COMPLETE SHIP STABILITY

FUNDAMENTAL CONCEPTS AND PRACTICE ON SHIPS

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Pre sea Courses: 1-9

2nd Mate FG & NCV NWKO : Ch. 1-6, 8, 9, 7 (part), 9(part), 11(part), 12(part).

1st Mate Phase 1: Ch 1-16.

1st Mate Phase 2: Ch 1-10, 11 (part), 12, 14, 17-23.

Gaspard-Gustave de Coriolis or Gustave Coriolis (21 May 1792 - 19 September 1843) was a French mathematician, mechanical engineer and scientist. He is best known for his work on the Coriolis Effect. Coriolis was the first to coin the term "work" for the product of force and distance.



Chapter 1 Understanding basic terms

Mass and weight: - Mass is a measure of quantity of matter in a body. It must be understood and differentiated from the weight which is force acting on the mass towards earth's centre.
The unit of mass in SI system is kilogram; tonne being a popular unit used for ship board calculations and is equal to 1000 kg. The gravitational force acting on 1kg of mass is equal to 9.81 Newton.

Force: - is a vector quantity which can cause an object with mass to accelerate. Force has both magnitude and direction . According to Newton's second law, an object with constant mass will accelerate in proportion to the net force acting upon it. Thus force is equal to rate of change of momentum or is equal to the product of mass and acceleration. The unit of force in SI system is Newton

Moment of force: - (*often* just *moment*) is a synonym for torque, an important basic concept in physics. One or the other may be preferred in a specific context. For example, "torque" is usually used to describe a rotational force in respect of a shaft, or in respect of a turning screw-driver, whereas "moment" is more often used to describe a bending force on a beam.
The moment is directly proportional to the magnitude of force and the length of lever. Although the unit in physics is Newton metre or kilo Newton metre but for shipboard used often tonnes metre is used for ease of calculations. This does not cause any problem as the regulatory criteria are given in the same unit.

Torque: - is the tendency of a force vector to rotate an object about some axis (or fulcrum).
The magnitude of torque depends on three quantities: First, the force applied; second, the length of the *lever arm* connecting the axis to the point of force application; and third, the angle between the two. In symbols: $\tau = r \times F \sin \theta$

Where,
τ is the torque vector and is the magnitude of the torque,
r is the lever arm vector (vector from the axis to the point of force application) and is the length (or magnitude) of the lever arm vector,
F is the force vector, and is the magnitude of the force,
θ is the angle between the force vector and the lever arm vector,
The SI unit for torque is the Newton meter (N·m).

Work: - done is the amount of energy transferred by a force acting through a distance. Like energy, it is a scalar quantity, with SI units of joules.

Centre of Gravity: - That point at which all the vertically downward forces are assumed to be acting from and in fact is the center of the mass of the vessel. The centre of mass is normally referred to as the centre of gravity.

Draft: Is the vertical distance from waterline to lower point of the keel.

Centre of flotation: - Centre of flotation is the centroid of ship's waterplane area. In rolling and piching the vessel pivots about this point. The hydrostatic draft is measured at centre of flotation.

Displacement of the vessel (Δ):- is actually the mass of the vessel. For the normal shipboard calculations the displacement is referred to as the weight of the ship. The term displacement in respect of a ship is derived from the fact that a vessel displaces the equivalent mass of water in which she floats. The unit used is metric tonnes.

Centre of Buoyancy (COB): - is the centroid of under water portion of the vessel. At COB the entire buoyancy force acting vertically upwards is assumed to act.

Even keel: - A ship is said to be on a even keel when the keel is horizontal and hence the draft forward and aft are same.

KB or VCB: - is the vertical distance between the centre of buoyancy of a vessel and her keel. (When vessel is upright)

Transverse Metacentre: - While the ship rolls on either side of upright equilibrium, the COB would go to and fro of its mean position. Uprights drawn through these COB's would meet at the transverse metacentre of the ship.
If we assume that the COB goes to and fro along a swing, then the imaginary suspended point of the swing can be understood as transverse metacentre.
The vertical distance BM_T for any equilibrium position is found by following formula:

$$BM_T = \frac{\text{moment of inertia of water plane area about centreline}}{\text{under water volume}}$$

Metacentric height: - Is the vertical distance from the met center to the center of gravity of a ship. If the center of gravity is below the metacentre the vessel is stable and vice versa.

Longitudinal metacentre:- While the ship pitches slightly either way of normal trimmed equilibrium, the COB would go longitudinally to and fro of its mean position. Uprights drawn through these COB's would meet at the longitudinal metacentre of the ship.
If we assume that the COB goes longitudinally to and fro along a swing, then the imaginary suspended point of the swing can be understood as longitudinal metacentre.
The vertical distance BM_L for any equilibrium position is found by following formula:

$$BM_L = \frac{\text{moment of inertia of water plane area about athwart ship line through COF}}{\text{under water volume}}$$

KM_T: - is the vertical height of transverse meta center above keel.

KM_L: - is the vertical height of longitudinally metacenter above keel.

KG: - is the vertical height of COG of vessel above keel.

Length over all: - The extreme length of the ship measured form the foremost point of the stem to the aftermost part of the stern.

Length between perpendicular (LBP):- The length of a ship between the forward and after perpendiculars. The forward perpendicular is vertical line at the intersection of the fore side of the stem and the summer load waterline. The after perpendicular is a vertical line at the intersection of the summer load line and the after side of the rudder post or sternpost.

LCB or AB: - is the longitudinal (along the ship's fore and aft line) distance of COB forward of aft perpendicular.

LCF or AF: - is the longitudinal (along the ship's fore and aft line) distance of COF forward of aft perpendicular.

LCG or AG: - is the longitudinal (along the ship's fore and aft line) distance of COG forward of aft perpendicular.

Tonnes per cm (TPC):- at any draft is the weight in tonnes that must be loaded or discharged to change the present draft by 1 cm. unless specified for other densities TPC means the TPC in salt water.

Moment to change the trim by 1 cm (MCTC):- at any draft is the longitudinal moments in tonnes metre that will change the trim by 1 cm. unless specified for other densities MCTC means the MCTC in salt water.

Equilibrium: - Equilibrium means the state of rest which is achieved when the following two conditions are satisfied:
(i)The vector sum of all *external forces* is zero.
(ii) The sum of the moments of all *external forces* about any line is zero.
In case of a ship the major forces are the weight and the buoyancy. The other external factors (wind, swell etc) can cause movement of ship about rolling axis, pitching axis and heaving axes or along an axis formed by combination of these basic axes. We may normally say that a ship is standstill or stationary or is at rest when she is not rolling pitching or heaving. Thus a listed ship, a ship at angle of loll, a ship that is trimmed or even grounded ship is at equilibrium if at rest. A rolling or a pitching vessel is not in equilibrium and is in the process of attaining equilibrium.

For a ship at equilibrium:
1. The weight force (W) is equal to buoyancy force (B).
2. COB and COG are in the same vertical line
3. The righting lever GZ_T, GZ_L are both zero.
4. On the GZ curve the heel angles at which the ship can be at equilibrium are indicated by the points at which GZ curve touches x-axis.

Heel: - The inclination of a ship to one side. Normally heel is understood as inclination due to external forces as against list which is the inclination due to the weight distribution within the ship. The term heel is also used in place of list. E.g. 'grain heeling moment' is the term normally used to mean grain listing moment.

Trim Difference between the drafts forward and aft.

Stability: - Stability is a ability of vessel to return to the up-right equilibrium. In case of a listed vessel or the vessel at angle of loll it would be the ability to return to the respective angles of equilibrium. The stability of a ship thus is GZ_T rather than GM_T. The GZ at various angles of heel i.e. GZ curve therefore represents the true stability status or picture of the ship. One glance at the GZ curve would provide a clear picture of ship's stability status. The ship's stability information must be such that the Master is able to get a clear stability picture of his ship in rapid and simple manner in all service conditions including in the various damage conditions. This objective of SOLAS can be met only if the stability information provides the GZ curve for all the conditions in which Master may find his vessel.

Under the influence of external forces B would shift out of the vertical line (GB) causing a loss of equilibrium. As a rule the vessel tries to attain equilibrium by B following G to once again come in a vertical line. It is a misnomer that a trimmed vessel has LCB ≠ LCG with many mariners. Well LCB has to be equal to LCG when the ship is trimmed and is still. In the formula,

$$\frac{(LCB \sim LCG)Displacement}{100MCTC} = Trim$$

We must know the following:-
LCB is even keel LCB, (as given in the hydrostatic particulars).
LCG is as per the present load condition & thus the present LCG.
Trim is the change of trim from the even keel condition which is given in hydrostatic particulars. Trim should not be understood as the total trim.

Pythagoras: Born between 580 and 572 BC, died between 500 and 490 BC) was an Ionian Greek mathematician and founder of the religious movement called Pythagoreanism. He is often revered as a great mathematician, mystic and scientist; however some have questioned the scope of his contributions to mathematics and natural philosophy. Herodotus referred to him as "the most able philosopher among the Greeks".
He is best known for the Pythagorean Theorem, which bears his name. Known as "the father of numbers", Pythagoras made influential contributions to philosophy and religious teaching in the late 6th century BC.



Ch. 2 Basic shapes, areas and volumes

It is important that a mariner has a fair idea of calculation involving areas & volumes of various regular shapes. This will often help him swiftly do different cargo and stability calculations. He can quickly get an approximate idea of stowage / stability and will feel more confident and at home in any situation. Following are some of the important formulae for regular shapes. Thereafter various examples are done where by these formulae are made use of.

Ex. 1 Find the length of diagonal of a square whose area is $400m^2$.
Sol^n: - Area of square = $l^2 = 400m^2$. $\therefore$ l = 20m.

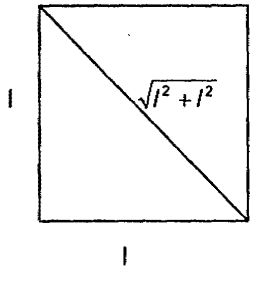
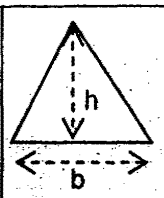
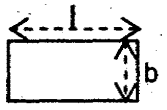
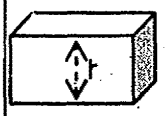
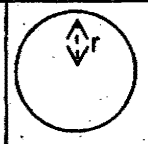
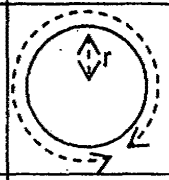
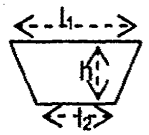


Fig. 1

Length of diagonal = $\sqrt{l^2+l^2} = \sqrt{800} = 28.28m$

Ex. 2 Find the length of a rectangle if its area is $36m^2$ and one of the sides is 4.8m.
Sol^n: - l x b = 36 $\therefore$ l x 4.8 = 36 $\therefore$ $l = \frac{36}{4.8} = 7.5m$

Ex. 3 PQRS is a trapezium shaped bulkhead of a tank in which SR // PQ and SR is 5m longer than PQ. If the area of trapezium is $38m^2$ and the height of the tank is 4m. Find the width of the tank top and bottom.
Sol^n:- let PQ, the side at top be = X m, then SR = X + 5
Area of PQRS = ½ x 4 x (X + X+ 5) = 38
$\therefore$ 4X + 10 = 38, gives X = 7m.
$\therefore$ The sides are 7m and 12m

Area of triangle		$\frac{1}{2} \times b \times h$	b is the base of triangle and h is the height of the apex above base. The centroid of a triangle is the intersection of the medians and the distance to the base along a straight line is one third the total distance from the apex to the base.
Area of rectangle		l x b	l is the length and b is the breadth of the rectangle
Area of square		l^2	
Volume of a cuboid tank		Lbh	h is the height of the tank
Area of circle		πr^2	r is the radius of the circle. In case of a semi circle the distance of centroid to diameter is $\frac{4r}{3\pi}$
Circumference of circle		$2\pi r$	r is the radius of the circle
Area of trapezium		$\frac{1}{2}h(l_1 + l_2)$	l_1 and l_2 are the lengths of the parallel sides and h the distance between the parallel side
Volume of a cylinder		$\pi r^2 h$	r is the radius and h is height of the cylinder
Area of curved surface of cylinder		$2\pi r h$	r is the radius and h is height of the cylinder

Ex. 4 A right circular cylinder has a height of 2.8m and a radius of 72 cm. find its volume, area of curved surface and total area.

Sol^n: -

h =2.8 m, r = 72cm= 0.72m

Volume $= \pi r^2 h = \frac{22}{7} \times 0.72 \times 0.72 \times 2.8 m^2$

$= 4.562 m^3$

Area of curved surface $= 2\pi rh = 2 \times \frac{22}{7} \times 0.72 \times 2.8 m^2$

$= 12.672\ m^2$

Total surface area $= 2\pi r^2 + 2\pi rh$

$= 2\pi r\,(r + h)$

$= 2 \times \frac{22}{7} \times 0.70(0.7 + 2.8) m^2$

$= \frac{2 \times 22 \times 0.70 \times 3.5}{7} m^2 = 15.4 m^2$

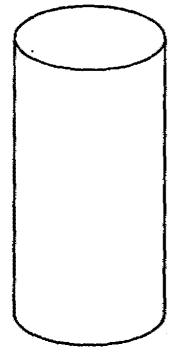


Fig. 2

Ex.5 A metal pipe 154 cm long, has an outer radius equal to 5.5 cm and an inner radius of 4.5 cm. What is the mass of the pipe if the density of material is 5.8t / m^3?

Sol^n: -

Outer volume $= \pi r^2 h = \frac{22}{7} \times (5.5)^2 \times 154 cm^3$

Inner volume $= \frac{22}{7} \times (4.5)^2 \times 154 cm^3$

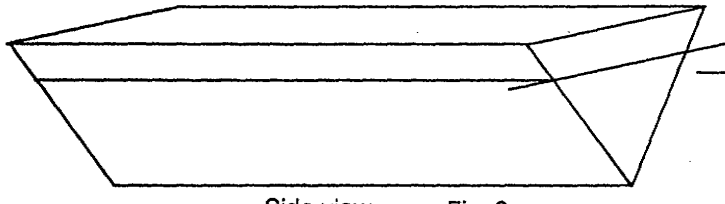
Volume of metal = outer volume – inner volume

$= \frac{22}{7} \times 154 \times (5.5)^2 - \frac{22}{7} \times 154 \times (4.5)^2 = 4840 cm^3 = 0.00484 m^3$

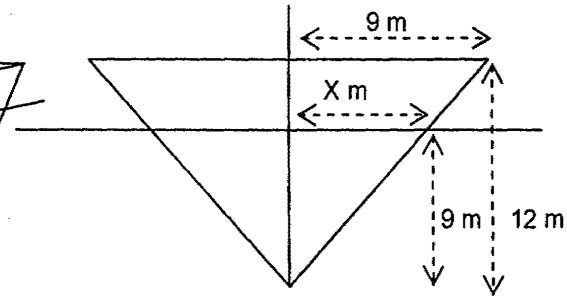
Mass of pipe = v x δ = 0.00484 x 5.8 = 0.0281t

Ex. 6 A vessel with triangular transverse section with apex down and longitudinally uniform has a length of 90m and breadth at deck level equal to 18m. Find the underwater volume if her depth is 12m and is floating at even keel draft of 9m.

Sol^n:-



Side view Fig. 3



View from stern Fig. 4

Using the principle of similar triangle to find the width at water level:

$\frac{x}{9} = \frac{\text{draft}}{\text{depth}} = \frac{9}{12}$

$\therefore x = \frac{9 \times 9}{12} = 6.75 m$. ∴ Breadth at waterline = 6.75 x 2 = 13.5m

Underwater volume = transverse area x length = ½ x 13.5 x 9 x 90 =5464.5m^3
Ans. UW volume = 5464.5m^3

Ex. 7 A tank has semicircular cross section of radius 4m and length 6m. It has rounded portion at the base and the flat portion on top. The oil in the tank is filled up to a sounding of 2m. Find the quantity of oil.

Sol^n:-

$\theta = \text{Sin}^{-1}\ \frac{2}{4} = 30°$

By Pythagoras side BG = 3.464m

$$\frac{\text{area of sector ABF}}{\text{area of complete circle}} = \frac{\theta°}{360°}$$

$\therefore$Area of sector ABF = πr^2 x $\frac{30}{360}$ = 4.187m^2

Area of triangle BFG = ½ x 2 x 3.464 = 3.464m^2

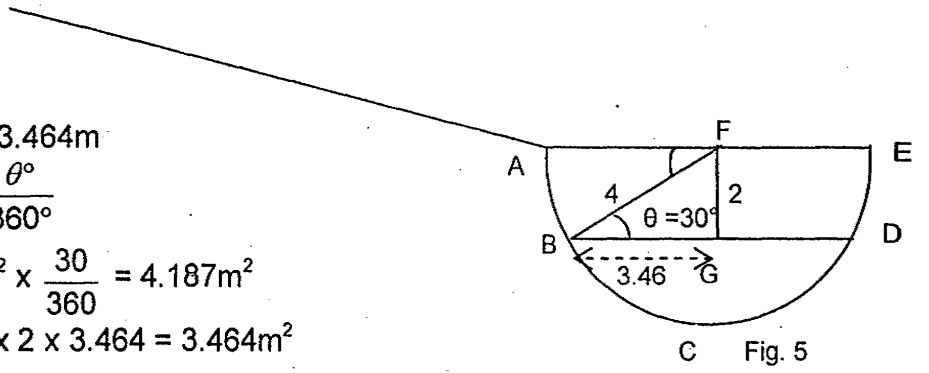


Fig. 5

Area of ABGF = 4.187 + 3.464 = 7.651 m^2
$\therefore$ Area ABDE = 2 x 7.651 = 15.302m^2
Transverse area BCDG = area of semicircle – 15.302 m^2 = 25.12 – 15.302 = 9.818m^2.
Underwater volume = 90 x 9.818 = 883.62m^3.

Exercise 2

Q. 1 A tank is 6 metres long 4 metres broad and 5 metres high. Find the area of the four side walls. Also find the area of the tank bottom. If it costs USD 3.5 to paint 1 m^2 of plating find the cost of painting the tank from inside.
Ans. Walls, 100m^2, Bottom, 24m^2. Painting cost, USD 434.

Q. 2 A tank is of dimensions l = 7.3m, b = 5.4m and h = 5m. The tank top from inside is to be painted @ USD 5 per m^2, the sides and bottom is to be painted @ USD 3 per m^2. Find the cost of painting the tank from inside.
Ans. 197.1 + 381 = USD 578.1.

Q. 3 In trapezium ABCD, AB = AD = BC = 6 m and CD = 10m. Find the area of the trapezium.
Area = ½ (6 + 10) x 5.66
Ans. 45.28m^2

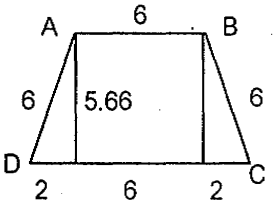


Fig. 6

Q. 4 A trapezium ABCD has two right angles at A and D. Measurements in centimeters are given as shown in the fig. find the area of the trapezium.

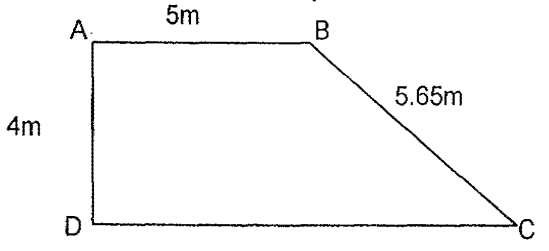


Fig. 7

Ans. 28m^2

Q. 5 A cuboidal FW tank with the length and width of its base being 5m and 4m respectively contains 72 m^3 of water. What is the sounding of the water in the tank?
Sol^n: - volume of the water = area of the bottom x sounding

$$\text{Sounding in the tank} = \frac{\text{volume}}{\text{base area}} = \frac{72}{20} = 3.6m$$

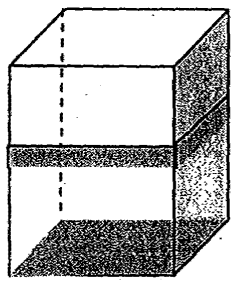


Fig. 8

Q. 6 A cuboidal tank of base area 3m x 4m and height 5m full of water is released into a cylindrical tank of radius 1.2 m and height 2.4m till the tank is full. What is the new sounding of the cuboidal tank?
Sol^n:-
Volume of water in cuboidal tank = 60m^3.

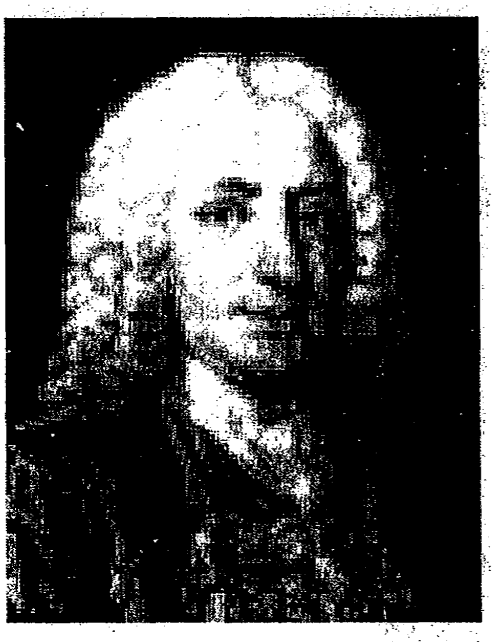
$$\text{Volume of cylinder} = \pi r^2 h = \frac{22}{7} \times 1.2 \times 1.2 \times 2.4m^3 = 10.86m^3$$

Remaining volume in cuboidal tank = 60 -10.86 = 49.14m^3

$$\text{Sounding in the tank} = \frac{\text{volume}}{\text{base area}} = \frac{49.14}{12} = 4.094m^2$$

Ans. 4.094m

Dr. Daniel Bernoulli: The groundwork for the basic principle of flight was laid by a Swiss mathematician named Daniel Bernoulli (1700-1785). Not only did he coin the term "hydrodynamics," but he also discovered that a fluid's pressure is inversely proportional to its flow velocity. In other words, the faster the fluid moves, the lower its pressure will be. Later airplane designers, including the Wright brothers, saw that a wing that was flat on the bottom and curved on the top allowed the air flowing over it to move faster over the top than over the bottom. Curved surfaces have more surface area, so the air spreads out over the larger surface as it speeds up. This has the unique effect of producing a lower pressure above the wing than below, creating lift.



Ch 3 Calculation of KB and LCB for symmetrical volumes

The center of buoyancy is the centroid of the underwater volume of a ship. This is the point at which up-thrust or the force of buoyancy is assumed to act. In many stability based situations it becomes important to find the position of COB with respect to a reference base or 'fore and aft end' which normally is keel and aft perpendicular of the vessel. In case of box shaped vessel that is on even keel COB lies at the half way length and depth which means that KB = ½ draft and LCB = ½ LBP.

In case of a vessel that is longitudinally uniform and has a triangular transverse section with apex down and is floating on even keel, KB is ⅔ draft and LCB = ½ LBP.

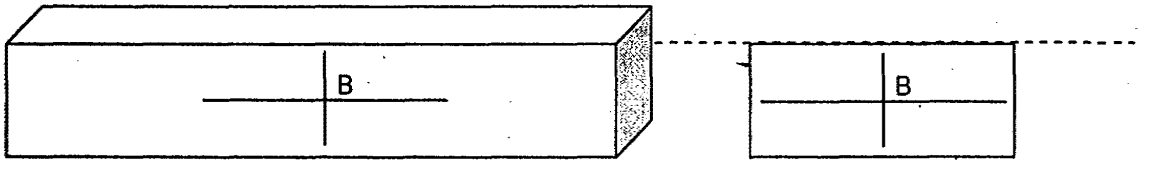


Fig. 1

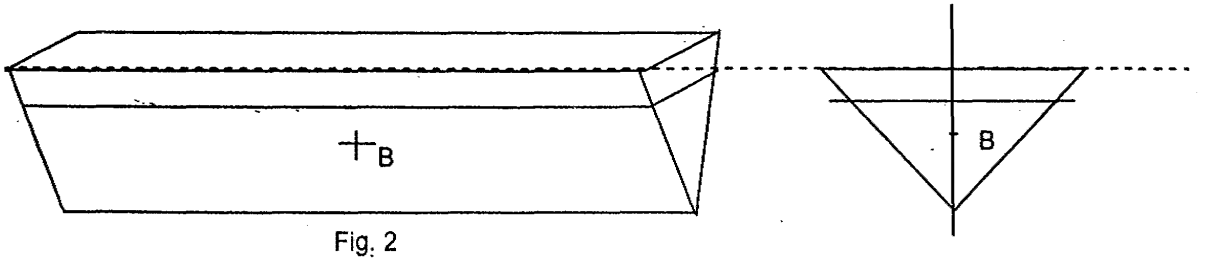


Fig. 2

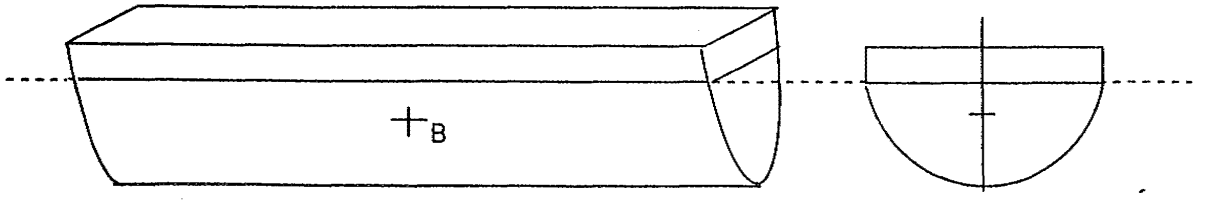


Fig. 3

Ex. 1 A box shaped vessel l = 110m, b = 20m is floating at a draft of 8m. Find KB and LCB.
Sol^n: - KB for box shape or wall sided vessel is half of the draft.
Also LCB for vessels with longitudinally uniform transverse area is half of the LBP.
KB = ½ draft = ½ x 8 = 4m
LCB = ½ LBP = ½ x 110 = 55m.

Ex. 2 A vessel with triangular transverse section is longitudinally uniform and has KB = 4m, beam = 15m and LCB = 46m, is floating in sea water. If her freeboard is 1.6m find displacement and her buoyancy above water level.
Sol^n: -
Since the transverse section is triangular KB = ⅔ draft

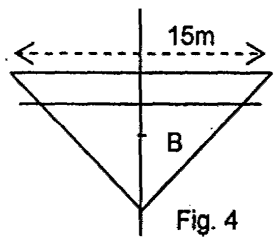


Fig. 4

$$\therefore \text{Draft} = \frac{3}{2} \times KB = \frac{3}{2} \times 4 = 6m$$

LBP = 2 x 46 = 92m

$$\frac{\text{Breadth at waterline}}{\text{beam}} = \frac{draft}{depth} = \frac{6}{7.6}$$

$$\text{Breadth at waterline} = 15 \times \frac{6}{7} = 11.842m$$

Displacement = UW volume x density = transverse UW area x l x 1.025
= ½ x11.842 x 6 x 92 x 1.025 = 3350.1t
Depth = draft + free board = 6 + 1.6 = 7.6m
Volume of the whole ship = ½ x 15 x 7.6 x 92 = 5244m^3
Volume of the under water part = ½ x 11.842 x 6 x 92 = 3268.4m^3
Hence the volume above water level = 1975.6m^3. (This is the reserve buoyancy of the vessel at the draft of 6m)

Ex. 3 A vessel has semi circular transverse section below rectangular area and is longitudinally uniform. Her beam is 12m and draft is 8m LBP = 105m, is floating in sea water. Calculate her KB and LCB.
Sol^n: - If the vessel is longitudinally uniform then LCB = ½ LBP = 52.5m.
Also since the vessel has longitudinally uniform transverse UW area, the distance of COB above keel must be same as distance of centroid of transverse UW area above keel.
To find the position of centroid of transverse UW area wrt. keel.

Distance of centroid of semicircle from diameter

$$= \frac{4r}{3\pi} = \frac{4 \times 6}{3 \times 3.14} = 2.548\,\text{m}$$

∴ Distance from water line = 4.548m.
Area of semi circle ½ πr^2 = 56.52m^2
Taking moments of transverse UW areas about WL:

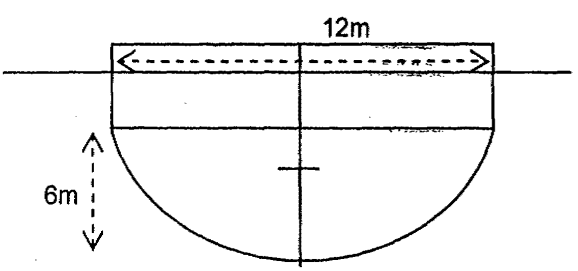


Fig. 5

$$\text{Distance of common centroid from WL} = \frac{A_1 d_1 + A_2 d_2}{A_1 + A_2} = \frac{56.52 \times 4.548 + 24 \times 1}{80.52} = 3.490\text{m}$$

Distance from keel = 8 – 3.49 = 4.51m.
∴ KB = 4.51m.

Ex. 4 A vessel 110m long has uniform water plane areas at different drafts. Her waterplane amidships is 22m broad and 60m long. Forward of this the waterplane breadth tapers to zero in

30 m and abaft this waterplane the breadth tapers to zero in 20 m. find LCB and KB if the vess floats even keel on a draft of 6m.

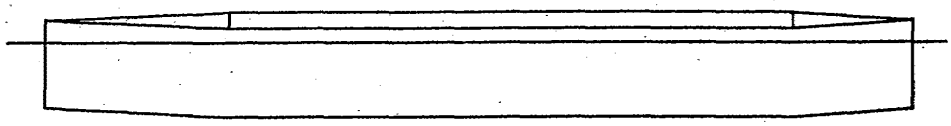


Fig. 6

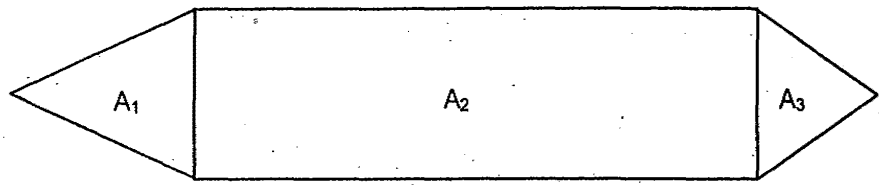


Fig. 7

Hint: KB = 3m = half of the draft as the water plane is vertically uniform.
Also LCF must be equal to LCB. LCF is found by taking moments of WPAs about aft.

$$LCF = \frac{A_1d_1 + A_2d_2 + A_3d_3}{A_1 + A_2 + A_3} = 52.745\text{m.} = \text{LCB.}$$

Exercise 3

Q. 1 A vessel 100 m long has uniform water plane areas at different drafts. Her waterplane amidships is 20m broad and 70m long. Forward of this the waterplane breadth tapers to zero in 20 m and abaft this rectangle the waterplane is semicircular. Find LCB and KB if the vessel floats even keel on a draft of 8m.

Ans. WPA vertically uniform: - $KB = \frac{d}{2} = 4\text{m}$

$$LCB = \frac{157\times5.754 + 1400\times45 + (200\times86.67)}{157+1400+200} = 46.236\text{ m}$$

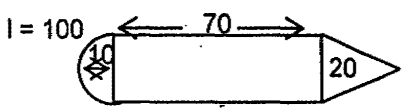


Fig 8

Q. 2 A vessel with triangular transverse section is longitudinally uniform and has draft = 6.4m, beam = 16m and LBP = 94m, is floating in sea water. If her freeboard is 1.2m find displacement, KB and LCB.

Ans.

$$\frac{\text{breadth WL}}{6.4} = \frac{16}{(6.4+1.4)}$$

Breadth WL = 13.128m

$$\text{u/w Vol} = \frac{13.128\times6.4}{2}\times94 = 3948.902$$

$$\Delta = 4047.62\text{ t.}\quad KB = \frac{2}{3}\times de = 4.267m\quad LCB = \frac{94}{2} = 47m$$

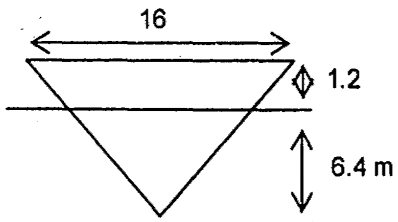


Fig 9

Q. 3 A vessels has semi circular transverse section below rectangular area and is longitudinally uniform. Her beam is 14m and draft is 9m LBP = 44m, is floating in sea water. Calculate her KB and LCB.

Ans. LCB = 22 m $KB = \frac{28\times8 + 77\times4.028}{105} = 5.087$

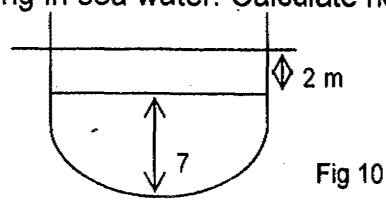
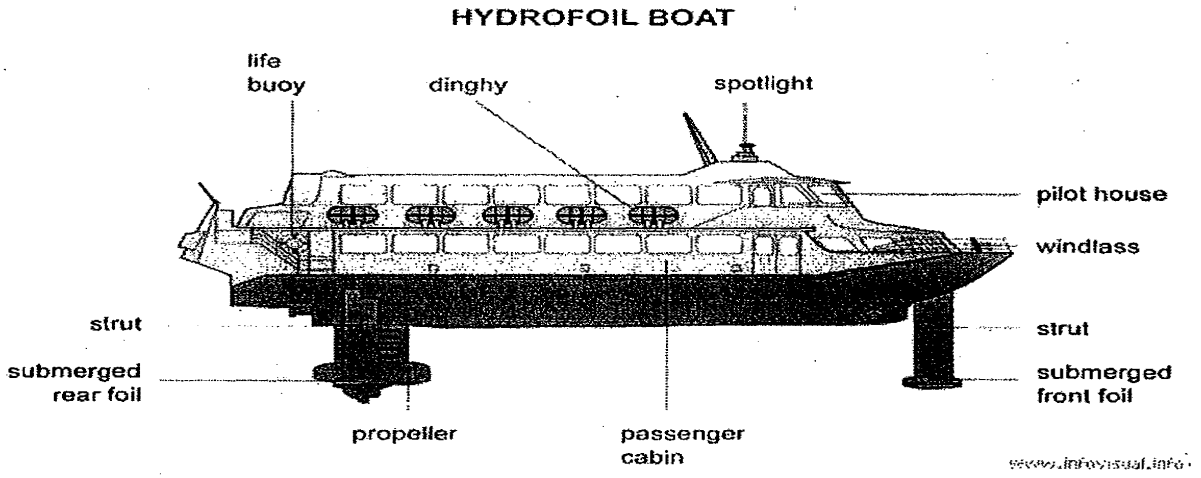


Fig 10

Hydrofoil: A hydrofoil is a boat with wing-like foils mounted on struts below the hull. As the craft increases its speed the hydrofoils develop enough lift for the boat to become foilborne - i.e. to raise the hull up and out of the water. This results in a great reduction in drag and a corresponding increase in speed. Some of the principle advantages of hydrofoil ships are to operate effectively in nearly all sea environments, and an improved ratio of power to displacement in the 30 to 50 knot speed range



Chapter 4 Form coefficients

The coefficient of fineness of the water plane area, Cw:-

The coefficient of fineness of the water plane area at any draft is the ratio of the water plane area of a vessel to the area of circumscribing rectangle having the same length and maximum breadth.

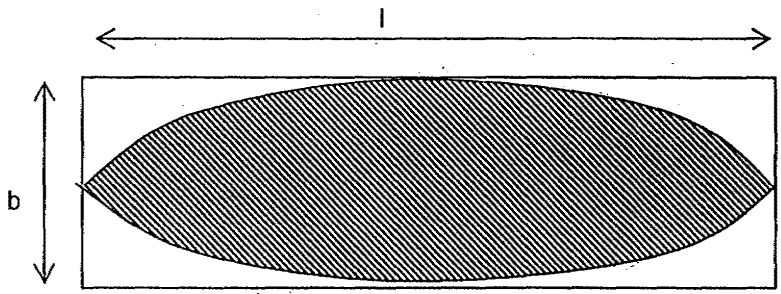


Fig. 1

In the fig above the area of the ships water plane is shown shaded. The circumscribing rectangle has its length and breadth equal to the maximum length and breadth respectively of the waterplane area.

$$\text{Coefficient of fitness} = \frac{\text{water plane area}}{\text{area of circumscribing rectnagle}}$$

$$= \frac{\text{area of water plane}}{l \times b}$$

Water plane area = $l \times b \times C_w$

Ex. 1
Find the water plane area of a ship for a draft at which its length is 106 metres and breadth 21 metres and the coefficient of water plane of 0.84. Also calculate the TPC at this draft.

Water plane area $= l \times b \times C_w$
$= 106 \times 21 \times 0.84$
Water plane area $= 1869.84\ m^2$

TPC $= \dfrac{WPA \times 1.025}{100} = 19.16$

The block coefficient (C_b): -
The block coefficient of a ship at any draft is the ratio of the under water volume (volume of liquid displaced) to the volume of just fitting rectangular block i.e. having the minimum length breadth and depth necessary to accommodate the underwater part of the vessel at that draft.

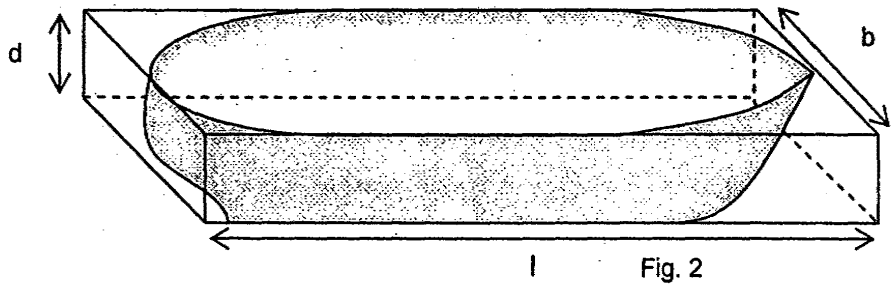


Fig. 2

In fig above the shaded portion represents the under water volume of the ship at a given draft. The vessel fits in a rectangular block having dimensions just enough to accommodate the under water hull.

$$\text{Block coefficient} = \frac{\text{under water volume}}{\text{volume of just accomodating block}}$$
$$= \frac{\text{under water volume}}{l \times b \times \text{draft}}$$
Under water volume = l x b x draft x C_b

Ex. 2 A ship 134 metres long with a beam 26 metres, has a summer draft of 9.48 metres. The block coefficient at this draft is 0.68. Find the summer displacement.
Sol^n: -
Summer displacement $= l \times b \times \text{draft} \times c_b \times 1.025t$
$= 134 \times 26 \times 9.48 \times 0.68 \times 1.025t$
$= 23020.7\ t$

Ex. 3 A ship 124m long with a beam 24m, has a summer draft of 9.6m. At light draft her length is 106m, beam 18m and draft 4.4m. The block coefficients are 0.72 and 0.60 respectively. Find the summer deadweight.
Sol^n: -
Light displacement $= l \times b \times \text{draft} \times c_b \times 1.025t$
$= 106 \times 18 \times 4.4 \times 0.6 \times 1.025$
$= 5163.0\ t$
Load displacement $= l \times b \times \text{draft} \times c_b \times 1.025t$
$= 124 \times 24 \times 9.6 \times 0.72 \times 1.025t$
$= 21084.4\ t$
Summer dwt = load displacement – light displacement
$= 21084.4\ t - 5163.0\ t$

Summer dwt = 15921.4 t

The midships coefficient: The midships coefficient at any draft is the ratio of the transverse under water area of the midships section to a circumscribing rectangle that will just accommodate such midships section.

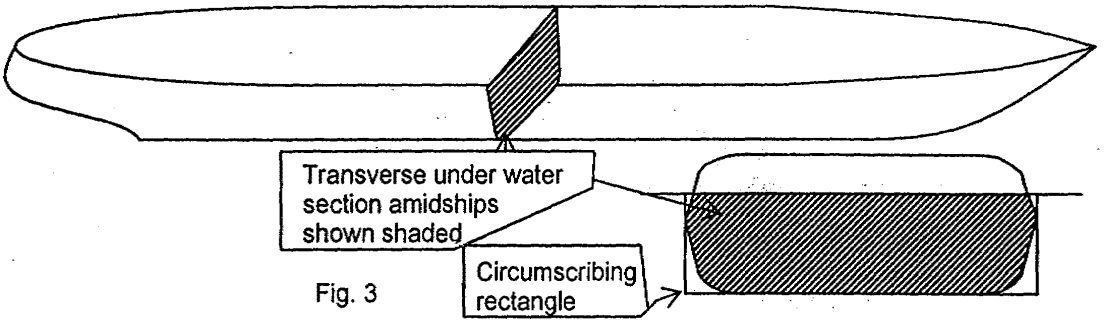


Fig. 3

In fig the shaded portion represents the underwater transverse section amidships. This section is enclosed in a rectangle having the breadth and depth just enough to accommodate the shaded area.

$$\text{Midships coefficient} = \frac{\text{area of midships transverse UW section}}{\text{area of rectangale}}$$

$$C_m = \frac{\text{area of midships transverse UW section}}{\text{area of rectangale}}$$

Or midship transverse area $= b \times d \times C_m$

Ex. 4 Find the area of transverse underwater section amidships of a vessel 120m long at a certain draft, if the midships coefficient at this draft is 0.92, the under water volume 14800m^3 and C_b is 0.78.

Sol^n: -

$$\text{Block coefficient} = \frac{\text{under water volume}}{\text{volume of just accomodat ing block}}$$

$$\therefore \text{Volume of rectangular block} = \frac{\text{under water volume}}{C_b} = \frac{14800}{0.78} = 18974.36\text{m}^3$$

$$\text{Area of rectangle amidships} = \frac{18974.36}{120} = 158.12\text{m}^2$$

Area of transverse underwater section amidships = 158.12 x 0.92 = 145.47m^2

The prismatic coefficient:-

The prismatic coefficient of a ship at any draft is the ratio of the under water volume at that draft to the volume of a prism having the length just enough to accommodate the under water volume and has same cross sectional area as the ships transverse under water area amidships.

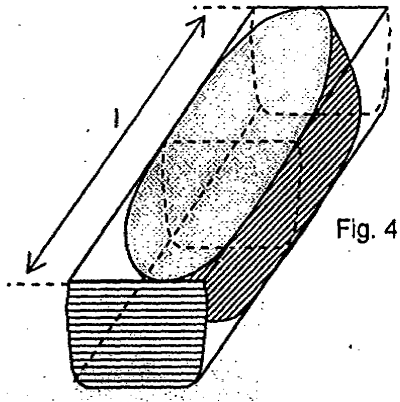


Fig. 4

The prism has a transverse area same as UW transverse area amidships

In fig the under water hull is shown shaded. This part of the hull is shown enclosed in a prism whose transverse area is longitudinally uniform and is equal to the transverse under water section amidships.

$$\text{Prismatic coefficient } (C_p) = \frac{\text{volume of ship}}{\text{volume of prism}}$$

It can be shown that the product of midships coefficient and prismatic coefficient gives block coefficient.

$$C_m \times c_p = \frac{\text{area of midships transverse UW section}}{\text{area of rectangale}} \times \frac{\text{volume of ship}}{\text{volume of prism}}$$

$$= \frac{\text{area of midships transverse UW section}}{\text{volume of prism}} \times \frac{\text{volume of ship}}{\text{area of rectangle}}$$

$$= \frac{1}{l} \times \frac{\text{volume of ship}}{\text{area of rectangle}} = \frac{\text{volume of ship}}{\text{volume of rectangle}} = C_b$$

$$\therefore C_m \times c_p = C_b$$

Ex. 5 A vessel of length 126m, beam 24m floating in salt water at the summer draft of 8.6m had midship coefficient equal to 0.94 and prismatic coefficient of 0.78. Find her displacement.

Sol^n:-

$\because C_m \times c_p = C_b$

$C_b = 0.94 \times 0.78 = 0.7332$

Under water volume $= l \times b \times dr \times 0.7332$

$= 126 \times 24 \times 8.6 \times 0.7332 = 19067.9 m^3$

Displacement $= 19067.9 \times 1.025 = 19544.6t.$

Exercise 4

Q. 1 Find the water plane area of a ship for a draft at which its length is76 metres and breadth 18 metres and the coefficient of fineness of WPA is 0.82. Also calculate the TPC at this draft.

Ans. $WPA = 76 \times 18 \times 0.82 = 1121.76 m^2$

$$TPC = \frac{WPA \times 1.025}{100} = 11.498$$

Q. 2 A ship 164 metres long with a beam of 28 metres, has a summer draft of 9.82 metres. The block coefficient at this draft is 0.71. Find the summer displacement.

Ans. $S\Delta = 164 \times 28 \times 9.82 \times 0.71 \times 1.025 = 32816.75$ t

Q. 3 A ship 132 m long with a beam 26 m, has a summer draft of 9.2 m . At light drafts are length is 100m, beam 17m and draft 4.1m. The block coefficients are 0.74 and 0.59 respectively. Find the summer deadweight.
Ans. SDW = (132 x 26 x 9.2 x 0.74 x 1.025) – (100 x 17 x 4.1 x 0.59 x 1.025) = 19734.07 t

Q. 4 Find the area of transverse underwater section amidships of a vessel 116 m long at a certain draft, if the midships coefficient at this draft is 0.94, the under water volume 15300m^3 and C_b is 0.76.

Ans. 116 x b x d x 0.76 = 15300 b x d x 0.94 = $\frac{15300}{116\times0.76}\times0.94 = 163.14\ m^2$

Q. 5 A vessel of length 136m, beam 25.4m floating in salt water at the summer draft of 8.8m had midship coefficient equal to 0.922 and prismatic coefficient of 0.74. Find her displacement.
Ans. $C_b = C_p \times C_m = 0.682$ $S\Delta = 21258.95$ t

Q. 6 A ship 115m long 16 m beam and 13m deep is floating on an even keel at a draft of 6.8m block coefficient 0.78. The ship is floating in salt water. Find the cargo to discharge so that the ship will float at the same draft in fresh water.
Ans. 115 x 16 x 6.8 x 0.78 x 1.025 – X = 115 x 16 x 6.8 x 0.78 x 1 = 243.984 t

Exercise on M.V ALPHA SHIP with hints

Q. 1 Find the hydrostatic particulars of M V ALPHASHIP when floating is seawater at draft 7.86m
Sol^n: -
M V ALPHASHIP's hydrostatic particulars are provided for sea water (RD 1.025) and even keel draft and tables can be entered with any one of the two arguments viz. draft and displacement.

draft	Δ	TPC	MCTC	LCB	LCF	VCB	KM_T	KM_L
7.80	22625.4	32.77	272.44	87.169	84.936	4.144	9.878	247.24
8.00	23289.	32.95	276.36	87.105	84.714	4.252	9.849	243.74
7.86	22824.48	32.82	273.61	87.149	84.869	4.17	9.86	246.19

8.00 – 7.80 = 0.2
7.86 – 7.80 = 0.6
Ratio $\frac{Dr - Dr_1}{Dr_2 - Dr_1} = \frac{0.06}{0.2} = 0.3$ is a common factor that is used for interpolation thus,
To find displacement for 7.86m draft
$[(\Delta_2-\Delta_1) \times \text{factor}] + \Delta_1 = 228424.48$t.
Similarly other hydrostatic particulars are found by interpolation.

Q. 2 find the hydrostatic draft and other hydrostatic partic0ulars for M V ALPHASHIP when Floating in SW and has displacement of 26250t

Displ.	Draft	TPC	MCTC
25991	8.80	33.62	
26671.4	9.00	33.79	
26250			

$\Delta_2-\Delta_1 = 680.4$
$\Delta-\Delta_1 = 259$

Ratio $\frac{\Delta - \Delta_1}{\Delta_2 - \Delta_1} = 0.3807$ factor to be used

$TPC = [(TPC_2 - TPC_1) \times \text{factor}] + TPC_1$

$= 33.68$

Δ	draft	TPC	MCTC	LCB	LCF	VCB	KMT	KML
25991	8.8	33.62	292.6	86.821	83.893	4.674	9.823	232.82
26671.4	9	33.79	296.52	86.745	83.721	4.782	9.83	230.44
26250	8.876	33.68	294.09	86.792	83.827	4.715	9.825	231.91

Q. 3 Find the hydrostatic particulars for MV ALPHASHIP when floating in D.W of RD 1.012 at hydrostatic draft of 9.6m.

Sol": - As has been stated earlier the hydrostatic particulars are given for SW, in DW the tables must be used with some caution. When the tables are entered with draft; LCB, LCF, VCB KM_T & KM_L may be picked up and used as they are as these particulars depends on underwater volume & shape of vessel but for TPC and MCTC some modification must be done.

$TPC = WPA \times \frac{1}{100} \times \text{density}$

$TPC \propto \text{density} \ldots\ldots\ldots\ldots\ldots \left(\frac{WPA}{100} \text{ is constant for a given draft}\right)$

$$\frac{TPCDW}{TPCSW} = \frac{DWD}{SWD}$$

$TPC_{DW} = TPC_{SW} \; TPC_{SW} \times \frac{DWD}{SWD}$ or $TPC_{SW} \times$ reducing factor

$$MCTC = \frac{\Delta GM_L}{100L} = \left(\frac{\text{uw vol} \times \text{density} \times GM_L}{100L} \text{ approximately is constant for a given draft}\right)$$

$$MCTC \propto \text{density} \left(\frac{\text{uw vol} \times GM_L}{100L} \text{ is constant for a given draft}\right)$$

$$\frac{MCTC_{DW}}{MCTC_{SW}} = \frac{\text{density DW}}{\text{density SW}}$$

$MCTC_{DW} = MCTC_{SW} \times \frac{DDW}{DSW}$

$= MCTC_{SW} \times$ reducing factor

Thus from tables we have

	draft	Δ	TPC	MCTC	LCB	LCF	VCB	KM_T	KM_L
From tables	9.60	28215.6	34.24	308	86.511	83.226	5.108	9.876	222.88
For DW	9.60	27857.74	33.806	304.1	86.511	83.226	5.108	9.876	222.88

$\Delta_{DW} = 28215.6 \times \frac{1.012}{1.025} = 27857.74$ t.

$TPC_{DW}\ 34.24 \times \frac{1.012}{1.025} = 33.806$

$MCTC_{DW} = 308 \times \frac{1.012}{1.025} = 304.1$tm

Other particulars will be as they are

Q. 4 Find the hydrostatic particulars of M V ALPHASHIP whose displacement 200000 t and is presently floating in DW of RD 1.005

Sol': - Displacement actually means the mass. The displacement does not depend on the density of water in which the vessel is floating.
A vessel of a certain displacement however will sink more in lighter water as compared to sea water. Thus impression of a heaviour ship when floating in lighter water (higher underwater volume). Since draft LCB, LCF, KM_T, KM_L depend on under water volume and shape.
Draft LCB, LCF, KM_T, KM_L must be seen for a vessel of higher displacement having the underwater volume in seawater equal to present underwater volume in dockwater. Thus tables are entered with Δ_1 so that
$\Delta_1 = \Delta$ x increasing factor

$$\Delta_1 = \Delta \times \frac{SWD}{DWD}$$

All hydrostatic particulars are picked up from tables for Δ_1
Draft, LCB, LCF, KM_T, KM_L are used as they are but TPC & MCTC for the reasons stated in last question are further multiplied by reducing factor viz. $\frac{DWD}{SWD}$

$$\Delta_1 = 20000 \times \frac{1.025}{1.005} = 20398t$$

	Δ	draft	TPC	MCTC	LCB	LCF	VCB	KMT	KML
From	20018.6	7.00	32.13	257.32	87.385	85.927	3.724	10.071	263.2
tables	20665.4	7.20	32.29	260.96	87.337	85.671	3.828	10.010	258.58
In DW	20398	7.117	31.59	254.39	87.356	85.776	3.785	10.035	260.48

$$\frac{\Delta - \Delta_1}{\Delta_2 - \Delta_1} = \frac{379.4}{646.8} = 0.5866$$

Draft = [(7.20 – 7.00) x 0.5866] + 7.00
= 7.117m

Q. 5 Calculate the block coefficient and water plane coefficient of M.V ALPHA SHIP at her summer draft assuming the maximum breadth of water plane at that draft to be the moulded breadth.
Hint: -
At summer draft 10.156
L = 171.792
B = 24
TPC = 34.56

$$WPA = \frac{34.56 \times 100}{1.025} = 3371.71m^2$$

$$C_a = \frac{3371.71}{171.792 \times 24} = 0.818 \qquad C_b = \frac{30634.2/1.025}{171.792 \times 24 \times 10.156} = 0.714$$

Q. 6 M V ALPHA SHIP with a displacement 29,635t is floating in dock water, of R.D 1.010. Find her draft and TPC. If the length & breadth of the water plane is 170m & 24m respectively, find the block coefficient & water plane area coefficient at that draft.
Hint: - Entering tables with displacement in DW

Tables are entered for $\Delta_1 = \frac{\Delta \times 1.025}{1.014} = 29956.5$

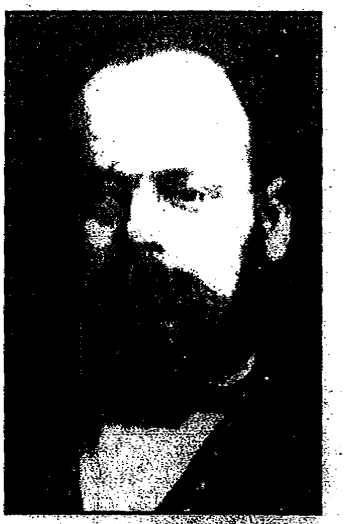
Draft will be as found in tables i.e. 9.959m
TPC to be multiplied by reducing factor

Thus $34.525\frac{1.014}{1.025} = 34.155$

Since the TPC for DW is 34.155, WPA = $34.155\ \frac{100}{1.014} = 3368.3\text{m}^2$

$C_a = \frac{3368.3}{170 \times 24} = 0.826$ $\qquad$ $C_b = \frac{29635\ /1.014}{170 \times 24 \times 9.959} = 0.719$

Samuel Plimsoll, born in Bristol in February, 1824. Plimsoll became involved in shipping coal to London and soon became one of Britain's leading experts on trading in this community. In the 1868 General Election, Plimsoll was elected as MP for Derby. Samuel campaigned to protect seamen who at the time could be fined and sent to prison if they refused to sale in unsafe (overloaded) ships. He is responsible for legally starting the trend of the marking of a line on a ship's sides which would disappear below the water line if the ship was overloaded. Samuel Plimsoll died in 1898.



Chapter 5 Law of Floatation & Basic stability concepts, Density & Loadlines

The law of floatation:

Archimedes principle: When a body is wholly or partially immersed in a liquid it suffers an apparent loss of mass which is equal to the mass of the liquid displaced by the immersed part.

Wooden log suspended by Archimedes spring balance

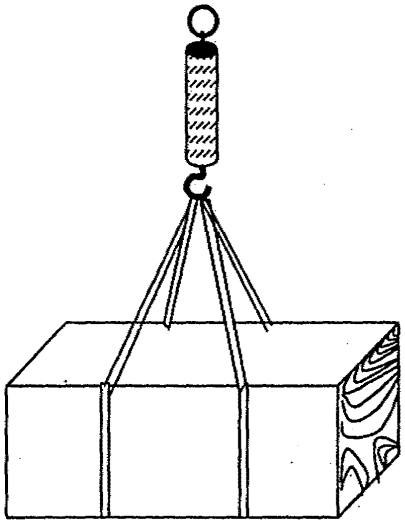


Fig. 1

Weight indicated 1000 kg

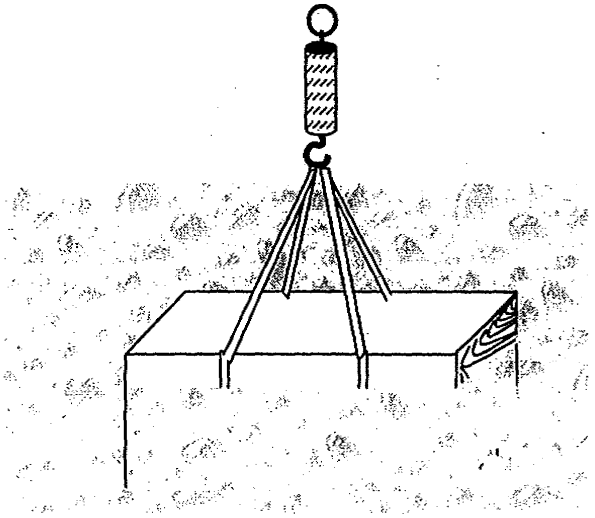


Fig. 2

Weight indicated nil, log floats free. Mass of liquid displaced = 1000kg.

Granite block suspended by Archimedes spring balance

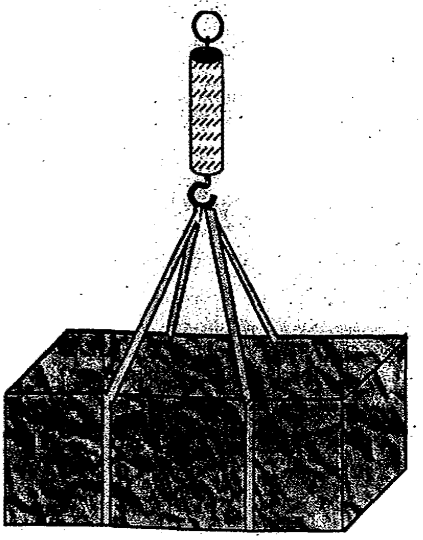


Fig. 3

Weight indicated 6000 kg

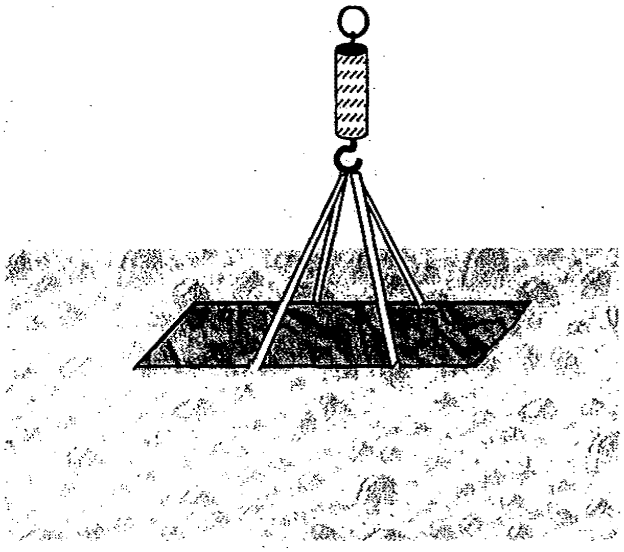


Fig. 4

Weight indicated 4800 kg. mass of the liquid displaced = loss of weight = 1200kg.

We start our Journey of understanding the stability of ship by taking a box vessel of length say 90 m and breadth 12 m. Let the draft be 6 m and let the box vessel be on even keel. Let the vessel be floating in sea water.

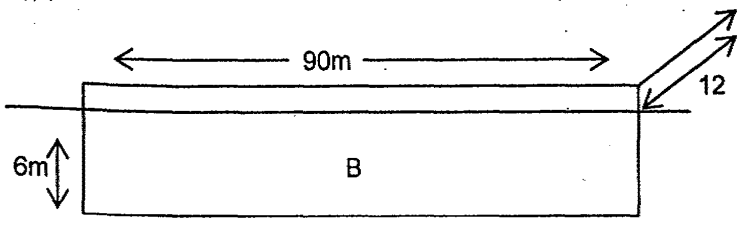


Fig. 5

Applying the above law and principle to the box vessel, the mass of liquid displaced is equal to the under water volume of vessel x density of sea water.
= 90 x 12 x 6 x 1.025 ..... (Density of sea water is 1.025t / m^3 or 1025 kg / m^3) = 6642t
This is also the mass of the ship, popularly known as displacement for the reason that the vessel displaces the equivalent mass of liquid.

Ex. 1 What will be draft when the above vessel goes to fresh water (density 1.000t/m^3?)
Ans. The mass or displacement of the vessel will not change from one medium of floatation to other and therefore the product of under water volume and density will be a constant for both the situations. We can find the draft in fresh water (d_2) as follows:
90 x 12 x 6 x 1.025 = 90 x 12 x d_2 x 1.000

$$d_2 = \frac{90 \times 12 \times 6 \times 1.025}{90 \times 12 \times 1.000} = 6.150\text{m}$$

Similarly the draft in the dock water of density 1.015 t /m^3 will be

$$d_2 = \frac{90 \times 12 \times 6 \times 1.025}{90 \times 12 \times 1.015} = 6.059\text{m}$$

An approximate thumb rule to find the change of draft, when the ship goes from one floatation medium to another is as follows: (Meaning of FWA & the proof will be discussed later)
Ratio of difference in draft = Ratio of difference in densities

$$\frac{\text{change of draft}}{\text{FWA}} \approx \frac{\text{difference of densities}}{1.025 - 1.000}$$

Where FWA (fresh water allowance) is the sinkage when a vessel floating at summer load line goes from S.W to F.W. Thus the port authorities shall give an allowance equal to FWA, beyond summer draft when the vessel completes loading in fresh water river port.
Note: The fresh water allowance of above stated vessel therefore is 0.150m or 150 mm.

Ex. 2 the box vessel in Q 1 goes from the water of density 1.015t /m^3 to water of 1.005t/m^3. Find the change of draft by ratio formula:

$$\frac{\text{change of draft}}{\text{FWA}} \approx \frac{\text{differntof densities}}{1.025 - 1.000}$$

$$\therefore \text{Changeof draft} \approx \frac{\text{differntof densities} \times \text{FWA}}{1.025 - 1.000}$$

$$= \frac{(1.015 - 1.005) \times 150}{1.025 - 1.000} = 60\ mm = 0.060\ m$$

Since the vessel went to lighter water the draft would increase and the new draft would be 0.06m more than the draft in 1.015.

Tonnes per centimeter immersion (TPC): -
The TPC at any draft is the mass which when loaded or discharged will change the ship's hydrostatic draft by 1cm.
In the hydrostatic particulars this value is given for the change of draft in salt water

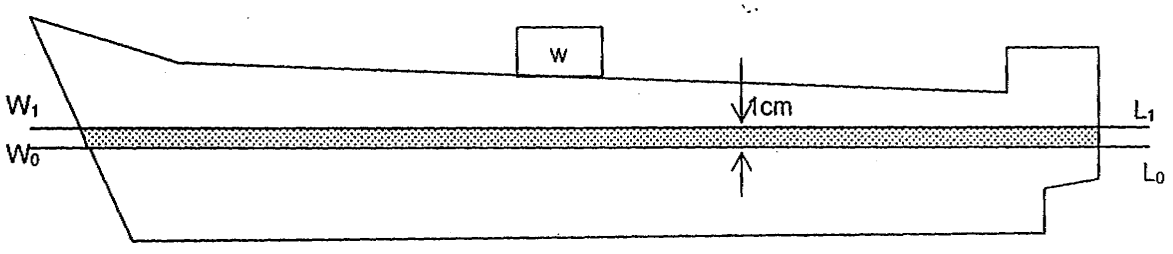


Fig. 6

In the above fig a ship is shown initially floating at W_0 L_0 in salt water. a mass of w tonnes is placed on board vessel to increase the draft by 1cm bringing the vessel to a new waterline W_1 L_1. The extra mass of displaced water is equal to the mass that is loaded on board vessel. Since the increase in draft is 1cm, the value of mass must be TPC.
Assuming for this small change of draft the vessel is wall sided, it can be said that

$$\text{increase in under water volume} = \text{WPA} \times \frac{1}{100}$$

$$\text{TPC} = \text{WPA} \times \frac{1}{100} \times 1.025\,.$$

In the same way TPC in dock water is given by:

$$TPC_{DW} = WPA \times \frac{1}{100} \times \text{dock water density}$$

It is a well known fact that a body submerges more in the lighter water. On the same lines it can be said that it requires less mass to submerge the vessel by 1cm in fresh water or brackish water.

$$\frac{TPC_{dw}}{TPC_{sw}} = \frac{\text{density of dock water } (RD_{dw})}{\text{density of salt water } (RD_{sw})}$$

Or

$$TPC_{dw} = \frac{RD_{dw}}{1.025} \times TPC_{dw}$$

Metacentre

In chapter 1 we had understood the term metacentre as follows:

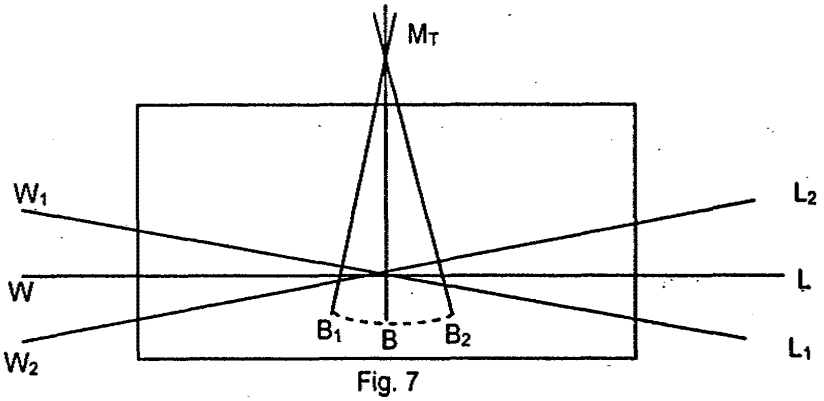


Fig. 7

While the ship heels slightly on either side of upright equilibrium, the COB would go to and fro of its mean position. Uprights drawn through these COB's would meet at the transverse metacentre of the ship.

If we assume that the COB goes to and fro along a swing, then the imaginary suspension point of the swing can be understood as transverse metacentre.

The vertical distance BM_T for any equilibrium position is found by following formula:

$$BM_T = \frac{\text{moment of inertia of water plane area about centreline}}{\text{under water volume}}$$

The BM_T for a box vessel therefore $= \frac{lb^3/12}{lbd} = \frac{b^2}{12d}$. Thus we may say that BM_T which contributes to the positive stability is directly proportional to the square of the beam and inversely proportional to the draft for a given box vessel. We may also say that for a box vessel of a certain length and breadth BM_T should decrease with increase of draft.

If we describe the keel, COB, COG, M_T as K, B, G & M in a transverse section of the box vessel, they would normally appear in the vertical order as shown in the fig below:

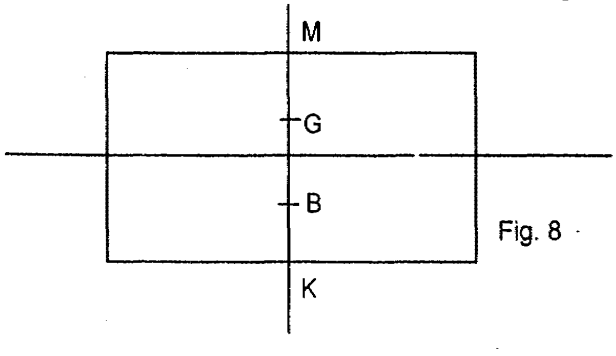


Fig. 8

Ex. 3 Draw a curve of metecentre for a box shape vessel 100m in length and 20m in breadth

Draft	KB	BM_T	KM_T
0	0	NA	NA
1	0.5	33.33	33.83
2	1	16.67	17.67
3	1.5	11.11	12.61
4	2	8.3	10.3
5	2.5	6.67	9.17
6	3	5.56	8.56
7	3.5	4.76	8.26
8	4	4.17	8.17
9	4.5	3.70	8.2
10	5	3.33	8.33
11	5.5	3.03	8.53
12	6	2.78	8.78
13	6.5	2.56	9.06
14	7	2.38	9.38

Metacentric Diagram

Shows the variation in the height of the metacentre (M_T) with variation in draught. The construction of the diagram can be as follows:

A line is drawn through the origin at 45°. A vertical line drawn upwards from the required draft when turns left at this line also shows the water line with X-axis as the keel. This allows the position of the metacentre, COB, keel to be seen relative to the waterline. This construction enables the values of KB and BM to be read off separately at any given draught.

Now KM = KB + BM

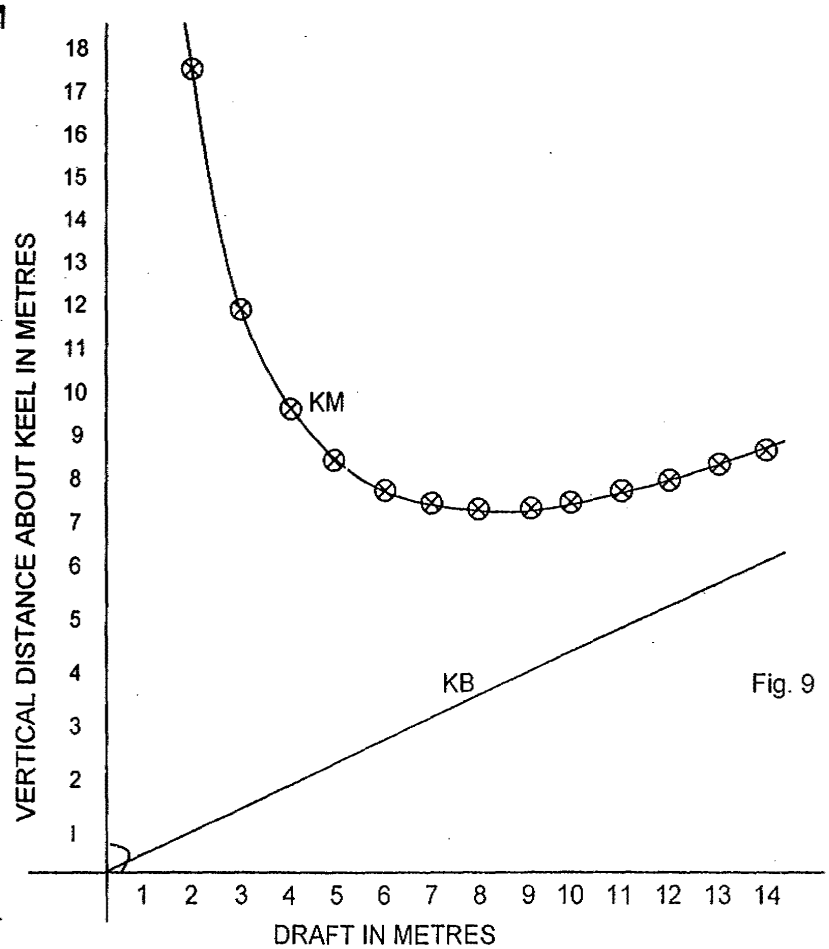


Fig. 9

Equilibrium:-
Equilibrium means state of rest and this means that the algebraic sum of forces acting on the body is zero and also the algebraic sum of moments of acting at any point on the body total up to zero. Particularly in case of the ship we may say that for equilibrium:
Displacement must equal buoyancy force in free float condition, whether the vessel is in stable, unstable or neutral condition.
Displacement must equal buoyancy and ground reaction in grounded condition. The vessel must be at rest which means no righting lever, no rolling and no pitching. COG and COB must be in the same vertical line.

In stable equilibrium COG must be below metacentre.
In stable equilibrium, when the vessel is heeled by external disturbance righting lever is developed which tries to bring the vessel back to upright equilibrium. In doing so vessel rolls to and fro about the upright position.

In unstable equilibrium COG is above the metacentre. This will cause the vessel to roll away from upright equilibrium when disturbed by external forces. Fortunately the vessel's water plane area increases, which in turn causes the BM_T to increase due to increase of moment of inertia about centerline. The vessel thereafter is likely to come to an angle of equilibrium where the GM_T becomes positive. This is angle of loll. M though is not in the centerline.

Stable equilibrium

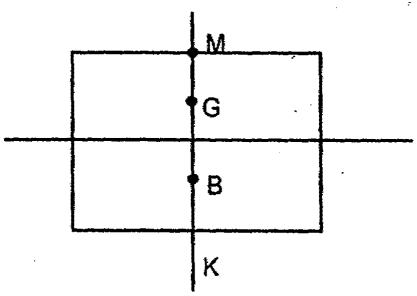


Fig. 10

Unstable equilibrium

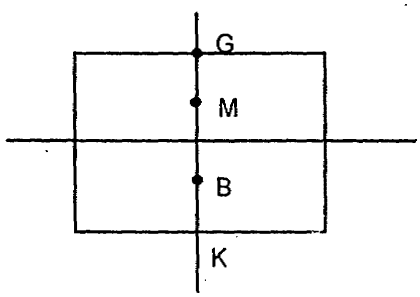


Fig. 11

Neutral equilibrium

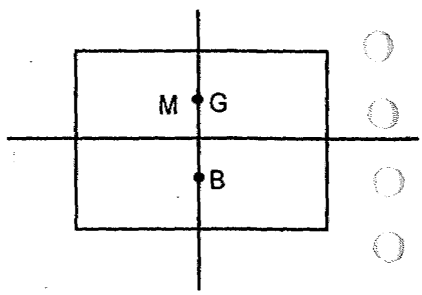


Fig. 12

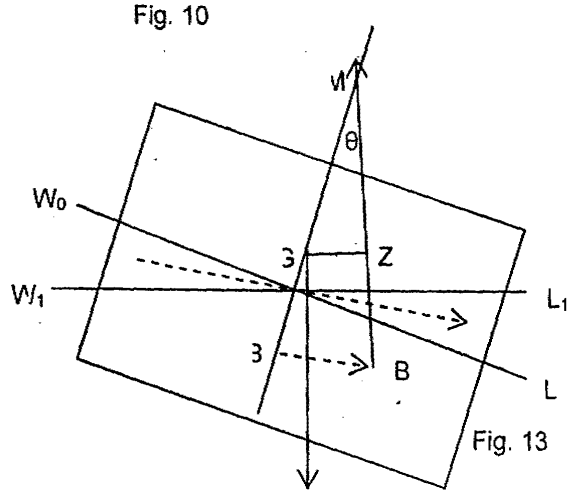


Fig. 13

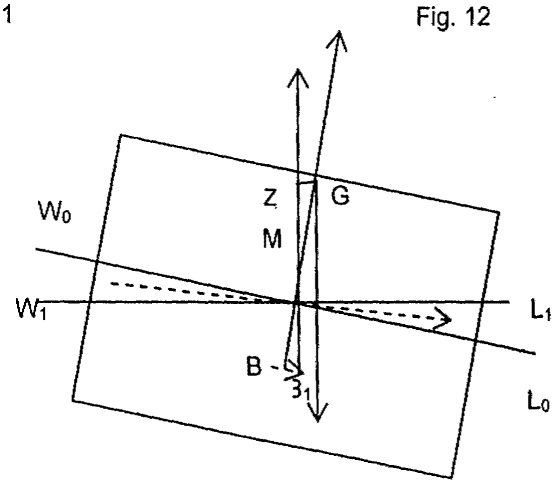


Fig. 14

Action to take in situations of unstable & neutral equilibrium:-
The vessel has very sluggish behaviour in tender condition. A vessel may be nearing neutral stability or a zero upright GM very gradually sometimes by consumption of bunkers in the double bottom and developing free surface effect and sometimes by water accumulation in deck

cargo and some times by both. Some time the change may be sudden and can be due to placing heavy loads on deck or mistake in loading / ballasting. A vessel with low GM would normally have a very large rolling period. Ships officers must closely monitor the ship's behaviour and take necessary action. When required the COG must be lowered. The various steps that may be taken are:

1. Fill up the bottom tanks, smaller tanks to be preferred to larger tanks. Also centreline tanks to be preferred for filling to wing tanks.
2. Shift of liquids to lower tanks like for example in case of bunkers from higher tanks to the double bottom tanks would swiftly lower the COG. Even the free surface effect would reduce.
3. Weights can be loaded below the COG level. The loading however should be done by shore crane. Operating ship's cargo gear may worsen the situation.
4. Weights above the COG level may be discharged. Shore crane to be used instead of ship's gear.

Stiff vs tender ships & optimum GM_o: -

Stiff or tender are the terms used to indicate the status of stability in loose terms. A stiff vessel means a vessel with large GM_o or a vessel with large righting levers. These vessel will have large righting moments when inclined by an external cause. Since GZ is dependent on GM_0 (GZ is function of GM_0 as can be seen in wall sided formula). A vessel with large righting moment is likely to return to upright more swiftly as compared to a vessel with small righting moment.

The initial metacentric height is given by the formula $GM_o = \left[\frac{fb}{T_r}\right]^2$. This means $T_r^2 = \left[\frac{(fb)^2}{GM_o}\right]$

Or $T_r = \frac{fb}{\sqrt{GM_0}}$ ..... (1)

Where f is the rolling coefficient and depends on the weight distribution about the rolling axis, b is beam of the vessel and T_r is the true rolling period of the vessel.

