rectangular log of wood 8 m long, 2 m wide and 2 m high floats in FW at a draft of 1.6 m with one face horizontal. Find its mass and RD.
- 2 A rectangular log of wood 5 m x 1.6 m x 1.0 m weighs 6 t and floats with its largest face horizontal. Find its draft in SW and its RD.

- 3 A rectangular log 3 m broad and 2 m high floats with its breadth horizontal. If the density of the log is 0.7 tm^{-3} , find its draft in water of RD 1.01.
- 4 A cylinder 2 m in diameter and 10 m long floats in FW, with its axis horizontal, at a draft of 0.6 m. Find its mass.
- 5 A barge of triangular cross section is 20 m long, 12 m wide and 6 m deep. It floats in SW at a draft of 4 m. Find its displacement.
- 6 A cylindrical drum of 1.2 m diameter and 2 m height floats with its axis vertical in water of RD 1.016 at a draft of 1.4 m. Find the maximum mass of lead shots that can be put in it without sinking it.
- 7 A rectangular barge 10 m long and 5 m wide, floating in SW at a draft of 3 m, is being lifted out of the water by a heavy-lift crane. Find the load on the crane when the draft has reduced to 1 m.
- 8 A rectangular box 2.4 m long, 1.2 m wide and 0.8 m high, floats in water of RD 1.012 at an even keel draft of 0.2 m. Find the maximum mass of SW that can be poured into it without sinking it.
- 9 A box-shaped vessel of 18450 t displacement is 150 m long and 20 m wide. Find its draft in SW.
- 10 A box-shaped vessel 120 m long and 15 m wide is floating in DW of RD 1.005 at a draft of 5 m. If her maximum permissible draft in SW is 6 m, find how much cargo she can now load.

دشت: دشت (Deadweight) به معنی بار اضافی است که یک کشتی می‌تواند حمل کند. این بار شامل کالاهای مختلف، سوخت، آب شیرین و غیره می‌شود.

4

در /

SOME IMPORTANT TERMS

Displacement is commonly used to denote the mass of a ship in tonnes. Technically, it is the mass of water displaced by a ship and, when floating freely, the mass of water displaced equals to the mass of the ship, as explained in Chapter 3.

* Light displacement ^{وزن کشتی خالی} is the mass of the empty ship — without any cargo, fuel, lubricating oil, ballast water, fresh and feed water in tanks, consumable stores, and passengers and crew and their effects.

Load displacement is the total mass of the ship when she is floating in salt water with her summer loadline at the water surface.

Present displacement is the mass of the ship at present. It is the sum of the light displacement of the ship and everything on board at present.

* Deadweight (DWT) of a ship is the total mass of cargo, fuel, freshwater, etc., that a ship can carry, when she is floating in salt water with her summer loadline at the water surface.

$$\text{DWT of ship} = \text{load displ} - \text{light displ}$$

Deadweight aboard is the total mass of cargo, fuel, ballast, fresh water, etc., on board at present.

$$\text{DWT aboard} = \text{present displ} - \text{light displ}$$

$$DWT \text{ available} = TPC + \frac{\text{Summer Displacement}}{(2.5 \text{ ton})}$$

26

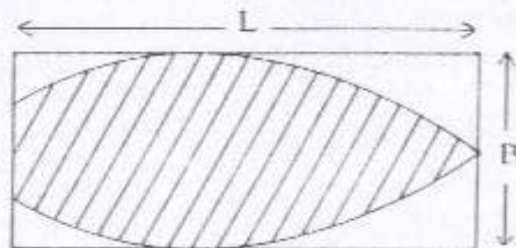
* Deadweight available is the total mass of cargo, fuel, fresh water, etc., that can be put on the ship at present to bring her summer loadline to the water surface in salt water.

$$DWT \text{ available} = \text{load displ} - \text{present displ.}$$

* Waterplane coefficient (C_w), or coefficient of fineness of the water-plane area, is the ratio of the area of the water-plane to the area of a rectangle having the same length and maximum breadth.

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

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



* Block coefficient (C_b), or coefficient of fineness of displacement, at any draft is the ratio of the underwater volume of the ship at that draft to a rectangular box having the same extreme dimensions.

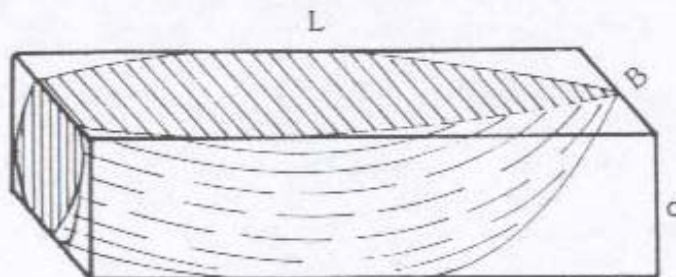
$$C_b = \frac{\text{Underwater volume}}{L \times B \times d}$$

$$\text{Underwater volume} = L \times B \times d \times C_b$$

The term block coefficient may also be used with respect to a tank in which case it would be the ratio of the volume of the tank to the volume of a rectangular box having the same extreme dimensions as the tank.

$$C_b \text{ of tank} = \frac{\text{Volume of tank}}{L \times B \times D}$$

$$\text{Volume of tank} = L \times B \times D \times C_b$$



✈ Reserve buoyancy (RB) is the volume of the enclosed spaces above the waterline. It may be expressed as a volume in m^3 or as a percentage of the total volume of the ship.

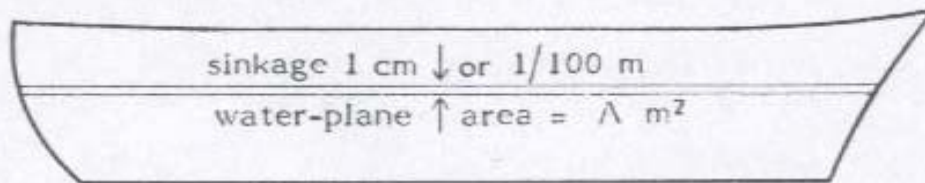
$$RB = \text{Total volume} - \text{underwater volume}$$

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

Reserve buoyancy is so called because, though it is not displacing any water at that time, it is available for displacement if weights are added or if bilging takes place. Bilging is the accidental entry of water into a compartment, due to underwater damage and is discussed in volume II.

✈ Tonnes per centimetre (TPC) is the number of tonnes required to cause the ship to sink or rise by one centimetre. In SI units TPC is indicated as $t \text{ cm}^{-1}$.

Considering 1 cm sinkage



$$\text{Increase in underwater volume} = \Delta \times \frac{1}{100} \text{ m}^3$$

$$\text{Increase in } W = \frac{\Delta}{100} \times \text{density of water displaced.}$$

$$\text{Or TPC} = \frac{\Delta}{100} \times \text{density of water displaced}$$

$$\text{TPC in SW} = \frac{\Delta}{100} \times 1.025 = \frac{1.025\Delta}{100}$$

$$\text{TPC in FW} = \frac{\Delta}{100} \times 1.000 = \frac{\Delta}{100}$$

$$\text{TPC in DW RD } 1.017 = \frac{\Delta}{100} \times 1.017 = \frac{1.017\Delta}{100}$$

In the foregoing formulae, the area of the water-plane of a ship-shape has been considered constant since the sinkage or rise being considered is only 1 cm. However, the area of the water-plane of a ship-shape usually increases as draft increases. Hence, its TPC also increases as draft increases. In view of this, calculations involving TPC should generally be confined to small values of sinkage or rise, say less than about 20 cm, in the case of ship-shapes. Otherwise, the accuracy of the calculation will tend to suffer.

In the case of a box-shaped vessel, the area of the water-plane is the same at all drafts and hence its TPC does not change with draft.

Example 1

A box-shaped vessel is 120 m long and 16 m wide and has a load draft of 8 m. If her present draft is 6 m, find the DWT available.

$$W = \text{u/w volume} \times \text{density of water displaced.}$$

$$\text{Load } W = 120 \times 16 \times 8 \times 1.025 = 15744 \text{ t}$$

$$\text{Present } W = 120 \times 16 \times 6 \times 1.025 = 11808 \text{ t}$$

$$\text{DWT available} = 15744 - 11808 = 3936 \text{ t}$$

Example 2

The length and breadth of the water-plane of a ship are 100 m and 12 m. If the coefficient of fineness of the water-plane is 0.7, find her TPC in SW and in FW.

$$\begin{aligned} \text{Water-plane area} &= L \times B \times C \\ &= 100 \times 12 \times 0.7 \\ &= 840 \text{ m}^2 \end{aligned}$$

$$\text{TPC} = \frac{A}{100} \times \text{density of water}$$

$$\text{In SW, TPC} = \frac{840}{100} \times 1.025 = 8.610 \text{ t cm}^{-1}$$

$$\text{In FW, TPC} = \frac{840}{100} \times 1 = 8.400 \text{ t cm}^{-1}$$

Example 3

A ship floating in DW of RD 1.010 at a draft of 5 m, is 90 m long and 10 m wide at the water-line. If her block coefficient is 0.72 and her light displacement is 1200 t, find the DWT aboard.

$$W = \text{u/w volume} \times \text{density of water displaced.}$$

$$\begin{aligned}
 \text{Present W} &= 90 \times 10 \times 5 \times 0.72 \times 1.010 \\
 &= 3272.4 \text{ t} \\
 \text{Light W} &= \underline{1200.0 \text{ t}} \\
 \text{DWT aboard} &= 2072.4 \text{ t}
 \end{aligned}$$

Example 4

A box-shaped vessel is 120 m long and 14 m wide and 12 m high. If her displacement is 13776 t, find her reserve buoyancy % in SW.

$$W = \text{u/w volume} \times \text{density of water displaced.}$$

$$\begin{aligned}
 13776 &= V \times 1.025 \\
 V &= \frac{13776}{1.025} = 13440 \text{ m}^3
 \end{aligned}$$

$$\text{Total volume} = 120 \times 14 \times 12 = 20160 \text{ m}^3$$

$$\begin{aligned}
 \text{RB} &= \text{Total vol} - \text{underwater vol} \\
 &= 20160 - 13440 = 6720 \text{ m}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{RB \%} &= \frac{\text{Above water volume}}{\text{Total volume}} \times 100 \\
 &= \frac{6720}{20160} \times 100 = 33.333\%
 \end{aligned}$$

Example 5

A ship is floating in FW at a draft of 6.8 m. If her maximum FW draft is 7.0 m, and her SW TPC is 40, find the DWT available.

$$\begin{aligned}
 \text{SW TPC} &= \frac{A}{100} \times 1.025 \\
 40 &= \frac{A}{100} \times 1.025
 \end{aligned}$$

$$\text{Or } A = \frac{40 \times 100}{1.025} = 3902.4 \text{ m}^2$$

$$\text{FW TPC} = \frac{A}{100} = \frac{3902.4}{100} = 39.024 \text{ t cm}^{-1}$$

$$\text{Sinkage required} = 7.0 - 6.8 = 0.2 \text{ m} = 20 \text{ cm.}$$

$$\begin{aligned} \text{Cargo to load} &= \text{Sinkage} \times \text{TPC} = 20 \times 39.024 \\ &= 780.48 \text{ t.} \end{aligned}$$

$$\text{DWT available} = 780.48 \text{ t.}$$

Exercise 4

Displacement, DWT, RB, TPC, etc.

- 1 A box-shaped vessel 120 m long and 15 m wide has a light draft of 4 m and a load draft of 9.8 m in SW. Find her light displacement, load displacement and DWT.
- 2 A box-shaped vessel 100 m long and 14 m wide is floating in SW at a draft of 7.6 m. Her light draft is 3.6 m and load draft 8.5 m. Find her present displacement, DWT aboard and DWT available.
- 3 A ship is 200 m long and 20 m wide at the waterline. If the coefficient of fineness of the water-plane is 0.8, find her TPC in SW, FW and DW of RD 1.015.
- 4 A double bottom tank 20 m x 10.5 m x 1.0 m has a block coefficient of 0.82. Calculate how much fuel oil of RD 0.95 it can hold.
- 5 A ship floating in SW at a draft of 8 m is 110 m long and 14 wide at the waterline. If her block coefficient is 0.72, find her displacement.

If her load displacement is 12000 t, find the DWT available.

- 6 A vessel of 14000 t displacement is 160 m long and 20 m wide at the waterline. If she is floating in SW at a draft of 6.1 m, find her block coefficient.
- 7 A box-shaped vessel 18 m x 5 m x 2 m floats in SW at a draft of 1.4 m. Calculate her RB%.
- 8 A box-shaped vessel of 2000 t displacement is 50 m x 10 m x 7 m. Calculate her RB% in FW.
- 9 The TPC of a ship in SW is 30. Calculate her TPC in FW and in DW of RD 1.018.
- 10 A ship is floating at a draft of 8.2 m in DW of RD 1.010. If her TPC in SW is 40, find how much cargo she can load to bring her draft in DW to 8.4 m.

5

EFFECT OF DENSITY ON DRAFT & DISPLACEMENT

Part I: When displacement is constant

When a ship goes from SW to FW, her draft would increase and vice versa. This can be illustrated by a simple example. Consider a ship of 10000 tonnes displacement.

$$W = u/w \text{ volume} \times \text{density of water displaced}$$

In salt water

$$10000 = V_{SW} \times 1.025$$

$$\text{or } V_{SW} = \frac{10000}{1.025} = 9756 \text{ m}^3$$

$$\text{Underwater volume in SW} = 9756 \text{ m}^3$$

In fresh water

$$10000 = V_{FW} \times 1$$

$$\text{or } V_{FW} = 10000 \text{ m}^3$$

$$\text{Underwater volume in FW} = 10000 \text{ m}^3$$

From the foregoing example it is clear that when a ship goes from SW to FW her underwater volume (and hence her draft) increases, and vice versa, though her displacement is constant.

FRESH WATER ALLOWANCE

FWA is the increase in draft when a ship goes from SW to FW and vice versa.

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

Where: W is the displacement of the ship in salt water, expressed in tonnes.
 TPC is the tonnes per centimetre immersion in salt water.
 FWA is the fresh water allowance in centimetres.

FWA of a ship usually increases as draft increases. This is because W depends on underwater volume whereas TPC depends on waterplane area. As draft increases, both W and TPC increase but W increases at a faster rate. Hence FWA, as calculated by the foregoing formula, also increases as draft increases. The table on the next page is taken from the hydrostatic particulars on an actual ship in service.

The FWA calculated, by the foregoing formula, for the summer load condition is called the FWA of the ship. This FWA is mentioned in the loadline certificate and is considered constant for those loadlines marked on the ship's sides — T, S, W and WNA. When a ship is loading down to her marks in FW, she can immerse her loadline by the FWA of the ship so that when she goes to SW, she would rise to her appropriate loadline.

If it is desired to find the FW draft of the ship when she is not immersed upto the loadline marked on the ship's sides, the FWA must be calculated by

the formula and added to the SW draft of the ship at that time.

Draft m	W t	TPC tcm ⁻¹	$\frac{W}{40 \text{ TPC}}$	=	FWA cm
3.000	5478	20.90	$\frac{5478}{40 \times 20.9}$	=	6.6
5.000	9788	22.08	$\frac{9788}{40 \times 22.08}$	=	11.1
7.000	14299	22.95	$\frac{14299}{40 \times 22.95}$	=	15.6
9.000	19051	24.14	$\frac{19051}{40 \times 24.14}$	=	19.7
9.233 (load draft)	19617	24.28	$\frac{19617}{40 \times 24.28}$	=	20.2

DOCK WATER ALLOWANCE

DWA is the increase in draft when a ship goes from saltwater to dockwater, and vice versa, where the dockwater is neither fresh nor salt i.e., RD between 1 and 1.025. When loading in a dock, the ship can immerse her loadline by the DWA so that when she goes to sea, she would rise to her appropriate loadline.

When a ship goes from SW to FW (change of RD of .025) she increases her draft by FWA. So for any change of RD between 1.025 and 1.000, linear interpolation may be done. For example:-

			Change of RD	Change of Draft
SW 1.025	to	FW 1.000	.025	FWA
SW 1.025	to	DW 1.017	.008	$\frac{.008}{.025} \times \text{FWA}$
SW 1.025	to	DW 1.020	.005	$\frac{.005}{.025} \times \text{FWA}$
FW 1.000	to	DW 1.016	.016	$\frac{.016}{.025} \times \text{FWA}$
DW 1.017	to	DW 1.005	.012	$\frac{.012}{.025} \times \text{FWA}$

From the foregoing example, it is clear that:-

$$\text{Change of draft} = \frac{\text{change of RD}}{.025} \times \text{FWA}$$

The change of draft, so obtained, would be in the same units as the FWA — mm, cm or m.

This formula holds good for any change of RD. However, when the change of draft is calculated between SW and DW, it is called DWA. The term dock water is used here only symbolically to represent water whose RD is between 1.000 and 1.025 and, for stability purposes, includes the water of rivers, harbours, etc., even though they may not have enclosed docks.

Part II: When draft is constant

When a ship floats at the same draft, on different occasions, in water of different RD, her displacement each time would be different. This is illustrated by a simple example.

Suppose the underwater volume of a certain ship at 7 m draft is 14000 m³.

In SW, at 7 m draft, $W = 14000 \times 1.025 = 14350 \text{ t.}$

In FW, at 7 m draft, $W = 14000 \times 1.000 = 14000 \text{ t.}$

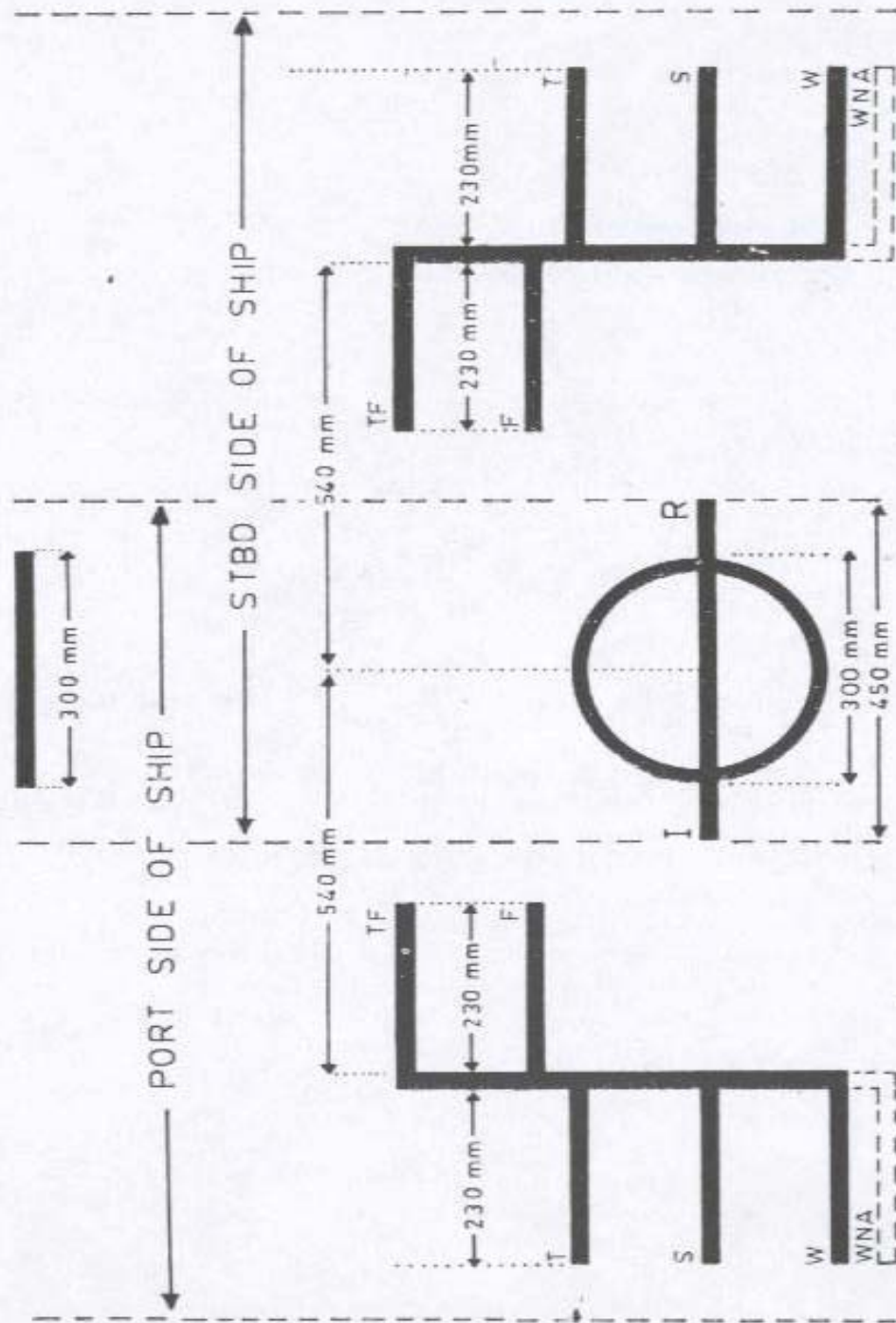
RD 1.01, at 7 m draft, $W = 14000 \times 1.010 = 14140 \text{ t.}$

RD 1.02, at 7 m draft, $W = 14000 \times 1.020 = 14280 \text{ t.}$

LOADLINES OF SHIPS

The following diagram shows the port and starboard side loadlines of a cargo ship. To see the port side loadlines, cover up the the right 1/3 of the sketch. To see the starboard side loadlines, cover up the left 1/3 of the sketch. The WNA loadline has been included in dotted lines as it is only required by vessels less than 100 metres in length, trading in the North Atlantic during the winter season. The exact limits and dates of the winter zone in the North Atlantic are given in the loadline rules.

All the lines are 25 mm thick, are cut into the shell plating and are painted white or yellow on a dark background or black on a light background. The upper edge of each loadline indicates its exact level.



The top of the deck line indicates where the top of the freeboard deck would meet the outer side of the shell plating, if produced. Directly below the deck line is the Plimsoll mark (or loadline disc) and the vertical distance between them is called the Statutory Summer Freeboard. The centre of the loadline disc is at the middle of the upper edge of its 25 mm thick, painted, diametric line. The deck line and the Plimsoll mark are situated exactly amidships.

Exactly 540 mm forward of the disc is a vertical line 25mm thick with horizontal lines, measuring 230 mm x 25 mm, on each side of it. On its forward side the lines are marked S, T and W (also WNA if applicable). The lines on the after side are marked F and TF.

The upper edge of the line marked S is in line with the horizontal line of the Plimsoll mark. In summer zones, the ship can load up to this line in salt water. The vertical distance between the upper edges of S and T (and also between S and W) is $1/48$ of the summer draft of the vessel. The dates and limits of winter, summer and tropical zones are given in the loadline rules. The WNA mark, if applicable, is situated exactly 50 mm below the W mark (measured between their upper edges).

The vertical distance between the upper edges of the lines marked S and F, and also between T and TF, is the FWA of the ship.

Example 1

A ship's load displacement is 16000 t and TPC is 20. If she is in DW of RD 1.010, find by how much she may immerse her loadline so that she will not be overloaded when she goes to sea.

$$\text{FWA} = \frac{W}{40 \cdot \text{TPC}} = \frac{16000}{40 \times 20} = 20 \text{ cm}$$

$$\begin{aligned} \text{DWA} &= \frac{(1.025 - d_d)}{.025} \times \text{FWA} = \frac{(1.025 - 1.010)}{.025} \times 20 \\ &= 12 \text{ cm} \end{aligned}$$

Hence, ship can immerse her SW loadline by 12 cm.

Example 2

A vessel of FWA 200 mm goes from water of RD 1.018 to water of RD 1.006. Find the change in draft and state whether it will be sinkage or rise.

$$\begin{aligned} \text{Change of draft} &= \frac{\text{Change of RD} \times \text{FWA}}{.025} \\ &= \frac{(1.018 - 1.006) \times 200}{.025} \\ &= 96 \text{ mm.} \end{aligned}$$

Since the RD of water has decreased the draft will increase.

Hence, the vessel will sink by 96 mm.

Example 3

A box-shaped vessel 24 x 5 x 3 m has a mean draft of 1.2 m in DW of RD 1.009. Calculate her draft in DW of RD 1.019.

$$W = \text{u/w volume} \times \text{density of water displaced.}$$

$$\text{In DW RD 1.009, } W = 24 \times 5 \times 1.2 \times 1.009$$

$$\text{In DW RD 1.019, } W = 24 \times 5 \times d \times 1.019$$

Since displacement is constant,

$$24 \times 5 \times d \times 1.019 = 24 \times 5 \times 1.2 \times 1.009$$

$$d = \frac{1.2 \times 1.009}{1.019} = 1.188 \text{ m}$$

Hence, draft in DW of RD 1.019 = 1.188 m.