A well known formula for still water rolling is $T = \frac{2\pi k}{\sqrt{g.GM}}$ ..... (2)

Where k is radius of gyration and g is acceleration due to gravity.

In both the above expressions the true rolling period is found to be inversely proportional to square root of metacentric height.

From the above expressions it is also evident that more the weight distributed away from the rolling axis longer is the rolling period.

Some vessels by the nature and location of the cargo they carry or owing to the construction of the vessel are prone to having a large rolling period. Thus a container vessel or a vessel loaded with deck cargo of timber will normally have a low GM_o and therefore be called tender vessel. The GM_o of such vessels may be as low as 20 cm and rolling period as large as over 30 seconds. A bulk carrier loaded with iron ore will have a very large GM_o and therefore are stiff. The GM_o may be well over 7m and the rolling period may be as low as 9 sec.

The stiff vessels tend to roll violently, cause increased stress on the ship's structure & cause unpleasantness to the crew & passengers. The tender ships on the other hand roll easily, cause less stress on the ship's structure. Rolling is not unpleasant as in case of a stiff vessel.

Righting lever at small angle of heel & wall sided formula: -

Whenever a vessel is disturbed by an external cause her equilibrium is disturbed. The COB and COG are no more in a vertical line. The transverse distance between them is called righting lever and is the measure of righting capability of the vessel. For the small angles of heel say upto 7 degrees (where the GZ curve is almost a straight line), the GZ is given by formula:

GZ = GM Sin θ.
GZ for wall sided conditions i.e. where the sides of immersed wedge and emerged wedge are parallel to each other can be found by the following formula:
GZ = (GM + ½ BM $\tan^2$ θ) Sin θ

In the adjacent fig
In the transverse section vessel is seen heeled to a small angle θ

Sin θ = $\frac{GZ}{GM}$

∴GZ at small angles of or heel Can be found by multiplying the Metacentric height with Sine of the angle of heel.

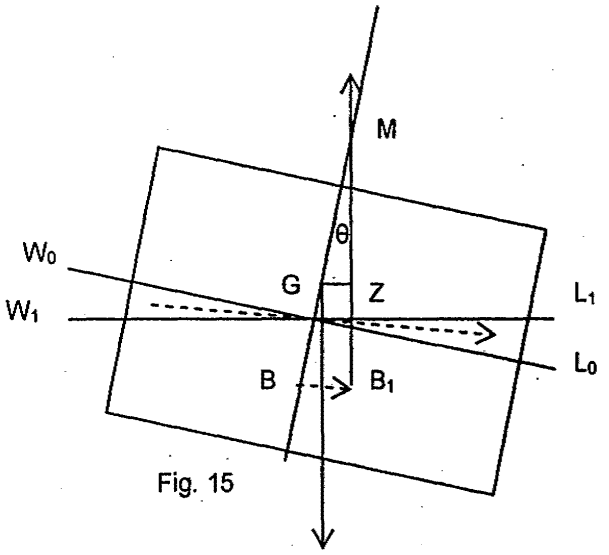


Fig. 15

Wall sided formula: -
In case of box shaped vessel as shown in the diagram the ships side at immersed wedge and emerged wedge are seen parallel to each other. So long as the deck edge is not immersed these sides will remain parallel to each other and also the wedges will be symmetrical about centreline. In case of ship shaped vessels for most of the loaded conditions, for most of the length of the vessel the sides of the wedges can be considered as parallel to each other and the heel may be considered as wall sided till the deck as immersion.
In the fig 16 a vessel of breadth 2b is heeled to a large angle θ. The inclination is wall sided. Let g and g_1 be the centres of gravity of the immersed and emerged wedges. The volume of the two wedges must be equal. Let this volume be v.
Let X be the mid point of W_0W_1 or L_0L_1.

Now $XL_1 = \frac{b}{2}Tan\theta$ and $v = \frac{b^2}{2}Tan\theta$ .dx .....dx is the length of an elementary strip along the ship's length.
Also if hh_1 is the horizontal (transverse) distance between gg_1 and BR is the horizontal (transverse) shift of COB of the vessel then:

BR = $\frac{v \times hh_1}{V}$, where V is the underwater volume of the vessel.

hh_1 is 2/3rd of of projection on W_1L_1 or 4/3rd of projection of CS & SX on W_1L_1.
Also in triangle CPS, ∠PCS = θ and CP = b Cos θ..... (1)
And in triangle SPL_1 ∠PSL_1 = θ and SL_1 = b tan θ. ∴ SX = ½ b tan θ.....(2)
Also projection of SX on W_1L_1 = ½ b tan θ. sin θ..... (3)
Taking the values from (1) & (3) we get,

$$hh_1 = \frac{4}{3}\left(b\cos\theta + \frac{b}{2}\tan\theta.\sin\theta\right) = \frac{4}{3}b\cos\theta\left(1 + \tfrac{1}{2}\tan^2\theta\right)$$

$$v \times hh_1 = \tfrac{1}{2}\int b^2 \tan\theta\, dx \times \frac{4}{3}b\cos\theta\left(1 + \tfrac{1}{2}\tan^2\theta\right)$$ ..... Integrating over the entire length

$$= \frac{2}{3}\int b^3\, dx \sin\theta\left(1 + \tfrac{1}{2}\tan^2\theta\right)$$

But $\frac{2}{3}\int b^3\,dx$ = moment of inertia of waterplane about centreline

$$\frac{vxhh_1}{V} = \frac{MI_{CL}}{V}Sin\theta\left(1+\tfrac{1}{2}Tan^2\theta\right) = \quad BM\,Sin\,\theta\left(1+\tfrac{1}{2}Tan^2\theta\right) = BR$$

$GZ = BR - BG\,Sin\,\theta = BM\,Sin\,\theta\left(1+\tfrac{1}{2}Tan^2\theta\right) - (BM - GM)\,Sin\,\theta$

$$\therefore GZ = Sin\,\theta\left(GM + \tfrac{1}{2}BM\,Tan^2\theta\right)$$

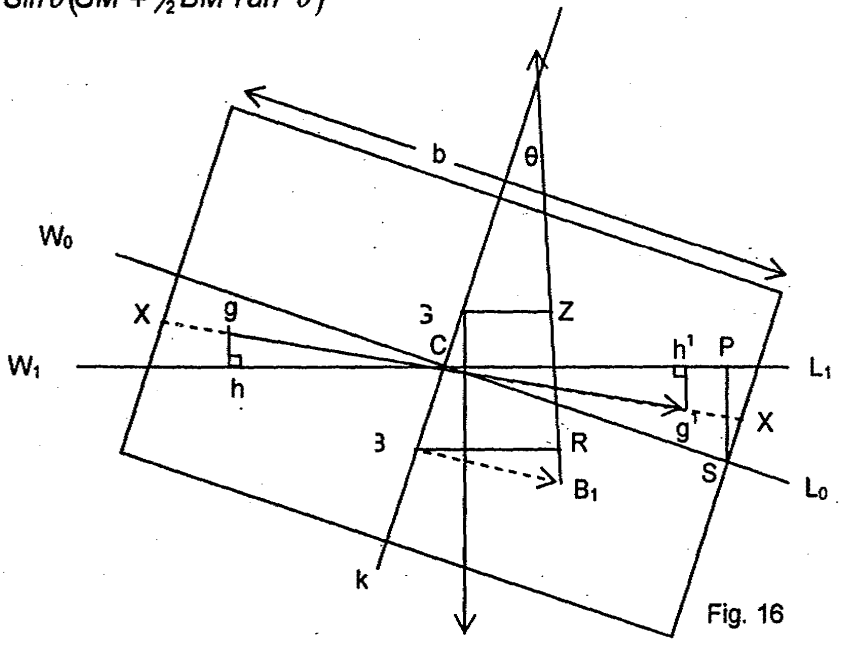


Fig. 16

Wall sided vessel seen at large angle of heel

Ex. 4 Assuming that a vessel is wall sided for the drafts involved, find the righting moment for a heel of 25°. Her GM is 1.15m, BM is 3.6m & the displacement is 10200t.

Sol^n:

$GZ = Sin\,\theta\left(GM + \tfrac{1}{2}BM\,Tan^2\theta\right)$

$= Sin\,25°\left(1.15 + \tfrac{1}{2}3.6\,Tan^2 25°\right)$

$= 0.65m.$

Ex . 5 A vessel of constant rectangular cross-section has a breadth of 12 metres & metacentric height of one quarter of her draught. The vertical centre of gravity lies on the waterline. Calculate her draught.

Sol^n: -

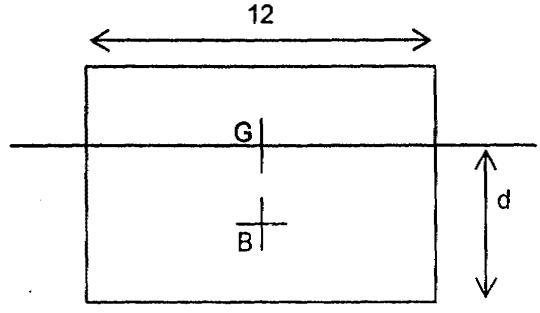


Fig. 17

Given KG = d .....(1) & GM = ¼ d.....(2)

But KB = ½ d..... [wall sided].....(3)

For this type of ship BM = $b^2/12d$ = 144/12d = 12/d.....(4)

KM = (3) + (4) = ½ d + 12/d..... (5)
KM = KG + GM
(5) = (1) + (2) or ½ d + 12/d = d + ¼ d
∴ 12/d = d – ½ d + ¼ d = ¾ d
∴ d^2 = 48/3 = 16.
∴ d = 4m.....Ans.

Load lines & allowance due variation in density: -
Discussions now are based on the following two situations in respect of ship's draft:

1. Restriction of draft on the basis of the loadline zone or the weather in that zone.
2. Change of draft due to change of density of water in which the ship is floating.

Restriction of draft: The ships are awarded statutory free boards considering various factors stated in loadline regulations. The vessel must not submerge the loadline pertaining to relevant zone in which she is going to ply. This will provide her with the free board that would be appropriate to the weather expected. The density of sea water that is considered for all the three load lines viz. summer, tropical and winter is 1.025 t /m^3.
The free board provides reserve buoyancy or safety against damaging green seas and is preventive measure against progressive flooding.

2. Change of draft due to change of density: - Many a times the water at the berth at which the vessel is loading is other than seawater. When the vessel has to load down to marks in these berths an extra sinkage called Dock Water Allowance is permitted. In the ports with fresh water the allowance is called Fresh Water Allowance.

The *fresh water allowance (FWA)* normally represented in millimetres is the amount by which the draft of a vessel changes when she passes from salt water to fresh water, or vice versa whilst floating at summer draft in sea water.

$$\text{FWA (mm)} = \frac{displacement(in\ tonnes)}{4 \times TPC}$$

The proof is as follows:

Let the vessel be afloat at her summer draft in salt water (at the waterline WL).
Let V be the UW volume of salt water displaced.
The UW volume in fresh water is V + v.
∴ 'v' is the extra volume of water displaced in fresh water.

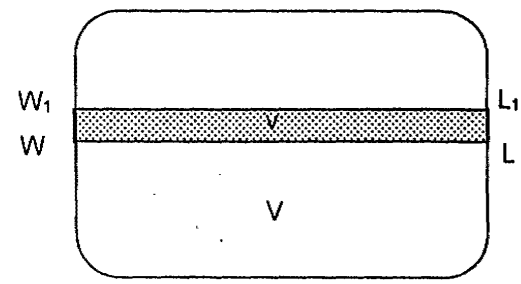


Fig. 18

∵ Mass = UW volume x density
∴ Mass of SW displaced = 1025 V & mass of FW displaced = 1000 (V + v)
But ∵ the mass or displacement remains constant in the two situations.
1000 (V+ v) = 1025 V
∴ 1000 V + 1000 v = 1025 V
∴ 1000 v = 25V
∴ v = V/40
Now let w be the mass of salt water in volume v and let Δ be the mass of salt water in volume V.
∴ w = Δ/40

$$\text{But } w = \frac{FWA}{10} \times TPC$$

$$\frac{FWA}{10} \times TPC = \Delta/40$$

$$\text{Or FWA} = \frac{\Delta}{4 \times TPC} \times mm$$

Where Δ = summer displacement

The fig below shows the load line on starboard side. A line 300mm long and 25 mm broad drawn in level with or wrt. free board deck called deck line can be seen right on top. Distance from the upper edge of this line and the centre of the disc is equal to the ships statutory freeboard. A vertical line 540 mm forward of the disc and 25 mm thick contains various loadline on it, each of thickness 25 mm and length 230mm. The upper edge of the one such line is in level with the centre of disc and is marked 'S'. This is Summer load line. Tropical and Winter load lines are marked above and below this line with a vertical separation of 1/48th of the Summer draft. Load lines marked 'F' and 'TF' are marked abaft the vertical line and the upper edge of these lines indicates the draft to which the ship may be loaded when floating in fresh water in a summer/ tropical zones respectively. A loadline named WNA (Winter North Atlantic) is placed 50mm below Winter loadline on the ship which are 100m in length or less.

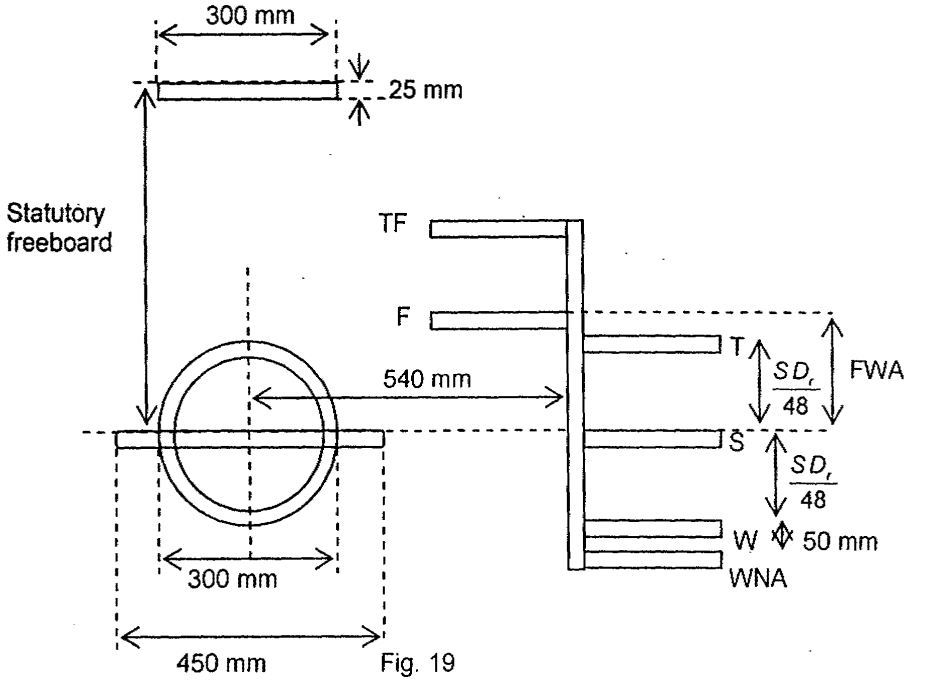


Fig. 19

The distance in millimeters between the upper edge of 'S' and 'F' is therefore the ships fresh water allowance. In brackish water where the density is in between that of FW and SW the allowance is less than FWA. The dock water allowance is found in practice by simple firmula as follows:

∵ Change of draft must be proportional to the change of densities (small changes in draft may be considered wall sided and thus more the change in density, more the change in draft).

$$\therefore \frac{\text{Change of draft SW} \sim \text{DW}}{\text{Change of draft SW} \sim \text{FW}} = \frac{DWA}{FWA} = \frac{\text{SW desnsity} - \text{DW density}}{\text{SW desnsity} - \text{FW density}} = \frac{1025 - DWD}{1025 - 1000}$$

$$\text{Dock water allowance} = \frac{\text{FWA} \times (1025 - \text{DWD})}{25}$$

Timber loadline: if the vessel is loaded on deck with timber in a compact way and appropriate securing arrangement are done as prescribed in timber code then the owners of such ships are likely to take advantage of loading at reduced freeboard which is calculated by giving allowance to the reserve buoyancy added by the deck cargo. The vessel however must comply with required conditions. The timber load lines when awarded are marked as follows:
LW, 1/36th of LS draft below LS. LT, 1/48th of LS draft above LS. LWNA, marked on all ships which have timber loadline either on the same level as the W mark (for ships more then 100m in length) or on the same level as WNA marked for other ship.

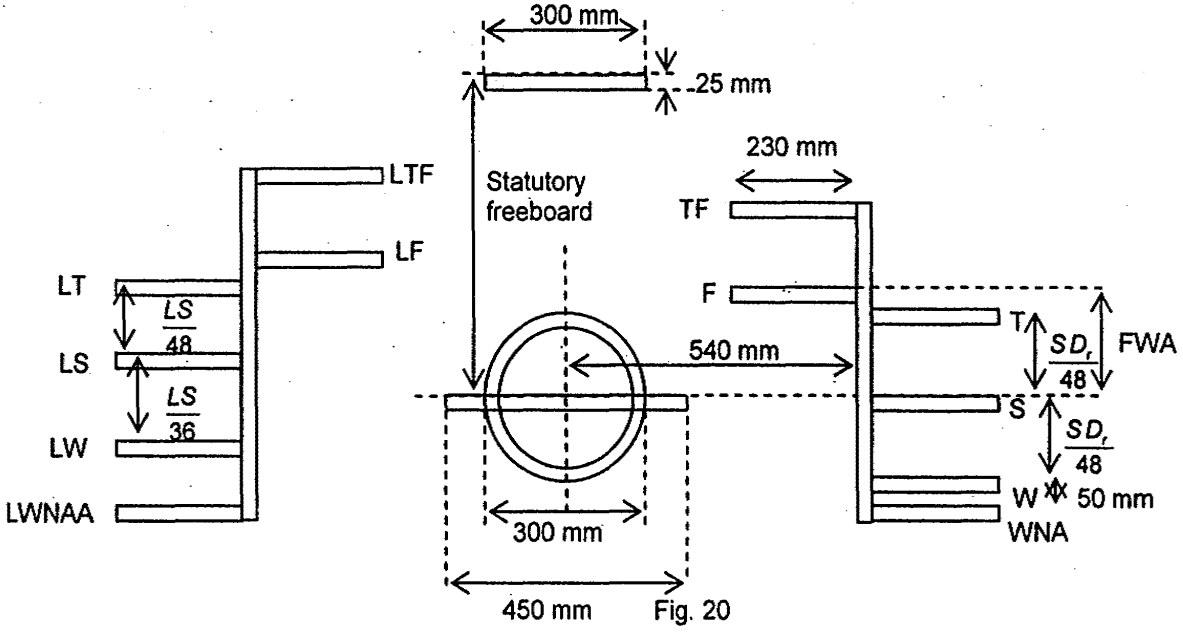


Fig. 20

Ex. 5 A vessel of summer displacement 16400t, TPC 22 and a summer draft of 8.4m is floating in SW (density 1.025t / m^3). Find the draft when she goes to;
a. fresh water port (density 1.000t / m^3).
b. a dock (density 1.015t / m^3).
Sol^n: -

$$\text{FWA (mm)} = \frac{\text{displacement}}{4 \times \text{TPC}} = \frac{16400}{4 \times 22} = 186.4\text{mm} = 0.186\text{m}$$

$$\frac{DWA}{FWA} = \frac{\text{SW desnsity} - \text{DW density}}{\text{SW desnsity} - \text{FW density}} = \frac{1025 - 1015}{1025 - 1000} = \frac{10}{25}$$

$$\therefore \text{DWA} = \frac{186.4 \times 10}{25} = 74.56\text{mm} = 0.075\text{m}$$

$\therefore$ draft in fresh water = 8.4 + 0.186 = 8.586m and draft in DW = 8.4 + 0.075 = 8.475 m

Ex. 6 A vessel of summer draft 9.6 m is floating in dock water of RD 1.010 with her summer load line immersed by 6 cm. She is to sail into a Tropical Zone. Calculate the maximum amount of cargo she can still load. Her FWA and TPC are 25 cm and 20 respectively.

Sol^n: - Distance from 'S' to 'T' = $\frac{1}{48} \times 9.6 = 0.20m$ = 20 cm.

∴ Tropical displacement – Summer displacement = 20 x 20 = 400 t.

$$\frac{DWA}{FWA} = \frac{SW\,desnsity - DW\,density}{SW\,desnsity - FW\,density} = \frac{1025-1010}{1025-1000} = \frac{15}{25}$$

$$DWA = \frac{250 \times 15}{25} = 150mm = 15cm$$

Submersion permitted to sail to Summer zone = DWA - 6 = 15 – 6 = 9cm

$$DW\,TPC = \frac{SWTPC \times DWD}{SWD} = \frac{20 \times 1010}{1025} = 19.71$$

Cargo to load for Summer zone = 9 x 19.71 = 177.39 t.
Cargo to load for Tropical zone = 177.39 + 400 = 577.39 t

Alternately: tropical draft = 9.6 + 0.2m = 9.8m
Summer displacement = FWA (mm) x 4TPC = 250 x 4 x 20 = 20000 t
∴ Tropical displacement = 20400 t

$$Tropical\ FWA = \frac{20400}{4 \times 20} = 255.5mm = 25.50\ cm$$

$$DWA = \frac{255 \times 15}{25} = 153mm = 15.3cm = 0.153m$$

Sailing draft in DW for tropical = 9.80 + 0.153 = 9.953m.
Her present draft = 9.6 + 0.06 = 9.66m
Thus the submersion permitted = 9.953 - 9.66 = 0.293m = 29.3cm
The cargo to load = 29.3 x 19.71 = 577.5 t
Ans. 577.5 t

Ex. 7 A vessel loaded down to Summer mark is floating in fresh water dock. She is loaded with 240t of cargo and arrives in open sea where she was again at Summer mark. Find Summer displacement of the vessel.

Sol^n: - Let the UW volume be V when she is floating at the Summer mark.
1.025 x V must be her summer displacement.
The displacement when she was in fresh water dock = 1.000 x V.
1.000 V + 240 = 1.025V
∴ 0.025V = 240
V = 9600m^3
∴ Summer displacement = 1.025 x 9600 = 9840t.
Ans. 9840 t

Ex. 8 A vessel arrives at certain port at the mouth of river. Her displacement is 14000t and arrival draft 6.40m in RD 1.015. She is to cross a bar upriver before entering a fresh water port. The depth marked for the bar is 6.20m and RD 1005. If her TPC is 24, find the quantity of cargo to off-load at the port at river mouth so that she may cross the bar with an under keel clearance of 0.8m. (Height of tide expected at bar is 0.4m).

Sol^n: - bar depth + HOT = draft + UKC
∴ Draft = bar depth + HOT – UKC = 6.2 + 0.4 – 0.8 = 5.8m.
Assume the vessel arrives at the location where density of water is 1.005 t / m^3.

$$FWA\ (mm) = \frac{14000}{4 \times 24} = 145.8mm \quad \frac{change\ of\ draft}{FWA} = \frac{1015-1005}{25} = \frac{10}{25}$$

$\therefore$ Change of draft $= \frac{FWA \times 10}{25} = \frac{0.1458 \times 10}{25} = 0.058m$.

The new draft = 6.458m.
But the draft required = 5.8m.
Bodily rise required = 0.658m = 65.8cm
Cargo to discharge = Bodily rise required x TPC in RD 1.005 = $\frac{65.8 \times 24 \times 1.005}{1.025}$ = 1548.4t

Ans. 1548.4t

Ex 9 A vessel in water of RD 1.020 floats at a EK summer draft of 7.5m with a UKC of 1.5m. If a cargo of 240 t is discharged at COF & later at ebb tide the RD of water became 1.005. What will be the new UKC? Given summer displacement = 15,000t, TPC 19. Fall of tide = 80 cm.

Hint: Divide the answer in 3 stages:

Stage 1: Only density changes, change (sinkage) = FWA x $\frac{1020 - 1005}{25} = 11.842\ cm$

Stage 2: Cargo is discharged, change (rise) = $\frac{240}{DW\ TPC} = 12.883$ cm

Draft = 7.500 + 0.118 – 0.128 = 7.490m. UKC = 1.5 + (7.5 – 7.49) = 1.51m.

Stage 3: Tide falls by 0.8m. New UKC = 1.51 – 0.8 = 0.71 m.

Exercise 5

Q. 1 A Vessel with LBP 144.OM has her COF 2.5M AFT of midlength, She, is floating at a draught of F 6.5M A 5.9m. Find her hydrostatic draught.

Ans. 6.189m

Q. 2 Two barges have the same length overall and maximum breadth. Barge A is box – shaped and Barge B is box - shaped with a triangular shaped bow. The distance of the centre of floatation from aft of Barge A will be greater/lesser than that of Barge B.

Ans. Greater

Q. 3 A box - shaped barge 30 m x 5 m x 4 m deep floating in water or RD 1.020 displaces 180 t when empty. If 350t of ore is loaded in the barge, calculate.

i. Her' reserve buoyancy then;
ii. The change produced in the KB by loading 350 t;
iii. The further weight of ore that can be loaded if the freeboard is not to be less than 40 cm.

Ans. i) 80.4m^3 ii) 1.144m iii) 20.9t

Q. 4 A drum of mass 1.2 t when empty, is 3 m long and 1.8 m in diameter. Find its draft in salt water if it contains 1900m^3 of oil of relative density 0.86.

A 1.087 m

Q. 5 A cube of wood of relative density 0.76 has sides 1.2 m long if a mass of 300 kgs is placed on the top of the cube with its centre of gravity vertically over that of the cube, find the draft in salt water.

Ans. 1.093 m

Q. 6 A box shaped tank, l 7m, b 4m & height 5m is open on top and is floating in fresh water at a draft of 15 cms. Calculate the minimum amount of fresh water which must be poured into the tank to sink it.

Ans. 135.8t

Q.7 A rectangular tank has a height of 75 cm & has no lid and is floating in fresh water at a draft of 15 cms. Calculate the minimum sounding to which fresh water must be poured into the tank to sink it.

Ans. 60 cm

Q.8 A homogeneous log of rectangular cross section is 50 cms wide and 32 cms in height. The log floats at a draft of 20 cms. Find reserve buoyancy and the distance between the centre of buoyancy and the centre of gravity.

Ans. BG = 6 cm. 37.5%.

Q. 9 A box shaped barge 95m x 12m x 6m displaces 1240 tonnes when light. if 1800 tonnes of iron are loaded while the barge is floating in salt water find her final draft and reserve buoyancy.
Ans. Draft 2.574 m. RB = 3905m^3 or 57.1%.

Q. 10 (a) A vessel was floating at her Summer draft in salt water. On her passage to a river port (R.D. 1.010), she consumed 120t of fuel oil and 30t-of fresh water, but her arrival draft was again the Summer draft. Find the Initial & Final displacement.
(b) If for the above vessel, KM = 7.0m, Initial KG = 6.2m. Kg of fuel tanks = 1.6m and Kg of fresh water tanks = 1.8m, calculate the Righting Moment at 80 angle of heel if the FSM in the final condition was 1200tm.
Ans. a) 10,250t & 10,100t b) $GM_{(F)}$ = 0.613m R.M = 862.3t.m.

Q.11. Vessel of length 120m, breadth 17 m, summer draft 6.6 m has a Block Coefficient of 0.88 and waterplane area coefficient of 0.75, at that draft. Calculate her FWA.
Ans. Δ = 12144.5t TPC = 15.68 FWA = 193.6mm

Q.12 When the tide falls, a moored barge grounds in soft homogeneous mud of specific gravity 1.35. With the keel just touching the mud, the barge was at a draft of 1.65m even keel in salt water of RD 1.025. The tide then falls a further 18cm. Assuming that the barge is box-shaped 25m long and 5m in breadth, calculate the draft after the tide has fallen. What weight must be removed to free the barge from the mud?
Ans. Draft = 1.47 + 0.137 = 1.607m, To disch. 23.056t

Q.13 The length of a ship is 18 times its draught, while the breadth is 24 times it's draught. At the load water plane, the water place area coefficient is 0.83 and the difference between the TPC in seawater and the TPC in fresh water is 0.7. Determine the length of the ship and the TPC in fresh water.

Q.14 A Vessel is floating in dock water of RD 1.008 with her star board winter North Atlantic mark 30 mm below and her port Winter North Atlantic Mark 70 mm below the water line. If her summer draft is 8.4 m, TPC 301'FWA 160mm, calculate how much cargo the vessel can load to bring her down to her tropical loadline in SW.
Ans. Tr. Δ = 19725 t Tr. FWD = 164.4 mm
To immerse 46.1cm & To load = 1360.1t

Q.15 i) A box - shaped vessel of length 200 m, breadth 30 m and depth 12 m is floating in salt water. If her summer draft is 8 m, calculate her displacement when she is floating at her Tropical, Fresh and winter drafts.
ii) A vessel with a uniform transverse cross section of a circle having a diameter of 18 m and length of 100 m is floating at a draft of 9 a in fresh water. Find her block coefficient and water plane coefficient at this draft. If she transfers to salt water, calculate her reserve buoyancy.
Ans. i) T = 50227.05t F = 50430t W = 48172.95t
ii) C_b = 0.785 C_w = 1 R.B. = 13027.17 m^3

Q. 16 A vessel of displacement 12000 t, TPC 20 t, arrived at a river port; at an even keel draft of 6.20 m, in water of RD 1.020. The tide is expected to fall by 70 cm at low water, when the RD of water is expected to be 1.012. If on arrival the under keel clearance was 30 cm, find the minimum amount of cargo to discharge to ensure that she will have an under keel clearance of 20 cm at low water.
Ans. submersion due density change = 4.77cm cargo to discharge = 1278.95t.

Q. 17 A vessel of length 200m, breadth 24m, summer draft 7.2m, Cb =0.85, Cw = 0.9 is presently floating with her tropical draft mark 3cm below the water line in water of R.D. 1.020. The under keel clearance is 0.5m. The tide is expected to fall by 60cm and the R.D. to change to 1.015. Find the quantity of cargo to be discharged if the underkeel clearance is required to be 0.3m after the fall in tide.
Ans. S. Disp = 30110.4t TPC = 44.28. Density sinkage 3.44cm cargo to disch 1904.76t.

Q. 18 A vessel of Length 120 m, Breadth 22 m, Summer draft 7.2 m, Block Co-efficient 0.83, Co-efficient of Waterplane Area 0.85, is presently floating upright in fresh water with the water-line 6 cms. below the Winter load line. Find the quantity of cargo to load so that she reaches her Tropical load line '.in salt water . Also calculate her draft in water of R.D. 1.020.
Ans. S. Disp = 15976.2t, Tropical FWA = 17.74cm. To load 928.22t.
Draft in D.W. = 7.385m Draft in FW 7.527m

Q. 19 A Vessel is floating in dock water of relative density 1.006 with her starboard WNA mark 25mm below the water line and her port WNA mark 50 mm below the water line. Calculate how much cargo can be loaded to bring the vessel to her summer draft in in Salt Water. Summer Salt Water draft 8.3 m; TPC : 30 t; FWA : 150 'mm
Ans. 113 mm & To load = 879.19t.

Q. 20 A vessel displacing 10,000 t is floating in SW with an under keel clearance of 0.5 m. When she moves to dock of water of R.D. 1.015, her freeboard changes by 8 cm. She then loads 125 t of cargo in dock. Find the under keel clearance in SW if the height of tide has remained the same.
Ans. FWA = 203mm TPC (DW) = 12.195 UK/CL = 0.4775m

Q. 21 A vessel floats in dock-water of relative density 1.016 with her winter loadline 100 mm below water on the port side and 180 mm below water on the stbd side. If her FWA is 200 mm TPC : 24 and summer load draft is 9.6 m, find the DWT available.
Ans. 311.32t

Q. 22 A vessel arrives at Port X at the mouth of river. Her displacement is 12000t and arrival draft 5.77m in RD 1.020. She is to cross a bar upriver before entering Port Y. The depth at the bar is 6.0m and RD 1005. If her TPC is 25, find the quantity of cargo to off-load at Port X so that she may cross the bar with an under keel clearance of 0.6m.
Ans. 1083.42 t

Q. 23 A Vessel of Displacement 16000 t increases her draft by l0cms when she arrives in dock water, of RD 1.015 from sea. The waterline was found to be 6cms above the Summer loadline Calculate the quantity of cargo that can be loaded so that the vessel will be floating to her Tropical mark in dock water, if Summer draft = 9.6m.
Ans. 221.8 t 218.53

Q. 24 A vessel has a summer freeboard of 4.2m which corresponds to a draft of 8.9 m. Her fresh water allowance is 178 mm and TPC is 22.5 t. The vessel is floating in water of R.D. 1.010 in tropical zone with present freeboards 4.4rn (starboard) and 4.3m (port). It is estimated that vessel will consume 70 t of fuel and 5 t of fresh water on her passage down river to sea. What is the maximum amount of cargo she may load in the river?
Ans. 1055.36

Exercise on M.V ALPHA SHIP with hints:

Q.1 M.V ALPHA SHIP loads to her Summer draft, in fresh water, and proceeds down river to another port consuming 40t of bunkers and water, At this port she loads some cargo after which WL is again at her Summer draft in water of RD 1.016. Find the number of tonnes of cargo loaded at the second port.

Hint: -

summer displacement Δ_S = 30634.2t (from tables)

Since vessel is in FW the displacement for summer draft = $30634.2 \times \frac{1.000}{1.025}$

= 29887.02 t

Δ_{DW} for summer draft = $30634.2 \times \frac{1.016}{1.025}$ = 30365.2 t

Δ_{FW} – 40 + cargo loaded 2nd port = Δ_{DW}

Cargo loaded at 2nd port = $\Delta_{DW} - \Delta_{FW} + 40$ = 518.18t

Ans. 518.18t

Q. 2 M V ALPHA SHIP arrived port in water of RD 1.014 at a draft of F 6.82m, A 7.88m. After discharging some cargo her drafts in water of RD 1.025 was F 5.26 m, A 6.04 m. If 90 t of fuel was consumed and 200t of FW was received in port. Calculate the amount of cargo discharged.

Hint: -

LCF for mean draft 85.491m ta = $\frac{t \times LCF}{LBP} = \frac{1.06 \times 85.491}{171.792} = 0.527$

Hydrostatic draft (DW)= 7.88 – ta = 7.352m

Δ found from tables = 21160.16 t

But since ship is DW correct displacement = 21160.16 x red. factor = 20933.1t

Final H. Draft(FW) = 5.65m

Final Δ = 15706.3t

Initial displacement - cargo discharged - 90 + 200 = final displacement

Cargo discharged = initial Δ - final Δ - 90 + 200 = 5336.8t

Ans. 5336.8t

Q. 3 M V ALPHA SHIP loading in dock, water of density 1010 kg/m^3 has her starboard plimsol 6cm above water line and her port plimsol 8cm below the water line. Calculate the maximum amount of cargo she can still load so that she would be at her summer mark in water of density 1025,kg/m^3, if 80 t of fuel and fresh water is expected to be consumed before sailing.

Hint:-

Mean load line mark $\frac{8-6}{2} = 1$cm below w/L

H draft = 10.156 + 0.01 m

= 10.166m

Entering table with draft in DW

Δ to be read and multiplied by reducing factor

Thus $30668.65 \times \frac{1.010}{1.025} = 30219.8$t

30219.8 + cgo. to load – 80 = summer Δ

Cgo to load = summer Δ + 80 – 30219.8 = 30634.2 + 80 – 30219.8 = 494.4t

Ans. 494.4t

Q. 4 M V ALPHA SHIP floating on an even keel in dock water of R.D. 1.016 with her starboard plimsoll 15cms above water and port plimsoll 11.6cms above water is to sail from the dock with a maximum even keel draft of 10.02m. Calculate (a) the maximum amount of cargo that can be loaded, (b) her draft on reaching the sea.

Hint: -

Mean load line mark = $\frac{15+11.6}{2} = 13.3\text{cm}$ above WL

Draft = 10.156 – 0.133
= 10.023m

Δ = 30176.38 x $\frac{1.010}{1.025} = 29734.8\text{t}$

Final draft in DW = 10.12m

Δ = 30510.3 x $\frac{1.010}{1.025} = 30063.8\text{t}$

Cgo to load = 329t

To find draft in SW simply enter tables with final displacement thus draft SW = 9.990m

Ans. 329t, 9.990m.

Q. 5 M V ALPHA SHIP is floating in dock water of R.D. 1.012 and draft fwd. 5.67m & aft 6.62m. Nos.1 & 4 (P, S) DBs which were full of ballast of R.D. 1.018, are emptied out. No. 3 and 5 DBs which were empty are filled with H.F.O. Calculate the maximum cargo to load so that she will float at her summer draft in salt water.

Hint: -

Trim = 0.95m (aft)

Mean draft 6.145m LCF = 86.846m

H draft = 6.62 – 0.480 = 6.140m

Δ Initial = 17270.54 x $\frac{1.012}{1.025} = 17051.5\text{t}$

Vol. of No 1 and 4 P/S DB = 1057.47m^3

Weight of ballast = 1057.47 x 1.018 = 1076.5t

Vol of No 3 P/S and 5 P/S = 876.414m^3

Weight of HFO = 832.59t

Δ Initial - 1076.5 + 832.59 + cgo to load = summer Δ

Cgo to load = summer Δ - Δ initial + 1076.5 – 832.59
= 13826.61t

Ans. 13826.61t

Q. 6 M V ALPHA SHIP KG 7.3 m arrived in port in partly loaded condition with drafts F 7.13m, A 7.64m in water of RD 1.010. Calculate the maximum quantity of cargo that can be loaded if the vessel has to sail on an even keel from the port in summer zone.

Hint:

Trim = 0.51 mean draft = 7.385m LCF = 85.449m

HD = 7.64 - $\frac{0.51 \times 85.449}{171.792} = 7.386\text{m}$

Δ = 21270.83 x $\frac{1.010}{1.025} = 20959.5\text{t}$

Cgo to load = 31361 – 20959.5t = 10401.5 t

To find draft in DW enter tables with $\Delta_1 = 31361 \times \frac{1.025}{1.010}$

Δ_1 = 31826.75 t draft $_{DW}$ = 10.502m

Ans. Present draft 10.502m. Quantity that can be loaded = 10401.5 t.

Q. 7 M V ALPHASHIP has to load at Mumbai for Gibraltar maximum cargo with ROB and zone details are as follows:
Mumbai to port Suez is 9 days of tropical zone Port Suez to Port Said is 1 day's canal transit Port Said to Gibraltar is 8 days of seasonal winter zone in winter season.
Daily consumption of heavy oil is 32 t, diesel oil 4 t, fresh water 20 t, lub oil / stores 1 t.
Consumption of DO in canal transit is 40 t. HO is not consumed in canal. At any given time there must be 3 days reserve of HO, DO, FW. Assume the vessel had no cargo and minimum bunkers FW & stores at Mumbai. The vessel has a constant of 75t. Bunkers & FW can be picked up at Mumbai or Port Suez. Find the quantity of cargo that can be lifted at Mumbai the ROB required at Mumbai and bunkers FW to lift at Port Suez. If the dockwater density at Mumbai port is 1.019t/m^3 find even keel draft at dep Mumbai.
At dep Mumbai the vessel carries tropical dead weight i.e. = 24149.4 t
Weights other than cargo:

HFO for (9+3) d @ 32t / day	= 384 t
DOFW stores for (9+3) d @ 25 t / day	= 300 t
Constant	= 75
Max cargo she can lift	= 24149.4 – [759] = 23390.4t
At dep Port Said the vessel carries winter dead weight i.e.	= 22679 t
Weights other than cargo are	
HFO for (8+3) d @ 32t / day	= 352 t
DO FW stores (8 + 3) d @ 25t / day	= 275 t
Constant	= 75
Max cargo she can have at dep Port Said	= 22679 – 702 = 21977 t

Dep Port Said is controlling point to decide the maximum cargo that can be loaded at Mumbai

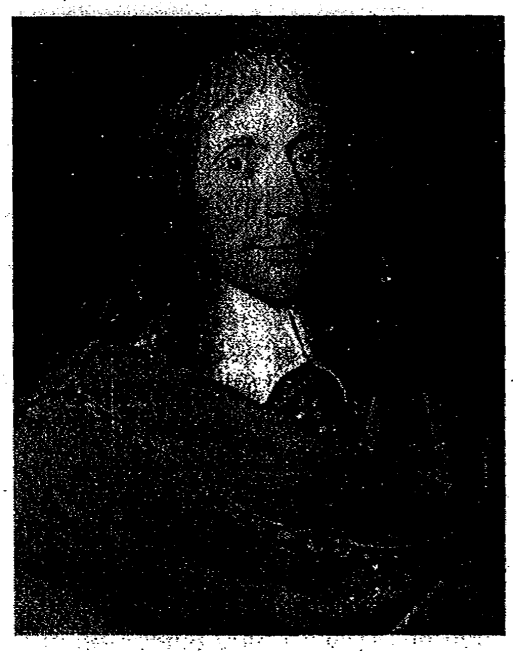
At Mumbai light weight	= 7211.6 t
Cargo	= 21977.0 t
HFO	= 384.0 t
DO, FW, stores	= 300 t
Constant	= 75 t
Displacement (total wts)	= 29947.6 t

Since the vessel is floating in DW the tables will be entered with $\Delta_1 = \frac{29947.6 \times 1.025}{1.019} = 30123.9$ t.

The draft for Δ_1 in tables = 10.008m.
At arrival Port Suez the vessel will have reserves of bunkers & FW for 3 days. She must pick up the bunkers and fresh water that will be consumed for next 1day of canal transit + 8 days of Mediterranean passage. i.e. 40 t of DO + 20 t of FW (canal), (32 + 4) x 8 = 288 t of bunkers + 20 x 8 = 160 t of water (Mediterranean).
Thus at Port Suez the vessel will lift 256 t of HFO, 72 t of DO & 180 t of FW.

Ans. a. Dep Mumbai ROB: HFO 384 t, DO 48 t. FW 240 t. b. cargo qty 21977.0 t. c. 256 t of HFO, 72 t of DO & 180 t of FW will be procured at Port Said.

Blaise Pascal (June 1623 - August 1662) was a French mathematician, physicist, and religious philosopher. He was a child prodigy who was educated by his father, a civil servant. Pascal's earliest work was in the natural and applied sciences where he made important contributions to the construction of mechanical calculators, the study of fluids, and clarified the concepts of pressure and vacuum by generalizing the work of Evangelista Torricelli.
Following Galileo and Torricelli, in 1646 he refuted Aristotle's followers who insisted that nature abhors a vacuum. His results caused many disputes before being accepted.



Chapter 6 Pressure and thrust

Pressure is defined as force per unit area. The unit of pressure used in the marine fiel therefore is Newton per m^2. Some times Newton per cm^2 or kilo Newton per cm^2 is also used for certain applications. In this chapter we will deal with pressure due to liquid. The tank plating i exposed to the pressure that is dependent on the density of liquid and the depth of the point below the surface liquid. A tank may be exposed to high pressures due to liquid heads i sounding pipe and air pipes. During a voyage the tank plates are also exposed to varyin pressures due to changing liquid levels in these pipes due to rolling & pitching.

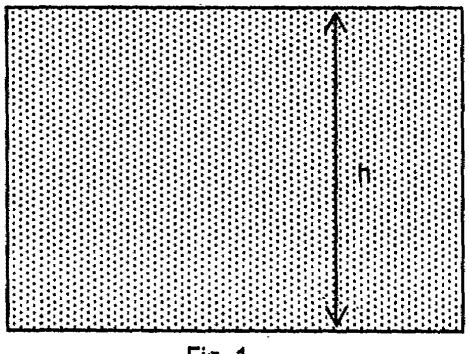


Fig. 1

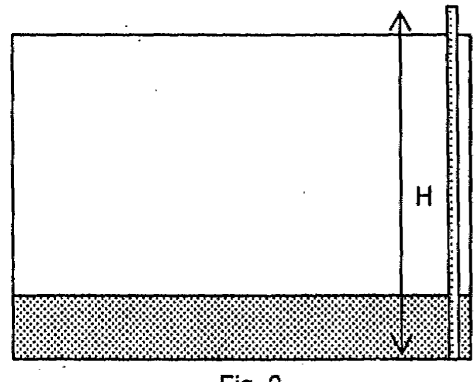


Fig. 2

In the above fig tank on the left is filled up with liquid. The pressure on tank bottom is dependent on the height (h) water coloumn and the density (δ) of liquid in tank. The pressure at the tank bottom = h δ. Unit of pressure commonly used for ship board use is tonnes per m^2.
In the fig on the right the double bottom tank is pressed up with the water filled up in sounding pipe.
The height of coloumn of water in sounding pipe is H. The density of liquid is same as that in the tank on the left. The pressure at the tank bottom = H δ. This means if H > h, the pressure at the tank bottom of the tank on the right is higher than the left side tank.

Thrust on a plating is found by multiplying the pressure with the area of plate. Thrust acts at right angles to the immersed surface. Also it is a known fact that the pressure at any depth is equal in all directions.
Thus in above example the thrust on the tank bottom on the right is more than that on the left, although only the double bottom is filled up and not the entire compartment as is seen in the fig on left.

In case of vertical bulkhead that form the side of a tank, the thrust on bulkhead is = pressure at centroid x area of the bulkhead.

Ex. 1 Calculate the upthrust on the bottom plating of a box shaped vessel 80 metres long 12 metres wide, when floating at a draught of 6 metres in sea water.

Sol^n: -

Thrust = area x height of coloumn of liquid x density of liquid
= a x h x δ
= (80 x 12) x 6 x 1.025
= 5904t

Ans. 5904t

Note: the thrust on the bottom is same as the vessel's displacement.

Ex. 2 A pressure test is conducted on a double bottom tank by filling up the sounding pipe with salt water to a sounding of 7m. What was the thrust on tank top plating if the DB tank measured 12m x 18m x 2m.

Sol^n: -

Head of water above tank top = 7 – 2 = 5m

Thrust on tank top = area x height of coloumn of liquid x density of liquid
= a x h x δ
= 12 x 18 x 5 x 1.025
= 1107t

Ans. 1107t

Ex. 3 A rectangular lock gate 24 metres wide 18 metres deep, has 6 metres of water of R.D. 1.025 on one side whilst on the other side there is 9 metres of water of R.D 1.010. Calculate the thrust on each side.

On the salt water side thrust = a x h x δ = (24 x 6) x 3 x 1.025 = 442.8t.
On the dock water side thrust = a x h x δ = (24 x 9) x 4.5 x 1.010 = 981.72t.
Ans. 442.8t and 981.72t.

Ex. 4 A collision bulkhead bounding the forepeak tank is 27 metres in depth and has starting from the top the following equally spaced ordinates: - 36.0, 34.1, 30.9, 29.4, 25.5, 16 and 7 metres. Calculated the thrust on the bulkhead when the tank is full of water R.D. 1.015.

Sol^n: -

Note: Simpsons rules are explain in chapter 14. This example however is included here to understand the principles of pressure and thrust as it applies to curvilinear shapes.

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever x	(5) = (3) x (4) ∫yxdx
36.0	1	36.0	0	0.0h
34.1	4	136.4	h	136.4h
30.9	2	61.8	2h	123.6h
29.4	4	117.6	3h	352.8h
25.5	2	51.0	4h	204.0h
16	4	64.0	5h	320.0h
7	1	7.0	6h	42.0h
		S-1= 473.8		S-2 = 1178.8h

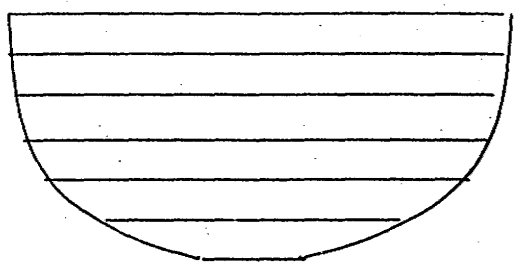


Fig. 3

Uniform interval between the ordinates = $\frac{27}{6} = 4.5m$.

Area of bulkhead = $\frac{h}{3} \times S-1 = \frac{4.5}{3} \times 473.8 = 710.7m^2$

Dist of centroid from the 1st ordinate = $\frac{\text{moment of area}}{\text{area}} = \frac{\frac{h}{3} \times S-2}{\frac{h}{3} \times S-1} = \frac{S-2}{S-1} = \frac{1178.8h}{473.8} = 11.195m$

Thrust on the bulkhead = area of bulkhead x depth of centroid x density
= 710.7 x 11.195 x 1.015 = 8075.63t.

Exercise 6

Q. 1 Given that the height of - the overflow pipe of a DB tank above the tank top is 15 m; The total depth of the tank is 1.5 m; and the area of a horizontal manhole, cover on the tank top is 0.25 m^2. If the tank is filled and overflowing with freshwater, the thrust on the manhole cover.
Ans. 3.75t

Q. 2 A vessel of constant water plane of length 150 m and maximum breadth 16 m ar water-plane coefficient 0.833 is at an even keel draft of 7.5 m. She has a midship rectangular double bottom tank of length 19 m, width 16 m and depth 1.2 m. Calculate the thrust on the tar top if that tank is run up by opening the sea valves.
Ans. Thrust 2019.447t.

Q. 3 A deep tank has two lids each 4m x 4m resting on coamings which are 28 cms. High find the water pressure on each of the two lids and the total thrust on both lids when the tank is filled with salt water to a head of 6m above the crown of the tank.
Ans. Total thrust on both lids = (6-0.28) 1.025 x 4 x 4 x 2 = 187.62 t

Q. 4 A rectangular plate 2m x 3m is held vertically in fresh water with the 2m. edge on the waterline. Find the thrust on one side of the plate.
Ans. 1.5 x 1 x 6 = 9 t

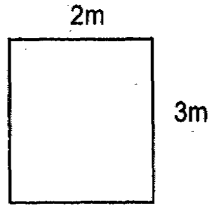


Fig. 4

Q. 5 A lock gate 16m wide has water of density 1016 kgs per m^3. to a depth of 11 m on one side and water of density 1019 kgs per cu. m. to a depth of 7m on the other side. Find the resultant thrust on the lock gate and state on which side it acts.

Ans. Resultant thrust = $\frac{11}{2}$ x 1.016 x 11 x 16 ~ $\frac{7}{2}$ x 1.019 x 7 x 16
= 584.04 t on inner side.

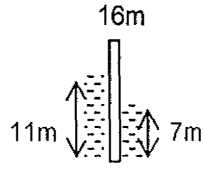
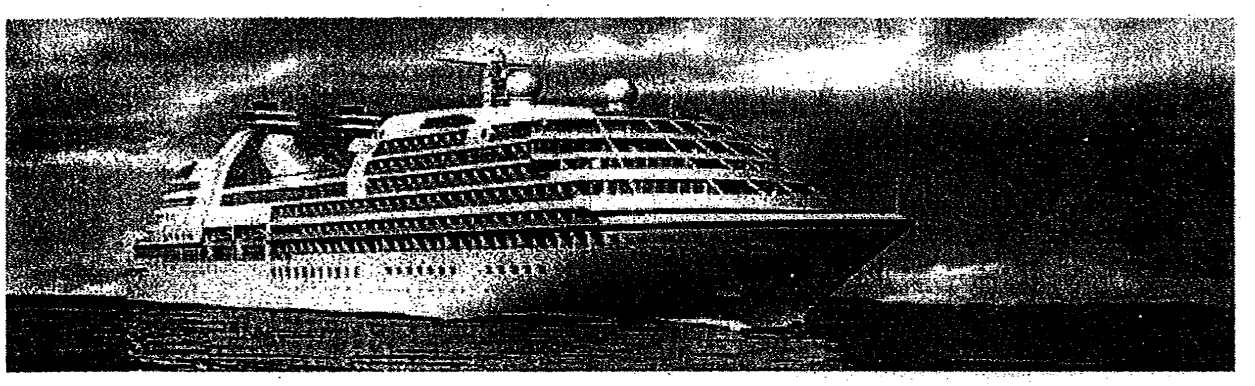


Fig. 5

In June 2009, Seabourn Cruise Line's newest ship Seabourn Odyssey is scheduled to embark on her inaugural journey. Touted as the world's most luxurious cruise vessel. Seabourn, the 32,000-ton, 450-passenger luxury vessel will come loaded with an array of lavish amenities. There will be 225 suites altogether and 90 percent of those will include balconies. The list of luxury amenities is quite long. The salient features include 11 passenger decks touting 225 ocean-view suites,



Chapter 7 Free surface effect

The free surface of liquid, or movable weights like free drums, whether on deck or inside a tank / hold cause virtual loss of GM. The officers on board ships should have a thorough knowledge of the effects of free surface on transverse stability since an excessive amount of free surface can change a vessel with a good positive GM into a tender vessel or one even with a negative GM. This means excessive free surface effect can even cause capsizing of the vessel.

This is because the free surface effect causes virtual rise of G. Actually the shift of G of ship is parallel to the shift of wedge of liquid which travels transversely during rolling of the vessel. This means the shift is more or less horizontal in athwart ship direction. Still the shift is considered vertically upwards. This is explained by the diagram in which G is shown moving parallel to the shift of 'g' of the liquid. This reduces the righting lever (GZ) of the ship at all angles of heel. The equivalent righting lever at a heel say θ^0 would also be found if G had sifted vertically upwards instead of athwart ship. The G therefore in spite of shifting athwart ship, in effect is considered to shift upwards. Thus we may say that net effect of free surface is to reduce the righting lever or reduce the righting capability of the ship.

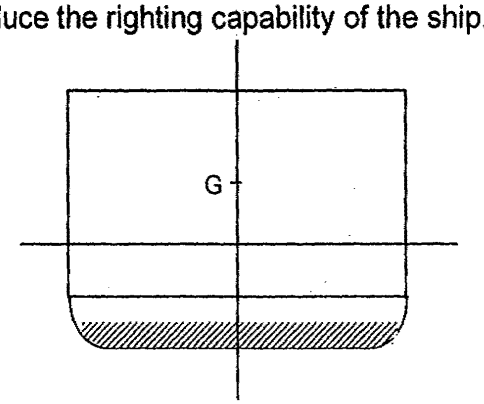


Fig. 1

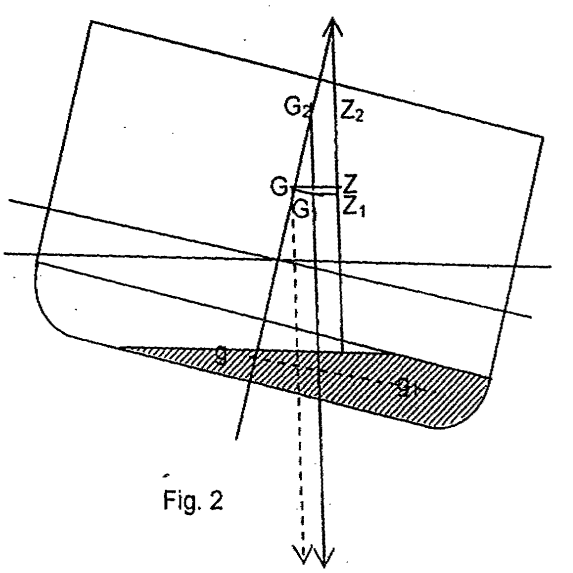


Fig. 2

The free surface effect is caused due to the listing moment caused by the liquid shift in rolling in athwart ship direction. This means the reduction in righting lever is proportional to the product 'w x d'. Thus we may say that if either of the two viz. w or d is very small the free surface effect will be negligible. 'w' is very small if the tank is almost empty or almost full. Also d is small when the athwart ship distance of liquid moment is controlled.

Let there be a tank of length l, breadth b with free surface of liquid. The moment of inertia of the liquid surface about its fore and aft axis passing through centroid of surface is given by;

$\frac{lb^3}{12}$ m^3. The free surface moment (FSM) is equal to the product of moment of inertia and density

$$FSM = \frac{lb^3}{12} \times \delta_i$$

$$FSE = \frac{\frac{lb^3}{12} \times \delta_i}{\text{displace ment}}$$

Following are the general principles in respect of movable liquid / cargo:-
The free surface effect depends upon the dimensions of the moving surface. The effect also depends upon the displacement of the vessel. The free surface effect depends upon the specific gravity of the movable liquid / material in the compartment. The effects also depend upon the specific gravity of the liquid in which the vessel is floating. The free surface effect does not depend upon the total amount of liquid / material having free surface.
It should also be noted that the swinging motion of any cargo or provision that is hanging will also produce a virtual rise in the center of gravity.

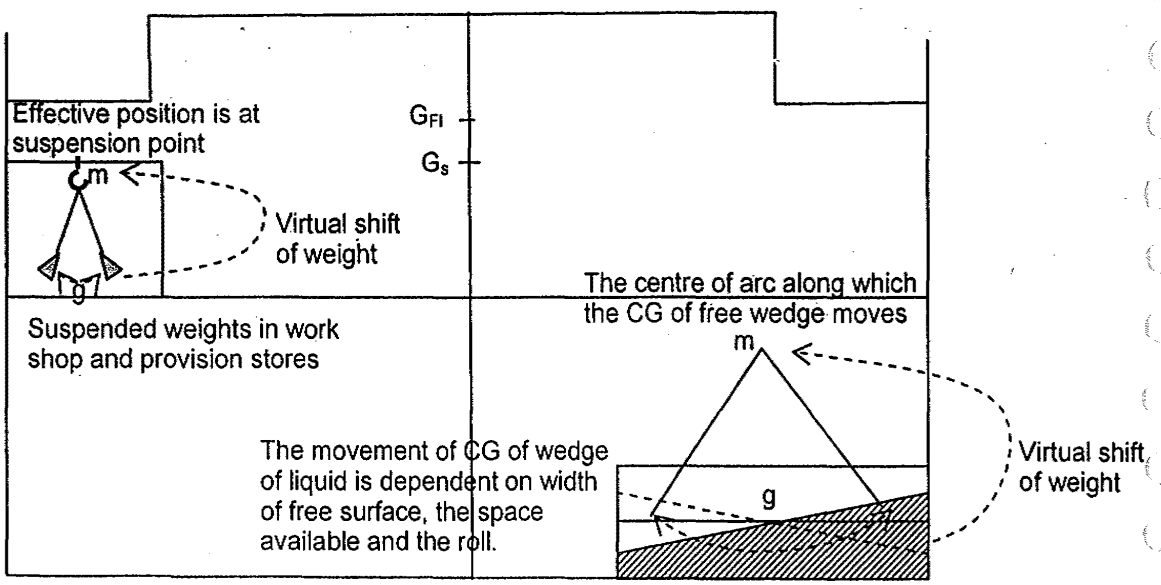


Fig. 3

In the above fig let the original position of CG of moving weights be at g in 'still' condition. In rolling the g virtually rises to a new position m. The distance gm is the virtual distance through which the g travels. The movable mass is revolving in the arc of a circle with m as center. The weight of the mass is in effect felt at m.
In case of a vessel we have $BM_t = I_{CL} / V$.

On the same lines gm = d = i/v, where 'i' in case of the tank is the moment of inertia of the liquid and v the volume of the liquid in the tank.
Thus we can say that the virtual rise of g is equal to i/v. the mass of the water in the tank is v x δ_i (density of liquid in tank).
The vertical movement of the center of gravity of a vessel can be found by the following formula:

$$GG' = \frac{w \times d}{\Delta}$$

Where: w is v x δ_i
Also d is i/v
Δ is V x δ_o (density of water out side).

$$GG' = \frac{v \times \delta_i \times i}{V \times \delta_o \times v} = \frac{\delta_i \times i}{V \times \delta_o} = \frac{\delta_i \times i}{\Delta}$$

Effect of amount of liquid in tank: -
It is an interesting fact that the amount of liquid in a tank does not vary the free surface effects. In the following examples we shall assume a vessel with an underwater volume of 10,000 m^3 in sea water & hence a displacement of 10,250 t. She has a tank which is 20 m in length 10 m wide and 2 m high. We shall calculate the free surface effects when the tank is three fifth full and when one half full both by usual free surface formula and also by the theory of moments (considering the weight of water in the tank lifted through its virtual rise thus changing the position of the center of gravity of the vessel.)
Usual free surface formula:

$$GG' = \frac{lb^3 \times \delta_i}{12 \times V \times \delta_o} = \frac{lb^3 \times \delta_i}{12 \times \Delta} \frac{20 \times 10^3 \times 1.025}{12 \times 10250} = 0.167 \text{ m.}$$

Free surface effects then have caused a rise of 0.167m in G, reducing metacentric height by this distance. Now using the theory of moments with the tank three fifth full.

Capacity of tank = 20 x 10 x 2 = 400 m^3
Three fifth capacity = (3/5) x 400 = 240m^3
Weight of water = 240 x 1.025 = 246 t.
Virtual rise of g = lb^3 / 12v= 20 x 10^3 / 12 x 240 = 6.944m

$$GG' = \frac{w \times d}{\text{displ.}} = \frac{246 \times 6.944}{10000 \times 1.025} = 0.167\text{m}$$

When the tank is three fifth full the free surface effects calculated by both methods show G rising by 0.167m. Now consider the tank to be half full.

One half capacity = 20 x 10 x 1 = 200m^3.
Weight of water = 200 x 1.025 = 205t.
Virtual rise of g = lb^3 12v = 20 x 10^3 / 12 x 200 = 8.333 m.

$$GG' = \frac{w \times d}{displ} = \frac{205 \times 8.333}{10000 \times 1.025} = 0.167\text{m} = 0.167 \text{ m}$$

Usual free surface formula: -

$$GG' = \frac{lb^3 \times \delta_i}{12 \times V \times \delta_o} = \frac{lb^3 \times \delta_i}{12 \times \Delta} \frac{20 \times 10^3 \times 1.025}{12 \times 10250} = 0.167 \text{ m.}$$

With the tank one half full free surface effect once more is exactly the same as calculated by both methods providing that these effects do not depend upon the weight of the water in the tanks.

It may be difficult to precisely state any exact correction to the stability curve for free surface at large angles of heel. This is because the movement of loose water in a tank or compartment can be very complex during the heeling of ship as the ship inclines. To correct the stability curve we must know the virtual position of the center of gravity of the loose water. We do know this position when the ship is erect. The breadth of the free surface changes with heel. This change is very complex since it varies not only with the angle of inclination but also with the breadth and depth of the compartment, the depth of the liquid in the compartment and the number of obstructions which might exist within the compartment. When the tank is almost full or almost empty the free surface effects is negligible.

Ex.1 the fore peak tank on a ship carrying ballast has the following athwart-ship semi ordinates measured from centerline from forward to aft: 1m, 2.4m, 4m, and 6m. The uniform interval between the ordinates being 4m. Find the FSM caused due to free surface effect when;

a. The tank is undivided,
b. The tank has a centerline water tight bulkhead.

Sol^n:- To calculate FSM, moment of inertia about a fore and aft axis // to centerline of ship must be calculated. This is multiplied with the density of liquid in tank to get the FSM.
Note: Basics of Simpson's is dealt in chapter 14.

(1) Ord Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4) = (3) x (1) $\int y^2 dx$	(5)= (4) x (1) $\int y^3 dx$
6	1	6	36	216
4	3	12	48	192
2.4	3	7.2	17.8	41.47
1	1	1	1	1
		S-1	S-2	S-3
		26.2	101.28	450.47

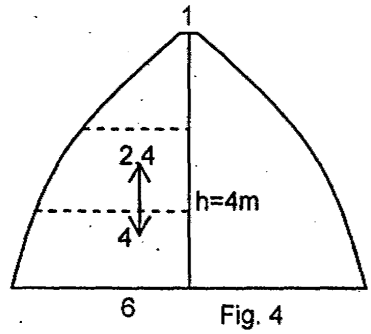


Fig. 4

To find MI of liquid surface of undivided tank:

MI about centerline of tank // to CL = $\frac{1}{3} \times 2\frac{3h}{8} \times S - 3 = \frac{1}{3} \times 2\frac{3 \times 4}{8} \times 450.47 = 450.47m^4$

FSM = 450.47 x 1.025 = 461.73t.m

To find FSM when the tank is divided by centerline W/T bulkhead:

The area of half of the tank = $\frac{3h}{8} \times S - 1 = \frac{3 \times 4}{8} \times 26.2 = 39.3m^2$

The moment of surface area of half of the tank about CL =

$\frac{1}{2} \times \frac{3h}{8} \times S - 2 = \frac{1}{2} \times \frac{3 \times 4}{8} \times 101.28 = 75.96m^3$

Distance of centroid of the surface from centerline = $\frac{75.96}{39.3} = 1.933m$

MI of free surface of half the tank about CL = $\frac{1}{3} \times \frac{3h}{8} \times S - 3 = \frac{1}{3} \times \frac{3 \times 4}{8} \times 450.47 = 225.24m^4$

MI of free surface of half the tank about F & A axis through centroid and // to CL = $225.24 - 39.3 \times 1.933^2 = 78.39m^4$

Total MI from both the tanks = 78.39 x 2 = 156.78m^4
The FSM = 156.78 x 1.025 =1 60.70tm
Ans. a. 461.73t.m, b. 1 60.70t.m.

Ex. 2 A pontoon of circular cross section 8 m in dia. and 8 metres deep floats in S.W. displacing 250 Tonnes, with its axis vertical. 50 tonnes of S.W. ballast is run into the pontoon and weight of one tonne is placed on deck 2 metres away from its centre. Calculate resulting angle of list KG of pontoon alone is 2.3 m.

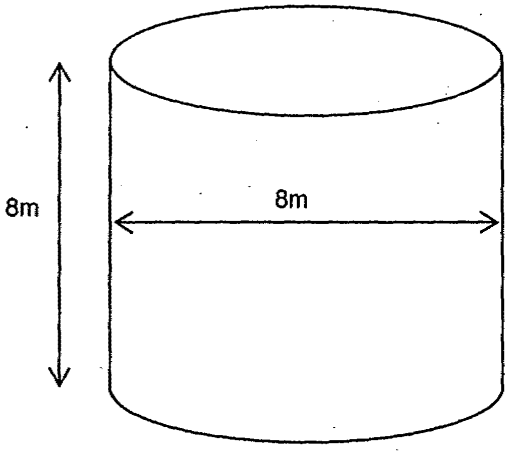


Fig. 5

Sol^n*:* - Area of water plane = $\pi r^2 = 50.265m^2$

Height of water in the tank = $\frac{50}{50.265 \times 1.025} = 0.97m$.

KG of this ballast = 0.485m.

Weights	KG(m)	Vert Moments (t.m)
250	2.3	575
50	0.485	24.25
1	8	8
301		607.25

New KG = 2.017m.

TPC = $\frac{WPA \times 1.025}{100} = 0.515m$

Draft = $\frac{uwvol}{WPA} = 5.842m$

KB = ½ draft = 2.921m

BM = $\frac{MI}{uwVol} = \frac{\pi D^4}{64V} = 0.685m$

KM = KB + BM = 3.606m

GM_S = KM – KG = 3.606 – 2.017 = 1.589m.

FSC = $\frac{\pi D^4 \times \delta_i}{64\Delta} = 0.685m$

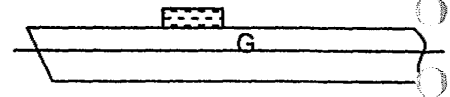
GM_F = 1.589 – 0.685 = 0.904.

List moment = Displ x (GM_F tan θ) = w x d = 2 t.m $\therefore \tan\theta = \frac{2 \times 1}{301 \times 0.904}$ $\therefore \theta = 0.44°$

Exercise 7

Q. 1 A pontoon of circular cross section diameter 4 meters floats with its axis vertical at a draft of 4m. The Kg is 2.5m, 50M/T of salt water is run into the pontoon and a weight of half a tones is placed on deck at a Kg of 9m & 0.5m away from the centreline. Calculate the angle of heel.
Ans. Draft 7.921m FSC = 0.126m GM_F = 1.703m Lit 0°4.9'.

Q. 2. A ship of displacement 1600 tonnes has 2 metres freeboard with her centre of gravity of 0.2 metre above the waterline. A rectangular deck area 20 metres long and 10 metre wide is filled to a depth of 0.5 metre when the vessel ships seas in heavy weather. Find the change in vessel's righting lever at 8° angle of heel.
Ans. SW qty = 20 x 10 x 0.5 x 1.025 = 102.5 t.



$$\text{Red}^{n} \text{ of GZ due rise of G} = \frac{102.5\times(2-0.2+0.25)}{(1600+102.5)}\times \text{Sin}\,8^{\circ} = 0.017 \text{ m.}$$

$$\text{Reduction of GZ due FSE} = \frac{20\times10^{3}\times1.025}{102.5}\times \text{Sin}\,8^{\circ} = 0.140 \text{ m.}$$

Q. 3 A ship of 16000 tonnes displacement is floating in dock water density 1014 kgs per cu. m. and is carrying oil of relative density 0.88 in a double bottom tank. The tank is 25m long 15 m wide and is divided at the centre line. Find the virtual loss of GM due to this tank being slack.

$$\text{Ans. V. Loss} = \frac{\left[\frac{25}{12}\times\left(\frac{15}{2}\right)^{3}\times0.88\right]}{16000} \text{ or } \frac{1}{2^{2}}\times\frac{\left[\frac{25\times15^{3}}{12}\times0.88\right]}{16000} = 0.0967\,\text{m}$$

Q. 4 A ship of 12000 tonnes displacement and has a deep tank l = 14 m b = 12m and is partly filled with veg oil of relative density 0.94. Find the virtual loss of GM due to the free surface.

$$\text{Ans. V. Loss} = \frac{\frac{14\times12^{3}}{12}\times0.94}{12000} = 0.158 \text{ m}$$

Q. 5 A ship of 12000 tonnes displacement has KG = 6.4 m and KM = 7.6 m. a double bottom tank 16m x 2m is subdivided at the entre line and is full of salt water ballast. Find the new GM if this tank is pumped out half.

$$\text{Ans. } \frac{(12000\times6.4)-16\times12\times1\times1.5}{12000-(16\times12\times1\times1.025)} = \frac{76512}{11803.2} = 6.482 \text{ m}$$

$$\text{FSC} = \frac{1}{4}\times\frac{16\times12^{3}}{11803.2} = 0.050$$

GM_{FL} = 7.6 – 6.482 – 0.050 = 1.068 m.

Stability in the intermediate stages can be critical. In the picture a capsized ship can be seen. There were still a few containers still to load, whilst lifting one of the containers, using the ship's own crane,. the vessel suddenly heeled over to port towards the quayside. The Master attempted to control the list with the ballast but this did not produce the desired effect, the vessel continued to list further until she capsized.



Chapter 8 Effect of loading, discharging and shifting of weights

The centre of gravity of the ship is a point at which the total weight is assumed to act downwards. The vertical distance of this point from keel is called the KG and the longitudinal distance of this point from aft perpendicular is called LCG. For equilibrium to occur the centre of gravity must be vertically in line with the center of buoyancy.
Adequate initial GM is one of the most convincing stability conditions which is always checked by a ships master. Now all stability manuals must have a graph of minimum GM or maximum KG versus the draft to quickly check whether the vessel is suitable for intact / damaged conditions. Since to calculate the GM in any condition it is required to calculate the KG using the KG of light ship, it is important that the KG of light ship is known with great accuracy.

Whenever a weight is loaded anywhere on the ship the COG moves in the direction of the point of loading and the shift is proportional to the product of weight that is loaded and the distance between the original COG and the location of loading.

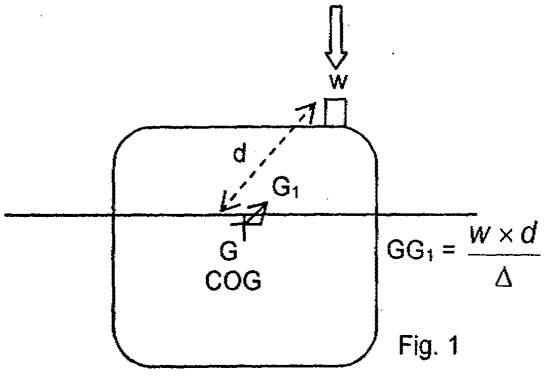


Fig. 1

Effect of loading a weight

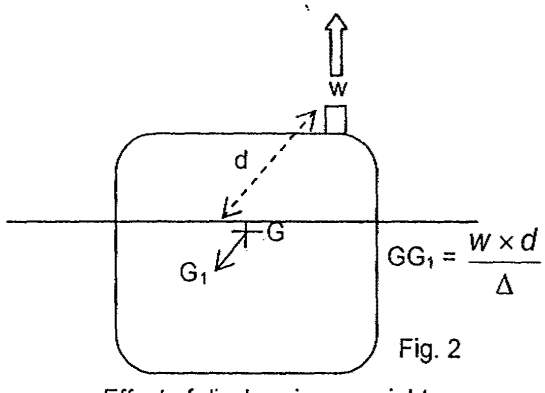


Fig. 2

Effect of discharging a weight

In above diagrams GG_1 indicates the actual shift of COG in the direction of loading or in the direction opposite to the position of discharging. The 'vertical shift component' or 'athwartship component' may be found if the d that is used is the vertical or athwartship component respectively.
The vertical component of GG_1 is responsible for increase or decrease of GM whereas the athwartship component is responsible for causing / changing the list.

The shift of COG is given by the formula $GG_1 = \frac{w \times d}{\Delta}$

(Δ is the final or resultant displacement).

Ex. 1 A tank weighting 40 tonnes is discharged from the upper deck. Its KG is 15 m. Displacement of the vessel before discharging was 8000 tons, KG 7 m. Find the upward shift of COG.

$$GG' = \frac{w \times d}{\Delta} = \frac{40 \times 8}{7960} = 0.040 \text{ m}$$

Note: Point of discharge is 15 – 7 = 8m above the COG, hence the COG will shift downwards to reduce the KG. The new KG therefore = 7 – 0.040 = 6.960 m.

Effect of shifting of weights: -

Whenever a weight is shifted from one location to the other the COG shifts in a direction parallel to the shift and proportional to the product of w & d, where w is the weight shifted and d is the distance through which the weight is shifted.

The shift of COG is given by the formula $GG_1 = \frac{w \times d}{\Delta}$.

Although this shift is caused in an oblique direction that is parallel to shift but if d is measured in vertical, athwartship or longitudinal direction the GG_1 will also be in vertical, athwartship or longitudinal respectively. The vertical shift causes GM to change, athwartship shift causes list to change whereas the longitudinal shift causes trim to change.

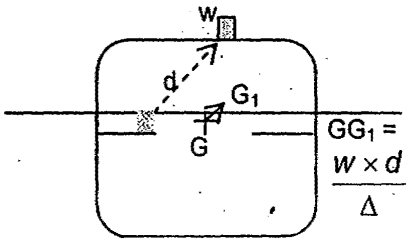
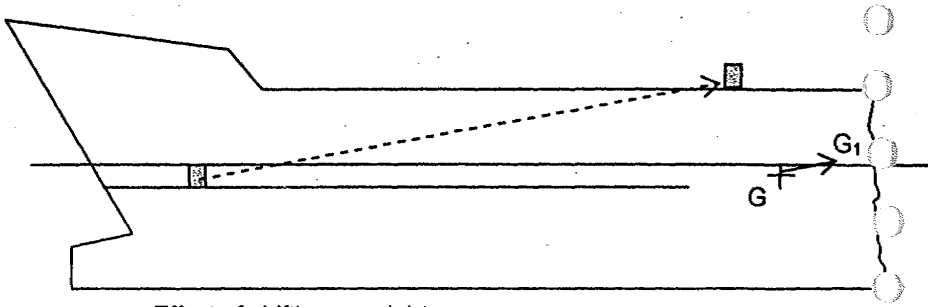


Fig. 3



Effect of shifting a weight

Fig. 4

Let Δ be the light displacement of a vessel and the distance of its COG above keel be KG. the ship may be loaded with various cargo consignments, bunkers, stores weighing w_1, w_2, w_3 etc at vertical distance above keel as kg_1, kg_2, kg_3 etc. There may be many more such weights located at different positions. The distance of common centre of gravity above keel can be found by a method called 'taking moments of weights about keel'. Thus the final KG or KG_1 is calculated as follows:

One must start with writing the correct light weight and KG of light shift in the first two rows of the table.

Find the quantity in tonnes and KG in metres for various weights (cargo, fuel, water stores etc.)
Multiply these distances (Kg_s) by the weights in the respective locations.
Add total weights including weight of light ship.
Add total moments including the moment of light ship.
Divide total moments by total weights to calculate final KG.

Weights (t)	Vertical above keel (m)	Vertical moments (t.m)
Δ	KG	Δ .KG
w_1	kg_1	$w_1 . kg_1$
w_2	kg_2	$w_2 . kg_2$
w_3	kg_3	$w_3 . kg_3$
$\Delta + w_1 + w_2 + w_3$	KG_1	$\Delta . KG + w_1 . kg_1 + w_2 . kg_2 + w_3 . kg_3$

$$KG_1 = \frac{\Delta . KG + w_1 . kg_1 + w_2 . kg_2 + w_3 . kg_3}{\Delta + w_1 + w_2 + w_3}$$

Similarly the distance of final or common centre of gravity of the ship from aft perpendicular may be found if the moment of different weights is taken about aft perpendicular. The LCG_1 is calculated as follows:

Weights (t)	Vertical above keel (m)	Vertical moments (t.m)
Δ	LCG	Δ .LCG
w_1	lcg_1	$w_1 . lcg_1$
w_2	lcg_2	$w_2 . lcg_2$
w_3	lcg_3	$w_3 . lcg_3$
$\Delta + w_1 + w_2 + w_3$	LCG_1	$\Delta . KG + w_1 . lcg_1 + w_2 . lcg_2 + w_3 . lcg_3$

$$LCG_1 = \frac{\Delta . LCG + w_1 . lcg_1 + w_2 . lcg_2 + w_3 . lcg_3}{\Delta + w_1 + w_2 + w_3}$$

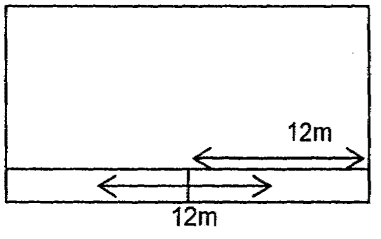
Ex. 2 150t of ballast was transferred from DB tank 5 port to the DB tank 5 stbd. The tanks are rectangular with width of 12m each. If the displacement of vessel was 14000t calculate the transverse shift of COG.

Sol^n: -

Distance shifted = Distance between the centroids of the two DBs = 12m.

Transverse shift of COG = $\frac{w \times d}{\Delta} = \frac{150 \times 12}{14000} = 0.129m$.

Fig. 5



Ex. 3 A ship at a displacement of 12500t, KG = 7.5m has 2 deep tanks each of capacity 240t with common bulkhead at centre line and cuboidal in shape. These tanks are 8m high and each has its centre of gravity 4.5m from centreline. If the port deep tank that was initially full of SW leaks off to the starboard deep tank that was empty earlier, till the levels in the two tanks are equal, find the new KG and position of COG of ship with respect to centerline. (The vessel was upright initially)

Sol^n: -

Since the two deep tanks are identical, after equilibrium the levels will be equal with equal quantity in each. Sounding in each tank will become 4 m.

We may assume that effectively a certain mass of liquid is shifted downwards and to starboard. To understand this we may assume that a rectangular block 4 m in height, weighing 120t with its kg = 6m is shifted to a new position with kg = 2 m. Alternately it may be assumed that a mass of 120t is shifted downwards by 4m and athwartship by 9m.

Transverse shift of COG = $\frac{w \times d}{\Delta}$ =

$\frac{120 \times 9}{12500} = 0.086m$.

Downwards shift of COG =

$\frac{w \times d}{\Delta} = \frac{120 \times 4}{12500} = 0.038m$.

The new KG therefore will be 7.5 – 0.038 = 7.461m.

Since the tanks are cuboidal with common bulkhead at CL, breadth of the tank must be 9m.

l x b x d x 1.025 = 240 t, gives l = 3.252m.

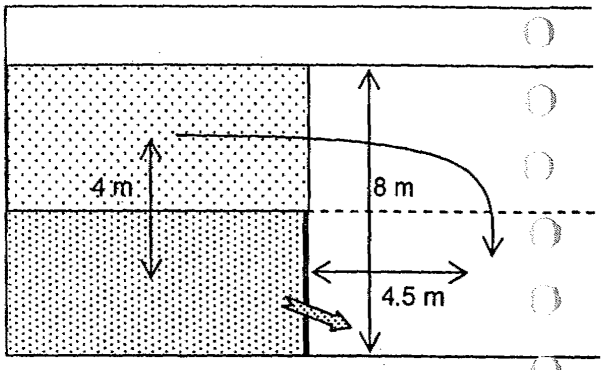


Fig. 6

FSC due these two tanks = $2 \times \frac{3.252 \times 9^3 \times 1.025}{12 \times 12500} = 0.0324m$

Ans. KG = 7.4934m, COG off centre by 0.086m.

Ex. 4 A vessel floating at her light draft displaces 5,000 tonnes. The light ship KG is 6.1 m above the keel. 300 t are loaded 3.2m above the keel and 360 t, 8.1m above the keel. What will be the new KG of vessel?

Weights (t)	Vertical above keel (m)	Vertical moments (t.m)
(+) 5000	6.14	(+) 30,700
(+) 300	3.2	(+) 960
(+) 360	8.1	(+) 2,916
5660		34576

$KG_1 = \frac{34576}{5660} = 6.109m$

Ex. 5 A vessel floating at her light draft displaces 12500 tonnes has a KG of 7.2m. 600t are loaded in a position 4.2 m above the keel and 430 tonnes were discharged from a position 8.1 m above the keel. A consignment of 200 tonnes was shifted vertically downwards by 7 m. Calculate the new KG of vessel?

Weights (t)	Vertical above keel (m)	Vertical moments (t.m)
(+) 12500	7.2	(+) 90000
(+) 600	4.2	(+) 2520
(-) 430	8.1	(-) 3483
(0)200	7	(-)1400
12670		87637

200t in the 1st coloumn neither added nor subtracted. The moments in the last coloumn subtractive because shift is towards keel.

KG = $\frac{87637}{12670} = 6.917$m.

Shift of COG in case of a weight suspended by the ship's gear: -

When a weight is lifted by the ship's own gear, the weight is transferred to the point from which it is suspended. This is a very important fact that must be understood well by mariners. Thus if a ship's crane picks up a load of 30t from say lower hold even by a few centimeters, the weight as if moves to the head of the crane. If the head of crane is say 25m above the lower hold deck, the distance moved by the weight in upward direction is 25m. If the displacement of ship at that Moment is 12,000t, KG 7.5m, the reduction in GM due to above operation will be $\frac{30 \times 25}{12000} = 0.063m$

The new KG will be 7.5 + 0.063m = 7.563m.

Let us now deal with the situation where the weight is being lifted by shore crane. As soon as the weight is lifted off the deck it can be considered discharged from the ship. Let us say that the original kg of the weight was 2.5m. the vertically upward shift of COG can be calculated as follows:

Upward shift of COG = $\frac{w \times d}{\Delta} = \frac{25 \times (7.5 - 2.5)}{12000 - 25} = 0.010m$.

The new KG will be 7.5 + 0.010m = 7.510m.

Whenever a vessel's own gear is used to load or discharge the cargo, care must be taken when loading or discharging the deck cargo, specially at the time of commencing the discharge or completion of loading. The vessel may reach a very low GM with a large listing moment at the instant when the cargo is suspended over the wharf. Ships have actually capsized on wharf due to this.

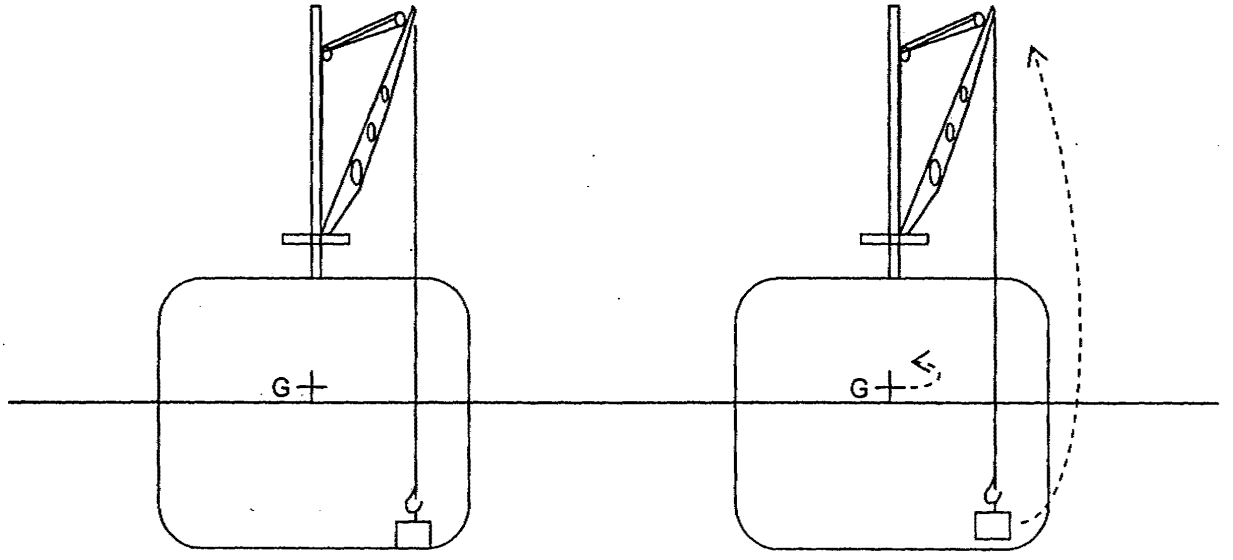


Fig. 7 Fig. 8

Exercise 8
Single shift/ loading / discharging

Q. 1 A ship sails with displacement 12100 tonnes and KG = 7.5 m. During the voyage 180t of bunkers were consumed from KG 1.0m. Find the change in KG and hence the KG at the end of the voyage.

Ans. increase = $\frac{180 \times 6.5}{11920} = 0.098m$. New KG = 7.598m.

Q. 2 On board a ship of displacement 11000t, KG 7.08m, a weight of 200t was shifted downwards vertically by 10m, find the new KG.
Ans. 7.08 – 0.18 = 6.9m

Q. 3 From a timber carrying ship's main deck (displacement 11075t) a timber consignment 75t (KG 12m) was released to sea. If the GM prior release was 0.08m, calculate the GM after the release of deck load. Loaded KM = 8.08m.

Ans. increase in GM = $\frac{75 \times 4}{11000} = 0.027m$

KG by moments: -
Q. 4 A ship of 15400 tonnes displacement has KG 6.5m, and loads the following cargo

- 2000 tonnes KG 5.8 m
- 1100 tonnes KG 4.8 m
- 900 tonnes KG 7 m

She then discharges 600 tonnes of ballast at KG 0.8m. Find how much deck cargo at KG 10m can be loaded so that the KG of ship does not exceed 7m.
Ans. 1066.7t

Q. 5 A ship has light displacement 4800 tonnes and light KM 8.1 m. She loads 1200 tonnes of cargo at KG 5.3m and 1800 tonnes at KG 7.0m. The KG is then found to be 6.46m. Find the light GM.
Ans. light ship KG 7.425 GM 0.675

Q. 6 A ship presently is at displacement 9500 tonnes and KG 8.1m. The following cargo is loaded
1250 tonnes KG 3.5 m
1190 tonnes KG 5.0 m
650 tonnes KG 7.0 m
If the KM for sailing draft is 9.4m, find the amount of cargo that can be loaded in no.3 tween deck (KG 9m) so that the sailing GM is 1.5m.
Ans. 6941.8t

Q. 7 A ship loaded with timber cargo under deck and at present displacement of 12000 tonnes and KG 7.4m and KM 7.3 m. she is to make a 15 day passage consuming 28 tonnes of oil (KG 1m) per day. Find how much deck cargo (KG 12m) she can load, if the GM on arrival at the destination should not be not less than 0.34 m. Given, KM at full-load draft is 8.42m. Also it has to be assumed that the deck timber will absorb 10 percent by weight of moisture.
Ans. 1200t.

Q. 8. A vessel of displacement 16000 t KG 9.0 m loaded cargo as follows 1000 t Kg 8.0 m, 2000t Kg 6.0 m and 1500 t Kg 10.0 m. A further 2000 t of cargo is to be loaded for which space is available in the lower hold kg 5.0 m and in the tween deck Kg 11.0 m. Calculate the weight to be loaded in each space so that her final KG (fl) would be 8.85 m. The total FSM is 2250 mt.
Ans. L.H. = 687.5t T.D. = 1312.5t

Q. 9 A ship of displacement 6200 t, KM 6.4m. GM ($_{FL}$) 0.8 m, FSC 0.1m, has to load another 600t of cargo. At what KG should this cargo be loaded so that she would have a righting moment of 320 t/m at a heel of 3° after completion of loading?
Ans. KG = 4.48m of 600t cgo.

Q. 10 A vessel floating to her Summer freeboard in salt water has KM 8 m, KG 6.8 m & FSM 1,100 tm. She consumes 120 t of bunkers KG 3.2 m & 50 t of fresh water, KG 6 m resulting in an additional FSM of 200 tm. She arrives in port of R.D. 1.015 & was floating to her summer freeboard. Find the righting lever at 5° angle of heel in port.
Ans. Initial Displacement = 17425t, Final Disp. = 17255 KG = 6.827m GM_F = 1.097 GZ = 0.0956m

Q. 11 A vessel of displacement 10,000 t, KG 6 m arrives from sea to anchorage in water of RD 1.015 thus changing her draft by 8 cm. Under keel clearance at anchorage was 0. 5 m. Find the quantity of ballast of RD 1.025 required to be pumped out from No. 3 DB tank (length 20 m, breadth 8 m and depth 1 m), which was initially full so that the under keel clearance increases to 0.6 m. Also find the GM (Fluid) in final condition if the KM is 7.5 m.
Ans. FWA = 203mm, Need to Pump out 121.95t at KG 0.628m
New KG = 6.066m GM_F = 1.423 m.

Q. 12 A vessel with displacement 8,700 tonnes, KM 9.2m, KG 8.1m, FSM 1240tm is required to sail with a GM (fluid) of 1.1m. Calculate the quantity of deck cargo (Kg 13.5m) to be discharged. (Assume KM to be constant).
Ans. 229.63t

Q. 13 A vessel floating in salt water has a displacement 8275 t, KG 9.3 m and KM 9.3 m. She has two deep tanks.' port and starboard, each being 9 m long, 6. 1 m wide and 7.7 m deep. The port tank is full of salt water ballast and the starboard tank is empty. Ballast is transferred from port tank to starboard tank until both are at equal level. Calculate the final GM_{FL}.
Ans. GM_{FL} = 0.0586m

Q. 14 A water barge 45m. long has a uniform transverse cross - section throughout, consisting of a rectangle above a triangle. The rectangle is 8m. broad and 5m high. The triangle is apex downwards, 8m. broad and 3m deep. KG and displacement when empty are 4.5m and 900t respectively. Find the GM when floating in FW with the triangular portion full of FW.
Ans. 1.177m

Q. 15 A ship of displacement 1400 tonnes has 2 metres freeboard with her centre of gravity of 0.2 metre above the waterline. A rectangular deck area 20 metres long and 10 metre wide is filled to a depth of 0.5 metre when the vessel ships seas in heavy weather. Find the change in vessel's righting lever at 5° angle of heel.
Ans. Increase in KB = 102.5 / 2TPC. Decrease in BM = M.I. / 20021.4. Increase in KG = 0.14m
Change in righting level = Change in GM x Sin 5°

Q. 16 Box shaped vessel 120 m x 18 m is floating at an even keel draft of 8.8M in FW with KG 7.278 m. A weight of 432 t is loaded at the centre line at a KG of 11.981 m. Calculate her KG and KM correct to the nearest 0.1 of a centimetre and hence find her righting moment at the angle of heel at which her deck edge immerses.
Ans. Assume Depth = 11.981m. GM = 0 Deck edge immersion at 22° 47.3' R. moment = 1995.55tm

Q. 10 A vessel floating to her Summer freeboard in salt water has KM 8 m, KG 6.8 m & FSM 1,100 tm. She consumes 120 t of bunkers KG 3.2 m & 50 t of fresh water, KG 6 m resulting in an additional FSM of 200 tm. She arrives in port of R.D. 1.015 & was floating to her summer freeboard. Find the righting lever at 5° angle of heel in port.
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Ans. FWA = 203mm, Need to Pump out 121.95t at KG 0.628m
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Ans. 1.177m

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Ans. Increase in KB = 102.5 / 2TPC. Decrease in BM = M.I. / 20021.4. Increase in KG = 0.14m
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Q. 16 Box shaped vessel 120 m x 18 m is floating at an even keel draft of 8.8M in FW with KG 7.278 m. A weight of 432 t is loaded at the centre line at a KG of 11.981 m. Calculate her KG and KM correct to the nearest 0.1 of a centimetre and hence find her righting moment at the angle of heel at which her deck edge immerses.
Ans. Assume Depth = 11.981m. GM = 0 Deck edge immersion at 22° 47.3' R. moment = 1995.55tm

Exercise on M.V ALPHA SHIP with hints:

Q. 1 M V ALPHA SHIP KG 8.3 m arrived in port in partly loaded condition with drafts F 7.13m, A 7.64m in water of RD 1.010. Calculate the maximum quantity of cargo that can be loaded if the vessel has to sail on an even keel from the port in summer zone.
If this quantity of cargo is equally loaded in No. 2 and No. 4 lower hold completely filling them, find the righting lever at 5° angle of heel and the draft in dock water if FSM was 1100 t.m.
Hint: -
Trim = 0.51 mean draft = 7.385m LCF = 85.449m

$$HD = 7.64 - \frac{0.51 \times 85.449}{171.792} = 7.386m$$

$$\Delta = 21270.83 \times \frac{1.010}{1.025} = 20959.5t$$

Cgo to load = 31361 – 2099.5t
= 10401.5 t

To find draft in DW enter tables with $\Delta_1 = 31361 \times \frac{1.025}{1.010}$

Δ_1 = 31826.75 t draft $_{DW}$ = 10.502m

Weights (t)	KG (m)	V. marks (t.m)
(+) 20959.5	8.3	(+) 173963.8
(+) 5200.75	5.478	(+) 28489.7
(+) 5200.75	5.489	(+) 28546.9
31361	7.366	231000.4

For Δ 31361 and vessel in DW
KM_T to be found by entering tables for Δ_2 31826.75t
$KM_{T\ (DW)}$ = 9.992m
$GM_{T\ (solid)}$ = 2.626m
FSC = 1100 / 31361 = 0.035m
$GM_{T\ (FI)}$ = 2.591m
Righting lever at 5° heel = $GM_{T(FI)} \sin \theta$
= 2.571 x sin 5°= 0.226 m
Ans. Present Draft 10.502m. Can load 10401.5 t Righting lever = 0.226 m

Q. 2 M V ALPHA SHIP is floating in SW at a draft of F 5.86m A 6.57m. In this condition her FSC is 0.87m and GM Fluid) is 0.79m. Vessel departs from port after she;
i) Loads 470T in nr. 4 TD
ii) Receives 280T fuel oil equally distributed in No. 3 DB tanks (port and starboard), which earlier were empty.
iii) Discharges 800t cargo from No.2LH (COG of cargo 6.1m above keel)
Calculate GM (Fluid) on her departure.
Hint: -
Trim = 0.71m, mean draft = 6.215m, LCF = 86.785m

$$H.\ draft = 6.57 - \frac{0.71 \times 86.785}{171.792} = 6.211m$$

Δ = 17495.8t, KM_T = 10.408m
$KM_T - KG - FSC = GM_{F1}$
$KG = KM_T - FSC - GM_{F1}$ = 8.748m

Weights (t)	KG_m	V moments (t.m)
(+) 17495.8	8.748	(+) 153053.3
(+) 470	11.836	(+) 5562.9
(+) 280	0.703	(+) 196.8
(-) 800	6.1	(+) 4880.0
17445.8	9.383	163693

Initial FSM = 0.87 x 17495.8 = 15221.3
If 280 t of full oil is taken in No 3 DB P % S it will not full up the tanks hence GSE will be caused
FSM added = 422.22 x 2 x 0.95
= 802.2

New FSC $= \frac{16023.5}{174453.8} = 0.918m$

Final KM_T = 10.414m
GM_{F1} = 10.414 – 9.383 – 0.918 = 0.113 m

Q. 3 M V ALPHA SHIP in condition no.2, ballasts No.2 D.B Tanks P&S discharges 1200t of cargo from No.2 TwDk. Calculate the vessel's righting lever at 8° angle of heel in port of R.D 1.010.
Hint: -

Weights (t)	KG_m	V moments (t.m)
(+) 30634.2	7.727	(+) 236710.5
(+) 657.2	0.682	(+) 448.2
- 1200	11.79	(-) 14148.0
30091.4	7.411	223010.7

$GM_{FI} = 9.935 - 7.411 - \frac{1352.3}{30091.4} = 2.479m$

By formula: -
Assume 8° to be a small angle of heel
And hence GZ = GM Sin θ
= 2.479 x sin 8° = 0.345m

By KN method: KN $= \left[(1.843 - 0.924) \times \frac{3}{5}\right] + 0.924$
= 1.473

GZ = KN – KG_F Sin θ
$= 1.473 - \left[7.411 + \frac{1352.3}{30091.4}\right] \sin\theta$
= 0.435

Q. 4 M V ALPHA SHIP arrives in condition no. 1 when the following operations were carried out: 900t loaded in no. 2 hold; 1200t loaded in no.3 hold, 1000t loaded in no.5 hold. No 4 DB tanks were completely filled up. Drinking water tanks port and starboard were completely filled up. Ballast from bulbous bow was removed. Find the GM (fluid) in the final condition.

Hint: -

Weights (t)	KG_m	V moments (t.m)
(+) 9626	7.542	(+) 72599.2
(+) 900	5.478	(+) 4930.2
(+) 1200	5.5	(+) 6600
(+) 1000	7.601	(+) 7601
(+) 528	0.714	(+) 377
(+) 18	11.8	(+) 212.4
(-) 287	3.52	(-) 1010.2
12985	7.032	91309.6

$$FSC = \frac{3839 - 1033.8 - 147}{12985} = 0.205m$$

KM_T = 11.659 GM_F = 4.422m

Q. 5 M V ALPHA SHIP at a hydrostatic draft of 8.00M in FW has KG 8.01m. She has yet to load 1400 t of cargo. At what kg should this cargo be loaded so that she would have a GM of 0,5 m in SW

Hint: -

Δ = 23289 x $\frac{1.000}{1.025}$ = 22721t

Final Δ = 24121 t

KM_T = 9.832

Final KG = 9.832 – 1.5 = 8.332m

Let the point of loading be x m above keel = $\frac{22721 \times 8.01 + 1400x}{24121} = 8.332m$

X = 13.557 m above keel.

Q. 6 M V ALPHA SHIP in condition NO. 2 discharges the entire cargo from No.1 tdk and No.3 tdk. The entire HFO from setting and service tanks P & S are shifted to No. 2 DB tanks port & starboard. Find the final KG and GM (fluid).

Hint: -

Weights (t)	KG_m	V moments (t.m)
(+) 30634.2	7.727	(+) 236716.8
(-) 942	12.28	(-) 11567.7
(-) 1620	11.40	(-) 18468.0
(0) 196.5	(6.4-0.682)	(-)1123.6
28072.2	7.322	205557.5

*(-) sign as shift is towards keel (0) sign because only shifting

New FSC = $\frac{1352.3 - 32.3 + 2537.4}{28072.2} = 0.137m$

KM_T = 9.856m

GM_{F1} = 2.397m

Q. 7 M V ALPHA SHIP at a river port in water of R.D. 1.007 has a displacement of 14100t. FSM 1200t.m, GM (Fluid). 0.64m. She loads 450t cargo KG 9.5m, 150t of water ballast is run in to no.1 DB tk that was empty. Find her GM (Fluid).

Hint: -
Δ = 14100t
Since vessel is in DW must be entered

For $\Delta_1 = 14100 \times \frac{1.025}{1.007} = 14352$ t

KM_T= 11.118m FSC = $\frac{1200}{14100} = 0.085$

KM – KG – FSC = GM_{F1}
KG = KM - GM_{F1} – FSC = 10.393m

Weights (t)	KG_m (m)	V moments (t.m)
14100	10.393	146541.3
(+) 450	9.5	4275
(+) 150	1.197	179.5
14700	10.272	150995.8

New FSC $= \frac{1200 + 779.34 \times 1.007}{14700}$
$= 0.135$
KM_T final in SW = 11.032m
GM_{FI} = 0.625m

Q. 8 M V ALPHA SHIP is floating at a mean draft of 8.20 m, KG 8.5m, F S Moment 1884tm and is required to load 1600 tonnes of cargo in No.3 hold and No.2 T.D. How much will you load in each space so as to complete loading with a GM (fluid) of 1 metre.
Hint: -
Δ = 23962.4t
Final Δ = 25562.4t

FSC = $\frac{1884}{25562.4} = 0.074$m

Let x + be loaded in hold 3 and (1600 – x) No 2 TD
Final KM_T = 9.820
Final KM_T final KG – final FSC = 1.25m
Final KG = final KM – FSC – 1.25 = 8496

Weights (t)	KG_m	V moments (t.m)
(+) 23962.4	8.5	203680.4
(+) x	5.5	5.5 x
(+)(1600 – x)	11.407	(1600-x) 11.407
25562.4	8.496	

$8.496 = \frac{203680.4 + 5.5x + (1600 - x)11.407}{25562.4}$

X = 804.72 t on Hold 3
795.28t in hold 2 TD

Q. 9 M V ALPHA SHIP arrives port in condition No,2. One of the consignments, weighing 90 tonnes is to be discharged from no 2 tween deck using the ship's jumbo derrick, the head of which is 27 meters above keel. Find her GM (fluid).
(a) When the weight is hanging on the derrick, 20cm above the deck.
(b) When the weight has been discharged.
Hint: -
CG of suspended weight shifts to point of suspension. For suspended condition

Weights (t)	KG_m (m)	V moments (t.m)
(+) 30634.2	7.727	(+) 236716.8
(0) 90	(27 – 11.792)	(+) 1368.7
30634.2	7.772	238085.5

$GM_{F1} = 9.955 - 7.772 - 0.044 = 2.139m$

When discharged

Weights (t)	KG_m (m)	V moments (t.m)
(+) 30634.2	7.727	(+) 236716.8
(-) 90	11.792	(-) 1061.3
30544.2	7.715	235655.5

$$\text{FSC in final condition} = \frac{FSM}{\Delta Final} = \frac{0.1352.3}{30544.2} = 0.443$$

KM = 9.951
GM_{F1} = 2.192m

Q. 10 M V ALPHA SHIP at a displacement of 12087.3t, KG 7.45m, FSC 0.103m, is in water of density 1.012t/m^3 No.2 Hold (5226.8 m^3) and No.5 Hold (997 m^3) were available, loaded with cargo (S.F. 1.20 m^3/t in No.2 Hold and S.F. 1.08m3/t in No.5 Hold). The After Peak tank which was empty is filled with dock water. Calculate her GM (Fluid) in the final condition upon reaching sea.

Initial Δ = 12087.3t

$$\text{Cargo in hold 2} = \frac{5226.88}{1.20} = 4355.73t$$

$$\text{Cargo in hold 5} = \frac{997}{1.08} = 923.15t$$

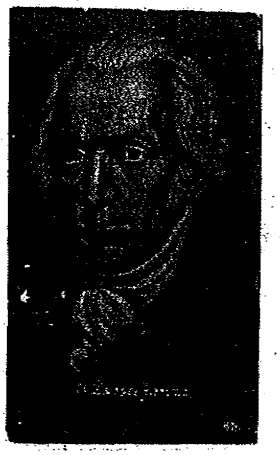
Ballast taken in A.Pk 141.68t
New Δ = 17507.68t

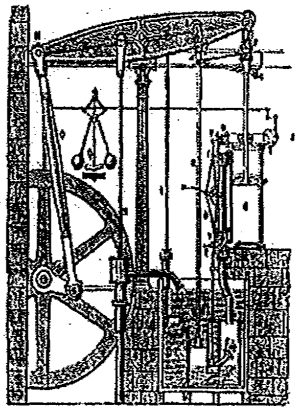
$$\text{New FSC} = \frac{0.103 \times 12087.3}{17507.68} = 0.071$$

Wt (t)	KG	V moment (t.m)
12087.3	7.45	90050.39
4355.73	5.478	23860.69
923.1	7.601	7016.48
141.68	9.4	1331.79
17507.81	6.983	122259.4

KM_T = 10.406m
GM_{F1} = 10.406 – 6.983 - 0.071 = 3.352m.
Ans. 3.352m

Watt, James (1736-1819). Scottish engineer whose improvements to Newcomen's design, including the separate condenser, turned the steam engine into the motive force of the Industrial Revolution. Watt exhibited great manual dexterity and an aptitude for mathematics.
Watt continued to invent other things before and during his semi-retirement. He invented a new method of measuring distances by telescope, a device for copying letters, improvements in the oil lamp, a steam mangle and a machine for copying sculptures





Chapter 9 List

Normally the merchant vessels are symmetrical about the center line and are upright without any necessity to adjust weights for this. Transverse shift of a weight will cause the COG of vessel to shift away from centerline of the vessel. To understand this let us considerer a shift of weight in purely transverse direction along deck, with no longitudinal or vertical component.

A student must understand the following drawing about list & should be able to draw it in correct sequence. BB_1 is drawn parallel and proportional to the product of volume and the shift of wedge. ($BB_1 = \frac{v \times gg_1}{V}$). Through B_1 a vertical line perpendicular to $W_1 L_1$ is drawn. A transverse line drawn parallel to the shift of weight or deck must meet this vertical line at G_1. This is because G_1 & B_1 must lie in the same vertical line in listed condition as the ship is in equilibrium when listed. For small angles the list can be found by the formula:

$$\text{Tan } \theta = \frac{GG_1}{GM}$$

(in Δ GG_1M, $\angle G = 90°$, GG_1 is transverse shift of COG & M is transverse metacentre).

It should be noted that GG_1 is parallel and proportional to product of weight shifted and distance through which the shift is caused.

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

Large amount of list can be found by subtracting or treating the upsetting arm curve (GG_1 Cos θ curve) from righting arm curve. This is dealt in chapter 12.

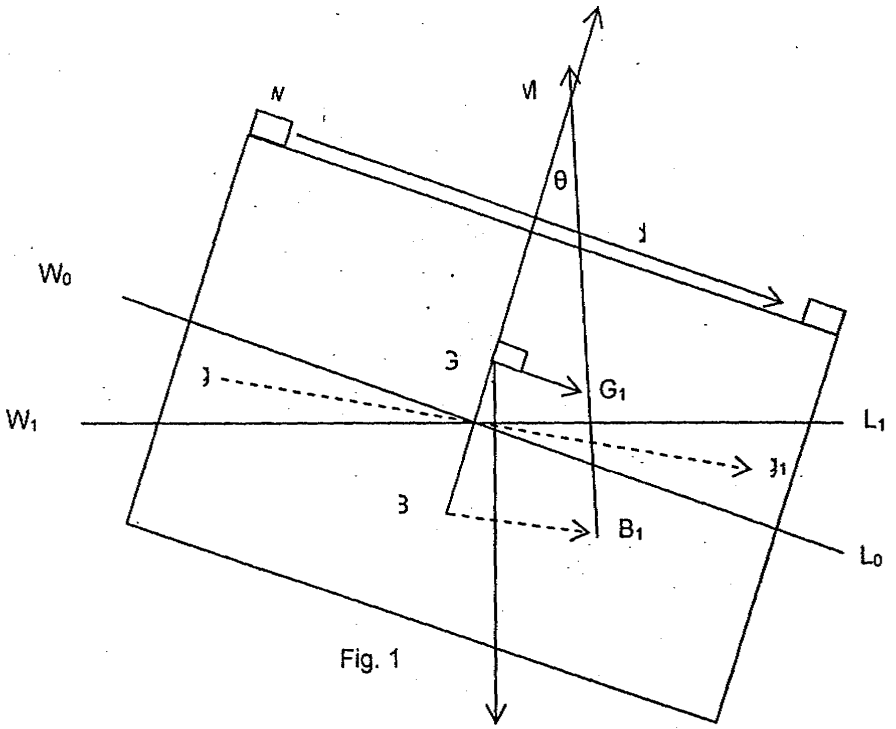


Fig. 1

In chapter 5 we have dealt with a situation where the vessel is heeled due external cause. A vessel in heeled condition is not in equilibrium where as a listed vessel is in equilibrium. A student of stability must clearly understand the difference between the two diagrams viz. the transverse section of listed vessel and the transverse section of a heeled vessel.
The two diagrams are similar in certain respects. Thus:

- BB_1 is parallel & proportional to gg_1.
- The volume of emerged wedge is equal to the volume of immersed wedge.

The differences are:

- In heel diagram the COG continues to be in centreline whereas in list diagram COG shifts off centre.
- In heel diagram GZ is parallel to present waterline whereas in list diagram GG_1 is parallel to deck or initial waterline.
- Vessel is in equilibrium when listed & but not when heeled.
- Heel is caused due to external cause whereas list is due to internal distribution of weights.
- In heel diagram the triangle is right angled at Z and the formula is GZ = GM Sin θ. In list diagram the triangle is right angled at G and the formula is Tan $\theta = \frac{GG_1}{GM}$.

The numericals in respect of list can be divided in 3 types.viz.

1. Where one or more listing moments are caused to a vessel that initially is upright.
2. Where one or more listing moments are caused to vessel that initially is listed.
3. Where correcting or counter listing moment is provided to a vessel initially listed, to correct the list.

In the numericals that are done under this chapter, following assumptions are made:

- KM remains unchanged in the process of listing..
- For a given list θ, the listing moment = Δ GM Tan θ.

Type 1: One or more listing moments are caused to a vessel initially upright.

Ex. 1 A ship of displacement 8000t, KM 8.4m, KG 7.2m is floating with no list. A weight of 110t is shifted transversely through 6m. Calculate the resulting list.

Sol^{n}: -

$GG_1 = \frac{w \times d}{\Delta} = \frac{110 \times 6}{8000} = 0.0825m$

GM = KM – KG = 8.4 - 7.2 = 1.2m

$\text{Tan } \theta = \frac{GG_1}{GM} = \frac{0.0825}{1.2}$

$\theta = 3.9°$.

Ex. 2 A ship of displacement 14800t, KM 10.4m, KG 9m was floating upright. The following operation will carried out:

- 210t loaded at KG 7.2m, 6m to starboard of centreline.
- 280t of ballast taken at KG 0.8m, CG of tank 7m to port of centreline.
- 75t of ballast was shifted from 3 port DB to 3 starboard DB through 14m.

Find the resultant list.

Sol^{n}: -

Weight (t)	KG (m)	Vertical moments (t.m)	Distance from CL (m)	Port listing moment (tm)	Stbd listing moment (tm)
(+)14800	9	(+)133200		00	00
(+)210	7.2	(+)1512	6		1260
(+)280	0.8	(+)224	7	1960	
(0)75	0	0	14		1050
15290	8.825	134936		1960	2310

Final KG $= \frac{\text{total vert moments}}{\Delta} = \frac{134936}{15290} = 8.825m$

Final GM = KM – KG = 10.4 – 8.825 = 1.575m.

Final listing moment (FLM) = 2310 – 1960 = 350tm.

Since FLM $= \Delta \times GG_1 = \Delta \, GM \, \text{Tan } \theta$

$\therefore \text{Tan } \theta = \frac{FLM}{\Delta GM} = \frac{350}{15290 \times 1.575} = 0.0145$

$\theta = 0.83°$ or 0° 50'stbd.

Type 2 One or more listing moments are caused to vessel initially listed

Ex. 3 A ship of displacement 18400t, KM 11.2m, KG 9.8m was listed 1½° to starboard. The following operations were carried out:

- 310t discharged from KG 8.2m, 5m to starboard of centreline.
- 200t each of ballast taken at KG 0.7m, at 3 centre DB and 3 port. DB. CG of port tank 8.2m to port of centreline.
- 75t of heavy oil was shifted from 5 port DB to the settling tank. The separation between the tank vertically is 8m. The CG of settling tank is 7m to starboard of the CG of port DB.

Find the resultant list.

Sol^{n} - Whenever the vessel is listed initially, the initial listing moment (ILM) must be found.

Initial GM = 11.2 - 9.8 = 1.4m

ILM = Δ x GG_1 = Δ GM Tan θ = 18400 x 1.4 x Tan 1.5° = 674.55t.m (stbd).

Weight (t)	KG (m)	Vertical moments (t.m)	Distance from CL (m)	Port listing moment (tm)	Stbd listing moment (tm)
(+)18400	9.8	(+)180320			674.5
(-)310	8.2	(-)2542	5	1550	
(+)200	0.7	(+)140	0		
(+)200	0.7	(+)140	8.2	1640	
(0)75	8	(+)600	7		525.0
18490	9.662	178658		3190	1199.5

Final KG $= \frac{\text{total vert moments}}{\Delta} = \frac{178658}{18490} = 9.662m$

Final GM = KM – KG = 11.2 – 9.662 = 1.538m.

Final listing moment (FLM) = 3190 – 1199.5 = 1990.5tm.

Since FLM = Δ x GG_1 = Δ GM Tan θ

∴ Tan θ $= \frac{FLM}{\Delta GM} = \frac{1990.5}{18490 \times 1.538} = 0.07$

θ = 4° to port.

Type 3 Correcting or counter listing moment is provided to a vessel initially listed, to correct the list

Ex. 4 A vessel of displacement 10400t, GM 1.2m is listed 1¾° to starboard. 400t is to be loaded in positions, 1) 7m to the port of centreline, 2) 3m to starboard of centreline. Find the quantity to load in the two locations in order to correct the list.

Sol$^{n:}$ -

Initial GM = 1.2m.

ILM = Δ x GG_1 = Δ GM Tan θ = 10400 x 1.2 x Tan 1.75° = 381.3t.m (stbd).

Since a counter listing moment equal to this must be caused to port and we need to load on port as well as starboard side, port listing moment must be more than starboard listing moment.

PLM > SLM or PLM – SLM = ILM = 381.3.m

Let X t be loaded on port side and 400 – X be loaded on starboard side.

7X – 3 (400 – X) = 381.3

∴ 10X = 381.3 + 1200 = 1581.3

∴ X = 158.13t

Hence 158.1t must be loaded on port side and 241.9t must be loaded on starboard side.

Note:

It is not necessary to calculate the final GM because so long as the vessel is upright Δ GM Tan θ will be 0, whatever the GM may be. So long as GM is positive the vessel will be upright because the listing moments are nil.

Examples involving use of ship's cargo gear with suspended weights during cargo operation.

Ex. 5 A ship of displacement 15000t, KM 9.6m, KG 8.8m, FSC 0.158m is listed ½ ° to starboard. A weight of 75t is to be discharged from a position on main deck (KG 11m) 7.5m to starboard of centreline. The weight is to be discharged on wharf at a point 18m from centreline. The tip of crane is 25m above keel. Find the list when:

a. The weight is just picked up,

b. The weight is suspended above wharf,
c. The weight is discharged.

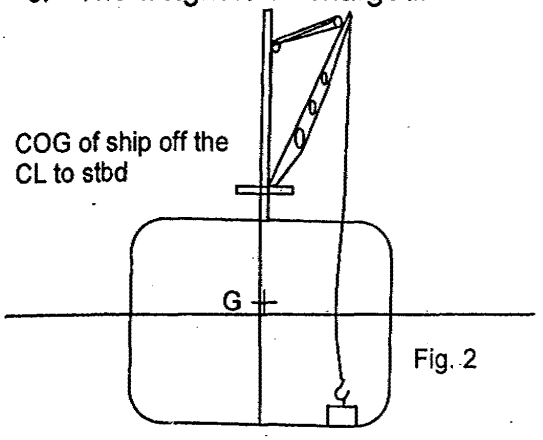


Fig. 2

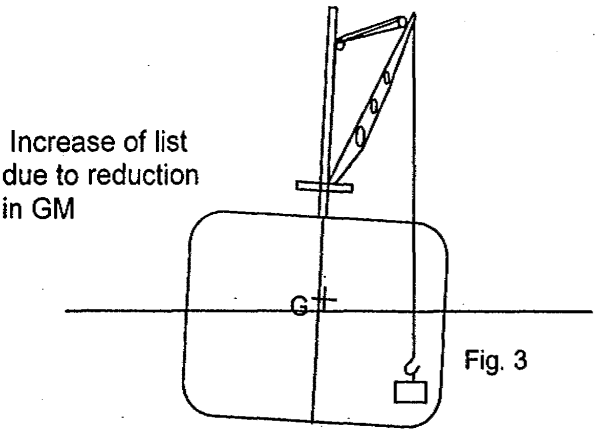


Fig. 3

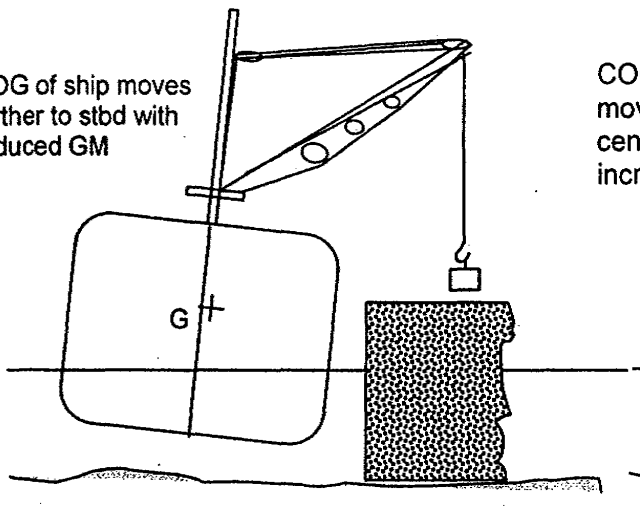


Fig. 4

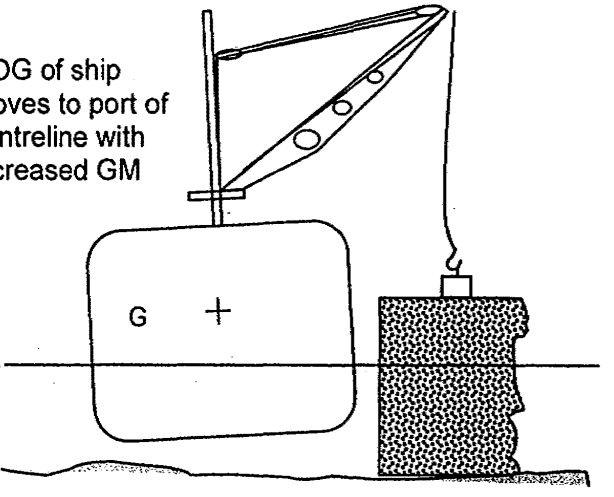


Fig. 5

Sol^n: -
Initial GM = 0.8m.
FSC = 0.158m
GM_F = 0.642m
ILM = $\Delta \times GG_1 = \Delta\, GM_F \text{ Tan } \theta = 15000 \times 0.642 \times \text{Tan } 0.5° = 84$ t.m (stbd).
Since the list is dependant on the listing moment as well as the GM, the list will vary during the discharge operation. The variation of list and GM is discussed in the following text.

a. *The weight is just picked up:*
As soon as weight is picked up from the deck the CG moves to the tip of crane reducing the GM of ship.

$$\text{Reduction in GM} = \frac{75 \times (25-11)}{15000} = 0.07$$

$$\therefore \text{ New GM} = 0.8 - 0.07 - 0.158 = 0.572\text{m}$$

The listing moment remains same viz. 84t.m

$$\text{Tan } \theta = \frac{LM}{\Delta GM_{FL}} = \frac{84}{15000 \times 0.572} = 0.0098$$

$$\theta = 0.56°$$

b. *The weight is suspended above wharf:*
In this state the GM_{FL} remains same as in (a) viz. 0.572m but the listing moment increases due to extension of listing arm.

Increase of listing moment = w x d, where w = 75t and d is the shift in athwartship direction.
New listing moment = 84 + [75 x (18-7.5)] = 871.5t.m

$$\text{Tan } \theta = \frac{LM}{\Delta GM_{FL}} = \frac{871.5}{15000 \times 0.572} = 0.1016$$

$$\theta = 5.8°$$

c. The weight is discharged: -

When the weight is discharged off the ship, the displacement would change. It is immaterial whether the discharging was done by ship's gear, shore crane or manually. The net effect is that the cargo is discharged from a position of KG = 11m. Thus in this part we will be ignorant about the role and existence of ship's crane.

To find new KG by moments

Weight (t)	KG (m)	Vertical moments (t.m)	Distance from CL (m)	Port listing moment (tm)	Stbd listing moment (tm)
(+)15000	8.8	(+)132000			84
(-)75	11	(-)825	7.5	562.5	
14925	8.789	131175		562.5	84

$$\text{Final KG} = \frac{\text{total vert moments}}{\Delta} = \frac{131175}{14925} = 8.789m$$

Assuming that KM does not change new GM_s = 9.6 – 8.789 = 0.811m

$$\text{FSC} = \frac{original\ FSM}{New\ \Delta} = \frac{\Delta \times 0.158}{14925} = 0.159m$$

GM_{FL} = 0.811 - 0.159 = 0.652m

FLM = 562.5 – 84 = 478.5 t.m

Since FLM = $\Delta \times GG_1 = \Delta\ GM \text{ Tan } \theta$

$$\therefore \text{Tan } \theta = \frac{FLM}{\Delta GM} = \frac{478.5}{14925 \times 0.652} = 0.049$$

θ = 2.8° to port.

Note:

When a weight is lifted by the ship's own gear, the weight is transferred to the point from which it is suspended.

Exercise 9:

Q. 1 A ship of 8000 tonnes displacement is upright and has KG 7.4 m and KM 7.95 m. it is required to list the ship 1.5° to starboard by shifting a weight of 45 tonnes transversely. Find the distance through which it must be shifted.

$$\text{Ans. } x = \frac{\tan 1.5° \times 8000 \times 0.55}{45} = 2.56m$$

Q.2 A ship of displacement 12000 t, KG 7.6m, KM 8.4m, FSM 800tm is upright. 400 t is loaded at kg 6m, 5m to port of CL, 200t is loaded at kg 8m, 3m to starboard of CL, 100t shifted 8m vertically downwards & by 2m athwartship to portside. Find the resultant list.

Ans. 8.55° port.

Q.3 A ship of displacement 11,000t, KG 7.9m, KM 9m is upright. 400t is discharged from a position kg 10m, 5m to port of CL, 100t is loaded at position, kg 3m & 2m to starboard of CL. Find resultant list.
Ans 7°49.4' to port.

Q.4 A ship of displacement 18000t, GM 1.8m is initially upright. A weight of 45t is lifted from wharf from a position 16m from CL. The jib of crane is 30m above keel. Find the list at the instant when the weight is lifted off the wharf.
Ans 1.3°

Q. 4 A Ship displacing, 8500T and having KM 11.0m and KG 9.8m is listed 4° to stbd. She then loads 2500t of cargo at centre line. Her final GM is 1.2m. Find out if the list will change and if yes find new angle of list.
Ans. 3.093°

Q. 5 A ship of 11000 tonnes displacement has KG 6.8 m, KM 7.9 m and is listed 4° to port. Assuming that the KM remains constant find the final list if 140 tonnes of bunkers are loaded in nr 3 starboard tank whose centre of gravity is 0.8 metre above the keel and 6.4 metres out from the centre line.
Ans. ILM = 11000 x 1.1 x tan 4° = 846.11 t.m (port) $\tan\theta = \frac{896 - 846.11}{\Delta_1 GM_1}$

$\text{Tan}\,\theta = \frac{49.28}{11140 \times (7.9 - 6.725)}$ $\therefore \theta = 0.2°$ stbd

Q. 6 A vessel of Displacement 12500 tons KM 7 m, KG 6.4m, has a 3° list to stbd and has yet to load 500 tons of cargo. The space is available in the tween deck at a KG of 10m & 6m., each side of the center line. Calculate the amount to be loaded on each side to complete the ship upright.
Ans. 282.76t port & 217.24t stbd

Q. 7 A ship of 11500 tonnes displacement is floating upright and has GM = 0.19m. a weight of 120 tonnes is shifted 1.8 m vertically downwards and 7.1m transversely to starboard. Find the list.
Ans. increase in GM = $\frac{120 \times 1.8}{11500}$ $\tan\theta = \frac{120 \times 7.1}{11500 \times 0.209} = 0.34$ m

Q. 8 A ship of 9000 t, has KM 8.7m, KG 7.2m. She is presently listed 8° to port. She has port and stbd deep tanks, each 10m long, 10m wide and 8m deep. The port side deep tank, which was full of SW, is pumped out until its sounding is 6 m. Assuming that no other tanks are slack, find the final list.
Ans. KG of block of liquid pumped out = 7 m

New KG solid = $\frac{9000 \times 7.2 - 10 \times 10 \times 2 \times 7 \times 1.025}{8795} = \frac{63365}{9895} = 7.205$m

ILM = 9000 x 1.5 x tan 8° = 1897.3 tm
SLM caused = 200 x 5 = 1025 m

Final L.M = 18973 – 1025 = 872.3 tm FSC = $\frac{\frac{10 \times 10^3}{12} \times 1.025}{8795} = 0.097$

$$\text{Tan } \theta = \frac{872.3}{8795 \times 1.301} \quad \theta = 4.36 \text{ (port)}$$

Q. 9 Approximately 200 tonnes of grain shifts 16 m. horizontally and 1.8 m vertically in a ship of displacement 14000t. If the ships original GM was 0.8 m. find the resulting list.

$$\text{Tan } \theta = \frac{F.LM}{\Delta GM} = \frac{3200}{1600 \times (0.8 - 0.0225)} \quad \theta = 14.93°$$

Q. 10 A ship of displacement 7500t, KM 8.6 m, KG 7.8 m, lost a quantity of deck cargo of KG 12 m, from 4 m to stbd of the centreline. If the resulting list was 3°20' to port, calculate the weight of deck cargo lost.
Ans. 86.36t

Q. 11 A ship of 13,500 tonnes displacement, KM 7.2 m, KG 6.4m, is listed 2.5° to starboard. She has to load a further 300 tonnes. Space is available in No. 4 TD, KG 8.4 m, on the port side 7m from the centre line and on the starboard side, 5m from the centre line. How much cargo should be loaded on each side to complete loading upright.
Ans. P = 164.295 & S = 135.705t

Q. 12 A ship of displacement 8,600t, KG 7.3m has to load a 2,200t parcel of cargo and then a heavy lift of 100t using her Jumbo derrick, the head of which is 26m above the keel with an outreach of 16m from the centreline. If her KM at a displacement of 10,900t is 8.2m, at what maximum KG can the 2,200t parcel be loaded so that the list when loading the heavy lift will not exceed 8 degrees?
Ans. KG of parcel = 5.734 m

Q. 13 A V/L of length 130m, breadth 24m, draft 9.6m, C_b 0.72 GM 0.9 m & KG 7 m is floating upright in SW. Due to heavy weather, a parcel of deck cargo with the KG of 9.0m and placed 2.5 m inboard of the bulwark is lost overboard. This has resulted in 3°P list. If KM in the final condition is 7 .8 m; find the weight of cargo lost overboard.
Ans. Δ =130 x 24 x 9.6 x 0.7166 x 1.025 = 22000t

$$Tan\ 3° = \frac{9.5\chi}{(\Delta - \chi)\left\{7.8 - \left[\frac{22000 \times 7 - 9\chi}{22000 - \chi}\right]\right\}}$$

$$\text{Gives } x = \frac{208538 \pm \sqrt{208538.6^2 - 4 \mp \times 9.437 \times 20292800}}{2 \times 9.437} = 97.7t$$

Q. 14 A ship of displacement 10000 tonnes, KM 7.5m. KG 6.9m is listed 5.5° to port. A heavy lift weighing 120 tonnes lying 6m to port of the center line and KG 10.2 m is to be shifted to the lower hold KG 2m on the center line of the ship by the ship's derrick whose head is 29 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 center line;
iii) The list after the shifting operation is completed.

Ans. i) 8°46.3'P ii) 2°10.6'S iii) 1°10.4'S

Q. 15 A vessel with displacement 21,000t, KG 8.5m, KM 10.0m, FSM 3,200tm, has a heavy lift of 100t in the lower hold. KG 3m and 5m to the port of centreline. This weight is discharged using her jumbo derrick with derrick head 42m above the keel and having an outreach of 18m from the centerline. Calculate the list when:

a) The derrick is plumbed over the quay on the stbd side with the weight still suspended and
b) The weight is discharged.
Ans. a) GM_F = 1.1619m List = 5.38° (S)
b) GM_F = 1.3206m List = 1.04° (S)

Q. 16 A vessel of length 130 m, breadth 24 m, draft 9.6 m, block coefficient 0.85 and KG 6.4 m is presently floating upright in salt water. Due to heavy weather, a parcel of deck cargo with vertical centre of gravity 9.0 m above the keel and placed 3.0 m inboard of the bulwark is lost overboard. This has resulted in 4° port list. If KM in the final condition is 7.0 m, find the weight of cargo lost overboard.
Ans. 130.8t

Q. 17 A pontoon of circular cross-section diameter 4 metres floats with its axis vertically at a draft of 4 m. The KG is 2.5 m. 50 M/T of salt water is run into the pontoon and a weight of half a tonne is placed on deck at a KG of 9 m 2.05 m. away from the centreline. Calculate the angle of heel.
Ans. Final KG = 2.258m BM_T = 0.126m List = 020.3°' or 0.34°
Exercise on M.V ALPHA SHIP with hints:

Q. 1 M V ALPHA SHIP displacement 24,000 t is upright and has a heavy lift (weight 90 t) on board at KG 11.9m and 7m to port of centreline. The heavy lift is to be discharged into a freighter. The derrick for this must be plumbed 16m to starboard of centreline. The derrick head is 31m above keel. What must be the initial KG of the vessel if the list is not to exceed 7° during this operation.

Hint : -
List max = 7° at time when weight is suspended and derrick swung out by 16m.

$$\text{Tan } 7° = \frac{GG_1}{GM} \text{ but } GG_1 = \frac{wd}{\Delta}$$

$$\text{Tan } 7° = \frac{wd}{\Delta GM} \quad GM = \frac{wd}{\Delta \times \tan 7°} = \frac{90\times(7+16)}{24000\times\tan 7°} = \frac{90\times 23}{24000\times\tan 7°} = 0.702\text{m}$$

KM_T = 9.834 KG = 9.132 when weight suspended

(+) 24000	X	(+) 24000x
(0) 90	(31-11.9)	1719
24000	9.132	24000x+1719

$$= \frac{24000x + 1719}{24000} = 9.132$$

X = 9.060 (initial KG)

Ans. Initial kg = 9.06 m

Q. 2 M V ALPHA SHIP in condition No 2 loads and discharges as follows:
Discharges 450 tonnes from No 1 tween deck, centre of gravity 6m to starboard of centre line.
Discharges 200 tonnes from No 3 tween deck, centre of gravity 8m to port of CL and kg 11.15m.
Fills up D.O. in No. 6 tank Stbd, (originally empty), centre of gravity 4.4m from centr e line. A parcel of cargo weighting 60 tonnes is shifted 7.2m vertically downwards and 2m transversely to starboard. Calculate the resultant list.

Hint: -

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 30634.2	7.727	(+) 236716.8	-	-
(-) 450	12.28	(-) 5526	450 x 6	-
(-) 200	11.15	(-) 2230	-	200x8
(+) 142	0.61	(+) 86.6	-	142 x 4.4
(0) 60	7.2	(-) 432	-	60 x 2
30126.2	7.588	228615.4	2700	2344.8

Resultant LM = 355.2 tm (port)

KM_T = 9.936m

$GM_{F1} = 9.936 - 7.588 - \frac{1352.3}{30126.2} = 2.303m$

$\text{Tan } \theta = \frac{RLM}{\Delta GM_{F1}} = \frac{355.2}{30126.2 \times 2.303} = 0.3° \text{ P}$

Q. 3 M V ALPHA SHIP in condition No. 2 floating in salt water: discharges the entire cargo from No.1 & 4 tween decks; consumes 60 tonnes of Diesel oil from No. 5 DB tank port (Centre of gravity 6.4m off the centre line). Consumes all the fresh water from DW tanks port and starboard. Calculate the resultant list.

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 30634.2	7.727	(+) 236716.8	-	-
(-) 942	12.28	(-) 11567.76		
(-) 1347.2	11.83	(-) 15937.38		
60	0.89	(-) 53.4		
90	11.8	(-) 1062	-	60 x 6.4
28195	7.381	208096.26		384

$KM_T = 9.860$

$GM_{F1} = 9.86 - 7.381 - \frac{(1352.3 + 281.5 - 147)}{28195} = 2.426$

$\text{Tan } \theta = \frac{384}{28195 \times 2.426}$ $\theta = 0.32°$(stbd)

Q. 4 M V ALPHA SHIP in condition 2 receives 88 t of Diesel oil in No 7 port DB tank CG 6.6m from the centre line. 300t of cargo is discharged from No. 2 tween deck from 4m to starboard of centre line. Calculate the resultant list.

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 30634.2	7.726	(+) 236716.8	-	-
(+) 88	2.9	(+) 255.2	88x6.6	-
(-) 300	11.79	(-) 3537	300x4	
30422.2	7.673	233435	1780.8	

KM_T = 9.947m

$GM_{F1} = 9.947 - 7.673 - \frac{1352.3}{30422.2} = 2.229m$

$$\text{Tan } \theta = \frac{1780.8}{30422.2 \times 2.229} \quad \theta = 1.5°\text{(port)}$$

Q. 5 M V ALPHA SHIP at displacement of 23630t, FSC 0.1 m, KG 8.5m is floating in SW with a list of 2° to Port. If the entire 150t of fuel oil in No.4 (P) DB tank, CG 6.2m off the centre line is transferred to No. 4 (S) DB tank (CG 6.2m off the centre line) which was empty before, find the resultant list.

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 23630	8.5	(+)200855	1024.9	
(0) 150	0	(0)		150 x 12.4
(+) 23630	8.5	(+)200855		RLM = 835.1

KM_T = 9.842, KG = 8.5 FSC = 0.1
ILM = Δ GM_{Fl} x tan θ = 23630 x 1.242 x tan 2° = 1024.9tm
FSE remains unchanged as 4 ports FS is now transferred to 4 stbd & is same in extent. Also there is no change of displacement. Since there is no changed of displacement and vertical shift of weight the GM also is unchanged.

$$\text{Tan } \theta = \frac{835.1}{23630 \times 1.242} \quad \theta = 1.6° \text{ (stbd)}$$

Q.6. M V ALPHA SHIP at a hydrostatic draft of 7.70 m in SW, KG = 8.1 m, FSC 0.1m, loads 900 t of cargo at a KG of 11.407 m and 3 m to port of centreline, discharges 123.5 t from a position of kg 14 m & 4 m to port of centreline in dock water of RD 1.010. Calculate the list produced.

Hint: -
For H D 7.70 m Δ = 22297.8 t. Initial FSM = 2229.8 tm

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 22297.8	8.10	(+) 180612.2		
(+) 900	11.407	(+) 10266.3	900 x 3	
(-) 123.5	14	(-) 1631		123.5 x 4
23074.3	8.202	189247.5	2700	494

Table entered with Δ_1 = 23074.3 x $\frac{1.025}{1.010}$ = 23417t

H Draft = 8.038m

KM_T = 9.846m, FSC = $\frac{2229.8}{23074.3}$ = 0.097 m

GM_T = 9.846 – 8.202 – 0.097 = 1.547m

$$\text{Tan } \theta = \frac{2226}{23074.3 \times 1.547}$$

θ = 3.54° (port)

Q. 7 M V ALPHA SHIP, KG 8.4m is presently floating in dock water of R.D. 1.012 with her winter loadline 4cm below the water line.

(a) Find the quantity of cargo to load if she has to float at her summer draft in salt water.
(b) If 200 tonnes of this cargo is loaded in No. 2 tween deck 4m off the centre line (stbd.) and the balance in No.3 tween deck 6m off centre line (port), find the resultant list in dock water. (FSM in final condition 1200tm).

Hint: -
Present draft = 9.945 + 0.04
= 9.985m in DW

Δ = $30045.5 \times \frac{1.012}{1.025} = 29664.5t$

Cargo to load = summer Δ - 29664.5 = 969.7t

Wt (t)	KG (m)	V. moments (tm)	PLM (tm)	SLM (tm)
(+) 29664.5	8.4	(+) 249181.8		
(+) 200	11.792	(+) 2358.4		200 x 4
(+) 769.7	11.407	(+) 8780.0	769.7 x 6	
30634.2	8.498	260320.2	4618.2	800

RLM = 3818.2 (P)
Since vessel in DW to enter table

Use $\Delta_1 = 30634.2 \times \frac{1.025}{1.012} = 31027.7t$

KM_T = 9.967 (use as found)

$GM_{F1} = 9.967 - 8.498 - \frac{1200}{30634.2} = 1.430$

$\text{Tan } \theta = \frac{3818.2}{30634.2 \times 1.43}$ $\theta = 4.98°$ (port)

Q. 8 M V ALPHA SHIP is floating in dock water of R.D. 1.012 at drafts F: 8.66m and A: 9.66m
a) When a parcel of cargo weighing 100 tonnes was shifted transversely through 6m, she developed a list of 2°. Find her GM & KG.
b) If the vessel moves to salt water and has a FSM of 1,842tm, find the new list.
Hint: -
(a) Trm = 1m, mean draft = 9.16m LCF = 83.571m

HD = $9.66 - \frac{1 \times 83.571}{171.792} = 9.174m$

Δ = $27263.3 \times \frac{1.012}{1.025} = 26917.6t$

KM_T = 9.841 m (use as found)

$\text{Tan } 2° = \frac{wd}{\Delta GM_{F1}} = \frac{100 \times 6}{26917.6 \times GM_{FI}}$

GM_{FI} = 0.638m

$GM_s = 0.638 + \frac{1842}{26917.6} = 0.706$

KG = 9.135m

(b) In SW enter table with Δ

KM_T = 9.835m (normal reading of table)

$GM_{FI} = 9.835 - 9.135 - \frac{1842}{26917.6} = 0.632m$

$\text{Tan } \theta = \frac{100 \times 6}{26917.6 \times 0.632} \theta = 2.02°$

Q. 9 M V ALPHA SHIP afloat at a displacement of 23100t in water of RD 1.014, KG 8.35m, FSM 2026 tm, is listed 2 ½° to stbd. She has to load 3000t in the dock. Space is available in No.3TD (2.5m to stbd of centre line) and in N0.5 TD (6.4 m to port of centre line). Find the quantity to load in each space so that the ship will finish upright.

Hint : -

Since vessel is in DW and displacement is given tables must be entered with Δ_1

$= 23100 \times \frac{1.025}{1.010} = 23350.6$ t

KM_T = 9.848 m

$GM_{FI} = 9.848 - 8.35 - \frac{2026}{23100} = 1.410m$

ILM = Δ GM_{FI} x tan θ = 23100 x 1.410 x tan 2.5° = 1422.1 tm.

Let x t be loaded in no 5 TD.

Port listing moment must be more than starboard listing moment by amount 1422.1 tm.

6.4x – (3000 – x) 2.5 = 1422.1

x =1002.5t in no 5 and 1997.5 in no 3 TD



Richard Trevithick (1771 -1833) A British inventor, made first working railway steam locomotive. Picture shows replica of the world's first steam-powered railway locomotive. In 1808 Trevithick patented a steam tug with a floating crane. His other achievements were improvements of iron floating docks, iron ships, telescopic iron masts, improved ship structures, iron buoys, 'Cornish boiler' & 'Cornish engine' (which was the most efficient in the world at that time). He died of Pneumonia in 1833, penniless. His colleagues made a collection for his funeral expenses. He was buried in an unmarked grave in East Hill, Dartford.

Chapter 10 Increase of draft due to list

The draft of a vessel is indicative of the underwater extension of the ships hull below the waterline. In passage planning the draft is an important criteria to determine clear depth channel and decide the safe route for the vessel. The draft of the vessel is likely to increase during the rolling and pitching conditions. Also the under keel clearance is likely to decrease owing to squat. In conditions of swell, rolling & pitching the vessel is disturbed from her equilibrium & tries to attain equilibrium. In doing so the draft may considerably increase.

To find the actual increased draft in case of a ship shaped vessel in a situation where the vessel is heeled, trimmed is in waves & or is influenced by squat is not possible mathematically. We may however at least consider the effect of heeling & pitching on the draft in static water within the wall sided range of a box shaped vessel.

Situation 1: box shaped vessel heeled to θ°
Assumption:

- The water surface is static,
- The vessel remains on even keel,
- There is no increase due to hydrodynamic interaction.

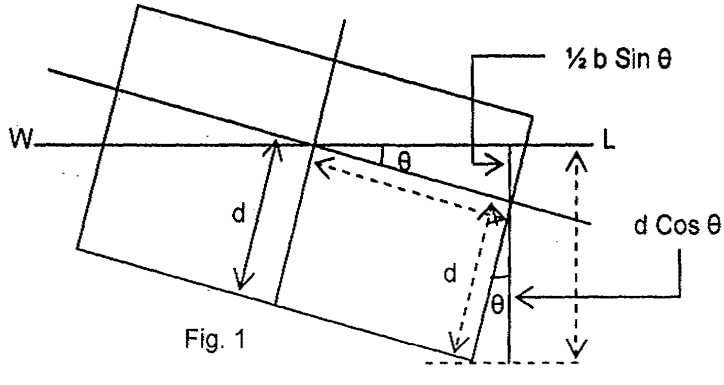


Fig. 1

New draft = ½ b Sin θ + d Cos θ

From the above fig, new draft = ½ beam Sin heel + old draft Cos heel

Ex. 1 A box shaped ship of beam 16m, floating upright at an even keel draft of 8m. Find the increase in draft if the vessel heels to 20 degrees.

Sol^{n}: -

New draft = ½ beam Sin heel + old draft Cos heel
= ½ x 16 Sin 20° + 8 Cos 20°
= 2.736 + 7.518 = 10.254m.

Situation 2: Box vessels with rise of floor heeled to θ°

Assumption:

- The water surface is static,
- The vessel remains on even keel,
- There is no increase due to hydrodynamic interaction.

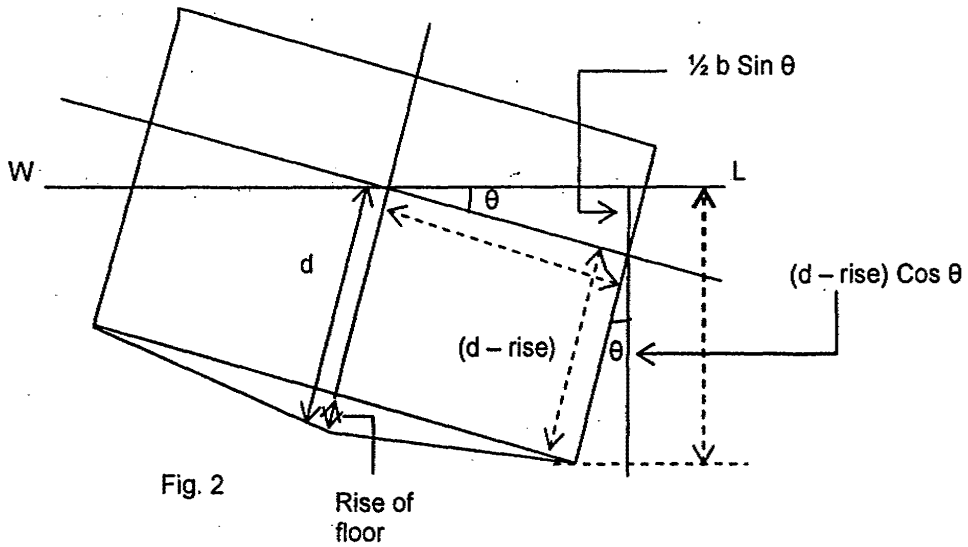


Fig. 2

New draft = ½ b Sin θ + (d- rise) Cos θ

Ex. 2 A ship of beam 26 m is floating upright at even keel draft of 7.2m. If the rise of floor is 0.28m, calculate the new draft if the ship is heeled by 15 degrees.

Sol^{n}: -

New draft = ½ beam Sin heel + (old draft- rise) Cos heel
= ½ x 26 Sin 20° + (7.2- 0.28) Cos 20°
= 4.446 + 6.503 = 10.949m.

Situation 3: Box vessel pitching

Assumption:

- The water surface is static,
- The vessel initially is on even keel,
- There is no increase due to hydrodynamic interaction.

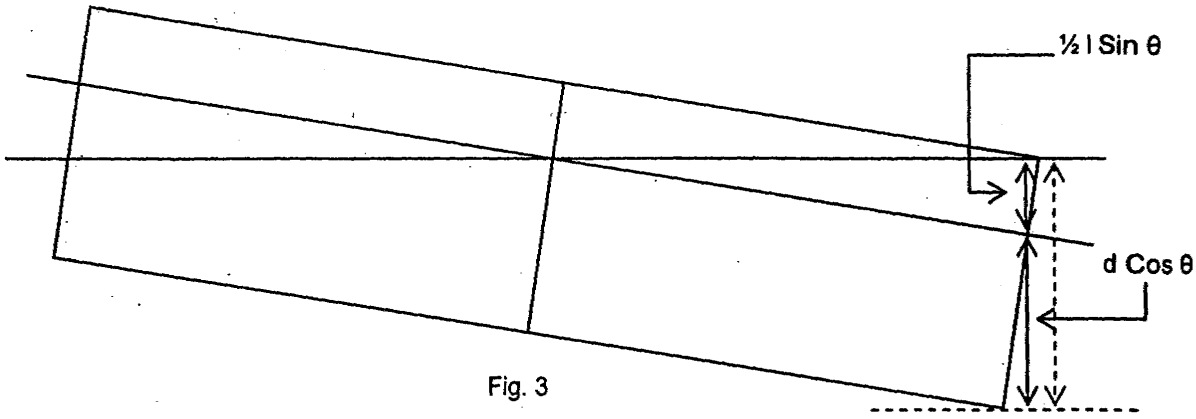


Fig. 3

New draft = ½ l Sin θ + d Cos θ where θ is trim angle and is equal to $\tan^{-1}\frac{\text{trim}}{\text{LBP}} \approx \frac{Freeboard}{\frac{1}{2}LBP}$

Ex. 3 box vessel 90m long, draft 6m, freeboard 3m is pitching in calm seas. Find the new draft when:

a. vessel pitches to an angle of 2°
b. pitches till deck edge submersion.

Sol^n: -

a. New draft = ½ l Sin θ + d Cos θ
   = ½ x 90 x Sin 2° + 6 Cos 2°
   = 1.570 + 5.996 = 7.566m.

b. The trim angle at deck edge immersion for pitching is given by $\tan^{-1}\frac{\text{free board}}{\frac{1}{2}\text{LBP}}$

Trim angle = $\tan^{-1}\frac{3}{45}$ = 3.81°

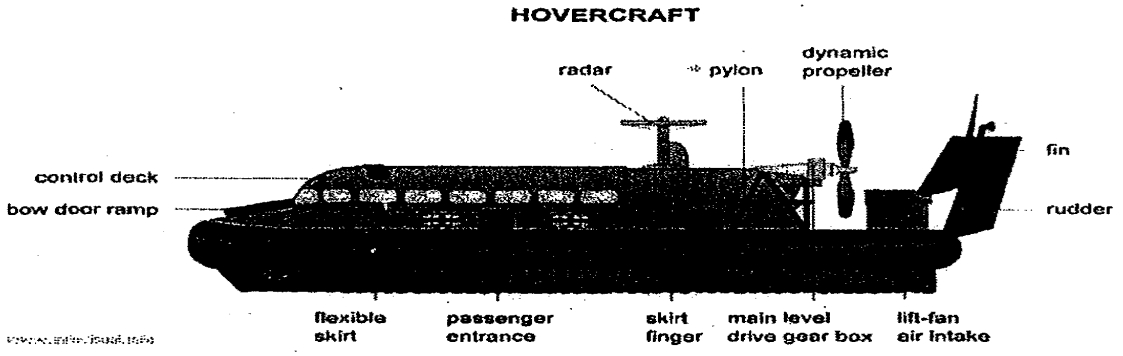
New draft at deck edge immersion for pitching = ½ x 90 x Sin 3.81° + 6 Cos 3.81° = 2.990 + 5.987 = 8.977 m
Thus increase in draft = 2.977 m (slightly less than the free board)

Exercise 10

1. A box shaped ship of beam 14m, floating upright at an even keel draft of 7 m. Find the increase in draft if the vessel heels to 18 degrees.
Ans. increase = (7 Sin 18° + 8 Cos 18°) – 8 = 1.772 m

2. A ship of beam 22 m is floating upright at even keel draft of 8.2 m. If the rise of floor is 0.24 m calculate the new draft if the ship is heeled by 14 degrees.
Ans. New draft = 11 sin 14° + (8.2 – 0.24) Cos 14° = 10.385 m.

Hovercraft: A Hovercraft is also sometime called an Air Cushion Vehicle or ACV. This is a vehicle that flies like a plane but can float like a boat, can drive on land like a car but will traverse ditches and small gullies like it is flat terrain. The Hovercraft is a unique method of transportation. The hovercraft engine provides the power to drive large fans that blow air under the craft. The air is retained by a rubber 'skirt' that enables the craft to travel over a wide range of terrain. The skirt simply gives way when an obstacle is encountered. To maintain the lift the engine and propeller or fans have to be sufficiently powerful enough to provide a high airflow rate into the chamber.



Chapter 11 Trim, Change draft & trim due to change of density

A box shaped vessel always has the COF at midlength. In even keel condition it will also have the COB at midlength. If the vessel is loaded in such a way that the COG is also at midlength then the vessel will meet equilibrium in the even keel condition. Vessel will remain on even keel. Let us now consider that the loading is done in such a way that COG is aft of midlength. This will cause a torque that will trim the vessel stern-wise till the COB comes vertically below COG. Vessel will come at rest in stern trimmed condition.

This is explained in two steps as follows:

1. Let a mass of w tonnes be loaded aft of midships. To understand the 1st step it may be assumed that the loading is at midship position so that in 1st step the ship bodily sinks uniformly by $\frac{w}{100\,TPC}m$.
2. In the second step *w.d*, the aft loading causes the COG to shift from midship position towards the position of loading. $\frac{w.d}{\Delta} = GG_1$. The new longitudinal distance between COB and COG viz. (LCB ~ LCG_1 = GG_1) forms the trimming lever. (GG_1) x Displacement is the trimming moment.

We know that MCTC is moment in tonnes metre that will change the trim of ship by 1 cm. We can say that,

$$\text{Change of trim from even keel condition (m)} = \frac{(GG_1) \times \text{Displace ment}}{100\text{MCTC}}$$

Where, LCB is for even keel condition. LCG is for present loaded condition.