Note: This problem could also be worked by calculating the displacement, SW TPC, FWA and then the change of draft, all by various formulae. However such a method would be unduly tedious.

Example 4

A box-shaped vessel 20 x 6 x 4.5 floats in DW of RD 1.010 at a draft of 2.4 m. Calculate her percentage reserve buoyancy in DW of RD 1.020.

$W = \text{u/w volume} \times \text{density of water displaced.}$

In DW RD 1.010, $W = 20 \times 6 \times 2.4 \times 1.010$

In DW RD 1.020, $W = V \times 1.020$

Since displacement is constant,

$$V \times 1.020 = 20 \times 6 \times 2.4 \times 1.010$$

$$V = 285.176 \text{ m}^3$$

$$\text{Total volume} = 20 \times 6 \times 4.5 = 540 \text{ m}^3$$

$$\text{Above water volume} = \text{Total volume} - \text{u/w volume}$$

$$= 540 - 285.176 = 254.824 \text{ m}^3$$

$$\text{RB\%} = \frac{\text{Above water volume}}{\text{Total volume}} \times 100 = \frac{254.824}{540} \times 100$$

$$= 47.19\%$$

Hence, RB% in DW of RD 1.020 = 47.19%

Example 5

A vessel displaces 5000 t at a certain draft in DW of RD 1.018. Find her displacement when floating at the same draft in DW of RD 1.012.

$W = \text{u/w volume} \times \text{density of water displaced.}$

$$\begin{aligned} \text{In DW RD 1.018, } 5000 &= V \times 1.018 \\ \text{or } V &= \frac{5000}{1.018} = 4911.591 \text{ m}^3. \end{aligned}$$

Hence, u/w vol of ship at that draft = 4911.591 m³.

$$\begin{aligned} \text{In DW' RD 1.012, } W &= 4911.591 \times 1.012 \\ &= 4970.53 \text{ t} \\ &= 4971 \text{ t} \end{aligned}$$

Example 6

A vessel displaces 16000 t at her summer load draft in SW. If she is now floating in DW of RD 1.015 with her summer loadline on the water, calculate how much DWT is available.

$W = \text{u/w volume} \times \text{density of water displaced.}$

At Summer load draft, $16000 = V \times 1.025$

$$\text{or } V = \frac{16000}{1.025} = 15609.756 \text{ m}^3$$

Hence, underwater volume of ship at summer draft =
= 15609.756 m³

$$\text{Present disp} = 15609.756 \times 1.015 = 15843.9 \text{ t}$$

$$\begin{aligned} \text{DWT available} &= \text{Maximum disp} - \text{present disp} \\ &= 16000 - 15843.9 \\ &= 156.1 \text{ t} \\ &= 156 \text{ t} \end{aligned}$$

Example 7

A vessel is in SW with her summer loadline 60 mm above the water on the port side and 10 mm above the water on the starboard side. Find the DWT available, if her TPC is 40.

Obviously, the vessel is listed to starboard. Since both, port and starboard loadlines are of same name (above water), mean distance from water will be half the sum of the distances.

$$\text{Mean distance of loadline} = \frac{60 + 10}{2} = 35 \text{ mm}$$

Hence, when upright, loadlines will be 3.5 cm above water.

$$\begin{aligned} \text{DWT available} &= \text{Sinkage} \times \text{TPC} = 3.5 \times 40 \\ &= 140 \text{ t} \end{aligned}$$

Example 8

A vessel is in SW with her port summer loadline 80 mm below water and her starboard, 200 mm above. Find the DWT available if TPC is 30.

Obviously the vessel is listed to port. Since the loadline on one side is above the water and the other, below the water (different names), the mean distance of the loadline from the water will be half the difference between the distances. The name (above or below) of the mean distance will be the same as that of the larger of the two distances.

$$\text{Mean distance of loadline} = \frac{200 - 80}{2} = 60 \text{ mm}$$

Hence, when upright, loadline will be 6.0 cm above water.

$$\begin{aligned}\text{DWT available} &= \text{Sinkage} \times \text{TPC} = 6 \times 30 \\ &= 180 \text{ t}\end{aligned}$$

Example 9

A vessel floats in DW RD 1.016 with her winter loadline 100 mm below water on the port side and 180 mm below water on the starboard side. If her FWA is 200 mm, TPC is 24 and summer load draft is 9.6 m, find DWT available.

Port winter loadline is 100 mm below water

Stbd winter loadline is 180 mm below water

$$\begin{aligned}\text{Mean distance from water} &= \frac{1}{2} (180 + 100) \\ &= 140 \text{ mm below}\end{aligned}$$

Hence, when upright, winter loadline will be 14 cm below water.

$$\begin{aligned}\text{Distance W to S} &= \frac{1}{48} \times \text{Summer draft} \\ &= \frac{1}{48} \times 9.6 = 0.2 \text{ m} \\ &= 20 \text{ cm}\end{aligned}$$

$$\begin{aligned}\text{Hence, distance from present waterline to S} \\ &= 20 - 14 = 6 \text{ cm}\end{aligned}$$

$$\begin{aligned}\text{DWA} &= \frac{(1.025 - 1.016)}{.025} \text{ FWA} = \frac{.009}{.025} \times 200 = 72 \text{ mm} \\ \text{DWA} &= 7.2 \text{ cm}\end{aligned}$$

$$\text{Hence, total sinkage permissible} = 6 + 7.2 = 13.2 \text{ cm}$$

$$\text{TPC} = \frac{\Delta}{100} \times \text{density of water}$$

Note: TPC given is always SW TPC unless specifically stated otherwise.

$$\text{In SW, } 24 = \frac{A}{100} \times 1.025 \text{ or } \frac{A}{100} = \frac{24}{1.025}$$

$$\begin{aligned} \text{In DW, TPC} &= \frac{A}{100} \times 1.016 = \frac{24}{1.025} \times 1.016 \\ &= 23.79 \text{ tcm}^{-1} \end{aligned}$$

$$\text{DWT available} = \text{sinkage} \times \text{TPC} = 13.2 \times 23.79 = 314 \text{ t}$$

Example 10

A vessel arrives at port X at the mouth of a river. Her displacement is 12000 t and arrival draft 5.77 m in RD 1.020. She is to cross a bar upriver before entering port Y. The depth at the bar is 6.0 m and RD 1.005. If her TPC is 25, find the minimum quantity of cargo to off-load at port X so that she may cross the bar with an under-keel clearance of 0.5 m.

$$\text{FWA} = \frac{W}{40 \times \text{TPC}} = \frac{12000}{40 \times 25} = 12 \text{ cm}$$

$$\begin{aligned} \text{Change of draft} &= \frac{\text{Change of RD} \times \text{FWA}}{.025} \\ &= \frac{(1.020 - 1.005) \times 12}{.025} \\ &= 7.2 \text{ cm} = .072 \text{ m} \end{aligned}$$

$$\text{Depth of water over bar} = 6.0 \text{ m}$$

$$\text{Under-keel clearance} = 0.5 \text{ m}$$

$$\text{Max draft to arrive at bar} = 5.5 \text{ m}$$

$$\text{Change of draft due to RD} = 0.072 \text{ m}$$

Max draft on dep port X	=	5.428 m
Draft on arrival port X	=	5.770 m
Required mean rise at port X	=	0.342 m
	=	34.2 cm

$$\text{TPC at Port X} = \frac{25}{1.025} \times 1.020 = 24.88 \text{ tcm}^{-1}$$

$$\begin{aligned} \text{Cargo to discharge} &= \text{rise} \times \text{TPC} \\ &= 34.2 \times 24.88 \\ &= 850.9 \text{ t} \end{aligned}$$

Hence, required to discharge 851 t at port X.

Note: The TPC given is always the SW TPC unless clearly stated otherwise. The TPC used in the final stage of this problem is the TPC at RD 1.020 because the cargo lightening operation is being carried out at port X whose RD is 1.020. This is purely of academic interest because any cargo calculation involving TPC is approximate only. If the SW TPC was used in this problem, the answer would be only 4 tonnes different. In actual practice at sea, the displacement of the ship at the required draft of 5.5 m in RD 1.005 would be found out (using the hydrostatic particulars of the ship) and that, subtracted from the present displacement, would give the quantity of cargo to off-load at port X. This is explained in Chapter 17.

Exercise 5

- 1 A ship of 16000 t displacement and TPC 20 is floating in SW at a draft of 8.0 m. Find her draft in FW.
- 2 A ship goes from water of RD 1.008 to SW. Find the change in draft, if her FWA is 180 mm, and state whether it would be sinkage or rise.
- 3 A vessel goes from water of RD 1.010 to FW. If her FWA is 160 mm, state whether she would sink or rise and by how much.
- 4 A ship of FWA 175 mm goes from water of RD 1.006 to water of RD 1.018. Find the amount of sinkage or rise.
- 5 A ship's stability data book gives her load displacement to be 18000 t and TPC to be 25. If she is now loading in DW of RD 1.018, by how much may her loadline be immersed so that she would not be overloaded?
- 6 A box-shaped vessel 20 x 4 x 2 m has a mean draft of 1.05 m in SW. Calculate her draft in DW of RD 1.012.
- 7 A box-shaped vessel 18 x 5 x 2 m floats in DW of RD 1.000 at a draft of 1.4 m. Calculate her percentage reserve buoyancy when she enters SW.
- 8 The hydrostatic particulars of a ship indicate that her displacement in SW at a draft of 5 m is 3000 t. Find her displacement when floating at 5 m draft in water of RD 1.018.

- 9 A vessel displaces 4500 t of FW at a certain draft. Find her displacement at the same draft in water of RD 1.020.
- 10 A ship 100 m long and 20 m wide, block coefficient 0.8, floats in SW at a mean draft of 8.0 m. Calculate the difference in displacement when floating at the same draft in FW.
- 11 A vessel displaces 14 500 tonnes, if floating in SW upto her winter load-line. If she is in a dock of RD 1.010, with her winter load-line on the surface of the water, find how much cargo she can load, so that she would float at her winter load-line in SW.
- 12 A vessel of 12000 t displacement arrives at the mouth of a river, drawing 10.0 m in SW. How much cargo must she discharge so that her draft in an upriver port of RD 1.012 would be 10.0 m.
- 13 A vessel floating in DW of RD 1.005 has the upper edge of her summer loadline in the waterline to starboard and 50 mm above the waterline to port. If her FWA is 180 mm and TPC is 24, find the amount of cargo which the vessel can load to bring her to her permissible draft.
- 14 A vessel is floating at 7.8 m draft in DW of RD 1.010. TPC is 18 and FWA is 250 mm. The maximum permissible draft in SW is 8.0 m. Find the DWT available.
- 15 A vessel's statutory freeboard is 2.0 m. She is loading in DW of RD 1.015 and her freeboard is 2.1 m. TPC = 24. FWA = 200 mm. Find the DWT available.

- 16 A vessel is lying in a river berth of density 1.010 tonnes per m^3 , with her summer loadline 20 mm above the water on the starboard side and 50 mm above the water on the port side. Find how much cargo she can load to bring her to her summer loadline in SW, if her summer displacement is 15000 tonnes and TPC is 25.
- 17 A vessel is floating in dock water of RD 1.005 with her starboard WNA mark 30 mm below, and her port WNA mark 60 mm below the water line. If her summer SW draught is 8.4 m, TPC is 30 and FWA is 160 mm, calculate how much cargo can be loaded to bring the vessel to her summer draught in SW.
- 18 A vessel is loading in a SW dock and is lying with her starboard Winter loadline 60 mm above and her port Winter loadline 20 mm below the surface of water. If her summer draught in SW is 7.2 m and TPC is 20, find how many tonnes of cargo the vessel can load to bring her down to her Tropical loadline in SW.
- 19 From the following details, calculate the DWT available:- Present freeboards: port 3.0 m, starboard 2.9 m in water of RD 1.020. FWA 200 mm. TPC 30. Statutory summer freeboard 2.8 m.
- 20 From the following information, calculate the DWT available upto the Tropical loadline in SW:-

Present freeboards: port 1.68 m, starboard 1.79 m in RD 1.017.

Tropical SW freeboard : 1.63 m
 Tropical SW draft : 9.6 m
 FWA 150 mm, TPC 20.4

CENTRE OF GRAVITY

The centre of gravity (G or COG) of a ship is that point through which the force of gravity may be considered to act vertically downwards, with a force equal to the weight of the ship.

The position of the COG of a ship is indicated by its distance in metres from three reference lines:

- (i) Its height above the keel. This distance is referred to as KG where K represents the keel. KG affects the stability of the ship.
- (ii) Its distance from the after perpendicular (A) of the ship. This distance is referred to as AG. AG affects the trim of the ship.

Note: The after perpendicular (A) of a ship is the after part of the stern post. If the vessel does not have a stern post, then it is the axis of the rudder stock.

Some shipyards use midships (H) for reference instead of the after perpendicular (A). The distance of the COG is then referred to as HG, in this book, but then it must be stated whether the COG is forward or abaft midships in each case. HG affects the trim of the ship.

Note: Midships is taken to be the line drawn at right angles to the keel, midway between the forward and after perpendiculars.

(iii) Its distance from the centre line of the ship. This distance causes the ship to list. Since mariners like to keep their ship upright at all times, this distance should preferably be zero.

The position of the COG of a ship depends on the distribution of weights on board and not on the total weight.

When a weight is added (loaded), the COG of the ship moves directly towards the COG of the added weight.

When a weight is removed (discharged), the COG of the ship moves directly away from the COG of the removed weight.

When a weight already on board is shifted, the COG of the ship moves in a direction parallel to that moved by the weight.

The foregoing statements are illustrated by the following figures wherein G is the COG of the ship before loading/discharging/shifting and G₁ is the COG of the ship after the loading/ discharging/ shifting is completed.

So far, only the direction of shift of COG has been considered. The distance through which the COG would move is given by the following formula:

$$GG_1 = \frac{wd}{W}$$

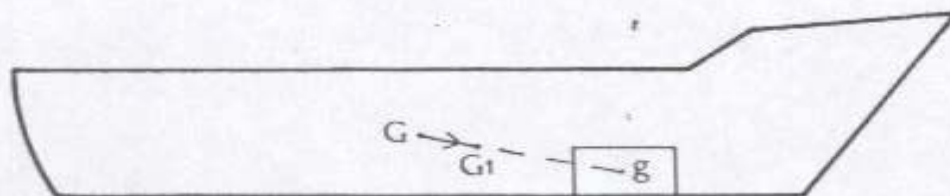
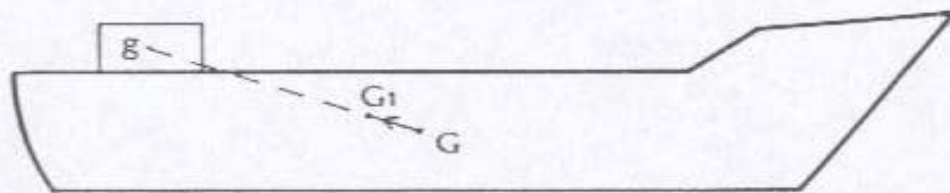
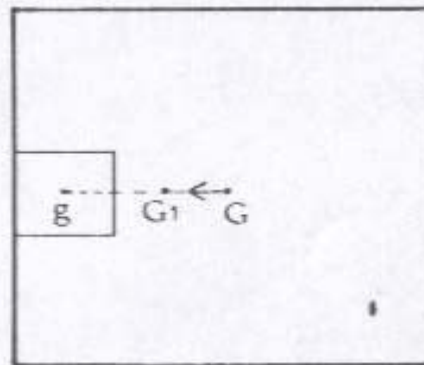
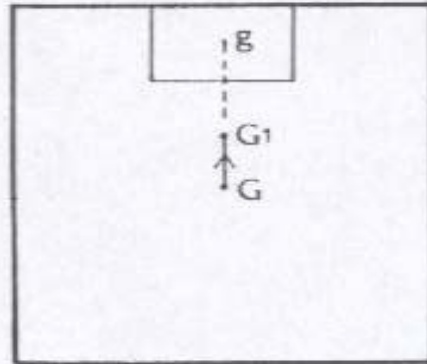
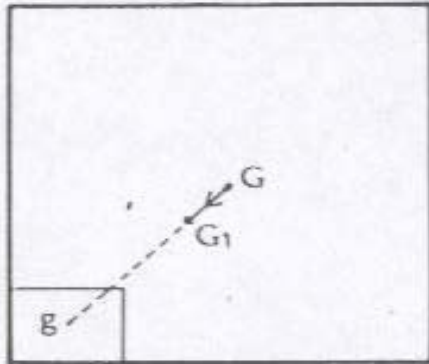
Wherein,

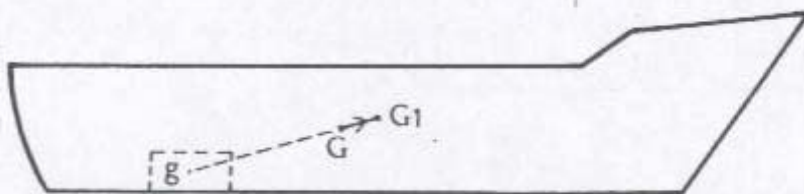
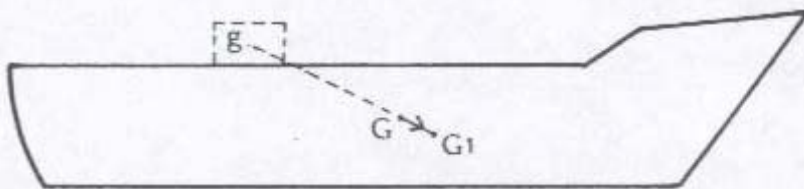
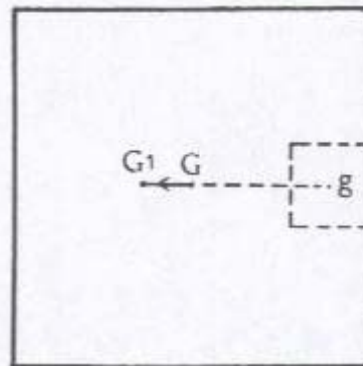
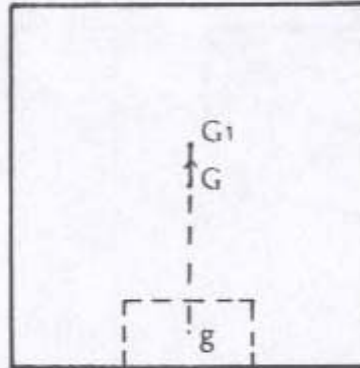
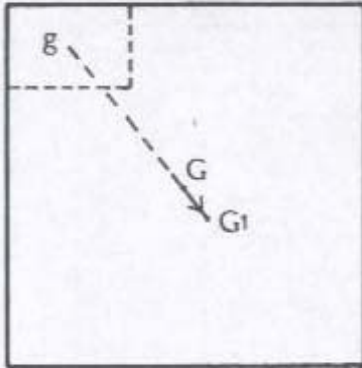
GG₁ is the shift of COG of ship in metres.

w is the weight loaded/discharged/shifted, in tonnes.

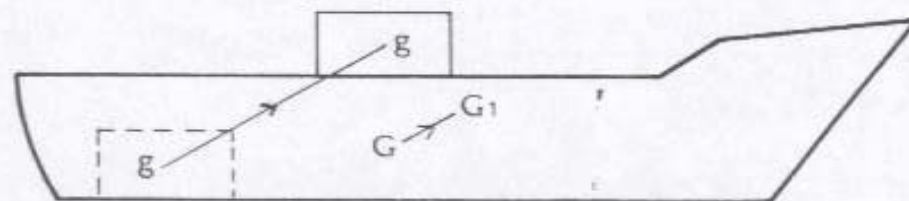
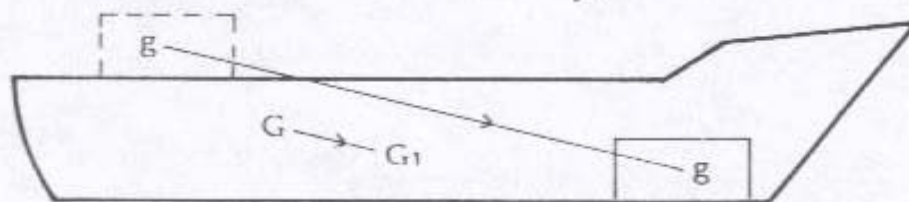
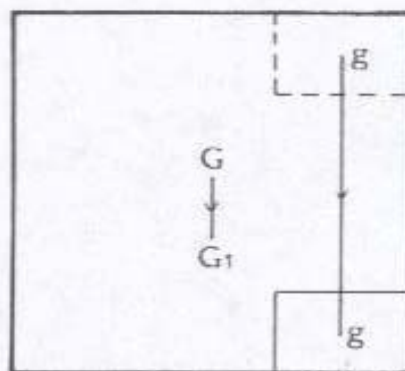
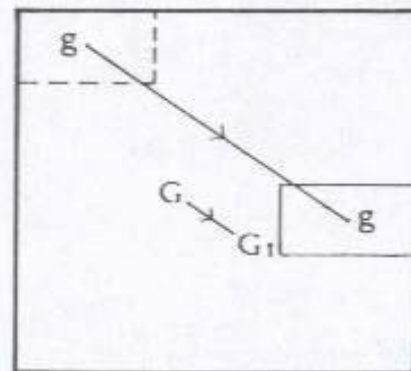
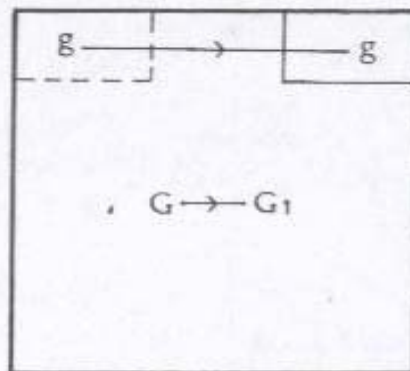
W is the final displacement of ship in tonnes i.e., after the weight has been

Effect of adding a weight



Effect of removing a weight

Effect of shifting a weight



loaded/discharged/shifted.

- d When loading/discharging, d is the distance in metres between the COG of the ship and the COG of the weight.

When shifting a weight, d is the distance moved by the weight.

In stability calculations, the vertical, longitudinal and transverse movements of COG are calculated separately. In other words, the actual movement of COG is split into its three components and each component is calculated separately, as shown in later chapters.

FINAL KG

Part I: Considering a single weight only.

When loading, discharging or shifting a single weight, the vertical shift of the COG of a ship is given by the formula:-

$$GG_1 = \frac{wd}{W}$$

Wherein,

GG_1 : Vertical shift of COG of ship in metres.

w : Weight loaded/discharged/shifted in tonnes.

W : Final displacement of ship in tonnes.

d : When loading or discharging, 'd' is the vertical distance between the COG of the ship and the COG of the weight.

When shifting a weight already on board, 'd' is the vertical distance moved by the weight.

Example 1

In a vessel of 12000 t displacement, KG 9 m, 200 t of cargo was shifted from the upper deck (KG 12 m) to the lower hold (KG 2 m). Find the new KG.

KG of cargo while on UD = 12 m

KG of cargo when in LH = 2 m

Hence $d = 10$ m downwards

$$GG_1 \downarrow = \frac{wd}{W} = \frac{200 \times 10}{12000} = 0.167 \text{ m}$$

Original KG = 9.000 m

$GG_1 \downarrow = 0.167$ m

KG₁ or new KG = 8.833 m

Example 2

In a vessel of 7850 t displacement, KG 8.4 m, 150 t of cargo is loaded on the UD (KG 10 m). Find the final KG.

Final $W = 7850 + 150 = 8000$ t

$w = 150$ t, $d = 1.6$ m

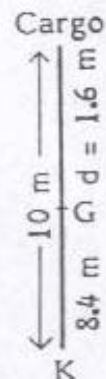
$$GG_1 = \frac{wd}{W} = \frac{150 \times 1.6}{8000} = 0.03 \text{ m}$$

Since the cargo was loaded above the COG of the ship, GG_1 will be upwards.

Original KG = 8.400 m

$GG_1 \uparrow = 0.030$ m

KG₁ or new KG = 8.430 m



Example 3

In a ship of 12300 t displacement, KG 10 m, 300 t of cargo was discharged from the lower hold (KG 2 m). Find the final KG.