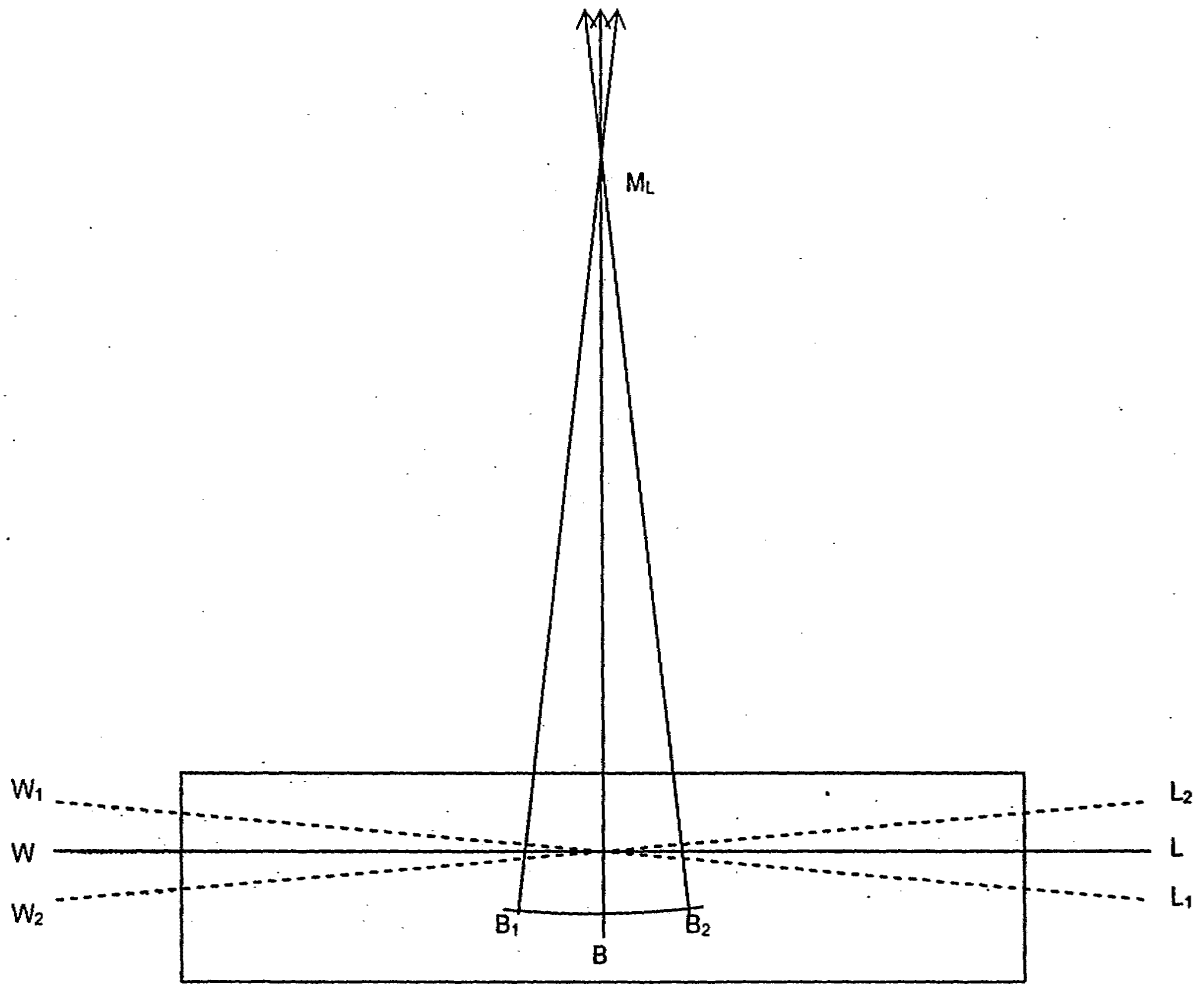


Fig. 1

Longitudinal metacentre is a point at the intersection of the uprights at the centres of buoyancy when the vessel pitches over a range of small angles in static water condition. The vertical distance BM_L depends on the waterplane area and the underwater volume.

$$BM_L = \frac{\text{Moment of inertia of water plane about athwart ship axis through COF}}{\text{under water volume}}$$

$$\frac{BL^3/12}{L \times B \times d} = \frac{L^2}{12d}$$

To establish the relation between GM_L and change of trim (t_{rc}). To prove MCTC $= \frac{\Delta \times GM_L}{100L}$:

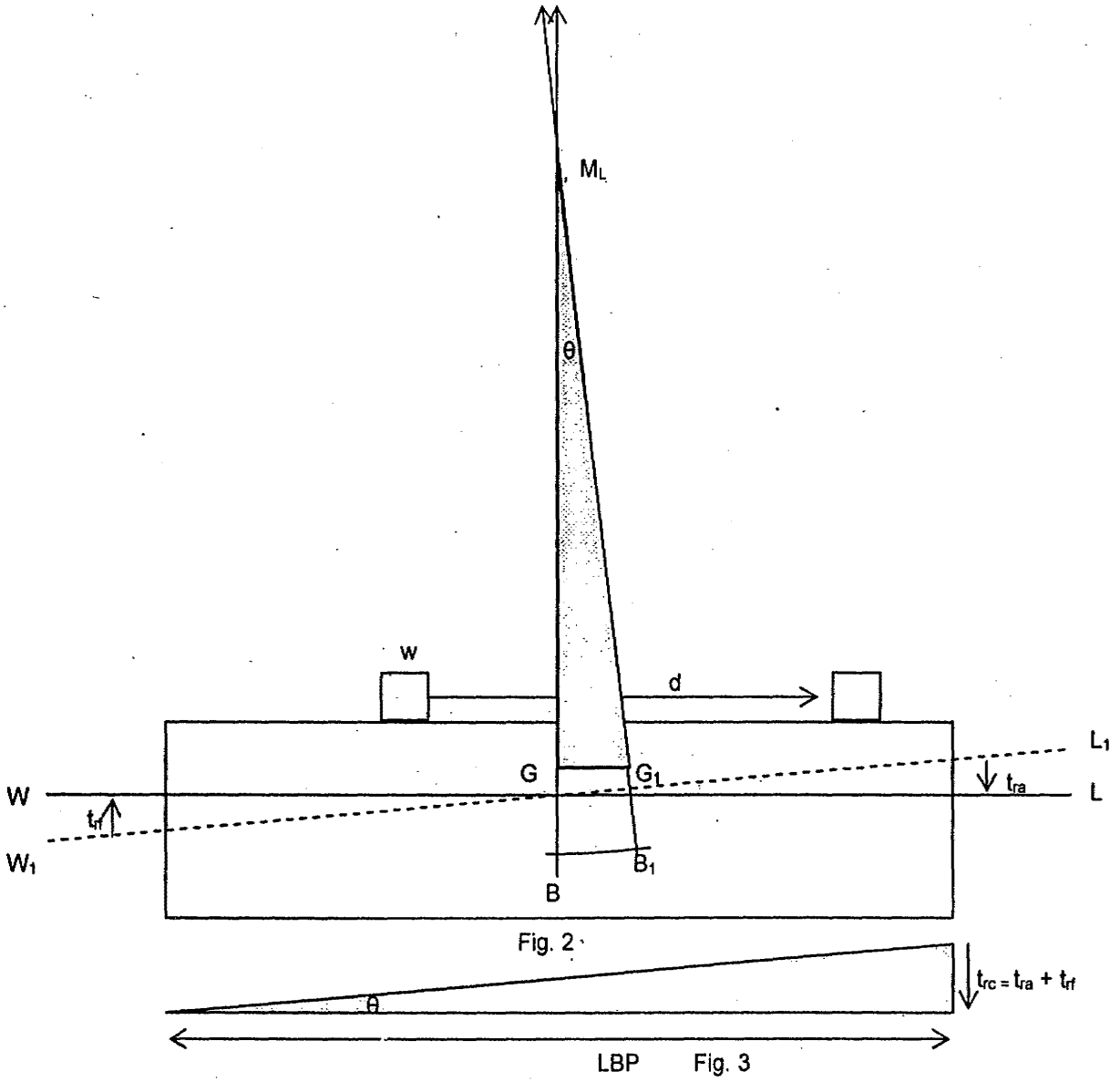


Fig. 2

Fig. 3

In above fig a weight w is shifted aft (longitudinally) by d metres to cause a trimming moment = (w.d) t.m. This causes the shift of COG = $\frac{w \times d}{\Delta} = GG_1$

The couple caused due to forces at B and G_1 will trim the vessel aft so as to bring COB vertically below G_1 as the vessel settles at new waterline W_1L_1.
The vertical through B_1 meets the original vertical through B at M_L.
Triangle GG_1M_L is a right angled triangle. This triangle is similar to the right angled triangle formed by sides t_{rc} and LBP. It can be said that,

Tan θ $= \frac{t_{rc}}{LBP} = \frac{GG_1}{GM_L}$

Also tan θ $= \frac{GG_1}{GM_L} = \frac{w \times d}{\Delta} \times \frac{1}{GM_L}$

If the change of trim due to shift of weight is 1cm, then w x d is the trimming moment to change the trim by 1cm.

$\text{Tan } \theta = \frac{\frac{1}{100}}{L} = \frac{1}{100L}$ ..... (1)

But tan θ is also equal to $\frac{w \times d}{\Delta} \times \frac{1}{GM_L}$ ..... (2)

Equating (1) and (2) we get $\frac{1}{100L} = \frac{w \times d}{\Delta \times GM_L}$

Since w x d is MCTC, we have MCTC = $\frac{\Delta \times GM_L}{100L}$

The change of draft forward and aft, in fact at any point along the ships length is due to:

1. Bodily rise or bodily sinkage,
2. Change of trim.

Let us consider a case where a certain weight is loaded at centre of floatation. The drafts all over will change uniformly and the changes of drafts are *purely due to bodily sinkage.*

Let us now consider a case where a certain weight is shifted longitudinally on board a ship. The drafts will change all over the vessel except at centre of flotation. The changes in drafts at different points along the ships length are *purely due to change of trim alone.*

Whenever loading or discharging operations are conducted on board a ship, the changes in drafts forward and aft are due to both the reasons stated above. In the numericals to follow we will apply these changes in two steps.

Ex. 1 A box shaped vessel 110m x 16m x 6m floats in salt water on an even keel draft of 5m. Find the new drafts if a weight of 80 tonnes already on board is shifted longitudinally forward through a distance of 40 metres. (ship's KG = 3.5 m)

Sol^n: -

Δ = 110 x 16 x 5 x 1.025 = 9020t

KB = 2.5 m.

$BM_L = \frac{L^2}{12d} = \frac{110^2}{12 \times 5} = 201.67\,m$

GM_L = KB + BM_L – KG = 200.67m

$MCTC = \frac{\Delta \times GM_L}{100L} = \frac{9020 \times 200.67}{100 \times 110} = 164.55$

$t_{rc} = \frac{\text{trimming moment}}{100\ MCTC} = \frac{80 \times 40}{100 \times 164.55} = 0.194\,m$

$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{0.194 \times 55}{110} = \frac{1}{2}\, t_{rc} = 0.097m$

$t_{rf} = t_{rc} - t_{ra} = 0.097m$

Drafts /Cause		F'd		Aft
Initial		5.000		5.000
Sinkage		0.000		0.000
Due t_{rc}	t_{rf} (+)	0.097	t_{ra} (-)	0.097
Final		5.097		4.903

Ans. Drafts for'd 5.097m aft 4.903

Ex. 2 A ship 130m long is floating at draft for'd of 7.5m and aft 8.7m. It has centre of flotation 4 m aft of amidships, MCTC 216 tm, displacement 13000 tonnes. Find the new drafts if a weight of 150 tonnes on boards is shifted forward through a distance of 40 metres.

Sol^n: - LBP = 130 m

$$LCF = \left(\frac{130}{2} - 4\right) = 61m$$

Trimming moment = 150 x 40 = 6000 tm.

$$t_{ra} = \frac{\text{trimming moment}}{100\ MCTC} = \frac{6000}{100 \times 216} = 0.278m$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{0.278 \times 61}{130} = 0.130m$$

$$t_{rf} = t_{rc} - t_{ra} = 0.278 - 0.130 = 0.148m$$

Drafts / Cause		For'd		Aft
Initial		7.500		8.700
Sinkage		0.000		0.00
Due t_{rc}	t_{rf} (+)	0.148	t_{ra} (-)	0.130
Final		7.648		8.570

Ans. draft for'd 7.648m, aft 8.570m.

Ex. 3 A ship 116 m long is floating at draft 6.5m for'd and 7.8 m aft. The centre of flotation is 2.5m aft of amidships, TPC 18, MCTC 196 t.m. Find the new drafts if a weight of 250 tonnes is loaded in a position 44m forward of midships & 300t is loaded 20m aft of midships.

Sol^n: -

LBP = 116m

$$LCF = \left(\frac{116}{2} - 2.5\right) = 55.5m$$

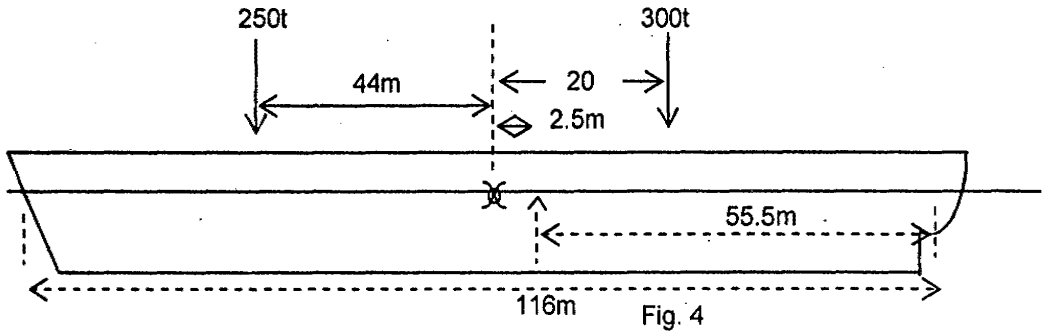


Fig. 4

Bodily sinkage = $\frac{250 + 300}{(100 \times 18)}$ = 0.306m

For'd trimming moment = 250 x (44+2.5)
= 11625 tm

Aft trimming moment = 300 x (20-2.5)
= 5250 tm

Resultant trimming moment = (11625 – 5250) tm
= 6375 tm forward

$$t_{rc} = \frac{\text{trimming moment}}{100\ MCTC} = \frac{6375}{100 \times 196} = 0.325\ m$$

$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{0.325 \times 55.5}{116} = 0.155m$

$t_{rf} = t_{rc} - t_{ra} = 170$

Drafts		For'd		Aft
initial		6.500		7.800
bodily sink	(+)	0.306	(+)	0.306
change due t_{rc}	t_{rf} (+)	0.170	(-)	0.155
final		6.976		7.951

Ans. Draft for'd 6.976m, aft 7.951m.

Ex. 4 A ship 120 m long arrives in port with draft 6m for'd and 7.3 m aft, her TPC is 21& MCTC is 186 tm. The centre of flotation is 3m aft of amidships. If 90 tonnes of cargo is loaded in a position 44m forward of amidships and 230 tonnes of cargo is discharged from 32m aft of amidships what will be the final drafts?

Sol^{n}: -

Cargo loaded = 90t

Cargo discharged = 230t

Net discharged = 140t

Bodily rise $= \frac{140}{(100 \times 21)} = 0.067m.$

Loading for'd trimming moment = 90 x (44+3)
= 4230 tm.

Discharging trimming moment = 230 x (32-3)
= 6670 tm.

Resulting trimming moment = (4230 + 6670)
= 10900 tm forward.

$T_{rc} = \frac{10900}{100 \times MCTC} = \frac{10900}{100 \times 186} = 0.586m$

$LCF = \frac{120}{2} - 3 = 57m$

$t_{ra} = \frac{0.586 \times 57}{120} = 0.278m.$

$t_{rf} = 0.586 - 0.278 = 0.308m.$

drafts		F'd		Aft
initial		6.000		7.300
bodily rise	(-)	0.067	(-)	0.067
		5.933		7.233
	t_{rf} (+)	0.308	(-)	0.278
Final		6.241		6.955

Ans. Draft for'd 6.241m, aft 6.955m

Ex. 5 A vessel of 9600 tonnes displacement 105m in length, GM_L 180m is drawing 6.9m F & 6.7m Aft. The centre of flotation is 3m abaft midlength. How much cargo should be discharged form a position 24m forward of amidships so that the vessel would be trimmed 10cm by the stern?

Let w tonnes of cargo be the discharged from the given position. Trimming moment caused about the centre of flotation = 27w t.m..... (1)

Present draughts for'd 6.90m aft 6.70m. Present trim = 0.20m by the head

$$MCTC = \frac{\Delta \times GM_L}{100L} = \frac{9600 \times 180}{100 \times 105} = 164.57$$

Required trim 0.10m by the stern
Change of trim required 0.30m by the stern
The moment required to cause the above change of trim = 30 x 164.57 ..... (2)
(1) = (2) ∴27w = 30 x 164.57 gives w = 182.8t
Ans. 182.8t.

Ex. 6 A vessel 140m in length, 20m in breadth, MCTC 176 t.m, TPC 24 is on drafts for'd 8.45 m aft 8.77m and carries out the following operations :-
250 tonnes loaded 45m forward of COF,
840 tonnes loaded 18m forward of COF,
100 tonnes shifted 30m longitudinally forward
220 tonnes discharged from 40m forward of COF
120 tonnes ballast removed from 58m forward of COF
The centre of flotation is 3m abaft midships. Calculate the new draughts forward and aft.

Operation	Weight (t)	distance from COF (m)	F'd trimming moment (tm)	Aft trimming moment (tm)
loaded	250	45 (for'd)	11250	
loaded	840	18 (for'd)	15120	
Shifted	100	through 30m	3000	
discharged	220	40 (for'd)		8800
discharged	120	58 (for'd)		6960
			29370	15760

Resultant moment = 13610 tonnes metres forward.
Net loading = 750t.

$$\text{Sinkage} = \frac{\text{weight loaded}}{100\,\text{TPC}} = \frac{750}{2400} = 0.313\text{m}$$

$$\text{Change of trim} = \frac{\text{resultant moment}}{100\,\text{MCTC}} = \frac{13610}{17600} = 0.773\text{m by the head}$$

$$\text{LCF} = \frac{140}{2} - 3 = 67\text{m}$$

$$t_{ra} = \frac{0.773 \times 67}{140} = 0.370\text{m(-)}$$

$$t_{rf} = 0.773 - 0.370 = 0.403\text{m(+)}$$

Drafts	F'd		Aft
initial	8.450		8.770
bodily sinkage (+)	0.313	(+)	0.313
	8.763		9.083
t_{rf} (+)	0.403	(-)	0.370
Final	9.166		8.713

Ans. draft for'd 9.166m, aft 8.713m.

Ex. 7 A vessel of displacement 11800 tonnes, length 114m, GM_L 184m is trimmed 14cm by the head. After loading 320 tonnes 36 metres forward of the midlength 515 tonnes 34 metres abaft midlength and discharging 150 tonnes from midlength it is noted that she is settled to a stern trim of 16cm. Calculate the position of the centre of flotation. (Assume MCTC constant over the range of drafts given)

Sol^n: -
Initial trim = 0.14 m by the head. Final trim =0.16 m by the stern.
Change of trim = 30 cm by the stern.

$$MCTC = \frac{W \times GM_L}{100L} = \frac{11800 \times 184}{100 \times 114} = 190.46 \text{ tonnes metres}$$

The moment required to change the trim 30 cm = 30 x 190.46 = 5713.7tm

Let us assume that the COF is 'x' metres abaft midlength.
Then taking moments about the centre of flotation we may say
Aft trimming moment – forward trimming moment = 5713.7 tm
Forward trimming moment = 320 (36+x)
Aft trimming moments = 150x + 515 (34 - x)
ATM – FTM = [150x + 515 (34 - x)] – [320 (36+x)] = 5713.7 tm
685 x = 276.3 gives x = 0.403m
The centre of flotation is 0.403m abaft midlength.
(Negative answer would mean that the assumptions regarding the COF being aft of midlength was wrong.

Ex. 8 A vessel 160m in length, MCTC 180 tm, TPC 28, centre of flotation 5m abaft midlength, is loading at a port. Find a position at which to load a consignment of 150t so that the aft draft remains constant.
Sol^n: -
For the aft draft to remain constant in spite of loading, the bodily sinkage (+) must equal t_{ra} (-). t_{ra} being the change of draft aft due to change of trim.
Also for t_{ra} to be negative loading must be done forward of COF
Let the consignment of w tonnes be loaded d metres forward of COF.

$$\text{Bodily sinkage} = \frac{w}{100TPC} \quad \ldots\ldots\ldots\ldots (1)$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} \;\&\; t_{rc} = \frac{w \times d}{100MCTC}$$

$$\therefore\ t_{ra} = \frac{w \times d \times LCF}{100MCTC \times LBP} \quad \ldots\ldots\ldots\ldots (2)$$

(1) = (2)

$$\therefore \frac{w}{100TPC} = \frac{w \times d \times LCF}{100MCTC \times LBP}$$

$$\frac{1}{TPC} = \frac{d \times LCF}{MCTC \times LBP}$$

$$d = \frac{MCTC \times LBP}{LCF \times TPC} = \frac{180 \times 160}{75 \times 28} = 13.7\text{m}.$$

= 13.7m. metres forward of the centre of flotation.

Ex. 9 A vessel 150m in length MCTC 176 tm TPC 24 centre of flotation 5m abaft midlength is loading. Find a position at which to discharge a certain quantity of cargo so that the forward draft remains constant.

For the for'd draft to remain constant in spite of discharging the bodily rise (-) must equal t_{rf} (+). t_{rf} being the change of draft for'd due to change of trim.
Also for t_{rf} to be positive discharging must be done from a position aft of COF.
Let the load of w tonnes be discharged from a position d metres aft of COF.

Bodily rise $= \frac{w}{100TPC}$ ..... (1)

$t_{rf} = t_{rc} - t_{ra}$ & $t_{ra} = \frac{t_{rc} \times LCF}{LBP}$

$\therefore t_{rf} = t_{rc} - \frac{t_{rc} \times LCF}{LBP} = t_{rc}\left(1 - \frac{LCF}{LBP}\right)$

But $t_{rc} = \frac{w \times d}{100MCTC} \therefore t_{rf} = \frac{w \times d}{100MCTC}\left(1 - \frac{LCF}{LBP}\right)$ ..... (2)

(1) = (2)

$\therefore \frac{w}{100TPC} = \frac{w \times d}{100MCTC}\left(1 - \frac{LCF}{LBP}\right)$

$\frac{1}{TPC} = \frac{d}{MCTC}\left(1 - \frac{LCF}{LBP}\right) = \frac{d}{MCTC}(0.533)$

$d = \frac{MCTC}{0.533TPC} = 13.76m.$

= 13.76m. metres forward of the centre of flotation.

Ex. 10 A vessel drawing 7.25m forward 8.45m aft, MCTC 160 tonnes metres, TPC 21, has cargo space available in position 42m forward and 36m abaft the centre of flotation which is at midlength. How much cargo should be loaded in each hold if the ship is to complete loading with a mean draught of 7.96m and trimmed 70 cm by the stern.

Sol^n:-

When COF is at midlength, mean draft = hydrostatic draft
Initial mean or hydrostatic draft = 7.85m and trim = 1.2m
Final mean or hydrostatic draft = 7.96m.
Cargo to load = Change of hydrostatic draft x 100TPC = 0.11 x 100 x 21 = 231 t.
Final trim 0.70m by the stern.
Change of trim 0.5m by the head.
For'd trimming moment is more than aft trimming moment by an amount = trim change x 100 MCTC.
Let w tonnes be loaded forward and (231 – w) be loaded aft
For'd trimming moment = 42w tm
Aft trimming moment = 36(231 – w)
For'd trimming moment – Aft trimming moment = 0.5 x 100 x 160
42w + 36w – 8316 = 8000

$w = \frac{16316}{78} = 209.2t$

Cargo loaded aft = 231-209.2 = 21.8t.

Ex. 11 A vessel length 138m MCTC 120 tm, TPC 19, LCF 62, is at drafts 7.8m for'd and 9.1m aft. It is required to bring the after draught to 7.86m by pumping out water from the after peak tank which is 58m abaft the COF. How much water must be pumped out?

Sol^n: -
The bodily rise as well as change of draft aft due change of trim (t_{ra}) are both negative as after peak tank is aft of COF.
Change in draft required = 1.24m.
Bodily rise + t_{ra} = 1.24m.

$$\frac{w}{100TPC} + \frac{t_{rc} \times LCF}{LBP} = \frac{w}{100TPC} + \frac{w \times d \times LCF}{100MCTC \times LBP} = 1.24$$

$$\frac{w}{100}\left(\frac{1}{TPC} + \frac{d \times LCF}{MCTC \times LBP}\right) = 1.24$$

$$w\left(\frac{1}{19} + \frac{58 \times 62}{120 \times 138}\right) = 1.24 \times 100$$

$$w\,(0.0526 + 0.2171) = 124$$

$$\therefore w = \frac{124}{0.2697} = 459.8\ t$$

Ex. 12 A vessel at drafts forward 6.60m aft 7.80m has displacement equal to 12000t. It is desired to have a draft of 7.00m forward and 7.70m aft by loading cargo. Space available to load the cargo is a: 30m forward of midships, b: 30m aft of midships. Given: LBP is 120m, TPC is 26, MCTC is 212tm and LCF is 55m
Sol^n: -
Initial trim = 7.80 - 6.60 = 1.20m aft.

$$\text{Initial HD} = \text{Draft aft} - t_a = 7.8 - \left(1.2 \times \frac{LCF}{LBP}\right) = 7.8 - \left(1.2 \times \frac{55}{120}\right) = 7.25m$$

Final trim = 7.70 – 7.00 = 0.70m aft.

$$\text{Final HD} = \text{Draft aft} - t_a = 7.7 - \left(0.7 \times \frac{LCF}{LBP}\right) = 7.7 - \left(0.7 \times \frac{55}{120}\right) = 7.379m$$

Bodily sinkage = 7.379 – 7.25 = 0.129m
Cargo to load = 0.129 x 100 TPC = 0.129 x100 x 26 = 335.4t
Let w tonnes be loaded forward & (335.4 – w) be loaded aft of COF.
Since initial trim = 1.20m aft and final trim = 0.70m aft
Change of trim = 0.50m forward.
Forward trimming moment (FTM) > Aft trimming moment (ATM)
Or FTM - ATM = 0.50 x 100 x 212
Or 35w - (335.4 – w) x 25 = 10600
Or 35w – 8385 + 25w = 10600
Gives 60 w = 18985.
w = 316.42t to be loaded in position 30m forward of midships and 18.98t to be loaded in position 30m aft midship.
Ans. 316.42t forward and 18.98t aft

Ex. 13 On a vessel of length 140m, MCTC 192, while at drafts 7.20m for'd 8.70m aft, a weight of 125t was loaded in position 65m from aft perpendicular. The resulting drafts were 7.25m for'd and 8.75m aft. Where should another 100t be loaded so that the aft draft is never more than 8.75m and the vessel maintains maximum stern trim.

Sol^n: - In this question TPC and position of COF is indirectly given. After loading 125t in a certain position the trim does not change means the loading was done at COF.
Also since the trim does not change the change of hydrostatic draft = change of mean draft.

$\because$ Change of mean draft = 5cm, TPC = $\frac{125}{5} = 25$. Also LCF = 65.

Hereafter the aft draft must remain constant at 8.75m.

As explained in Ex. 9 bodily sinkage = $t_{ra} = \frac{t_{rc} \times LCF}{LBP}$

Or $\frac{w}{100TPC} = \frac{w \times d \times LCF}{100MCTC \times LBP}$

$\therefore d = \frac{MCTC \times LBP}{LCF \times TPC} = \frac{192 \times 140}{65 \times 25} = 16.54m.$

= 16.54 m. metres forward of the centre of flotation.

Change of draft & trim due to change of density: -
Whenever a vessel moves from water of one density to the water of another density, the underwater volume changes. If vessel moves from say sea water to fresh water the change of underwater volume is given by the expression;

$$V_1 \sim V_2 = \frac{\Delta}{\delta_1} \sim \frac{\Delta}{\delta_2} = \frac{\Delta}{1.025} \sim \frac{\Delta}{1.000}$$

Equilibrium means state of rest. In respect of a vessel it occurs when COB and COG are in the same vertical line or when LCB is equal to LCG. Thus when rolling or pitching, the vessel is not in equilibrium and in fact is trying to attain equilibrium. A listed vessel at rest is in equilibrium. A vessel at any trim if at rest is in equilibrium too. Her 'LCB in trimmed condition' is equal to LCG. A box vessel has 'even keel LCB' = ½ LBP. In case of a ship shaped vessel even keel LCB can be found out from the stability booklet. This means that COG in case of a box vessel trimmed by stern is abaft the midships or LCG < ½ LBP and vice-versa.
In case of ship shaped vessel the COG for a stern trimmed condition is abaft the 'even keel COB' or LCG < 'Even keel LCB'. Also for a head trimmed vessel LCG > 'Even keel LCB'. When vessel goes to a different density, the COB moves towards / away from the centroid of volume that is added / deducted, causing a disturbance in the earlier state of equilibrium. To attain equilibrium for the new underwater volume vessel trims to again bring the COB on line with the COG.
In the following explanation 4 situations are discussed to understand the effect of change of density on draft and trim of vessel. It is assumed that changes are wallsided so that the waterplane area and LCF do not change for the small change of draft.

Situation 1: SW to FW (higher density to lower density) LCF > LCG

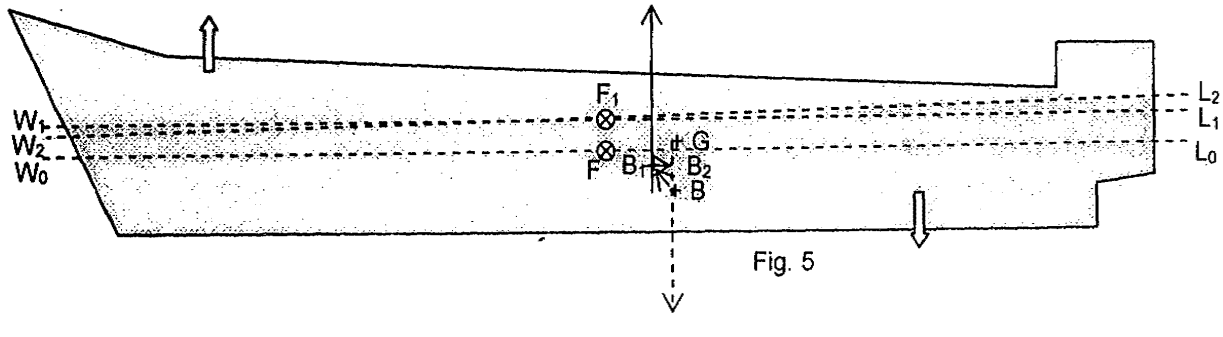


Fig. 5

The under water volume increases, the buoyancy gained is effectively added at COF. This causes COB to move towards COF. This results in COB moving forward of COG. A couple is created between B and G, trimming the vessel aft. In final trimmed condition COB comes back at B_2 that is vertically under G.

Situation 2: SW to FW (higher density to lower density) LCG > LCF

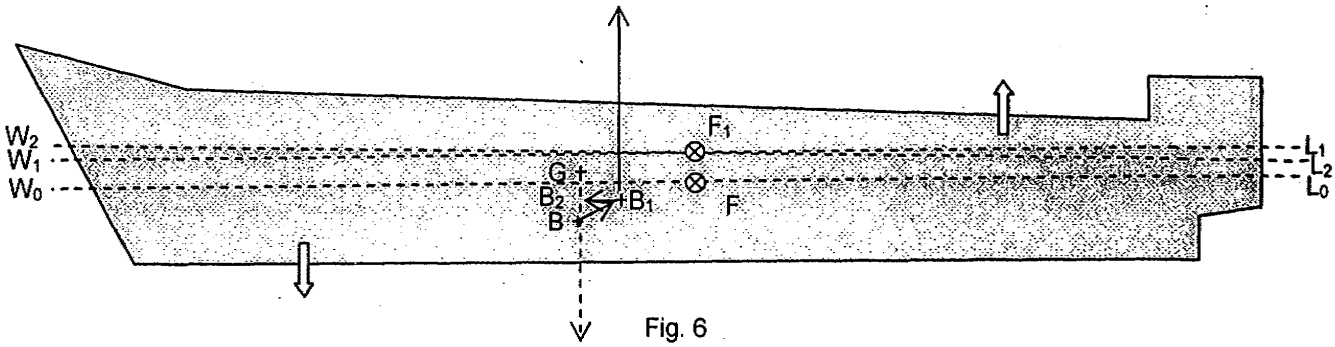


Fig. 6

The under water volume increases, the buoyancy gained is effectively added at COF. This causes COB to move towards COF. This results in COB moving aft of COG. A couple is created between B and G, trimming the vessel forward. In final trimmed condition COB comes back at B_2 that is vertically under G.

Situation 3: fresh water to salt water (lower density to higher density) LCG < LCF

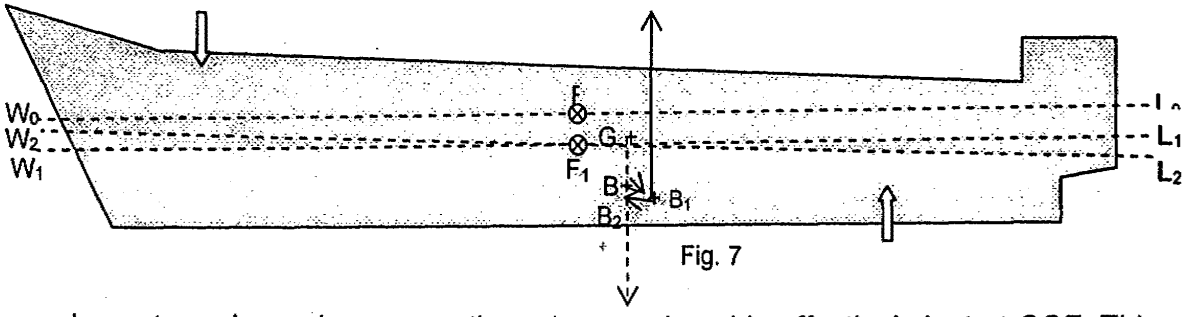


Fig. 7

The under water volume decreases, the volume reduced is effectively lost at COF. This causes COB to move away from COF. This results in COB moving aft of COG. A couple is created between B and G, trimming the vessel forward. In final trimmed condition COB comes back at B_2 that is vertically under G.

Situation 4: fresh water to salt water (lower density to higher density) LCG > LCF

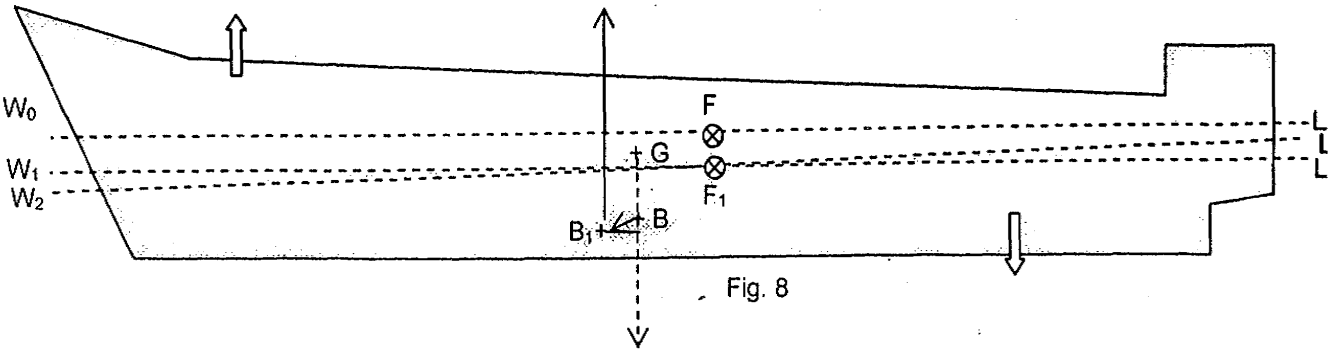


Fig. 8

The under water volume decreases, the volume reduced is effectively lost at COF. This causes COB to move away from COF. This results in COB moving forward of COG. A couple is created between B and G, trimming the vessel aft. In final trimmed condition COB comes back at B_2 that is vertically under G.

Change of underwater volume is found by expression $v = (V_1 \sim V_2) = \left(\frac{\Delta}{\delta_1} \sim \frac{\Delta}{\delta_2}\right)$

The bodily rise or bodily sinkage = $\frac{v}{\text{water plane area}}$

Since the increase or decrease of UW volume occurs at COF, (LCB~LCF) is the trimming lever.

$$BB_1 = \frac{v \times (LCB \sim LCF)}{V_2}$$

$$\frac{t_{rc}}{LBP} = \frac{BB_1}{GM_L} \text{ or}$$

$$t_{rc} = \frac{(LCB \sim LCG)\Delta}{100MCTC} \qquad (BB_1 = LCB \sim LCG)$$

t_{ra} & t_{rf} can now be found out. After applying bodily rise / sinkage & t_{ra} / t_{rf} to initial drafts, the final drafts can be found.

Ex. 14 A ship of displacement 15000t, LCG 70m, LBP 142m, LCF 66m, drafts fwd 8.00m aft 9.42m TPC 26 and MCTC 192t.m moves from salt water to fresh water. Find new drafts.

Sol^n:- change of underwater volume $= \frac{\Delta}{1.025} \sim \frac{\Delta}{1.000} = 365.85m^3$

Since the ship was in equilibrium in salt water. LCB in SW = LCG

COB will move towards COF $BB_1 = \frac{v \times (LCB \sim LCF)}{V(final)} = 0.098.$ (LCB = LCG)

$MCTC_{FW} = \frac{MCTC_{SW} \times 1}{1.025} = 187.32$

Trim change $= \frac{(LCB \sim LCG)\Delta}{100MCTC_{FW}} = \frac{0.098 \times 15000}{100 \times 187.32} = 0.078m$

Bodily sinkage $= \frac{v}{WPA} = \frac{v}{100TPC/1.025} = \frac{365.85 \times 1.025}{100 \times 26} = 0.144m$

$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{0.078 \times 66}{142} = 0.036m$

$t_{rf} = t_{rc} - t_{ra} = 0.042m$

Initial	8.000		9.420
B/sinkage	0.144		0.144
	8.144		9.564
t_{rf} +	0.042	t_{ra} -	0.036
Final	8.186m		9.528m

Ans. The drafts in fresh water will be fwd 8.186m, aft 9.528m.

Ex. 15 A vessel of displacement 19200t, LBP 235t, KM 10.2m, KG 9m, TPC 32m, MCTC 254 is floating at drafts forward 9.42m and aft 10.88m in dock water of density 1.005t/m^3. The COF is 5m abaft the midships and COG is 3m forward of midships. The vessel moves to a dock where density is 1.020t/m^3. Find the new drafts.

$$v = \frac{19200}{1.005} \sim \frac{19200}{1.020} = 280.9$$

$$BB_h = \frac{280.9 \times 8}{19200 / 1.020} = 0.119 \text{ m}$$

$$t_{rc} = \frac{BB_H \times \Delta}{100MCTC}$$

$$MCTC = \frac{254 \times 1.020}{1.025} = 252.76 \text{ m}$$

$$t_{ra} = \frac{0.090 \times 112.5}{235} = 0.043 \text{ m} \qquad t_{rf} = 0.047 \text{ m}$$

$$WPA = \frac{SW\,TPC \times 100}{1.025} = 3121.95 m^2 \qquad \text{B'ly rise} = \frac{280.9}{3121.95} = 0.090$$

Drafts
F = 9.420 – 0.090 – 0.047 = 9.283 m
A = 10.88 – 0.090 +0.043 = 10.833 m

Exercise 11

Q. 1 A vessel of length 160 m, COF 3 m abaft the midlength, TPC 18t, MCTC 200mt is at a draft of F 7.8 m, A 8.1 m. To effect repairs at the bow, it is necessary to reduce the forward draft to 6.5m. The maximum permissible draft where the ship is to be berthed for carrying out repairs is 7.0 m, and cargo can be discharged from No. 1, 70 m forward of midlength and No. 4, 30m abaft midlength. Calculate the minimum cargo to be discharged from each hold.
Ans. No. 1 621.1t No. 4 1531.15t

Q. 2 A vessel floating at a draft of 7.0m for'd, 10.0m aft, MCTC 220mt, TPC 25, COF amidships, has to reduce her after draft to 9.0m without changing the draft for'd. Find the minimum cargo to discharge from No. 2 hold, 30 m for'd of the COF and No. 4 hold 50 m abaft COF to achieve the desired drafts.
Ans. 743.75t (4) 506.25t (2)

Q. 3 A ship of 10200 tonnes displacement has TPC 16 tones MCTC 146 tm and the centre of floatation amidships. Space is available at 40m for'd and 30m aft of midships. The present drafts are 7.5 m F and 8.1m A, the load draft is 8.2m. Find how much cargo is to be loaded in each space to finish on even keel.
Ans. To load 640t. 399.4t in for'd space & 240.6t in aft space.

Q. 4 A vessel of length 140m, COF 2 m abaft midlength, MCTC 200 mt, TPC 15t, is at a draft of 7.7m for'd and 7.9 m aft. It is necessary to reduce the for'd draft to 6.7 m without change in the after draft. Calculate the weight to be discharged and the position with respect to midlength from where it should be discharged.
Ans. 728.5 to be discharged from a point 25.45m f'd of mid length.

Q. 5 A vessel of length of 125m floating in salt water, at a draft forward 6.84m, aft 7.24m, Displacement 11923 tonnes, GM_L 130m, COF 2.5 m aft of midship & TPC 18.4. The vessel is required to enter a lock with a maximum draft of 7m and trim of 0.6m by stern. Calculate the minimum amount of ballast water to be removed from two tanks whose longitudinal centres of gravity are 50 m for'd and 25m aft of midship.
Ans. 218.54t, 399.7t

Q. 6 A vessel of length 120 m, displacement 8200 t, TPC 13, LCB 55 m, LCF 59 m, is in salt water at a draft of 4.35 m forward and 4.80 m aft. Calculate her draft forward and aft on proceeding to water of density 1 .005 if MCTC in that water is 80 tm.
Ans. F 4.4348m, Aft 4.9648m.

Q. 7 A ship of length 120 m, MCTC 180 t, TPC 25 t, COF 2 m for'd of mid-length is at a draft of for'd 6.60 m Aft 7.80 m. 300 t of cargo is to be discharged keeping her for'd draft unchanged. Calculate the position w.r.t. midlength from where the cargo should be discharged. Also calculate her drafts fore and aft after discharging.
Ans. Discharge from or point 14.9m abaft COF. F'd 6.60m Aft 7.552m

Q. 8 A vessel of length 142 m, COF 2 m abaft mid-length, MCTC 124 tm, TPC 16 is at a draft of for'd 5.22 m and aft 7.18 m. Her for'd draft is to be reduced to 4.5 m to enable certain repairs to be carried out. The maximum draft allowable at the repair berth is 6.15m. Cargo can be discharged from No.2, 42m for'd of mid-length and no.5, 47m abaft mid-length. Calculate the amount to be discharged from each hold.
Ans. To discharge from no. 2 = 668.23 t & from no.5 = 738.81 t.

Q. 9 A ship 128 m in length and 20 m in breadth is trimmed 0.70 m by stern and floating in dock water of relative density 1.017. She is required to complete on an even keel in DW at her present aft draft. Calculate the quantity of cargo to load and its location w.r.t. amidships if the co-efficient of fineness of waterplane is 0.82 [LCF 61m, MCTC 130tm].
Ans. MCTC 130 is for S.W. Find E K draft is in Dock water. 712.185t at 12.68m forward of COF or 9.68m for'd of midships.

Q. 10 The drafts of a vessel at anchor in a tidal river were read carefully at two successive slack waters, her displacement remaining unchanged. The drafts were for'd 4.35 m, aft 4.80 m and for'd 4.50 m, Aft 4.91 m respectively. Explain your inference as regards the position of her COF relative to her COB.
Ans. Position of COF is abaft COG or COB. To attain equilibrium ship trims forward. Since sinkage is caused the second slack water is of less density.

Q. 11 The drafts of a vessel at anchor in a tidal river were read carefully at two successive slack waters, the ship's displacement remaining unchanged. The drafts were F: 4.35m, A: 4.8m and F:4.6m, A: 5.01 m respectively. Show by systematic arguments, the inference that may be obtained regarding the position of her COF relative to COB.
Ans. Approximately [0.23 x WPA] m^3 is the buoyancy added at COF causing B to shift & cause change of trim.

Exercise on M V ALPHA SHIP

Q. 1 M V ALPHA SHIP is floating in SW at drafts of F 8.41m A 8.69m. She carries out the following operations.
a) Loads 200 tonnes of cargo in No 2 TDK,
b) Consumes 30 tonnes of F.W. from drinking water tank (Port). Calculate the final drafts F & A.

Sol^n: - Mean draft = 8.55m, LCF = 84.131m

$$\text{H draft} = 8.69 - \frac{0.28 \times 84.131}{171.792} = 8.553m$$

Whenever the forward and aft drafts are given & hydrostatic table is available, it is possible to find out LCG using the standard trim formula.

$$\text{trim} = \frac{(\text{LCB} \sim \text{LCG})\,\Delta}{100\,\text{MCTC}}$$

Draught	Displacement	M.C.T.C.	L.C.B.
8.40	24637.2	284.34	86.967
8.60	25313.4	288.4	86.895
8.553	25154.5	287.4	86.911

In the formula above LCB is the even keel LCB picked up from the tables. LCG is the one obtained after loading i.e. the present LCG. Trim in this formula is the change of trim from even keel position. If present LCG is less than even keel LCB the ship will be down by stern in equilibrium condition and vice versa.

Hence for the present drafts we may say $\text{LCB} - \text{LCG} = \frac{\text{trim} \times 100\,\text{MCTC}}{\Delta}$

$$86.911 - \text{LCG} = \frac{0.28 \times 100 \times 287.4}{25154.5} \quad \therefore \text{LCG} = 86.591\text{m}$$

Weights (t)	LCG (m)	Long Moments (tm)
(+) 25154.5	86.591	(+) 2178153
(+) 200	124.6	(+) 24920
(-) 30	6.8	(-) 204
25324.5	86.986	2202869

Δ	draft	MCTC	LCB	LCF
25313.4	8.60	288.4	86.895	84.080
25991.	8.80	292.6	86.821	83.893
25324.5	8.603	288.46	86.893	84.076

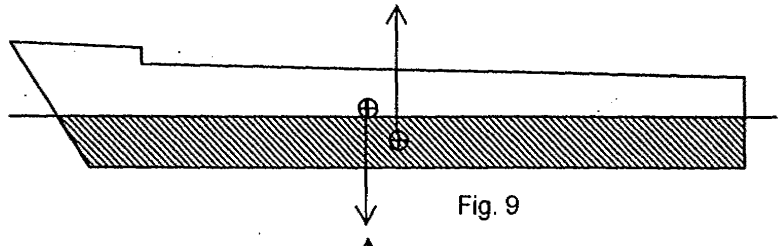


Fig. 9

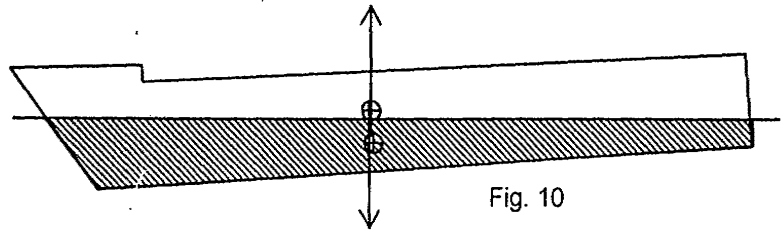


Fig. 10

If LCG was equal to EK LCB the vessel would have remained even keel. But since G is forward of EK LCB, for attaining equilibrium the couple will trim the vessel by head & make the COB shift & come vertically under COG.

Present LCG > EK LCB ∴ vessel trims by head.

$$\text{trim} = \frac{(\text{LCB} \sim \text{LCG})\,\Delta}{100\,\text{MCTC}} = \frac{0.093 \times 25324.5}{288.46 \times 100} = 0.082\text{m}$$

$$\text{Correction to H draft} = \frac{\text{trim} \times \text{LCF}}{\text{LBP}}, (-\text{ve as ship trimmed by head})$$

$$\text{Draft aft} = 8.603 - \frac{0.082 \times 84.076}{171.792} = 8.563\text{m}$$

Draft f'd = 8.563+0.082 = 8.645m.

Ans. 8.645m, 8.563m

Q. 2 M V ALPHA SHIP arrives port in condition 2 and discharges the entire cargo from No.1, 2 & 5 TD, No: 2 D B tanks (P & S) are filled with water ballast. Calculate the final drafts forward and aft.

Hint: -

Weights (t)	LCG (m)	Long Moments (tm)
(+) 30634.2	85.98	(+) 2633929
(-) 942	149.6	(-) 140923
(-) 1563	124.6	(-) 194750
(-)1370	20.6	(-)28222
(+)657.23	122.64	(+)80603
27416.43	85.738	2350637

Δ	draft	MCTC	LCB	LCF
27351.8	9.20	300.3	86.667	83.533
28033.6	9.40	304.36	86.590	83.379
27416.43	9.218	300.68	86.659	83.518

$$\text{Trim} = \frac{(86.659 \sim 85.738)27416.43}{100 \times 300.68} = 0.840\,m$$

$$\text{Draft aft} = 9.218 + \frac{0.84 \times 83.518}{171.792} = 9.626\,m$$

Draft f'd = 9.626 – 0.84 = 8.786m.

Q. 3 M V ALPHA SHIP in Condition No.2 discharges the entire cargo in No.2 TD, and fills in the bulbous bow with 180 t of water ballast. A negligible quantity of sea water was inadvertently taken in No.2 P & S DB tanks causing them to become slack. Calculate her GM (Fluid) and drafts F & A in the final condition.

Weights (t)	KG (m)	Vert Moments (tm)	LCG (m)	Long Moments (tm)	FSM ™
(+) 30634.2	7.727	236716.80	85.98	(+) 2633929	1352.3
(-) 1563	11.79	18427.77	124.6	(-) 194750	
(+)180	3.52	633.60	167.5	(+)30150	28.7
2P & S					2737.7
29251.2	7.416	218922.6	84.418	2469329	4118.7

Δ	draft	MCTC	LCB	L F	KM
28215.6	9.60	308	86.511	83.226	9.876
29408.4	9.80	311.64	86.432	83.089	9.900
29251.2	9.773	311.16	86.442	83.107	9.897

$$\text{Trim} = \frac{(86.442 \sim 84.418)29251.2}{100 \times 311.16} = 1.903\,m$$

$$\text{Draft aft} = 9.773 + \frac{1.903 \times 83.107}{171.792} = 10.693\,m$$

Draft f'd = 10.693 – 1.903 = 8.790m.

$$GM_{Fl} = 9.897 - 7.416 - \frac{4118.7}{29251.2} = 2.340\,m$$

Q. 4 M V ALPHA SHIP arrives port in water of RD 1.027 drawing 7.6m f'wd and 8.8m aft. Find her f'wd & aft draughts upon berthing in a fresh water dock.

Hint: -

Mean draft = 8.20m, LCF = 84.490 m

$$\text{H draft} = 8.80 - \frac{1.2 \times 84.490}{171.792} = 8.210m$$

	Draught	Displacement	M.C.T.C.	L.C.B.
	8.20	23962.4	280.28	87.038
	8.40	24637.2	284.34	86.967
From Tables	8.21	23996.1	280.48	87.034
In DW	8.21	24042.9	281.02	87.034

$$\text{Trim} = \frac{(LCB \sim LCG)\,\Delta}{100\ MCTC}$$

Hence for the present drafts we may say $LCB - LCG = \frac{\text{trim} \times 100\,MCTC}{\Delta}$

$87.034 - LCG = \frac{1.2 \times 100 \times 281.02}{24042.9}$ ∴LCG = 85.631m. LCG & Δ won't change in FW.

While in FW the table must be entered with $\Delta_1 = \frac{24042.9 \times 1.025}{1.000} = 24644\,t$

	Δ	draft	MCTC	LCB	LCF
	24637.2	8.40	284.34	86.967	84.285
	25313.4	8.60	288.4	86.895	84.080
From Tables Δ_1	24644	8.402	284.38	86.966	84.282
For FW	24042.9	8.402	277.443	86.966	84.282

$$\text{Trim} = \frac{(LCB \sim LCG)\,\Delta}{100\ MCTC} = \frac{1.335 \times 24042.9}{277.443 \times 100} = 1.157m$$

$$\text{Draft aft} = 8.402 + \frac{1.157 \times 84.282}{171.792} = 8.969m$$

Draft f'd = 8.969 – 1.157 = 7.812 m.

Ans. 7.812 m, 8.969 m

Q. 5 M V ALPHA SHIP in condition No. 2 has to discharge 800 tonnes prior to sailing. From where, with respect to the aft should this weight be discharged to ensure that after draft remains unaltered.

Hint: -

Draft at AP in cond. 2 = 10.328m = final draft aft.

Final Δ = 30634.2 – 800 = 29834.2 t

Δ	Draft	LCF	MCTC	LCB
29408.4	9.80	83.089	311.64	86.432
30097.2	10.00	82.952	315	86.354
29834.2	9.923	83.004	313.71	86.383

t_a = 9.923 ~ 10.328 = 0.405m

$$= \frac{t \times LCF}{LBP} \therefore t = \frac{LBP \times t_a}{LCF} = \frac{171.792 \times 0.405}{83.004} = 0.838\,m$$

Draft f'd = 10.328 – 0.838 = 9.490m.

In final condition:

$$LCB - LCG = \frac{\text{trim} \times 100\,MCTC}{\Delta} \therefore 86.383 - LCG = \frac{0.838 \times 100 \times 313.71}{29834.2}$$

LCG = 85.502 m.

Let the lcg of discharge point be x met.

Weights (t)	LCG (m)	Long Moments (tm)
(+) 30634.2	85.98	(+) 2633929
(-) 800	x	(-) 800x
29834.2	85.502	2633929 - 800x

$$\frac{2633929 - 800x}{29834.2} = 85.502$$

X = 103.81m. i.e. fore part of hold 2.

Q. 6 M V ALPHA SHIP in condition No.2, before proceeding on a voyage is required to sail out on even keel with the same amount of cargo. What is the transfer required to be done between Tw Dk spaces of no 1 and 5?

Hint: -

Weights (t)	LCG (m)	Long Moments (tm)
(+) 30634.2	85.98	(+) 2633929
(0) x	149.6 – 20.6	(+) 129 x
30634.2	86.352	2645324

Even keel LCB for final condition is 86.352m. For the vessel to be on even keel even the LCG should be 86.352m.

2633929 +129x = 2645324, gives x = 88.34 t.

Ans. 88.34 t must be shifted from tween deck 5 to tween deck 1.

Q. 7 M V ALPHA SHIP in condition No. 2 before departing for next port has to discharge 1900t from hold no 1 and 5 and 400t from hold 3. (all tween decks). Find the cargo that should be discharged from each hold so that the vessel sails with a trim of 1m by the stern.

Ans.

Final Δ = 30634.2 – 2300 = 28334.2 t.

Δ	draft	MCTC	LCB	LCF
28033.6	9.40	304.36	86.590	83.379
28715.6	9.60	308	86.511	83.226
28334.2	9.488	305.96	86.555	83.311

$$86.555 - LCG = \frac{trim \times 100MCTC}{\Delta} = \frac{1 \times 100 \times 305.96}{28334.2} \therefore 86.555 - LCG = 1.080m$$

LCG = 85.475m.

Weights (t)	LCG (m)	Long Moments (tm)
(+) 30634.2	85.98	(+) 2633929
(-) 400	96.9	(-) 38760
x from hold 1	149.6	(-) 149.6x
1900 - x	20.6	(-) 20.6 (1900-x)
28334.2	85.475	2421865

2633929 – 38760 - 149.6x - 20.6 (1900-x) = 2421865
129 x = 134164, gives x = 1040 t.
Ans. 1040 t from hold 1 & 860 t from hold 5.

Q. 8 M V ALPHA SHIP in dock water of R.D. 1.007 is at a draft of for'd 8.38m aft 8.74m. Calculate the distance from A.P. where 960 t of cargo should be loaded so as to bring the vessel on an even keel.

Hint: -

Mean draft = 8.56m, LCF = 84.121 m

$$\text{H draft} = 8.74 - \frac{0.36 \times 84.121}{171.792} = 8.564 \text{ m}$$

	Draught	Displacement	M.C.T.C.	L.C.B.
	8.40	24637.2	284.34	86.967
	8.60	25313.4	288.4	86.895
From Tables	8.564	25191.7	287.6	86.907
Actual in DW	8.564	24749.3	282.5	86.907

$$\text{Trim} = \frac{(LCB \sim LCG)\,\Delta}{100\ MCTC}$$

$$86.907 - LCG = \frac{0.36 \times 100 \times 282.5}{24749.3} \therefore LCG = 86.496 \text{ m.}$$

New Δ = 25709.3 t

$$\text{The table must be entered with } \Delta_1 = \frac{25709.3 \times 1.025}{1.007} = 26168.8 \text{ t}$$

	Δ	draft	LCB
	25991.	8.80	86.821
	26671.4	9.00	86.745
From Tables Δ_1	26168.8	8.852	86.801
Actual in DW	25709.3	8.852	86.801

Final LCG = EK LCB = 86.801.

Weights (t)	LCG (m)	Long Moments (tm)
24749.3	86.496	2140715
960	x	960x
25709.3	86.801	2231593

2140715 + 960x = 2231593, gives x = 94.664m
Ans. 94.664m for'd of AP.

Q. 9 Transfer of 150t of HFO from No.2 DB(P) to No.4 DB(S) was done by mistake in M V ALPHA SHIP while in Condition No. 1. Find the GM(fluid) and the new drafts after the transfer. Assume CGs of No.2 DB(P) and No.4 DB(S) are each 7.2m from the centre line & liquids were equally distributed in port & stbd DBs initially.

Hint: -

Weights (t)	KG (m)	Vert Moments TM	LCG (m)	Long Moments TM	PLM TM	SLM TM	FSM TM
(+)9626	7.542	(+)72599.2	77.676	(+)747713	-	-	3839
(0) 150	.71-.68	(+) 4.5	52.9	(-) 7935	-	2160	-1268.7* -37.8**
(+)9626	7.542	72603.7	76.852	739778	-	2160	2532.5

*No 2 DB P is emptied. **Liquid on top is HFO, hence FSM is reduced by 37.8 tm. (504 x 1.025 - 504 x 0.95 = 37.8)

draft	Δ	MCTC	LCB	LCF	KM_T
3.66	9626	218.08	87.6	87.774	13.476

$$GM_{FI} = 13.476 - 7.542 - \frac{2532.5}{9626} = 5.671m$$

$$\text{Tan } \theta = \frac{RLM}{\Delta GM_{FI}} = \frac{2160}{9626 \times 5.671}$$

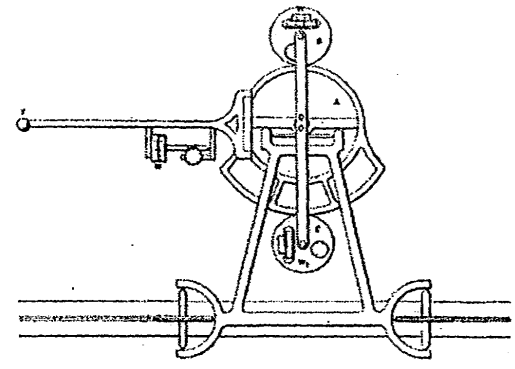
$$\theta = 2.27°S.$$

$$\text{Trim} = \frac{(LCB \sim LCG)\Delta}{100\ MCTC} = \frac{10.748 \times 9626}{21808} = 4.744\ m$$

$$t_a = \frac{t \times LCF}{LBP} = \frac{4.744 \times 87.774}{171.792} = 2.424\ m$$

Aft draft = 3.66 + 2.424 = 6.084 m. For'd draft = 6.084 - 4.744 = 1.34m.

Amsler modified his planimeter to make it an integrating machine in such a manner that in addition to area it gives the first and second moment of a figure about an axis in its plane. An instrument giving all three quantities simultaneously is known as Amsler's integrator or moment-planimeter. It was a very useful instrument in constructing cross curves of stability, though the process was tedious.



Chapter 12 GZ curve & Angle of loll

What is the stability at varying angles of heel?

Stability is the ability of the vessel to come back to upright equilibrium when heeled to that angle by an external force. This capability at a given angle of heel is not only dependent on the righting lever at that angle but also the size of the curve till that angle which is a measure of the dynamic stability at that angle. This however is not a realistic value because the GZ curve or curve of statical stability available on board is prepared for the static water level, whatever may be the angle of heel. At sea in a certain wave condition, the under water volume or the position of COB etc. will determine the actual size of GZ. Thus in wave conditions the GZ at a given angle may be smaller or bigger than static GZ that is available from Stability booklet.

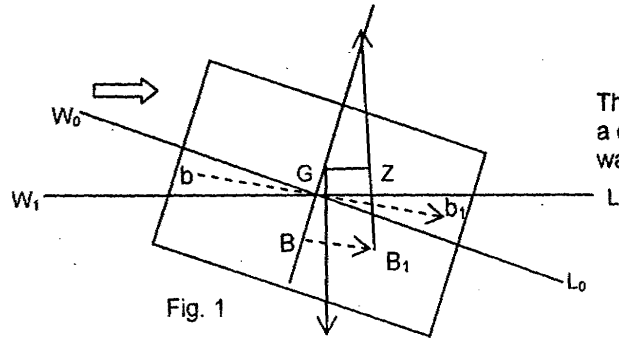


Fig. 1

The fig shows the righting lever for a certain angle of heel with final water level static. BB_1 // bb_1.

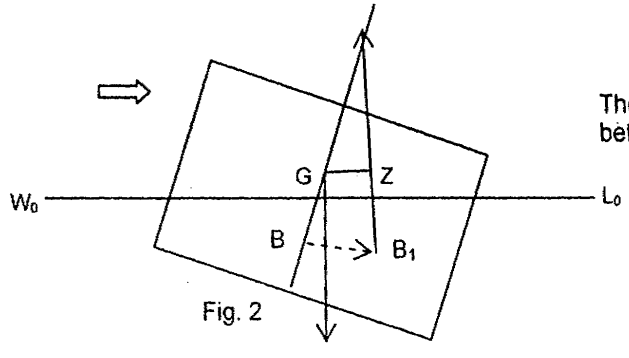
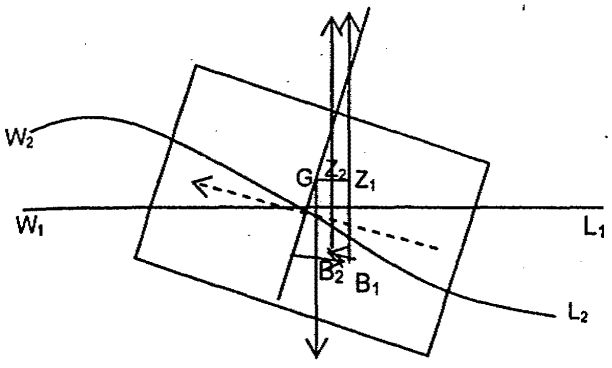


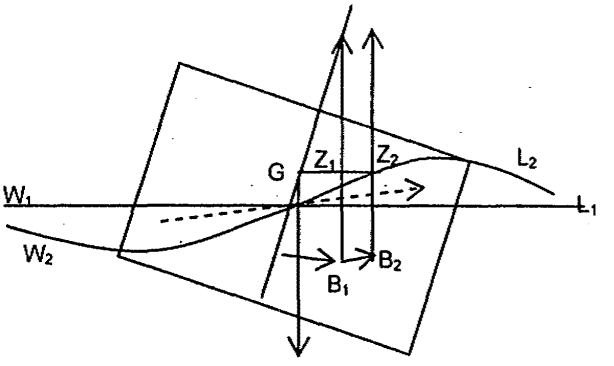
Fig. 2

The righting lever is athwartship distance between COG and new COB.(B_1).



If in the same heel condition vessel has crest on high side and trough on the low side B_1 will move to B_2 and the righting lever reduces to a size smaller than the righting lever of static stability

Fig. 3



If in the same heel condition the vessel has trough on high side and crest on the low side B_1 will move to B_3 and the righting lever increases to a size bigger than the righting lever of static stability

Fig. 4

If the stability of the ship could be represented by a single expression at one glance & in totality, then such an expression can be GZ curve only. In SOLAS Ch. II/1 it is stated that "The Master should get a clear picture of her stability, whether she is intact or damaged." This means that master should have means on board to find GZ curve for different service conditions. The data should be provided for any probable situation that the ship can be in. Thus the GZ curve should be provided for different intact & damaged conditions.

Dynamic Stability for a heel can be understood as the energy required or work done by an external agency to heel the ship to that angle. Mathematically this is equal to the product of displacement of the vessel and area under the curve in meter-radians.

The area under the curve is normally found by Simpson's method. GZ curve indicates the stability behaviour & capability of the ship for various angles of heel.

Following are different types of stability curves.

1. Typical curve for the freighters.
2. Typical curve of a stiff vessel with good dynamic stability at all angles but medium range of positive stability.
3. Curve of a vessel with low GM_0 with large range of positive stability and good dynamic stability at higher angles of heel.
4. Curve of a tender vessel with medium range of positive stability.
5. Curve of a listed vessel.
6. Curve of a vessel with negative upright stability and angle of loll.
7. Curve of a vessel with good initial GM but poor righting capability at large angles of heel.

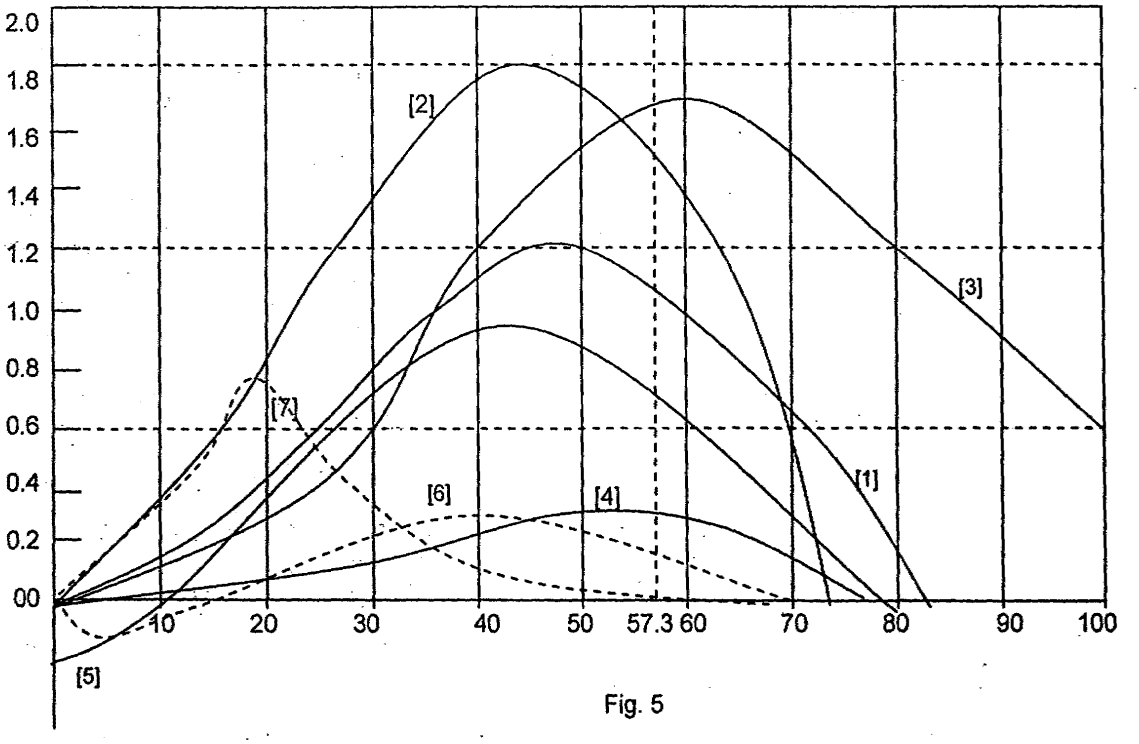


Fig. 5

Why such stability information must be provided on ships?
Stability which is comprised of the values of righting levers at different angles of heels is a very important tool for doing different stability calculations. A GZ curve or a curve of statical stability is constructed using the GZ values for different angles of heel. This information is very important in order to:

- Provide instant status of stability at one glance.
- Demonstrate compliance with Intact Stability Criteria
- Prove compliance with International Stability Regulations for carriage of movable bulk cargo such as grain.
- Determine the list of ship during the heavy lift operations.
- Correct the ship's condition subsequent to the flooding, cargo shift, grounding etc.
- Demonstrate the Damaged Stability Criteria.
- Find the resultant list or angle of loll as a result of a certain load condition or subsequent to some internal shift of cargo.

What information is available from a GZ curve?
The initial GM: The slope of GZ curve at the origin is indicative of 'Initial stability' (GM_0). The GM_0 can be found by drawing a tangent at origin and by finding the intercept on the ordinate drawn at 57.3° heel. It is difficult to draw the tangent at origin if detailed values of curve are not available for small angles of heel. To draw the tangent a straight line may be drawn along the GZ curve for small angles of heel say upto 7° and then extended further.

Maximum righting arm: Is the maximum vertical distance or separation of the GZ curve from the baseline. The maximum righting moment can be found by multiplying the maximum GZ with displacement.

The angles of Equilibrium: The heel angles at which the GZ curve touches the X-axis or the base line are the angles at which the ship can be at equilibrium. At these heel angles the vessel can be at state of rest. The vessel will have the zero value of GZ at these angles.

The range of positive stability: Is the range in degrees between the upright equilibrium angle and angle of vanishing stability.

Angle of deck edge immersion: The initial part of the curve is concave in nature where as after the deck is immersion the curve tends to become convex. The point at which the concaveness changes to convexity is called point of contra flexure. Before deck edge immersion volumes of wedges as well as the distance between their centroids increase. After deck edge immersion though the volumes of wedges increase, their centroids come closer & closer to centre line. This is the reason that GZ increases after deck edge immersion but with less intensity.

Angle of maximum stability: Angle of maximum stability is related to angle of deck edge immersion. This is the angle which appears dangerous to a mariner and yet it can be said that the ship may be having maximum stability at this angle of heel.

Angle of maximum list that the vessel can sustain: The list is caused by listing moment. The angle at which listing moment equals righting moment gives the angle of list. Normally it is said that if the listing moment caused is more than the maximum righting moment the ship will capsize. The expression is better explained with following diagrams, where listing moment curve is drawn by pecked line. Where the range of positive stability is more than 90°, ship has advantage. The reason being the Cosine curve has maximum value in upright condition & zero value at 90° inclination.

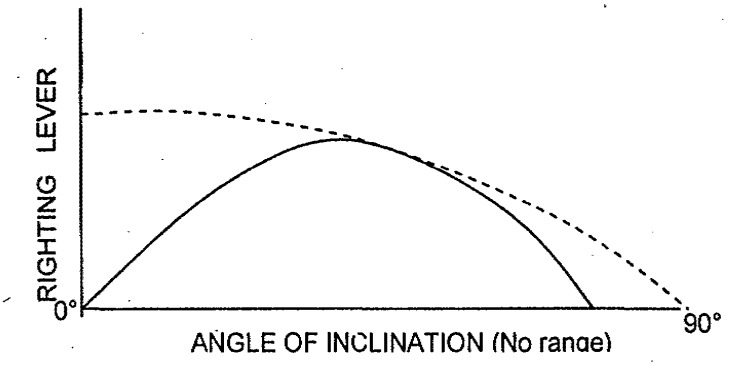


Fig. 6

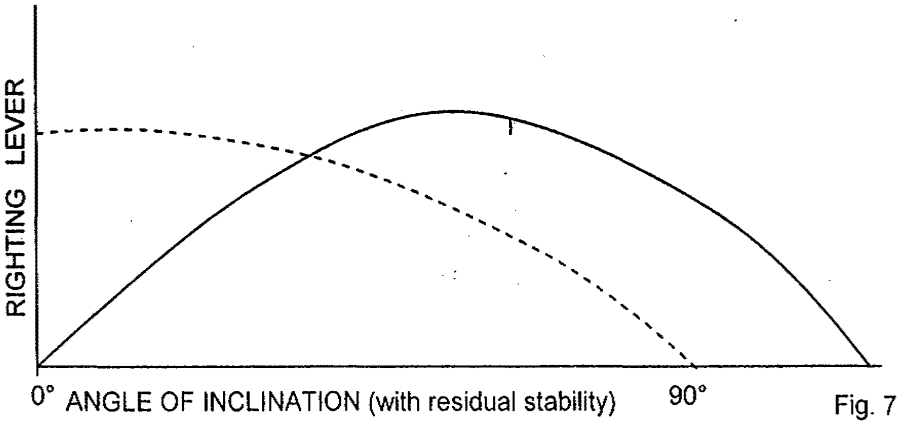


Fig. 7

Angle of dangerous list: Some say that the angle half the maximum permitted list angle is the limiting danger angle of list. There is no hard and fast rule to determine the limiting dangerous

list angle but the master must ascertain the same considering various factor. Some of these may be the following:

- The weather conditions specially the swell. The stability data that the master has is for static condition and the data will be different in swell.
- The professional knowledge of stability blended with the knowledge of seamanship and lessons learnt from incidents involving similar ships / weather.

Angle of loll for the condition of negative upright GM_0: This is the dangerous condition. The angle of loll for wall sided condition is found by putting the value of GM + ½ BM^2 tan θ equal to zero.

The angle of list due to G being off centre: This is found by the intersection of cosine curve (GG_1 cos θ) with original GZ curve. (GG_1 is the athwartship distance between COG & centre line of ship)

Termination of positive stability: The angle of heel at which the GZ curve intersects the baseline is the termination of positive stability. This is also called the angle of vanishing stability, some times also referred to as the angle of maximum roll.

Dynamic stability: dynamic stability at any angle of heel is found by multiplying the area under the curve till that angle by the displacement of the vessel. The dynamical stability is represented in the units of metre radian.

What is the influence of form on GZ:-

The Form of ship above & below water both are important in deciding the size & shape of GZ curve. The 3 elements of form are draft, beam & free board. To analyse the details we will study the result of an experiment conducted on a box vessel of draft 6.4 m. Draft was kept constant & the other two parameters were varied. In first case beam was 15.4m & freeboard 1.98m.

In the fig. 8 ship immerses deck edge at 14½° after which rate of increase of GZ becomes slower. Angle of vanishing stability is 38° (Curve 'A' in the figure)

The beam is now increased by 1.37m. The curve's starting phase is steeper now. This is because GM_0 has increased & therefore GZ at various angles. There is a change in maximum GZ & now angle of vanishing stability is 45°. (The curve is 'B' of the figure)

Let there be an increase in freeboard of 1.37m instead of beam now to original box shaped vessel. The initial part of the curve starts same was as for A. Angle of vanishing stability shoots up to 72° & maximum GZ now is at 40°. (Curve 'C' in figure).

Observations: Increase of beam does not influence the size to GZ curve to that great an extent as can be done by increase in freeboard. The freeboard has tremendous effect on stability at moderate and large angles of heel. Since the free board determines the angle of deck edge immersion and hence the maximum values of stability, the overall stability may also be considered as a function of free board. At the same time it is worth noting that freeboard has no effect on initial stability.

In condition 'C' if G is raised. The GM & GZ are immediately affected. Range of positive stability reduces as shown for curve 'D' in the figure

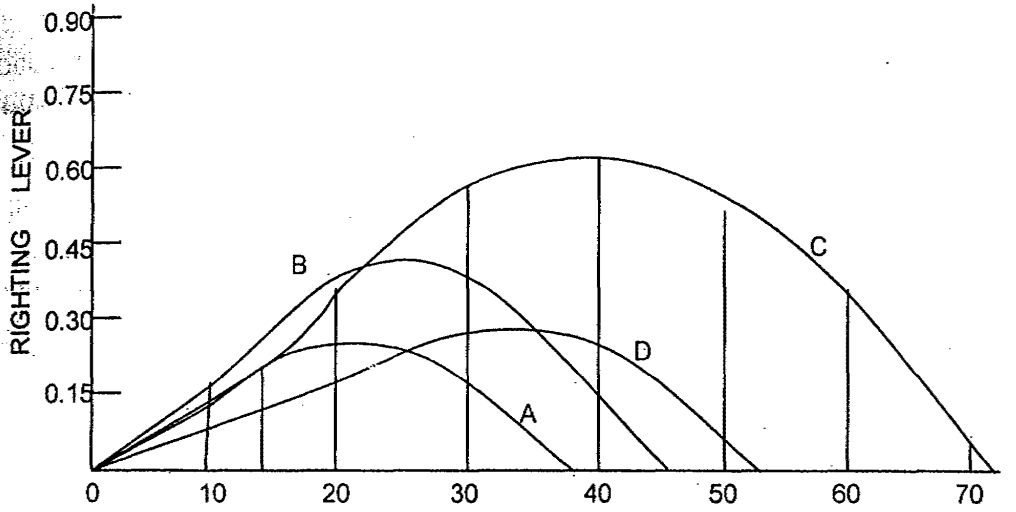


Fig. 8

How is the GZ at various angles of heel found?

Often the Initial Metacentric height (GM_o) is considered by most mariner as a measure to evaluate or describe the status of stability but actually GM_o is a measure of stability for small angles of heel where the righting lever is directly proportional to GM_o. At higher angles of heel the GZ or the righting lever is not a direct function of GM_o, though may bear some relevance for standard shapes. The GZ at higher angles of heel is found in many ways.

Wall Sided Formula:-

Wall sided formula is strictly true for box shaped vessels till the deck edge immersion. For ship shaped vessels the wall sided formula may be used for the range of angles of heel in which the sides of immersed and emerged wedges are parallel to each other generally over the most length.

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

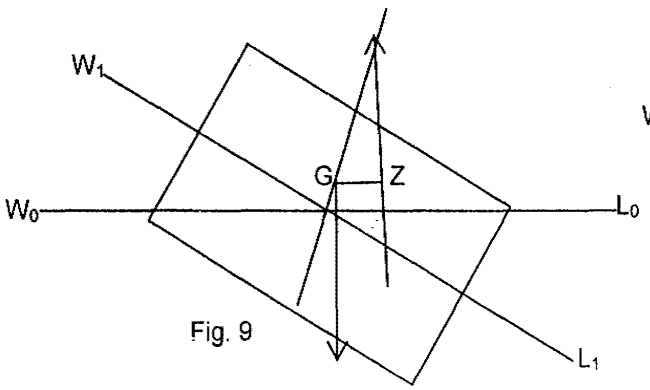


Fig. 9

A box vessel heeled. Wall sided formula can be used till deck edge immersion

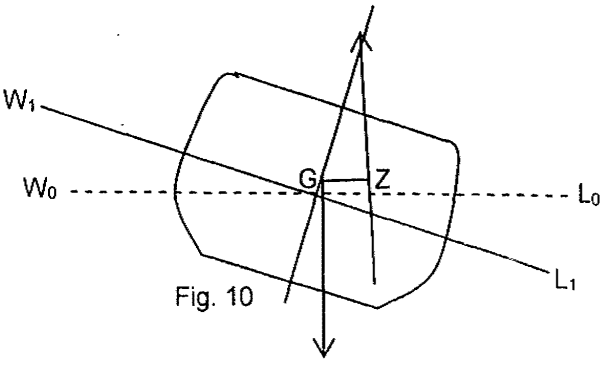


Fig. 10

A ship shaped vessel heeled. Wall sided formula can be used till wedge sides are parallel

For the small angles the 2nd component of the bracket can be neglected & we would get GZ = GM Sinθ. In the above formula GM is still the dominating component. If we improve the ship's GM the stability at large angles of heel also would improve.

Statical Stability Curves: Assumption is that the ship heels in the still water condition. Righting arm values are provided for different angles of heel with water level static. Separate curves being drawn for different displacement. A nominal value of KG is assumed.

Let the vessel be inclined to an angle θ° so that the COB shifts to a new position B_1. The righting lever value tabulated in the stability tables is GZ for an assume value of KG. But the ship's COG presently may be at G_1. ($KG_1 < KG$). G_1 is below G by an amount equal to GG_1.
In the fig below GZ is the tabulated value of righting lever and G_1Z_1 is the actual value of righting lever at an angle of heel = θ.

Now $GZ = PZ_1$. $G_1Z_1 = GP + PZ_1 = GG_1 \sin\theta + PZ_1 = GZ + GG_1 \text{ Sin } \theta$.
The correct righting lever will be $G_1Z_1 = GZ + GG_1 \text{Sin}\theta$ (- sign to be used when actual KG is more than assumed KG). The general formula therefore being
$G_1Z_1 = GZ +/- GG_1\text{Sin}\theta$

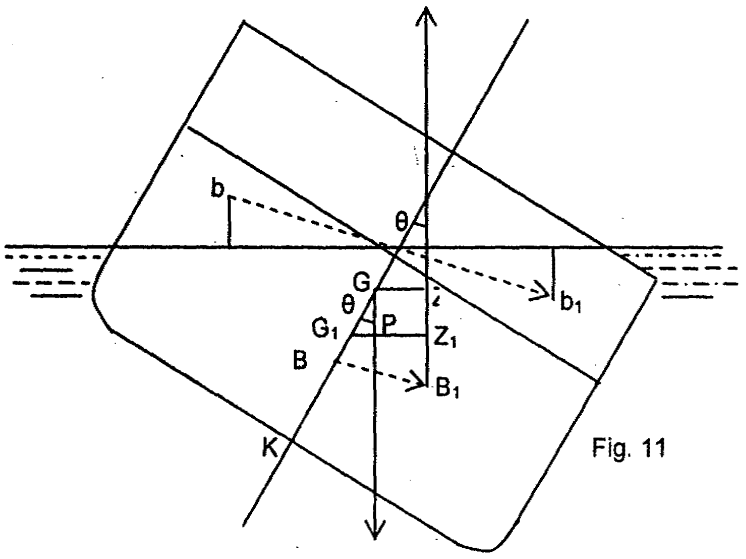
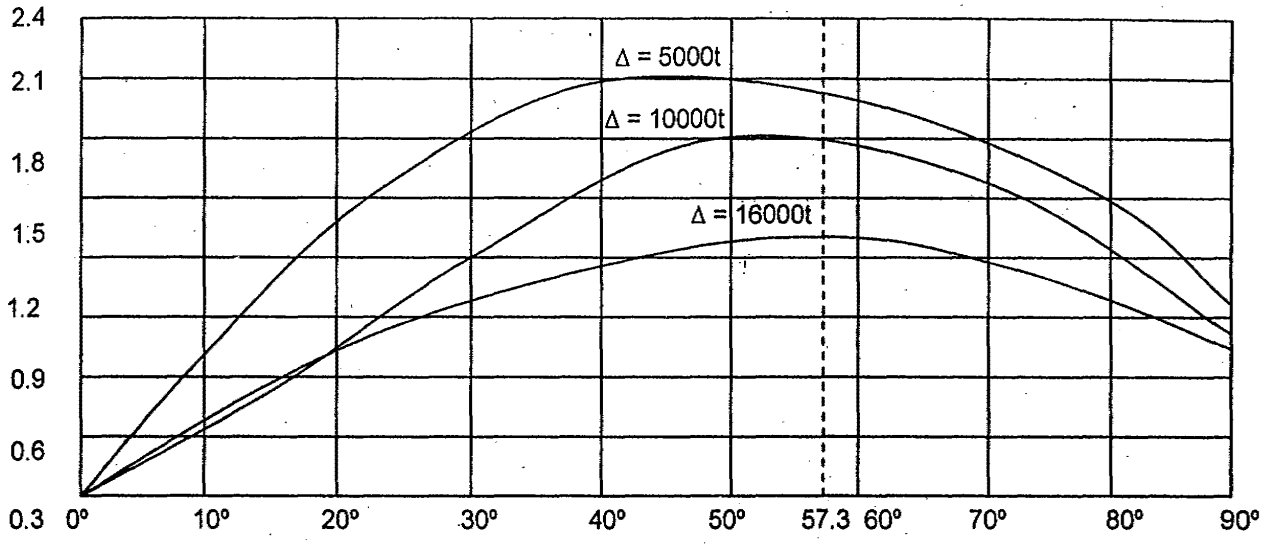
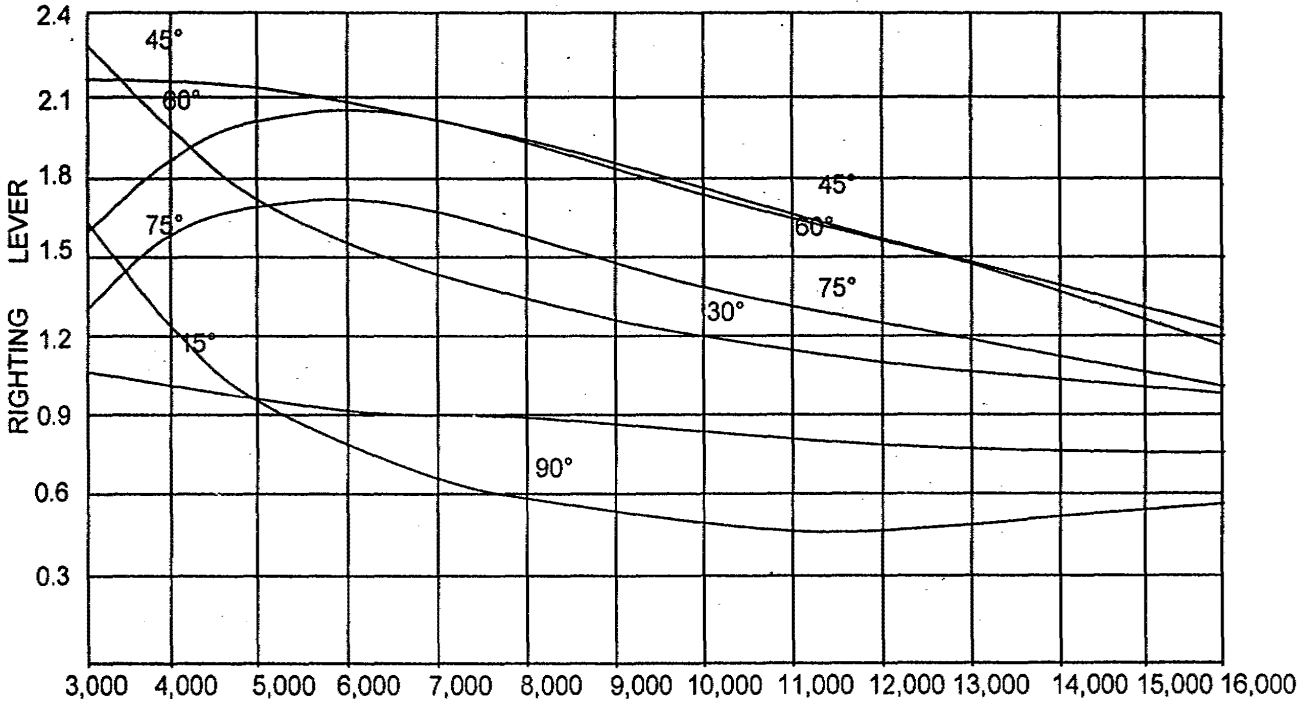


Fig. 11

Cross curves of stability for assumed KG: Alternately Cross curves of stability for a certain KG provide righting arm values for different displacement of the ship. Separate curves being drawn for different angles of heel. A nominal value of KG is assumed. The GZ is found in the similar way as above.



(Statical stab Curves angle of inclination for an assumed KG of 6.00m) Fig. 12



(Cross curves of stability for an assumed KG of 6.00 m) Fig. 13

KN Curves or tables of Stability: Cross curves of stability or tables where righting arm values are provided for different displacement of the ship. Separate curves being drawn for different angles of heel. Assumed value of KG being 0. Thus GZ = KN – KG Sin θ.

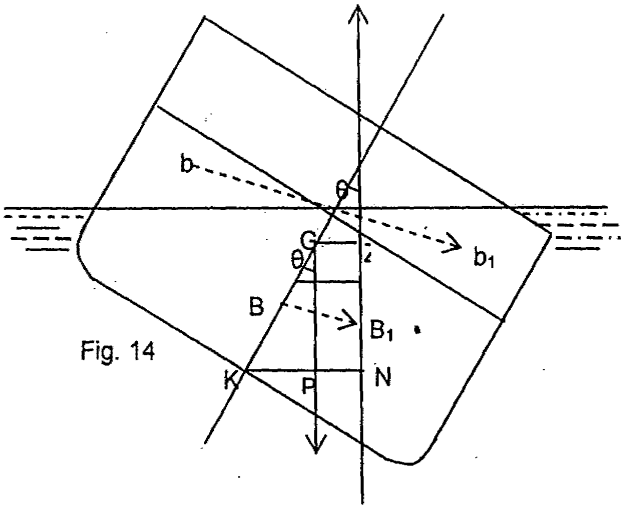


Fig. 14

(Transverse section of a vessel heeled showing GZ and KN at θ°)

In the fig above KN is the tabulated value of righting lever for a hypothetical position of G at keel. GZ is the actual value of righting lever at an angle of heel = θ°.

Now GZ = PN. & PN = KN – KP = KN - KG Sin θ.

Let the figure below represent the cross-section of a ship inclined to a large angle θ°. WL is the original water-line, and B the original COB. In the inclined position she floats at the waterline W_1L_1. Intersection point for large angles will not usually be in the middle line of the ship. The volume of the "emerged wedge" and the volume of "immersed wedge" are equal. Let this volume be denoted by v. The center of buoyancy of the vessel when floating at water-line W_1L_1 is at B_1. Also bh & b_1h_1 are perpendicular to the new waterline W_1L_1. The transverse shift of centroid of wedges then will be hh'. The transverse shift of COB parallel to new water line is equal to BB_h.

$BB_h = \frac{v \times hh_1}{V}$ where V is the underwater volume of the vessel.

Now GZ is the righting lever of the vessel.

$GZ = BB_h - BP$

$= BB_h - BG \sin \theta$, the sign is positive when an KG < KB.

The general formula therefore being:

Lever of statical stability at any angle θ° = Δ (BB_{h+} +/– BG Sin θ)

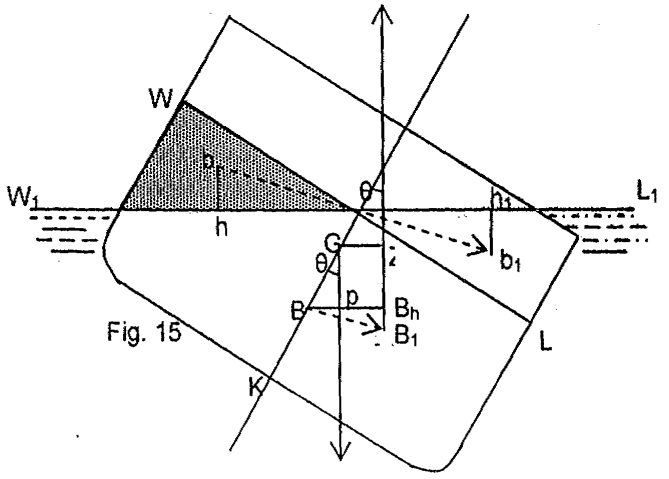


Fig. 15

This is known as "Atwood's Formula"

What is the effect of internal shift of weights and hence COG on the GZ curve?

Correction for Transverse shift of G: Stability curve can be used to find the effect of transverse shift of weight on transverse stability of the ship.

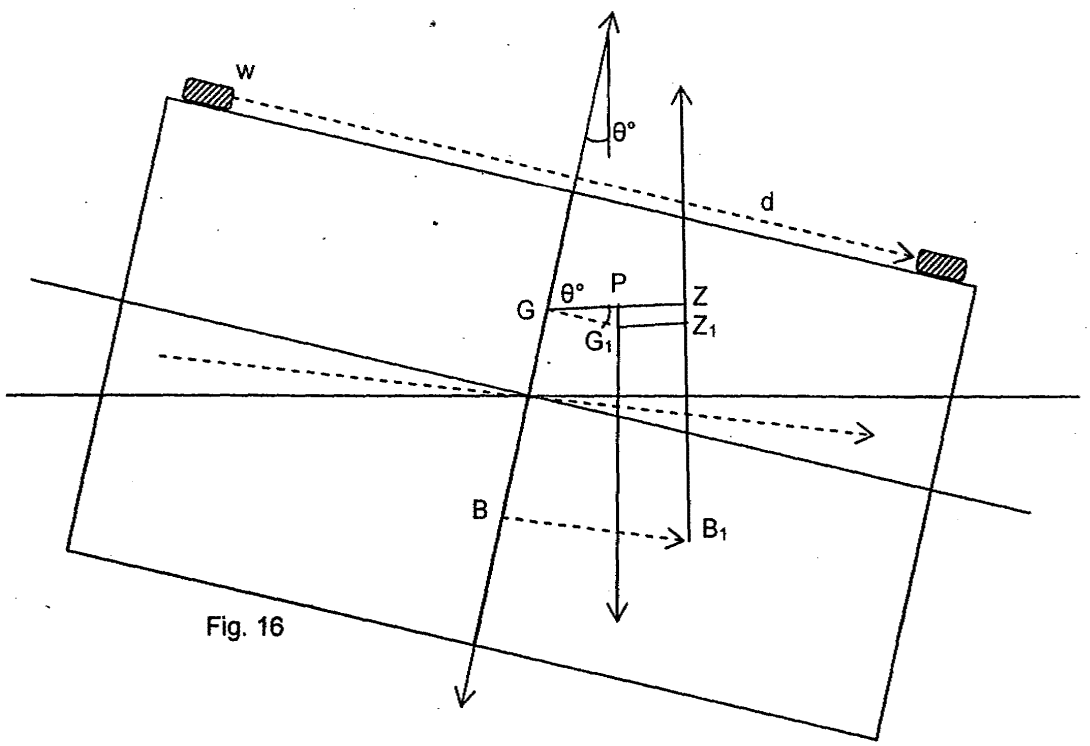


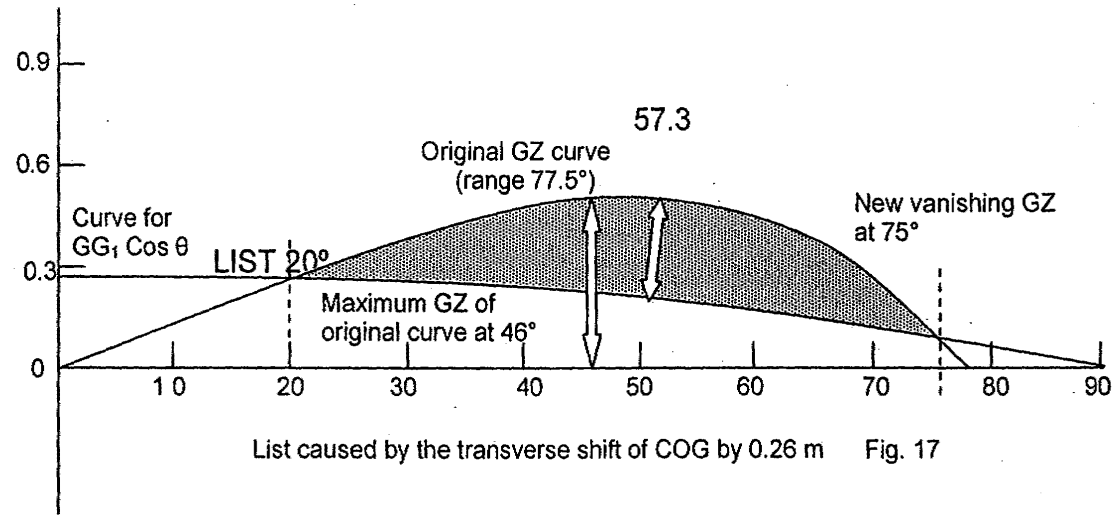
Fig. 16

Let there be a weight w on deck, shifted athwartship by d metres. The COG of the vessel will shift // & proportional by an amount = $GG_1 = \frac{w \times d}{\Delta}$ where Δ is the displacement of the vessel.

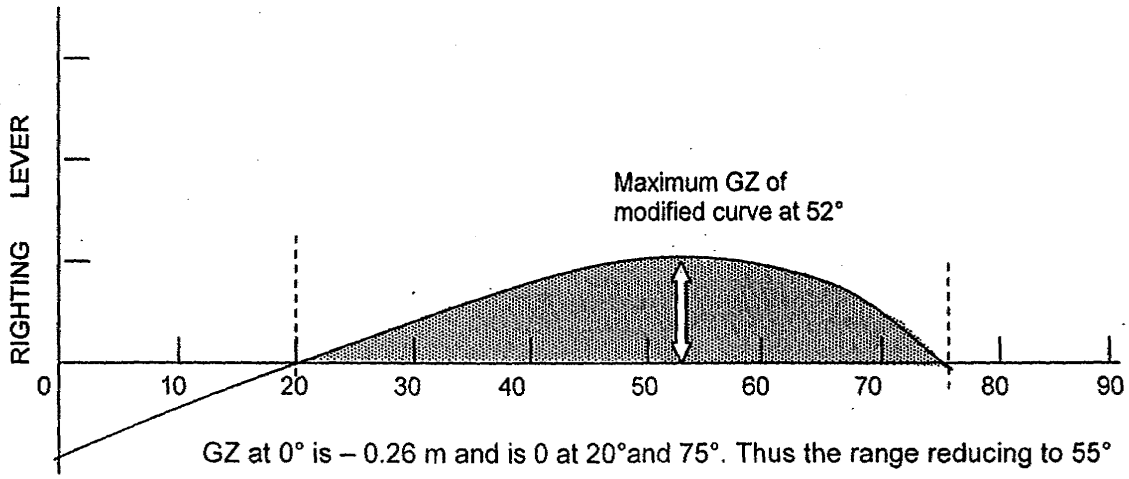
GG_1 is the transverse shift and the resolved component of this // to the heeled water line is GG_1 Cos θ.

In the fig above $GP = GG_1 \cos\theta$ & $PZ = G_1Z_1$. Also $GZ = GP + PZ = GG_1 \cos\theta + G_1Z_1$.
The new righting lever for the given angle of heel, $G_1Z_1 = GZ - GG_1 \cos\theta$.

It is worth noting that the ship's GZ curve on the listed side is reduced in size in respect of area under the curve, range of positive stability, the maximum GZ. The angle of vanishing stability may remain same or may reduce in size. The GZ curve on the other side improves in parameters but this is of no merit to the overall stability of the ship. The effect on the listed side is reduction of the righting lever by an amount = $GG_1 \cos\theta$ at any angle of heel. (θ° is the angle of heel).



List caused by the transverse shift of COG by 0.26 m Fig. 17



GZ at 0° is – 0.26 m and is 0 at 20°and 75°. Thus the range reducing to 55°

Fig. 18

Correction for vertical shift of G: Let there be a weight w under deck. Let the weight be shifted upwards by d metres. The COG of the vessel will shift // & proportional by an amount = $GG_1 = \frac{w \times d}{\Delta}$ where Δ is the displacement of the vessel.

GG_1 is the vertical shift and the resolved component of this // to the heeled water line is, GG_1 Sin θ.

In the fig below $GP = GG_1$ Sin θ & $PZ = G_1Z_1$. Also $GZ = GP + PZ = GG_1$ Sin θ + G_1Z_1.

The new righting lever for the given angle of heel, $G_1Z_1 = GZ - GG_1$ Sin θ.

$G_1Z_1 = GZ + GG_1$ Sin θ for downward shift.

It is worth noting that the ship's GZ curve for an upward shift is reduced in size in respect of area under the curve, range of positive stability & invariably the maximum GZ. The angle of vanishing stability reduces in size. The reverse is likely to happen for a downward shift. The net effect thus is the reduction of the righting lever by an amount = GG_1 Sin θ for the upward shift & increase of the righting lever by an amount = GG_1 Sin θ for the downward shift on all angles of heel.

In case of a ship with low GM_o, the vessel may capsize with no righting capability or heel over to an angle of loll subsequent to an upward shift of weight.

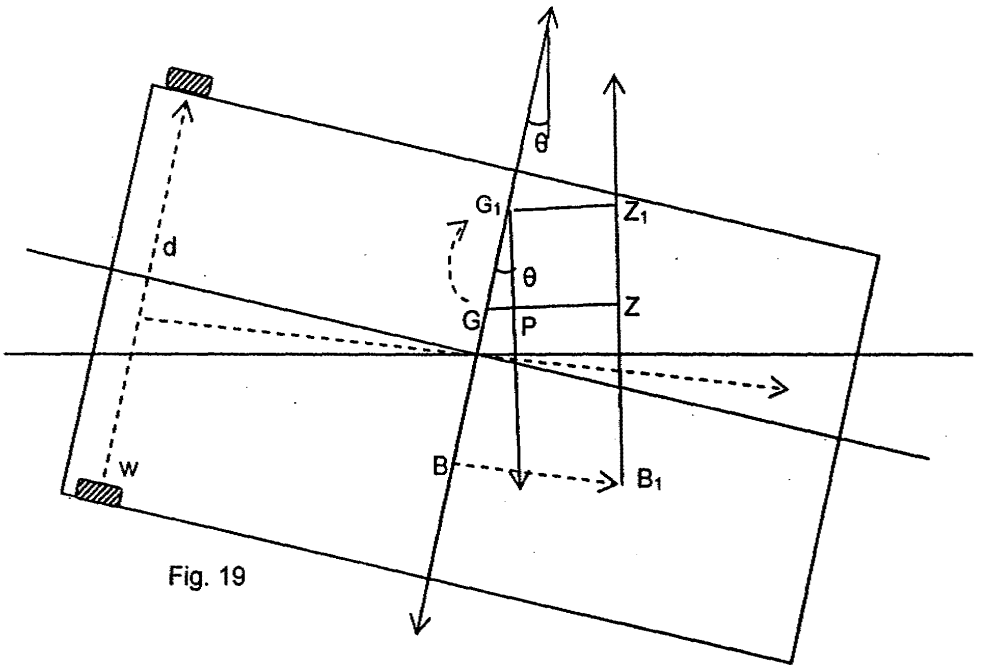


Fig. 19

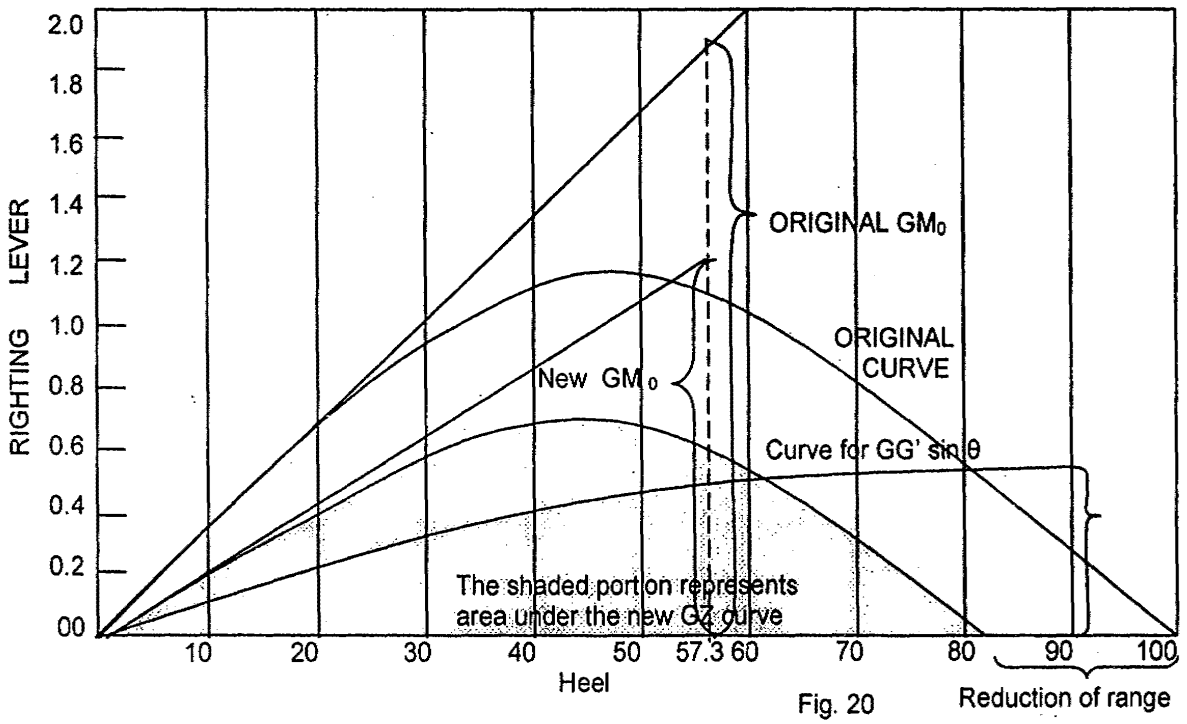


Fig. 20

(original curve – curve for GG' sin θ = new GZ curve)

To show that the intersection of ordinate at 57.3° & the tangent drawn at origin gives initial GM:

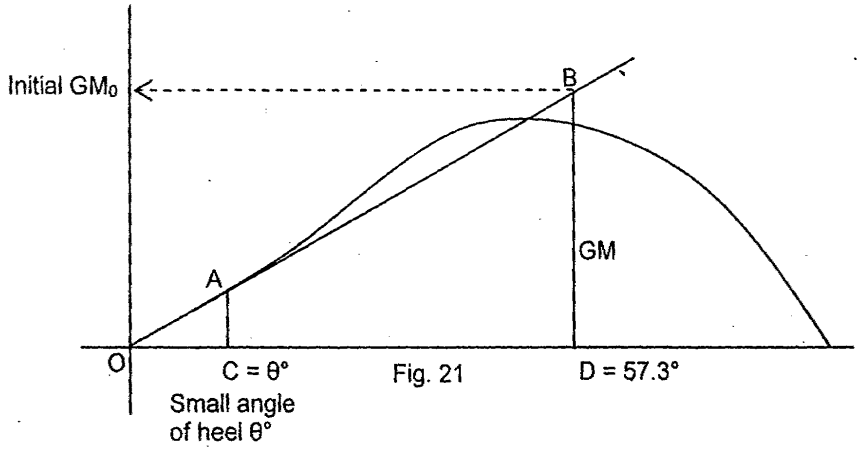


Fig. 21

In above fig Δ OAC & Δ OBD are similar

$$\frac{BD}{OD} = \frac{AC}{OC}$$

$$BD = OD \times \frac{AC}{OC} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

But AC = GZ for an angle of heel θ°. (θ° being a small angle of heel).

$$\because \frac{OD}{OC} = \frac{57.3°}{\theta°} \quad \therefore OD = OC \times \frac{57.3°}{\theta°}$$

Substituting OD in eq (1) and simplifying we get $BD = \frac{57.3°}{\theta°} \times AC = \frac{57.3°}{\theta°} \times GZ \text{ at } \theta°$

But GZ at small angles of heel = GM sin θ, substituting we get

$$BD = \frac{57.3°}{\theta°} \times GM \sin \theta°$$

But small angles of heel Sin θ ≈ θ in radians $= \frac{\theta}{57.3^0}$, substituting we get

$$BD = \frac{57.3°}{\theta°} \times GM_0 \times \frac{\theta}{57.3^0}$$

$BD = GM_0$, hence proved.

Ex 1 The GZ valves for a ship at different angles of heel are as follows:
5° = 0.168m, 10° = 0.39m, 15° = 0.54m, 20° = 0.70m, 25° = 0.80m,
A weight of 40T shifted to stbd through 8m W = 9,000T find the resultant list?
Sol^n: -

$GZ_1 = GZ - GG_1 \cos \theta$

$$GG_1 = \frac{wd}{w} = \frac{40 \times 8}{9000} = 0.036$$

Heel	0°	5°	10°	15°	20°	25°
GZ	0.0	0.168	0.39	0.54	0.70	0.80
$-GG_1 \cos \theta$	-0.036	0.036	0.035	0.035	0.034	0.033
$GZ-GG_1 \cos \theta$	-0.036	0.132	0.355	0.505	0.666	0.767

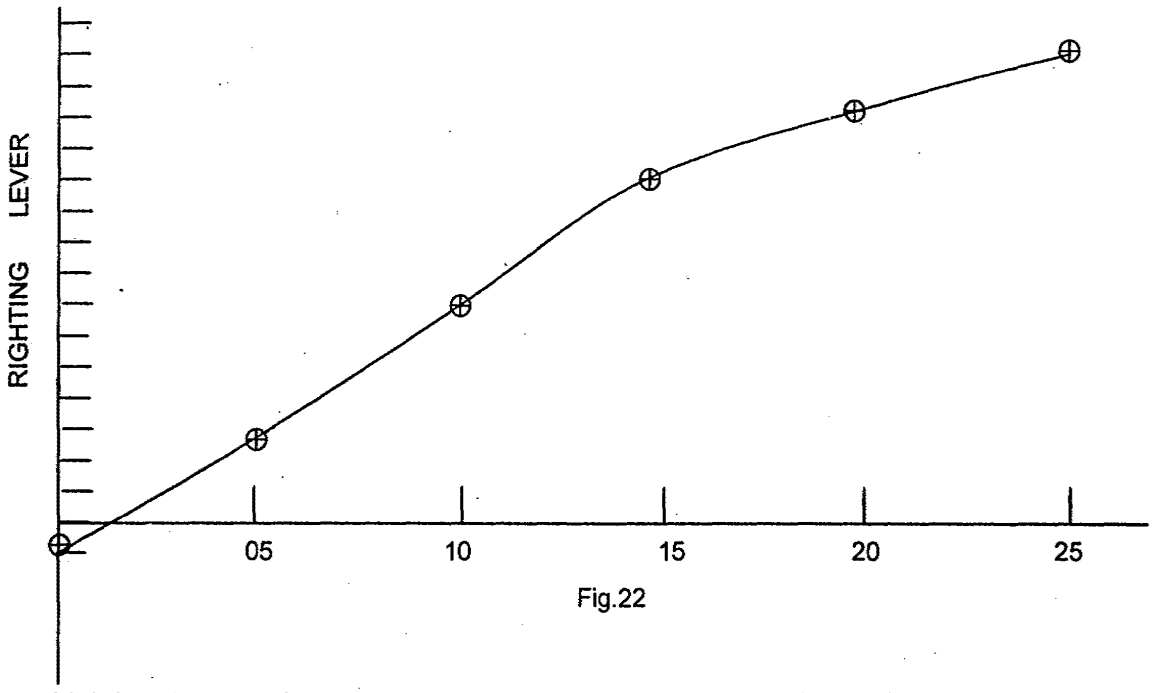


Fig.22

Angle of loll implies an alternate posture other than the normal upright posture of a ship where the ship can be at rest or can be at equilibrium. This results out of a negative equilibrium in upright position.

A vessel having negative stability in upright position means the transverse metacentre below the COG in that position. The vessel if heels will have no righting lever to bring her to upright status. The vessel will continue to heel and is likely to reach a position of another equilibrium where the following conditions are met:

1. COG & COB are in a vertical line.
2. The water plane area increases in breath thereby increasing BM_T, & taking the transverse metacentre above COG.

At angle of loll the vessel has positive GM_T and would heel about angle of loll. The righting lever at angle of loll is zero and this is indicated by the GZ curve touching x axis. The area under the GZ curve on the positive side is reduced as compared to a normal healthy GZ curve. The area under the GZ curve is a measure of work which must be done to heel the ship. This means the ship can be easily heeled to a large angle. The vessel may even heel to the angle of loll on the other side. Ships are symmetrical about centreline and therefore the angle of loll must exist on both the sides.

Wall sided formula for angle of loll

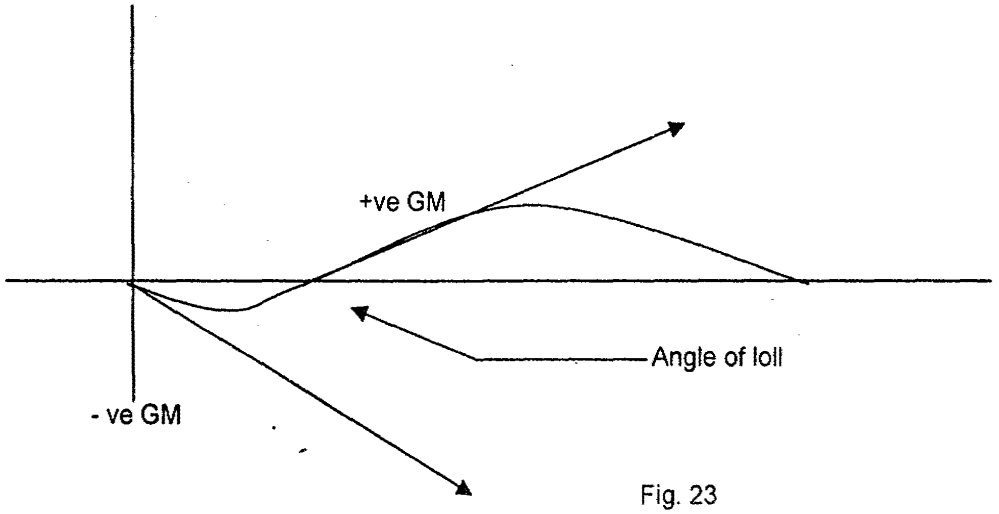


Fig. 23

The wall sided formula for the righting lever is;

$GZ = \left[GM + \frac{1}{2} BM \tan^2\theta\right] \sin\theta$

At angle of loll the righting lever is zero. Which means the R.H.S. of above formula is zero. Since the vessel is at angle of loll θ exits and is not zero. This means

$\left[GM + \frac{1}{2} BM \tan^2\theta\right] = 0$

Or $\left[GM = -\frac{1}{2} BM \tan^2\theta\right]$

Or $\tan^2\theta = \frac{-2GM}{BM}$

Or $\tan\theta = \sqrt{\frac{-2GM}{BM}}$

The above formula can be used even for ship shaped vessels where the sides are more or less parallel for the water levels in question.

The GM_T at angle of loll is $2 \times -GM_o \times \sec\theta$

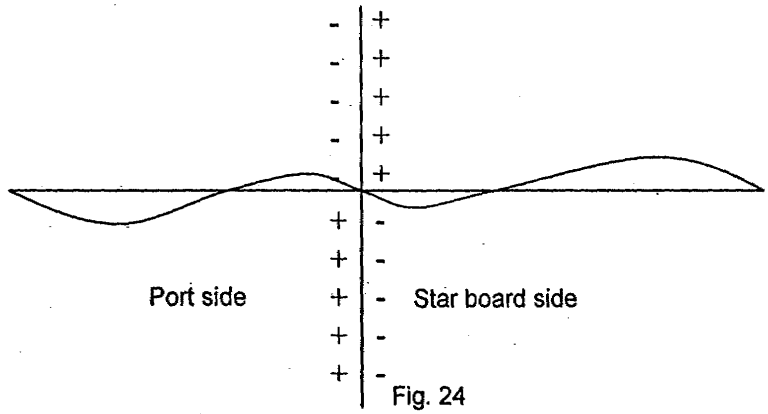


Fig. 24

Ex. 2 The GZ values of a ship of displacement 10000t are as follows:

Heel°	5°	10°	20°	30°	40°	50°	60°	70°
GZ m	0.5	0.11	0.3	0.55	0.8	1.0	0.85	0.54

A weight of 800t is shifted vertically upwards by 10m. With the help of GZ curve find the effect on the stability of vessel. Compare the results obtained from graph versus the results from wall sided formula. Given: KM = 7m KG = 6.35m BM = 3.2m

Sol^n: -

$$GG^1 = \frac{w \times d}{\Delta} = \frac{800 \times 10}{10000} = 0.8m$$

This will cause a reduction of GZ at all angles of heel by an amount equal to $GG_1 \sin\theta$.

Heel°	0°	5°	10°	20°	30°	40°	50°	60°	70°
GZ m	0	0.5	0.11	0.3	0.55	0.8	1.0	0.85	0.54
$-GG_1 \sin\theta$	0	0.07	0.14	0.27	0.4	0.5	0.6	0.69	0.75
New GZ	0	-0.02	-0.03	0.03	0.15	0.3	0.4	0.16	-0.21

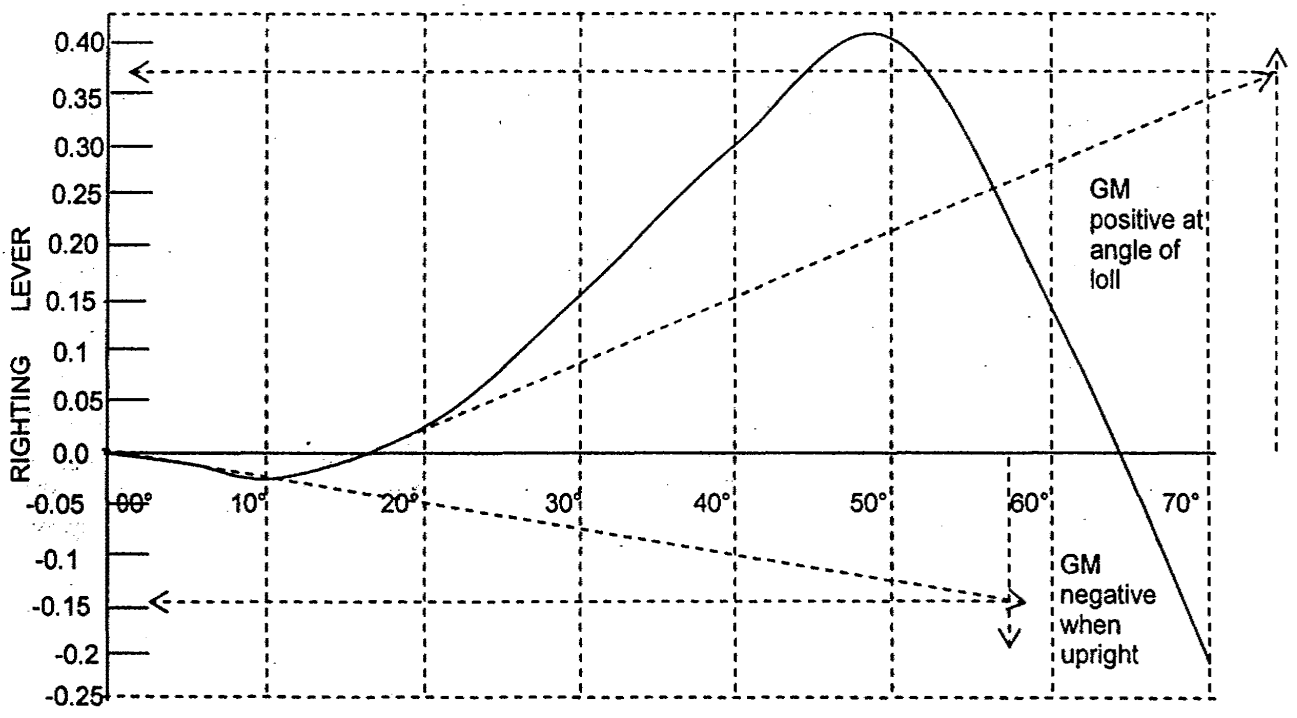


Fig. 25

Due to vertical shift of weight the COG of vessel moves upwards. The KG increases from 6.35 to 7.15m (increases by 0.8m). By plotting a graph of new GZ curve it is found that the curve shows negative values till 17°, where after the values are positive again. At 17° vessel attains equilibrium. The ship has positive GM at angle of loll. In light disturbing conditions the vessel will roll about this point.

The range of positive stability, the areas under the curve, the maximum GZ is obviously reduced.
The curve shows a negative GM of 0.14m when vessel is upright and a positive GM of 0.37m at angle of loll.
By formula:

Assuming wall sided conditions, $\tan\theta° = \sqrt{\frac{-GM_0}{BM}} = \sqrt{\frac{-(-0.3)}{3.2}} = \sqrt{\frac{0.3}{3.2}} = 0.306.$

Gives $\theta = 17°$.
GM at angle of loll = $-2\,GM_0 \sec\theta° = -2 \times -0.15 \times \sec 17° = 0.314$m.

Calculation of KN values or determination of cross curve of stability:-
The integrator is a very common instrument for finding out the areas and position of centroid wrt. a given axis. It is therefore used to find the position of COB and hence the righting lever at a given angle of heel. The process is tedious however.
A user must understand that when the curves are made by the following conventional methods certain assumptions are made while constructing the curves.

1. The sides & decks are assumed to be water tight for the range over which curves are drawn.
2. CG is taken in same position in the ship. No shift of weight is caused through out inclination.
3. The trim is assumed to be unchanged i.e. ship heels about a horizontal longitudinal axis which remains horizontal but moves vertically as per required displacement.

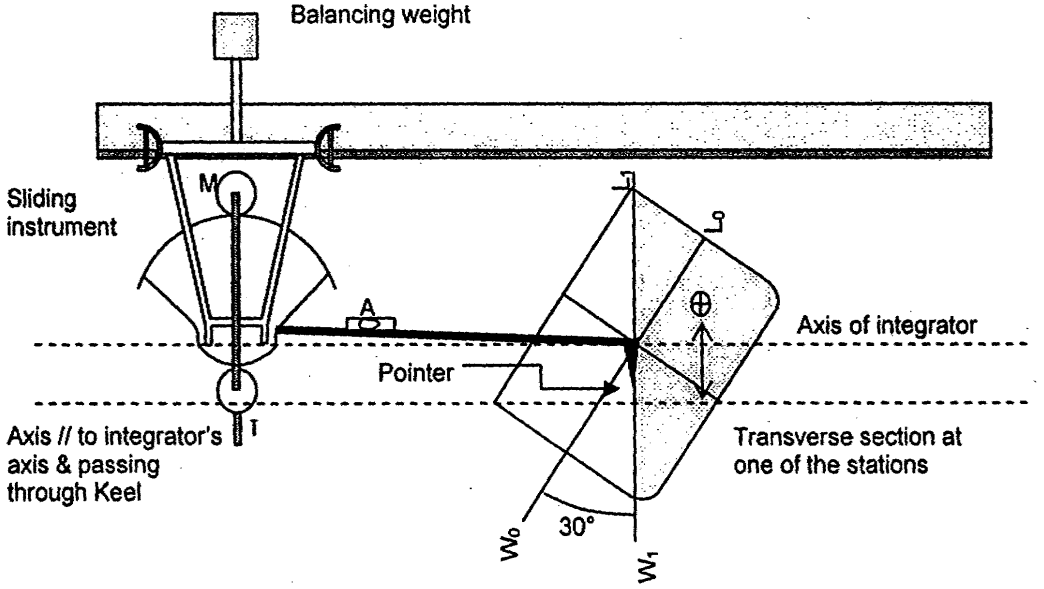
Some of the important methods of constructing curves are:

1. Blom's mechanical method.
2. Barne's method.
3. Direct method.
4. Amsler's Integrator giving cross curves.
5. Hok's method.

To get a basic idea about finding the position of COB at various angles of heel / drafts, a brief idea in respect of one of the above methods is given below:

Amsler's Integrator:-

Integrator is extension of planimeter which is used for finding out area of irregular shape drawn in two dimensions. It has a bar with groove to allow wheeled instrument to run along the groove. A mass is attached on the opposite side of instrument to let instruments run smoothly. Three small wheels run on paper. A pointer (like in planimeter) is traversed along the periphery of relevant area.



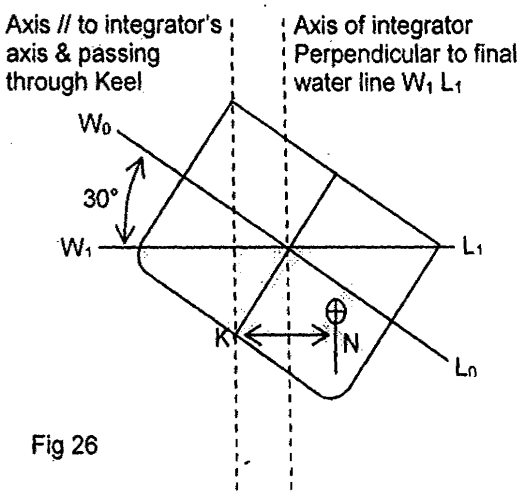


Fig 26

Different wheels (in the fig these wheels are denoted as A, M, & I respectively), run according to the traverse made by the pointer. Preset gears & counters give numbers which when multiplied with suitable multiplier will give area, moment of area, moment of Inertia respectively.

Let us take a body plan drawn for both port & starboard sides showing the vessel inclined to say 30°. Transverse underwater sections at equidistance stations are cut. One of such sections is shown in the diagram. The template of this section is placed on table in such a way that the final waterline is perpendicular to the axis of integrator and the pointer is placed at the one of the points along periphery of submerged portion. Submerged part is shown shaded. An axis parallel to the axis of integrator and passing through keel K is our reference axis for the experiment. The position of centroid is noted from this axis.

Taking the pointer through the periphery of the underwater portion we can determine 1) Area & 2) Moment of area about reference axis. This is repeated for all the sections & at various inclinations. Summation of all areas using Simpson's rules gives underwater volume
Summations of all moment of areas give moment of underwater volume about reference axis. The ratio will give distance of COB in inclined condition about the vertical line through keel or KN.

Exercise 12

Q. 1 A vessel is in upright condition and displaces 12000 tonnes. She has a KG of 7.64m. The values of GZ are as follows:

Heel (degrees):	0	10	20	30	40	50	60	70
G Z (metres):	0	0.19	0.50	0.94	1.16	1.03	0.0	0.06

Cargo is then redistributed so as to move the center of gravity of vessel horizontally to the port side by 0.13 m. From the curve of statical stability,
Find: (a) The resulting list
(b) The residual dynamical stability available to the vessel up to an angle of heel of 30°.
Ans. List 7.5° port, RDS 1693.2 t m^c

Q. 2 The GZ - curve of a vessel is as follows:

Heel (degrees)	0	5	10	20	30	45	60	75
GZ (metres)	0	0.212	0.448	1.040	1.520	1.813	1.622	0.616

Draw the curve, and find the following:
Initial - GM, Maximum GZ. and angle at which it occurs, Range of Positive stability.
Ans. i) 2.46m ii) 1.815 at 46.5° iii) 81°

Q. 3 A Vessel of displacement 18193 t, KG 7.45m, FSM 1552m has the following KN values:

Heel°	5°	10°	15°	20°	25°	30°	45°
KN(m)	0.759	1.513	2.249	2.990	3.636	4.320	5.997

A 190t parcel of cargo is shifted transversely through 10m. Draw her statical stability curve in that condition and from the curve determine the angle of list produced.

$$GG_H = = \frac{190 \times 10}{18000} = 0.10555m$$

Heel	0°	5°	10°	15°	20°	25°	30°	45°
KN – KG Sin θ – GG_H Cosθ	-0.1055	0.00454	0.1154	0.2188	0.3428	0.3918	0.5036	0.6545

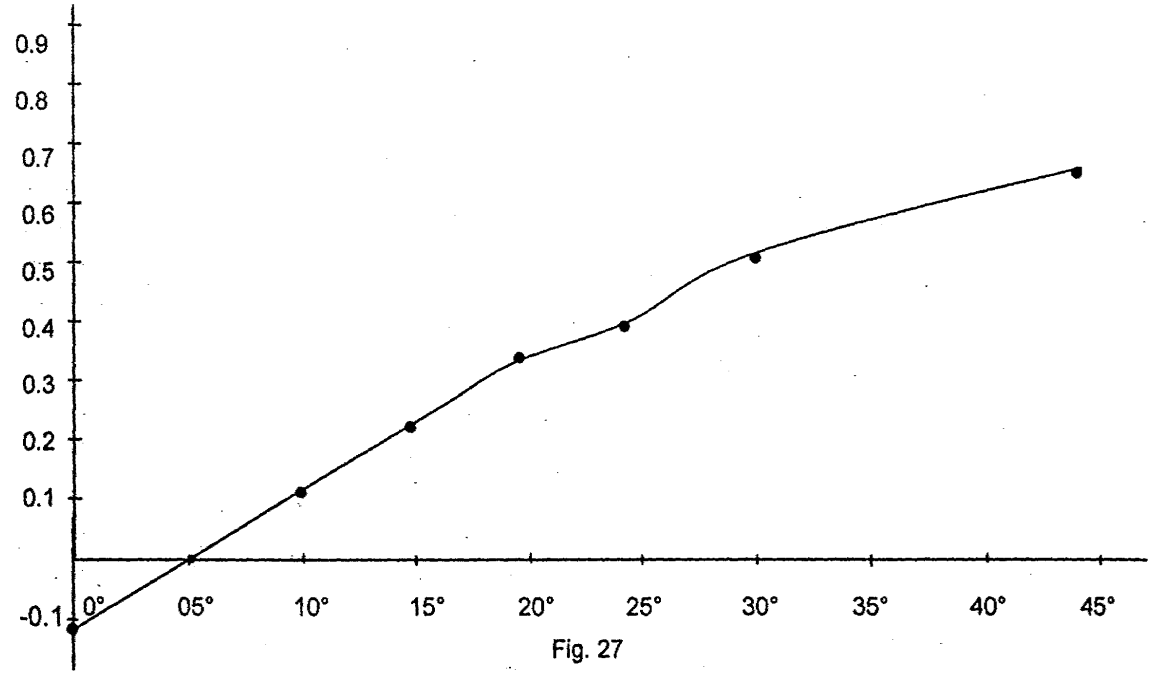


Fig. 27

Exercise on M.V. ALPHA SHIP:-

Ex. 1 M V ALPHA SHIP floating in salt water at 8.8m draft has a KG of 9.93m & FSM 480tm. At this draft and inclinations, assuming that the ship behaves wall sided, calculate the angle of loll? What is the GM at angle of loll?

Hint: -

$$GM = KM - (KG + FSC) = 9.823 - (9.93 + \frac{480}{25991}) = -0.125 \text{ m.}$$

$$BM = KM - KB = 9.823 - 4.674 = 5.149 \text{ m}$$

$$\tan\theta = \frac{-2 \times (GM)}{BM} = \sqrt{\frac{-2 \times (-0.125)}{5.149}}, \quad \theta = 12.43°$$

GM at angle of loll = - 2 GM_0 Sec θ = -2 (-0.125) × Sec 12.43° = 0.256 m

Ans. Angle of loll = 12.43°, GM at angle of loll = 0.256m.

Q. 2 M V ALPHA SHIP is in condition No.2 and is floating in water of RD 1.025. Rough weather causes 440 tones of cargo to shift horizontally through a distance of 9.6 meters and vertically downwards through a distance of 4 meters. Draw the curve of statical stability up to a heel of 45°, after the shift of cargo has taken place. From the curve estimate the resulting angle of list.

Hint: -

$$GG_V = \frac{440 \times 4}{30634.2} = 0.057 \text{m} \quad GG_H = \frac{440 \times 9.6}{30634.2} = 0.1379 \text{ m}$$

Items	Weight tonnes	K.G. (m)	Vert. Moments m.t	L.C.G Ford (A.P)	Long. Moments m.t	Free surface m.t
Displacement	30634.2	7.727	236716.8	85.98	2633929	1352.3

Heel	0°	5°	10°	15°	20°	30°	40°	45°
GZ	0	0.253	0.498	0.629	0.755	1.000	1.203	1.148
$+GG_V$ Sin θ	0	0.005	0.010	0.015	0.019	0.029	0.037	0.040
$-GG_H$ Cos θ	0.138	0.137	0.136	0.133	0.130	0.119	0.106	0.097
New GZ	-0.138	0.121	0.372	0.511	0.644	0.91	1.134	1.091

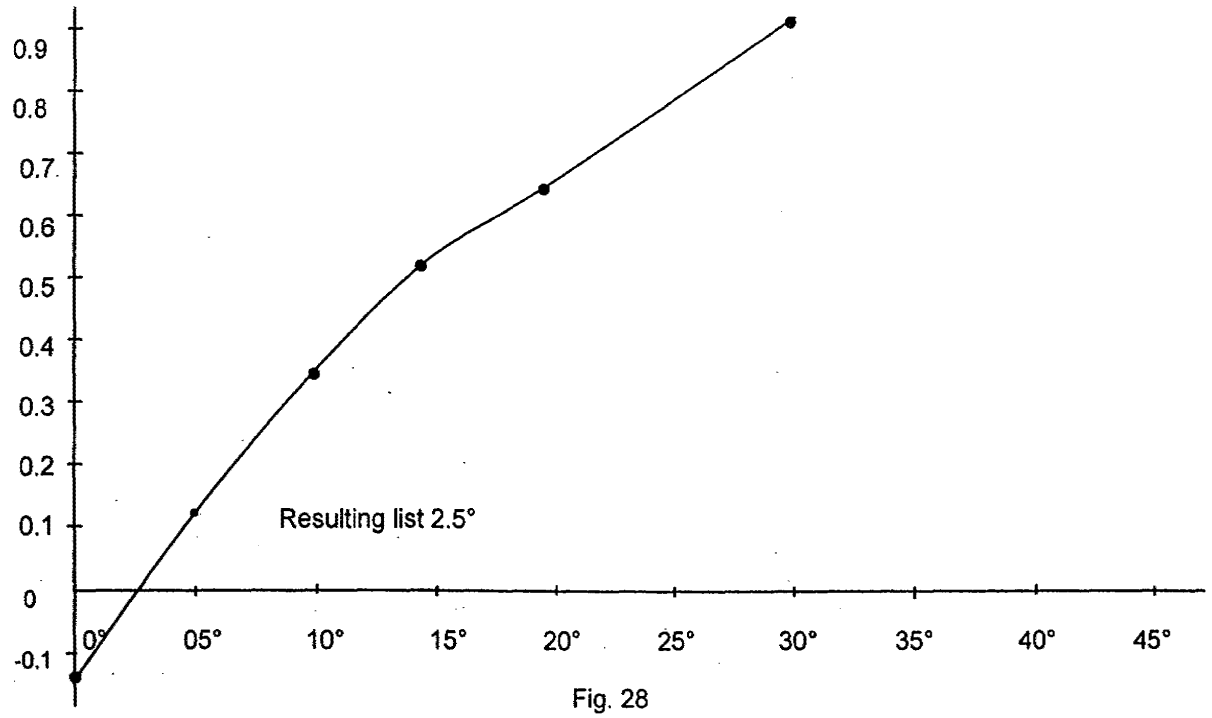


Fig. 28

Q. 3 M V ALPHA SHIP at a draft of for'd 7.37m, aft 9.746m has KG 8.36m and FSM 1272 tm, angle of flooding is 43°. Draw her curve of statical stability up to an angle of 40°. State if intact stability criteria are satisfied. Calculate her dynamical stability at an angle of heel of 40°, using ordinates at 10° intervals.

Mean draft = 8.558 m, LCF = 84.123 m

$$\text{H. draft} = 9.746 - \frac{2.376 \times 84.123}{171.792} = 8.583\ m$$

Draught	Δ	KM_T
8.40	24637.2	9.824
8.60	25313.4	9.818
8.583	25254.6	9.819

KG_F = 8.41m

Displacement In tonnes	10°	20°	30°	40°
25200	1.823	3.585	5.110	6.466
25900	1.820	3.557	5.073	6.422
25254.6	1.823	3.583	5.107	6.462

θ	0°	10°	20°	30°	40°		
KN from curve	0	1.823	3.583	5.107	6.462		
- 8.41 Sin θ	0	1.460	2.876	4.205	5.406		
GZ = KN-KG sin θ	0	0.363	0.707	0.902	1.056		
Simpson's multiplier	1	3	3	1			
	0	1.089	2.121	0.902		Sum	4.112
Simpson's multiplier	1	4	2	4	1		
	0	1.452	1.414	3.608	1.056	Sum	7.53

$$\text{Area under curve till } 30° = \frac{3 \times h}{8} \times 4.112 = \frac{3 \times 10}{8 \times 57.3} \times 4.112 = 0.269 m^c$$

$$\text{Area under curve till } 40° = \frac{h}{3} \times 7.53 = \frac{10}{3 \times 57.3} \times 7.53 = 0.438 m^c$$

Dynamical stability till 40° = Area x Δ = 0.438 x 25254.6 = 11062.7 t.m^c

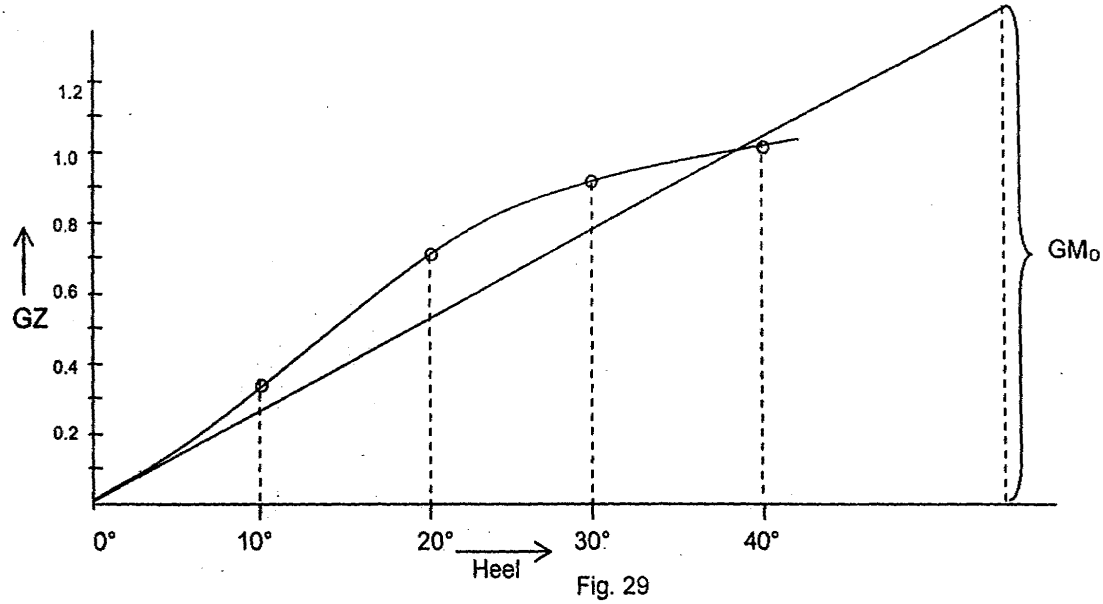


Fig. 29

Intact stability criteria	Required	Obtained	Remarks
The area up to θ = 30° should not be less than	0.055 m^c	0.269 m^c	Satisfied
The area up to θ = 40° or θ_f if < 40°. should not be less than	0.09 m^c	0.438m^c	Satisfied
The area between 30° and 40° or θ_f, if < 40°, not less than	0.03 m^c	0.169 m^c	Satisfied
The righting lever at least / at heel equal to or greater than	0.20m / 30°	> 0.2 m at > 30°	Satisfied Satisfied
The maximum righting arm preferably at heel exceeding	30° & not < 25°	At > 40°	Satisfied
The initial metacentric height GM_o should not be less than	0.15m	1.41	Satisfied

Conclusion: all basic intact stability criteria satisfied

Q. 4 In above condition determine if the vessel satisfies the severe wind criteria. The data of M V ALPHA SHIP required for the severe wind criterion is as follows:
A = area 1560 m^2, centre of Windage 6.8 m above water level. k = 1 as the ship has no bilge keels. Angle of flooding 34°. X_1, X_2, r, s, obtained from tables are 0.8, 1, 1.36 and 0.06 respectively.

Hint: - the candidate may refer to the example shown in standard condition 1 and 2 of M V ALPHASHIP in chapter 26.

Q. 5 M V ALPHA SHIP at Δ 25200 t, KG 8.4 m & FSM 1220 tm has homogenous cargo stowing at 1.84 cu.m. per tonne in No. 3 hold. Consider No; 3 hold to be cuboidal, (length and breadth of the hold remain constant over the entire height) of length 28 m and breadth 26m. The cargo in the compartments shifts, rising the surface on the Port side by 1.8 m and lowering the surface to the stbd by the same amount. Draw the curve of statical stability and hence determine her list.

Volume of the wedge of cargo = $\left(\frac{13 \times 1.8}{2}\right) \times 28 = 327.6 m^3$

Mass of wedge = $\frac{327.6}{1.84} = 178.04t$

Distance between the centroids of the wedges = 2 x $\frac{2}{3} \times \frac{b}{2} = \frac{2b}{3}$ = 17.33m.

$GG_H = \frac{178.04 \times 17.33}{25200} = 0.122$ m

Centroid of the wedge is vertically 1/3rd of 1.8m i.e. 0.6m from original level

$GG_V = \frac{178.04 \times 1.2}{25200} = 0.008m$

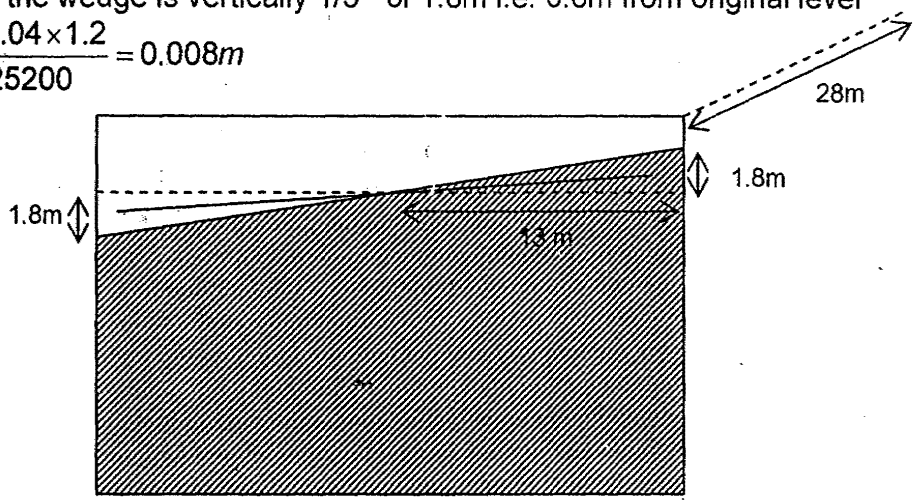


Fig. 30

KG_{FL} = (KG + FSC) = (8.4 + 0.048) = 8.448 m

	0°	5°	10°	15°	20°	25°	30°
KN	0	0.917	1.823	2.700	3.585	4.305	5.110
- KG_F Sin θ	0	0.736	1.467	2.186	2.889	3.57	4.224
- GG_b Sin θ	0	0.0007	0.001	0.002	0.003	0.003	0.004
- GG_H Cos θ	0.122	0.122	0.120	0.118	0.115	0.110	0.106
Corrected GZ	-0.122	0.0583	0.235	0.394	0.578	0.622	0.776

Alternately correct GZ can be found by first correcting KG. Thus Correct KG = KG_F + GG_V. New GZ = KN – corrected KG Sin θ – GG_H Cos θ

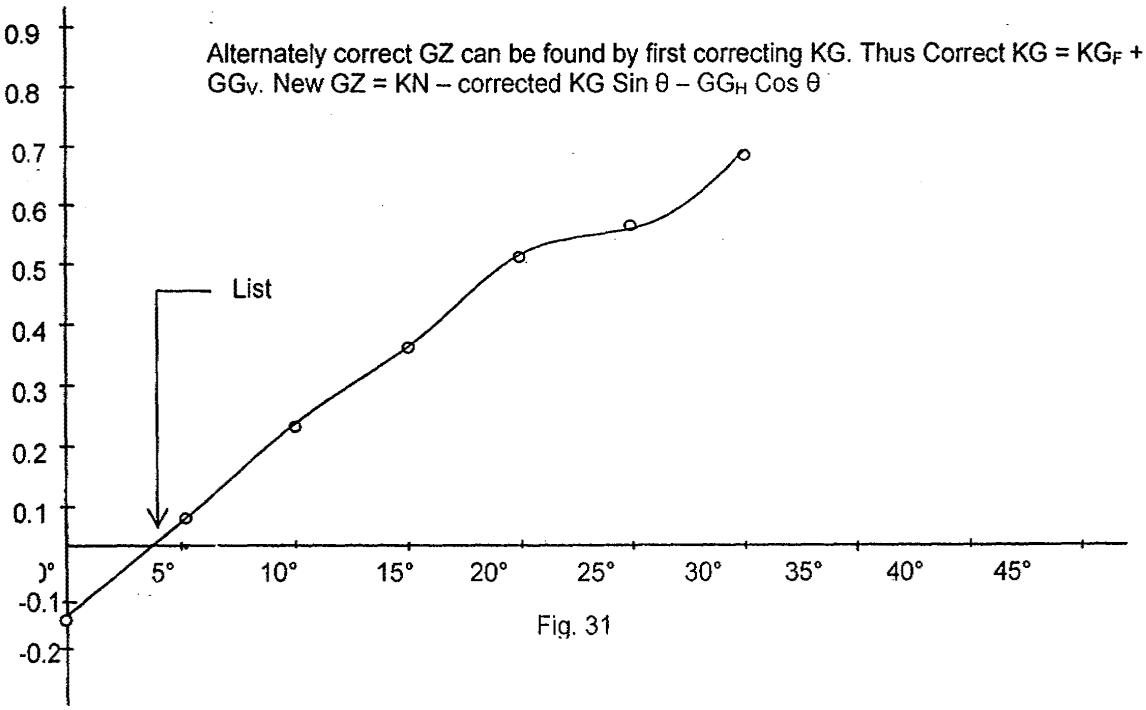


Fig. 31

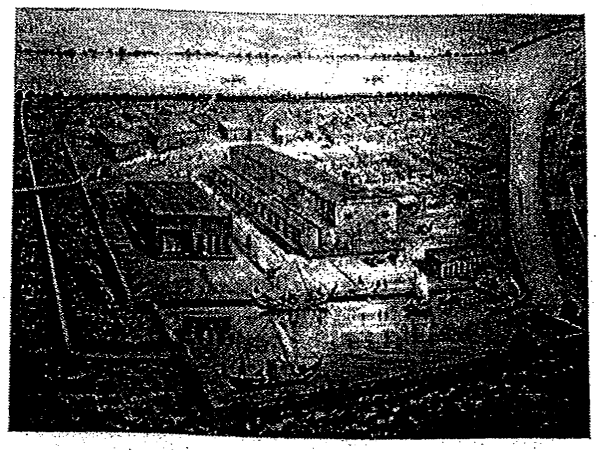
List found from curve = 3.7°

To find list by formula:

KM = 9.819. GM_{FL} = 1.371m. Reduction in GM = vertical rise = 0.008 m ∴ new GM = 1.363 m.

Tan θ = $\frac{GG_H}{GM} = \frac{0.122}{1.363}$, *gives* $\theta = 5.11°$

Earliest Dock: Lothal's dock—the world's earliest—connected the city to Sabarmati river on the trade route between Harappan cities in Sindh and the peninsula of Saurashtra. Lothal is situated in Ahmedabad district. In 1961, archaeologists unearthed channels connecting the dock with the river. The findings consist of a mound, a township, a marketplace and the dock. The meaning of Lothal (a combination of Loth and thal) in Gujarati being the "the mound of the dead"



Chapter 13 Grounding & Drydocking

Grounding indicates the status of a vessel and means that the ship hull touches the seabed. If the ship is not aground then she must be afloat. In Charter Party or the other legal documents the terms like always afloat, safely aground, made fast, anchored, underway are commonly used to indicate the status of a ship.

Beaching is causing of an intentional grounding for the purpose of carrying out some emergency repairs, inspection of hull of small vessels. Ships are also beached in an emergency for averting collision or sinking.

Stranded condition means a vessel subsequent to intentional or accidental grounding is unable to refloat herself out of own will / efforts & continues to remain aground.

Whenever a vessel is aground she is not floating free, which means her weight is not fully supported by buoyancy force. Because the buoyancy force is not adequate, part of the weight is supported by the upthrust at the contact point.

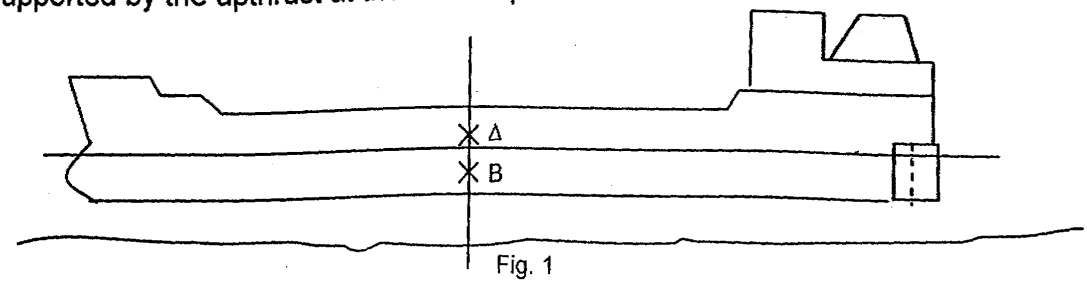


Fig. 1

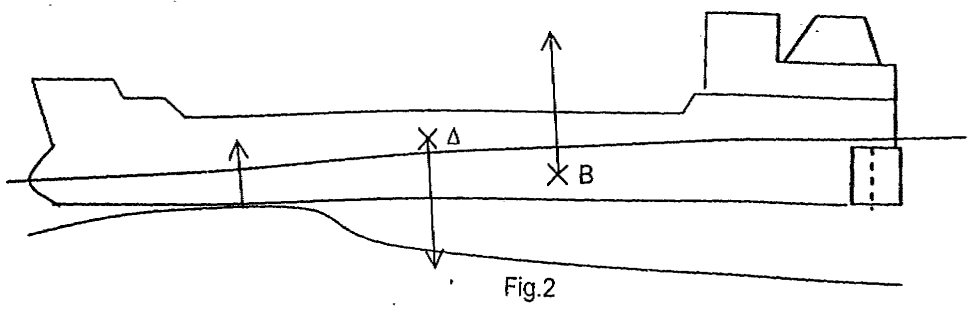


Fig.2

In fig 2 the upthrust created at point of contact can be assumed as a weight discharged at the point of contact or keel. A discharge of weight will cause the following:

1. Bodily rise,
2. Change of trim,
3. Rise of centre of gravity &
4. Reduction in displacement.

In case of grounding, the effects 1 and 2 viz. Bodily rise and Change of trim are apparent & actual but the effects 3 and 4 viz. Rise of centre of gravity & reduction in displacement are considered virtual. This is because actually the displacement & KG of ship is not changing.

To find virtual loss of GM assuming that the G remains in original position & Metacentric point shifts downwards:

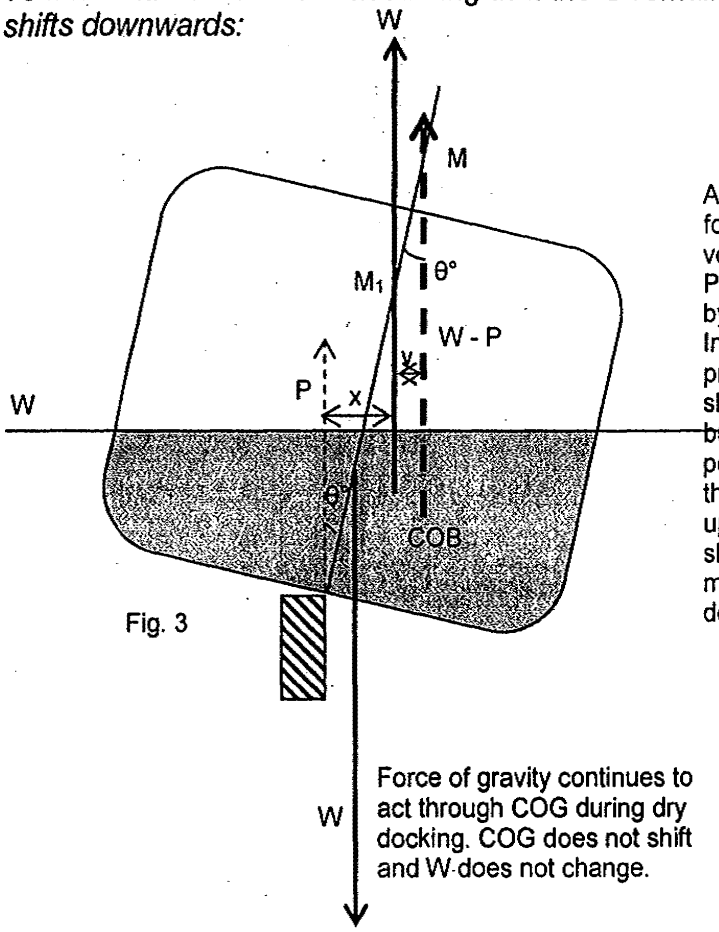


Fig. 3

As the water level is lowered the buoyancy force reduces due to reduction of under water volume. Let the reduction in buoyancy force be P tonnes. This is equal to the upthrust provided by the block.
In this fig COB and the water line is for the present draft and not the free floating draft. M shown is therefore for present draft. Upward buoyancy force through present COB (bold pecked line) meets CL at M. W, the resultant of the force (W-P) & upthrust at block (P) act upward through an intermediate point and is shown by bold arrow in upward direction meeting CL at M_1. MM_1 is virtual loss due dry docking.

Force of gravity continues to act through COG during dry docking. COG does not shift and W does not change.

Position of resultant of the two parallel forces P and (W-P) is found as follows:

Distance of resultant W from these forces is inversely proportional to their respective magnitudes.

$$\frac{x}{y} = \frac{W-P}{P}$$

$\therefore$ (W-P) x y = P x x
But $y = MM_1 \sin\theta$ & $x = KM_1 \sin\theta$. Substituting we get:

$(W-P) \times MM_1 \sin\theta = P \times KM_1 \sin\theta$
$(W-P) \times MM_1 = P \times KM_1$
$W\ MM_1 - P\ MM_1 = P \times KM_1$
$W \times MM_1 = P \times KM_1 + P \times MM_1$
$= P\ (KM_1 + MM_1)$
$= P \times KM$

$$MM_1 = \frac{P \times KM}{W}$$

To find virtual loss of GM assuming that the Metacentric point remains in original position & G shifts upwards:

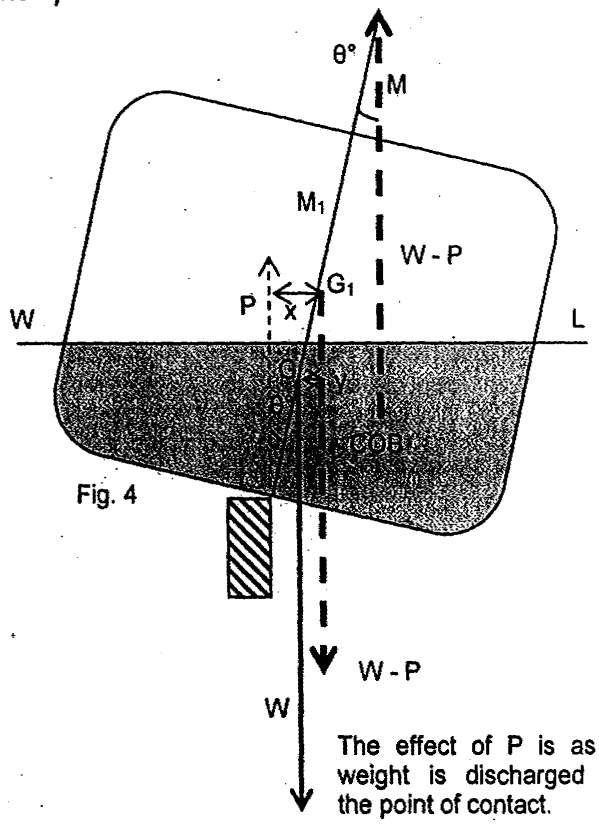


Fig. 4

As the water level is lowered the buoyancy force reduces due to reduction of under water volume. Let the reduction in buoyancy force be P tonnes. This is equal to the upthrust provided by the block.
In this fig COB and the water line is for the present draft and not the free floating draft. M shown is therefore for present draft. Upward buoyancy force through present COB (bold pecked line) meets CL at M. Downward force (W - P) which is the resultant of the gravity force W & upthrust at block (P) acts downwards through G_1. Higher the value of P, more the lateral shift of W-P from the line of W. GG_1 is virtual loss due dry docking.