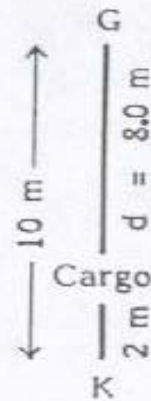
Final $W = 12300 - 300 = 12000$ t.

$$w = 300 \text{ t}, \quad d = 8 \text{ m}$$

$$GG_1 = \frac{wd}{W} = \frac{300 \times 8}{12000} = 0.2 \text{ m}$$

Since cargo was discharged from below the COG of ship, GG_1 will be upwards.

$$\begin{aligned} \text{Original KG} &= 10.0 \text{ m} \\ GG_1 \uparrow &= 0.2 \text{ m} \\ KG_1 \text{ or new KG} &= 10.2 \text{ m} \end{aligned}$$



Example 4

On a vessel of 6000 t displacement KG 7.4 m, how many tonnes of cargo may be discharged from the lower hold (KG 2.0 m) in order to have a final KG of 8.0 m?

$$\begin{aligned} \text{Old KG} &= 7.4 \text{ m} & \text{Original W} &= 6000 \text{ t} \\ \text{New KG} &= 8.0 \text{ m} & \text{Discharged} &= w \\ GG_1 \uparrow &= 0.6 \text{ m} & \text{Final W} &= 6000 - w \end{aligned}$$

$$GG_1 = \frac{wd}{W} \quad \text{or} \quad 0.6 = \frac{w(5.4)}{6000-w} \quad \text{or} \quad w = 600 \text{ t}$$

Hence, cargo to discharge = 600 tonnes.

Example 5

A vessel of 11 000 t displacement has KG 6.3 m. A jumbo derrick is used to shift a weight of 250 t from the lower hold (KG 3 m) to the UD (KG 8.5 m). The head of the derrick is 19.5 m above the keel. Find the KG of the ship:

- When the weight is hanging by the derrick and
- When the shifting is over.

This problem is to be worked in two stages.

Stage 1: As soon as the weight is lifted off the tank-top, the COG of the weight shifts from the LH to the derrick head.

$$\begin{aligned}\text{KG of weight when in LH} &= 3.0 \text{ m} \\ \text{Height of derrick head above keel} &= 19.5 \text{ m} \\ \text{Hence, } d &= 16.5 \text{ m}\end{aligned}$$

$$GG_1 \uparrow = \frac{wd}{W} = \frac{250 \times 16.5}{11\,000} = 0.375 \text{ m}$$

$$\begin{aligned}\text{Original KG} &= 6.300 \text{ m} \\ GG_1 \uparrow &= 0.375 \text{ m} \\ \text{KG}_1 \text{ or new KG} &= 6.675 \text{ m}\end{aligned}$$

Hence KG at the end of stage 1 = 6.675 m answer (a).

Stage 2: As soon as the weight is placed on the upper deck, the COG of the weight shifts from the derrick head to the UD.

$$\begin{aligned}\text{Height of derrick head above keel} &= 19.5 \text{ m} \\ \text{KG of weight when on UD} &= 8.5 \text{ m} \\ \text{Hence, } d &= 11.0 \text{ m}\end{aligned}$$

$$GG_1 \downarrow = \frac{wd}{W} = \frac{250 \times 11}{11\,000} = 0.250 \text{ m}$$

$$\begin{aligned}\text{New KG (end of stage 1)} &= 6.675 \text{ m} \\ GG_1 \downarrow &= 0.250 \text{ m} \\ \text{Final KG (end of stage 2)} &= 6.425 \text{ m}\end{aligned}$$

KG when shifting is over = 6.425 m answer (b).

Example 6

A vessel of 6000 t displacement, KG 7.1 m, loads a heavy lift weighing 150 t by her jumbo derrick whose head is 16 m above the keel. If the weight is placed on the tween deck (KG 8 m) find:

- (a) the KG when the weight is hanging 1 m above the tween deck and
 (b) the KG when the loading is over.

Stage 1: As soon as the jumbo derrick takes the heavy lift off the wharf, the COG of the weight acts on the derrick head — equivalent to loading the weight 16 m above the keel. The height of the weight above the deck is of no importance.

$$\begin{aligned}\text{Final } W &= 6000 + 150 = 6150 \text{ t} \\ d &= 16 - 7.1 = 8.9 \text{ m}\end{aligned}$$

$$GG_1 \uparrow = \frac{wd}{W} = \frac{150 \times 8.9}{6150} = 0.217 \text{ m}$$

$$\begin{aligned}\text{Original KG} &= 7.100 \text{ m} + \\ GG_1 \uparrow &= 0.217 \text{ m} \\ KG_1 \text{ or new KG} &= 7.317 \text{ m}\end{aligned}$$

Hence, KG at the end of stage 1 = 7.317 m ans (a).

Stage 2: As soon as the weight is placed on the TD, the COG of the heavy lift shifts from the derrick head (KG 16 m) to the TD (KG 8 m). i.e., $d = 16 - 8 = 8 \text{ m}$ downwards

$$GG_1 \downarrow = \frac{wd}{W} = \frac{150 \times 8}{6150} = 0.195 \text{ m}$$

$$\begin{aligned}\text{New KG (at end of stage 1)} &= 7.317 \text{ m} - \\ GG_1 \downarrow &= 0.195 \text{ m} \\ \text{Final KG (at end of stage 2)} &= 7.122 \text{ m}\end{aligned}$$

Hence, KG after shifting is over = 7.122 m ans (b).

Exercise 6

Final KG by GG_1 formula

- 1 In a vessel of 8800 tonnes displacement and KG 6.2 m, 200 tonnes of cargo was loaded in the lower hold, 1.7 m above the keel. Find the final KG.
- 2 600 tonnes of cargo were discharged from a vessel from the upper deck 11 m above the keel. If the original KG and displacement were 6 m and 12 600 tonnes, calculate the final KG.
- 3 In a vessel of 9900 tonnes displacement and KG 4 m, a heavy lift of 100 tonnes is loaded on the UD (KG 15 m). Find the final KG.
- 4 500 tonnes of cargo was discharged from the lower hold (KG 3 m) of a vessel whose displacement and KG before discharging were 11500 tonnes and 6.3 m. Find the final KG.
- 5 500 tonnes of cargo was shifted 15 metres vertically downwards in a vessel of 10 000 tonnes displacement. Find the effect it has on the KG of the vessel and state whether KG increases or decreases.
- 6 In a vessel of 9000 tonnes displacement, KG 10.5 m, 300 tonnes of cargo was shifted from the LH (KG 2.5 m) to the UD (KG 11.5 m). Find the resultant KG of the vessel.
- 7 In a vessel of 9009 tonnes displacement, KG 8.7 m, how many tonnes of cargo can be loaded on the upper deck (KG 15 m) so that the final KG would be 9 m?

- 8 A heavy lift derrick, whose head is 20 m above the keel, is to shift a locomotive weighing 300 tonnes from the UD (KG 8 m) to the LH (KG 2 m). If the displacement and initial KG of the vessel were 12000 tonnes and 7.6 m, find the KG of the vessel (a) when the derrick has taken the weight off the UD and (b) after shifting is over.
- 9 On a vessel of 4,950 tonnes displacement, KG 9.2 m, the ship's jumbo derrick is used to load a weight of 50 tonnes from the wharf, on to the UD (KG 8 m). If the head of the derrick is 25 m above the keel, calculate the KG of the vessel (a) when the weight is hanging by the derrick on the centre line but 2 m above the UD, and (b) after loading.
- 10 A ship's derrick, whose head is 22 m above the keel, is used to discharge a weight of 20 tonnes (KG 5 m), lying on the centre line. If the vessel's displacement and KG before discharging were 6000 tonnes and 8 m, calculate the KG (a) as soon as the derrick lifts the weight and (b) after discharging.

Part II: Considering several weights

The GG_1 formula, which seems adequate when considering a single weight at a time, becomes impracticable for general use of ships because several weights are loaded, discharged and/or shifted, at a time. In such cases, the calculation of final KG is done by taking moments about the keel.

The initial moment of the weight of the ship about its keel plus the moments about keel of all weights loaded minus the moments about keel of all weights discharged gives the final moment. This final moment about keel divided by the final displacement of the ship gives the final KG. In cases where

weights have been shifted vertically, the weight multiplied by the vertical distance shifted gives the change in moment, to be added if the shift is upwards; to be subtracted if the shift is downwards.

Calculation of final KG by taking moments about keel can be done even when only a single weight is being loaded, discharged or shifted.

Example 7

On a ship of 10 000 t displacement, KG 7.75 m, the following changes took place:

1000 t of cargo discharged from No.2 LH, KG 4.0 m.
 2000 t of cargo discharged from UD, KG 9.8 m.
 500 t of FW taken into peak tanks, KG 6.5 m.
 500 t of fuel oil taken into No.4 DBT, KG 0.5 m.
 500 t of cargo shifted from No.2 TD to No.2 LH, through a vertical distance of 8 m.

Find the final KG of the ship.

Remarks	Weight (t)		KG (m)	Moment by Keel (tm)	
	Loaded	Disch		Loaded	Disch
Ship	10,000	-	7.75	77,500	-
2LH Cargo	-	1,000	4.0	-	4,000
UD Cargo	-	2,000	9.8	-	19,600
Peaks FW	500	-	6.5	3,250	-
HFO 4 DBT	500	-	0.5	250	-
Total	11,000	3,000		81,000	23,600
		3,000		23,600	
Final W =	8,000			57,400	
		500 t shifted 8 m down (-)		4,000	
				Final moment =	53,400

$$\text{Final KG} = \frac{\text{Final moment}}{\text{Final W}} = \frac{53,400}{8,000} = 6.675 \text{ m.}$$

Exercise 7

Final KG by moments about keel

- 1 A ship of displacement 2000 t and KG 4.2 m, loads 300 t of cargo (KG 2.0 m), 200 t of cargo (KG 3.2 m) and 500 t of bunkers (KG 1.0 m). Find her final KG.
- 2 A ship of displacement 3000 t and KG 3.9 m, loads cargo as follows:- 200 t in No.1 LH (KG 3.0 m), 300 t on deck (KG 6.4 m), 150 t in No.3 TD (KG 5.2 m) and 350 t in No.4 LH (KG 4.0 m). Find the final KG.
- 3 A ship of load displacement 10,000 t, KG 6.0 m, discharges cargo of 250 t (KG 3.0 m) and 150 t (KG 4.0 m). Find her final KG.
- 4 A ship of displacement 12,000 t, KG 4.3 m, discharges cargo as follows:- 200 t from No.1 LH (KG 2.6 m), 250 t from No.2 TD (KG 3.4 m), 1000 t from No.3 LH (KG 4 m) and 550 t from UD near No.5 (KG 8 m). Find final KG.
- 5 Ship of 2000 t displacement and KG 3.66 m, loads 1500 t (KG 5.5 m), 3500 t (KG 4.60 m), and takes 1520 t of bunkers (KG 0.60 m). She discharges 2000 t cargo (KG 2.44 m) and consumes 900 t of bunkers (KG 0.40 m). Find the KG at the end of the voyage.
- 6 A ship of 3200 t displacement, KG 6.2 m, loads 5200 t of cargo (KG 4.8 m). Find the amount of deck cargo (KG 10.4 m) that can be loaded so that the KG shall be 6.0 m when loading is completed.

- 7 A ship of 2600 t displacement, KG 4.88 m, loads 4600 t of homogeneous cargo (KG 5.0 m). Find how much deck cargo (KG 10 m) may be loaded to obtain a final KG of 5.11 m.
- 8 A heavy-lift derrick is used to discharge a 100 t package from a ship of displacement 8000 t, KG 8.2 m. If the KG of the weight while on board is 3 m and if the derrick head is 25 m above the keel, find the KG of the ship (a) while discharging and (b) after discharging.
- ✓ 9 On a ship of 15000 t displacement KG 7.9 m, a weight of 200 t is loaded on the UD (KG 12 m) using the ship's Stulken derrick whose head is 30 m above the keel. Find the KG of the ship (a) while loading and (b) after loading.
- ✓ 10 On a ship of 11000 t displacement KG 7.2 m, a shore crane is used to shift a 180 t heavy-lift from the UD (KG 12 m) to the LH (KG 3 m). Find the KG of the ship (a) during shifting and (b) after shifting.

CENTRE OF BUOYANCY

The centre of buoyancy (B or COB) of a ship is that point through which the force of buoyancy may be considered to act vertically upwards, with a force equal to the weight of water displaced by the ship. It is the geometric centre of the water displaced i.e., the geometric centre of the underwater volume of the ship.

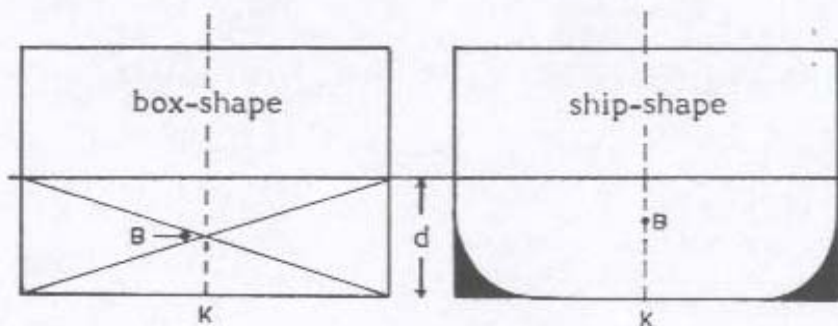
The position of the COB of a ship is indicated by:

- (i) Its height above the keel. This distance is referred to as KB.
- (ii) Its distance from the after perpendicular of the ship. This distance is referred to as AB. Some shipyards use midships (H) for reference instead of the after perpendicular (A). The distance of the COB is then referred to as HB, in this book, but then it must be stated whether the COB is forward or abaft midships in each case.

Note: Definitions of the after perpendicular and midships are given in chapter 6.

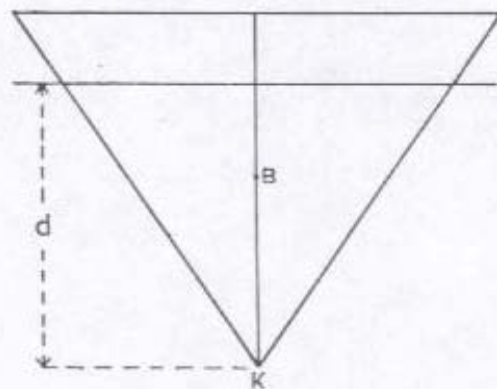
Both KB and AB depend on the shape and volume of the underwater portion of the hull and are therefore dependant on the ship's draft. KB and AB (or HB) are given in the hydrostatic particulars of the ship in the form of curves or tables against draft. Further explanation of AB is given in volume II under the heading 'Trim'.

The KB of a box-shaped vessel would be exactly half the draft, if the vessel is upright and on an even keel. The KB of a ship-shape will, however, be a little greater than half draft, as illustrated by the following figures:



From the above figure, it is obvious that if the shaded part of the box-shaped figure is removed, the figure becomes ship-shaped. The KB of a ship-shape would, therefore, be about five to ten percent more than half its draft.

KB of a triangular-shaped vessel would be two-thirds of its draft, when on an even keel and upright, as shown in the following figure:



Exercise 8
Centre of buoyancy

- 1 A box-shaped vessel of displacement 1640 t is 50 m long, 10 m wide and 8 m high. Find her KB in SW, if she is on an even keel and upright.
- 2 A box-shaped vessel 60 m x 10 m x 10 m floats in DW of RD 1.020 at an even keel draft of 6 m. Find her KB in DW of RD 1.004.
- 3 A triangular-shaped vessel of displacement 650 t floats in DW RD 1.015. Her water plane is a rectangle 30 m x 8 m. Find her KB.
- 4 A triangular-shaped vessel floats in SW. Her water plane is a rectangle 40 m x 12 m. If her KB is 3.6 m, find her displacement.
- 5 A homogeneous log of wood 3 m x 0.75 m x 0.75 m floats in SW with one face horizontal. If the RD of the log is 0.8 m, calculate the vertical distance between its COG and its COB.
- 6 A homogeneous log of wood of 0.5 m square section floats in water of RD 1.005 at a draft of 0.4 m with one of its faces horizontal. Find the vertical distance between its COG and its COB in water of RD 1.020.
- 7 A cylindrical drum of 0.8 m diameter and 1.5 m height weighs 10 kg. 490 kg of steel is put in it such that it floats with its axis vertical in FW. Find its KB. (Assume π to be $22/7$).
- 8 A barge is prism-shaped such that its deck and keel are identical and parallel; its sides vertical. Its deck consists of three shapes —

triangular bow of 12 m each side; rectangular mid-part 80 m long and 12 m wide; semi-circular stern of radius 6 m. If the light displacement of the barge is 500 t and it has 5000 t of cargo in it, find its KB when floating on an even keel in SW. (Assume π to be 3.142).

- 9 The deck and keel of a flat-bottomed barge are identical. Its sides are vertical. The deck consists of two sections — the bow is a triangle 12 m broad and measures 12 m in the fore and aft direction; the mid-body is a rectangle 50 m long and 12 m broad. If it is floating on an even keel in SW with a displacement of 3444 t, find the position of its COB with reference to the keel and with reference to its after end.
- 10 A barge 45 m long has a uniform transverse cross-section throughout, which consists of a rectangle above a triangle. The rectangle is 8 m broad and 4 m high. The triangle is apex downwards, 8 m broad and 3 m deep. If the displacement of the barge is 1620 t, find the position of its COB with reference to the keel and also with reference to the after end, if it is upright and on an even keel in FW.

TRANSVERSE STATICAL STABILITY

While studying statical stability it is important to distinguish between list and heel.

List

List is the transverse inclination caused by unequal distribution of weights on either side of the centre line of the ship. In other words, list is caused when the COG of the ship is not on the centre line — an internal cause. A ship with a list will become upright only if the COG is brought to the centre line.

Heel

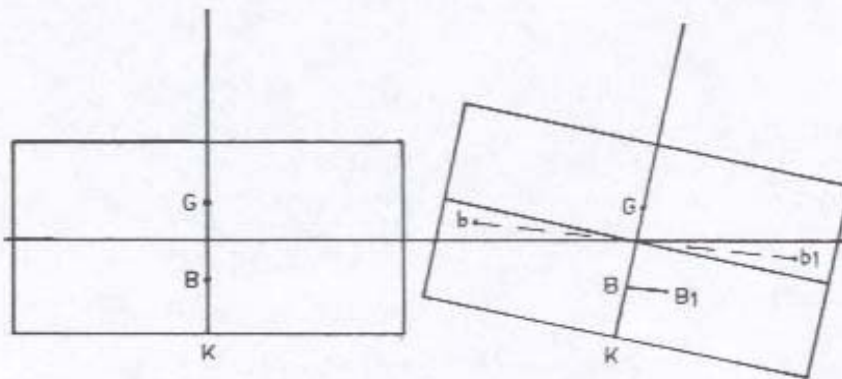
Heel is the transverse inclination of the ship, caused by external forces such as wind, waves, centrifugal force during course alterations, over-tight moorings in port, etc. Since no transverse shift of weights has taken place on board, the position of the COG of the ship remains unaffected by heel.

Transverse Shift of B

When a ship is floating in still water, her COG and COB will be in a vertical line. The forces of gravity and buoyancy, being equal and opposite, will cancel each other out and the ship will be in static equilibrium.

When a ship is heeled over to one side, say to starboard, her underwater volume increases on the

starboard side and decreases on the portside. The COB, being the geometric centre of the underwater volume of the ship, will shift to the lower side (starboard side in this case), as shown in the following figure:-



In the foregoing figure :

- b is the geometric centre of the emerged wedge (of the part that came out of the water due to heeling).
- b₁ is the geometric centre of the immersed wedge (of the part that went underwater due to heeling).
- B is the COB before heeling.
- B₁ is the COB after heeling.
- BB₁ is the shift of COB caused by heeling.

Note: BB₁ is parallel to bb₁ . BB₁ is not parallel to the water line. BB₁ is not parallel to the keel. Angle GBB₁ is not a right angle.

Transverse metacentre (M)

When a vessel is heeled (inclined by an external force), the force of buoyancy, acting vertically upwards through the new position of COB, cuts the centre line of the ship at a point called the transverse metacentre (M). This is illustrated in the next figure.

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. However, over small angles of heel (say upto about 15°) the increase of KM is generally small. Hence, KM is considered constant for small angles of heel, for the sake of convenience in stability calculations, and is sometimes referred to as initial KM.

KM is calculated by adding KB and BM, each of which is calculated separately. The initial KM is, therefore, a function of the draft of the vessel. On board a ship, the initial KM is obtained by consulting a table or graph, supplied by the shipyard, wherein KM is indicated against draft.

Metacentric height (GM)

It 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 and negative when G is above M i.e. when KG is greater than KM. GM is illustrated in the next figure.

Over small angles of heel, wherein KM may be considered constant, GM also is considered constant and is referred to as initial GM.

Righting lever (GZ)

When a vessel is heeled (inclined by an external force), 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 is illustrated by the following figure.

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 (upto about 15°), wherein KM, and hence GM, may be considered constant, $GZ = GM \cdot \sin \theta$ in which θ is the angle of heel and GM is the initial GM, as is apparent in the following figure.

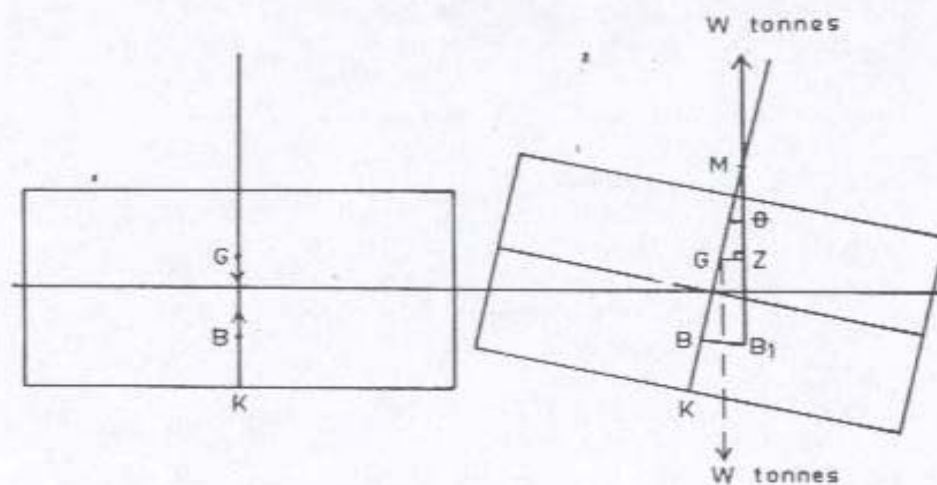
For large angles of heel, GZ can be calculated by the wall-sided formula:

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

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. θ is the angle of heel, GM the initial GM, and BM is the height of the initial metacentre above the COB before heeling, as shown in the following figure.

On board ships, the value of GZ can be obtained for various angles of heel by use of cross curves of stability (GZ curves or KN curves) described in volume II. These curves are supplied by the shipyard.

FIGURE ILLUSTRATING BM, KM, GM, GZ, etc.



- K : Keel. G : COG.
 θ : Angle of heel.
 B : COB before heeling.
 B₁ : COB after heeling.
 BB₁ : Shift of COB due to heel.
 M : Transverse metacentre.
 GM : Metacentric height.
 GZ : Righting lever.
 W : Displacement in tonnes.
 W . G Z : Righting moment.

Righting moment

When a vessel is heeled (inclined by an external force), 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'.

$$RM = W \cdot GZ \text{ for all angles of heel.}$$

For small angles of heel, where GM may be considered constant, $GZ = GM \cdot \sin \theta$ and hence

$$RM = W \cdot GM \cdot \sin \theta \text{ for small angles of heel.}$$

Exercise 9

Moment of statical stability

- 1 A ship of 10 000 t displacement has a GM of 0.4 m. Calculate the moment of statical stability when she is heeled by 5° .
- 2 A ship of 12 000 t displacement is heeled by 6° . If her righting lever is then 0.1 m, find the moment of statical stability. If her KM is 8.2 m, find her KG .
- 3 When a ship of 14000 t displacement is heeled by 8° , her moment of statical stability is 400 tm. If KG is 7.3 m, find KM .
- 4 A ship of 8000 t displacement has KB 3.5 m, KM 6.5 m, and KG 6 m. Find her moment of statical stability at 20° heel, assuming that her deck edge remains above water (i.e. she is still wall-sided at that angle of heel).
- 5 A ship of 4000 t displacement has KG 5.1 m, KB 2.1 m, KM 5.5 m. Find the moment of statical stability when she heels 24° , assuming that she is wall-sided.

10

EQUILIBRIUM OF SHIPS

Stable equilibrium

When a vessel is heeled (inclined by an external force), if she tends to come back to her original condition, she is said to be in stable equilibrium.

For a vessel to be stable, her GM must be positive i.e. KG must be less than KM, as shown in the figure on the next page.

Note As explained in Chapter 9, the position of COG remains unaffected by heel whereas the COB shifts to the lower side. The forces of gravity and buoyancy form a couple which tends to return the vessel to her original condition. A vessel with a list also may be stable.