The effect of P is as if a weight is discharged from the point of contact.

Position of resultant of the two parallel forces P and W is found as follows:
Resultant force (W-P) acts downwards through G_1 such that:

$W \times y = P \times x$

But $y = GG_1 \sin\theta$ and $x = KG_1 \sin\theta$

$W \times GG_1 \sin\theta = P \times KG_1 \sin\theta$

$W \times GG_1 = P \times KG_1$

$= P (KG + GG_1)$

$= P \times KG + P \times KG_1$

$W \times GG_1 - P \times GG_1 = P \times KG$

$GG_1 (W-P) = P \times KG$

$$GG_1 = \frac{P \times KG}{W - P}$$

Alternately:-
Upward force P may be considered as a weight discharge at contact point. In this particular case the contact point is at a distance of KG from the original COG of the vessel. The G will shift away from the contact point by an amount = $\frac{P \times KG}{W - P}$

The grounding calculations are very similar to the trim calculations.
Like in trim, even in grounding calculations the following principles are used:
Change of draft at any point is because of two causes viz. bodily rise or bodily sinkage.

The grounding situations can be of two types viz.

- *Flat bed grounding*
- *Grounding on pinnacle:*

Ex. 1 A ship of draft fwd of 8.00m and draft aft of 9.2m grounds lightly on a flat bed. The tide falls thereafter. Find the drafts forward and aft when tide falls by
a. 60cm
b. 2m
(Given: MCTC = 190, TPC = 24, LCF = 60m, LBP 125m).

In flat bed grounding the first thing that must be done is to find fall of tide required to make the vessel sit all over, so that for any given amount of tide fall, we know whether the vessel is sitting all over or pivoting.

$t_{rc} \times 100 \times MCTC = P \times LCF$

$$P = \frac{1.2 \times 100 \times 190}{60} = 380t$$

$$\text{Bodily Rise} = \frac{w}{100TPC} = \frac{380}{2400} = 0.158m$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{1.2 \times 60}{128} = 0.563m$$

$t_{rf} = 1.2 - 0.563 = 0.638m$

Initial	8.000	9.200
B/Rise	- 0.158	- 0.158
t_{rf}	+ 0.638 t_{ra}	- 0.562
final	8.480m	8.480m

An up thrust equal to 380t at aft point is necessary to make the vessel sit all over.

1) P can be considered as weight discharged at point of contact. This will change trim, cause bodily rise etc.
2) Draft at any point changes due to 2 reasons
   i. Bodily rise / sinkage,
   ii. Change of draft due changed trim.
3) change of draft at point contact is always equal to rise or fall of tide.

This means the fall of tide necessary to make the vessel even keel is equal to the change of draft aft i.e. 9.20-8.48 = 0.72m. This means that for fall of tide of 60cm vessel is still pivoting.

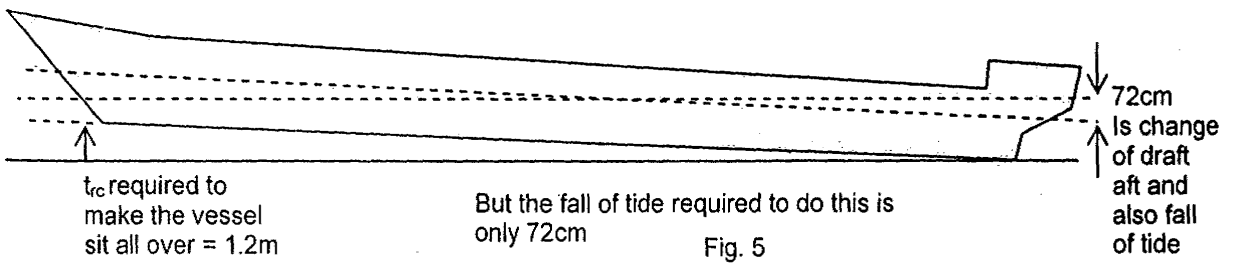


Fig. 5

a.
If the vessel is still pivoted after the fall of tide, the principle used is that the fall of tide which is equal to change of draft at point of contact is due to two separate reasons viz. bodily rise and change of trim, thus

$0.60 = \text{B/Rise} + t_{ra}$

$0.6 = \frac{P}{100\ TPC} + \frac{t_{rc} \times LCF}{LBP}$

But $t_{rc} = \frac{P \times LCF}{100\ MCTC}$ substituting t_{rc} in above equation.

$\therefore 0.60 = \frac{P}{100\ TPC} + \frac{P \times LCF^2}{100\ MCTC \times LBP} = \frac{P}{100 \times 24} + \frac{P \times 60^2}{100 \times 190 \times 125}$

$0.60 = 0.00042\ P + 0.00152\ P$

$0.60 = 0.00194P$ gives $P = 309.3t$.

$\text{B/Rise} = \frac{P}{100\ TPC} = \frac{3093}{2400} = 0.129m$

$t_{rc} = \frac{P \times LCF}{100 MCTC} = \frac{309.3 \times 60}{100 \times 190} = 0.977$

$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{0.977 \times 60}{125} = 0.469$

$t_{rf} = t_{rc} - t_{ra} = 0.977 - 0.469 = 0.508m$

Initial	8.000	9.200
B/Rise	- 0.129	- 0.129
	7.871	9.071
	t_{rf} + 0.508	t_{ra} - 0.469
Final	8.379m	8.602m

b. When the tide falls by 2m, the vessel positively must be sitting all over. This is because the ship is on even keel drafts at the fall of tide by 0.72m.
Aft draft at 2m fall of tide = 9.20 – 2.0 = 7.20m.
Since the vessel is on even keel, even the fwd draft will be 7.2m.

Ex. 2 In the last question what is the loss of GM_o when:

i. Tide falls by 0.60m,
ii. The vessel sits allover
iii. Tide falls by 2m

(Ship's KG = 7.5m, Δ =14000t)

Sol^n: -

Virtual loss of GM when the tide falls by 0.60m $\frac{309.3 \times 7.5}{14000 - 309.3} = 0.169m$

Virtual loss of GM when the vessel just sits all over = $\frac{380 \times 7.5}{14000 - 380} = 0.209m$

Further fall of tide after even keel condition = 2.00m – 0.72m = 1.28m.
The up thrust at the stage when vessel just sits all over = 380t
Increase of upthrust = (1.28 x 100 x TPC) = 3072 t.
Total P = 380 + 3072 = 3452 t.

Virtual loss of GM when the tide falls by 2.0m = $\frac{3452 \times 7.5}{14000 - 3452} = 2.454m$

Ans. a. 0.169m b. 0.209m c. 2.454m

Ex. 3 A vessel with drafts fwd 7.26m aft 9.14m grounds lightly on a flat seabed. Her LBP = 120m, LCF = 54m, TPC = 22m, MCTC = 180 t.m. Her Δ is 11000 t & KG is 7.8m. Find her drafts when tide falls by a. 0.40m b. 2.2m.

t_{rc} x 100 x MCTC = P x LCF

$$P = \frac{1.88 \times 100 \times 180}{54} = 626.66t$$

$$\text{B/Rise} = \frac{P}{100TPC} = 0.285m$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = 0.846$$

$t_{rf} = t_{rc} - t_{ra} = 1.034m$

Initial	7.260	9.140
B/Rise	0.285	0.285
	6.975	8.855
	t_{rf} + 1.034	t_{ra} - 0.846
Final	8.009m	8.009m

Fall of tide required = change of aft draft = 9.140 – 8.009 = 1.131m

a. This means that at 0.40 m fall the vessel is still pivoting.

$$0.40 = \frac{P}{100\,TPC} + \frac{P \times LCF^2}{100\,MCTC \times LBP}$$

0.40 = 0.00045P + 0.00135P

P = 222.2t, B/Rise = 0.101m, t_{rc} = 0.667m, t_{ra} = 0.300

Initial	7.260	9.140
B/Rise	0.101	0.101
	7.159	9.039
	t_{rf} + 0.367	t_{ra} - 0.300
Final	7.526m	8.739m

Final draft aft for 2.2m FOT = 8.009 – (2.2 – 1.131) = 6.94m or 9.14-2.2 = 6.94m.

Since the vessel is on even keel, even the draft forward is 6.94m.

P = (2.2 – 1.131) x 100 x 22 = 2351.8

Total P = 2351.8 +626.66 = 2978.5 t

Ex. 4 A vessel 130m long, LCF 61m, TPC 26, MCTC 212 has drafts Fwd: 8.40m and Aft: 9.16m while a float. She lightly grounds at a point 40m abaft stem on a pinnacle. Find drafts fwd and aft after the tide falls by 80cm.

Sol^n: - As it has been discussed in the last question, the vessel if pivoted after the fall of tide, the principle used is that the fall of tide, which is equal to change of draft at point of contact is due to two separate reasons viz. bodily rise and change of trim, thus

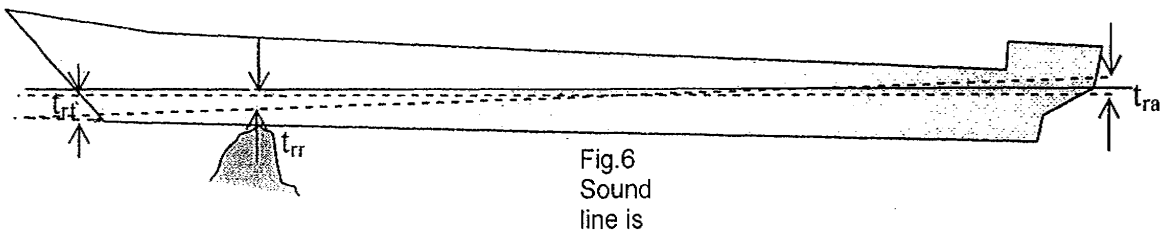


Fig.6
Sound line is initial WL

$$0.80 = \frac{P}{100TPC} + \frac{P \times RF^2}{100MCTC \times LBP}$$

$$0.80 = \frac{P}{100 \times 26} + \frac{P \times 29^2}{100 \times 212 \times 130}$$

$$= 0.000385P + 0.000305P = 0.00069P$$

$$\therefore P = 1159.4t$$

$$t_{rc} = \frac{P \times RF}{100MCTC} = \frac{1159.4 \times 29}{100 \times 212} = 1.586\ m$$

$$t_{ra} = \frac{1.585 \times 61}{130} = 0.744\ m$$

$$t_{rf} = t_{rc} - t_{ra} = 0.842m$$

$$\text{Bodily rise} = \frac{P}{100TPC} = \frac{1159.4}{100 \times 26} = 0.446m$$

Initial		8.400		9.160
B/Rise,	-	0.446	-	0.446
		7.954		8.714
	t_{rf} -	0.842	t_{ra} +	0.744
Final		7.112m		9.458m

Final drafts fwd = 7.112m aft 9.458m.

Ex. 5 A vessel 130m long, LCF 61m, TPC 26, MCTC 212 has drafts Fwd: 8.40m and Aft: 9.16m while afloat. She lightly grounds on a pinnacle. Final drafts fwd and aft were 7.11m, 9.46m after the tide had fallen by 80cm. Find the position wrt stem where the ship is aground.

Initial hydrostatic draft = $9.16 - \left(0.76 \times \frac{61}{130}\right) = 8.803$. Initial trim = 0.7m (aft)

Initial hydrostatic draft = $9.46 - \left(2.35 \times \frac{61}{130}\right) = 8.357$. Final trim = 2.35m aft

Change of hydrostatic draft = 0.446m (reduction)

The upthrust is equivalent to the amount of cargo discharged. Since the trim is changing aft wards the point of contact is forward of COF.

P = 0.446 x 100 x 26 = 1159.6t

$\therefore$ Change of draft at point of contact = fall of tide = $0.80 = \frac{P}{100\,TPC} + \frac{P \times RF^2}{100\,MCTC \times LBP}$

$$0.80 = \frac{1159.6}{100 \times 26} + \frac{1159.6 \times RF^2}{100 \times 212 \times 130} = 0.446 + 0.000421 \times RF^2$$

$\therefore RF^2 = 840.8$

RF = 29.0m fwd of COF.

Ex. 6 A vessel 130m long, LCF 61m, TPC 26, MCTC 212 has drafts Fwd: 8.40m and Aft: 9.16m while afloat. She lightly grounds on a pinnacle at a point 29m abaft the steam. Final drafts fwd and aft were 7.11m, 9.46m after the tide had fallen by 80cm. Find the rise of tide required to float free the vessel.

Sol^n: - Rise or fall of tide is change of draft at the point of contact. The change of draft at contact point will therefore also be the rise of tide required.
From the last question we know that upthrust P at the low water is 1159.6t

$$\text{Rise of tide reqd} = \frac{P}{100TPC} + \frac{P \times RF^2}{100MCTC \times LBP}$$

$$= \frac{1159.6}{100 \times 26} + \frac{1159.6 \times 29^2}{100 \times 212 \times 130}$$

$$= 0.446 + 0.354$$

Ans. Rise of tide reqd = 0.80cm

Ex. 7 A ships whose displacement 7200t, drafts fwd 4.20m, aft 5.10m, grounds lightly on a pinnacle 10m abaft the stem. Find the drafts for'd and aft and the fall of tide when the virtual GM becomes 0. Given: LBP is 120m, LCF 62m, MCTC 110, TPC 16, KG 6m & KM 6.4m.

Sol^n: - Free float GM = KM – KG = 0.4m. For GM to become 0 virtual loss of GM must be 0.4m.

$$0.4 = \frac{PKG}{W-P} \text{ or } \frac{PKM}{W}$$

$$0.4 = \frac{P \times 6}{(7200-P)} \text{or} \frac{P \times 6.4}{7200}$$

Both the formulae give P = 450t.

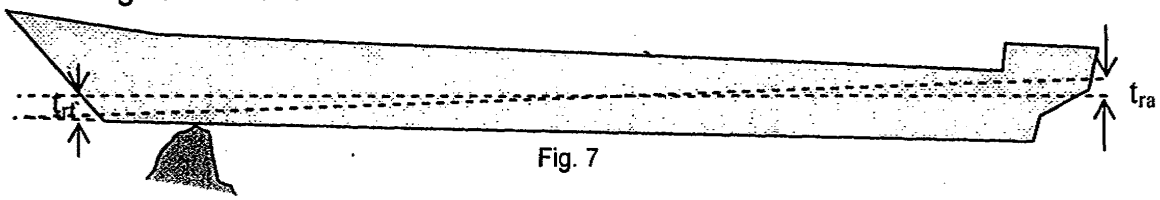


Fig. 7

$$\text{F.O.T} = \frac{P}{100 \times TPC} + \frac{P \times RF^2}{100 \times MCTC \times LBP}$$

$$\therefore \text{F.O.T} = \frac{450}{100 \times 16} + \frac{450 \times (48)^2}{100 \times 110 \times 120} = 0.281 + 0.785 = 1.066m$$

$$\therefore t_{rc} = \frac{P \times RF}{100 \times MCTC} = \frac{450 \times 48}{100 \times 110} = 1.964m$$

$$\therefore t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{1.964 \times 62}{120} = 1.015m$$

$$\therefore t_{rf} = t_{rc} - t_{ra}$$
$$= 1.964 - 1.015$$
$$= 0.949m$$

Initial	4.200	5.100
B/Rise	- 0.281	- 0.281
	3.919	4.819
t_{rf}	- 0.949 t_{ra}	+ 1.015
Final	2.970m	5.834m

Ex. 8 A vessel whose length is 150m, drafts fwd is 7.00m, aft 9.00m & LCF 70m. The vessel lightly grounds aft on a pinnacle and there after the tide fell by 70cms. Find the drafts fwd & aft and virtual GM there after. Initial KG 5m, KM 7.6m, TPC 24, MCTC 200tm & Δ = 12,000t.

Sol^{n}: -

Fall of tide = change of draft at contact point.

$$\frac{P}{100\times24}+\frac{P\times70}{100\times200}\times\frac{70}{150}=0.70$$

$\therefore$ 0.000 4167P + 0.001633P = 0.70
$\therefore$ 0.002049 P = 0.70
$\therefore$ P = 341.6t

$$\therefore \text{Bodily rise} = \frac{341.6}{100\times24}=0.142m.$$

$$t_{rc} = \frac{341.6\times70}{100\times MCTC}=1.196\,m.$$

$$t_{ra} = \frac{t_{rc}\times LCF}{LBP} = \frac{1.196\times70}{150}=0.558m.$$

$t_{rf} - t_{rc} - t_{ra}$
= 1.196 – 0.558
= 0.638m

Initial		7.000		9.000
B/Rise		- 0.142		- 0.142
		6.858		8.858
	t_{rf} +	0.638	t_{ra} -	0.558
Final		7.496m		8.300m

Virtual loss of GM due to grounding

$$\frac{PKG}{W-P} \text{ or } \frac{PKM}{W}$$

$$\frac{341.6\times5}{12000-341.6} \text{ or } \frac{341.6\times7.6}{12000}$$

= 0.147m ~~or~~ 0.216m
$\therefore$ Virtual GM = ~~2.183~~m or = ~~2.383m~~

Ans. Drafts F = 7.496m A = 8.300m. Virtual GM = ~~2.163m~~ or = 2.~~383~~m.

Ex. 9 a. A vessel of LBP 116m, LCF 52m, TPC 20, MCTC 146, drafts fwd 5.00m, aft 7.00m lightly grounds aft on a pinnacle. There after the tide falls by 80cm.
b. What will be the drafts if the position of grounding is 20m abaft the stem?
Hint: -
0.0005 P + 0.001596 P = 0.80m
$\therefore$ 0.002096 P = 0.8
$\therefore$ P = 381.68T

$$\therefore t_{rc} = \frac{381.68\times52}{100\times146}=1.359m \quad \text{Bodily rise} = \frac{381.68}{100\times20}=0.191m$$

$t_{rf} = t_{rc} - t_{ra}$ = 1.359 – 0.609 = 0.75m (+)
Ans. Drafts F = 5.559m A = 6.200m

b. $0.8 = \frac{P}{100\,TPC} + \frac{P \times RF^2}{100\,MCTC \times LBP} = s \quad \frac{P}{100 \times 20} + \frac{p \times 44}{100 \times 146} \times \frac{44}{116}$

$\therefore P$ = 487.805t & bodily rise = .244m

T_{rc} = 1.470m, t_{ra} = 0.659m & t_{rf}= 0.811m

Ans. Drafts F = 3.945 A = 7.415m

Ex. 10 a. In question above find the draft fwd and aft if the vessel grounded on a flat bed and the fall of water was 1.4m.

b. Find the virtual GM at the time when the ship sits all over and at the time when water has fallen by 1.4m. Given: KM = 8m, KG = 7m, Δ = 12000t.

Hint: - The upthrust P required to trim the vessel to even keel is given by

$P = \frac{2 \times 100 \times 146}{52}$ = 561.54t.

This will give the final drafts fwd and aft as 5.822m.

Since change of HD x 100TPC = P, we can say that the change of HD = $\frac{P}{100\,TPC}$ = *bodily rise.* Also the vessel when on even keel shows hydrostatic drafts all over.

The final even keel draft = initial hydrostatic draft – bodily rise.

Thus $6.103 - \frac{561.54}{100 \times 20}$ = 6.103 – 0.281 = 5.822m

Change of draft aft.= 7.000 - 5.822, = 1.178m is the fall of tide required to trim the vessel even keel. Since the fall of tide is 1.4m, further fall of water after the vessel is even keel = 1.4 – 1.178 = 0.222m.

Final drafts all over will reduce to 5.822m – 0.222m = 5.600m

b. When the vessels comes to even keel, P = 561.5.

$\therefore$ Virtual GM = 1- 0.344 = 0.656m, or 1- 0.374 = 0.626m

For a fall of tide of 1.40m additional up thrust = 0.222 x 20 x 100 = 444t

$\therefore$ Total thrust = 561.5 + 444 = 1005.5 t

Virtual GM = 1- 0.640 = 0.36m or 1- 0670 = 0.33m.

Ans. a. even keel draft = 5.822m. Virtual GM when water falls by 1.4m. = 0.36m or 0.33m.

Drydocking:

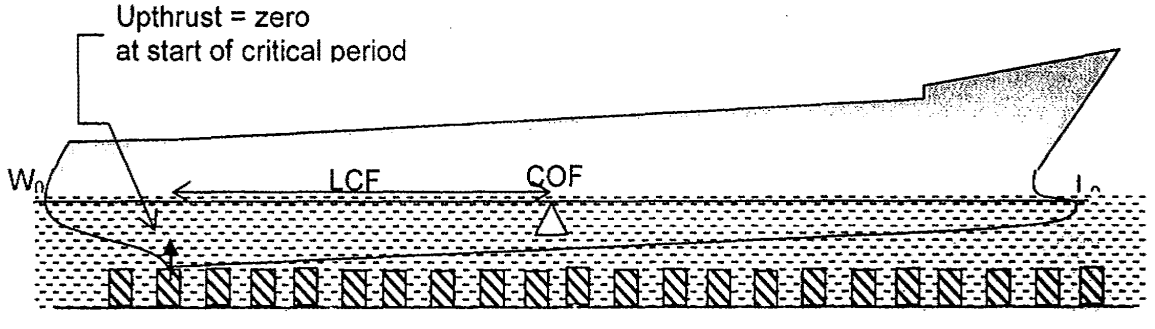


Fig. 8

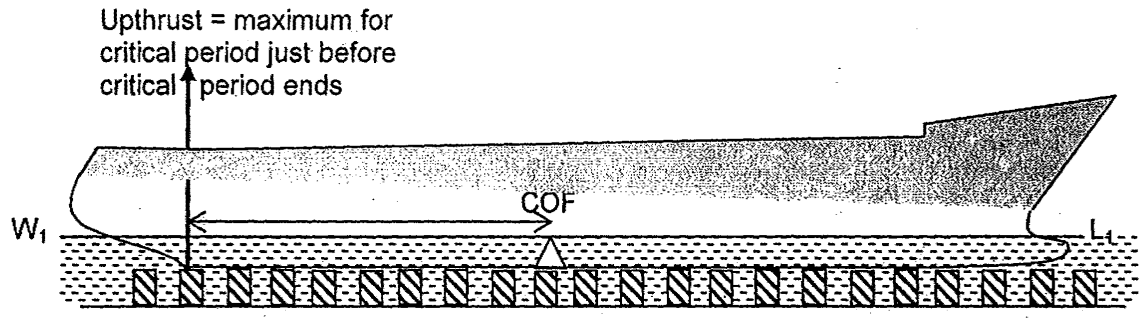


Fig. 9

Ex. 11 A vessel of displacement 5440t, draft. for'd 4.52 m, aft 6.02 m, length 124 m, KM 7.00m, KG 5.96 m, COF 3m abaft midships, TPC 18, MCTC 128 tm is dry docked. Find the GM and drafts at critical instant. At what drafts F and A would she become unstable?

Sol^{n}: -

Trim = 1.5m

∴Trim change required (t_{rc}) to make the vessel sit all over 1.5m.

Upthrust P at aft increases with the fall of water level. Let P be the upthrust at critical instant.

LCF = ½ x 124 – 3 = 59m

P x LCF = t_{rc} x 100 x MCTC

$$P = \frac{t_{rc} \times 100 \times MCTC}{LCF} = \frac{1.5 \times 100 \times 128}{59} = 325.4\ t$$

$$\text{Bodily Rise} = \frac{325.4}{100TPC} = \frac{325.4}{1800} = 0.181m$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{1.5 \times 59}{124} = 0.714\ m$$

$$t_{rf} = 1.5 - 0.714 = 0.786\ m$$

Initial		4.520		6.020
B/Rise	(-)	0.181	(-)	0.181
		4.339		5.839
	t_{rf}	0.786	t_{ra}	0.714
Final		5.125m		5.125m

The vessel will take the blocks all over at draft 5.125m. This is also thus the drafts forward and aft at that instant.

Virtual loss of GM due to drydocking

$$= \frac{PKG}{W-P} \text{ or } \frac{PKM}{W}$$

$$= \frac{325.4 \times 5.96}{5440 - 325.4} \text{ or } \frac{325.4 \times 7.0}{5440}$$

= 0.379m 0.419m

Free floating GM = 1.04 m

∴Virtual GM = 0.661m or 0.621 m.

Ex. 12. A vessel of length 126 m, displacement 5800 t, LCF 59, TPC 22, KM 8.6m, KG 7.5 m, at a hydrostatic draft of 6.2 m. Her MCTC is 162 tm. Calculate the drafts if she is to have a minimum GM of 30cm on taking blocks overall.

Sol^{n}: -

Free floating GM = 1.1m

GM required at critical instant = 0.3m

Virtual loss of GM = 1.1 – 0.3 = 0.8m

Virtual loss of GM due to drydocking = $\frac{PKG}{W-P}$ or $\frac{PKM}{W}$

$\frac{PKG}{W-P} = \frac{7.5P}{5800-P} = 0.8$, gives P = 559.0 t

P x LCF = t_{rc} x 100 x MCTC

$t_{rc} = \frac{P \times LCF}{100MCTC} = \frac{559 \times 59}{100 \times 162} = 2.036m$

$\frac{PKM}{W} = \frac{8.6P}{5800} = 0.8$ Gives P = 539.5t

$t_{rc} = \frac{P \times LCF}{100MCTC} = \frac{539.5 \times 59}{100 \times 162} = 1.965m$

Ans. the maximum trim permitted = 2.036 m or 1.965 m

Ex. 13 A vessel of length 154 m, displacement 8,200 t, KM 10.4 m, KG 8.90 m, MCTC 205 tm, TPC 26, LCF 74.5 m, is afloat in a dry dock at a draft of F: 5.02 m, A: 6.50 m. The water level is 7 m above the top of the blocks. Calculate her effective GM and drafts F & A when the water level is lowered by 1.2m. Also calculate draft at which the vessel will take the blocks all over.

Sol^{n}: -

When the water is pumped out, for the first 50 cm of pumping out the vessel will be still free floating (7- 6.5 = 0.5 m). After the stern touches the block a further fall of water level by 70 cm is caused. (1.2 – 0.5 = 0.7).

It must be first found, whether the vessel after a fall of water level by 70 cm is still pivoting or is sitting all over. For this we must find the fall of water level required to make the vessel sit all over.

P x LCF = t_{rc} x 100 x MCTC

$P = \frac{t_{rc} \times 100 \times MCTC}{LCF} = \frac{1.48 \times 100 \times 205}{74.5} = 407.2t.$

Bodily Rise = $\frac{P}{100TPC} = \frac{407.2}{2600} = 0.157m$ m

$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{1.48 \times 74.5}{154} = 0.716m$

t_{rf} = 1.48 – 0.716 = 0.764m

Initial	5.020		6.500
B/Rise (-)	0.157	(-)	0.157
	4.863		6.343
	t_{rf}(+)0.764	t_{ra}(-)	0.716
Final	5.627m		5.627m

An up thrust equal to 407.2t is necessary to make the vessel sit all over. The vessel will take the blocks all over at draft of 5.627m. The fall of water after stern has taken the block = 6.5 - 5.627 = 0.873m. This means that when waterfalls by 70cm after the stern has touched, the vessel is still pivoting.

For the pivoted condition, change of draft aft = 0.70 = B/Rise + t_{ra}

$$\therefore 0.70 = \frac{P}{100\ TPC} + \frac{P \times LCF^2}{100\ MCTC \times LBP} = \frac{P}{100 \times 26} + \frac{P \times 74.5^2}{100 \times 205 \times 154}$$

$$0.60 = 0.00038\ P + 0.00175\ P$$

$$0.60 = 0.00213P \text{ gives } P = 281.69t.$$

$$\text{B/Rise} = \frac{P}{100\ TPC} = \frac{281.69}{2600} = 0.108m$$

$$t_{rc} = \frac{P \times LCF}{100 MCTC} = \frac{281.69 \times 74.5}{100 \times 205} = 1.024$$

$$t_{ra} = \frac{t_{rc} \times LCF}{LBP} = \frac{1.024 \times 74.5}{154} = 0.495m$$

$$t_{rf} = t_{rc} - t_{ra} = 1.024 - 0.495 = 0.529m$$

Initial		5.020		6.500
B/Rise	(-)	0.108	(-)	0.108
		4.912		6.392
	t_{rf} (+)	0.529	t_{ra} (-)	0.495
Final		5.441m		5.897m

Ans. vessel will sit all over at 5.627m draft. With fall of level of 1.2m her drafts will be forward 5.441m, aft 5.897m.

Exercise 13

Q. 1 A vessel with draft forward 8m and aft 10m, LCF 76m, LBP 160 TPC 22 and MCTC 200t.m. find the fall of tide required subsequent to her grounding on even keel seabed to make the drafts even fore and aft. Find the even keel draft. Also find the upthrust when;
a. vessel just sits all over, b. the tide falls by 2m.
Ans. Fwd draft = 8.00 – 0.239 +1.05 = 8.811m. Aft draft 10.00 – 0.239 – 0.95 = 8.811m. Fall of tide required = 10.00 - 8.811m = 1.189m. P at even keel = 526.3t. P when tide falls by 2m = 2310.5t.

Q. 2 A vessel with draft forward 8m and aft 10m, LCF 76m, LBP 160, TPC 22 and MCTC 200t.m lightly grounds on a pinnacle 30 abaft the stem. Thereafter the fall of tide is 90cm. find the drafts fwd and aft.
Ans.Upthrust = 658.96t. Draft fwd = 8.00 – 0.299 – 0.934 = 6.767m. aft = 10.00 – 0.299 + 0.845 = 10.546m

Q. 3 A vessel of length 130m, displacing 12420t, CF: 3m abaft mid length, KG: 5.25m, KM: 5.90m, TPC: 18t, MCTC 140 tm, at a draft of 5 4m for'd and 6.62m aft, grounds on a rock 8m abaft her stem. Calculate her residual GM and drafts F & A if the tide fell 80cm after grounding.
Ans. 0.513m or 0.50 F = 4.514 m A = 7.090m.

vessel of length 170 m, displacement 27,000t, LCB 90m, LCF 82, TPC 29.8, KG 9.82m, draft of for'd 8.72 m, aft 10.0m, in salt water proceeds to a dry-dock where the water is of 1.0004. Her MCTC and KM in water of R.D. 1.004 are 162 tm and 10.2 m respectively. by calculation whether she can be dry-docked in her present condition if she is to have a um GM of 30 cm on taking blocks overall.
Yes. F: 9.05 A: 10.06 GM(v) At Crit instant = 0.305m

A vessel of length, 120m, Displacement 6400 tonnes, TPC 15 tonnes, MCTC 110tm, KM m, KG 5.1 m, CF 2 m for'd of the mid-length grounds on a rock 4.5 m for'd of mid-length. tide then falls by 80 Cm. Calculate the residual GM then.
Ans. 0.133m or 0.108m

A vessel of length 174m, displacement 28,200 t, KM 11.43m, KG 10.90m, MCTC 400.5 TPC 28.1 t, LCF 88.5m, is afloat in a dry dock at a draft of F: 7.92 m, A: 9.30 m. The water level is 10 m above the top of the blocks. Calculate her effective GM and drafts F & A when the water level is lowered by 1.2m. Also calculate her for'd draft at which the head will take the blocks.
Ans. 0.3978 or 0.393 F= 8.166 A=8.00, Draft = 8.376 EK

A vessel of length 120m, Displacement 6400 tonnes, TPC 15 tonnes, MCTC 110 KM 4m, KG 5.1m, CF 2 m for 'd of the midlength, grounds on a rock 45 m for'd of midlength. The tide then falls by 80 cm. Calculate the residual GM then.
Ans. 0.972 or 0.913m

Q. 8 A vessel of length 120m, displacement 12320 t, TPC 15 t, MCTC 110 mt, CF 2 m abaft amidships at a draft of F 5.22 m A 5.37 m, KG 7.3m, KM 7.6 m, grounds lightly on a pinnacle rock 12m abaft her stem, on the centre line. The tide is expected to fall 80cm. Ascertain whether the ship would remain upright and her drafts F and A, at low water.
Ans. F = 4.278m A: 5.848m

Q. 9 A vessel of length 140m, displacement 7200 t, C of F 3m abaft midlength, MCTC 120 mt, TPC 22 t, KM 7.2m KG 6.6m, floats in a dry-dock at a draft of 3.82m for'd, 5.60m at. The water level in the dry dock is 6 m above the top of the blocks. Calculate her residual GM when the water level is lowered by 1.2 m.
Ans. 0.357 or 0.344m

Q. 10 A vessel drawing 10.20 m for'd 9.00 m aft has sustained damage at the fore end and is to be dry-docked to effect repairs. Her hydrostatic data in the damaged condition are as follows: KM 11.25 m, KG 10.60 m, MCTC 440 mt TPC 39.5 LCF 84 m Length 176m Displacement 35,500t. The vessel touches the blocks 10 m abaft the for'd perpendicular. Calculate the effective GM and the drafts forward and aft on taking blocks all over.
Ans. 0.4542 or 0.446 Draft E K = 9.409m

Q. 11 A vessel of length 160m, Displacement 8240 t, LCF 83 m, KM 6.42m, KG 5.65m, MCTC 130 tm, TPC 22 t is floating in a dry dock at a draft of F:4.32 m, A:5.40m. The water level in the dock is 6.5 m above the top of the blocks. Calculate the vessel's residual GM when the water level is lowered by 2m. What would be her drafts for'd and aft then?
Ans. 0.205m Q0.187m 4.5m EK (Horizontal)

Q. 12 A vessel of displacement 7200 t, length 156 m, CF 3 m for'd of midlength, MCTC 122 tm, TPC 18 t, KM 7.2 m, KG 6.5 m, at a draft of 4,72 m for'd and 6.94 m aft is afloat in a dry dock

where the water level is 7.3 m above the top of the blocks calculate her residual GM and drafts F & A when the water level is lowered by 1.5 m.
Ans. 0.4152 or 0.4323 F: 5.471m A: 5.801m

Q. 13 A vessel of length 120m, displacement 8,200 tonnes, LCB 55m, LCF 59m, FWA 16 cm, drafts F: 4.35m, A : 4.80m in salt water is to be dry-docked where the R.D. of water is 1.000. Given the following hydrostatic data in fresh water, MCTC 80tm, KM 7.55, KG 7.30m, calculate her residual GM on taking blocks all over.
Ans. Initial LCG = LCB = 55m, Assume LCF nearly constant,
Residual GM = 0.183m or 0.181m.

Q. 14 A vessel has the following particulars: LBP: 140 m; MCTC: 130 M/T; COF 3 m. forward of centre; TPC: 18; Displacement 6240 M/T; KM: 6.4 m; KG: 5.8 m; drafts fwd: 5.23 m, aft: 5.74 m. She grounds lightly on a rock 12 m. abaft the stem. The tide then falls by 80 cms. Calculate the virtual GM and her drafts fwd and aft.
Ans. Virtual GM = 0.244m or 0.230m Drafts F 4.30m A 6.336m

Q. 15 A vessel of length 120 m, displacement 6500 t, CF 2m forward of mid-length, MCTC 110 tm, TPC 15, KM 6.9m, KG: 6.0m, at a draft of F: 4.00m, A: 6.20m, is floating in a dry-dock where the water level is 6.5m above the top of the blocks. Calculate the residual GM of the vessel when: (a) the water level is lowered by 1m. (b) the water level is lowered a further 1m.
Ans. (a) 0.714 or 0.693 (b) 0.003 or 0.002m

Q. 16 A vessel of displacement 4740 t, mean draft.4.22 m, length 120 m, KM 6m, KG 5.5 m, CF amidships, TPC 10 t, MCTC 79 tm, is to be dry docked. If the GM on taking the blocks F and A is to be not less than 0.3 m, what is the maximum permissible trim by the stern? At what drafts F and A would she become unstable?
Ans. Max permissible trim = 1.263m or 1.2m. Unstable at 3.825m draft

Q. 17 A vessel is to be dry docked in a damaged condition. She is floating at drafts F 12.60 m and A 9.00 m. It is estimated that she will take the blocks 15 m aft of the forward perpendicular.
Estimated data:
KG 8.9 m, KM 9.4m, TPC 21.3 t/cm, MCTC 290 tm/cm, AF 76m, LBP 165m, displacement 19500 tonnes.
a) Is it safe to dry dock the vessel in this condition? Support your answer with calculations.
b) Estimate the drafts at the perpendiculars on taking to the block fore and aft.
Ans. 9.996 m the virtual loss at taking blocks 0.648m or 0.680m which is more that initial GM. Also up thrust at the point of 1st contact is 1410:8 tonnes at Critical instant. Due Strengthening would be required.

Q. 18 A vessel of displacement 7200 tonnes, length 120 m, MCTC 110 t-m, KG 6.0 m TPC 16 tonnes, center of floatation 2 mts. Forward of midship, grounds on a rock 10 mts. Abaft her forward perpendicular. Given initial draft F: 4.2m, A:5.1 m.
Find the fall in tide in cm, that will make the vessel unstable, given KM at that moment equal to 6.4 mts. What will be the drafts forward and aft at that moment ?
Ans. a) 1.0668m b) F 2.970m 5.834m

Examples on M V ALPHASHIP:-

1 M V ALPHASHIP displacing 13540 tonnes and trimmed 1.04m by the stern is to be dry-docked for some urgent attendance. KG 9.72 m FSC 0.124 m. calculate:-

1. The fore and aft drafts of vessel and GM before entering dry dock.
2. The virtual GM of the vessel when her keel takes the blocks all over.
3. The for'd and aft draft at which the virtual GM of the vessel becomes zero.
4. The fall in water level during critical period.
5. The fall in water level, between the vessel taking blocks all over and her virtual GM becoming zero.
6. GM_T at a fall of water level by 40cm in critical period.

Hint :-

1. For Δ 13540 t

Displacement	Draught	M.C.T.C.	L.C.F.	K.M.(T)
13087.2	4.80	231.56	87.568	11.614
13703.2	5.00	233.52	87.500	11.372
13540	4.95	233.008	87.518	11.436

$t_a = \frac{t \times LCF}{LBP} = \frac{1.04 \times 87.518}{171.792} = 0.530$ ∴draft aft = 4.95 + 0.53 = 5.480m

Forward draft = 5.480 -1.04 = 4.440m.

GM_{FL} = 11.436 – (9.72 + 0.124) = 1.592m

2. The upthrust increases in amount as the water level is lowered and trim decreases. Since it is acting at AP, it causes a trimming moment = P x LCF at the end of critical period and is responsible for the change of trim that is equal to original trim.

We may say that $P = \frac{t \times 100 \times MCTC}{LCF} = \frac{1.04 \times 100 \times 233.008}{87.518} = 276.9t$

MCTC & LCF could be again seen for (W-P) and the calculation redone, but this with not change P appreciably, hence not required.

Calculations can be done by two different methods involving different formulae about virtual loss of GM. In exam any one method may be used by a student.

Virtual displacement on taking blocks all over = W – P = 13540 – 276.9 = 13263.1t

KM and FSC must be seen for the present water level or the present virtual displacement.

$\therefore FSC = \frac{FSC \times \Delta}{\Delta - P} = \frac{FSM_{initial}}{\Delta - P} = \frac{1678.96}{13263.1} = 0.127m$

Displacement	Draft	K.M.(T)
13087.2	4.80	11.614
13703.2	5.00	11.372
13263.1	4.857	11.545

KM for Δ - P = 11.545 m

Draft for Δ - P = 4.857 m (the vessel will be on even keel at this draft)

KG = 9.720 m

GM = 1.825 m

FSC = -0.127 m

GM (fluid) = 1.698 m

Virtual loss of GM $= \frac{P \times KG}{\Delta - P} = \frac{276.9 \times 9.720}{13263.1} = 0.203m$ by method 1

Residual GM = 1.698 – 0.203 = 1.495m

Virtual loss of GM $= \frac{P \times KM}{\Delta} = \frac{276.9 \times 11.545}{13540} = 0.236m$ by method 2

Residual GM = 1.698 – 0.236 = 1.495m

3. For the virtual GM (during dry docking) to become zero the virtual loss of GM should be equal to her GM_{FL}, at that instant of dry docking without considering the virtual loss due to dry docking. To find her GM_{FL} we use the upthrust P which is calculated using the stability parameters at the free floating draft when P was zero. The virtual loss of GM due to dry docking is a function of P. We may say that the virtual loss is directly proportional to P. Or P is directly dependent on the virtual loss of GM. It is important that KM and FSC is used for the present water level otherwise a wrong value of GM to be lost will give a wrong value of P and hence (Δ - P). For this purpose P must be calculated in two stages first being to get displacement = (Δ - P) which then in 2nd stage would give more accurate P.

KM for Δ, 13540 is 11.436 m. KG = 9.72 m and FSC = 0.124 m.
Approximate calculation of upthrust P (first stage)
Free floating GM_{FL} = 1.592

$1.592 = \frac{P \times KG}{W - P} = \frac{P \times 9.72}{13540 - P}$ by method 1, gives P = 1905.56t

$1.592 = \frac{P \times KM}{W} = \frac{P \times 11.436}{13540}$ by method 2, gives P = 1884.90t

Accurate calculation of force P and virtual displacement: (second stage)
Method 1
Virtual displ. = 13540 – 1905.56 = 11634.44 t
KM for this displ = 12.327m.

$GM_{FL} = 12.327 - 9.72 - \frac{FSC \times \Delta}{\Delta - P} = 2.463m$

$\frac{P \times KG}{\Delta - P} = \frac{P \times 9.72}{13540 - P} = 2.463$ Gives P = 2737.34 t

V displ. Then =13540 – 2737.34 = 10802.66 t. Hydrostatic draft for this displ. = 4.051 m. Since the vessel is already on even keel at draft 4.857 m, she will be at even keel subsequently on all drafts.

Accurate calculation of force P and virtual displacement: (second stage)
Method 2
Virtual displ. = 13540 – 1884.90t = 11655.1t
KM for this displ = 12.537m.

$GM_{FL} = 12.537 - 9.72 - \frac{FSC \times \Delta}{\Delta - P} = 2.673m$

$\frac{P \times KM}{\Delta} = \frac{P \times 12.537}{13540} = 2.463$ gives P = 2660.05 t

V displ. Then =13540 – 2660.05 = 10879.95 t Hydrostatic draft for this displ. = 4.077 m.
She will be at even keel at this draft.

4. Since the fall of water level = change of draft at point of contact, the fall during critical period = 5.480 – 4.857 = 0.623 m
5. The fall of water level till the GM becoming zero = 5.480 – 4.051 = 1.429 m or 5.480 – 4.077 = 1.403 m
6. Two part formula for pivoted condition may be used. Thus 40 cm = t_{ra} + bodily rise. Once P is found KM_T for (W-P) is found,

Q. 2 M V ALPHASHIP floating at a displacement of 21600 tonnes KG 9.000m, FSC 0.108m, is to be drydocked.
Calculate the maximum trim by the stern and her drafts F & A allowable to ensure a virtual GM of at least 0.4 m on taking the blocks fore and aft. At the maximum permissible trim thus calculated, find the draft forward at which the head would take the blocks and the fall in water level between taking blocks aft and taking blocks for'd

Displacement	Draught	M.C.T.C.	L.C.F.	K.M.(T)
21316.4	7.40	264.6	85.431	9.959
21970.2	7.60	268.52	85.174	9.917
21600	7.486	266.30	85.319	9.941

GM_{FL} = 9.941- 9.000 – 0.108 = 0.833 m
Residual GM required. = 0.400 m
Loss of GM permissible = 0.433 m
As has been discussed in the last question, the virtual loss of GM is directly dependent on relevant P, whenever P has to be calculated for a relevant loss of GM, the P must be found in 2 stages. This is because GM that will be lost is not known accurately initially & a small difference in GM to be lost will have a large difference in the values of P.

Approximate calculation of upthrust P (first stage)

Virtual loss of GM = $\frac{P \times KG}{\Delta - P}$ by method 1.

$0.433 = \frac{P \times 9.00}{21600 - P}$ gives P = 991.5 t.

Virtual loss of GM = $\frac{P \times KM}{W}$, by method 2

$0.433 = \frac{P \times 9.941}{21600}$, gives P = 840.8 t

Accurate calculation of force P and virtual displacement: (second stage)
Virtual displ. On taking blocks all over = 21600 – 991.5 = 20608.5 t (method 1)

Virt loss allowed = $(GM_{FL} - 0.40) = 10.015 - 9.0 - \frac{0.108 \times 21600}{20608.5} - 0.40 = 0.502$ m.

$0.502 = \frac{P \times 9}{21600 - P}$, gives P = 1141.15 t.

P x LCF = t x 100 xMCTC

$t = \frac{P \times LCF}{MCTC \times 100} = \frac{1141.15 \times 85.693}{260.64 \times 100} = 3.752$m

To find the free floating drafts:

$t_a = \frac{t \times LCF}{LBP} = \frac{3.752 \times 85.319}{171.792} = 1.863$m

Draft aft = 7.486+1.863 = 9.349 m
Draft f'd = 9.349 – 3.752 = 5.597 m
At the instant of taking blocks for'd (end of critical period) drafts all over will be hydrostatic drafts i.e. 7.182 m. & fall of water level in critical period = 9.349 – 7.182 = 2.167 m.

Displacement	Draught	M.C.T.C.	L.C.F.	K.M.(T)
20018.6	7.00	257.32	85.927	10.071
20665.4	7.20	260.96	85.671	10.010
21316.4	7.40	264.6	85.431	9.959
20608.5	7.182	260.64	85.693	10.015
20759.2	7.228	261.48	85.637	10.003

Virtual displ. on taking blocks all over 21600 – 840.8 = 20759.2 t (method 2)

Virt loss allowed = $(GM_{FL} - 0.40) = 10.003 - 9.0 - \frac{0.108 \times 21600}{20759.2} - 0.40 = 0.491$ m.

$0.491 = \frac{P \times 9}{21600 - P}$, gives P = 1116.59 t.

P x LCF = t x 100 x MCTC

$t = \frac{P \times LCF}{MCTC \times 100} = \frac{1116.59 \times 85.637}{261.48 \times 100} = 3.657\,m$

To find the free floating drafts:

$t_a = \frac{t \times LCF}{LBP} = \frac{3.657 \times 85.319}{171.792} = 1.816\,m$

Draft aft = 7.486+1.816 = 9.302 m
Draft f'd = 9.302 – 3.657 = 5.645 m
At the instant of taking blocks for'd (end of critical period) drafts all over will be hydrostatic drafts i.e. 7.228 m. & fall of water level in critical period = 9.302 – 7.228 = 2.074 m.

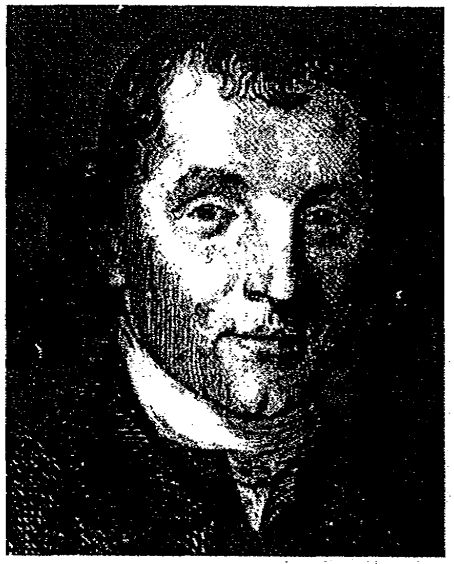
Q.3 M.V. ALPHASHIP in condition nr 2 grounds lightly on a pinnacle with no damage to hull. Subsequently with the fall of tide drafts were F 9.20 & aft 10.4m. Find upthrust on hull, position of rock & rise of tide required to refloat her.

Hint: After fall of tide the mean draft = 9.80m. LCF = 83.089m. HD = 9.82m.
Displacement, LCB & MCTC for this draft = 29477.28, 86.424 & 311.976 resp.
Displacement in condition 2 = 30634.2 t.
P the upthrust = difference of displacements = 1156.92 t
(LCB-LCG) x 29477.28 = 1.2 x 100 x 311.976, gives LCG = 85.155m.
The long moments in condition 2 are 2633929 tm. Let the pinnacle be x m forward of AP.

$85.155 = \frac{Long\ moments - 1156.92x}{29477.28} = \frac{2633929 - 1156.92x}{29477.28}$

Gives x = 107m.
To find rise of tide required find the draft at pt of contact before & after fall of tide. The difference is the rise required.

Thomas Simpson
(1710-1761)England.
Simpson received little formal education. He did attend school in Market Bosworth for a while but his first job was as a weaver. He taught himself mathematics. He moved away from his home town to take up a position as a schoolmaster in Nuneaton, Warwickshire. From about 1725, when Simpson was fifteen years old, until around 1733, he taught mathematics in Nuneaton. Simpson was the most distinguished of a group of itinerant lecturers who taught in the London coffee houses. In 1743 Simpson was appointed as the head of mathematics at the Royal Military Academy at Woolwich. 1745 Simpson was elected a fellow of the Royal Society.



Chapter 14 Simpson's Rules and their applications

Simpson's rules are used for approximate integration and the origin can be traced back to many other mathematicians and even Newton.

Trapezoidal rule: -
A trapezoid is a quadrilateral with two sides parallel to each other. Trapezium is the word used in English English whereas trapezoid is the word used in American English.. In the following fig these two opposite parallel side are of length y_1 & y_2 separated by a distance equal to h. then the area of trapezoid is equal to $A = \frac{1}{2}h(y_1 + y_2)$

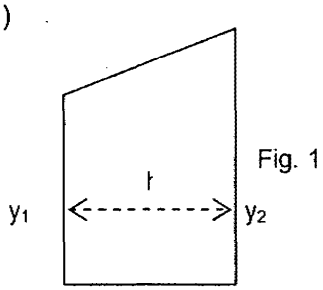


Fig. 1

A curvilinear fig can be divided in many near – trapezoids. The successive parallel sides can be of size $y_1, y_2, y_3, y_4 \ldots\ldots y_n$

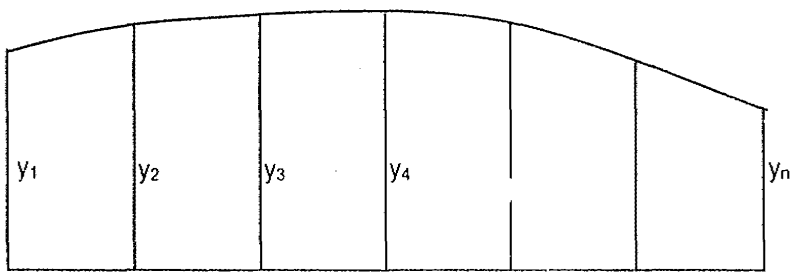


Fig. 2

The area of first trapezoid from left = $A = \frac{1}{2}h(y_1 + y_2)$. Also the areas of subsequent trapezoids = $A = \frac{1}{2}h(y_2 + y_3)$. $A = \frac{1}{2}h(y_3 + y_4) \ldots\ldots\ldots\ldots A = \frac{1}{2}h(y_{n-1} + y_n)$ respectively. By adding all the term will get the total area to be equal to $A = h(\frac{1}{2}y_1 + y_2 + y_3 \ldots\ldots + \frac{1}{2}y_n)$.

More the number of ordinates more accurate the area will be we can work out the formulae for moments and hence to find the centroid of the shape but the calculations done under Simpsons rules are more convenient and popular.

Simpson's first rule:-

The curvilinear shape is divided into even number of segments (n). The area is then considered to have (n + 1) number of ordinates and each having the spacing of h. Basic assumption of Simpsons first rule is that the curve conforms to the equation of second order parabola viz. $y= ax^2 + bx + c$. The Simpson's multipliers to the ordinates along the sequence are 1, 4, 2, 4, ...4, 1. The rule is also called 'h by 3, one four one rule'.

Let there be 3 equally spaced ordinates y_1, y_2 & y_3.

Let the uniform interval between the ordinates be h.

As per Simpson's first rule the area $A = \frac{h}{3}(y_1 + 4y_2 + y_3)$

If five equally spaced ordinates are y_1, y_2, y_3, y_4 and y_5. with the uniform interval as h.

The area would be $A = \frac{h}{3}(y_1 + 4y_2 + 2y_3 + 4y_4 + y_5)$

Thus the rule 1 can be used when the number of segments are even in number.

Ex. 1 The ordinates of a curvilinear area are 4m, 6m, 8m, 7m and 6m. The uniform spacing between them being 2m. Find the area a. by trapezoidal rule b. by Simpsons first rule

Sol^n: -

a. by trapezoidal rule

$A = h(\frac{1}{2}y_1 + y_2 + y_3 ..... + \frac{1}{2}y_n)$

$= 2 (½ \times 4 + 6 + 8 + 7 + ½ \times 6) = 2 \times 26 = 52m^2$

b. by Simpsons first rule

$$A = \frac{h}{3}(y_1 + 4y_2 + 2y_3 + 4y_4 + y_5)$$

$$A = \frac{2}{3}(4 + 4 \times 6 + 8 \times 2 + 7 \times 4 + 6) = \frac{2}{3} \times 78 = 52m^2$$

Simpson's second rule: -

This rule is developed from a third order equation and can be reduced to the expression for area as:

$$A = \frac{3h}{8}(y_1 + 3y_2 + 3y_3 + y_4)$$

The rule can be used when the number of segments are divisible by 3 or no of equidistant ordinates are 3 + 1, (where n is no of segments) this rule is also called '3h by 8, one three three one rule'.

Ex. 2 The transverse ordinates of a tank measured from center line of the ship are 4m, 6.5m, 8.2m and 10m respectively. If the fore and aft spacing between the ordinates is 4m, find the area of tank.

Sol^n: - $A = \frac{3 \times h}{8}(y_1 + 3y_2 + 3y_3 + y_4)$

$$A = \frac{3 \times 4}{8}(4 + 3 \times 6.5 + 3 \times 8.2 + 10) = \frac{3}{2}(58.1) = 87.15m^2$$

Simpson's third rule: -

This particular Simpson's rule is useful in giving the area between any two ordinates when three ordinates are known. The area between ordinate one or two is given by:

$$A = \frac{h}{12}(5y_1 + 8y_2 - y_3)$$

This rule can also be used for finding moments. The moment of area of that portion between ordinates 1 and 2 about 1st ordinate is given by:

$$MA = \frac{h^2}{24}(3y_1 + 10y_2 - y_3)$$

Ex. 3 The ordinates of a curvilinear shape are 5.4m, 4.8m and 3.2m, spaced at a uniform distance of 3m between them. Find the area between the last 2 ordinates.

Soln: -

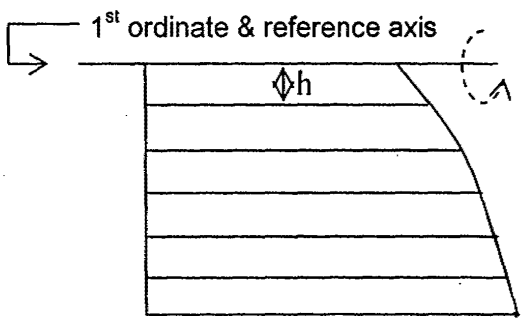
Since the area is to be found between the last two ordinates, we will name the ordinates as y_1 = 3.2, y_2 = 4.8, y_3= 5.4m.

$$A = \frac{h}{12}(5y_1 + 8y_2 - y_3)$$

$$A = \frac{3}{12}(5 \times 3.2 + 8 \times 4.8 - 5.4) = 12.25m^2$$

Ex. 4 A curve has the ordinates: 10.2m, 13.6m, 14m, 16.1m, 15.8m, 14.8m, and 15m, spaced 1.6m apart Calculate the area by Simpsons first rule and find distance of centroid from the first ordinate.

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever x	(5) = (3) x (4) ∫yxdx
10.2	1	10.2	0	0
13.6	4	54.4	h	54.4h
14.0	2	28	2h	56h
16.1	4	64.4	3h	193.2h
15.8	2	31.6	4h	126.4h
14.8	4	59.2	5h	296h
15.0	1	15.1	6h	90.6h
		SOP-1= 262.9		SOP-2 = 816.6h



Area of the curve = $A = \frac{h}{3} \times SOP - 1 = \frac{1.6}{3} \times 262.9 = 140.21m^2$ .....(1)

Moment of area about the first ordinate = $MA = \frac{h}{3} \times SOP - 2 = \frac{1.6}{3} \times 816.6 \times 1.6$ ..... (2)

Distance of centroid from the first ordinate = (2) ÷ (1) = $\frac{\frac{h}{3}SOP-2}{\frac{h}{3}SOP-1} = 4.970m$

Ex. 5 The areas of water planes of a ship 2 m apart (listed downwards from water level) are given below. Find the volume of displacement and position of VCB.

Waterplane	1	2	3	4	5	5 ½	6
Area	3868	3850	3600	3020	1650	650	180

Sol^{n}: -

When the ordinates are areas the volume can be found using Simpson's rules. In the following example rule 1 can be used to find the volume between ordinates 1 and 5, with h = 2m. The volume between 5 and 6 can also be found using Simpson's 1st rule but with h = 1m. Thus two separate calculations can be done independently and the volume may be added. Alternately the two calculations may be combined as follows:

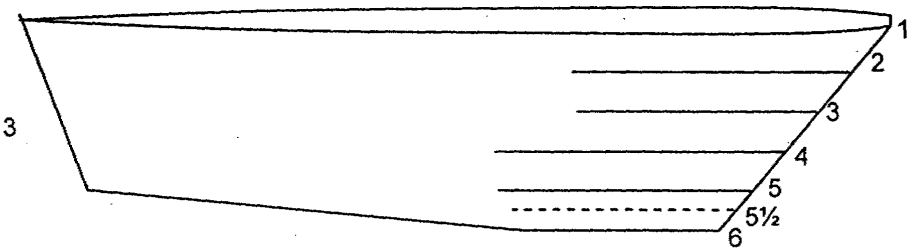


Fig. 3

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever x	(5) = (3) x (4) ∫yxdx
3868	1	3868	0	0h
3850	4	15400	h	15400h
3600	2	7200	2h	14400h
3020	4	12080	3h	36240h
1650	1+ ½ = 1 ½	2475	4h	9900h
650	½ x 4 = 2	1300	4.5h	5850h
180	½ x 1 = ½	90	5h	450h
		SOP-1= 42413		SOP-2 = 82240h

Note: the Simpson's multipliers for the last three ordinates are halved to compensate for half distance between them as compared to the other ordinates.

$$\text{UW volume } V = \frac{h}{3} \times SOP-1 = \frac{2}{3} \times 42413 = 28275.3m^3 \ldots\ldots\ldots (1)$$

$$\text{Moment of UW volume about first ordinate} = \frac{h}{3} \times SOP-2 = \frac{2}{3} \times 82980 = m^4$$

$$\text{Distance of COB from the first ordinate} = (2) \div (1) = \frac{\frac{h}{3}SOP-2}{\frac{h}{3}SOP-1} = \frac{82240 \times 2}{42413} = 3.878m$$

Since the distance between the first and last ordinate is 10m and the distance of COB from the first ordinate is 3.878m the VCB = 6.122m.

Ex. 6 The water line of a ship is 72 m long. Its half ordinates starting from forward and equally spaced are given below. Calculate the TPC & the LCF of the vessel.

Ord No.	1	2	3	4	5	6	7	8	9	10
½ ord (m)	0.0	3.2	6.4	8.8	10.6	10.2	8	6.2	3.8	1.0

Since AF is to be found out the tabulation of ordinate may done with aft ordinate as the first ordinate.

(1) Ordinate Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever X	(5) = (3) x (4) ∫yxdx
1.0	1	1	0	0h
3.8	3	11.4	h	11.4h
6.2	3	18.6	2h	37.2h
8	2	16	3h	48h
10.2	3	30.6	4h	122.2h
10.6	3	31.8	5h	159h
8.8	2	17.6	6h	105.6h
6.4	3	19.2	7h	134.4h
3.2	3	9.6	8h	76.8h
0	1	0	9h	0h
		SOP-1= 155.8		SOP -2 = 694.6h

½ the WPA of the curve = $A = \frac{h}{3} \times SOP - 1 = \frac{8}{3} \times 155.8 = 415.47 m^2$ ..... (1)

Moment of ½ of the WPA about aft ordinate = $MA = \frac{h}{3} \times SOP - 2 = \frac{8}{3} \times 694.6h$ ..... (2)

Distance of COF from aft = $\frac{(2)}{(1)} = \frac{694.6 \times 8}{155.8} = 35.666 m$

WPA of vessel = 2 x 415.47 = 830.94m^2

TPC = $\frac{WPA \times SWd}{100} = \frac{830.94 \times 1.025}{100} = 8.52$

Ans. LCF = 35.666m, TPC = 8.52.

Ex. 7 The sail of a boat has ordinates at a distance of 3m as 5.4m, 3.6m and 0.5m. It is required to paint the sail with red colour between the 1st two ordinates & green colour between the last two ordinates. If the consumption of paint is estimated at the rate of 2m^2 per liter, find the amount of red & green paint required to paint the sail.

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) SM for finding out area between 1st two ord	(5)
5.4	1	5.4	5	27
3.6	4	14.4	8	28.8
0.5	1	0.5	-1	-0.5
		SOP_1		SOP_2
		20.3		55.3

Total area of sail = $\frac{h}{3} \times SOP_1 = \frac{3}{3} \times 20.3 = 20.3m^2$

Area of sail between the 1st two ordinates = $\frac{h}{12} \times SOP_2 = \frac{3}{12} \times 55.3 = 13.83m^2$

Red colour, 6.92 l & Green colour, 3.24 l.

Ex. 8 A DB tank 2.4m deep has following equally spaced ordinates, which are horizontal areas: at top, 172m^2 at middle 140m^2 and at bottom 98m^2 respectively. The tank has oil of density 0.92 t / m^3 to a sounding of 1.2m. Calculate the quantity of oil & the COG of oil above the bottom.

Sol^n: -

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) SM for moment	(5)=(1)x(4) product for moments
98	5	490	3	294
140	8	1120	10	1400
172	-1	-172	-1	-172
		SOP_1		SOP_2
		1438		1522

The volume of oil = $\frac{h}{12} \times SOP_1 = \frac{1.2}{12} \times 1438 = 143.8m^3$

Qty = 143.8 x 0.92 = 132.3t.

The moment of volume about the first ordinate = $\frac{h^2}{24} \times SOP_2 = \frac{1.2^2}{24} \times 1522 = 91.32m^3$

Distance of COG above bottom = $\frac{91.32}{143.8} = 0.635m.$

Ex. 9 The TPC values for a ship at 1.2 meters intervals of draught commencing at the draft of 1.2m are 8.2, 16.5, 18.7, 19.4, 20.0, 20.5, and 21.1 respectively. Calculate her displacement at 8.4 m draught. The displacement & KB in SW at 1.2 m draft are 465 t & 0.7m respectively.

Since $TPC = \frac{WPA \times 1.025}{100}$, $WPA = \frac{100 \times TPC}{1.025}$ = T PC x 97.561 = TPC x k where k = 97.561.

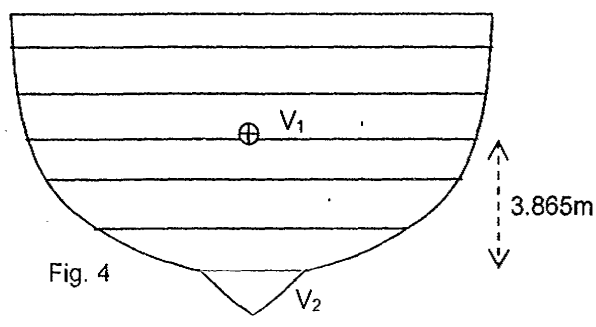


Fig. 4

(1) Ord Y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever x	(5) = (3) x (4) ∫yxdx
8.2k	1	8.2k	0	0
16.5k	4	66k	h	66hk
18.7k	2	37.4k	2h	74.8hk
19.4k	4	77.6k	3h	232.8hk
20k	2	40k	4h	160hk
20.5k	4	82k	5h	410hk
21.1k	1	21.1k	6h	126.6hk
		S-1= 332.3k		S-2 = 1070.2hk

The volume of the vessel between 1.2m and 8.4m = $\frac{h}{3} \times S-1 = \frac{1.2}{3} \times 332.3k$ ..... (1)

= 12963.9m^3

UW volume at 1.2m draft = $\frac{465}{1.025} = 453.6\,m^3$

Total underwater volume = 12963.9 + 453.6 = 13217.5 m^3

Displacement of the vessel = 13217.5 x 1.025 = 13547.9 t

Moment of volume about the first ordinate = $\frac{h}{3} \times S-2 = \frac{1.2}{3} \times 1070.2hk$ ..... (2)

Distance of centroid of above volume from the first ordinate = $\frac{(2)}{(1)} = \frac{1070.2hk}{332.3k} = 3.865m$

Distance of centroid from keel = 3.865 + 1.2 = 5.065m

Taking moment about keel KB = $\frac{V_1 d_1 + V_2 d_2}{V_1 + V_2} = \frac{12963.9 \times 5.065 + 453.6 \times 0.7}{13217.5} = 4.992m$

Ans. Displacement = 13547.9t, KB = 4.992m

Exercise 14

Q. 1 A ship of length 130m floats at a uniform draught of 6.5m. The areas of waterplanes1.3m apart are as follows:

Dist above base line	1.3	2.6	3.9	5.2	6.5
WPA (m^2)	1460	1630	1740	1790	1800

The appendage below 1.3-m waterline has a displacement of 1310 tonnes with KB of 0.67 metres. Determine the displacement of the ship in seawater and the position of centre of buoyancy above the keel.

Ans. Displacement = 10379.9 t, KB = 3.566 m.

Q. 2 A vessel of length 300 m floating at a draft of 20 m has half ordinates of water plane as follows, commencing from the after perpendicular. The ship's displacement at 20m draft is 117,000t.

Station	0	1/2	1	2	3	4	5	5½	6
½ordinate (m)	0.1	7.5	1	1	12.3	11.4	8	5.2	1.0

There is an appendage forward with an area of 2.8 m^2

Find: (a) The area of the water plane.

(b) (i) The TPC in salt water ii) The FWA at 20m draft

Ans. 5707.8 m^2 TPC 58.505, FWA 49.99 cm?

Q. 3 A double bottom tank is 1.5m deep. The horizontal areas of the tank at equal intervals commencing from the tank top are 192, 186 and 158 sq m respectively. The tank is ballasted to a sounding of 0.75m with water of RD 1.012. Calculate the weight of ballast and its KG.
Ans. Weight of ballast = 131.94t KG 0.385m

Q. 4 The breadths of a bulkhead, at 3.0m intervals from the top, are: 19.2, 18.0, 17.1, 16.2, 14.4, 12.0, 9.3 and 6.0 m. Find the distance of its geometric centre from the top. (Use Simpson's 1st rule for first five ordinates and 2nd rule for remaining ordinates).
Ans. 8.961 m

Q. 5 The water plane areas of a ship at 1 m intervals, commencing from the keel are as follows:

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

Calculate her KB and FWA at a draft of 6m.
Ans. KB = 3.012 m FWA = 148.22 mm

Q. 6 The transverse ordinates of a ship's waterplane 144 m in length at equal intervals commencing from forward are 0.0, 12.9, 15.6, 15..8, 15.8, 15.6. 15.0, 13.2 and 1.2 m. The ordinates midway between the first two and the last two ordinates as given above are 6.8 and. 7.4 m respectively. Calculate (i) the position of her CF with respect to midlength and (ii) her TPC.
Ans. 1) 0.156 m aft of midship 2) TPC = 19.47

Q. 7 The TPC of a ship are as follows:

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

The displacement and KB at 2m draft are 3280 t and 1.2 m respectively. Find the displacement and KB at 6m draft in SW.
Ans. Displ. 11846.32t, KB 3.253m

Q. 8 The breadths of a ship's water-plane 120 m long, measured at equal intervals from aft, are: 1.2, 9.6, 13.2, 15.0, 15.3, 15.6, 15.6, 14.7, 12.9, 9.0 and 0.0 m respectively. Find the water plane area, TPC in sea water & FWA if displacement is 6,690 t.
Ans. WPA 1483.2 m^2, TPC 15.203, FWA 110 mm

Q. 9 The areas of a, ship's waterplanes are as follows:

Draft (m)	6.0	4.8	3.6	2.4	1.2	0.6	keel
Area (m^2)	1960	1930	1840	1590	1110	570	100

Calculate her (a) displacement (b) KB and (c) FWA at a draft of 6.0m.
Ans. (a) 9255.75t (b) 3.544m (c) 115.18mm

Q. 10 The end bulkhead of a deep tank 10 m deep has the following horizontal ordinates at equal intervals, commencing from the top are 18.2, 16.7 and 15.6 m resp. Find the thrust on the bulkhead if the tank contains SW to a sounding of 5 m.
Ans. 206.94t, Centroid from bottom 2.528m

Q. 11 A double bottom tank is 1.5m deep. The horizontal areas of the tank at equal intervals, commencing from the tank top are 192, 186 & 158 sq.m respectively. The tank is ballasted to a sounding of 0.75m with water of R.D. 1.012. Calculate the weight of ballast and its KG.
Ans. Weight 131.94t, KG 0.385m

Q. 12 A wall sided tank 1.5 m deep has the following half ordinates of breadth at 4 m commencing at its after bulkhead. 6.1, 6.0, 5.9, 5.7, 5.4, 4.9 and 4.3 m. The after bulkhead of the tank is 65 m forward of the Centre of Floatation. Calculate the change in the ship's trim, if the tank is filled with fuel oil of RD 0.95. MCTC 200 mt.
Ans. Centroid 76.388m F'd of COF, Forward Trimming by 1.443m

Q. 13 A ship's waterplane is 216 m in length. The half ordinates of the waterplane commencing from forward are as follows:
0.4, 4.4, 8.8, 11.0, 11.6, 11.8, 11.8, 11.6, 9.6, 7.0, 0.4 respectively. The spacing between the first three and last three ordinates is half of the spacing between the other half ordinates. Calculate her waterplane area and the position of the CF with respect to the midlength.
Ans. 3763.2 & 14.755m aft of midships

Q. 14 A wall sided vessel, 150m in length of constant waterplane, the semi ordinates of which at equal intervals are: 0,5,9,10,9,5 and 0m, has a double bottom 1 m deep extending from side to side between the 9m and 9m half ordinates given. Calculate the thrust on the tank-top if the tank is run up by opening the sea valve, if her original even keel draft was 5.2m.
Ans. 4656.93t at Draft 5.70m

Q.15 The half breadths of a ship's water-plane at 12m intervals from aft are: 0.0, 3.3, 4.5. 4.8, 4,5, 3.6, 2.7 and 0.5m. The half - breadth, midway between the first two from aft is 2m. At the fore end is an appendage by way of a bulbous bow 4.5m long. Its area is $24m^2$ and its GC 2m from forward extremity. Find the area of the water-plane and the position of the COF.
Ans. WPA $608.4m^2$

Q. 16 The area of a ship's waterplanes, commencing from the load water-plane and spaced I m apart, are 800, 760, 700, 600, 450 and $10m^2$ respectively. Midway between the lowest two waterplanes, the area is 180^2. Find the load displacement in salt water and the height of centre of buoyancy above the keel.
Ans. 2965.66t & 2.997m

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Chapter 15 Grain loading hazards and calculations

A brief history of grain regulations: -

Bulk grain because of its semi fluid property is liable to shift as a result of the heavy rolling experienced by a vessel at sea. A shift of grain can cause a vessel to heel to a dangerous degree and possibly capsize. Because of this hazard regulations concerning the loading and carriage of grain have been in force for many years. SOLAS 1948 grain regulations required extensive use of expensive temporary fittings and/or bagged grain.

1960 regulations were more advantageous from an economic point of view than those adopted in SOLAS and many countries quickly accepted them, though the Convention itself did not enter into force until 1965. The regulations mainly aimed at restricting the movement of grain by installing temporary centerline shifting boards, feeders in hatchways, saucers and by over stowing of bulk grain bagged grain or other suitable cargo. Several ships loaded under the 1960 SOLAS rules were lost at sea probably because 1960 Convention had underestimated the amount of "sinkage". The regulations placed an over reliance on the ability of hatch feeders to eliminate under deck voids. The regulations did not adequately consider the potential for a grain shift due to these voids. Also just specifying a low limiting heeling moment for general cargo vessels without considering the inherent stability characteristics of the individual vessel was not correct.

IMO Assembly in 1969 adopted new grain regulations [resolution A.184 (VI)], which became known as the 1969 Equivalent Grain Regulations. These regulations were more practical and economical than the 1960 and were subsequently incorporated into the 1974 SOLAS Convention.

Grain Code:-

It applies to all ships - including existing ships and those of less than 500 gross that carry grain in bulk. Part A contains special requirements and gives guidance on the stowage of grain and the use of grain fittings. Part B deals with the calculation of heeling moments and general assumptions.

Presently chapter VI of SOLAS deals with "Carriage of Cargoes". This chapter is divided in 3 parts. Part A is General Provisions. Reg. 2 of this part "Cargo Information" partly deals with the carriage of bulk grain. Thus

"The shipper shall provide the master or his representative with appropriate information on the cargo sufficiently in advance of loading to enable the exercise of precautions which may be necessary for your proper stowage and safe carriage of the cargo. Such information shall be confirmed in writing and by appropriate shipping documents prior to loading the cargo on the ship. In case of bulk cargo information on the stowage factor of the cargo, the trimming procedures, likelihood of shifting including angle of repose, if applicable and any other relevant special properties.

PART C is Carriage of Grain. Reg. 9 deals with the requirement for cargo ships carrying grain. It states that in addition to any other applicable requirement of the present regulations, a cargo ship carrying grain shall comply with the requirement of the International grain code and hold a document of authorization as required by the code, thus making the code mandatory. A ship without such a document shall not load grain until the Master satisfies the Administration or the Contracting Government of the port of loading on behalf of the Administration that the ship will comply with the requirements of the International Grain Code in it's proposed loaded condition.

So, basically vessel can load grain even without a DOA as per Reg 9.2 SOALS ch VI Part C. It must be noted that due to vibration and movement of the ship at sea the grain settles down (by about 2% of its vol.) resulting in voids at the top of the compartment. Bulk grain has a low angle repose. Angle of repose has relationship with the amount of roll and the inclination of hopper tanks. If the ship rolls to an angle grater than angle of repose, risk of grain shift exits. A slope of hopper tank more than angle of repose would make a hold self trimming.

Intact stability Requirements: -

The intact stability of the ship carrying grain in bulk shall be shown to meet at least the following criteria after taking into account the assumed shift of grain. The assumed shift of grain is to an extent of 25° (15° for certain areas)

1. The angle of heel obtained from a plot of the statical stability curve and heeling arm curve shall not be greater than 12° .The administration will provide a lesser angle than 12° if considered necessary.
2. The residual area between the righting arm curve and the heeling arm curve up to an angle of 40° or the angle of flooding or the angle of maximum separation between the two curves whichever is least shall be at least 0.075 m-radian (not les than 0.075 m-radian)
3. The initial GM shall be at least 0.3 m.

Before loading the bulk grain the master shall if required by authorities demonstrate the ability of the ships to comply with the stability criteria required by this section. After loading master will ensure the vessel is upright before proceeding to sea.

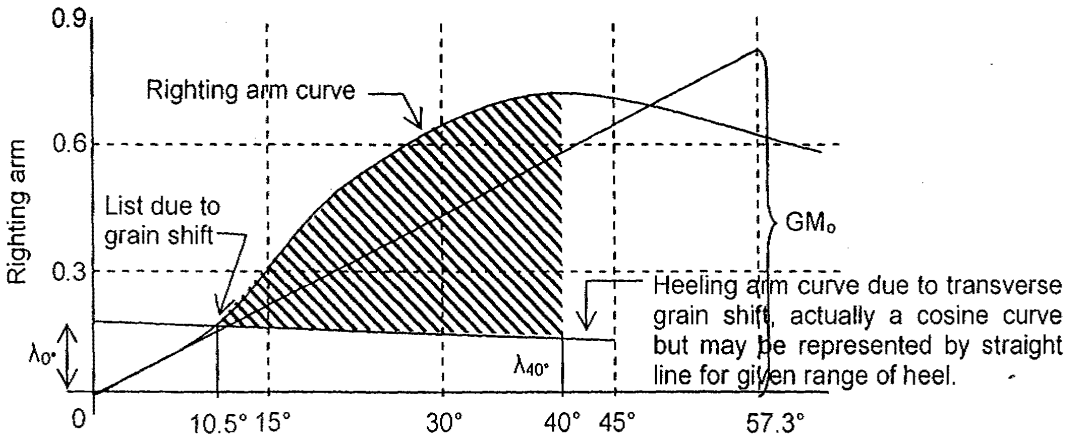


Fig. 1

In the above fig

$$\lambda_0 = \frac{\text{assumed volumetric heeling moment due to transverse shift}}{\text{stowage factor x } \Delta}$$

$\lambda_{40} = 0.8 \times \lambda_0$

Stowage factor = volume per unit weight of grain cargo.

Displacement = weight of ship, fuel, fresh water, stores etc. and cargo.

The righting arm curve shall be derived from cross curves which are sufficient in number to accurately define the curve for the purpose of these requirements and shall include cross curves at 12 degrees and 40 degrees.

Regulation 10 of the code has recommendations in respect of stowage of bulk grain. It says that all necessary and reasonable trimming shall be performed to level all grain surfaces and minimize the effect of grain shifting. In any filled compartment, trimmed, the bulk grain should be trimmed to fill up under deck spaces to maximum possible extent.

In untrimmed filled compartment maximum filling shall be done in the way of hatch opening and allowed to stow at its natural angle of repose on the periphery. A filled compartment is of this category if

1. Administration issuing DOA may under B 6 grant dispensation owing to geometry & filling possibilities under deck.
2. The compartment to be filled is specially suitable one where the dispensation from trimming is provided.

Unless account is taken of adverse heeling effect due to grain shift according to the grain code, the surface of partly filled compartment shall be secured so as to prevent a grain shift by over stowing. Alternately the surface may be secured by strapping or lashing.

Document of authorization (DOA): -

DOA is dealt under regulation 3 of the code and is issued by Administration or Recognized Organization to every ship capable of being loaded in accordance with grain code. It shall be accepted as evidence that the ship is capable of complying with relevant regulations.

The document is accompanied with grain loading manual which enables Master meeting the grain stability criteria and has required information as provided in A 6.

A ship without DOA shall not load grain until the Master demonstrates to the satisfaction of Administration or Contracting Government of port of loading on behalf of Administration that vessel is loaded appropriately for the intended voyage.

Regulation 9 of code deals with optional stability requirements for ships without DOA carrying partial cargoes of bulk grain. A ship without DOA may be permitted to load bulk grain provided

1. Total grain weight does not exceed 1/3rd deadweight of ship.
2. Filled compartments, trimmed shall be fitted with appropriate centre line divisions. (Saucers may be accepted).
3. All hatches to filled compartment, trimmed shall be closed and secured.
4. All free grain surfaces are leveled, secured by overstowing, strapping / lashing or by securing with wire mesh.
5. Through out the voyage GM_o, after correction of free surface shall be 0.3m or that given by the following formula whichever is greater.

$$GM_R = \frac{LBV_d\left(0.25B - 0.645\sqrt{V_d B}\right)}{SF \times \Delta \times 0.0875}$$

L is length of compartment (m), B the moulded breadth (m), SF the stowage factor (m^3/t), V_d the calculated average void depth (m) & Δ the displacement in tonnes.

6. Master must demonstrate to the satisfaction of Administration or Contracting Government of port of loading on behalf of Administration that the ship will comply with the requirements of this section.

Voids exist above all free grain surfaces in filled compartments. The extent of the voids depends on the dimensions of the compartment and the depth from the overhead to the grain surface. Assumption is made in respect of void depth and the angle to which the grain surface will be with respect to horizontal.

Grain heeling moments are produced by a grain shift. Grain heeling moment is the product of the weight of the shifted grain multiplied by the horizontal distance between its initial and final centres of gravity. Grain heeling moments are expressed in tonne.meters.

Volumetric heeling moment is the product of the volume of grain that would shift multiplied by athwartship distance through which it would shift. It is common practice to calculate and tabulate the volumetric heeling moment of different compartments instead of weight heeling moment. A ship may load the grain of different stowage factors. To obtain the actual weight heeling moment for a particular grain the volumetric heeling moment is divided by the stowage factor of that grain.

$$\text{Grain heeling moment} = \frac{\text{VHM}}{\text{SF}} = \frac{m^4}{m^3/t} = \text{t.m.}$$

Calculations of volumetric heeling moments

Volumetric heeling moments are calculated by naval architects and tabulated in the vessel's approved grain booklet. The grain stability booklet is required for vessel engaged in the carriage of bulk grain. Calculations can be complex-depending on the geometry of the compartment. In approved grain stability booklet the volumetric heeling moments are represented for individual compartments in either curved form or in tabulated form enabling the use to find the volumetric heeling moments for the full and slack conditions.

A sample table of maximum volumetric heeling moment for partly filled compartment

Hold	Capacity (m^3)	VCG (m)	Maximum VHM for partly filled (m^4)	VHM, Without centreline division (m^4)	VHM, With centreline division (m^4)
1	8727	7.8	1935	423	413
2	14545	7.6	5284	1164	1009
3	7909	7.5	2734	638	530
4	12000	7.7	3893	908	820
5	6090	7.8	1860	490	458

In the table above only the maximum volumetric heeling moments for partly filled compartments are shown.

Typical curves for volume, centre of gravity and volumetric heeling moment are provided for each hold: -

The curves for each hold are provided to give KG, volume and volumetric heeling moment for the cargo loaded and can be entered with the argument viz. depth from the tank top or ullage from the hatch coaming.

It can be seen that the volumetric heeling moment is zero at the base, maximum for half filled hold and minimal for the filled condition. KG for the present loaded condition can be obtained from the graph but KG for the complete compartment (geometric centroid) can be obtained from the tables.

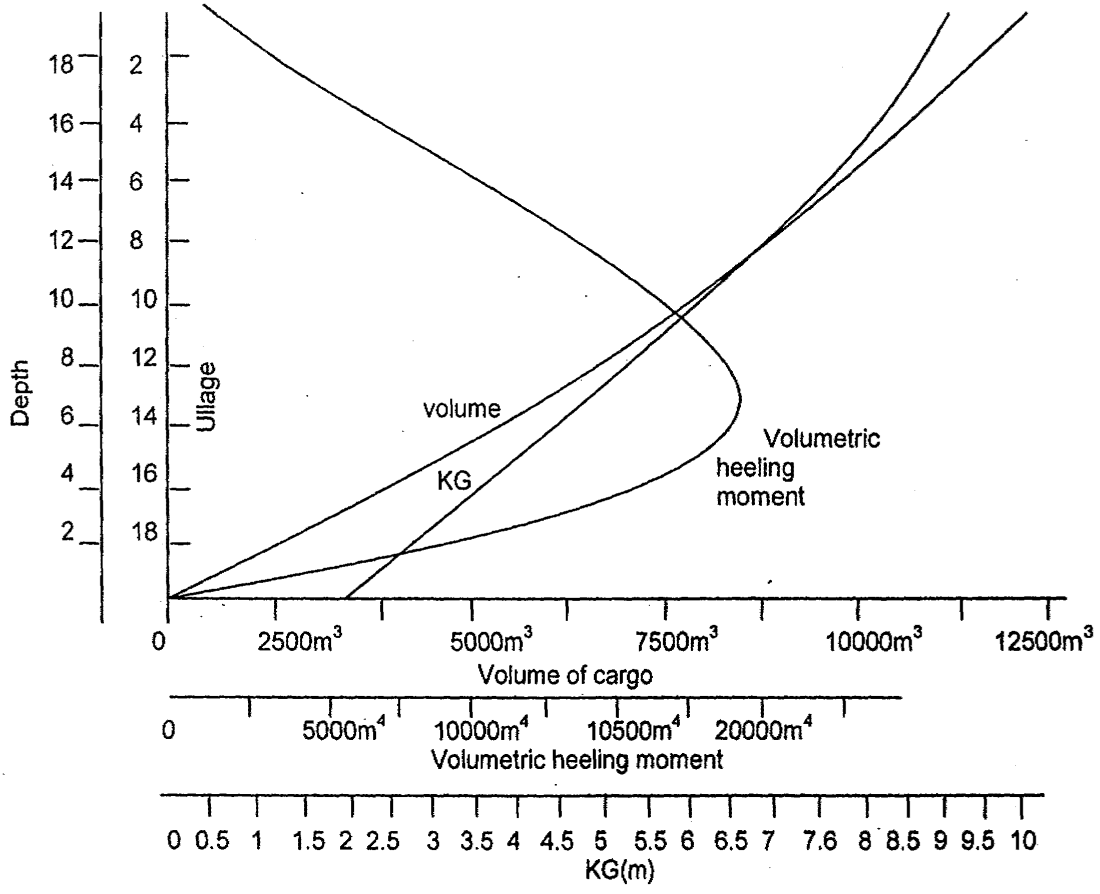


Fig. 2

Allowance for a vertical shift or grain: -

When grain shifts on a ship there is a net vertical upwards movement of the center of gravity of the grain which in turn raises the center of gravity of the ship and reduces the GM. In calculating the vessel's stability the allowance for this is made in the following manner:

In filled compartments untrimmed no compensation is necessary whether the KG is read from the curve or is read from the tables for the full compartment. But for the filled compartment if trimmed and KG is picked up from the curves, the VHM obtained is multiplied by 1.06.

In partly filled compartments the transverse volumetric heeling moments are increased by multiplying the same with factor 1.12, if the KG of the cargo is picked up from the curve for actual ullage / sounding.

Table of allowable heeling moments: -

Table of allowable heeling moments is a ready reckoner table where Master can at one glance know whether the grain stability criteria would be satisfied for the proposed cargo distribution. The grain stability booklet contains tables of maximum allowable heeling moments, complied for a wide range of combinations of displacement and KG_v. These tables are usually generated by computer using input data from the vessels cross curves of stability. A sample of such table has been shown in the following table:

Displ. tonnes	Fluid KG 6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
19000	7980	7468	7143	6728	6312	6535	5479	5061	4891	
18500	7744	7465	6935	6522	6131	5728	5325			
18000	7701	7438	6921	6533	6145	5757				
17500	7709	7338	6965	6590	6215					
17000	7648	7295	6921	6577						
16500	7610	7265	69							
16000	7657	732								
15500	745									
15000										

Fig. 3

Ex. 1 M V Grain Product has a light displacement of 5110 t. free surface moments 920t-m. Grain of SF 1.28m^3.t is loaded into the holds as follows:

Hold No 1 ullage 2.8m
Hold No 2 ullage 0.0m
Hold No 3 ullage 0.0m
Hold No 4 ullage 0.0m
Hold No 5 ullage 4.3m

KG for the full compartments was taken for centroid of entire hold space and for partly filled compartments the KG of the actual loaded cargo was taken.
Sol^n: In the example below the procedure of grain stability calculation is illustrated.

From the tables, values for grain volume, VCG and VHMs are noted down. The mass of grain in each compartment is calculated by the formula, mass (t) = $\frac{\text{volume (m}^3\text{)}}{\text{SF (m}^3\text{/t)}}$

The tabulated VHMs are multiplied by the appropriate correction factors to get the actual VHMs For holds 2, 3 and 4 no correction factor is necessary. Holds 1 and 5 are partly filled and the KG used is that of the actual grain cargo in the hold. The correction factor used therefore is 1.12.

Let's say the total grain that is loaded is 19200m^3. The mass is $\frac{19200}{1.28} = 15000$ tm

Load displacement = Lt Wt + Cargo + Bunkers + FW + Constant
= 5110 + 15000 + 1540 + 310 + 150 = 22110 t.

The VHM for filled compartments = 2100m^4, corrected VHM = 2100m^4
The VHM for partly filled compartments = 3121m^4, corrected VHM = 3121 x 1.12 = 3496m^4.
Total VHM's 5596 m^4
Taking all the weights on board into account KG is found by moments. Let the solid KG be 7.931m

$$\text{FSC (m)} = \frac{\text{free surface moments (t - m)}}{displacement} = \frac{920}{22110} = 0.042m$$

KG (fluid) = 7.931 + 0.042 = 7.973m.
KN values for various angles of heel and the ship's loaded displacement are noted down from the KN tables. KM is found for the sailing draft. Let this be 8.8m.
The curve of statical stability is plotted using appropriate scale.

$$\lambda_0 = \frac{\Sigma VHM}{SF \times \Delta} = \frac{5596}{1.28 \times 22110} = 0.198m$$

λ_{40} = 0.8 x λ_0 = 0.8 x 0.198 = 0.158m.
The heeling arm curve is plotted by joining λ_0 and λ_{40} points.

Where the heeling arm curve intersects the righting arm curve a vertical line is drawn till x axis to find the list angle for the assumed grain shift. This angle should be less than 12° or smaller angle applicable. In the present example this angle is 8°.

The residual area between the heeling arm and righting arm curve is to be calculated till the smaller of angle of flooding, maximum vertical separation and 40°. This area is to be not less than 0.075 m^c. Let the angle of flooding at present draft be 38°.

$$\text{The common interval h} = \frac{38° - 8°}{2} = 15°$$

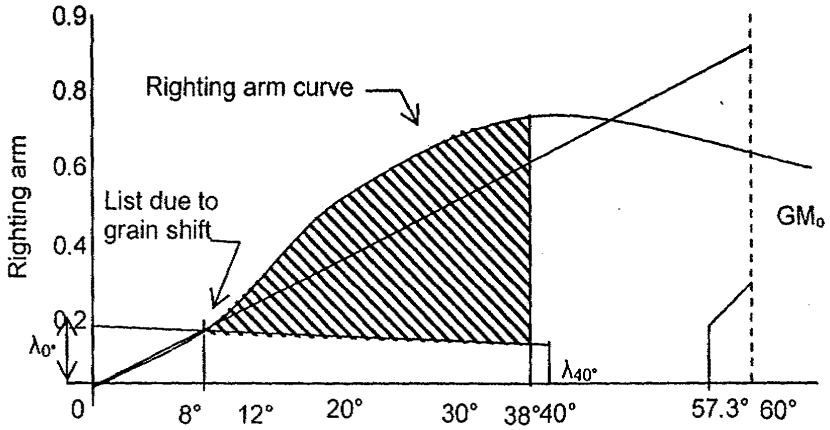


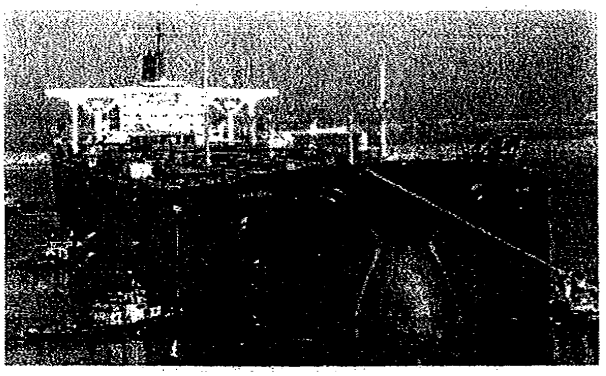
Fig. 4

The height of residual part at 23° and 38° from curve are 0.43m and 0.62m respectively.

$$\text{The area} = \frac{h}{3 \times 57.3}(sum\ of\ products) = \frac{15}{3 \times 57.3}(0 + 4 \times 0.43 + 0.62) = 0.204m^c$$

This area is more than 0.075m^c hence the condition satisfied.
The GM fluid is 8.8 - 7.973 = 0.863m.
The GM fluid as read from the curve is 0.85m, is almost the same as found from the graph.
The relevant condition satisfied
The ship's loaded condition complies with the minimum intact stability of the International Grain Code.

Largest Bulk Carrier: The Berge Stahl of 364,768 DWT is the world's largest bulker, 343 m long, has a beam of 65 m, and a draft of 23 m. She was built in 1986 by Hyundai Heavy Industries. Her Hyundai B&W 7L90MCE diesel engine is 9 m high, of 27,610 horsepower and drives a single 9 m screw, (20.59 MW), has a top speed of 13.5 knots and has a 9 m high rudder. She is owned by the Singaporean shipping company BW Group. Because of her massive size, the Berge Stahl can only tie up, fully loaded, at two ports in the world, terminal Maritimo de Ponta da Madeira in Brazil and Europoort near Rotterdam.



Chapter 16 Draft survey

Q. 1 M V ALPHASHIP arrived port with the following drafts F 10.20 m, A 10.20 m, mid 10.16 m. density of dockwater 1.012. ROB: HFO 276 t, DO 105 t, FW 120 t, stores and provisions 42 t constant 105t. After completion of discharge the drafts observed were forward 4.20 m and 4.22m aft 6.24m and 6.50m, mid ships 5.13 m & 5.53 m. If in port vessel received 200t of water & miscellaneous consumption was 76t during the stay, what was the quantity of cargo discharged? Given: forward draft marks are 2m abaft FP, midship draft marks are 3 m abaft midships and aft draft marks are 3m forward of AP.

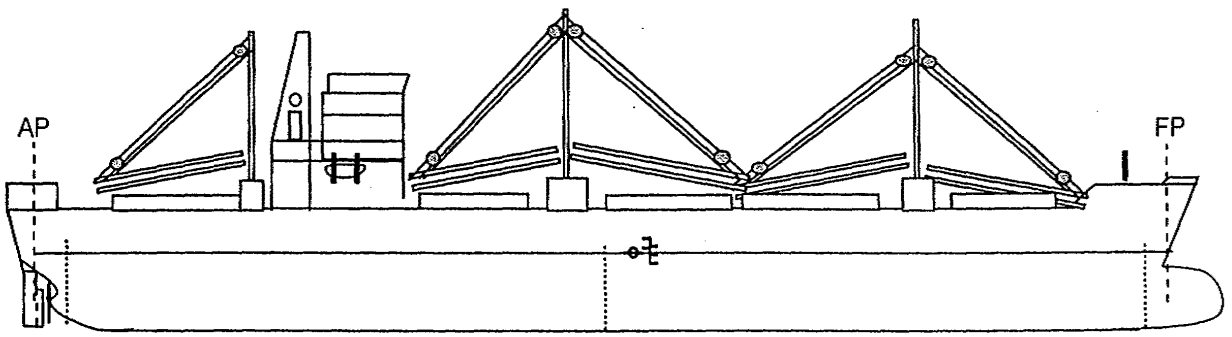


Fig. 1

Hint:-

Arrival mean of mean draft = $\frac{F + A + 6\,mid}{8} = \frac{10.2 + 10.2 + (6 \times 10.16)}{8} = 10.17m$

Since the vessel is on even keel and upright, this draft is also the hydrostatic draft

Δ from the tables for this draft = 30682.43 t. But since a vessel is floating dockwater the correct

$\Delta = \frac{30682.43 \times 1.012}{1.025} = 30293.3t.$

Observed final mean drafts are F 4.21 m, A 6.37 m, mid 5.33 m. Observed trim 2.16 m by stern.

Actual distance between marks = 171.792 – (2 + 3) = 166.792 m

Corn to observed drafts F = $\frac{2.16 \times 2}{166.792} = 0.026m$ ∴ Draft at FP = 4.21 – 0.026 = 4.184 m

The correction is negative as the FP is forward of markings. Since the vessel is trimmed b stern all the after drafts are more than the drafts to the forward. The sign of correction ca therefore be found from the diagram.

Corn to observed draft A and draft amidships = $\frac{2.16 \times 3}{166.792} = 0.039m$

Drafts at AP = 6.37 + 0.039 = 6.409 m. draft at midship = 5.33 – 0.039 = 5.291

Mean of means = $\frac{4.184 + 6.409 + (6 \times 5.291)}{8} = 5.292m$

½ LBP = $\frac{171.792}{2} = 85.896m$

LCF for the draft 5.292 m is = 87.368 m

COF is forward of midship by (87.368 – 85.896) = 1.472 m.

1st trim corn = $\frac{\text{observed trim} \times \text{dist.of COF form mid length}}{\text{length beteen draft marks}} = \frac{2.16 \times 1.472}{1.66.792} = 0.019$ m

= 0.019 m (-ve as COF is forward of midships)

True mean draft = 5.292 - 0.019 = 5.273 m

Δ for 5.273 m = 14548.88 t. ..... (1)

Trim between perpendiculars = corrected forward draft ~ corrected aft draft = 4.184 ~ 6.409 = 2.225 m.

2nd trim corn = $\frac{50 \times (\text{trim in m})^2 (MCTC_1 \sim MCTC_2)}{LBP}$

= $\frac{50 \times (2.225)^2 \times 9.835}{171.792}$ = 14.171 t (always +ve) ..... (2)

(MCTC are for the drafts 50 cm above and below the true mean draft found so far i.e. 5.273m.
MCTC for 4.773 m = 231.26 t.m MCTC for 5.773 m = 241.10 t.m)

Since the vessel is listed, a correction = 6 ($TPC_1 - TPC_2$) ($D_1 - D_2$)

Where D_1 and D_2 are the port and starboard midship drafts and TPC_1 & TPC_2 are the TPC_s corresponding to these drafts.

List correction = 6 x 0.2195 x 0.4 = 0.527 t. (+ve) ..... (3)

Note: This correction is always positive as a mean of midship drafts gives a draft which is less than the equivalent upright draft.

(1) + (2) + (3) = 14563.578 t.

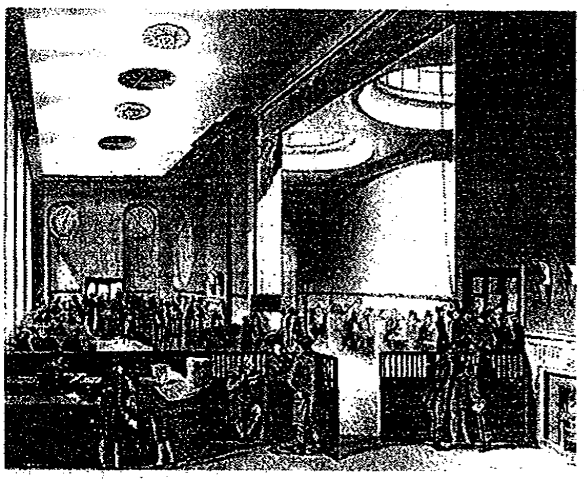
But since a vessel is floating dockwater the correct Δ = $\frac{14563.578 \times 1.012}{1.025} = 14378.869\ t.$

Now 30293.3 + 200 – 76 – cargo discharged = 14378.869 t

∴ cargo discharged = 16038.431 t

Ans. 16038.431 t

Edward Lloyd's Coffee House: In the 17th Century London's importance as a trade centre led to an increasing demand for ship and cargo insurance. Lloyd's coffee house became recognised as the place for obtaining marine insurance. From its first beginnings in Edward Lloyd's Coffee House in 1688, Lloyd's has been a pioneer in insurance. Starting with its roots in marine insurance, Lloyd's has grown over 300 years to become the world's leading market for specialist insurance.



Chapter 17 Intact stability criteria of different ships

'Intact Stability Code' is code on intact stability for all types of ships covered by IMO instruments. The purpose of code is to recommend stability criteria & other measures for ensuring safe operation to minimize risk to ships, personnel & environment. The shipyards, administrations, ship owner and ships officers are to be guided by this code so that the ships are constructed and operated in a safe way. The code is an out come of assembly resolution A.749(18) adopted on 4.11.93. The code recommends government concerned to ensure that inclining tests are conducted as per guidelines provided in chapter 7

The code is presently divided in 7 chapters. The various chapters are as follows:

Ch 1 GENERAL: Purpose, application, definitions.

Ch 2 GEN PROVISIONS AGAINST CAPSIZING & INFO FOR MASTER: Includes required contents of stability booklet, features operating booklet required for certain ships, general precautions against capsizing, operational procedures related to weather conditions.

Ch 3 DESIGN CRITERIA [all ships]: Is a very important chapter and contains intact stability criteria for all ships and details of weather criterion. This chapter also makes reference to free surface effect in tanks, assessment of compliance of criteria. Guidance regarding standard loading condition and calculation of stability curves is also provided.

Ch 4 SPECIAL CRITERIA [certain ships]: Provides alternate criteria for ships with timber deck cargo, fishing vessels, special purpose ships, cargo ships with bulk grain, OSVs, MODU [drilling units], pontoons, DSCs, container ships more than 100m / ships with wide flare.

Ch 5 ICING CONSIDERATIONS

Ch 6 CONSIDERATIONS ON WATER TIGHT INTEGRITY: Deals with hatchways, machinery space openings, doors, cargo ports, side scuttles, other deck openings, vent, air sounding pipes freeing ports etc.

Ch 7 DETERMINATION OF LIGHT SHIP DISPLACEMENT & CG: contains detailed guidance regarding preparation, conduct and precautions in respect of inclining tests. Determination of

stability by 'Rolling Period Test' for ships smaller than 70m in length, inclining test for MODUs and stability test for pontoon is also dealt in this chapter.
The code has annexes dealing with detailed guidance for conduct of inclining test and recommendation to skippers of Fishing Vessels.

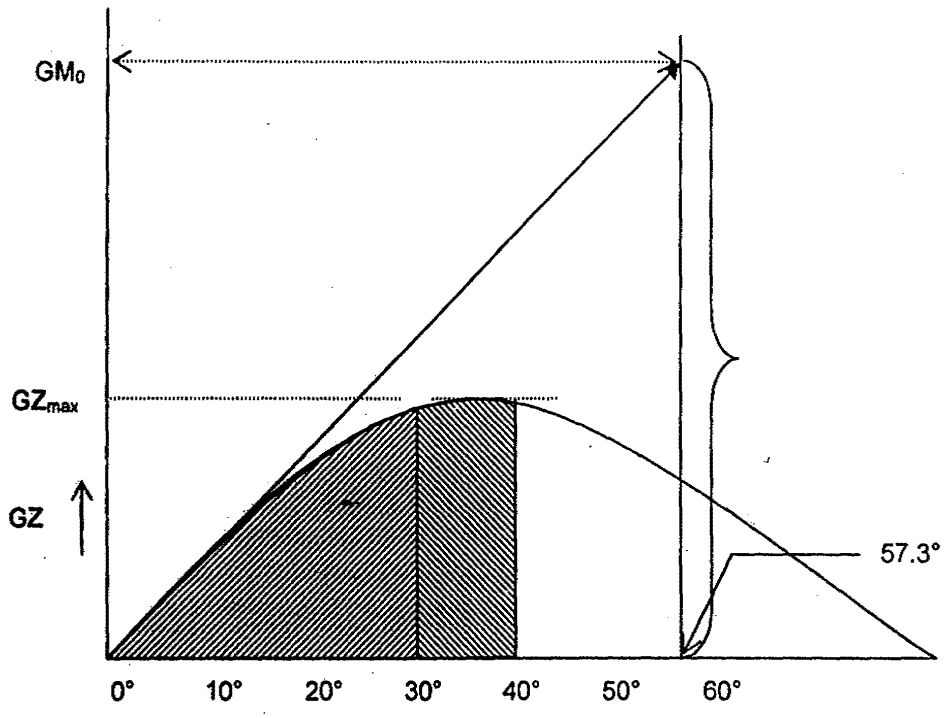
The stability data must be in official language or language of issuing country & language spoken / understandable by master. If none of these languages is English or French then text must include translation in one of these.

New stability books which are called loading & stability manual should include the following information. It has been emphasized that the stability information that is provided in the manual must be in simple language, readily understandable by Master. The document thus becomes a very useful tool for the Master to have a good control on the stability and safety of vessel. The stability document on board ship must contain the following:

1. Gen description of ship.
2. Instruction on how to use the information provided.
3. General Arrangement plans, watertight compartments, down flooding angle, free board diagrams.
4. Hydrostatic curves or tables.
5. Capacity plan or tables.
6. Tank soundings, capacity, details about free surface effect and centre of gravity.
7. Information on loading restrictions viz. KG maximum or GM minimum etc to check compliance and stability status at one glance.
8. Standard conditions & examples to develop other acceptable loading conditions.
9. Description of calculations and various assumptions.
10. Precautions to prevent unintentional flooding.
11. Special cross-flooding fittings.
12. Guidance to master for safe operation.
13. content and index.
14. Inclining test report or where data is based on sister ship, the details of the same. Light ship measurement report or if any other method of KG determination is employed then summary thereof.
15. Recommendation for determining stab by in-service inclining test. Alternate simplified & approved booklet is possible at discretion of authority.

General intact stability criteria for all the ships: -
The following criteria are recommended for passenger and cargo ships

- The area under the righting lever curve (GZ curve) should not be less than 0.055 metre-radian up to $\theta = 30^\circ$ angle of heel and not less than 0.09 metre-radian up to $\theta = 40^\circ$ or the angle of flooding θ_f, if this angle is less than 40°. Additionally, the area under the curve (GZ curve) between the angles of heel of 30° and 40° or between 30° and θ_f, if this angle is less than 40°, should not be less than 0.03 metre-radian.
- The righting lever GZ should be at least 0.20m at an angle of heel equal to or greater than 30°
- The maximum righting arm should occur at an angle of heel preferably exceeding 30° but on angle not less than 25°.
- The initial metacentric height GM_o should not be less than 0.15m.



Righting arm (GZ) curve Fig. 1

In addition, for passenger ships: -

- The angle of heel on account of crowding of passengers to one side as defined, should not exceed 10°.
- Also in addition, for passenger ships, the angle of heel on account of turning should not exceed 10° when calculated using the following formula.

$$M_R = 0.02\frac{v^2}{L} \times \Delta(KG - \frac{d}{2})$$

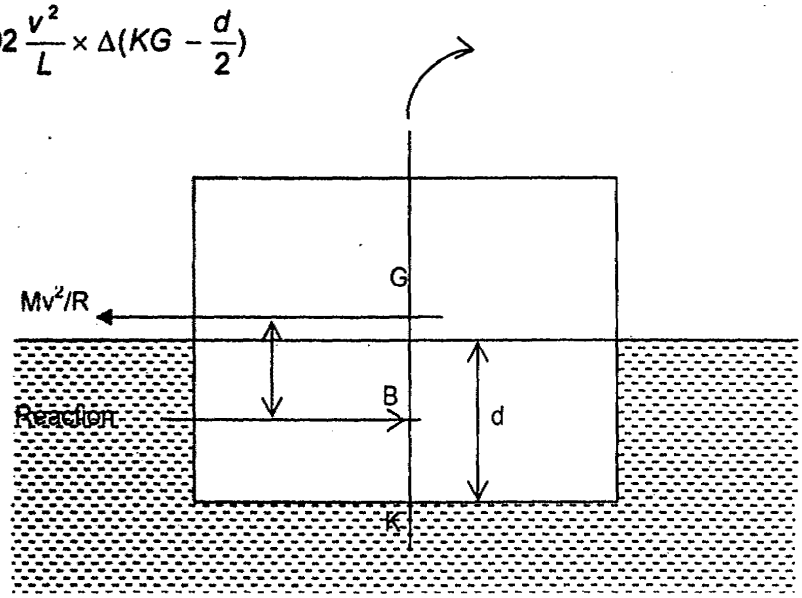


Fig. 2

M_R = heeling moments (m-t)
L = length of ship at waterline (m)
d = mean draught (m)
V_o = service speed (m/s)
Δ = displacement (t)
KG = height of center of gravity above keel (m)

Radial Force acting at COG $= \frac{MV^2}{R} = \frac{\Delta V^2}{gR}$

Upsetting Moment $= \frac{MV^2}{R} \times GB = \frac{\Delta V^2}{gR} \times (KG - \frac{d}{2})$ .....(1)

But righting moment = Δ GM Sinθ .....(2)

(1) = (2) gives $\frac{\Delta V^2}{gR} \times (KG - \frac{d}{2}) = \Delta GM Sin\theta$ or $\frac{V^2}{gR} \times (KG - \frac{d}{2}) = GM Sin\theta$

Or $Sin\theta = \frac{v^2}{gRGM} \times (KG - \frac{d}{2})$

∴The equilibrium is in heeled condition, the formula becomes $Tan\theta = \frac{v^2}{gRGM} \times (KG - \frac{d}{2})$

Where anti-rolling devices are installed on a ship, the Administration should be satisfied that th above criteria can be maintained when the devices are in operation.

A number of influences, such as beam wind on ships with large windage area, icing of topsides water trapped on deck, rolling characteristic, following seas, etc., adversely affect stability an the Administration is advised to take these into account, so far as is deemed necessary.
Provision should be made for safe margin of stability at all stages of the voyage allowance bein made to the adding of weights, such as those due to absorption of water and icing and t reduction of weight such as those due to consumption of fuel and stores.

Ex. 1 A vessel of tactical diam. 610m takes a turn speed 20kn. Ship's draft is 11m, GM 3.7m and KG 10.5m. Calculate angle of heel.

Hint : -

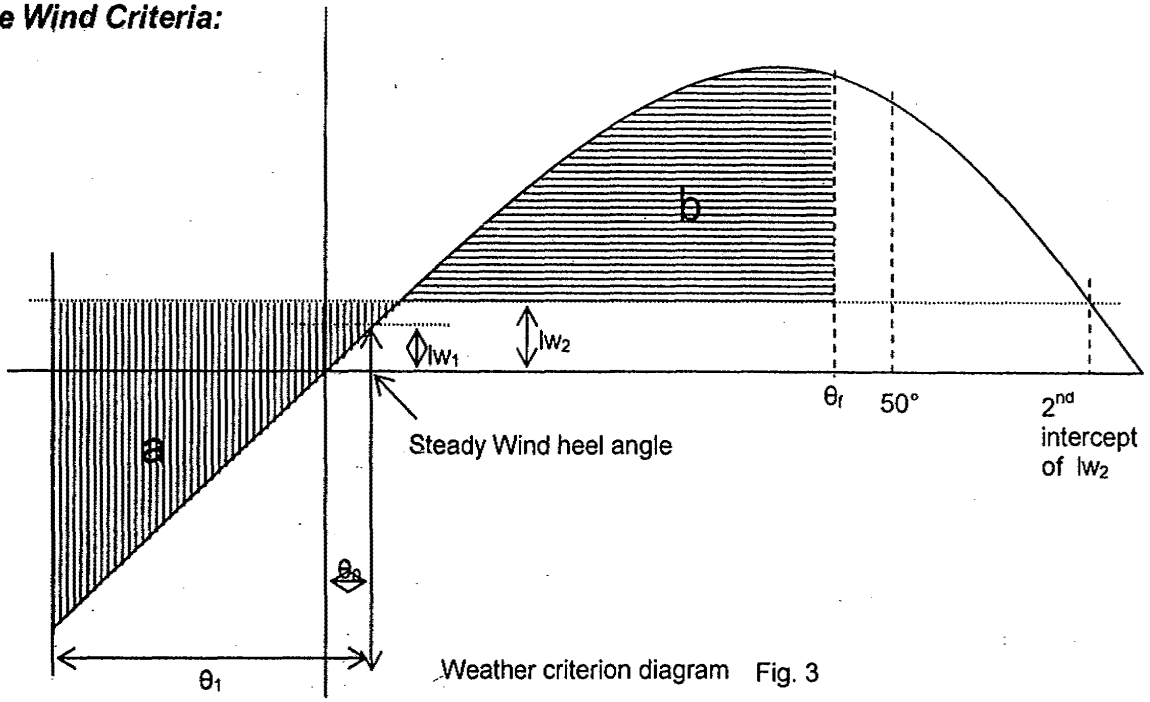
$Tan\theta = \frac{v^2}{gRGM} \times (KG - \frac{d}{2}) = \frac{(20 \times 0.5148)^2 (10.5 - 5.5)}{9.81 \times 305 \times 3.6}$ $\theta = 2.82°$

Gen precautions against capsizing:

Compliance to the criteria does not provide Immunity to capsizing, thus

- General Prudence must be observed.
- Cargo should be stowable on that particular ship.
- Stowage & lashings must be appropriate & adequate.
- IN tow – deck cargo must not be more than appropriate in prevailing conditions.
- Slack tanks must be minimum.
- No maximum values stated regarding area, GM, GZ etc but the same avoided as precaution against large accelerating forces
- Precautions are taken for solid bulk cargo as appropriate.
- Fixed Ballast may be required to be carried and approved by Administration.

Severe Wind Criteria:



Weather criterion diagram Fig. 3

Re- Severe Wind Criteria Diagram:-

The angles are defined as follows:-
θ_o = angle of heel under action of steady wind
θ_1 = angle of roll to windward due to wave action
θ_2 = angle of down flooding (θ_f) or 50° or θ_c whichever is less.

Where,
θ_f = angle of heel at which openings in the hull, superstructures or deck-houses, which cannot be closed weather-tight immerse. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open. lw_1 = Steady wind heel lever.
θ_c = angle of second intercept between wind heeling lever ($l\ w_2$) and GZ curves.

The wind heeling levers ($l\ w_1$) and ($l\ w_2$) are of constant values at all angles of inclination and should be calculated as follows:

$$lw_1 = \frac{PAZ}{100g\ \Delta}(m)$$

$$lw_2 = 1.5\ lw_1(m)$$

Where:
P = 504 N/m^2. The value of P used for ships in restricted services may be reduced, subject to the approval of the Administration;
A = projected lateral area of the portion of the ship and deck cargo above the waterline (m^2);
Z = vertical distance from the center of the underwater lateral area or approximately to a point at one half the draught (m);
Δ = displacement (t)
g = 9.81 m/s^2

The angle of roll (θ_1) referred should be calculated using the tables that are provided & is dependent on moulded (breadth & draft) ratio, block coefficient, type of bilge keel length of waterline, rolling period & position of CG wrt waterline.

$\theta_1 = 109\ kX_1X_2\sqrt{rs}$ (degrees)

Severe Wind Criterion: Area 'b' > or = Area 'a'

Note: 1. Excessive angle, θ_0 should be avoided. As a thumb rule, should not exceed lesser of 16° or 80% of deck edge immersion angle.
2. *FSE accounted for standard loading conditions.*

Ships Loaded With Timber Deck Cargo(Recommended Stability Criteria):-

For ships loaded with timber deck cargoes and provided that the cargo extends longitudinally between superstructures (where there is no limiting superstructure at the after end, the timber deck cargo shall extend at least to the after end of the aftermost hatchway), transversely for the full beam of ship, after due allowance for a rounded gunwale, not exceeding 4% of the breadth of the ship .Also provided that the cargo secured with supporting uprights which remains securely fixed at large angles of heel, the Administration may allow the following criteria which substitute the relevant criteria stated earlier for cargo ships.

- The area under the righting lever curve (GZ curve) shall not be less than 0.08 metre-

  radians up to ϕ = 40° or the angle of flooding if this angle is less than 40°.

- The maximum value of the righting lever (GZ) shall be at least 0.25 m.
- At all times during a voyage, the metacentric height GM_0 shall not be less than 0.1 m, taking into account the absorption of water by the deck cargo and/or ice accretion on the exposed surfaces.
- When determining the ability of the ship to withstand the combined effects of beam wind and rolling the 16° limiting angle of heel under action of steady wind shall be complied with, but the additional criterion of 80% of the angle of deck edge immersion may be ignored.

Stability booklet: -

The ship should be supplied with comprehensive information, which takes in to account timber deck cargo. Such information should enable the mater, rapidly and & in simple way, to obtain accurate guidance as to the stability of the ship under varying conditions of service. Comprehensive rolling period tables or diagrams have proved to be very useful aids in verifying the actual stability condition (Refer to regulation 11-1/22 at the 1974 SOLAS Convention, as amended, and regulation 10/2 at the 1966 LL Convention and the 1988 LL Protocol)

For ships carrying timber deck cargoes, the Administration may deem it necessary that the Master be given information setting out the changes in deck cargo from that shown in the loading conditions when the permeability of the deck cargo is significantly different from 25%.

For ships carrying timber deck cargoes, conditions should be shown indicating the maximum permissible amount of deck cargo, having regards to the lightest stowage rate likely to be met in service.

Operational measures: --

The stability of the ship at all times, including during the process of loading and unloading timber deck cargo, should be positive and to a standard acceptable to the Administration. It should be calculated having regards to:

- The increased weight of the timber deck cargo due to absorption of water in dried or seasoned timber and due to ice accretion, if applicable.
- Variations in consumables.
- The free surface effect of liquid in tanks and
- Weight of water trapped in broken spaces within the timber deck cargo and especially logs.

The Master should: -

i. Cease all loading operations if a list develops for which there is no satisfactory explanation and it would be imprudent to continue loading;
ii. Before proceeding to sea, ensure that:
    - The ship is upright;
    - The ship has an adequate metacentric height and
    - The ship meets the required stability criteria.

The Master of ships having a length less than 100m should also:-

1. Exercise good judgment to ensure that a ship, which carries stowed logs on deck, has sufficient additional buoyancy so that there is no subsequent overloading at sea;
2. Be aware that the calculate GM_o in the departure condition may decrease continuously owing to water adsorption by the deck cargo of logs and consumption of fuel, water and stores and ensure that the ship has adequate GM_o throughout the voyage;
3. Be cautioned that ballasting after departure may cause the ship's operating draught to exceed the timber load line. Ballasting and deballasting should be carried out in accordance with the guidance provided in Code of safe practice for ships carrying timber deck cargoes, 1991 [resolution a 715(17)]

Ships carrying timber deck cargoes should operate, as far as possible, with a safe margin of stability and with a metacentric height which is consistent with safely requirements but such metacentric height should not be allowed to fall below the recommended minimum, as specified.

Excessive initial stability though should be avoided as it will result in rapid and violent motion in heavy seas which will impose large sliding and racking forces on the cargo, causing high stresses on the lashings. Operational experience indicates that metacentric height should preferably not exceed 3% of the breadth in order to prevent excessive accelerations in rolling provided that the relevant stability criteria given for timber deck cargo ships are satisfied. This recommendation may not apply to all ships and the master should take in to consideration the the stability information obtained from the ship's stability booklet.

Calculation of stability:-

In addition to the provision given, the Administration may allow account to be taken of the buoyancy of the deck cargo, assuming that such cargo has a permeability of 25% of the volume occupied by the cargo. Additional curves of stability may be required if the Administration consider it necessary to investigate the influence of different permeabilities and /or assumed effective height of the deck cargo.

Containerships greater than 100m:-

The following requirements apply to the containerships greater than 100m. The Administration may also apply the following criteria to other cargo ships with considerable flare or large water plane areas.

The area under the righting lever curve (GZ curve) should not be less than $\frac{0.009}{C}$ metre-radian up to θ=30° angle of heel and not less than $\frac{0.016}{C}$ metre-radian up to θ=40° or the angle of flooding θ_f if this angle is less than 40°.

Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30° and 40° or between 30° and θ_f if this angle is less than 40°, should not be less than $\frac{0.006}{C}$ metre-radian.

The righting lever GZ should be at least $\frac{0.033}{C}$ m at an angle of heel equal or greater than 30°.

The maximum righting lever GZ should be at least $\frac{0.042}{C}$.

The total area under the righting lever curve (GZ curve) up to the angle of flooding θ_f should not be less than $\frac{0.029}{C}$ metre-radian.

In the above criteria the form factor should be calculated using the formula and figure.

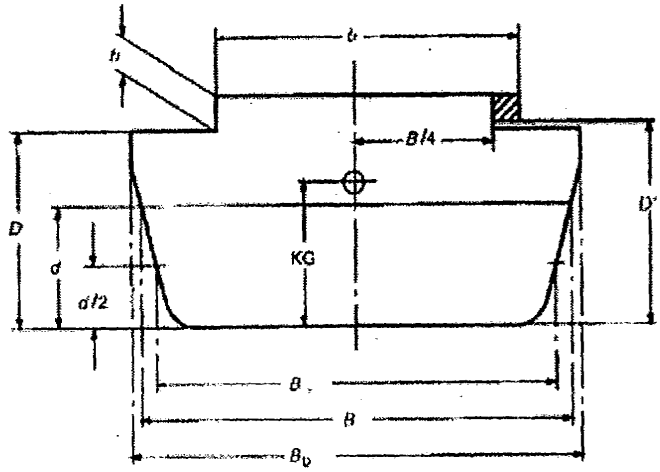


Fig. 4

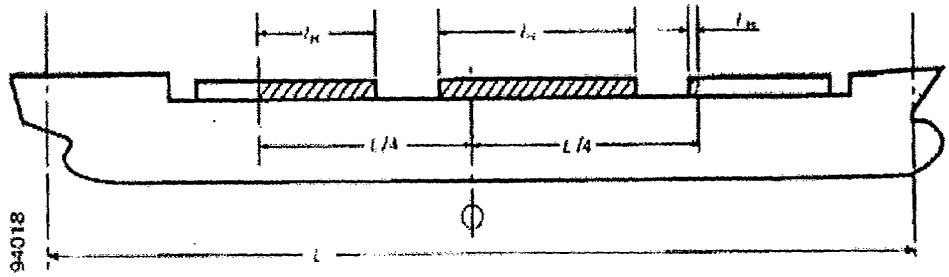


Fig. 5

The shaded areas in figure above represent partial volumes within the hatch coamings considered contributing to resistance against capsizing at large heeling angles when the ship is on a wave crest.

The use of electronic loading and stability instrument is encouraged in determining the ship's trim and stability during different operational conditions.

$$C = \frac{dD'}{B_m^2}\sqrt{\frac{d}{KG}}\left(\frac{C_B}{C_W}\right)^2\sqrt{\frac{100}{L}}$$

Where: -

D= mean draught (m)

D' = moulded depth of the ship, corrected for defined parts of volumes within the hatch coamings according to the formula:

$$D' = D + h \quad D' = D + h\left(\frac{2b - B_D}{B_D}\right)\left(\frac{2\sum l_H}{L}\right)$$

D = moulded depth of the ship (m).
B_D = moulded breadth of the ship (m).
KG = height of the centre of mass above base, corrected for free surface effect, not be taken as less than *d* (m).
C_B = block coefficient.
CW = water plane coefficient.
l_H = length of each hatch coaming within L/4 forward and aft from amidships (m).
b = mean width of hatch coamings within L/4 forward and aft from amidships (m).
h = mean height of hatch coamings within L/4 forward and aft from amidships (m).
L = length of the ship (m).
B = breadth of the ship on the waterline (m).
B_m = breadth of the ship on the waterline at half mean draught (m).

MSC at its 85th session adopted the text of the proposed International Code on Intact Stability, 2008. This Code has been assembled to provide, in a single document, mandatory requirements in the introduction and in part A and recommended provisions in part B relating to intact stability, based primarily on existing IMO instruments. Where recommendations in this Code appear to differ from other IMO Codes, the other Codes should be taken as the prevailing instrument.

Criteria included in the Code are based on the best "state-of-the-art" concepts, available at the time they were developed, taking into account sound design and engineering principles and experience gained from operating ships.

Motion of ships in a seaway should be treated as a dynamical system and relationships between ship and environmental conditions like wave and wind excitations are recognized as extremely important elements.

Part A of the Code address the mandatory criteria and part B contains recommendations and additional guidelines. Code contains intact stability criteria for the following types of ships and other marine vehicles of 24 m in length and above unless otherwise stated:

- Cargo ships;
- Cargo ships carrying timber deck cargoes;
- Passenger ships;
- Fishing vessels;
- Special purpose ships;
- Offshore supply vessels;
- Mobile offshore drilling units;
- Pontoons; and
- Cargo ships carrying containers on deck and containerships.

Administrations may impose additional requirements regarding the design aspects of ships of novel design or ships not otherwise covered by the Code.

Part A – mandatory criteria:
Chapter 1 – general
- Application,
- Dynamic stability phenomena in waves.

Chapter 2 – general criteria
- General
- Criteria regarding righting lever curve properties
- Severe wind and rolling criterion (weather criterion)

Chapter 3 – special criteria for certain types of ships
- Passenger ships,
- Oil tankers of 5,000 dwt and above,
- Cargo ships carrying timber deck cargoes,
- Cargo ships carrying grain in bulk,
- High-speed craft.

Part B – recommendations for certain types of ships and additional guidelines
Chapter 1 – General
- Purpose,
- Application.

Chapter 2 – Recommended Design Criteria for Certain Types of Ships
- Fishing vessels,
- Pontoons,
- Containerships greater than 100 m,
- Offshore supply vessels,
- Special purpose ships,
- Mobile offshore drilling units (MODUS).

Chapter 3 – Guidance in Preparing Stability Information:
- Effect of free surfaces of liquids in tanks,
- Permanent ballast,
- Assessment of compliance with stability criteria,
- Standard conditions of loading to be examined,
- Calculation of stability curves,
- Stability booklet,
- Operational measures for ships carrying timber deck cargoes,
- Operating booklets for certain ships.

Chapter 4 – Stability Calculations Performed by Stability Instruments:
- Stability instruments.

Chapter 5 – Operational Provisions against Capsizing:
- General precautions against capsizing,
- Operational precautions in heavy weather,
- Ship handling in heavy weather.

Chapter 6 – Icing Considerations:
- General,
- Cargo ships carrying timber deck cargoes,
- Fishing vessels,
- Offshore supply vessels 24 m to 100 m in length.

Chapter 7 -- Considerations for Watertight and Weather tight Integrity

- Hatchways,
- Machinery space openings,
- Doors,
- Cargo ports and other similar openings,
- Sidescuttles, window scuppers, inlets and discharges,
- Other deck openings,
- Ventilators, air pipes and sounding devices,
- Freeing ports,
- Miscellaneous.

Chapter 8 – Determination of Lightship Parameters :

- Application,
- Preparations for the inclining test,
- Plans required,
- Test procedure,
- Inclining test for modus,
- Stability test for pontoons.

Annex 1 – Detailed Guidance for the Conduct of an Inclining Test:

- Introduction,
- Preparations for the inclining test,
- Free surface and tankage,
- Mooring arrangements,
- Test weights,
- Pendulums,
- U-tubes,
- Inclincmeters,
- Equipment required,
- Test procedure,
- Initial walk through and survey,
- Freeboard/draught readings,
- The incline.

Annex 2 – Recommendations For Skippers of Fishing Vessels on Ensuring A Vessel's Endurance In Conditions of Ice Formation:

- Prior to departure,
- At sea,
- During ice formation,
- List of equipment and hand tools.

Some of the fetures stressed upon in the new code are as follows:

Passenger ships:-

In respect of stability calculations of passenger ships following assumptions are made:
A minimum weight of 75 kg shall be assumed for each passenger except that this value may be increased subject to the approval of the Administration. In addition, the mass and distribution of the luggage shall be approved by the Administration.

The height of the centre of gravity for passengers shall be assumed equal to:

1. 1 m above deck level for passengers standing upright. Account may be taken, if necessary, of camber and sheer of deck; and
2. 0.3 m above the seat in respect of seated passengers.

Passengers and luggage shall be considered to be in the spaces normally at their disposal, when assessing compliance with the general criteria.

Passengers without luggage shall be considered as distributed to produce the most unfavourable combination of passenger heeling moment and/or initial metacentric height, which may be obtained in practice, when assessing compliance with the special passenger ship criteria. In this connection, a value higher than four persons per square metre is not necessary.

Fishing Vessels:-

The stability criteria should be complied with for all conditions of loading unless the Administration is satisfied that operating experience justifies departures there from.

General precautions against capsizing: -

Apart from general precautions, the following measures should be considered as preliminary guidance on matters influencing safety as related to stability:

1. All fishing gear and other heavy material should be properly stowed and placed as low in the vessel as possible.
2. Particular care should be taken when pull from fishing gear might have a negative effect on stability, e.g., when nets are hauled by power-block or the trawl catches obstructions on the sea-bed. The pull of the fishing gear should be from as low a point on the vessel, above the waterline, as possible.
3. Gear for releasing the deck load in fishing vessels which carry the catch on deck, e.g., herring, should be kept in good working condition.
4. When the main deck is prepared for carrying deck load by dividing it with pound boards, there should be slots between them of suitable size to allow easy flow of water to freeing ports, thus preventing trapping of water.
5. To prevent a shift of the fish load carried in bulk, portable divisions in the holds should be properly installed.
6. Reliance on automatic steering may be dangerous as this prevents changes to course which may be needed in bad weather.
7. Necessary care should be taken to maintain adequate freeboard in all loading conditions, and where load line regulations are applicable they should be strictly adhered to at all times and
8. Particular care should be taken when the pull from fishing gear results in dangerous heel angles. This may occur when fishing gear fastens onto an underwater obstacle or when handling fishing gear, particularly on purse seiners, or when one of the trawl wires tears off. The heel angles caused by the fishing gear in these situations may be eliminated by employing devices which can relieve or remove excessive forces applied through the fishing gear. Such devices should not impose a danger to the vessel through operating in circumstances other than those for which they were intended.

Recommended general criteria: -

The general intact stability criteria should apply to fishing vessels having a length of 24 m and over, with the exception of requirements on the initial metacentric height GM, which, for fishing vessels, should not be less than 0.35 m for single-deck vessels. In vessels with complete

superstructure or vessels of 70 m in length and over the metacentric height may be reduced to the satisfaction of the Administration but in no case should be less than 0.15 m.

The adoption by individual countries of simplified criteria which apply such basic stability values to their own types and classes of vessels is recognized as a practical and valuable method of economically judging the stability. Where arrangements other than bilge keels are provided to limit the angle of roll, the Administration should be satisfied that the stability criteria are maintained in all operating conditions.

Severe wind and rolling criterion (weather criterion) for fishing vessels:
The Administration may apply the normal provisions of part A, to fishing vessels of 45 m length and over.

For fishing vessels in the length range between 24 m and 45 m, the Administration may apply the provisions of part A. Alternatively the values of wind pressure may be taken from the following table:

h (m)	1	2	3	4	5	6 and over
P (Pa)	316	386	429	460	485	504

Where *h* is the vertical distance from the centre of the projected vertical area of the vessel above the waterline, to the waterline.

Recommendation for an interim simplified stability criterion for decked fishing vessels under 30 m in length:
For decked vessels with a length less than 30 m, the following approximate formula for the minimum metacentric height *GM min* (in metres) for all operating conditions should be used as the criterion:

$$GM_{min} = 0.53 + 2B\left[0.075 - 0.37\left(\frac{f}{B}\right) + 0.82\left(\frac{f}{B}\right) - 0.014\left(\frac{B}{D}\right) - 0.032\left(\frac{l_s}{L}\right)\right]$$

Where:

L is the length of the vessel on the waterline in maximum load condition (m)
l_s is the actual length of enclosed superstructure extending from side to side of the vessel (m)
B is the extreme breadth of the vessel on the waterline in maximum load condition (m)
D is the depth of the vessel measured vertically amidships from the base line to the top of The upper deck at side (m)
f is the smallest freeboard measured vertically from the top of the upper deck at side to the actual waterline (m).

The formula is applicable for vessels having: -

1. *f/B* between 0.02 and 0.20;
2. *ls/L* smaller than 0.60;
3. *B/D* between 1.75 and 2.15;
4. Sheer fore and aft at least equal to or exceeding the standard sheer prescribed in regulation 38(8) of the International Convention on Load Lines, 1966 or the Protocol of 1988 as amended, as applicable; and
5. Height of superstructure included in the calculation is not less than 1.8 m.

The calculated value of GM should be compared with actual GM values of the vessel in all load conditions. If an inclining experiment based on estimated displacement, or another approximate

method of determining the actual GM is used, a safety margin should be added to the calculated *GM min.*

Permanent ballast:-
If used, permanent ballast should be located in accordance with a plan approved by the Administration and in a manner that prevents shifting of position. Permanent ballast should not be removed from the ship or relocated within the ship without the approval of the Administration. Permanent ballast particulars should be noted in the ship's stability booklet.

Assessment of compliance with stability criteria: -
Except as otherwise required by this Code, for the purpose of assessing , whether the stability criteria are met or not, stability curves using the assumptions given in this Code should be ok for the loading conditions intended by the owner in respect of the ship's operations. If the owner of the ship does not supply sufficiently detailed information regarding such loading conditions, calculations should be made for the standard loading conditions.

Standard conditions of loading to be examined:-
The standard loading conditions referred to in the text of the present Code are as follows.
For a passenger ship:

1. Ship in the fully loaded departure condition with cargo, full stores and fuel and with the full number of passengers with their luggage;
2. Ship in the fully loaded arrival condition, with cargo, the full number of passengers and their luggage but with only 10% stores and fuel remaining;
3. Ship without cargo, but with full stores and fuel and the full number of passengers and their luggage; and
4. Ship in the same condition as in 3. above with only 10% stores and fuel remaining.

For a cargo ship: -

1. Ship in the fully loaded departure condition, with cargo homogeneously distributed throughout all cargo spaces and with full stores and fuel;
2. Ship in the fully loaded arrival condition with cargo homogeneously distributed throughout all cargo spaces and with 10% stores and fuel remaining;
3. Ship in ballast in the departure condition, without cargo but with full stores and fuel; and
4. Ship in ballast in the arrival condition, without cargo and with 10% stores and fuel remaining.

For a cargo ship intended to carry deck cargoes:-

1. Ship in the fully loaded departure condition with cargo homogeneously distributed in the holds and with cargo specified in extension and mass on deck, with full stores and fuel; and
2. Ship in the fully loaded arrival condition with cargo homogeneously distributed in holds and with a cargo specified in extension and mass on deck, with 10% stores and fuel.

Calculation of stability curves: -
Hydrostatic and stability curves should be prepared for the trim range of operating loading conditions taking into account the change in trim due to heel (free trim hydrostatic calculation). The calculations should take into account the volume to the upper surface of the deck's heathing.

Furthermore, appendages and sea chests need to be considered when calculating hydrostatics and cross curves of stability. In the presence of port-starboard asymmetry, the most unfavourable righting lever curve should be used.

Operating booklets for certain ships: -

Special purpose ships and novel crafts should be provided with additional information in the stability booklet such as design limitations, maximum speed, worst intended weather conditions or other information regarding the handling of the craft that the master needs to operate the ship safely.

For double hull oil tankers of single cargo tank across design, an operation manual for loading and unloading cargo oil should be provided, including operational procedures of loading and unloading cargo oil and detailed data of the initial metacentric height of the oil tanker and that of free surface correction of liquids in cargo oil tanks and ballast tanks during loading and unloading cargo oil (including ballasting and discharging) and cargo oil washing of tanks.

The stability booklet of ro-ro passenger ships should contain information concerning the importance of securing and maintaining all closures watertight due to the rapid loss of stability which may result when water enters the vehicle deck and the fact that capsize can rapidly follow.

Stability calculations performed by stability instruments: -

A stability instrument installed onboard should cover all stability requirements applicable to the ship.

The scope of stability calculation software should be in accordance with the approved stability booklet and should at least include all information and perform all calculations or checks as necessary to ensure compliance with the applicable stability requirements.

An approved stability instrument is not a substitute for the approved stability booklet, and is used as a supplement to the approved stability booklet to facilitate stability calculations.

An operation manual is to be provided for the stability instrument. The language should be the same as used in the ship's approved stability booklet. Any change in software version related to the stability calculation should be reported to and be approved by the Administration.

Data entry system are of two types. A passive system requires manual data entry.

An active system replaces partly the manual entry with sensors reading and entering the contents of tanks, etc.

Three types of calculations performed by stability software are acceptable depending upon a vessel's stability requirements:

Type 1: Software calculating intact stability only (for vessels not required to meet a damage stability criterion).

Type 2: Software calculating intact stability and checking damage stability on basis of a limit curve.

Type 3: Software calculating intact stability and damage stability by direct application of pre-programmed damage cases for each loading condition.

Functional requirements: -

The stability instrument should present relevant parameters of each loading condition in order to assist the Master in his judgment on whether the ship is loaded within the approved limits. The following parameters should be presented for a given load condition:

1. Detailed deadweight data items including centre of gravity and free surfaces, if applicable,

2. Trim, list,
3. Draught at the draught marks and perpendiculars,
4. Summary of loading condition displacement; VCG; LCG, TCG; VCB, LCB, TCB, LCF, GM_T and GM_L;
5. Table showing the righting lever versus heel angle including trim and draught,
6. Down-flooding angle and corresponding down-flooding opening and
7. Compliance with stability criteria: listings of all calculated stability criteria, the limit values, the obtained values and the conclusions (criteria fulfilled or not fulfilled).

- If direct damage stability calculations are performed, the relevant damage cases according to the applicable rules should be pre-defined for automatic check of a given load condition.
- A clear warning should be given on screen and in hard copy printout if any of the limitations are not complied with.
- The data are to be presented on screen and in hard copy printout in a clear unambiguous manner.
- The date and time of a saved calculation should be part of the screen display and hard copy printout.
- Each hard copy printout should contain identification of the calculation program including version number.
- Units of measurement are to be clearly identified and used consistently within a loading calculation.

In addition the code provides for acceptable tolerances, approval procedure, user manual, installation testing, test conditions & periodical testing. It is the responsibility of the ship's Master to check the accuracy of the stability instrument at each annual survey by applying at least one approved test condition. If an Administration's representative is not present for the stability instrument check, a copy of the test condition results obtained by this check is to be retained on board as documentation of satisfactory testing for the Administration's representative's verification.

Q. 1 M V ALPHASHIP at a F 7.00 m, A 8.40, KG 8.72 m, FSM 1900 tm, turns in a circle of radius 410 m at a speed of 14.5 Kts. Calculate the angle of heel produced when taking a sharp turn.

For'd 7.00 m, Aft 8.40 m Trim 1.40 m by stern, Mean draft = 7.70 m, LCF = 85.055 m

Hydrostatic draft $= 8.40 - \frac{1.40 \times 85.055}{171.792} = 7.707$ m

draft	Δ	KB	KM
7.6	21970.2	4.04	9.917
7.8	22625.4	4.144	9.878
7.707	22320.73	4.096	9.896

GM (fluid) $= 9.896 - 8.72 - \frac{1900}{122320.73} = 1.160$ m

Speed $= 14.5$ kn $= \frac{14.5 \times 1852.3}{3600}$/s $= 7.46$ m/s

a) $\tan\theta = \frac{v^2BG}{g.r.GM} = \left(\frac{14.5\times1852.3}{3600}\right)^2 \times \frac{(8.72-4.096)}{9.81\times410\times1.16} = 0.0552$

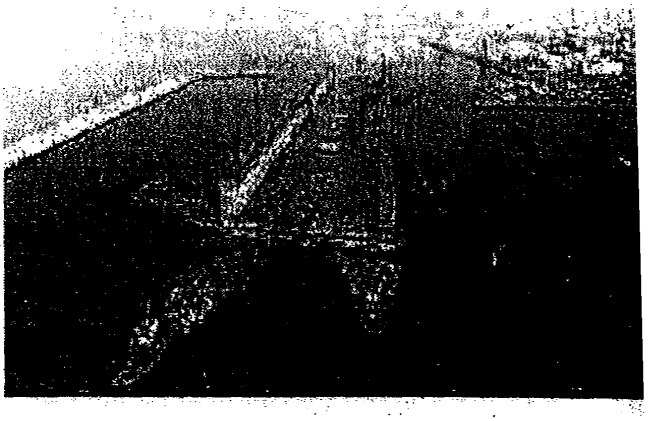
$\theta = 3.16°$

Q. 2 M V ALPHA SHIP at a draft of for'd 7.37m, aft 9.746m has KG 8.36m and FSM 1272 tm, angle of flooding is 43°. Draw her curve of statical stability up to an angle of 40^0. State if intact stability criteria are satisfied using ordinates at 10° intervals.
Mean draft = 8.558 m, LCF = 84.123 m
Ans. Refer to exercise on M V ALPHASHIP in chapter 12.

Q. 3 In above condition determine if the vessel satisfies the severe wind criteria. The data of M V ALPHA SHIP required for the severe wind criterion is as follows:
A = area 1560 m^2, centre of Windage 6.8 m above water level. k = 1 as the ship has no bilge keels. Angle of flooding 34° X_1, X_2, r, s, obtain from tables are 0.8, 1, 1.36 and 0.06 respectively.

Refer to exercise on M V ALPHASHIP in chapter 12.

Largest Floating Dock: PSM has been fitted to all ballast tanks on the refitted KOTKA floating dock. This is the largest floating dock of its type and made of concrete. The picture shows the dock being transported from Genoa where it had been for some years and gives a better idea of the real proportions of this giant. PSM has recently received a further order for the dock covering a six-point draft system to monitor deflection under load conditions.



Chapter 18 Moment of Inertia and theorem of parallel axes

Inertia is the property by the virtue of which stationary body continues to be stationary and a body in motion maintains similar state of motion unless affected by an external force.
The inertia or the resistance to the state of motion, in case of linear motion is governed by the mass of the body.

Moment of inertia: - Moment of inertia or the mass moment of inertia is the resistance to the state of motion in case of the rotational motion.
Thus we can say that in a rotational motion the moment of inertia is equivalent of the mass in linear motion.
Mathematically moment of inertia of a body about an axis is defined as the sum of the product of the masses of particles constituting the body and the square of there respective distances from the axis.
Let a body be made up of number of particles of masses m_1, m_2, m_3 ... at a distance of d_1, d_2, d_3 from the axis. The M.I. about the axis will be equal to $m_1d_1^2 + m_2d_2^2 + m_3d_3^2 + ...m_nd_n^2$
The radius of gyration if we consider that the whole mass is concentrated at a distance K from the axis of rotation, then the moment of inertia can be expressed as $M.I = Mk^2$ where k is equal to radius of gyration.

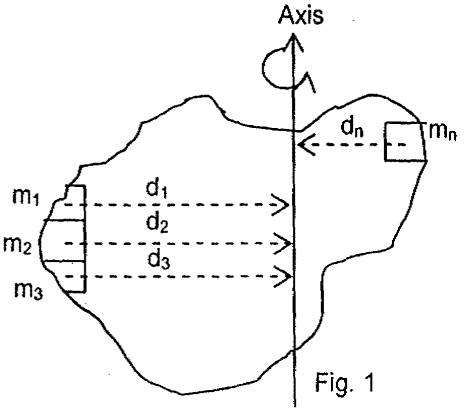


Fig. 1

$M.I. = m_1d_1^2 + m_2d_2^2 + m_3d_3^2 + ...m_nd_n^2$

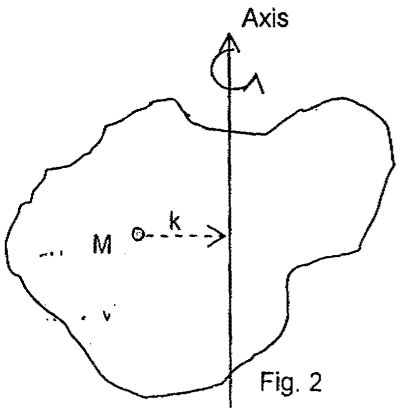


Fig. 2

$MI = Mk^2$

Let us now consider three objects of same mass / radius but of different shapes. These three objects are symmetrical about the axis through centroid and are

- A solid disk,
- A ring with the spokes and
- A solid sphere.

Obviously the moment of inertia will be maximum in case of a ring and minimum in case of the solid sphere.

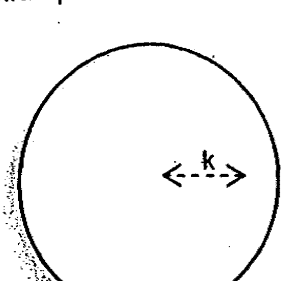


Fig. 3

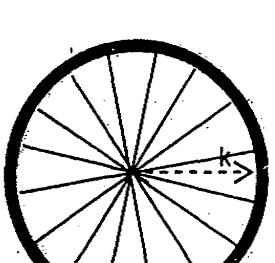


Fig. 4

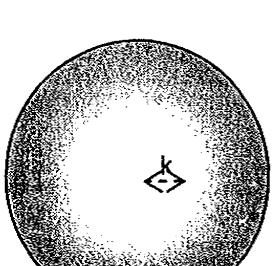


Fig. 5

A cycle wheel has weight concentrated away from axis. It is provided with spokes in order to have maximum MI for a given mass and there by providing uniformity in speed.

For a given body the moment of inertia would be minimum if the axis is through COG of the body for any other parallel axis the MI would increase by an amount equal to Md^2, where M is the mass of the body and d is the distance between the two parallel axes.

Let us apply this knowledge to the second moment of area or moment of inertia of an area.

The principle is applied to calculate BM_T, BM_L, FSE etc.
In the following area, bound by a curve the ordinates provided are y_1, y_2, y_3....etc at uniform distance of dx from each other & form very small elements of areas dA_1 , dA_2 , dA_3 etc. Each of these elements may be considered rectangular. It can be said that $dA_1 = y_1 \times dx$, $dA_2 = y_2 \times dx$,..
The axis of reference about which the M.I has to be found is parallel to the elements. These elements are at a distance of x_1, x_2, x_3 respectively

The MI of area of a plane about this axis (y axis) is equal to the sum of the products of all the elements of area and the square of distance of respective element from the axis.

Thus MI of area is equal to $dA_1 x_1^2 + dA_2 x_2^2 + dA_3 x_3^2$ ..... $dA_n x_n^2$.

Alternately we may proceed as follows: -
Let us consider one of the elements say 1st element of area dA_1.
MI about own axis $\frac{y_1 \times dx^3}{12}$

MI about reference axis (y axis in the following diagram) = $\frac{y_1 \times dx^3}{12} + (y_1.dx) \cdot x_1^2$.

$\because dx^3$ is v v small, neglecting the 1st term which also is v v small, the MI of 1st element about ref axis = $(y_1.dx) \cdot x_1^2$.

Total MI of all the elements about the ref axis = $\int (y.dx) \cdot x^2 = \int y.x^2 dx$.

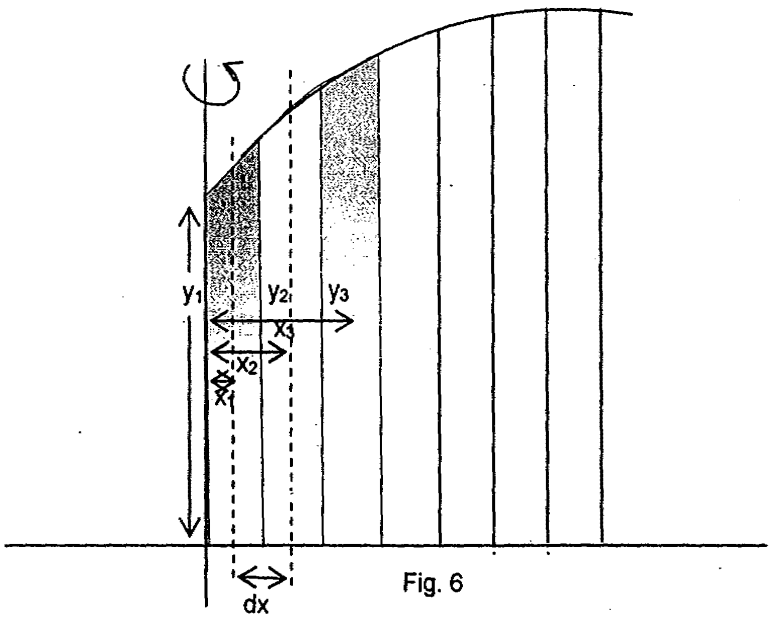


Fig. 6

In another example the axis is shown perpendicular to the elements. The moment of inertia about this axis (x axis, perpendicular to elements of area) is equal to

$$dA_1\left(\frac{y_1}{2}\right)^2 + dA_2\left(\frac{y_2}{2}\right)^2 + dA_3\left(\frac{y_3}{2}\right)^2 .....$$

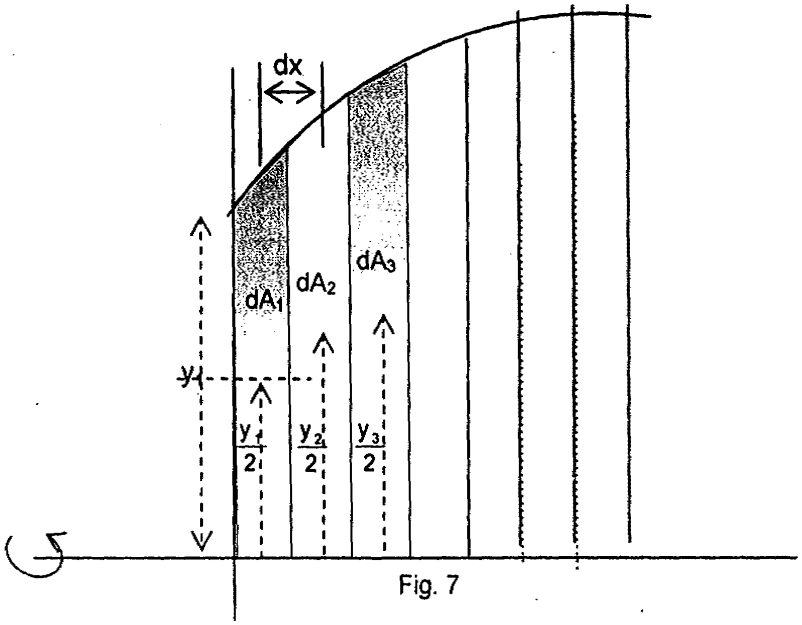


Fig. 7

Alternately we may proceed as follows: -

The ordinates provided are y_1, y_2, y_3....etc at uniform distance of dx from each other & form very small elements of areas dA_1 , dA_2 , dA_3 etc. Each of these elements may be considered rectangular. It can be said that $dA_1 = y_1 \times dx$, $dA_2 = y_2 \times dx$...

The axis of reference about which the M.I has to be found is perpendicular to the elements.

Let us consider one of the elements say 1st element of area dA_1.

MI of element dA_1 about own axis through centroid & // to reference axis = $\frac{dx \times y_1^3}{12}$

MI of element dA_1 about reference axis = $\frac{dx \times y_1^3}{12} + (dx.y_1).\left(\frac{y_1}{2}\right)^2 = dx\left(\frac{y_1^3}{12}\right) + \left(\frac{y_1^3}{4}\right) = dx\left(\frac{y_1^3}{3}\right)$

M.I all the elements about the ref axis = $\frac{1}{3}\int (y^3.dx)$.

The moment of inertia of area of some regular shaped areas about their respective centroids:

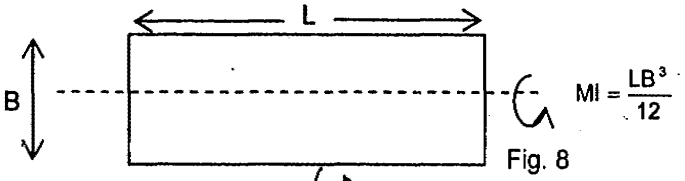


Fig. 8

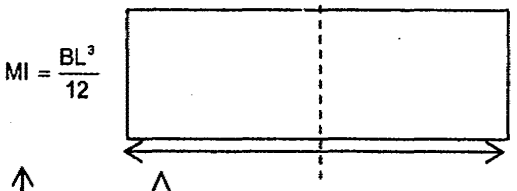


Fig. 9

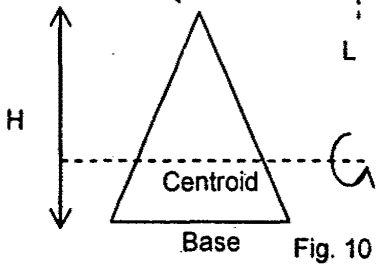


Fig. 10

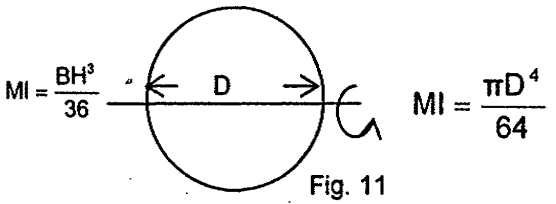


Fig. 11

The MI of area thus obtained is a function of the resistance to the rotational motion about the given axis. Once again the MI would be minimum if the axis passes through the centroid. For any other parallel axis the MI would increase by Ad^2, where A is the area of the plane and d is the distance between the two parallel axes.

Let us consider a uniform plate for making the rudder as shown in the fig below: In the first case the axis passes through the centroid and the effort required by the steering engine would be minimum. The effort required by the steering engine in the second case would be much higher.

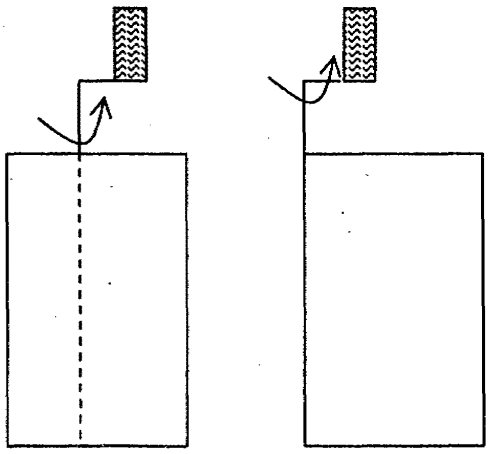


Fig. 12

In the following cases formulae are shown for MI about axis through centroid. On the right of the same MI about a // axis is given. MI increases by the amount Ad^2.