Unstable equilibrium

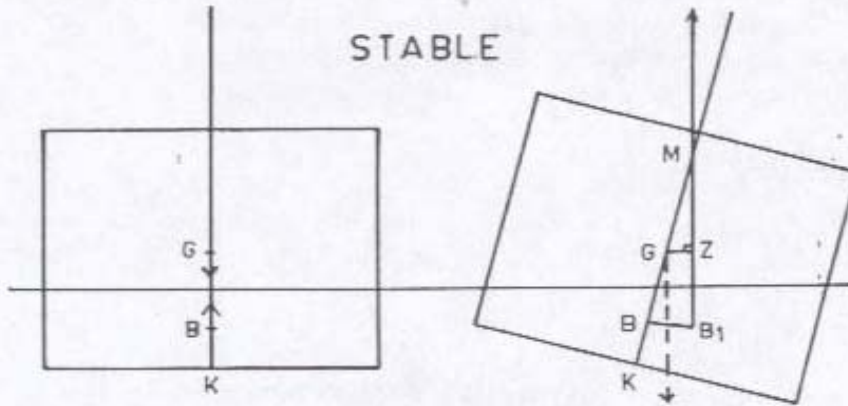
When a vessel is heeled (inclined by an external force), if she tends to continue heeling further, she is said to be in unstable equilibrium.

For a vessel to be unstable, her GM must be negative i.e., KG must be greater than KM, as shown in the figure on the next page.

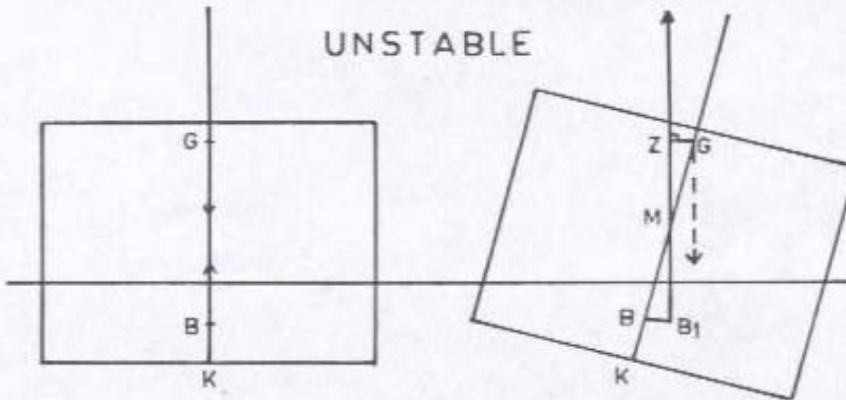
Note As explained in earlier chapters, the COB shifts to the lower side. M is directly above B₁. The

EQUILIBRIUM OF SHIPS

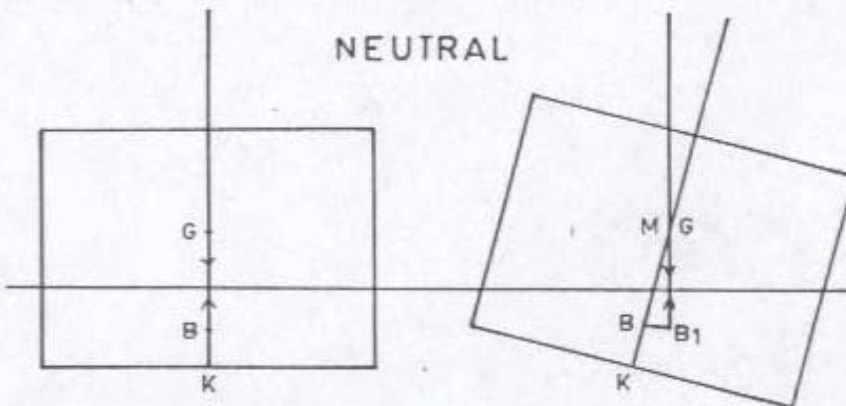
STABLE



UNSTABLE



NEUTRAL



forces of gravity and buoyancy form a couple but, G being higher than M , this couple tries to heel the vessel further. The moment of this couple is called a 'negative righting moment' or a 'capsizing moment'.

Neutral equilibrium

When a vessel is heeled (inclined by an external force), if she has no tendency to return to her original condition or to continue heeling further, she is said to be in neutral equilibrium.

For a vessel to be in neutral equilibrium, her GM must be zero i.e., KG equal to KM , as shown in the figure on the previous page.

Note As explained in earlier chapters, the COB shifts to the lower side. M is directly above B_1 . Since G and M are coincident, no righting lever, and hence no righting moment, is formed. The vessel thus has no tendency to continue heeling further or to return to her original condition.

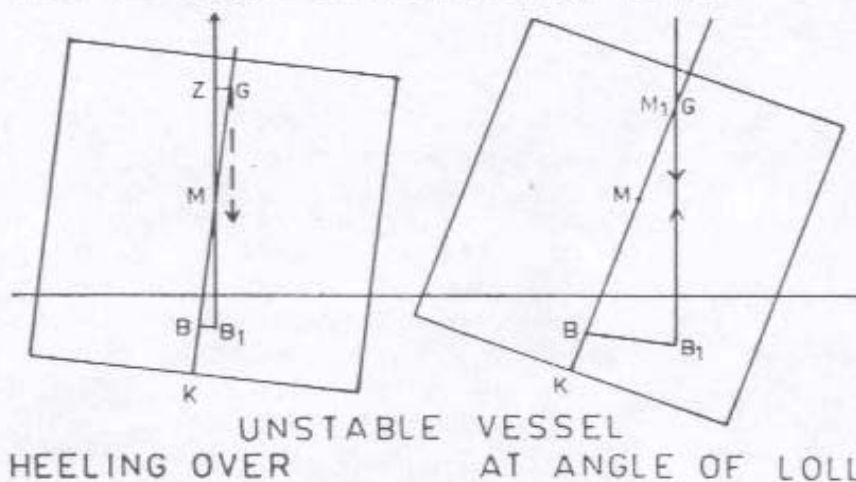
MORE ABOUT

UNSTABLE EQUILIBRIUM

The impression obtained by reading about unstable equilibrium, in the previous chapter, would be that an unstable vessel would continue heeling more and more until she capsized. Though this could happen, this is not always the case.

Angle of loll

It was mentioned earlier, under the definition of metacentre, that KM increases as angle of heel increases until it reaches a maximum value at some large angle of heel. As the unstable vessel heels over more and more, it may happen that, at some angle of heel, KM increases sufficiently to equal to KG . (see M_1 in the following figure). The vessel would then be in neutral equilibrium and the angle at which this happens is called the angle of loll.



In other words, when an unstable vessel heels over to progressively increasing angles of heel, it may happen that, at some angle of heel, the COB may come vertically below the COG. The vessel would then be in neutral equilibrium. The angle of heel at which this happens is called the angle of loll.

If any opening goes underwater, at this stage, progressive flooding would take place and the vessel would capsize. The angle of loll could be on either side of the vessel. If she is at her angle of loll to one side, and a wave was to roll her sufficiently to the other side, she would flop over to her angle of loll on the other side.

When at the angle of loll, if a wave causes the vessel to heel a little more, KM would increase and become more than KG. A small righting moment, so formed, would return the vessel to the angle of loll.

When at the angle of loll, if a wave causes the vessel to heel less, KM would decrease and become less than KG. A small capsizing moment, so formed, would return the vessel to the angle of loll.

The vessel at the angle of loll, therefore, appears to possess the characteristics of stable equilibrium.

Though the vessel appears to be temporarily safe, it must be emphasized here that the vessel at the angle of loll is in an extremely precarious and dangerous situation — wrong action or no action on the part of the ship's staff would result in certain disaster.

The corrective action to be taken at the angle of loll is elaborated later, in a separate chapter in volume II.

FREE SURFACE EFFECT

When a vessel with a slack (partly full) tank rolls at sea, the liquid in the slack tank would move towards the lower side during each roll, thereby causing the angle of roll and the period of roll to increase. Because the vessel behaves as if her GM has been reduced, we say that a slack tank causes a virtual (imaginary) loss of GM. This is called free surface effect (FSE).

The virtual loss of GM can be calculated quite easily and is called free surface correction (FSC). In order to indicate whether FSC has been applied or not, the GM before subtracting FSC is called 'Solid GM' and after subtracting FSC it is called 'Fluid GM'. In all stability calculations involving GM, it is fluid GM that is used.

FSC depends on the length and breadth (mainly breadth) of the slack tank. The quantity of liquid in the slack tank makes only a very small difference.

FSC can be calculated by the formula:

$$FSC = \frac{i}{V} \times \frac{d_1}{d_2}$$

Where i is the moment of inertia (or second moment of area) of the slack tank surface about its centre line, in m^4 .

V is the volume of displacement of the ship, in m^3 .

d_i is the density of liquid in the slack tank, in tm^{-3}

d_o is the density of water outside (in which the ship is floating), in tm^{-3} .

FSC is the free surface correction in m, caused by this slack tank.

Since displacement = volume of displacement \times density of water displaced, the denominator in the foregoing formula may be substituted by W , the displacement of the ship in tonnes. The formula then becomes:

$$FSC = \frac{i d_i}{W}$$

Since ' i ' is in m^4 and ' d_i ' is in tm^{-3} , ' $i d_i$ ' would be in tm and is hence called the free surface moment or FSM.

When several tanks are slack on a ship, the FSM of each tank is calculated separately and then added together to obtain the total FSM. This total FSM divided by the final W of the ship would give the total FSC of all the slack tanks.

On a ship, the ' i ' of each tank about the tank's centre-line is readily available in the stability particulars supplied by the shipyard.

Example 1

Given the following particulars of a ship, calculate her fluid GM:

$W = 10000$ t, $KG = 9.0$ m, $KM = 9.8$ m, moment

of inertia of surface of tank about its centre line = 1242 m^4 , RD of heavy fuel oil in the tank = 0.95.

$$\text{FSC} = \frac{i \text{ di}}{W} = \frac{1242 \times 0.95}{10,000} = 0.118 \text{ m}$$

KM	=	9.8 m
KG	=	9.0 m
Solid GM	=	0.8 m
FSC	=	0.118m
Fluid GM	=	0.682m

Example 2

The stability particulars of a ship indicate that, for her present condition, her $W = 5532 \text{ t}$, $KM = 8.7 \text{ m}$, 'i' of No.3 DBT about its centre line = 1428 m^4 . If No. 3 DBT is partly full of DO of RD 0.88, and the ship's KG is 8.5 m, calculate her fluid GM.

$$\text{FSC} = \frac{i \text{ di}}{W} = \frac{1428 \times 0.88}{5532} = 0.227 \text{ m}$$

KM	=	8.7 m
KG	=	8.5 m
Solid GM	=	0.2 m
FSC	=	0.227
Fluid GM	=	-0.027m

Note The ship has a negative fluid GM and is hence unstable.

Example 3

A vessel has a displacement of 16635 t, KM 8.25 m, KG 7.4 m. She has the following tanks slack:

No 1 DBT	containing	SW, i = 400 m^4
No 3 Centre	"	HFO, i = 1200 m^4

No 4 Stbd	containing	HFO	$i = 270 \text{ m}^4$
No 5 Port	"	DO	$i = 180 \text{ m}^4$
No 8 Port	"	FW	$i = 25 \text{ m}^4$
No 8 Stbd	"	FW	$i = 15 \text{ m}^4$

If RD of HFO is 0.95, DO is 0.88 and SW is 1.025, find her final fluid GM.

Tank,	Contents	$i \times d_i$	=	FSM
No.1 DBT	SW	400×1.025	=	410
No 3 Centre	HFO	1200×0.95	=	1140
No 4 Stbd	HFO	270×0.95	=	256.5
No 5 Port	DO	180×0.88	=	158.4
No 8 Port	FW	25×1	=	25
No 8 Stbd	FW	15×1	=	15
Final FSM				<hr/> 2004.9 tm

$$FSC = \frac{FSM}{W} = \frac{2004.9}{16635} = 0.121 \text{ m}$$

$$KM = 8.250 \text{ m}$$

$$KG = 7.400 \text{ m}$$

$$\text{Solid GM} = \frac{0.850 \text{ m}}{}$$

$$FSC = 0.121 \text{ m}$$

$$\text{Fluid GM} = \frac{0.729 \text{ m}}{}$$

Example 4

On a vessel of 18000 t displacement KM 8.9 m, KG 8.3 m, a DB tank is partly full of FW. If the tank surface is rectangular, 20 m long and 18 m wide, calculate her fluid GM.

$$i \text{ of rectangular tank about its centre line} = \frac{1b^3}{12} = \frac{20 \times 18^3}{12} \text{ m}^4$$

$$FSC = \frac{i d_i}{W} = \frac{20 \times 18^3}{12} \times \frac{1.0}{18000} = 0.54 \text{ m}$$

	KM	=	8.90 m
	KG	=	<u>8.30 m</u>
Solid	GM	=	0.60 m
	FSC	=	<u>0.54 m</u>
Fluid	GM	=	0.06 m

Example 5

On a vessel of 5000 t displacement, KM 7.8 m, KG 7.0 m, No.2 port DB tank is partly full of FW. If this tank is 15 m long and 9 m broad, find the fluid GM.

'i' of rectangular tank about its centre line

$$= \frac{lb^3}{12} = \frac{15 \times 9^3}{12} \text{ m}^4$$

$$\text{FSC} = \frac{i \text{ di}}{W} = \frac{15 \times 9^3}{12} \times \frac{1.0}{5000} = 0.182 \text{ m}$$

	KM	=	7.800 m
	KG	=	<u>7.000 m</u>
Solid	GM	=	0.800 m
	FSC	=	<u>0.182 m</u>
Fluid	GM	=	0.618 m

EFFECT OF TANK-BREADTH ON FSC

The breadth of a slack tank has an enormous effect on the FSC caused. This is illustrated simply by worked examples 6, 7, 8 and 9.

Example 6

On a ship of 10000 t displ, No 3 DB tank is partly full of SW. If the tank is 20 m long and is 18 m wide from shipside to shipside, calculate the FSC caused.

$$\begin{aligned}
 \text{FSC} &= \frac{i \, di}{W} = \frac{1b^3}{12} \times \frac{di}{W} \\
 &= \frac{20 \times 18^3 \times 1.025}{12 \times 10\,000} \\
 &= 0.996 \, \text{m}
 \end{aligned}$$

Example 7

Same ship as example 6, except that No.3 DB tank has a watertight centre girder dividing it into port and starboard tanks of equal breadth. Find the FSC when both, P & S tanks are slack.

$$\begin{aligned}
 \text{FSC for No 3 Stbd tank} &= \frac{i \, di}{W} = \frac{1b^3}{12} \times \frac{di}{W} \\
 &= \frac{20 \times 9^3}{12} \times \frac{1.025}{10\,000} \\
 &= 0.1245 \, \text{m}
 \end{aligned}$$

$$\text{FSC for No 3 Port tank} = \underline{0.1245 \, \text{m}} \quad (\text{tanks are identical})$$

$$\text{Total FSC for No 3 P \& S} = 0.249 \, \text{m}$$

Example 8

Same ship as example 6, except that No 3 DB tank is divided into three watertight tanks — P, S & C — of equal breadth. Find the FSC when all three tanks are slack.

$$\begin{aligned}
 \text{FSC for No 3 Port tank} &= \frac{i \, di}{W} = \frac{1b^3}{12} \times \frac{di}{W} \\
 &= \frac{20 \times 6^3 \times 1.025}{12 \times 10\,000} \\
 &= 0.0369 \, \text{m}
 \end{aligned}$$

$$\begin{aligned}
 \text{FSC for No 3 Stbd tank} &= 0.0369 \, \text{m} \\
 \text{FSC for No 3 Centre tank} &= \underline{0.0369 \, \text{m}} \quad (\text{because all three tanks are identical}) \\
 &= 0.1107 \, \text{m}
 \end{aligned}$$

Example 9

Same ship as example 6, except that No 3 DB tank is divided into four identical watertight tanks — Port Outer, Port Inner, Stbd Inner, Stbd Outer. Find the FSC when all four tanks are slack.

$$\begin{aligned}\text{FSC for No 3 PO tank} &= \frac{i d_i}{W} = \frac{lb^3}{12} \times \frac{d_i}{W} \\ &= \frac{20 \times 4.5^3 \times 1.025}{12 \times 10\,000} \\ &= 0.01557 \text{ m}\end{aligned}$$

$$\begin{aligned}\text{FSC for No 3 PI tank} &= 0.01557 \text{ m (because all} \\ \text{FSC for No 3 SI tank} &= 0.01557 \text{ m (four tanks} \\ \text{FSC for No 3 SO tank} &= 0.01557 \text{ m (are identical))}\end{aligned}$$

$$\text{Total FSC for all 4 tanks} = 0.0623 \text{ m}$$

Analysis of results of examples 6, 7, 8 & 9

$$\begin{array}{lll}\text{Single undivided DB tank,} & \text{FSC} & = 0.996 \text{ m} \\ \text{Divided into 2 tanks of} & & \\ \text{equal breadth, both slack,} & \text{total FSC} & = 0.249 \text{ m} \\ \text{Divided into 3 tanks of} & & \\ \text{equal breadth, all 3 slack,} & \text{total FSC} & = 0.111 \text{ m} \\ \text{Divided into 4 tanks of} & & \\ \text{equal breadth, all 4 slack,} & \text{total FSC} & = 0.062 \text{ m}\end{array}$$

From the foregoing it is clear that when a tank is divided, in breadth, into a number of identical watertight compartments (n), the total FSC when all the compartments are slack is $1/n^2$ of the FSC that would have occurred if the slack tank was undivided. This is elaborated below:-

Example 6

$$\text{Single undivided DB Tank FSC} = 0.996 \text{ m}$$

Example 7

$$n = 2, \text{ So FSC} = \frac{.996}{n^2} = \frac{.996}{4} = 0.249 \text{ m}$$

Example 8

$$n = 3, \text{ So FSC} = \frac{.996}{n^2} = \frac{.996}{9} = 0.111 \text{ m}$$

Example 9

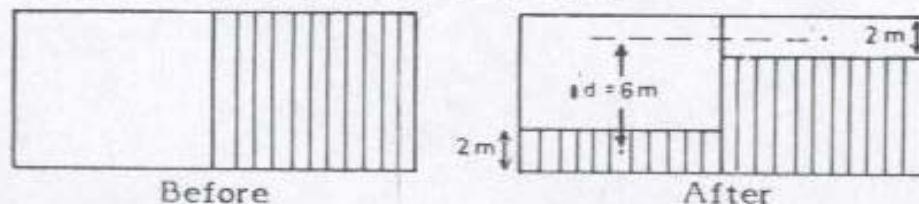
$$n = 4, \text{ So FSC} = \frac{.996}{n^2} = \frac{.996}{16} = 0.062 \text{ m}$$

Note: The answers arrived at above are the same as the answers obtained in each example wherein the FSC was calculated separately for each compartment and then added together.

The effect of the breadth of a slack tank on the FSC is a very important factor to consider when deciding on the action to take when a ship has a very small, or even negative, GM.

Example 10

A vessel of 10000 t displacement, KM 9.3 m, KG 7.3 m, has two rectangular, identical deeptanks, Port and Stbd, each 15 m long, 10 m wide and 8 m deep. The starboard deep tank is full of SW while the port deep tank is empty. Calculate the GM of the ship when one quarter of the water in the starboard deep tank is transferred to the port deep tank.



$$\begin{aligned}
 \text{Mass of SW in tank} &= \text{Volume of SW} \times \text{density of SW} \\
 &= 15 \times 10 \times 8 \times 1.025 \\
 &= 1230 \text{ t}
 \end{aligned}$$

$$\text{Mass of water transferred} = \frac{1}{4} \times 1230 = 307.5 \text{ t}$$

$$GG_1 \downarrow = \frac{dw}{W} = \frac{6 \times 307.5}{10\,000} = 0.185 \text{ m}$$

$$\text{Old KG} = 7.300 \text{ m}$$

$$GG_1 \downarrow = \underline{0.185 \text{ m}}$$

$$\text{New KG} = 7.115 \text{ m}$$

$$\text{KM} = \underline{9.300 \text{ m}}$$

$$\text{Solid GM} = 2.185 \text{ m}$$

$$\begin{aligned}
 \text{FSC for port tank} &= \frac{i \, di}{W} = \frac{1b^3}{12} \times \frac{di}{W} \\
 &= \frac{15 \times 10^3}{12} \times \frac{1.025}{10\,000} \\
 &= 0.128 \text{ m}
 \end{aligned}$$

$$\text{FSC for stbd tank} = \underline{0.128 \text{ m}}$$

$$\text{Total FSC for P \& S} = 0.256 \text{ m}$$

OR

$$\begin{aligned}
 \text{FSC if tank is undivided} &= \frac{1B^3}{12} \times \frac{di}{W} \\
 &= \frac{15 \times 20^3}{12} \times \frac{1.025}{10\,000} \\
 &= 1.025 \text{ m}
 \end{aligned}$$

$$\begin{aligned} \text{FSC when } n = 2, \text{ both sides slack} &= 1.025 \times \frac{1}{n^2} \\ &= \frac{1.025}{4} = 0.256 \text{ m} \end{aligned}$$

$$\text{Solid GM} = 2.185 \text{ m}$$

$$\text{FSC} = 0.256 \text{ m}$$

$$\text{Fluid GM} = 1.929 \text{ m}$$

Exercise 10

Free surface effect

- 1 On a ship of 5000 t displacement, a tank is partly full of DO of RD 0.88. If the moment of inertia of the tank about its centre line is 242 m^4 , find the FSC.
- 2 If the tank in question 1 was partly full of SW instead of DO, find the FSC.
- 3 On a ship of W 6000 t, KM 7.4 m, KG 6.6 m, a double bottom tank of $i 1200 \text{ m}^4$ is partly full of FW. Find the GM fluid.
- 4 Given the following particulars, find the GM fluid: W = 8800 t, tank of $i = 1166 \text{ m}^4$ is partly full of HFO of RD 0.95, KM 10.1 m, KG 9.0 m.
- 5 On a vessel of W 16000 t, No 4 port DB tank 20 m long and 8 m wide is partly full of DW ballast of RD 1.010. Find the FSC.
- 6 A vessel has a deeptank on the starboard side 12 m long 9 m wide which is partly full of coconut oil of RD 0.72. If W = 12000 t, KM = 9 m and KG = 8.5 m, find the GM fluid.
- 7 A vessel displacing 8000 t, has a rectangular deep tank 10 m long 8 m wide and 9 m deep full of SW. The KM is 7 m and KG 6.2 m. Find

the GM when 1/3 of this tank is pumped out.

Note: Since dimensions of tank are given, change of KG of tank due to change of sounding has to be considered.

- 8 A ship of W 5000 t has a tank 16 m long, 10 m wide and 4 m deep which is empty. KM is 7.2 m and KG 7.0 m. Find the GM fluid if 400 t of oil of RD 0.95 are received in it. (See note under previous question).
- 9 A vessel has two deep tanks, port and starboard, each 12 m long, 5 m wide and 8 m deep. The port side is full of SW while the starboard side is empty. W = 9840 t, KM = 8.5 m, KG = 8.0 m. Calculate the GM fluid if SW is transferred from P to S until each tank has equal quantity of ballast.
- 10 A Ship displacing 10000 t has KM 9.9 m. The following is her present condition:

Tank	KG (m)	1 (m ⁴)	Contents	RD	Remarks
FP Tank	6.3	10	SW	1.025	Full
No 1 DBT	1.15	420	HFO	0.95	Slack
No 2 P or S	0.65	720	HFO	0.95	Port slack stbd empty
No 3 P or S	0.65	240	SW	1.025	Port full stbd slack
No 3 C	0.60	1200	HFO	0.95	Full
No 4 P or S	0.70	300	FW	1.00	Both slack
No 5 P	0.85	180	DO	0.88	Slack
No 5 S	0.85	100	HFO	0.95	Full
AP Tank	8.80	20	SW	1.025	Empty

If the final KG is 8.954 m, find the final GM fluid.

- 11 Vessel in same condition as in question 10, transfers some HFO from No. 1 DBT to No 2 P such that No 2 P becomes full, while No 1 remains partly full. Find the resultant GM fluid if the final KG is 8.950 m.

Note 1: It is not necessary to rework the entire problem. Just make the necessary changes to the final part of the working of the answer to question 10, thus:

FSM obtained finally in question 10	2087.4 tm
No 2 DBT is now not slack	-684 tm
Final FSM for this question	1403.4 tm

Note 2: Where a tank was originally slack but has now become full or empty, its FSM has to be subtracted from the final FSM obtained in question 10.

Note 3: When a tank was originally empty or full but has now become slack, its FSM must be added to the final FSM obtained in question 10.

The final fluid GM can now be computed in the usual manner.

- 12 Vessel in same condition as in question 10, transfers SW ballast from FP into No 3S and into AP, such that No 3S becomes full while FP and AP remain partly full. Find the GM fluid if final KG is 8.880 m.

- 13 Vessel in same condition as in question 10, consumes the following while on passage:

All the HFO (200 t) from No 1 DB.
Half the HFO (i.e. 100 t) from No 3 C.

All the FW from No 4 P & S (Total 200 t).
Find the fluid GM on arrival at the next port.

Note 4: Find KG on arrival by taking moments about keel, as explained in chapter 7, and add an extra column for changes in FSM, as shown below. Bear in mind notes 1, 2 & 3, under question 11.

Remarks	Weight L	(t) D	KG (m)	Moment about keel (tm)		FSM (tm)
				L	D	
Ship in						
Q 10	10,000	-	8.954	89540	-	2087.4
No.1 DB	-	200	1.15	-	230	(-)399

and so on.

Note 5: When dealing with several tanks, as in a ship's calculation such as this, the change of KG of a tank due to change in its sounding may be ignored. This is the actual practice at sea.

For example: When half of the HFO (i.e. 100 t) from No 3 C is pumped out, the moment of the discharged weight about keel would be $100 \times 0.6 = 60$ tm.

- 14 Vessel in same condition as in question 10, consumes the following on a passage:

All HFO (i.e. 150 t) from No 2 Port.

Part HFO (i.e. 50 t) from No 3 C.

All FW (i.e. 100 t) from No 4 S.

Find the GM fluid on arrival port.

- 15 Vessel in same condition as in question 10, loads 1000 t cargo in No 2 LH KG 4 m; 2000 t cargo in No 4 LH KG 5 m. Find the final GM fluid, given that the final KM is 10.0 m.

- 16 A ship of 5000 t displacement has a DB tank 18 m long and 12 m wide, partly full of SW. Find the FSC in the following cases:

- (a) If the tank is undivided.
- (b) If the tank is divided into identical P & S watertight divisions and
 - (i) both sides are slack
 - (ii) only one side is slack.
- (c) If the tank is divided into P, S & C identical watertight divisions and
 - (i) all three of these are slack.
 - (ii) Only two of these are slack.
 - (iii) Only one of these is slack.
- (d) If the tank is divided into four identical watertight divisions — Port inner, Port outer, Stbd inner, Stbd outer — and
 - (i) All four of these are slack.
 - (ii) Any three of these are slack.
 - (iii) Any two of these are slack.
 - (iv) Any one of these is slack.

Note: The use of $1/n^2$ would be a very quick method of solving this question.

- 17 A ship of 10000 t displacement has a fresh water DB tank which is 20 m long and divided into P, S and C watertight divisions. The P & S divisions are each 4 m wide, while the C division is 12 m wide. Calculate the FSC in the following cases:-

- (a) Only the port side tank is slack.
- (b) Both port and stbd tanks are slack.
- (c) Only the centre tank is slack.
- (d) All three tanks — PS&C — are slack.
- (e) If all the three divisions were not separate but formed one undivided tank 20 m broad.

Note: $1/n^2$ cannot be used here as the watertight divisions are not identical.

- 18 A ship has a very small GM. It is decided to fill up SW ballast, one tank at a time, in six tanks whose particulars are:-

Tank	'i' about tank's centre line
No 1 DB	280 m ⁴
No 2 P or S	600
No 3 P or S	350
No 3 C	650

State the order in which the tanks must be filled so as to keep FSC at a minimum at all times.

- 19 An unstable vessel is at her angle of loll. The following tanks are available for SW ballast:-

Tank	'i' about tank's centre line
No 1 DB	400 m ⁴
No 2 P	700
No 2 S	700
No 4 P	250
No 4 S	250
No 4 C	800

If it is decided to ballast three tanks with SW, one at a time, state what order should be followed so as to keep FSE to a minimum.

- 20 A vessel of W 8000 t, KM 7.9 m, KG 7.0 m, has a tank 15 m long and 12 m wide, partly full of HFO of RD 0.95.

- (a) Find her moment of statical stability at 6° heel.

- (b) If her BM is 4.9 m, find her moment of statical stability at 20° heel assuming that she is wall-sided.

LIST

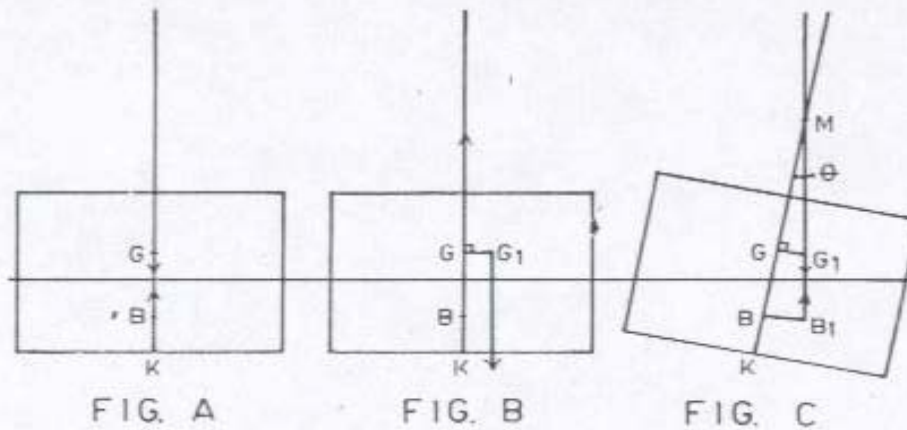
List is the transverse inclination caused when the COG of the ship is off the centre line.

For a ship to be in static equilibrium, the forces of buoyancy and gravity must cancel each other out. In other words, for a ship to be in static equilibrium,

- (i) the force of buoyancy must equal the force of gravity and
- (ii) the COB and COG of the ship must be in a vertical line, as illustrated in following figure A.

If the COG is moved out of the centre line of the ship, due to asymmetrical loading or discharging or due to transverse shift of weights aboard as shown in figure B,

- (i) the ship will sink or rise as necessary until the force of buoyancy equals the force of gravity and
- (ii) the forces of buoyancy and gravity will form a couple which will cause the ship to incline until the COB comes vertically below the COG as illustrated in figure C.



In the foregoing figures, GG_1 is the transverse shift of COG. The couple formed by the forces of gravity and buoyancy causes the ship to incline. As the ship inclines, the COB shifts to the lower side, as explained in chapter 9, and when it comes vertically under G_1 , the ship would be in static equilibrium. The angle of inclination at which this happens is the list — θ in foregoing figure C.

In right-angled triangle MGG_1 ,

$\tan \theta = \frac{GG_1}{GM}$ where θ is the angle of list,
 GG_1 is the transverse shift of COG,
 GM is the final fluid GM before listing.

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

$\tan \theta = \frac{dw}{W.GM}$ where θ is the angle of list,
 dw is the final listing moment in tonne metres,
 W is the final displacement in tonnes,
 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 $\tan \theta = \frac{dw}{W.GM}$

Example 1

On a ship of W 5000 t, GM 0.8m, 40 t of cargo is shifted transversely by 10 m. Find the list.

Final listing moment = $\overleftrightarrow{dw} = 10 \times 40 = 400$ tm.
 W remains unchanged.
 GM remains unchanged.

$$\tan \theta = \frac{\overleftrightarrow{dw}}{W.GM} = \frac{400}{5000 \times 0.8} = 0.1$$

Hence, $\theta = 5.71^\circ$ or $5^\circ 43'$.

Example 2

On a ship of W 8000 t, KG 7.0 m, KM 7.5 m, 100 t of cargo is loaded on the upper deck (KG 9.2 m) 2 m to port of the centre line. Find the list.

Final listing moment = $\overleftrightarrow{dw} = 2 \times 100 = 200$ tm to port

Final $W = 8000 + 100 = 8100$ t.

$$GG_1 \uparrow = \frac{wd}{W} = \frac{100 \times 2.2}{8100} = 0.027 \text{ m}$$

	KG	=	7.000 m
	$GG_1 \uparrow$	=	<u>0.027</u> m
Final	KG	=	7.027 m
	KM	=	<u>7.500</u> m

100

$$\text{Final GM} = 0.473 \text{ m}$$

$$\tan \theta = \frac{\frac{dw}{W \cdot \text{GM}}}{\frac{200}{8100 \times 0.473}} = 0.05220$$

Hence $\theta = 2.99^\circ$ or $2^\circ 59'$ to port.

Example 3

A ship of W 10000 t, KM 7.0 m, KG 6.0 m works cargo as follows:

Loads 800 t in No 2 LH (KG 3.75) 4 m to port of the centre line.

Loads 600 t in No 4 LH (KG 6.0 m) 8 m to starboard of the centre line.

Discharges 400 t from upper deck (KG 10.0 m) 2 m to port of the centre line.

If her free surface moment is 4400 tm, find the final list.

To find the FLM

Remarks	Weight (t)		dist off CL (m)	Listing mom(tm)	
	Loaded	Disch		Port	Stbd
Cargo No 2 LH	800	-	4 m to P	3200	-
Cargo No 4 LH	600	-	8 m to S	-	4800
Cargo UD	-	400	2 m to P	-	800
			Total	3200	5600
					- 3200
			FLM	=	2400 tm

The next step is to find the final fluid GM.

Remarks	Weight		KG	Moment by keel	
	Loaded	Disch		Loaded	Disch
Ship	10,000	-	6.0	60,000	-
Cargo 2 LH	800	-	3.75	3,000	-
Cargo 4 LH	600	-	6.0	3,600	-
Cargo UD	-	400	10.0	-	4,000
Total	11,400	400		66,600	4,000
	- 400			-4,000	
Final	11,000 t		Final	62,600 tm	

$$\text{Final KG} = \frac{62,600}{11,000} = 5.691 \text{ m}$$

$$\text{FSC} = \frac{\text{FSM}}{W} = \frac{4400}{11000} = 0.4 \text{ m}$$

$$\begin{aligned} \text{KM} &= 7.000 \text{ m} \\ \text{Final KG} &= 5.691 \text{ m} \\ \text{Solid GM} &= 1.309 \text{ m} \\ \text{FSC} &= 0.400 \text{ m} \\ \text{Fluid GM} &= 0.909 \text{ m} \end{aligned}$$

To find the list

$$\tan \theta = \frac{\text{FLM}}{W.GM} = \frac{2400}{11000 \times 0.909} = 0.24002$$

Hence, $\theta = 13.5^\circ$ or $13^\circ 30'$ to stbd.

Example 4

A ship of W 8000 t, GM 0.6 m, is listed 5° to starboard. How many tonnes of HFO must be transferred from No 2 S to No 2 P to upright the vessel, if the centres of the tanks are 7 m apart?

$$\tan \theta = \frac{\overleftrightarrow{dw}}{W \cdot GM} \quad \text{or} \quad \overleftrightarrow{dw} = W \cdot GM \cdot \tan \theta$$

$$\text{Hence, } dw = 8000 \times 0.6 \times \tan 5^\circ = 420 \text{ tm}$$

$$7w = 420 \text{ or } w = 60 \text{ t}$$

Example 5

A ship of 15000 t W, KM 9.0 m, KG 8.7 m is listed 10° to port. She now loads 150 t of cargo 7 m above the keel and 4 m to starboard of the centre line. Find the final list.

To find the initial listing moment

$$\tan \theta = \frac{\overleftrightarrow{dw}}{W \cdot GM} \quad \text{or} \quad dw = W \cdot GM \cdot \tan \theta$$

$$\text{Hence, } \overleftrightarrow{dw} = 15000 \times 0.3 \times \tan 10^\circ = 793.5 \text{ tm}$$

$$\text{Hence, initial listing moment or ILM} = 793.5 \text{ tm to port.}$$

To find final listing moment

$$\text{LM caused now} = 150 \times 4 = 600.0 \text{ tm to stbd.}$$

$$\text{ILM} = \underline{793.5} \text{ tm to port.}$$

$$\text{FLM} = 193.5 \text{ tm to port.}$$

To find final W & fluid GM

$$\text{Final W} = 15000 + 150 = 15150 \text{ t}$$

$$GG_1 \downarrow = \frac{dw}{W} = \frac{1.7 \times 150}{15150} = 0.017 \text{ m}$$

$$\text{Original KG} = 8.700 \text{ m}$$

$$GG_1 \downarrow = \underline{0.017} \text{ m}$$

$$\text{Final KG} = 8.683 \text{ m}$$

Final	KG	=	8.683 m
	KM	=	<u>9.000 m</u>
Solid	GM	=	0.317 m
	FSC	=	<u>0.000 m</u>
Fluid	GM	=	0.317 m

To find the list

$$\tan \theta = \frac{\text{FLM}}{W \cdot \text{GM}} = \frac{193.5}{15150 \times 0.317} = 0.04029$$

Hence, $\theta = 2.31^\circ$ or $2^\circ 18'$ to port.

Example 6

A ship of W 16000 t, KM 9.0 m, KG 8.0 m is listed 7° to starboard. She then works cargo as follows:

Loads 1600 t cargo KG 4.5 m, 5.0 m to port.

Loads 1400 t cargo KG 8.0 m, 4.5 m to stbd.

Discharges 1000 t KG 6.5 m, 1.0 from stbd.

Find how many tonnes of ballast must be transferred transversely to upright the vessel, if the P & S tank-centres are 10 m apart.

Note: The vessel is required to be upright. Hence FLM must be zero. Since final KG is not asked here, it need not be calculated.

To find the FLM

$$\begin{aligned} \text{ILM} &= W \cdot \text{GM} \cdot \tan \theta = 16000 \times 1.0 \times \tan 7^\circ \\ &= 1964.6 \text{ tm to stbd.} \end{aligned}$$

Remarks	Weight(t)		Dist from CL	Listing mom(tm)	
	Loaded	Disch	(m)	Port	Stbd
ILM	-	-	-	-	1964.6
Cargo	1600	-	5m to port	8000	-
Cargo	1400	-	4.5m to stbd	-	6300
Cargo	-	1000	1m from stbd	1000	-
				9000	8264.6
				- 8264.6	
			FLM	735.4	to port.

To upright vessel, required to cause a LM of 735.4 to starboard, by shifting ballast — tank-centres 10 m apart.

$$\text{Hence, } dw = 735.4$$

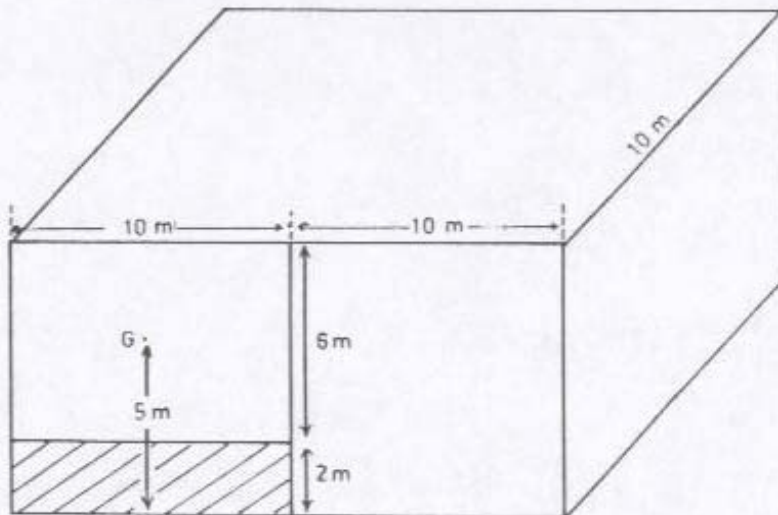
$$10w = 735.4$$

$$w = 73.54 \text{ t}$$

Required to shift 73.5 t from port tank to starboard tank.

Example 7

A ship displacing 9000 t has KM 8.7 m, KG 7.2 m. She is now listed 8° to port. She has port and starboard deep tanks, each 10 m long, 10 m wide and 8 m deep. The port side deep tank, which was full of SW, is pumped out until its sounding is 2 m. Assuming that no other tanks on the ship are slack, find the final list.



To find the FLM

$$\begin{aligned} \text{ILM} &= W \cdot \text{GM} \cdot \tan \theta = 9000 \times 1.5 \times \tan 8^\circ \\ &= 1897.3 \text{ tm to port} \end{aligned}$$

$$\begin{aligned} \text{Weight of SW pumped out} &= 10 \times 10 \times 2 \times 1.025 \\ &= 615 \text{ t} \end{aligned}$$

$$\begin{aligned} \text{LM caused} &= 615 \times 5 = 3075.0 \text{ tm to stbd} \\ \text{ILM} &= 1897.3 \text{ tm to port} \\ \text{FLM} &= 1177.7 \text{ tm to stbd} \end{aligned}$$

To find the final fluid GM

$$\begin{aligned} (9000 \times 7.2) - (615 \times 5) &= 8385 \times \text{Final KG} \\ \text{Final KG} &= 7.361 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{FSC} = \frac{i}{W} \cdot \frac{d_i}{12} &= \frac{10^3 \times d_i}{12 \times W} = \frac{10 \times 10^3 \times 1.025}{12 \times 8385} \\ &= 0.102 \text{ m} \end{aligned}$$

$$\begin{aligned}
 \text{KM} &= 8.700 \text{ m} \\
 \text{Final KG} &= \underline{7.361} \text{ m} \\
 \text{Solid GM} &= 1.339 \text{ m} \\
 \text{FSC} &= \underline{0.102} \text{ m} \\
 \text{Fluid GM} &= 1.237 \text{ m}
 \end{aligned}$$

To find the list

$$\tan \theta = \frac{\text{FLM}}{W \cdot \text{GM}} = \frac{1177.7}{8385 \times 1.237} = 0.11354$$

Hence, $\theta = 6.48^\circ$ or $6^\circ 29'$ to stbd.

Example 8

A ship of 15000 t displacement, KM 8.6 m, KG 7.0 m, is to discharge a 100 t heavy lift from the centre line of No 2 LH (KG 2 m) by her jumbo derrick whose head is 20 m above the keel. The FSM (free surface moment) is 1000 tm. Find the list caused when the derrick swings the weight 14 m away from the centre line of the ship.

To find the FLM

$$\text{FLM} = dw = 14 \times 100 = 1400 \text{ tm.}$$

To find the final fluid GM

(When weight is hanging from derrick head)

$$GG_1 \uparrow = \frac{dw}{W} = \frac{14 \times 100}{15000} = 0.120 \text{ m}$$

$$\text{FSC} = \frac{\text{FSM}}{W} = \frac{1000}{15000} = 0.067 \text{ m}$$

$$\text{Original KG} = 7.000 \text{ m}$$

$$GG_1 \uparrow = \underline{0.120} \text{ m}$$

$$\text{New KG} = 7.120 \text{ m}$$

New	KG	=	7.120 m
	KM	=	<u>8.600 m</u>
Solid	GM	=	1.480 m
	FSC	=	<u>0.067 m</u>
Fluid	GM	=	1.413 m

To find the list

$$\tan \theta = \frac{\text{FLM}}{W \cdot \text{GM}} = \frac{1400}{15000 \times 1.413} = 0.06605$$

$$\text{Hence } \theta = 3.78^\circ \text{ or } 3^\circ 47'.$$

When the weight is hanging from the derrick with an outreach of 14 m, the list would be 3.78° or $3^\circ 47'$.

Example 9

A ship of 8000 t displacement has a mean draft of 7.8 m and is to be loaded to a mean draft of 8.0 m. Her GM is 0.8 m and TPC is 20. She is listed 4° to starboard at present. How much cargo should be loaded into the port and starboard 'tween decks (centres 5 m & 6 m off the centre line respectively) for the ship to complete loading and finish upright.

$$\text{Sinkage} = 8.0 - 7.8 = 0.2 \text{ m} = 20 \text{ cm}$$

$$\text{Can load} = s \times \text{TPC} = 20 \times 20 = 400 \text{ t}$$

$$\begin{aligned} \text{ILM} = W \cdot \text{GM} \cdot \tan \theta &= 8000 \times 0.8 \times \tan 4^\circ \\ &= 447.5 \text{ tm to stbd.} \end{aligned}$$

Let the cargo to be loaded on the port side be x tonnes. Hence, the cargo to be loaded on the starboard side would be $(400 - x)$ tonnes.

	Port	Stbd
ILM	-	447.5
Cargo on port side	5 x	-
Cargo on stbd side	-	6(400 - x)
Total	5 x	447.5 + 6(400 - x)

To finish upright, port LM = stbd LM.

$$\text{Hence, } 5x = 447.5 + 6(400 - x)$$

$$\text{Hence, } x = 259 \text{ t (port side)}$$

$$\& (400 - x) = 141 \text{ t (stbd side).}$$

Example 10

A ship of W 11000 t, KM 7.4 m, and KG 6.0 m is listed 4° to port. A heavy lift weighting 150 t is to be discharged from No 3 LH using the ship's jumbo derrick whose head is 23 m above the keel and whose heel is on the centre line. While in No 3 LH, the COG of the weight is 3 m above the keel and 5 m to port of the centre line. Find the list at each of the following stages:

- As soon as the derrick picks up the load from the LH.
- When the derrick has swung the load 15 m to starboard of the centre line.
- After discharging the weight.

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

$$\text{Hence, ILM} = 11000 \times 1.4 \times \tan 4^\circ = 1076.9 \text{ tm to port}$$

Stage (i)

As soon as the derrick picks up the load, the COG of the weight shifts from LH (KG 3 m) to the

derrick head (KG 23 m) i.e., $d = 20$ m upwards.
Since the GM changes, the list would change.

$$GG_1 \uparrow = \frac{dw}{W} = \frac{20 \times 150}{11000} = 0.273 \text{ m}$$

$$\text{Original GM} = 1.400 \text{ m}$$

$$GG_1 \uparrow = 0.273 \text{ m}$$

$$\text{GM at stage (i)} = 1.127 \text{ m}$$

$$\tan \theta = \frac{LM}{W \cdot GM} = \frac{1076.9}{11000 \times 1.127} = 0.08687$$

Hence, θ at stage (i) = 4.96° or $4^\circ 58'$ to port.

Stage (ii)

When the derrick has swung out 15 m to starboard of the centre line, the weight has actually travelled 20 m to starboard because it was originally lying 5 m to port of the centre line.

$$LM \text{ caused} = 20 \times 150 = 3000.0 \text{ tm to stbd}$$

$$ILM = 1076.9 \text{ tm to port}$$

$$FLM = 1923.1 \text{ tm to stbd}$$

$$\tan \theta = \frac{FLM}{W \cdot GM} = \frac{1923.1}{11000 \times 1.127} = 0.15513$$

Hence, θ at stage (ii) = 8.82° or $8^\circ 49'$ to stbd.

Stage (iii)

As soon as the weight is discharged, the LM, GM and W change, causing the list to change.

$$\text{Final } W = 11000 - 150 = 10850 \text{ t}$$

$$\begin{aligned}
 \text{LM caused now} &= 15 \times 150 = 2250.0 \text{ tm to port.} \\
 \text{LM during stage (ii)} &= 1923.1 \text{ tm to stbd.} \\
 \text{FLM} &= 326.9 \text{ tm to port.}
 \end{aligned}$$

$$\begin{aligned}
 \text{KG of ship at stages (i) \& (ii)} &= 6.273 \text{ m} \\
 \text{Height of derrick head above keel} &= \underline{23.000} \text{ m} \\
 d &= 16.727 \text{ m}
 \end{aligned}$$

$$GG_1 \downarrow = \frac{dw}{W} = \frac{16.727 \times 150}{10850} = 0.231 \text{ m}$$

$$\text{GM during stages (i) \& (ii)} = \underline{1.127} \text{ m}$$

$$\text{GM during stage (iii)} = 1.358 \text{ m}$$

$$\tan \theta = \frac{\text{FLM}}{W \cdot \text{GM}} = \frac{326.9}{10850 \times 1.358} = 0.02219$$

Hence, Final $\theta = 1.27^\circ$ or $1^\circ 16'$ to port.

Exercise 11

List

- 1) On a ship of W 5000 t, GM 0.3 m, 20 t was shifted transversely by 5 m. Find the list.
- 2) On a ship of W 8000 t, GM 2.0 m, if the following transverse shiftings were done, find the list:

200 t cargo shifted 4 m to stbd

100 t cargo shifted 2 m to port

100 t cargo shifted 4 m to port

50 t stores shifted 20 m to stbd

- 3) If 200 t of cargo was shifted downwards by 10 m and to starboard by 5 m on a ship of W 10000 t, KG 7.0 m, KM 7.4 m, find the list.
- 4) A quantity of grain estimated to be 100 t shifts transversely by 12 m and upwards by 1.5 m, on a ship of W 12000 t, GM 1.2 m. Find the list caused.
- 5) A ship displaces 4950 t and has KG 4.85 m, KM 5.79 m. Cargo weighing 50 t is loaded 1.25 m above the keel and 4 m to port of the centre line. Find the list.
- 6) A weight of 100 t is discharged from a position 2.45 m above the keel and 6 m to port of the centre line of a ship of W 10000 t, KM 8.25 m, KG 7.45 m. Find the list.
- 7) A ship of 10000 t displacement, KG 8.3 m carries out the following cargo operations:

Qty. (t)	Loaded or discharged	KG (m)	Distance off centre line
200	D	10.0	5 m port
800	D	2.3	4 m stbd
500	D	5.2	3 m port
250	L	8.0	nil
250	L	12.0	nil

If the final KM is 9.6 m, find the list.

- 8) A ship of W 9000 t, KG 8.3 m loads 600 t of cargo (KG 4.0 m, 3 m to port of the centre line) and discharges 400 t of cargo (KG 9.0 m, from 5 m to port of the centre line). 200 t of cargo is then shifted upwards by 5 m and to starboard by 8 m. 300 t of cargo is then shifted 1 m downwards and 4 m port. Find the list if the final KM is 8.95 m.

- 9) A ship of W 18000 t, KG 7.75 m, discharges 1500 t (6.0 m above the keel and 3 m port of the centre line) and loads 500 t (10 m above the keel and 4 m port of the centre line). Cargo was then shifted as follows:

500 t upwards 2 m and to starboard 4 m
800 t downwards 2 m and to port 3 m.

If the final KM is 8.935 m, find the list.

- 10) A ship listed 8° to port, displaces 12000 t and has KM 7.54 m and KG 6.8 m. Find how many tonnes of SW ballast must be transferred from No 2 port DB tank to No 2 stbd DB tank, to upright in vessel, if the tank-centres are 10 m apart.
- 11) A ship displacing 4000 t has GM 1.0 m (KM 10.0 m & KG 9.0 m) and is listed 10° to port. If 16000 t of cargo is now loaded on the centre line and the final GM is 1.0 m (KM 9.0 m & KG 8.0 m), state whether the list would change. If yes, find the new list.
- 12) A ship of W 10000 t, GM 1.5 m, is listed 5° to stbd. If cargo is shifted vertically until her final GM is 0.5 m, state whether the list would change. If yes, find the new list.
- 13) A ship of W 8500 t, KM 9.0 m, KG 8.3 m, is listed $8\frac{1}{2}^\circ$ to stbd. The following cargo operations were carried out:

200 t discharged KG 4 m from 5 m stbd of CL.

300 t discharged KG 5 m from 2 m port of CL.

100 t loaded KG 2 m, 4 m to stbd of CL.

200 t shifted up by 2 m and port by 3 m.

If the final KM is 9.3 m, find the final list.

- 14) A ship of 15000 t displacement, KG 8.7 m, KM 9.5 m, is listed 10° to port. The following cargo work was carried out:

500 t loaded, KG 8.0 m, 5 m stbd of CL.

300 t discharged, KG 4.0 m, 4 port of CL.

Find the quantity of SW ballast that must be transferred transversely to bring the vessel upright, the tank centres being 12 m apart.

(Note: Since vessel is required upright, it is not necessary to calculate the final KG or GM unless specifically asked).

- 15) A bulk carrier presently of 12250 t, KM 9.8 m, KG 9.0 m has a list of $6\frac{1}{2}^\circ$ to starboard. She then loads 1250 t of ore (KG 8 m, 2 m to stbd of centre line) and discharges 250 t of ore (KG 2 m, 5 m from starboard of centre line). 160 t of SW ballast is then transferred from the stbd shoulder tank to the port DB tank (vertically downwards by 9 m and transversely by 10 m). Find the final list, assuming that there are no slack tanks, given that the final KM is 9.6 m.
- 16) From a ship of W 8000 t, KM 8.6 m, KG 8.0 m, some deck cargo was washed overboard (KG 10 m, 8 m from the centre line). If the resultant list is 3° , find the quantity of cargo lost.
- 17) A ship of W 16000 t, KM 7.5 m, KG 6.0 m, TPC 25, is listed 3° to port. Her present mean draft is 8.6 m and she is to finish loading at 8.8 m mean draft. Space is available 5 m off the centre line, on either

side. State how much cargo must be stowed on either side to finish upright.

- 18) A ship displacing 12000 t has KM 9.0 m, KG 7.25 m. A 200 t heavy-lift is to be loaded by ship's jumbo whose head is 24 m above the keel.

Find (i) The list as soon as the derrick picks up the weight from the wharf on the stbd side with an outreach of 15 m.

(ii) The list when the weight is placed on the upper deck KG 10 m, 7 m to stbd of the centre line.

- 19) A ship of W 10000 t, KM 7.3 m, KG 6.8 m, is listed 5° to port. A heavy-lift weighing 100 t, lying 6 m to port of the centre line and KG 10.0 m, is to be shifted to the lower hold KG 2.0 m on the centre line of the ship, by the ship's jumbo derrick whose head is 28 m above the keel.

Find (i) The list as soon as the derrick takes the load.

(ii) The list when the derrick swings the load to the centre line.

(iii) The list after the shifting is over.

- 20) A ship of W 13000 t, KM 8.75 m, KG 8.0 m, has a list of 6° to starboard. A heavy-lift weighing 150 t, lying on the upper deck 9 m above the keel and 5 m to stbd of the centre line, is to be discharged using the ship's jumbo derrick whose head is 22 m above the keel. Calculate

(i) The list as soon as the load is taken by the derrick.

(ii) When the load is hanging over the port side of the ship with an outreach of 10 m from the centre line.

(iii) After discharging the heavy-lift.

- 21) A ship of 10000 t displacement is floating in SW and has KM of 10.8 m and KG of 9.0 m. She is listing 10° to stbd. She has two rectangular deep tanks, one on either side, each 12 m long, 12 m wide and 9 m deep. The stbd tank is full of FW while the port one is empty. If FW is to be transferred from the stbd tank to the port one, find

(i) the quantity of FW to transfer to bring the ship upright.

(ii) the list if one third of the original FW in the stbd tank is transferred to the port tank.

Note: Fluid GM should be used here.

- 22) On a ship 8000 t displacement, 50 t is shifted transversely by 4 m. Find the list if the total FSM is 1216 tm, KM 7.0 m, KG 6.4 m.
- 23) A ship has W 10000 t, KM 7.8 m, KG 7.075 m, and is upright. No 3 port and stbd DB tanks are full of HFO RD 0.95. Each tank is rectangular, 15 m long, 12 m wide and 2 m deep. Calculate the list when HFO is consumed from No 3 stbd until the sounding is 1.2 m.
- 24) A vessel displacing 9000 t has KM 8.02 m, KG 7.5 m, and is upright. She loads 250 t KG 12 m, 3 m to stbd of the centre line; loads 1000 t KG 3 m, 1 m to port of the centre line; discharges 250 t KG 8 m, 2 m to stbd of the centre line. 100 t of cargo is then shifted

transversely 3 m to stbd. If the total FSM is 1200 tm, calculate the final list.

- 25) A ship of 14000 t displacement, KM 9.0 m, KG 7.8 m, has a total FSM of 2100 tm and is listed 8° to port. How many tonnes must be shifted transversely by 10 m to upright the ship?

STIFF AND
TENDER VESSELS

STIFF VESSEL

- 1 A stiff vessel is one with an unduly large GM for her type, size and nature.

Note: Type refers to general cargo, bulker, tanker, etc., while nature refers to peculiarities of the vessel.

- 2 Angle and period of roll is small.
- 3 Rolling is violent and irregular.
- 4 Uncomfortable for people on board because of jerky movements.
- 5 Severe stresses set up on hull.
- 6 General cargo likely to break loose due to jerky movements.

TENDER VESSEL

- A tender vessel is one with a small GM for her type, size and nature.

- Angle and period of roll is large.
- Rolling is smooth and regular.
- Less uncomfortable for people on board as movements are regular.
- Less severe stresses set up on hull.
- General cargo, once secured properly, is less likely to break loose.

- | | | |
|---|--|---|
| 7 | Bulk cargo less likely to shift as angle of roll is small. | Bulk cargo more likely to shift as angle of roll is large. |
| 8 | No likelihood of vessel becoming unstable during passage owing to consumption of fuel and fresh water from DB tanks and also due to FSE of tanks in use. | Likelihood of vessel becoming unstable during passage owing to consumption of fuel and fresh water from DB tanks and also due to FSE of tanks in use. |
| 9 | Greater ability to withstand loss of GM, if any, caused by bilging. | Less ability to withstand such loss of GM. |
- Note: Bilging is the flooding of a compartment, as a result of damage, whereby water has free access to come in and go out.
- | | | |
|----|--|---|
| 10 | Greater ability to withstand transverse shift of cargo — list caused by such shift is small. | Less ability to withstand transverse shift or cargo — list caused by such shift is large. |
|----|--|---|

Note: As explained in the previous chapter,

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

It is obvious from the foregoing formula that the list caused varies inversely as the GM fluid. Considering identical circumstances, the list resulting from transverse shift of cargo will be less if the vessel is stiff and much more if the vessel is tender.

STABILITY OF VESSELS WITH DECK CARGO OF TIMBER

A vessel with a considerable quantity of timber as deck cargo is likely to be tender at the commencement of the voyage itself, owing to such weight loaded so high up on the ship.

On passage, the GM will decrease further owing to the following reasons:-

- 1) Consumption of fuel oil and fresh water from double bottom tanks.
- 2) Free surface effect of tanks in use.
- 3) Absorption of water by the timber on deck. This depends on:
 - a) Type of wood — teak, oak, pine, etc.
 - b) Nature of timber — logs, blocks, planks, boards etc., — the greater the surface area exposed, the greater the absorption.
 - c) Age of timber — new timber would contain sap and hence not absorb much water whereas old timber would be dry and can absorb more.
 - d) The amount of precipitation and spray experienced. In the case of spray, the absorption may be asymmetrical — more on windward side than on leeward side.

In view of the foregoing points, the amount of water absorbed is variable and though it can be as high as thirty percent of the weight of timber, it is generally around ten to fifteen percent or so. This is equivalent to adding weight on deck, thereby causing a rise of the centre of gravity of the ship.

A vessel with a deck cargo of timber, therefore, becomes less and less stable, possibly unstable, during the passage. It may not be possible to increase the metacentric height before departure from the port, owing to lack of deadweight available — the vessel may already be down to her loadline.

In order to keep the vessel stable at all times, the following precautions should be taken:-

- i) Plan cargo stowage in lower holds and tween decks in such a manner as to have as large a metacentric height as possible.
- ii) Ensure that the number of slack tanks is kept to minimum and also restricted to those tanks with minimum moment of inertia about the tank's centreline.
- iii) During the passage, use fuel oil and fresh water first from the slack tanks until they are completely empty.
- iv) During the passage, fill up adequate ballast tanks, one at a time, those with smallest 'i' first, as and when the fuel oil and fresh water tanks get empty, ensuring that the vessel does not get overloaded at any time.

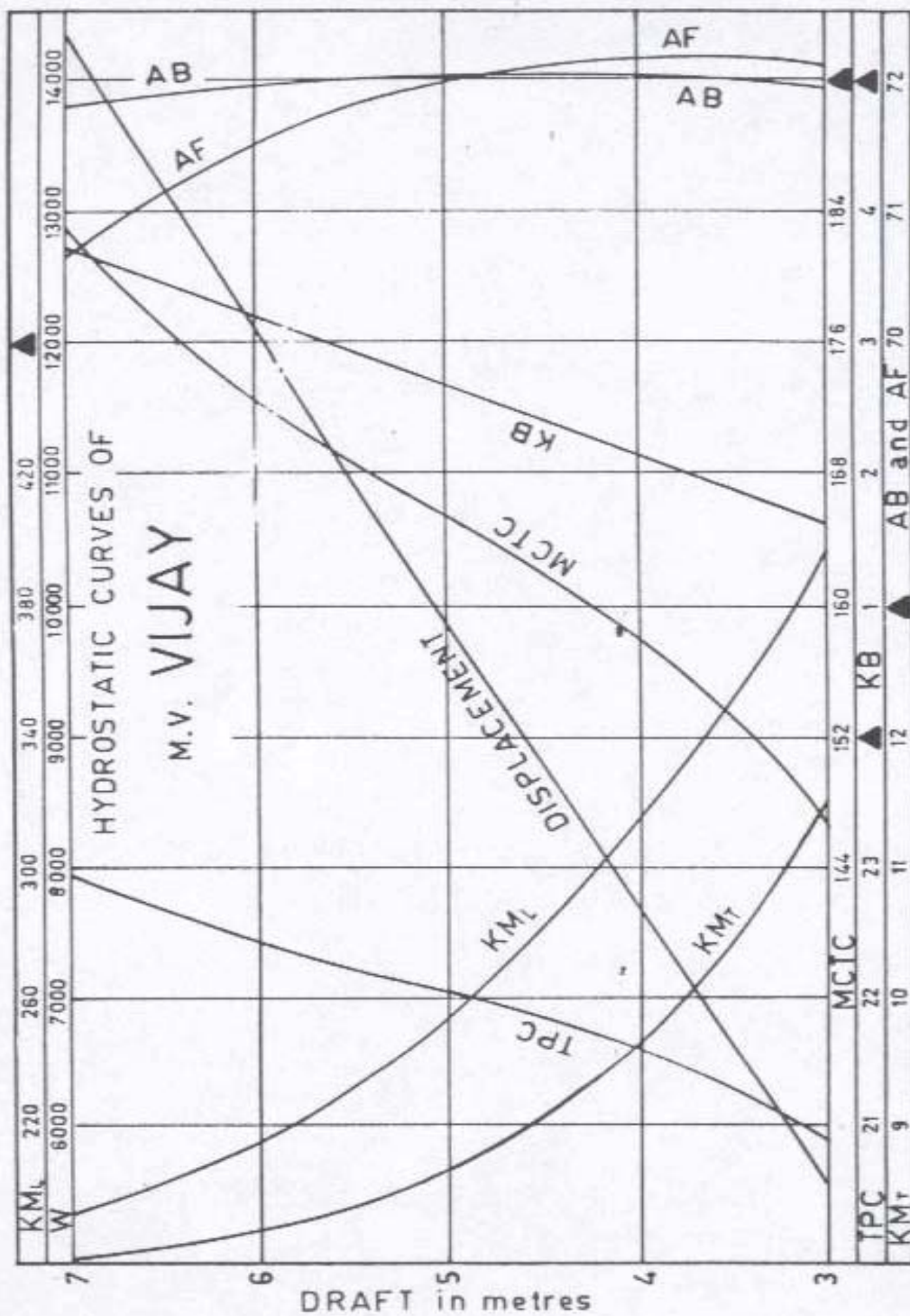
HYDROSTATIC CURVES

The hydrostatic particulars of a ship consist of displacement, deadweight, tonnes per centimetre (TPC), height of COB above keel (KB), distance of COB from after perpendicular (AB) or from midships (HB), height of transverse metacentre above keel (KMT), height of the longitudinal metacentre above keel (KML), distance of centre of flotation from after perpendicular (AF) or from midships (HF) and moment to change trim by one centimetre (MCTC).

Since each of these values depends on the draft of the ship, the hydrostatic particulars are given by the shipyard in the form of curves or tables plotted or tabulated against draft.

The foregoing terms have all been explained in earlier chapters with the exception of the last three — KML, AF (or HF) and MCTC. These will be explained in detail in volume II.

All the hydrostatic curves of a ship may be given, by the shipyard, on a single sheet of graph paper wherein draft may be indicated on the Y-axis and centimetres on the X-axis. For each curve, one centimetre on the X-axis represents a different value, as illustrated on the next page. Some shipyards include, on the same graph, curves of additional information which are dependant on draft, such as wetted surface area, midship area, block coefficient, water-plane area coefficient, etc.



In this chapter, the working will be confined to the construction of one curve at a time. Problems based on the hydrostatic particulars as a whole are included in the next chapter.

When constructing graphs, the following notes may be borne in mind:-

- i) The scale used should be the largest that will fit on the paper used.
- ii) The scale chosen on each axis should be clearly indicated.
- iii) The curves may be drawn to scale on ordinary paper. It is not necessary to use graph paper.
- iv) The graphs need to be drawn only within the given limits, for example: if the drafts are given between 2 m and 8 m, it is not normally necessary to show drafts less than 2 m or more than 8 m on the graph.

Example 1

Given the following information, construct a displacement curve:

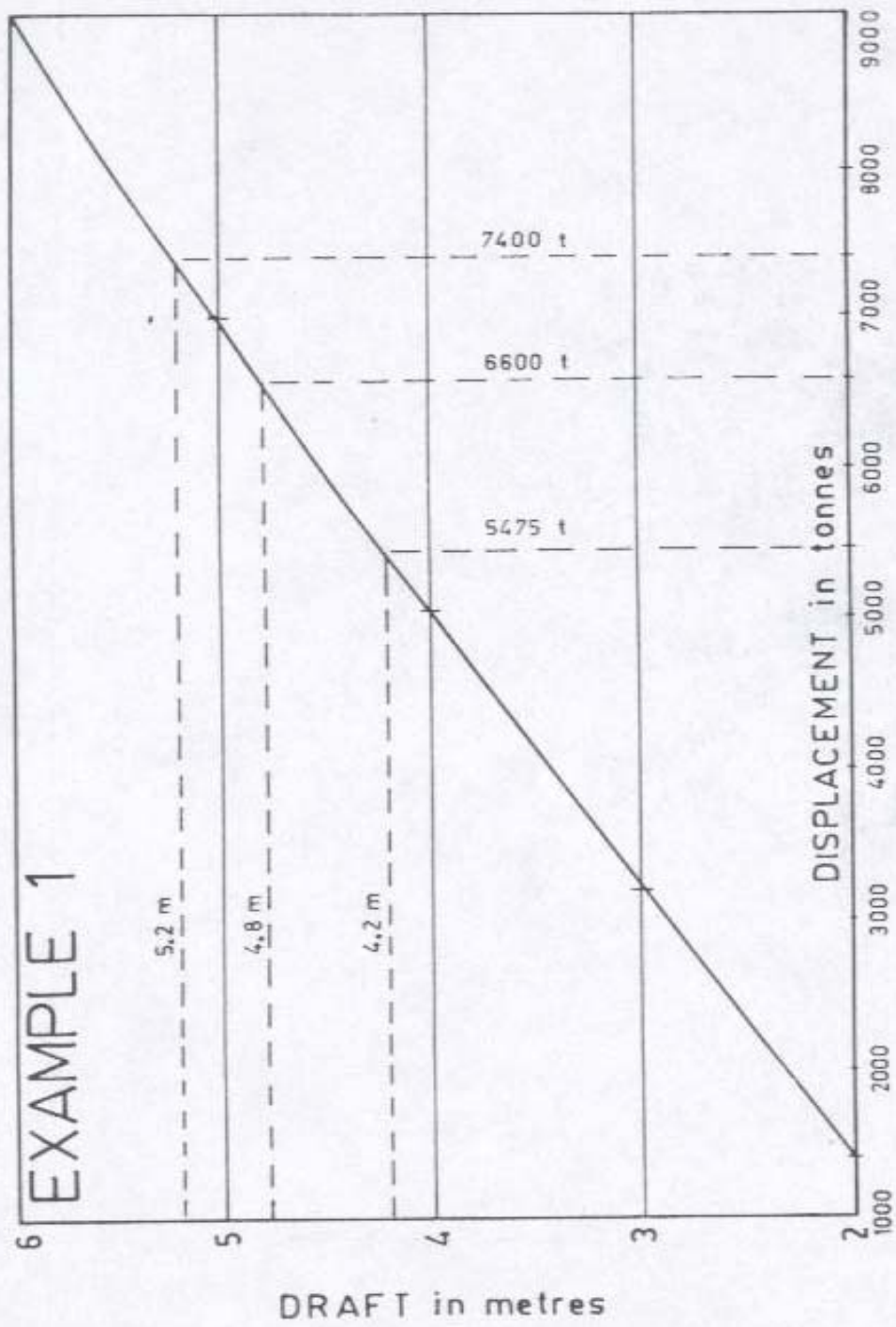
Draft (m)	2	3	4	5	6
Displ (t)	1400	3200	5050	7000	9000

From your curve,

- i) If the light displacement is 1300 t, find the DWT aboard at 4.2 m draft.
- ii) Find the TPC at 5 m draft.

i) From curve on next page,

Disp. at 4.2 m draft	=	5475 t
Light displacement	=	<u>1300 t</u>
DWT aboard	=	4175 t



$$\begin{array}{llll}
 \text{ii) Disp. at 5.2 m draft} & = & 7400 \text{ t} & \\
 \text{Disp. at 4.8 m draft} & = & \underline{6600 \text{ t}} & \\
 40 \text{ cm draft corresponds to} & & 800 \text{ t} & \\
 1 \text{ cm draft would mean} & & \frac{800}{40} = 20 \text{ t} &
 \end{array}$$

Hence, TPC at 5 m draft = 20

Example 2

Construct a TPC curve from the following information:

Draft	1	2	3	4	5
TPC	3.44	5.81	7.00	7.62	8.00

From your curve, find the area of the water plane at 3.6 m draft in SW.

From graph (next page) TPC at 3.6 m draft = 7.4

$$\frac{1.025A}{100} = 7.4 \text{ or } A = \frac{7.4 \times 100}{1.025} = 722 \text{ m}^2$$

Hence, area of WP at 3.6 m draft = 722 m²

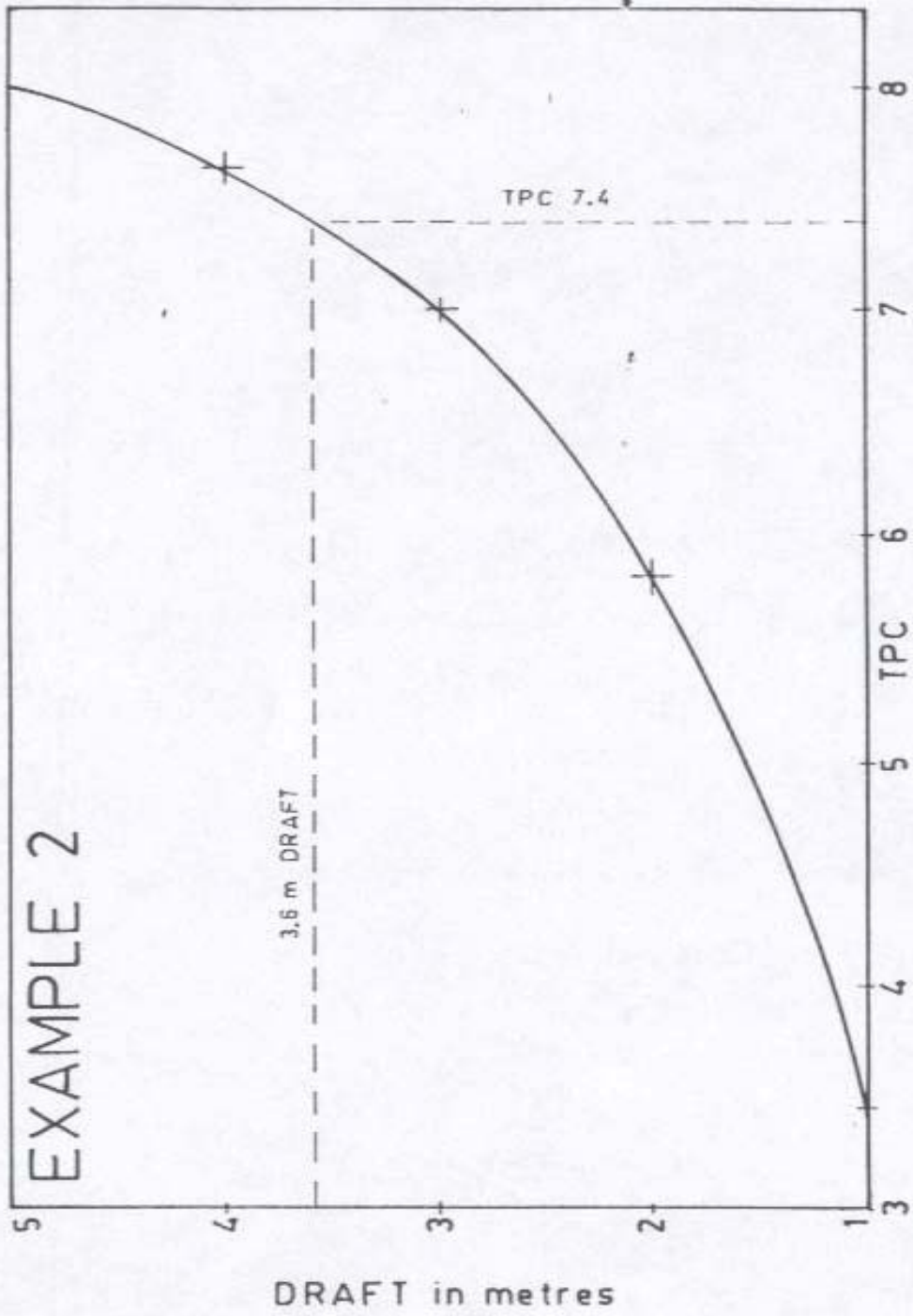
Example 3

Construct a KB curve for a box-shaped vessel 150 m long, 18 m broad between 4 m and 9 m draft.

If the BM at 6 m draft is 4.5 m, and the KG of the vessel is 6.0 m, find the GM at that draft.

Since KB = $\frac{1}{2}$ draft,

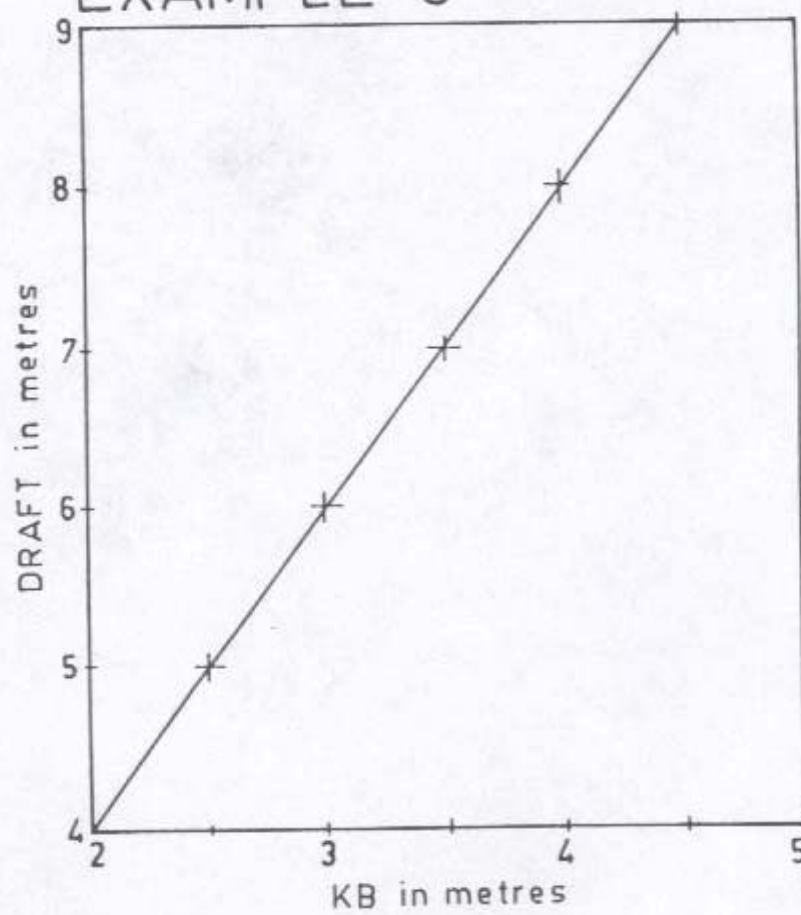
$$\begin{array}{ll}
 \text{At 6 m draft} & \text{KB} = 3.0 \text{ m} \\
 & \text{BM} = 4.5 \text{ m} \\
 & \text{KM} = \underline{7.5 \text{ m}} \\
 & \text{KG} = 6.0 \text{ m} \\
 & \text{GM} = \underline{1.5 \text{ m}}
 \end{array}$$



To construct graph

Draft	KB
4 m	2.0 m
5	2.5
6	3.0
7	3.5
8	4.0
9	4.5

EXAMPLE 3



Exercise 12Hydrostatic curves

- 1 Construct a displacement curve from the following information:-

Draft (m)	1	1.5	2	2.5	3
Disp (t)	330	1020	1950	2930	3850

From your graph, find:

- (a) TPC at 2 m draft.
 (b) The draft when disp is 3000 t.

- 2 Given the following information, construct a displacement curve:-

Draft (m)	4	5	6	7	8
Disp (t)	7600	9800	12000	14300	16600

If the present draft is 5.4 m, and the load draft is 7.8 m, find the DWT available.

- 3
- | | | | | | |
|-----------|-----|------|------|------|------|
| Disp (t) | 770 | 1270 | 1800 | 2400 | 3100 |
| Draft (m) | 1 | 2 | 3 | 4 | 5 |

Using the foregoing data, construct a displacement curve.

If on arrival, the draft was 1.8 m and then 2000 t of cargo was loaded, 200 t of ballast was pumped out, find the draft on sailing.

- 4 Construct a deadweight curve, from the following data:-

Draft (m)	2	3	4	5	6
DWT (t)	360	980	1680	2770	4080

- (a) Find the DWT aboard at 4.75 m draft.
 (b) Find the TPC at 4 m draft.

- (c) If the light displacement is 376 t, find the displacement at 5.4 m draft.

- 5 Construct a TPC curve from the following:-

Draft (m)	2	3	4	5	6	7
TPC	20.90	21.62	22.08	22.47	22.95	23.54

From your curve, find the TPC at 6.6 m draft and at 3.3 m draft.

- 6 The following is taken from a ship's hydrostatic particulars:-

Draft (m)	1	2	3	4	5	6
TPC	58.90	62.30	63.70	64.60	65.32	65.86

- (a) Find the area of the waterplane at 4.2 m draft.
 (b) At 4 m draft, the vessel loads 325 t of cargo. Find the new draft.

- 7 From the following information, construct a KB curve:-

Draft (m)	1	2	3	4
KB (m)	0.667	1.333	2.0	2.667

If at 2.4 m draft the BM is 2.5 m, find the KM.

- 8 Construct a KB curve for a box-shaped vessel 50 m long and 12 m wide between the drafts of 1 m and 5 m.
 If at 4 m draft the BM is 3 m, find the KM.

- 9 From the following information, construct a KM_T curve:-

Draft (m)	2	4	6	8	10
KM _T (m)	16.0	9.86	8.44	8.25	8.62

From your graph,

- (a) Find the minimum value of KM_T and the draft at which it occurs.
- (b) If the KG is 6.3 m, find the GM at 5.6 m draft.

10 The following is taken from the hydrostatic particulars of a ship:-

Draft (m)	2	3	4	5	6	8	10
KM_L (m)	560	391	303	248	211	174	156

If the KG is 8 m, find the GM_L at 7 m draft.

HYDROSTATIC TABLES

As mentioned in the previous chapter, the hydrostatic particulars of a ship may be given in the form of curves or tables plotted or tabulated against draft. Appendix I at the end of the book is the hydrostatic table of an imaginary general cargo ship n.v. 'VIJAY'. The use of the hydrostatic table can be understood properly by going through the following worked examples:

Example 1

Find the hydrostatic particulars of m.v. 'VIJAY' at a draft of 5.1 m in SW.

This is obtained by direct linear interpolation between the tabulated values against the drafts of 5.0 m and 5.2 m.

Required draft	5.100 m
Next below as per table	<u>5.000 m</u>
Difference from next below	.100 m
Tabulated interval	.200 m
Interpolation ratio	$\frac{.1}{.2} = 0.5$

	<u>Draft</u>	<u>W</u>	<u>TPC</u>	<u>MCTC</u>
Next below	5.0	9891	22.06	165.7
Next above	<u>5.2</u>	<u>10333</u>	<u>22.14</u>	<u>167.1</u>

	<u>Draft</u>	<u>W</u>	<u>TPC</u>	<u>MCTC</u>
Tabular difference	.2	442	.08	1.4
Interpolation ratio	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>
Diff. from top line	.1	221	.04	.7
Top line	<u>5.0</u>	<u>9891</u>	<u>22.06</u>	<u>165.7</u>
Required values	5.1	10112	22.10	166.4

	<u>Draft</u>	<u>AB</u>	<u>AF</u>	<u>KB</u>	<u>KM_T</u>	<u>KM_L</u>
Next below	5.0	72.014	71.913	2.685	8.686	254.3
Next above	<u>5.2</u>	<u>72.011</u>	<u>71.842</u>	<u>2.789</u>	<u>8.566</u>	<u>245.4</u>
Tab. diff.	.2	.003	.071	.104	.120	8.9
Int. ratio	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>	<u>x.5</u>
Difference	.1	.002	.036	.052	.060	4.5
Top line	<u>5.0</u>	<u>72.014</u>	<u>71.913</u>	<u>2.685</u>	<u>8.686</u>	<u>254.3</u>
Reqd. values	5.1	72.012	71.877	2.737	8.626	249.8

Note 1: W and KM_L may be worked to one decimal place and the others to three decimal places.

Note 2: In actual practice, the interpolation need not be shown so elaborately. Such interpolation may be done mentally, or in rough, or by a calculator and only the results shown.

Example 2

Find the hydrostatic particulars of m.v. 'VIJAY' at a displacement of 11762 t in SW.

This is obtained by direct linear interpolation between the tabulated values against the SW displacements just below and just above the given SW displacement.

Required displacement	11762 t
Next below as per table	<u>11672 t</u>
Difference from next below	90 t
Tabulated interval	450 t
Interpolation ratio = $\frac{90}{450} = 0.2$	

	<u>W</u>	<u>Draft</u>	<u>TPC</u>	<u>MCTC</u>
Next below	11672	5.8	22.37	171.3
Next above	<u>12122</u>	<u>6.0</u>	<u>22.45</u>	<u>172.9</u>
Tabular difference	450	0.2	.08	1.6
Interpolation ratio	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>
Diff. from top line	90	.04	.016	.32
Top line	<u>11672</u>	<u>5.80</u>	<u>22.370</u>	<u>171.3</u>
Required values	11762	5.84	22.386	171.6

	<u>W</u>	<u>AB</u>	<u>AF</u>	<u>KB</u>	<u>KMT</u>	<u>KML</u>
Next below	11672	71.977	71.586	3.102	8.298	223.0
Next above	<u>12122</u>	<u>71.960</u>	<u>71.472</u>	<u>3.205</u>	<u>8.234</u>	<u>217.2</u>
Tab. diff.	450	.017	.114	.103	.064	5.8
Int. ratio	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>	<u>x.2</u>
Difference	90	.003	.023	.021	.013	1.2
Top line	<u>11672</u>	<u>71.977</u>	<u>71.586</u>	<u>3.102</u>	<u>8.298</u>	<u>223.0</u>
Reqd. values	11762	71.974	71.563	3.123	8.285	221.8

See notes at the end of example 1.

Example 3

Find the displacement of m.v. 'VIJAY' when floating at a draft of 6.4 m in DW of RD 1.015.

At 6.4 m draft in SW, W = 13030 t.

(This was obtained from the hydrostatic tables).

At 6.4 m draft in SW, u/w volume = $\frac{13030}{1.025} \text{ m}^3$

Hence, u/w volume of ship at 6.4 m
draft in any water = $\frac{13030}{1.025} \text{ m}^3$

At 6.4 m draft in DW RD 1.015,

$$W = \frac{13030}{1.025} \times 1.015 = 12902.9 \text{ t}$$

Example 4

Find the draft of m.v. 'VIJAY' in DW of RD 1.010, at a displacement of 10650 tonnes.

Three methods of working this out are shown. The first one is more tedious but is very easy to understand. The second method is quicker to do, once the reasoning is understood. The third method is applicable only in this case, where displacement is given, and is hence not recommended for general use.

Alternative 1

Draft m	W in SW t	u/w vol m^3	W in DW of RD 1.010 t
5.2	10333	$\frac{10333}{1.025}$	$\frac{10333}{1.025} \times 1.010 = 10181.8$
5.4	10777	$\frac{10777}{1.025}$	$\frac{10777}{1.025} \times 1.010 = 10619.3$
5.6	11223	$\frac{11223}{1.025}$	$\frac{11223}{1.025} \times 1.010 = 11058.8$

The first two columns are taken from the hydrostatic table, while the next two are computed.

Interpolation is done between the first and last columns for the desired W of 10650 t in DW as shown on the next page:

135

<u>W in DW</u> <u>t</u>	<u>Draft</u> <u>m</u>	
10619.3	5.4	
11058.8	5.6	
<u>10650</u>	<u>5.414</u>	answer

Alternative 2

The underwater volume of a ship for a given draft is constant.

So at any draft,

$$\frac{W \text{ in SW}}{1.025} \times \text{density of DW} = W \text{ in DW (at same draft)}$$

OR

$$W \text{ in SW} = \frac{W \text{ in DW} \times 1.025}{\text{density of DW}} \quad (\text{at same draft})$$

In this case,

$$\begin{aligned} W \text{ at same draft in SW} &= \frac{10650 \times 1.025}{1.010} \\ &= 10808.2 \text{ t} \end{aligned}$$

Using the first two columns of the hydrostatic table, interpolate for W of 10808.2 t, as shown below:

<u>W in SW</u> <u>t</u>	<u>Draft</u> <u>m</u>	
10777	5.4	
11223	5.6	
<u>10808.8</u>	<u>5.414</u>	answer

Alternative 3

Entering the hydrostatic table with W of 10650 t, the draft and TPC, both for SW, can be obtained:

W	Draft (SW)	TPC (SW)
10333	5.2	22.14
10777	5.4	22.22
<u>10650</u>	<u>5.343</u>	<u>22.197</u>

$$\begin{aligned}
 \text{FWA at 5.343 m SW draft} &= \frac{W}{40 \text{ TPC}} \\
 &= \frac{10650}{40 \times 22.197} \\
 &= 12 \text{ cm} \\
 \text{DWA at 5.343 m SW draft} &= \frac{(1.025 - 1.010)}{.025} \times 12 \\
 &= 7.2 \text{ cm} = .072 \text{ m} \\
 \text{SW draft for W 10650 t} &= 5.343 \text{ m} \\
 \text{DWA} &= \underline{.072 \text{ m}} \\
 \text{DW draft for W 10650 t} &= 5.415 \text{ m}
 \end{aligned}$$

Note: This method can be used only where W is given and draft in DW or FW is to be calculated. It cannot be used to find W accurately, given draft in DW or FW. This method is, therefore, not recommended for general use.

Example 5

Find the hydrostatic particulars of m.v. 'VIJAY' at 6.8 m draft in DW of RD 1.015.

From the hydrostatic table,

Draft	W in SW	TPC	MCTC	AB	AF	KB	KM _T	KM _L
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4

AB, AF, KB, KM_T and KM_L are functions of the ship's underwater volume and shape and are hence dependant on the draft only, not on the density of water displaced. Their values tabulated against draft hold good in any water, whether SW, FW or DW, for that draft.

However, W, TPC, and MCTC are functions of the draft and the density of water displaced. A correction would have to be applied, for the density of DW, to the tabulated values which are for SW.

Note: A simple thumb rule for quick thinking would be that, among all the hydrostatic particulars tabulated against draft, those given in metres hold good for that draft in water of any density whereas those given in other units (t, t cm⁻¹, tm cm⁻¹) are for SW and need correction for DW or FW.

As explained in detail in example 4, at any draft,

$$W \text{ in DW} = \frac{W \text{ in SW} \times \text{density of DW}}{1.025} \quad (\text{at same draft})$$

$$\text{At 6.8 m draft in DW, } W = \frac{13943 \times 1.015}{1.025} = 13807 \text{ t}$$

The same correction for DW density must be applied to the tabulated TPC and MCTC.

$$\text{At 6.8 m draft in DW, TPC} = \frac{22.83 \times 1.015}{1.025}$$

$$= 22.607 \text{ t cm}^{-1}$$

$$\text{At 6.8 m draft in DW, MCTC} = \frac{180.3 \times 1.015}{1.025}$$

$$= 178.541 \text{ tm cm}^{-1}$$

Example 6

Find the hydrostatic particulars of m.v. 'VIJAY' at 12122 t displacement in FW.

As explained in detail in example 4,

$$\begin{aligned}
 W \text{ in SW} &= \frac{W \text{ in DW} \times 1.025}{\text{density of DW}} \quad (\text{at same draft}) \\
 &= \frac{12122 \times 1.025}{1} = 12425 \text{ t}
 \end{aligned}$$

Whereas she is displacing 12122 t of FW, she would displace 12425 t of SW at the same draft. The draft and the hydrostatic particulars may be interpolated for 12425 t of W in SW and the results obtained in two lots — the first lot requiring correction for density; the second lot being correct as it is.

$$\text{At any draft, } W \text{ in FW} = \frac{W \text{ in SW} \times 1}{1.025}$$

Hence, to convert SW W, TPC, and MCTC to FW divide each by 1.025.

From hydrostatic table

	W	Draft	TPC	MCTC
In SW	12122	6.0	22.45	172.9
In SW	12575	6.2	22.54	174.6
In SW	12425	6.134	22.510	174.03
Corrn.	$\div 1.025$		$\div 1.025$	$\div 1.025$
In FW	12122	6.134	21.961	169.79

From hydrostatic table,

Draft	AB	AF	KB	KMT	KML
6.0	71.960	71.472	3.205	8.234	217.2
6.2	71.939	71.329	3.309	8.180	211.6
6.134	71.946	71.376	3.275	8.198	213.4

These particulars, AB, AF, KB, KMT and KML, hold good at 6.134 m draft in water of any density.

Example 7

M.V. 'VIJAY', floating at 3.8 m draft in SW, loads 3640 t of cargo and pumps out 810 t of ballast. Find her new draft.

$$\begin{array}{rcl}
 \text{From hydrostatic table, at 3.8 m draft } W & = & 7277\text{t} \\
 \text{Cargo loaded} & = & 3640\text{t} \\
 & & \underline{10917\text{t}} \\
 \text{Ballast out} & = & 810\text{t} \\
 \text{New } W & = & 10107\text{t}
 \end{array}$$

Interpolating from hydrostatic table for W 10107t,

W	Draft
9891	5.0
<u>10333</u>	<u>5.2</u>
10107	5.098 m

Example 8

Initial SW draft of m.v. 'VIJAY' was 5.4 m and the final SW draft was 4.7 m. Meanwhile 2000 t of ballast was pumped out. Find the amount of cargo worked.

$$\begin{array}{rcl}
 \text{From hydrostatic table, } W \text{ at 5.4 m draft} & = & 10777\text{ t} \\
 \text{Ballast out} & = & \underline{2000\text{t}} \\
 \text{W before cargo work} & = & 8777\text{t} \\
 \text{From hydrostatic table, } W \text{ at 4.7 m draft} & = & \underline{9232\text{t}} \\
 \text{Hence, cargo loaded} & = & 455\text{ t}
 \end{array}$$

Note Though cargo work and deballasting may have been done simultaneously, it is easier to work it out as if the known quantity was handled first.

Example 9

M.V. 'VIJAY' arrives with a draft of 6.2 m in DW of RD 1.012. She is expected to load 2800 t of cargo and discharge 1098 t. Compute her departure draft in (i) DW (ii) SW.

$$\begin{aligned}
 \text{At 6.2 m draft, W in DW} &= \frac{W \text{ in SW} \times 1.012}{1.025} \\
 &= \frac{12575 \times 1.012}{1.025} \\
 &= 12415.5 \text{ t} \\
 \text{Hence arrival W} &= 12415.5 \text{ t} \\
 \text{Cargo loaded} &= \frac{2800.0 \text{ t}}{15215.5 \text{ t}} \\
 \text{Cargo discharged} &= \frac{1098.0 \text{ t}}{14117.5 \text{ t}} \\
 \text{Departure W} &= 14117.5 \text{ t}
 \end{aligned}$$

From hydrostatic table,	W	Draft in SW
	13943 t	6.8 m
	14402 t	7.0 m
	14117.5 t	6.876 m

Hence, SW draft on departure = 6.876 m = answer (ii)

To find the DW draft on departure, using hydrostatic table meant for SW, work as shown in example 4.

If draft is constant, u/w vol of a ship is also constant.

$$\frac{W \text{ in SW}}{1.025} = \frac{W \text{ in DW}}{\text{DW density}}$$

$$\begin{aligned}
 \text{Hence, at same draft, W in SW} &= \frac{14117.5 \times 1.025}{1.012} \\
 &= 14298.9 \text{ t}
 \end{aligned}$$

If ship is displacing 14117.5 t of DW, she would displace 14298.9 t of SW, at same draft. So entering the hydrostatic table with 14298.9 t, the draft can be obtained. This is the draft in DW at 14117.5 t W.

W	Draft
13943 t	6.8 m
<u>14402 t</u>	<u>7.0 m</u>
14298.9 t	6.955 m

Hence departure draft in DW = 6.955 m answer (i)
in SW = 6.876 m answer (ii)

Example 10

On arrival port, m.v. 'VIJAY' had a draft of 6.6 m when RD was 1.010. On departure the draft and RD were 5.4 m and 1.020. Find the amount of cargo worked.

$$\text{Arrival W} = \frac{13486 \times 1.010}{1.025} = 13288.6 \text{ t}$$

$$\text{Departure W} = \frac{10777 \times 1.020}{1.025} = 10724.4 \text{ t}$$

Hence, cargo worked in port: discharged 2564.2 t

Exercise 13 Hydrostatic table

- 1 Find the hydrostatic particulars of m.v. 'VIJAY' at 4.72 m draft in SW.
- 2 Find the hydrostatic particulars of m.v. 'VIJAY' at a displacement of 7990 t in SW.
- 3 If the draft of m.v. 'VIJAY' is 5.0 m in DW of RD 1.005, find the displacement.

- 4 Find the displacement when m.v. 'VIJAY' is at 5.63 m draft in water of RD 1.017.
- 5 Find the DW draft of m.v. 'VIJAY' when her displacement is 12650 t, if RD of DW is 1.009.
- 6 At 10,000 t displacement, find the draft of m.v. 'VIJAY' in DW of RD 1.020.
- 7 Find the hydrostatic particulars of m.v. 'VIJAY' at 5.0 m draft in DW of RD 1.015.
- 8 State the hydrostatic particulars of m.v. 'VIJAY' in FW at a draft of 6.1 m.
- 9 Calculate the hydrostatic particulars of m.v. 'VIJAY' at 4.7 m draft in DW of RD 1.013.
- 10 Find the hydrostatic particulars of m.v. 'VIJAY' at 10,000 t displacement in FW.
- 11 If m.v. 'VIJAY' has a displacement of 8576 t, find her hydrostatic particulars in DW of RD 1.018.
- 12 M.V. 'VIJAY' has a draft of 5.1 m in SW. She then loads 1800 t of cargo and takes on 400 t of bunkers and FW. Find her new draft.
- 13 The arrival and departure drafts of m.v. 'VIJAY' were 4.6 m and 5.0 m in SW. In port, 1500 t of bunkers, FW and stores were received. Find the amount of cargo worked. State whether the cargo was loaded or discharged.
- 14 M.V. 'VIJAY' at 4.0 m draft in SW loads 5000 t of cargo and pumps out 800 t of ballast. Find her final draft.
- 15 Initial draft of m.v. 'VIJAY' in DW of RD 1.010

is 5.3 m. She then loads 2500 t of cargo. Find her final draft (i) in the same dock. (ii) in SW.

- 16 M.V. 'VIJAY' is floating in DW of RD 1.017 at a draft of 5.6 m. How much cargo can be loaded so that her draft will be 6.4 m in SW?
- 17 M.V. 'VIJAY' arrives outside a river port at a SW draft of 6.0 m. She is to cross a 5.4 m deep bar in the river RD 1.015. Find the minimum cargo to discharge into lighters, so that she may cross the bar with an under-keel clearance of 0.4 m.
- 18 M.V. 'VIJAY' arrives at the port of Cochin (India) at 4.9 m draft in RD 1.006. On departure the draft was found to be 6.0 m—hydrometer reading 1.018. While in port, 2 heavy lifts weighting 200 t each were discharged. Find the amount of general cargo worked.
- 19 M.V. 'VIJAY' leaves the port of Bombay at 6.8 m draft in SW, bound for Calcutta. The owners want to know what would be the FW draft on arrival at the Calcutta pilot station. Can you help them out? Steaming time six days, consuming 20 t of fuel and 15 t of FW per day. State also the SW draft on arrival.
- 20 M.V. 'VIJAY' is expected to arrive at a river port at a FW draft not exceeding 6.3 m. She is at present in DW of RD 1.020 at 5.4 m draft. Find the maximum amount of cargo that may be loaded at present, if the steaming time to the river port is eight days, daily consumption of fuel being 14 t and FW 16 t.

HYDROSTATIC DRAFT

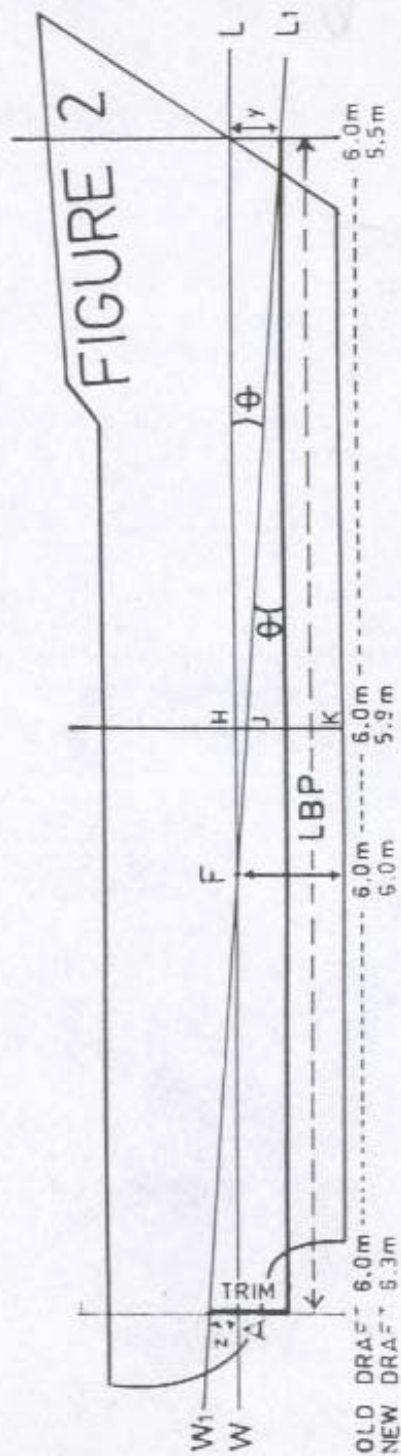
The hydrostatic particulars of a ship are indicated against hydrostatic draft which is the true draft of the ship. Hydrostatic draft may be a little different from the midship's draft (which is the arithmetical mean of the drafts for'd and aft) when the ship is not on an even keel.

The hydrostatic draft of a ship is the draft measured at the centre of flotation (COF).

COF is the geometric centre of the waterplane area of the ship and it is the point about which she would pivot, when her trim is changed. The position of COF is indicated by its distance forward of the after perpendicular of the ship (AF) or by its distance forward or abaft midships (HF). AF (or HF, as the case maybe) depends on the hydrostatic draft of the ship and its values are indicated against it in the hydrostatic particulars.

The meaning of hydrostatic draft is further explained as follows:

Imagine a ship floating at an even keel draft of 6.0 m. This means that her draft at the forward perpendicular is 6.0 m and at the after perpendicular also it is 6.0 m. Her mean draft (or draft amidships) is also 6.0 m. If some cargo is now shifted aft, the ship's after draft would increase and her forward draft would decrease — she would trim by the stern.



Trim is the difference between the drafts forward and aft.

If the COF is situated amidships i.e., if F and H were coincident, the ship would pivot about F and the change of drafts at the forward and after perpendiculars would be the same in value but opposite in sign, as shown in figure 1.

In figure 1, WL is the waterline before, & W_1L_1 the waterline after, the shifting of cargo towards aft. Because COF is amidships, the decrease in draft forward and the increase in draft aft are equal, indicated by x in figure 1. The trim caused would then be $2x$. The drafts before and after shifting of cargo are also indicated at the bottom of the figure at the forward perpendicular, the after perpendicular and amidships (mean draft). When the COF is amidships, mean draft and hydrostatic draft are the same.

If the COF is situated abaft amidships, as shown in figure 2, the change of drafts forward and aft would not only be opposite in sign (decrease forward & increase aft in this case) but would also be of different values — greater change forward and smaller change aft — indicated by y & z respectively in figure 2.

In figure 2, WL & W_1L_1 are the waterlines before and after shifting of cargo towards aft. The trim caused is $y+z$. The drafts before and after shifting cargo are indicated at each of four points — forward, aft, midships (mean) and at F. It may be noted that before, the drafts were 6.0 m all over but after shifting of cargo, the mean (midships) draft is 5.9 m in this case whereas the hydrostatic draft remains unaltered at 6.0 m.

Referring to figure 2 and omitting any specific numerals, in right angled triangle FIF₁,

$$\frac{HJ}{HF} = \tan \theta$$

$$\text{But } \tan \theta \text{ also} = \frac{\text{Trim}}{\text{LBP}}$$

$$\text{So } \frac{HJ}{HF} = \frac{\text{Trim}}{\text{LBP}} \text{ or } HJ = \frac{HF \times \text{Trim}}{\text{LBP}}$$

Hence, correction to apply to mean draft to obtain hydrostatic draft = $\frac{HF \times \text{Trim}}{\text{LBP}}$

This correction is positive when COF is abaft midships and the vessel is trimmed by the stern.

If the vessel was now trimmed by the head, by shifting cargo forward, the correction to apply to mean draft to obtain hydrostatic draft would be negative as illustrated by figure 3.

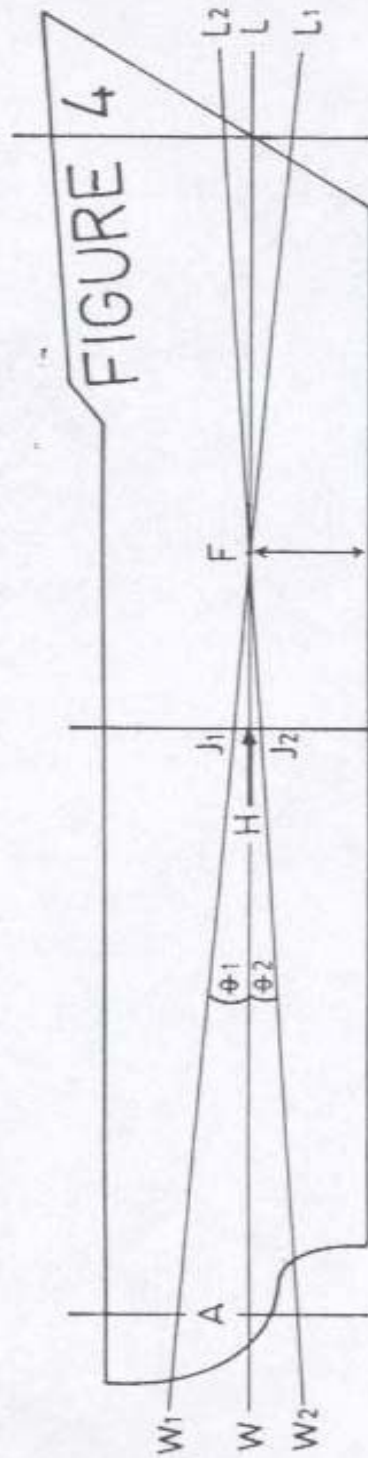
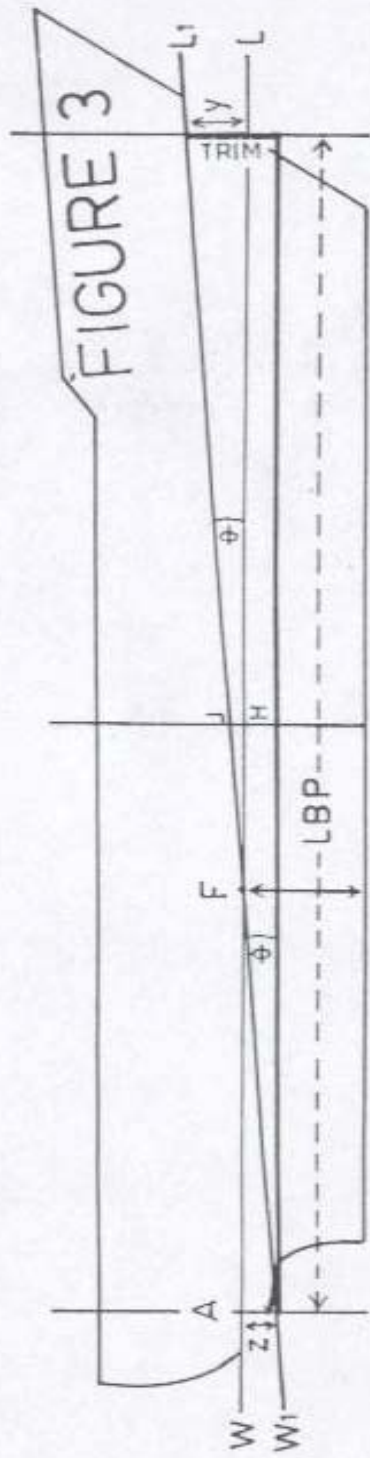
Similar simple illustrations can be made, where F is forward of midships, to show that:

Correction to apply to mean draft to obtain hydrostatic draft = $\frac{HF \times \text{trim}}{\text{LBP}}$ (See figure 4)

This correction is positive when HF and trim are of same name (both aft or both for'd) and negative when they are of contrary names (one for'd and other aft).

Note: HF is the distance of COF from amidships and is convenient to use if the ship's hydrostatic table indicates longitudinal distances from midships (H).

Hydrostatic draft may also be obtained by applying a correction to the aft draft of the ship. Referring to figures 2 & 3, it may be seen that the correction to apply to the aft draft to obtain



hydrostatic draft is z , to be subtracted when the ship is trimmed by the stern and added when trimmed by the head.

$$\frac{z}{AF} = \frac{\text{Trim}}{\text{LBP}} \quad (\text{Since both} = \tan \theta)$$

$$\text{Hence, } z = \frac{AF \times \text{Trim}}{\text{LBP}}$$

Hence, correction to apply to after draft to obtain hydrostatic draft = $\frac{AF \times \text{Trim}}{\text{LBP}}$

This correction is negative when the vessel is trimmed by the stern and positive when trimmed by the head.

Note AF is the distance of the COF from the after perpendicular of the ship and is convenient to use when the ship's hydrostatic table indicates longitudinal distances from the after perpendicular (A).

Example 1

A ship is floating at a draft of 4.9 m for'd & 6.3 m aft. Her LBP is 120 m. If her COF is 2 m abaft midships (HF 2 m aft or AF 58 m), calculate the hydrostatic draft.

For'd	4.9 m	For'd	4.9 m
Aft	6.3 m	Aft	6.3 m
Mean	5.6 m	Trim	1.4 m by stern

$$\begin{aligned} \text{Correction to mean draft} &= \frac{\text{HF} \times \text{Trim}}{\text{LBP}} \\ &= \frac{2 \times 1.4}{120} \\ &= 0.023 \text{ m} \end{aligned}$$

Since HF and trim are of same name (both aft), this correction is positive.

Mean draft	5.600 m
Correction	<u>+0.023 m</u>
Hydrostatic draft	5.623 m answer.

OR

$$\begin{aligned}\text{Correction to aft draft} &= \frac{AF \times \text{Trim}}{LBP} \\ &= \frac{58 \times 1.4}{120} = 0.677 \text{ m}\end{aligned}$$

Since trim is by stern, this correction is negative.

Aft draft	6.300 m
Correction	<u>-0.677 m</u>
Hydrostatic draft	5.623 m answer.

Example 2

Find the hydrostatic draft given the following particulars: Draft for'd 6.8 m, aft 5.0 m, COF 3 m aft of midships (i.e., HF 3 m aft or AF 60 m), LBP 126 m.

For'd	6.8 m	For'd	6.8 m
Aft	<u>5.0 m</u>	Aft	<u>5.0 m</u>
Mean	5.9 m	Trim	1.8 m by head

$$\begin{aligned}\text{Correction to mean draft} &= \frac{HF \times \text{Trim}}{LBP} \\ &= \frac{3 \times 1.8}{126} = 0.043 \text{ m}\end{aligned}$$

Since HF and trim are of contrary names, this correction is negative.

Mean draft	5.900 m
Correction	<u>-0.043 m</u>
Hydrostatic draft	5.857 m answer,

OR

$$\begin{aligned}\text{Correction to aft draft} &= \frac{AF \times \text{Trim}}{LBP} \\ &= \frac{60 \times 1.8}{126} = 0.857 \text{ m}\end{aligned}$$

Since trim is by head, this correction is positive.

Aft draft	5.000 m
Correction	<u>+0.857 m</u>
Hydrostatic draft	5.857 m answer.

Example 3

M.V. 'VIJAY' is floating in SW at 5.0 m for'd and 7.0 m aft. Find her hydrostatic draft, using the hydrostatic table given in Appendix I.

For'd	5.0 m	For'd	5.0 m
Aft	<u>7.0 m</u>	Aft	<u>7.0 m</u>
Mean	6.0 m	Trim	2.0 m by stern

For mean draft of 6.0 m, AF = 71.472 m

$$\begin{aligned}\text{Correction to aft draft} &= \frac{AF \times \text{Trim}}{LBP} \\ &= \frac{71.472 \times 2}{140} = 1.021 \text{ m}\end{aligned}$$

Since trim is by stern, this correction is negative.

Aft draft	7.000 m
Correction	<u>-1.021 m</u>
Hydrostatic draft	5.979 m answer.

OR

HF in this case is 1.472 m for'd

$$\begin{aligned}\text{Correction to mean draft} &= \frac{\text{HF} \times \text{Trim}}{\text{LBP}} \\ &= \frac{1.472 \times 2}{140} = 0.021 \text{ m}\end{aligned}$$

Since the trim and HF are of contrary names, this correction is negative.

Mean draft	6.000 m
Correction	<u>-0.021 m</u>
Hydrostatic draft	5.979 m answer.

Example 4

Find the hydrostatic draft of m.v. 'VIJAY' when at 4.9 m for'd draft and 5.5 m aft draft in DW of RD 1.010.

For'd	4.9 m	For'd	4.9 m
Aft	<u>5.5 m</u>	Aft	<u>5.5 m</u>
Mean	5.2 m	Trim	0.6 m by stern

From the hydrostatic table, AF is 71.842 m at 5.2 m draft in water of any density.

$$\begin{aligned}\text{Corrn to aft draft} &= \frac{\text{AF} \times \text{Trim}}{\text{LBP}} \\ &= \frac{71.842 \times 0.6}{140} = 0.308 \text{ m}\end{aligned}$$

Since trim is by stern, this correction is negative.

Aft draft	5.500 m
Correction	<u>-0.308 m</u>
Hydrostatic draft	5.192 m answer.

Note : This may also be worked using HF as illustrated in earlier examples.

Exercise 14
Hydrostatic draft

- 1 Drafts for'd 6.6 m, aft 8.6 m; COF 2 m for'd of midships; LBP 100 m. Find hydrostatic draft.
- 2 Given the following particulars, find the hydrostatic draft in DW of RD 1.016 : Drafts for'd 4.9 m, aft 4.3 m; HF 3.0 m for'd; LBP 120 m.
- 3 A vessel is floating in FW at drafts of 8.0 m for'd and 12.0 m aft. If her HF is 2.5 aft and LBP is 200 m, calculate her hydrostatic draft.
- 4 Drafts for'd 9.6 m, aft 8.2 in SW; COF 1.8 m abaft midships; LBP 180 m. Find hydrostatic draft.
- 5 A ship is floating in water of RD 1.012 at drafts of 7.2 m for'd and 8.8 m aft. Find her hydrostatic draft if the COF is amidships.
- 6 A ship of LBP 176 m is floating in FW at a draft of 12.6 m for'd and 12.6 m aft. If her COF is 3 m for'd of midships, find her hydrostatic draft.
- 7 Drafts in FW, for'd 6.6 m, aft 8.4 m, LBP 200 m; AF 96 m. Find hydrostatic draft.
- 8 M.V. 'VIJAY' is floating in DW of RD 1.020 at drafts of 4.2 m for'd and 6.0 m aft. Find her hydrostatic draft.
- 9 M.V. 'VIJAY' is floating in DW of RD 1.015 at drafts of 5.0 m for'd and 7.0 m aft. Find her hydrostatic draft in SW.

NOTE: Find hydrostatic draft in DW and then

compute hydrostatic draft in SW.

- 10 M.V. 'VIJAY' is floating at drafts of 6.2 m for'd and 7.8 m aft in FW. Find her present displacement. If the departure draft in SW is not to exceed 7.0 m state how much cargo she may load.

ANSWERS

Exercise 1

- 1 1123.2 t 2 1.158 m 3 1646.4 t, 0.24 m
 4 423.6 t, 0.291 m 5 1537.5 t 6 3.398 m, 5136.8 t
 7 1.5 m 8 0.333 m 9 6428.8 t, 0.41 m
 10 8956.3 t, 1.097 m

Exercise 2

- 1 164 t 2 47470 t (two sides 15150 t, two ends 2020 t and keel 30300 t) 3 2000 m 4 440.4 t towards shallower side.
 5 15.804 m 6 738 t 7 145.3 t
 8 6.864 t 9 50.02 t 10 8200 t, 4100 t outwards.

Exercise 3

- 1 25.6 t, 0.8 2 0.732 m, 0.75 3 1.386 m
 4 7.92 t 5 328 t 6 0.689 t 7 102.5 t
 8 1.749 t 9 6 m 10 2025 t

Exercise 4

- 1 7380 t, 18081 t, 10701 t 2 10906 t, 5740 t, 1291.5 t
 3 32.8 tcm $^{-1}$, 32.0 tcm $^{-1}$, 32.48 tcm $^{-1}$
 4 163.59 t 5 9092.16 t, 2907.84 t 6 0.7
 7 30‰ 8 42.857% 9 29.268 tcm $^{-1}$, 29.795 tcm $^{-1}$
 10 788.3 t

Exercise 5

- 1 8.2 m 2 12.2 cm rise. 3 6.4 cm sinkage.
 4 8.4 cm rise. 5 5.0 cm 6 1.063 m 7 31.71‰
 8 2979.5 t 9 4590 t 10 320 t 11 212.2 t
 12 152.2 t 13 397.7 t 14 620.8 t 15 427.8 t
 16 307.9 t 17 906 t 18 640 t 19 567.2 t
 20 309.7 t

Exercise 6

- 1 6.1 m 2 5.75 m 3 4.11 m 4 6.45 m
 5 Decreases by 0.75 m 6 10.8 m 7 450.45 t
 8 (a) 7.9 m (b) 7.45 m 9 (a) 9.358 m (b) 9.188 m
 10 (a) 8.057 m (b) 8.010 m

Exercise 7

- 1 3.380 m 2 4.100 m 3 6.109 m 4 4.183 m
 5 4.865 m 6 1272.7 t 7 225.8 m
 8 (a) 8.475 m 9 (a) 8.191 m 10 (a) 7.120 m
 (b) 8.266 m (b) 7.954 m (b) 7.053 m

Exercise 8

- 1 1.6 m 2 3.048 m 3 3.558 m 4 1328.4 t
 5 0.082 m 6 0.053 m 7 0.497 m 8 2.487 m
 9 KB 2.5 m, AB 28.107 m 10 KB 3.667 m, AB 22.5 m

Exercise 9

- 1 348.6 tm 2 1200 tm, 7.243 m 3 7.505 m
 4 GZ 0.239 m, RM 1912 tm 5 GZ 0.300 m, RM 1200 tm

Exercise 10

- 1 0.043 m 2 0.050 m 3 0.600 m 4 0.974 m
 5 0.054 m 6 0.456 m 7 0.785 m 8 0.386 m
 9 0.574 m 10 0.737 m 11 0.810 m
 12 0.833 m 13 0.285 m 14 0.458 m 15 1.874 m
 16 (a) 0.531 m (b) (i) 0.133 m (b) (ii) 0.066 m
 (c) (i) 0.059 m (c) (ii) 0.039 m (c) (iii) 0.020 m
 (d) (i) 0.033 m (d) (ii) 0.025 m (d) (iii) 0.017 m
 (d) (iv) 0.008 m 17 (a) 0.0107 m (b) 0.021 m

- 17 (c) 0.288 m (d) 0.309 m (e) 1.333 m
 18 No. 1, No. 3 any one side, No. 3 other side, No. 2 any one side, No. 2 other side, No. 3 centre.
 19 No. 4 wing tank on lower side, No. 4 wing tank on higher side, No. 1 DB tank.
 20 (a) 537.7 tm (b) GZ 0.331 m, RM 2648 tm

Exercise 11

- 1 3.81° or $3^\circ 49'$ 2 4.29° or $4^\circ 17'$ to stbd.
 3 9.46° or $9^\circ 28'$ to stbd. 4 4.81° or $4^\circ 49'$
 5 2.35° or $2^\circ 21'$ to port. 6 4.63° or $4^\circ 38'$ to stbd.
 7 8.23° or $8^\circ 14'$ to port. 8 4.21° or $4^\circ 13'$ to stbd.
 9 7.04° or $7^\circ 03'$ to stbd. 10 124.8 t
 11 2.02° or $2^\circ 01'$ to port. 12 14.71° or $14^\circ 42'$ to stbd.
 13 2.56° or $2^\circ 33'$ to stbd. 14 132 t from stbd. to port.
 15 4.93° or $4^\circ 56'$ to stbd. 16 31.7 t
 17 124.2 t on port side, 375.8 t on stbd side.
 18 (i) 9.46° or $9^\circ 28'$ to stbd. (ii) 3.85° or $3^\circ 51'$ to stbd
 19 (i) 7.78° or $7^\circ 47'$ to port. (ii) 2.91° or $2^\circ 55'$ to stbd.
 (iii) 1.61° or $1^\circ 36'$ to stbd.
 20 (i) 7.48° or $7^\circ 29'$ to stbd. (ii) 8.93° or $8^\circ 56'$ to port.
 (iii) 1.61° or $1^\circ 36'$ to stbd.
 21 (i) 264.5 t (ii) 6.69° or $6^\circ 42'$ to port.
 22 3.19° or $3^\circ 12'$ 23 10.69° or $10^\circ 41'$ to port.
 24 3.43° or $3^\circ 26'$ to port. 25 206.6 t to stbd.

Exercise 12

- 1 (a) 19.5 tcm $^{-1}$ (b) 2.55 m 2 5425 t 3 4.85 m
 4 (a) 2450 t (b) 8.75 tcm $^{-1}$ (c) 3616 t
 5 23.26 tcm $^{-1}$, 21.78 tcm $^{-1}$ 6(a) 6317.1 m² (b) 4.054 m
 7 4.100 m 8 5.000 m 9 (a) 8.2 m at 7.5 m draft.
 (b) 2.25 m 10 179 m

Exercise 13

1	Draft	RD	W	TPC	MCTC
	4.72	1.025	9275.8	21.938	163.66
	AB	AF	KB	KMT	KML
	72.016	71.987	2.535	8.894	268.0
2	W	RD	Draft	TPC	MCTC
	7990	1.025	4.130	21.665	158.972
	AB	AF	KB	KMT	KML
	72.011	72.109	2.218	9.495	301.3
3	9698.0 t	4	11202.2 t	5	6.321 m
7	Draft	RD	W	TPC	MCTC
	5.0	1.015	9794.5	21.845	164.083
	AB	AF	KB	KMT	KML
	72.014	71.913	2.685	8.686	254.3
8	Draft	RD	W	TPC	MCTC
	6.1	1.000	12047.3	21.946	169.512
	AB	AF	KB	KMT	KML
	71.950	71.401	3.257	8.207	214.4
9	Draft	RD	W	TPC	MCTC
	4.7	1.013	9123.9	21.673	161.586
	AB	AF	KB	KMT	KML
	72.017	71.992	2.525	8.910	269.0
10	W	RD	Draft	TPC	MCTC
	10000	1.000	5.162	21.585	162.765
	AB	AF	KB	KMT	KML
	72.012	71.855	2.769	8.589	247.1
11	W	RD	Draft	TPC	MCTC
	8576	1.018	4.427	21.663	160.386
	AB	AF	KB	KMT	KML
	72.015	72.050	2.381	9.156	283.5

- 12 6.084 m 13 622 t discharged. 14 5.905 m
15 (i) 6.427 m (ii) 6.343 m 16 1894.6 t
17 2327.5 t 18 Loaded 2947.5 t
19 6.858 m, 6.708 m 20 2005.8 t

Exercise 14

- 1 7.560 m 2 4.615 m 3 10.050 m
4 8.886 m 5 8.000 m 6 12.600 m
7 7.536 m 8 5.076 m 9 5.927 m
10 14035.0 t, 367.0 t

Appendix I
HYDROSTATIC TABLE OF M.V. 'VIJAY'

DRAFT	W	TPC	MCTC	AB	AF	KB	KM _T	KM _L
	t in SW	t cm ⁻¹	tm cm ⁻¹	m	m	m	m	m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

W displacement
A after perpendicular
K keel
SW salt water of RD 1.025

Load W 19943 t
Light W 6000 t
DWT 13943 t

LOA 150.00 m
LBP 140.00 m
GRT 10,000 Tons
NRT 5576 Tons

End Of Volume 01