MI through the centroid

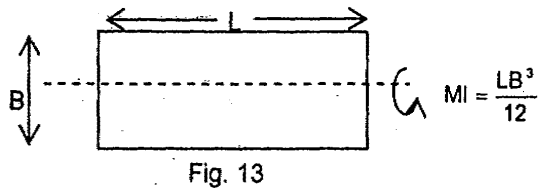


Fig. 13

MI through the centroid and through a // axis

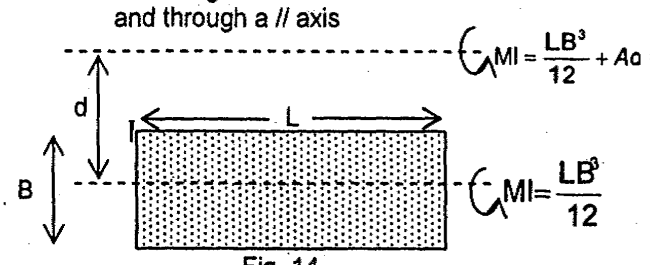


Fig. 14

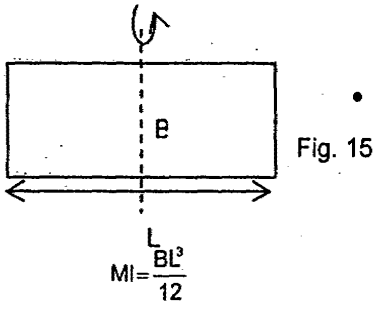


Fig. 15

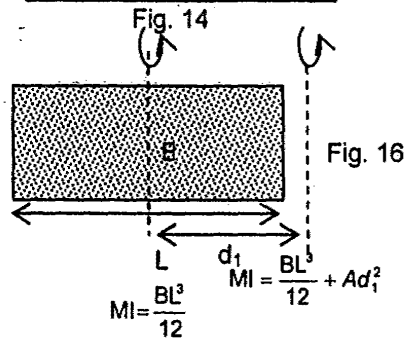


Fig. 16

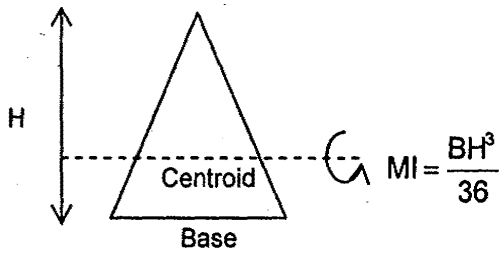


Fig. 17

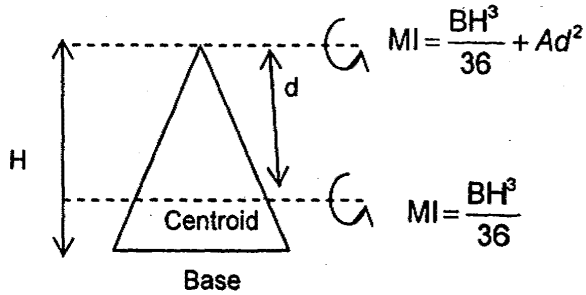


Fig. 18

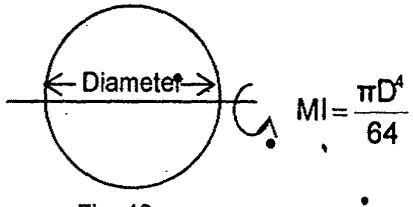


Fig. 19

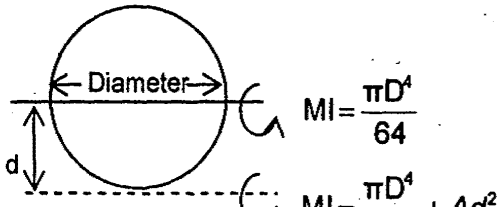


Fig. 20

Ex. 1 A rectangular plane has L = 10m and B = 4m. Find the moment of inertia about:

a) Axis passing through centroid and parallel to the longer side.
b) Axis passing through centroid and parallel to shorter side.
c) Axis along one of the longer sides.
d) Axis along one of the shorter sides.

Sol^n: -

a. $MI_{centroid} = \frac{LB^3}{12} = \frac{10 \times 4^3}{12} = 53.3\ m^4$

b. $MI_{centroid} = \frac{BL^3}{12} = \frac{4 \times 10^3}{12} = 333.3\ m^4$

c. $MI = \frac{LB^3}{12} + Ad^2 = \frac{10 \times 4^3}{12} + 40 \times 2^2 = 53.3 + 160 = 213.3\ m^4$

d. $MI = \frac{BL^3}{12} + Ad^2 = \frac{4 \times 10^3}{12} + 40 \times 5^2 = 333.3 + 1000 = 1333.3 m^4$

Ex. 2 A triangular plane has a base of 8m and the height of 9m. Find the MI about
a) Axis passing through centroid and parallel to base.
b) Axis passing through apex and parallel to the base.

Sol^n: -

$$MI_{\text{centroid // to base}} = \frac{BH^3}{36} = \frac{8 \times 9^3}{36} = 162m^4$$

$$MI_{\text{through apex // to base}} = \frac{BH^3}{36} + Ad^2$$

$$= \frac{8 \times 9^3}{36} + 36 \times 6^2 = 1458m^4$$

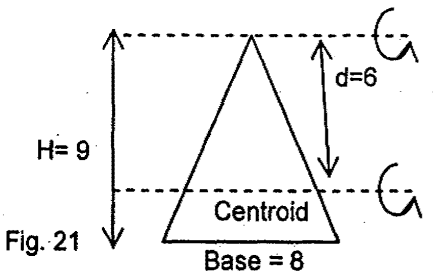


Fig. 21

Ex. 3 Find the MI about a. the diameter of a semicircle, b. about tangent to the full circle. (radius, 6m)

Sol^n: -

a.

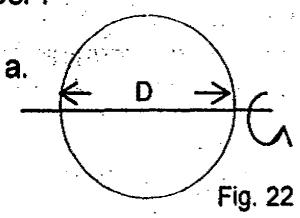
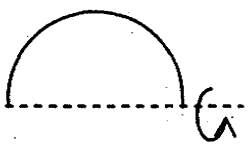


Fig. 22

$MI = \frac{\pi D^4}{64}$


Fig. 23

$MI = \frac{\pi D^4}{128} = \frac{\pi 12^4}{128} = 508.7m^4$

b. The MI about an axis // to the diameter can be found in case of a circle but to find MI about an axis // to diameter in case of semi circle, we must first find the MI about the // axis through the centroid, (minimum of the // axes). This MI is less by an amount equal to Ad^2. From the MI about the centroid axis, MI about any other // axis may be found.

Distance of centroid from diameter = $\frac{4R}{3\pi} = \frac{4x6}{3\pi} = 2.548m$

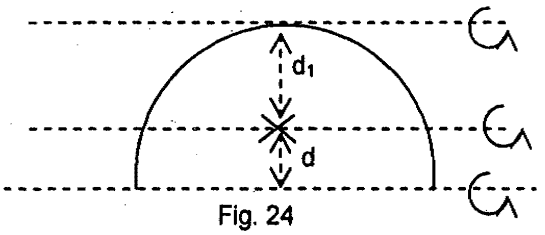


Fig. 24

$$MI_{\text{centroid // to diametre}} = \frac{\pi D^4}{64} - Ad^2 = 508.7 - 56.2 \times 2.548^2 = 141.7\ m^4$$

$$MI_{\text{axis tangent and // to diametre}} = \frac{\pi D^4}{64} - Ad^2 + Ad_1^2 = 141.7 + 669.7 = 811.4m^4$$

Ex. 4 A floating drydock has a DB tank of depth 4m & width 44m. The vertical side tanks on either side are 4 m wide & are above the DB tanks. If the draft of the drydock is 8m and KG is 4.5m. find the GM_T of dry-dock.

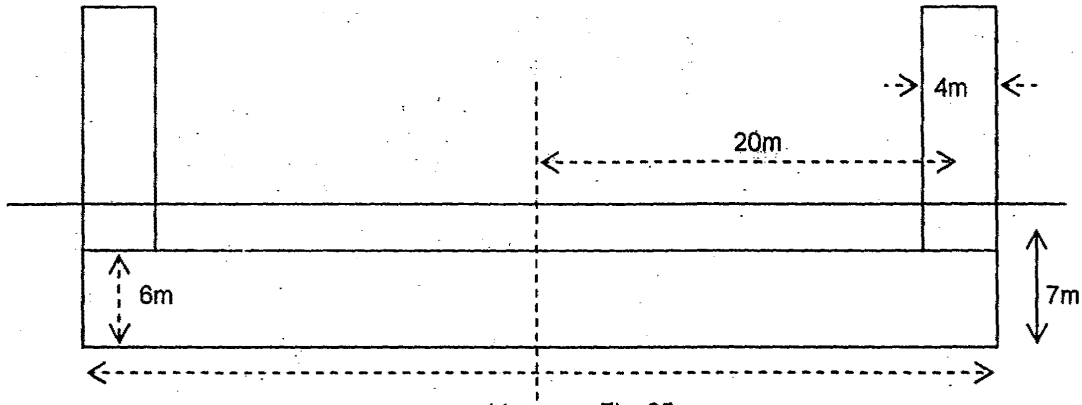


Fig. 25

Sol^{n}: -

The transverse stability parameters of a box vessel of longitudinally uniform vessel like a floating dry dock are independent of the length, hence to find KB, BM or GM we will not require to know the length of the dry dock. The distance of centroid of transverse under water area from base is also the distance of COB above base.

Taking moment of areas about base: $KB = \frac{\{(44 \times 6) \times 3\} + 2 \times \{(4 \times 2) \times 7\}}{(44 \times 6) + 2 \times (4 \times 2)} = \frac{904}{280} = 3.229\text{m}$

Viewing the Plan view of waterplane at the draft level:

The MI of the side wall tank area about own axis = $\frac{LB^3}{12} = \frac{L \times 4^3}{12}$

The MI of both the side wall tank area about centerline = $\left(\frac{L \times 4^3}{12} + L \times 4 \times 20^2\right) \times 2$

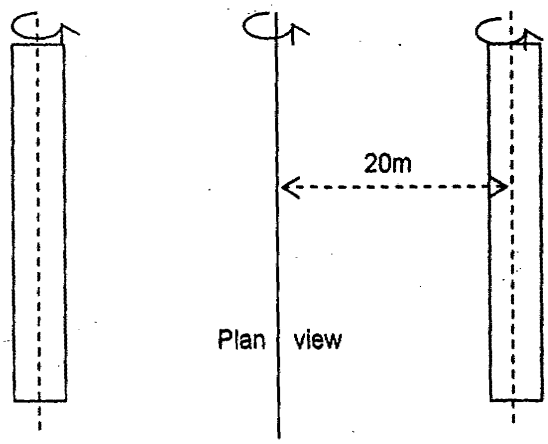


Fig. 26

$$BM_T = \frac{MI_{CL}}{UW\ Vol} = \frac{\left(\frac{L \times 4^3}{12} + L \times 4 \times 20^2\right) \times 2}{280 \times L} = \frac{L(1605.33) \times 2}{280 \times L} = 11.467\text{m}$$

$GM_T = 3.171 + 11.467 - 4.5 = 19.138\text{m}$.

Ans. $GM_T = 19.138\text{m}$.

Ex. 5 A box 4m broad is floating at a draft of 3 m & has a KG of 2.4m. Find it's GM_T. Also find the GM_T after it is connected with an identical box with a weight less platform on top in such a way that the boxes are 6m apart as measure CL to CL.

Sol^n: -

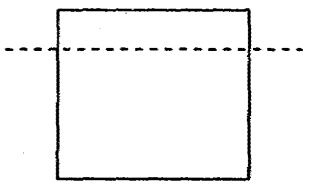


Fig. 28

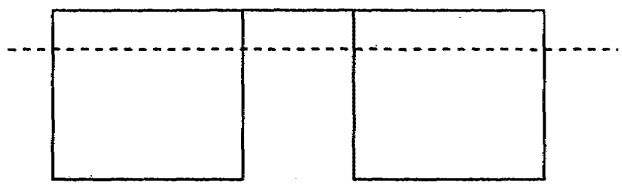


Fig. 27

KB of the single box = ½ x 3 = 1.5m.

$BM_T = \frac{B^2}{12d} = 0.444m$

$\therefore KM = 1.5 + 0.444 = 1.944$

$GM = KM - KG = 1.944 - 2.4 = -0.456m$

Since the platform on top is weightless the draft, KB, KG of the composite unit will remain same as that of the single box. The BM however will change and can be found as follows:

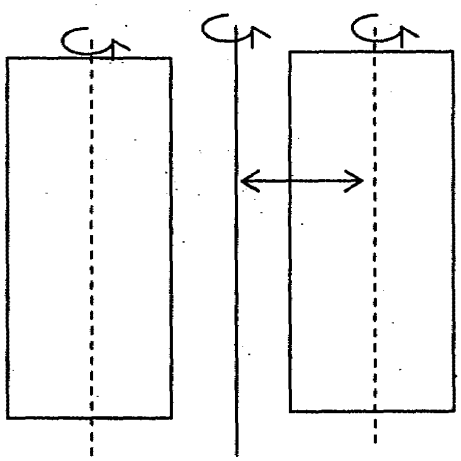


Fig. 29

$$BM_T = \frac{MI_{CL}}{UW\,Vol} = \frac{\left(\frac{L \times 4^3}{12} + L \times 4 \times 3^2\right) \times 2}{12 \times L} = \frac{L(41.333) \times 2}{12 \times L} = 6.889m$$

$\therefore KM = 1.5 + 6.889 = 8.389\ m$

$GM = KM - KG = 8.389 - 2.4 = 5.989m$

Ex. 6 A hull of displacement 248t and TPC 0.5 has a GM = 0.4m. Find the change in GM when the hull is connected with another identical hull using a weightless platform on top. (The distance between the hull from CL to CL is 7m).

Sol^n: -

$$WPA = \frac{100TPC}{1.025} = 48.78 \qquad UW\,V = \frac{\Delta}{1.025} = \frac{248}{1.025} = 241.951$$

Since the platform on top is weightless the draft, KB, KG of composite unit will not change as compared to the original hull.

$\therefore GM = KB + BM - KG$ & also KB and KG are unchanged, change in BM = change in GM.

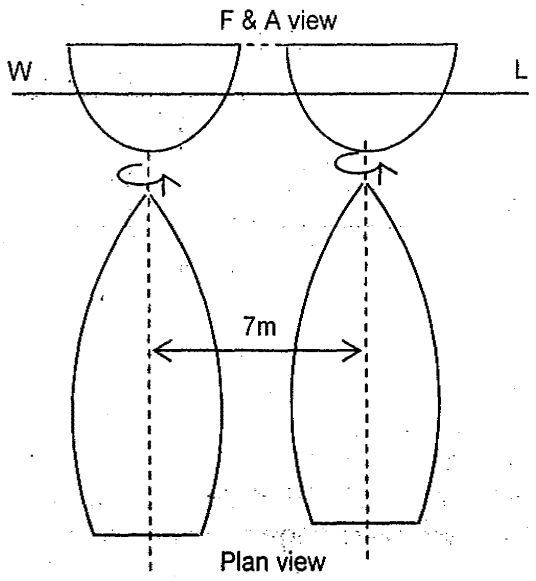


Fig. 30

BM_T of the single hull = $\frac{I_{CL}}{UWV} = \frac{I_{CL}}{241.951}$ ..... (1)

BM_T of the composite unit = $\frac{I_{COMMON\ CL}}{Tot\ UW\ V} = \frac{2(I_{CL} + WPA \times d^2)}{Tot\ UWV} = \frac{2(I_{CL} + 48.78 \times 7^2)}{2 \times 241.951}$

$= \frac{(I_{CL} + 48.78 \times 7^2)}{241.951}$ ..... (2)

Increase in GM = (2) – (1) $= \frac{(48.78 \times 7^2)}{241.951}$ = 9.879m

Ans. Increase in GM = 9.879m.

Ex. 7 The athwart ship semi ordinates of water plane area of a craft, at a uniform F & A spacing of 5m, as measured from aft are 2m, 4m, 5m, 6.5m, 7m, 7.2m, 6m, 5.4m, 3m & 0. The vessel is floating in salt water and has displacement of 2200t

(1) Ord Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4) Lever X	(5) = (3) x (4) $\int yxdx$	(6) = (5) x (4) $\int yx^2 dx$	(7) = (3) x $(1)^2$ $\int ydx^3$
2	1	2	0	0	0	8
4	3	12	h	12h	$12h^2$	192
5	3	15	2h	30h	$60h^2$	375
6 .5	2	13	3h	39h	$117h^2$	549.5
7	3	21	4h	84h	$336h^2$	1029
7.2	3	21.6	5h	108h	$540h^2$	1119.7
6	2	12	6h	72h	$432h^2$	432
5.4	3	16.2	7h	1130.4h	$7912.8h^2$	472.4
3	3	9	8h	72h	$576h^2$	81
0	1	0	9h	0h	0	0
		SOP_1		SOP_2	SOP_3	SOP_4
		121.8		530.4h	$2866.6h^2$	4258.4

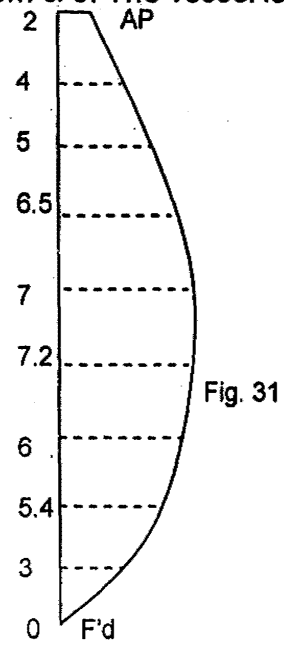


Fig. 31

Water plane area = $2 \times \frac{3h}{8} \times SOP_1 = 2 \times \frac{3 \times 5}{8} \times 121.8 = 456.75$

$$\text{TPC} = \frac{\text{WPA} \times 1.025}{100} = 4.682\text{m}$$

$$\text{FWA} = \frac{\Delta}{4TPC}\text{mm}\ \frac{2200}{4 \times 4.682} = 117.5\text{mm}$$

$$\text{LCF} = \frac{\text{moment of half WPA}}{\text{half WPA}} = \frac{\frac{3h}{8} \times 530.4h}{\frac{3h}{8} \times 121.8} = 21.77\text{m}$$

$$\text{MI of WPA}_{AP} = 2 \times \frac{3h}{8} \times SOP_3 = 2 \times \frac{3 \times 5}{8} \times 2866.6h^2 = 268762\text{m}^4$$

$$\text{MI of WPA}_{\text{ABOUT ATH AXIS THROUGH COF}} = 268762 - \text{WPA} \times \text{LCF}^2 = 52293.6$$

$$MI_{CL} = 2x\frac{1}{3} \times \frac{3h}{8} \times SOP_4 = 2x\frac{1}{3} \times \frac{3 \times 5}{8} \times 4258.4 = 5323\text{m}^4$$

$$BM_T = \frac{MI_{CL}}{\text{uw vol}} = \frac{5323}{2146.34} = 2.480\text{m}$$

$$BM_L = \frac{\text{MI of WPA}_{\text{ABOUT ATH AXIS THROUGHCOF}}}{\text{uw vol}} = \frac{52293.6}{2146.34} = 24.36m$$

Ex. 8 The half ordinates of vessel's water plane area 25m apart are:
0.4, 14.5, 26.6, 34.0, 37.0, 37.3, 37.1, 35.8, 28.8, & 6.0 meters respectively commencing from forward end.
If the SW displacement of the vessel up to that water plane is 15, 0,000 t, calculate transverse BM, Longitudinal BM
Note: Ordinates // to the axis under consideration.

[1]	[2]	[3] = [1] x [2]	[4]	[5] = [4] x[3]	[6] = [5] x [4]	[7] = [1]^2 [3]
Ord (y)	S.M.	For area, $\int y.dx$	Lever x	For Moment of Area $\int yx.dx$	For MI_{AP} $\int yx^2.dx$	For MI_{CL} $\int y^3 dx$
6.0	1	6	0	0	0	216
28.8	3	86.4	h	86.4h	$86.4h^2$	71663.6
35.8	3	107.4	2h	214.8h	$429.6h^2$	137648.1
37.1	2	74.2	3h	222.6h	$667.2h^2$	102129.6
37.3	3	111.9	4h	447.6h	$1790.4h^2$	155685.4
37.0	3	111	5h	555h	$2775h^2$	151959
34.0	2	68	6h	408h	$2448h^2$	78608
26.6	3	79.8	7h	558.6h	$3910.2h^2$	56463.3
14.5	3	43.5	8h	348h	$2784h^2$	9145.9
0.4	1	0.4	9h	3.6h	$32.4h^2$	0.1
		688.6		2844.6h	$14923.8h^2$	763519

L = 25 x 9 = 225m.
½ area = 3/8 x h x 688.6 m^2
Full area = 12911.25m^2.....(1)
LCF = 103.275m.
MI of whole area about athwartship axis thro' AP
= 2 x 3/8 x 25 x 14923.8 x 625 = 174888280 m^4
MI of whole area about athwartship axis thro' COF
= 174888280 – A $(LCF)^2$ m^4 = 37180431m^4

BM_L = MI of whole area about athwartship axis thro' COF / UW vol $-$ = 254.066m

Total MI about CL = 2 x 1/3 x $\int y^3 dx$ = 2 x 1/3 x 3 x25/8 x 763519
BM_T = MI_{CL} / UW vol = 32.609m.

Ex. 9 A pontoon is constructed of two box shaped barges, each of width 4 m, placed parallel to each other and 8 m apart, centreline to centreline, with a deck placed over them. When the barges are ballasted with SW to a depth of 1 m and a load placed on deck on the centreline of the pontoon, she floats at an even keel draft of 4 m in SW. In this condition her KG (solid) is 5.7 m. Calculate the angle to which she will incline. Show by calculation whether pumping out the entire ballast would improve or decrease her stability.

Ans.

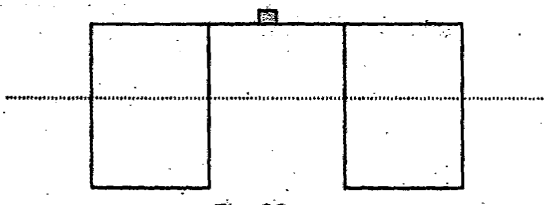


Fig. 32

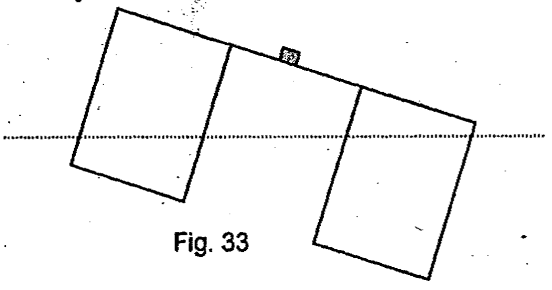


Fig. 33

Let the length of each pontoon be l metres.
MI of each pontoon about combined CL = $MI_{OWN\ AXIS} + Ad^2$

$$= \frac{lb^3}{12} + LB \times d^2 = 69.333L$$

$$BM = \frac{totalMI}{Tot\ uv\ vol} \quad \frac{2 \times 69.333L}{2V} \quad \frac{69.333}{16} = 4.333m.$$

KG = 5.7m, KB = 2m, KM = 6.333m
GM_S = 6.333 - 5.7 = 0.633m.

$$FSM = \frac{2LB^3 \times 1.025}{12} \text{ t.m. \& } FSC = \frac{FSM}{Displacement}$$

FSC = 0.333
GM = 0.3m (+ve) No list at this stage.
After pumping out, new draft = 3m, KB = 1.5m.BM for this draft = 5.778m.
Since the water is pumped out it will raise the KG but remove the FSC.
New Displacement in terms of L = 32.8L..... [24.6L – 8.2L]
New KG = 7.433m

KM = 7.278m. GM = -0.155m. $\tan^2\theta = \frac{-2GM}{BM}$.

Ship will list to 13.04°

Exercise 17

Q. 1 A vessel of length 200m, displacement 65,907.5t, KB 5.9m, KG 8.9m, has the following equally spaced half ordinates of water plane, commencing from aft :

Station	AP	1	2	3	4	5	6	7	8	9	FP
1/2ord (m)	0.0	10.0	13.0	14.0	14.2	14.3	14.1	14.0	11.5	6.2	0.2

Calculate her change in trim if 500 t is shifted 69 m longitudinally.
Ans. Area 4530.7m^2 LCF = 95.94m BM_L 163.67m MCTC = 529.45tm. Trim change = 65.16 cm.

Q. 2 A vessel of constant water-plane of length 150 m and maximum breadth 16 m and water-plane coefficient 0.833 is at even keel draft of 7.5 m. She has a midship rectangular double bottom tank of length 19 m, width 16 m and depth 1. 2 m. calculate the thrust on the tank top if. That tank is run up by opening the sea valves.
Ans. TPC = 20.492m Draft = 7.682m, 2019.9t.

Q. 3 A homogenous log of RD 0.72 is of square cross section. Show by calculations, whether it can float with one side parallel to the water surface, in dockwater of RD 1.020.
Hint: -
Transverse stability parameters are independent of length. Let the square crosssection be of 1 m x 1 m and let length be 10 m.∴ Mass = 1 x 1 x 10 x 0.72 = 7.2 t = 1 x draft x 10 x 1.020

Gives draft = 0.706m, KB = 0.353 m $BM_T = \frac{1^2}{12 \times 0.353}$ = 0.236 m, KM = 0.589, KG = 0.5 m.

∵ GM is +ve ∴ log will float horizontal.

Largest Container Ship: Container ship Xin Los Angeles from Samsung Heavy Industries is the World's largest container ship. She carries 9600 teu. She can carry a maximum of 18 rows of containers by eight tiers on the weather deck and 16 rows by 10 tiers in the holds. The principal dimensions of the ship are: LOA 336.7 m, beam 45.6 m, draught. 15.0 m The ship has 68,520 kW engine with a ballast service speed of 25.4 knots The record will be broken in the near future as SHI has developed a 12,000 teu container ship design with Lloyd's Register and is working on a container ship capable of carrying 14,000 teu.



Chapter 19 Centre of Pressure

On board ships we have several examples of the liquid column causing thrust on a wet bulkhead and on the bottom plating. The thrust is also caused on the hull of the ship due to the water in which the ship is floating. The study of thrust is also interesting in respect of lock gates and the drydock gates. In case of a ship side damage where internal strengthening or wedging is necessary, an idea of location of centre of pressure is useful.

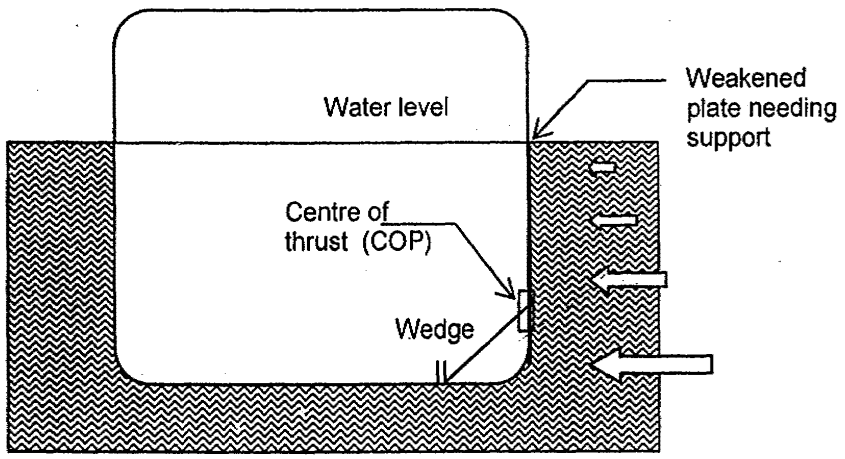


Fig. 1

The pressure increases with the depth of water. Thus in case of a sounding pipe that is filled up with water will cause a pressure of (h x d) t/m^2 at the bottom of the tank. Where h is the height of water column and d is the density of the liquid in the pipe. For a ballast tank whose sounding pipe column is 15 metre tall above the tank top, the pressure at the tank top will be about 15.4 t/m^2. And we know that the pressure at any level is horizontally uniform. The pressure all over the tank top therefore will be 15.4t/m^2. If the area of tank bottom is 200 m^2, the thrust on the tank top plating will be 15.4 x 200 = 3080 t. It is as if the hold above the tank top filled over the entire area to a height of 15m and carrying 3080t of liquid.

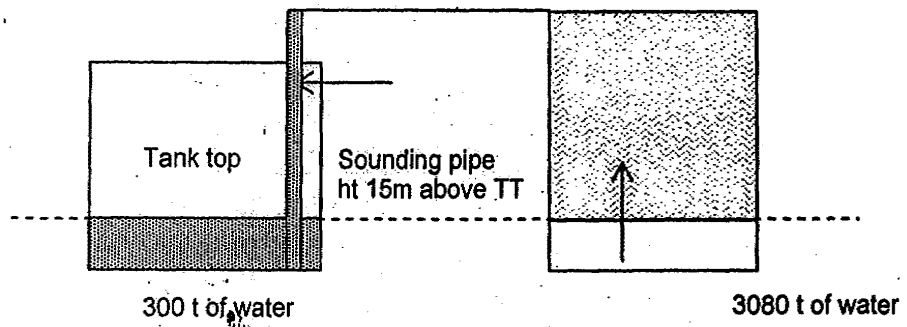


Fig. 2 Pressure & thrust on both the tank top platings will be equal

Let us consider a tank filled with water. One of its bulkheads is 8m wide and 6m in height. The pressure due to the liquid height is zero at top and maximum at the bottom. The graph of column versus total pressure (thrust due liquid particles) at that depth would appear triangular as liquid particles in the diagram with the height same as the height of bulkhead. The centroid of the triangle is one third the height from the base. The centre of pressure as we will see later is at one third of the height from the base.

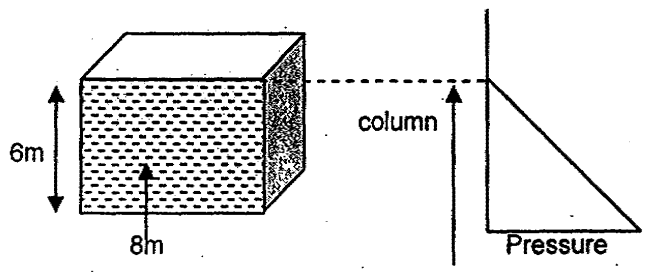


Fig.3

The bulkhead may be considered as made up of many strips of uniform thickness as shown in the figure 4 each strips is exposed to different thrust, the minimum or zero thrust being on the upper most strip and the maximum thrust being on the strip at the bottom. The strip at mid height has a pressure and the thrust which is mean of the maximum and minimum. If the entire thrust is assumed to act at a single point then that point is the centre of pressure. Thus the centre of pressure can be better understood as centre of thrust.

The thrust on the bulkhead can be calculated as follows:

Thrust on the bulkhead = pressure at mid height × area of the bulkhead. But we must know that mid height is not the centre of pressure.

The position of centre of pressure can be very easily calculated by the following formula:

$$\text{The distance of COP below WL} = \frac{\text{moment of inertia of wet plane about WL}}{\text{Area of wet plane} \times \text{depth of centroid below WL}}$$

To show that distance of cop below water level is *Independent of density:-*

$$\text{COP below WL} = \frac{\text{MI about WL}}{\text{Area} \times \text{depth of centroid below WL}}$$

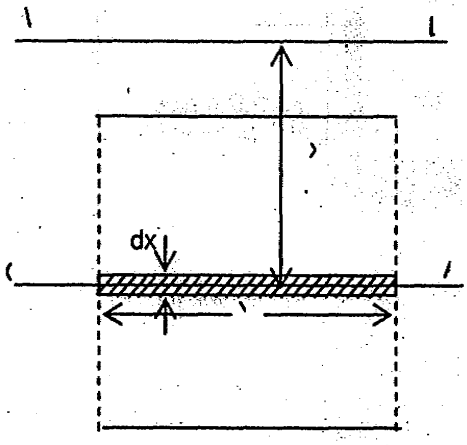


Fig. 4

In the fig elementary strip from the wet plane is shown shaded.
Let the width of the strip be y and the thickness be dx.

MI of elementary strip OA about own axis $= \frac{ydx^3}{12}$ (negligible)

MI of elementary strip about WL = negligible + Ad^2
(by theorem of // axes)
$= ydx \times x^2$

MI of entire area about WL $= \int yx^2dx$ ------ (1)

Thrust on strip $= ydx \times x \times \delta$ ..... (2)

Moment of thrust on strip about WL $= ydx \times x \times \delta \times x = \delta.yx^2dx$

Moment of thrust on entire area above WL $= \int \delta.yx^2dx = \delta \int yx^2dx$
$= \delta\ (M.I.)_{WL}$ - - - (3)

Total Thrust $= A \times Head \times \delta$ - - - - - - (4)

COP below W/L $= \frac{(3)}{(4)} = \frac{\delta\ (M.I.)_{WL}}{A \times Head \times \delta} = \frac{(M.I.)_{WL}}{A \times Head}$

Ex. 1 After side of a rectangular tank full of sea water ballast is 8m wide & 6m high. Find the position of centre of pressure and the thrust acting on the bulkhead.

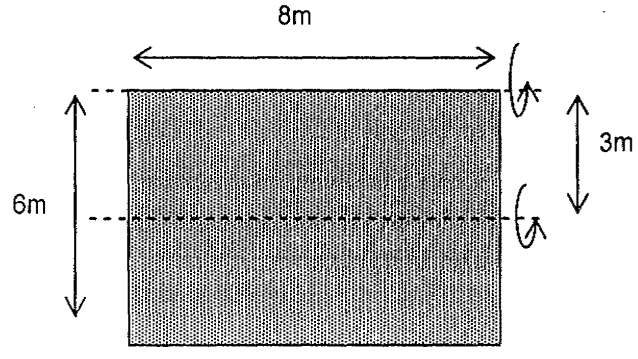
Sol^n: -

MI about horizontal through centroid $= \frac{LB^3}{12} = \frac{8 \times 6^3}{12} = 144m^4$

MI about water level $= 144 + Ad^2 = 144 + 432 = 576m^4$

The distance of COP below WL $= \frac{\text{moment of inertia of wet plane about WL}}{\text{Area of wet plane} \times \text{depth of centroid below WL}}$

$= \frac{576}{48 \times 3} = 4m$



Ex. 2 In above question find the position of COP if the tank is filled-up to a level 2m above the tank top in the sounding pipe.

Sol^n: -

MI about water level $= 144 + Ad^2 = 144 + 48 \times 5^2 = 144 + 1200 = 1344 m^4$

The distance of COP below WL $= \dfrac{\text{moment of inertia of wet plane about WL}}{\text{Area of wet plane} \times \text{depth of centroid below WL}}$

$= \dfrac{1344}{48 \times 5} = 5.6m$

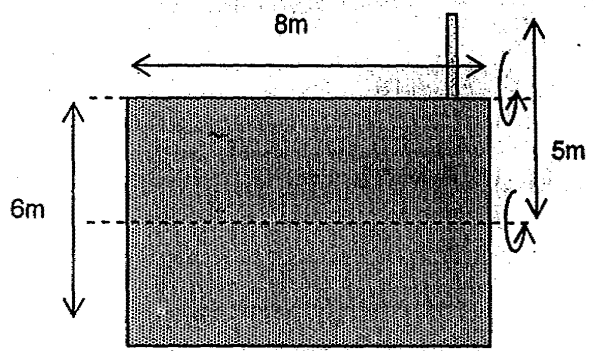


Fig. 6

Ex. 3 After side of an oil tank is filled up to a sounding of 11m. The tank is in the shape of inverted triangle with tank top 8m wide and depth 9m. Find the position of centre of pressure and the thrust acting on the bulkhead.

Sol^n: -

MI about WL $= \dfrac{BH^3}{36} + Ad^2 = \dfrac{8 \times 9^3}{36} + 36 \times 5^2$

$= 162 + 900 = 1062 m^4$

COP below WL

$= \dfrac{\text{MI about WL}}{\text{Area} \times \text{depth of centroid below WL}}$

$= \dfrac{1062}{36 \times 5} = 5.9m$

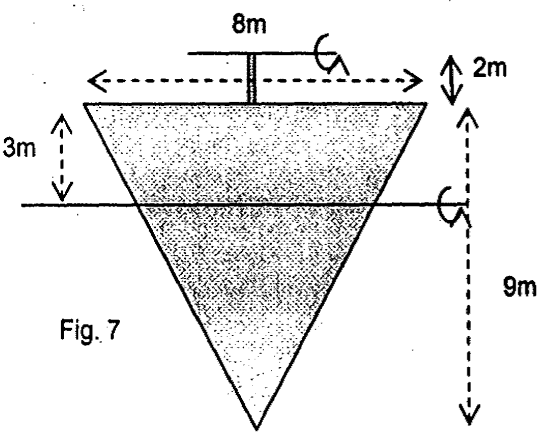


Fig. 7

Ex. 4 An oil tank has a circular side of diameter 9m and is full. Find the position of COP wrt the bottom of tank.

Sol^n: - Diam. of tank = 9m. C is Centre of the circular part.

$MI_{DD} = \dfrac{\pi D^4}{64} = 321.9\ m^4$

$MI_{TT} = \dfrac{\pi D^4}{64} + \text{Area} \times rad^2 = 1609.5\ m^4$

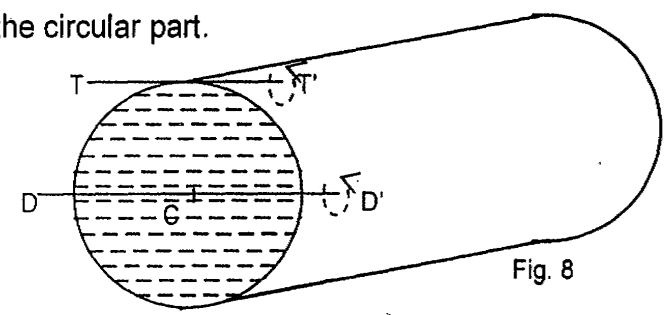


Fig. 8

Distance of COP below water level $= \dfrac{\text{MI of wet plane}}{\text{area of wet plane} \times \text{depth of centroid below WL}}$

$$= \frac{1609.5}{63.58 \times 4.5} = 5.625m$$

Ex. 5 Find MI of semicircular rudder of radius equal to 4.2m about xx' & about yy' through centroid & parallel to xx'.

Hint: -

$MI_{xx'} = \frac{\pi D^4}{128} = 122.1\ m^4$

Centroid is at a distance of $\frac{4R}{3\pi} = 1.783m$ from diameter.

$MI_{yy'} = \frac{\pi D^4}{128} + Ad^2 = 122.1 - 88.1 = 34\ m^4$

Ans.

MI about XX' = $122.1m^4$ & MI about YY' = $34m^4$

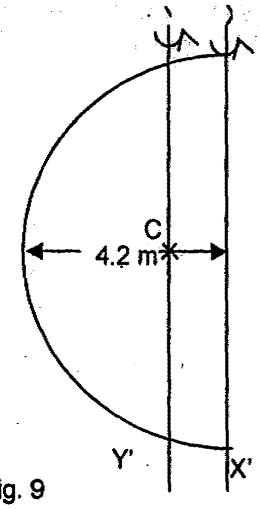


Fig. 9

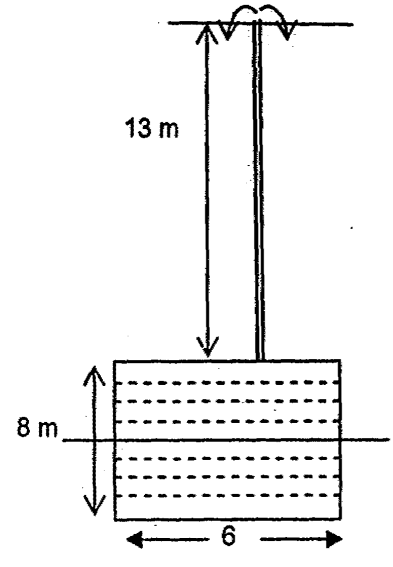
Ex. 6 A ballast tank has a bulkhead 8m tall and 6m in width and has a sounding pipe 13m above the tank top. Find the position of COP if the sounding pipe was full of ballast. Find the position of COP wrt the bottom of tank.

Sol^n: -

COP below W/L $= \frac{MI_{WL}}{Area \times Head}$

$$= \frac{\frac{6 \times 8^3}{12} + 48 \times 17^2}{48 \times 17} =$$

$$= \frac{14128}{816} = 17.314m$$



Ans. Distance of COP below the water level = 17.314m

Fig. 10

Ex. 7 After bulkhead of a tank is rectangular on top, 8m wide & 6m high. Lower part of bulkhead below rectangle is semicircular. Find the position of COP below tank top if there is head of 2m of water in the sounding above the tank top.

Sol^n: -

MI of rectangular part about own axis $= \frac{8 \times 6^3}{12} = 144m^4$

MI of rectangular part about water level $= 144 + 48 \times 5^2$

$= 1344m^4$ ..... (1)

MI of semi circular part about the diameter $= \frac{\pi \times d^4}{128}$

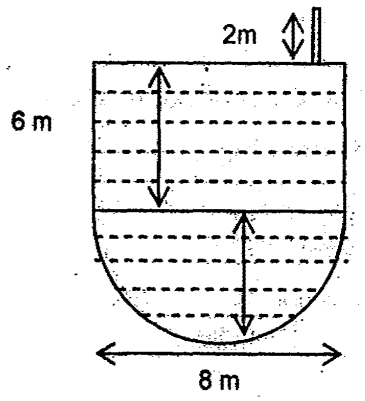


Fig. 11

$$= \frac{3.18 \times 8^4}{128} = 100.5m^4$$

Distance of centroid from diameter $= \frac{4R}{3\pi} = \frac{4 \times 4}{3 \times 3.14} = 1.699m$

Area of semicircle $= \frac{\pi r^2}{2} = \frac{3.14 \times 16}{2} = 25.12m^2$

MI about axis through centroid & // to diameter = 100.5 – 25.12 x 1.699^2 = $28m^4$

MI of semicircular part about WL = 28 + 25.12 x 9.699^2 = $2391m^4$ ..... (2)

Total MI about WL = (1) + (2) = 1344 + 2391 = $3735m^4$

To find the position of common centroid:

Taking moment of areas about tank top:

$$\text{Distance of common centroid from tank top} = \frac{A_1d_1 + A_2d_2}{A_1 + A_2} = \frac{48 \times 3 + 25.12 \times 7.699}{48 + 25.12}$$

$$= \frac{144 + 193.4}{73.12} = 4.614m.$$

Depth of common centroid from WL = 6.614m.

$$\text{COP below WL} = \frac{\text{total MI about WL}}{\text{total area} \times \text{depth of common centroid}} = \frac{3735}{73.12 \times 6.614} = 7.723m$$

Ex. 8 A vertical bulkhead is in form of a trapezium 2m broad on the top 4m broad at the base and 3m deep. Calculate the thrust and centre of pressure when the tank contains oil of RD 0.92 to a sounding of 4.5m.

Ans. The trapezium for the purpose of cop / thrust calculations can be considered as made of a rectangle & a triangle.

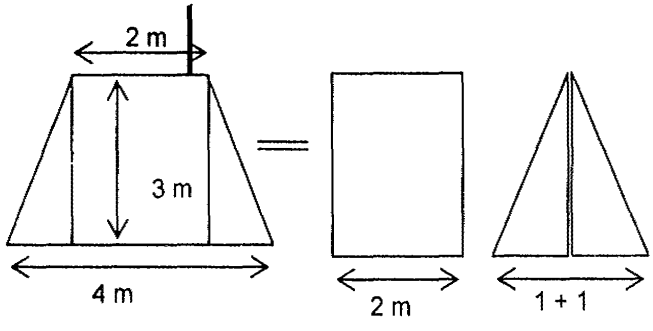


Fig. 12

Area of rectangular portion = 2 x 3 = $6m^2$
Area of triangular portion = 2 x 3x ½ = $3m^2$
To find the centroid of the whole area, moment of each is taken about the base, thus

Centroid above base $= \frac{(6 \times 1.5) + (3 \times 1)}{9} = \frac{12}{9} = 1.333m$ from base.

Water head (coloumn) above the centroid = 4.5-1.333 = 3.167m.
To find the total MI about the WL (using theorem of // axes)

MI of Rectangle about WL $\frac{2 \times 3^3}{12} + 6 \times 3^2$ + Triangle about WL $\frac{2 \times 3^3}{36} + 3 \times 3.5^2$

Total $MI_{[WL]} = 58.5 + 38.25 = 96.75\ m^4$

COP below WL $= \frac{96.7}{9 \times 3.167} = 3.394$ m

Thrust = Area of bulkhead x RD x Head = 9 x 0.92 x 3.167 = 26.22t...

Ans. COP below WL = 3.394m. Thrust = 26.22t

Ex. 9 A rectangular tank has a bulk head of breadth 8m & height 6m. Find the sounding of the tank if COP lies at a height of 2.4m above the base.
Sol^n: -
Let the head of water above tank top be x metres.
Thus the distance of COP below W/L (x + 3.6)

$$X+3.6 = \frac{\frac{8 \times 6^3}{12} + 48 \times (3+x)^2}{48 \times (3+x)}$$

Let (3 + x) = y

The equation can now be written as $(y + 0.6) = \frac{144 + 48y^2}{48y}$

Or $48y^2 + 28.8\ y = 144 + 48y^2$
$\therefore y = 5$
$\therefore x + 3 = 5m$
$\therefore x = 5 - 3 = 2m$

Ex. 10 The vertical ordinates of a bulkhead (boundary of a tank) measured downwards from the tank top at equidistant athwartship intervals are 0, 3, 5, 6, 5, 3 and 0 meters respectively. the sea water is filled in the sounding pipe upto 2 meters above the top of the tank. Find the depth of COP below the tank top, also find the thrust on the bulkhead.

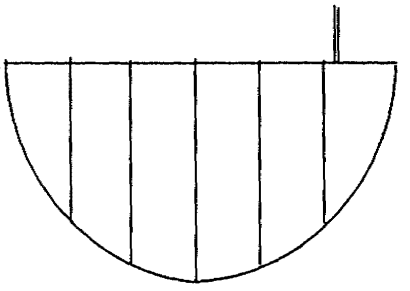


Fig. 13

Sol^n: - Nr. of ordinates = 7 & nr. of segments = 6, Rule 1 or 2 of Simpson can be used.
Note: Ordinates are perpendicular to the axis under consideration.

(1) Ord Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4)= (3) x (1) $\int y^2 dx$	(5)= (4) x (1) $\int y^3 dx$
0	1	0	0	0
3	4	12	36	108
5	2	10	50	250
6	4	24	144	864
5	2	10	50	250
3	4	12	36	108
0	1	0	0	0
		S - 1	S - 2	S -3
		68	316	1580

Area of bulkhead $= \frac{h}{3} \times 68m^2$..... (1)

Moment of area $_{[T\ TOP]} = \frac{1}{2} \times \frac{h}{3} \times S\text{-}2 = \frac{316h}{6} m^3$..... (2)

Distance of centroid from T Top $= \frac{\text{moment}}{\text{area}} = 2.3235m.$

$MI_{[TT]} = \frac{1}{3} \times \frac{h}{3} \times S - 3 = 175.55h\ m^4$.....(3)

$MI_{[\text{horizontal axis thr'o centroid}]} = (3) - \text{Area} \times d^2$

$MI_{[WL]} = (3) - \text{Area} \times d^2 + \text{Area}\ (d+2)^2$

$= (3) + \text{Area}\ (4.324^2 - 2^2)$

$= 476.97h$..... (4)

COP below WL $= \frac{\text{MI about WL}}{\text{Area} \times \text{Head}} = \frac{4}{\text{area} \times (d+2)} = 4.866m$

Ans. COP below WL = 4.866m. Thrust = Area of bulkhead x RD x Head = 100.47h t where h = one sixth of the breadth at T/top level.

Ex. 11 One of the sides of a tank is a bulkhead that measures as follows: the vertical ordinates measured vertically down from tank top at an equidistance interval of 3m are 0, 3.3, 5, 6, 5, 3.3, & 0 respectively. Find position of centroid. If water was finlled to a level 2 m above tank top in sounding pipe.

(1) Ordinate Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4)= (3) x (1) $\int y^2 dx$	(5)= (4) x (1) $\int y^3 dx$
0	1	0	0	0
3.3	4	13.2	43.56	143.75
5	2	10	50	250
6	4	24	144	864
5	2	10	50	250
3.3	4	13.2	43.56	143.75
0	1	0	0	0
		S-1	S - 2	S -3
		70.4	331.12	1651.5

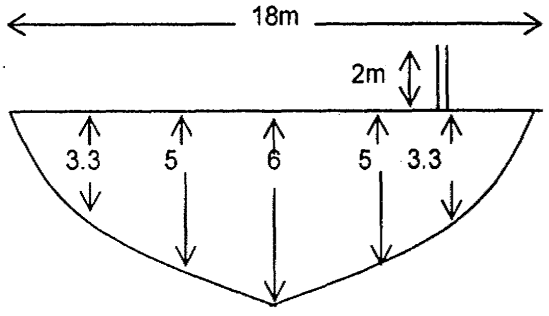


Fig. 14

Area of bulkhead $= \frac{h}{3} \times S-1 = \frac{3}{3} \times 70.4 = 70.4m^2$

Moment of area about tank top $= \frac{1}{2} \times \frac{3}{3} \times S-2 = \frac{1}{2} \times \frac{3}{3} \times 331.12$

Pos of centroid below tank top $= \frac{\text{moment of area about tank top}}{\text{area}}$

$$= \frac{\frac{1}{2} \times \frac{3}{3} \times 331.12}{\frac{3}{3} \times 70.4}$$

$$= \frac{331.12}{2 \times 70.7} = 2.342m$$

MI about tank top $= \frac{1}{3} \times \frac{h}{3} \times S-3$

$$= \frac{1}{3} \times \frac{3}{3} \times 1651.5$$

$$= 550.5m^4$$

MI about WL $= 550.5 + 70.4\,[4.342^2 - 2.342^2]$

$= 1491.6m^4$

Cop below WL $= \frac{\text{MI about WL}}{\text{area} \times \text{depth of centroid}}$

$$= \frac{1491.6}{70.4 \times 4.342} = 4.880m$$

Ex. 12 Forward bulk head of a tank has vertically equidistant horizontal ordinates as follows: Ordinates top to bottom are 15m, 13m, 10.5m, 5m respectively. The uniform separation being 4m. Find position of COP wrt tank top with water filled up in sounding pipe that extends 3m above the tank top.

(1) Ordinate Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4) Lever x	(5) = (3) x (4) $\int yxdx$	(6) = (5) x (4) $\int yx^2\,dx$
15	1	15	0	0	0
13	3	39	H	39h	$39h^2$
10.5	3	31.5	2h	63h	$126h^2$
5	1	5	3h	15h	$45h^2$
		S-1		S-2	S-3
		90.5		117h	$210h^2$

Area $= \frac{3h}{8} \times S-1 = \frac{3 \times 3}{8} \times 90.5 = 135.75m^2$

Centroid distance from tank top $= \frac{\text{moment of area about tank top}}{\text{area}}$

$$= \frac{\frac{3h}{8} \times S-2}{\frac{3h}{8} \times S-1} = \frac{117h}{90.5} = 5.171m$$

MI about 1st ordinate (tank top) $= \frac{3h}{8} \times S - 3$

$= \frac{3 \times 4}{8} \times 210 \times h^2$

$= 5040 m^4$

MI about water level $= 5040 + 135.75 [8.171^2 - 5.171^2] = 10473.5 m^4$

COP below WL $= \frac{\text{MI about } WL}{\text{Area} \times \text{depth of centroid}}$

$= \frac{10473.5}{135.75 \times 8.171} = 9.442 m$

Alternate method: -

The lever is taken directly about WL instead of the tank top or first ordinate.

(1) Ordinate Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4) Lever X	(5) = (3) x (4) $\int yxdx$	(6) = (5) x (4) $\int yx^2 dx$
15	1	15	3	45	135
13	3	39	7	273	1911
10.5	3	31.5	11	346.5	3811.5
5	1	5	15	75	1125
		S - 1		S - 2	S - 3
		90.5		739.5	6982.5

Distance centroid from WL $= \frac{\frac{3h}{8} \times s - 2}{\frac{3h}{8} \times s - 1} = \frac{739.5}{90.5} = 8.17 \text{ m}$

MI about WL $= \frac{3h}{8} \times s - 3$

$= \frac{3 \times 4}{8} \times 6982.5$

$= 10473.5 m^2$

COP below WL $= \frac{10473.5}{135.75 \times 8.171} = 9.442 m$

Ex. 13 The transverse ordinates of the side of a tank measured downwards from tank top are 13m, 16m, 16.6m, 17m, 17.3m, 16.3m, 15.3m and 12m. The uniform vertical separation between these ordinates is 3m. If the sounding pipe extends 3m above the tank top and is filled up till top, find the position of COP with respect to water level.

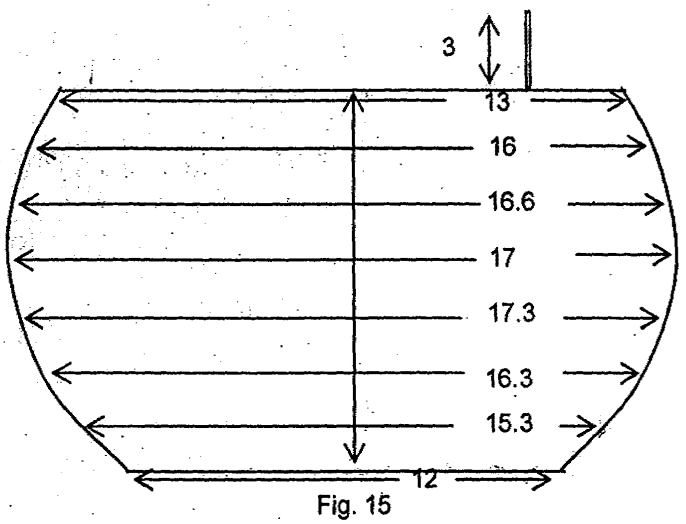


Fig. 15

	(1) Ordinate y	(2) SM	(3) = (1) x (2) ∫ydx	(4) Lever X	(5) = (3) x (4) ∫yxdx	(6) = (5) x (4) ∫yx² dx
A	13	1	13	0	0	0
R	16	3	48	h	48h	48 h²
E	16.6	3	49.8	2h	99.6h	199.2 h²
A_1	17	1	17	3h	51h	153 h²
			S-1		S-2	S-3
			127.8		198.6h	400.2h²
A						
R	17	1	17	0	0	0
E	17.3	4	69.2	h	69.2h	69.2 h²
A_2	16.3	2	32.6	2h	65.2h	130.4 h²
	15.3	4	61.2	3h	183.6h	550.8 h²
	12	1	12	4h	48h	192 h²
			SOP_1		SOP_2	SOP_3
			192		366.0h	942.4 h²

Area,A_1 $= \frac{3h}{8} \times s - 1 = \frac{3 \times 3}{8} \times 127.8 = 143.78 m^2$

Centroid distance A_1 from 1st ordinate $= \frac{\frac{3h}{8} \times S - 2}{\frac{3h}{8} \times S - 1} = \frac{198.6 \times 3}{127.8} = 4.662 m$

MI of A_1 about 1st ordinate $= \frac{3h}{8} \times S - 3$

$= \frac{3 \times 3}{8} \times 400.2 \times 3^2$

$= 4052 m^4$

MI of A_1 about WL = $4052 + 143.78 (7.662^2 - 4.662^2) = 9367.8$ .....(1)

Area A_2 $= \frac{h}{3} \times SOP_1 = \frac{3}{3} \times 192 = 192 m^2$

Centroid of A_2 from 1st ordinate of $A_2 = \dfrac{\frac{h}{3}\times SOP_2}{\frac{h}{3}\times SOP_1} = \dfrac{366\times 3}{192} = 5.719m$

MI of A_2 about 1st ordinate of $A_2 = \dfrac{h}{3}\times SOP_3$

$= \dfrac{h}{3}\times 942.4\times 3^2$

$= 8481.6m^4$

MI of A_2 about WL $= 8481.6 + 192\,(17.719^2 - 5.719^2) = 62482.7m^4$ ..... (2)

Total MI about WL $= (1) + (2) = 71850.5m^4$

To find pos of common centroid: -

Taking moment of areas about tank top

Distance of common cen from tanktop $= \dfrac{A_1d_1 + A_2d_2}{A_1 + A_2} = \dfrac{143.78\times 4.662 + 192\times 14.719}{335.78} = 10.413m$

COP below WL $= \dfrac{\text{total MI about WL}}{\text{total area} \times \text{depth of common centroid}} = \dfrac{71850.5}{335.78\times 13.413} = 15.953m$

Alternate method: -

The lever is taken directly about WL instead of the tank top or first ordinate.

	(1) Ordinate Y	(2) SM	(3) = (1) x (2) $\int ydx$	(4) Lever X	(5) = (3) x (4) $\int yxdx$	(6) = (5) x (4) $\int yx^2\,dx$
A	13	1	13	3	39	117
R	16	3	48	6	288	1728
E	16.6	3	49.8	9	448.2	4033.8
A_1	17	1	17	12	204	2448
			S-1		S-2	S-3
			127.8		979.2	8326.8
A						
R	17	1	17	12	204	2448
E	17.3	4	69.2	15	1038	15570
A_2	16.3	2	32.6	18	586.8	10562.4
	15.3	4	61.2	21	1285.2	26989.2
	12	1	12	24	288	6912
			SOP_1		SOP_2	SOP_3
			192		3402	62481.6

MI of A_1 about WL $= \dfrac{3h}{8}\times S - 3 = \dfrac{3\times 3}{8}\times 8326.8 = 9367.6$ ..... (1)

MI of A_2 about WL $= \dfrac{h}{3}\times SOP_3 = \dfrac{3}{3}\times 62481.6 = 62481.6$ ..... (2)

Total MI about WL = (1) + (2) = $71849.2m^4$

$$\text{Common centroid below WL} = \frac{\frac{3h}{8}\times S - 2 + \frac{h}{3}\times SOP_2}{\left(\frac{3h}{8}\times S - 1\right) + \left(\frac{h}{3}\times SOP_1\right)} = \frac{\frac{3\times 3}{8}\times 979.2 + \frac{3}{3}\times 3402}{\left(\frac{3x3}{8}\times 127.8\right) + \left(\frac{3}{3}\times 192\right)}$$

$$= \frac{4503.6}{335.77} = 13.413m$$

$$\text{COP below WL} = \frac{\text{total MI about WL}}{\text{total area} \times \text{depth of common centroid}} = \frac{71849.2}{335.77\times 13.413} = 15.953m$$

Ex. 14 A special tank has triangular bulkhead, apex upward. The base of the triangle is 10m and each of its sloping sides is 13m long. Calculate the distance of center of pressure from the base of bulkhead when the tank is filled with Fuel Oil of RD 0.95 to an ullage of 3.0m.

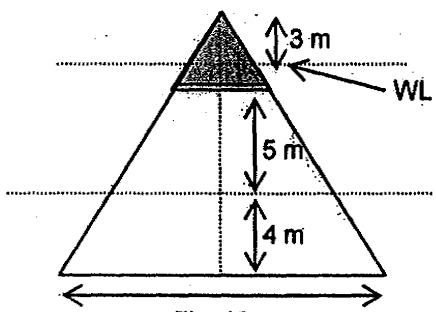


Fig. 16

Hint: -
Area of trapezium = 56.25m^2 10m
To find the position of CG proceed as follows:
Moment of triangle about base – moment of smaller triangle (dry part) about the base
New COG = 8.4m from Apex i.e. 5.4 m below the WL.
MI of trapezium about WL
= MI of complete triangle about WL – MI of dry triangle about WL

$$= \frac{10\times 12^3}{36} + \tfrac{1}{2} \times 10 \times 12 \times 5^2 - \frac{2.5\times 3^3}{36} \; [+ \tfrac{1}{2} \times 2.5 \times 3 \times 1^2] = 1974.375 \text{ m}^4$$

COP below WL = 1974.375 / 56.25 x 5.4 = 6.5m
The distance from base = 9 - 6.5 = 2.5m.....Ans
Alternately, the question can be done in the same way as example 8.

Exercise 19
Q. 1 A 10 meter high vertical bulkhead of a tank has the following equally spaced horizontal ordinates commencing from top:
7.2 m, 7.1 m, 6.6 m, 6.2 m & 5.0 m.
The tank is pressed up with seawater with a head of 1.5 m above the tank top. Calculate the thrust on the bulkhead & the position of centre of pressure above the bottom of the tank.

Hint: - $\int y.dx = 78.6$, Area = 65.5m^2 & $\int yx.dx = 149.2h$, Moment of area$_{TT}$ = 310.83 m^3
Centroid below TT = 4.745m. Head below WL = 6.245m.
$\int yx^2.dx = 384.4h^2$, $MI_{TT} = 2002.083m^4$, $MI_{WL} = 3081.85m^4$
COP below WL = 7.534m, Thrust on bulkhead = 419.27t, COP above bottom = 3.966m.

Q. 2 A 10 meter high vertical bulkhead of a tank has the following equally spaced horizontal ordinates commencing from top:
7.2 m, 7.1 m, 6.9 m, 6.6 m, 6.2 m & 5.0 m.
The tank is pressed up with seawater with a head of 1.5 m above the top the tank. Calculate the thrust on the bulkhead & the position of centre of pressure above the bottom of the tank.
Ans. Thrust on bulkhead = 424.5t, COP above bottom = 3.947m.

Q. 3 The end bulkhead of deep tank is 10 m broad & 6 m deep. When the tank is pressed up with fresh water, the centre of pressure is 2.5 m above the bottom of end bulkhead. Calculate the sounding or the tank.
Hint:

$(X+ 3.5) = MI / A.Hd$
Or $(X+3.5) = 10 \times 6^3 / 12 + 60 (3+X)$
$60 (3 + X)$

Gives X = 3m. Sounding of tank 9m. Water Coloumn of 3m in sounding pipe.

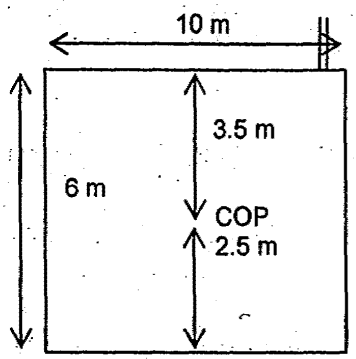


Fig. 16

Q. 4 A deep tank bulkhead is 6 m in height. The horizontal half ordinates of the bulkhead at equal intervals, commencing from the top, are 2.82, 2.54, and 2.26 m respectively. Calculate the thrust on the bulkhead when the tank contains salt water to a depth of 3 m.
Ans. 21.71t

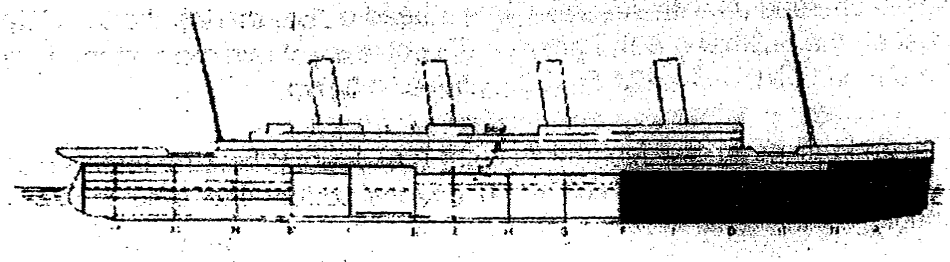
Q. 5 A vertical bulkhead is in the form of a trapezium with horizontal parallel edges of 2 m at top and 6 m at bottom. The bulkhead is 4 m deep. Calculate the thrust on the bulkhead and the position of its CP when ballast of R.D. 1.016 stands to one side of it, to its full depth.
Also calculate the thrust if the bulkhead is inclined at 40° to the vertical, with the ballast standing to the top of the inclined bulkhead.
Ans. Centroid below w/l = 2.333m, Position. of CP below W/L = 2.858m, Thrust 37.925t. Thrust when inclined 29.05t.

Q. 6 A 12 metre high vertical bulk head of a tank has the following equally spaced horizontal ordinates commencing from top; 8.8m, 8.5m, 8.2m, 8.0m, 7.6m, 7.1m, 6m top. The tank is pressed up with seawater with a head of 2m above the top of the tank. Calculate thrust on the bulk head & position of COP above the tank's bottom.
Ans. Thrust on bulkhead = 741.2t, COP position 4.778m above the tank bottom

Q. 7 The vertical ordinates of a bulkhead measured downwards from the horizontal deck, equal intervals are 3,5,7,8.5,7,5, and 3 meters. Find the position of the centre pressure from the top of the bulkhead when liquid level is at the top of the bulkhead.
Ans. 4.854m

Q. 8 A square plate of side 'a' is vertical and is immersed in water with an edge of its length in the free surface. Prove that the distance between the centres of pressure of the two triangles into which the plate is divided by a diagonal is $\frac{a\sqrt{13}}{8}$.

RMS Titanic was considered unsinkable as was divided in 16 watertight compartments by 15 bulkheads. Profile shows major watertight compartments of titanic. The front 6 bulkheads were damaged & gave way to flooding. Height of bulkheads was inadequate.



Chapter 20 Bilging calculations of box shaped vessels

Bilging means breach of under water part of hull causing a loss of buoyancy and subsequently a change of stability parameters. In the bilging examples that are shown in this chapter the new drafts and GM has been calculated for the bilged condition.
The bilging calculations are done by two methods viz.
1. Constant displacement method,
2. Added weight method.

Constant displacement method: - If the damaged compartment was empty or had dry rigid cargo or if the compartment was void of liquid, the displacement, intact under water volume, KG, LCG will not change after bilging.

Sinkage is found a very simple formula $\text{sinkage} = \dfrac{\text{lost buoyancy}}{\text{intact water plane area}}$

Lost buoyancy is calculated till the initial water level at the damaged compartment. Intact waterplane area (immersed part) is found by subtracting the transverse area of the damaged hold from the total waterplane area. This formula is very important & useful in estimating the sinkage & freeboard even before the damage has actually occurred.

Added weight method considers the water mass entering the ship as mass added that will cause a change in KG, LCG, displacement & hence the drafts. This is simple method to the extent that it's working is similar to the intact stability calculations but the sinkage cannot be found by straight method using single formula (in one step).

We will understand different principles of constant displacement method by examples using box shaped vessels. The principle can be extended to the ship shaped vessel if understood well.

Case: Damage to 'empty-centre line - midship compartment'. vertical extent not restricted by a watertight flat.

Ex. 1 A box shaped vessel of L = 120m, B = 15m is floating on an even keel draft of 6m. An empty midship compartment extending over the full breadth & 18m long is bilged. Compare the GM_T of vessel before and after damage. The KG of ship was 4.2m.
Sol^n: - Intact Condition

KB $= \dfrac{6}{2} = 3\text{m}$

BM = Moment of Inertia of water plane area about the centre line / under water volume.

$$= \frac{MI}{V}$$

$$= \frac{120\times15^3/12}{120\times6\times15} = \frac{15^2}{12\times6} = 3.125\text{m}$$

KM = KB + BM = 3 + 3.125m = 6.125m
KG = 4.2m
∴ GM_T = 6.125 – 4.2 = 1.925m.
Damaged Condition (Constant displacement method):
Lost Buoyancy = 18 x 15 x 6 = 1620 m^3
Lost buoyancy must equal replenished buoyancy from reserved areas.

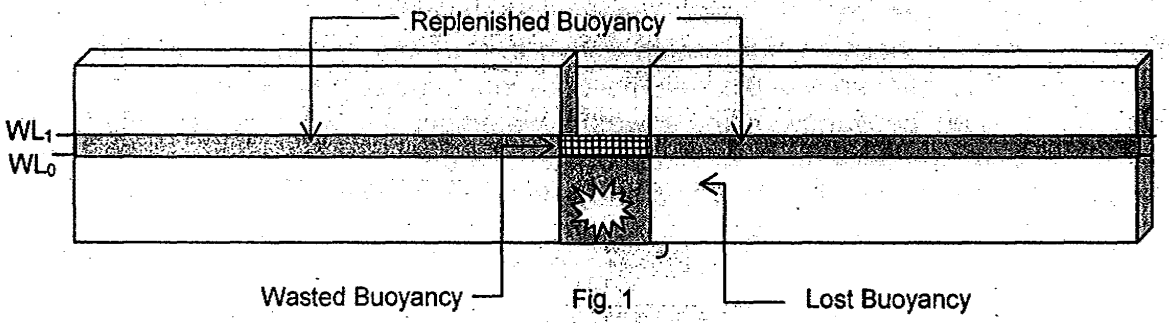


Fig. 1

Replenished buoyancy = sinkage x Intact water plane area.

$$\text{Sinkage} = \frac{\text{Lost Buoyancy}}{\text{Intact water plane area}}$$

Intact water plane area = Total water plane area at final water line – Lost water plane area
= (120 – 18) 15 = 1530 m^2

$$\text{Sinkage} = \frac{LB}{IWPA} = \frac{1620}{1530} = 1.059\text{m.}$$

New Draft = 7.059 m
In a case where: a) A vessel is wall sided, b) Damage is vertically uniform from keel till the final water line,

KB = ½ draft = 3.529 m.

$$BM = \frac{\text{Moment of Inertia of intact water plane area about the centre line}}{\text{Intact under water volume}}$$

Intact under water volume after damage is same as initial under water volume,

$$= \frac{(120-18)\times15^3/12}{120\times6\times15} = 2.656\,\text{m}$$

KM = KB + BM = 3.529 + 2.656 M = 6.185
KG = 4.2m
GM_T = 6.185 – 4.2 = 1.985M

Note: GM_T has increased after the damage.

Case: Damage to 'centre line compartment' located amidships, carrying a rigid cargo such as steel cargo. The vertical extent of damage is not restricted by any watertight flat.

Ex. 2 A box shaped vessel of length 140 m, breadth 21 m, draft 7.2 m has a midship compartment of length = 18 m & extending over full breadth, containing a cargo of permeability 70%. This compartment was bilged. Find GM of the vessel after damage using the (a) Constant displacement method. If initial KG was 8.501 m, find the change in GM_T.

Sol^n: - Initial KM = 3.6 + 5.104 = 8.704 m. Hence initial GM_T = 8.704 – 8.501 = 0.203 m.
In the present case 18 x 21 x 7.2 x 0.70 = 1905.12 m^3 is the lost buoyancy. Loss of buoyancy increases as permeability. The total volume up to original water line is multiplied with 0.70 as 70% is the permeability i.e. the % of volume taken over by the water. 30% of the space is still undisturbed. The cargo well secured within compartment holds on like the permanent members of the ship structures viz. pillars, undamaged deep tanks or other intact spaces within the damaged length. The lost buoyancy is replenished original w/c within damage length from the reserved areas except from the region above the. In this region only the 30% of immersed volume provides buoyancy, 70% volume does not provide the buoyancy. We may call this buoyancy wasted buoyancy. If there was a watertight flat at or below original water level, (restricting damage below it) then there would have been no wasted buoyancy. The 'B' shifts upwards as the centroid of replenished buoyancy is higher than the centroid of lost buoyancy.

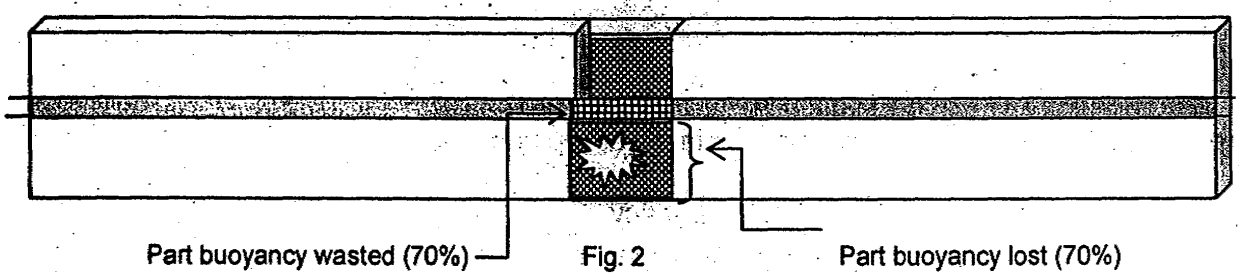


Fig. 2

In present case even the water plane at the final water line is damaged.

Intact water plane area = Total water plane area – lost water plane area
= 140 x 21 – 18 x 21 x 0.70
= 2675.4 m^2

Now Intact water plane area x sinkage = replenished buoyancy which also must equal lost buoyancy

$$\therefore \text{Sinkage} = \frac{\text{Lost buoyany}}{\text{Intact water plane area}}$$

$$= \frac{1905.1}{2675.4}$$

= 0.712 m.

New Draft = 7.912 m

In a case where: a) A vessel is wall sided, b) damage is vertically uniform over drafts from keel till the final water line,

KB = ½ draft.

New KB = 3.956 m.

$$\text{BM} = \frac{\text{Moment of Intertia of water plane area about the centre line}}{\text{Intact under water volume.}}$$

$$= \frac{\frac{140\times 21^3}{12} - \frac{18\times 21^3}{12}\times 0.7}{140\times 21\times 7.2}$$

= 4.645m

KM = 8.601m

KG = 8.501m
GM = 0.100 m

Note: GM has decreased.

Case: Damage to 'centre line compartment' that is located amidships, carries a solid cargo such as steel cargo. The vertical extent of damage is restricted by a watertight flat hence is limited. Damage occurs below the flat level.

Note: *When the damage occurs below the level of a water tight flat that is below the initial draft level, the loss of buoyancy is contained till the flat only. The water plane area above that level remains intact. The replenishing buoyancy comes from entire water plane area.*

Ex. 3 A box shaped vessel 80m x 16m at an even keel draft of 4.5m has a mid compartment 12m in length, extending from side to side, with a watertight flat 2m above the keel, KG = 4.72m. Calculate (a) her draft and (b) her GM after the compartment below the W/T flat with permeability of 70% is bilged.

Sol: -

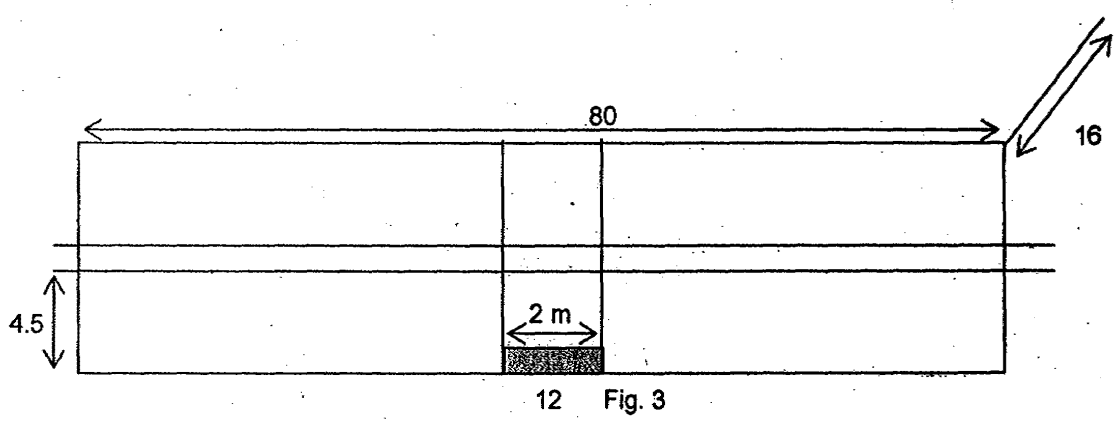


Fig. 3

GM_T before the damage = 2.271m.
Lost buoyancy = 12 x 16 x 2 x 0.7 = 268.8m^3
Intact WPA = Total – lost WPA = 80 x 16 = 1280m^2.

Sinkage $= \frac{L.Buoy}{IntactWPA} = \frac{268.8}{1280} = 0.21m$

New draft = 4.710 m.

New KB is found by taking moments about the keel & is equal to;

$$\frac{\text{Moment of total volume upto new WL} - \text{moment of volume not providing buoyancy}}{\text{Intact UW vol}}$$

$$= \frac{80 \times 16 \times 4.71 \times \tfrac{1}{2} \times 4.71 - [12 \times 16 \times 2 \times (\tfrac{1}{2}2)]0.7}{80 \times 16 \times 4.5}$$

= 2.418m.

MI of intact WPA about C/L axis = MI of initial (unbroken) WPA about CL axis – Lost MI about same axis

BM_T = $MI_{INTACT\ WP\ CL}$ /Intact UW vol

In this case water plane is not damaged i.e. is still intact.

$BM_T = \frac{80 \times 16^3}{12 \times 5760}$

BM_T = 4.74m, KB = 2.418m
$KB + BM_T$ = KM_T = 7.158ma
$KM_T - KG$ = GM_T = 2.438m
Draft = 4.71m, GM_T = 2.438m. (Note: GM_T before the damage was 2.271m)

Case: Damage to 'centre line compartment' that is located amidships, carries a solid cargo such as steel cargo. The vertical extent of damage is limited as the damage is contained above the watertight flat only. Damage occurs above the flat level.

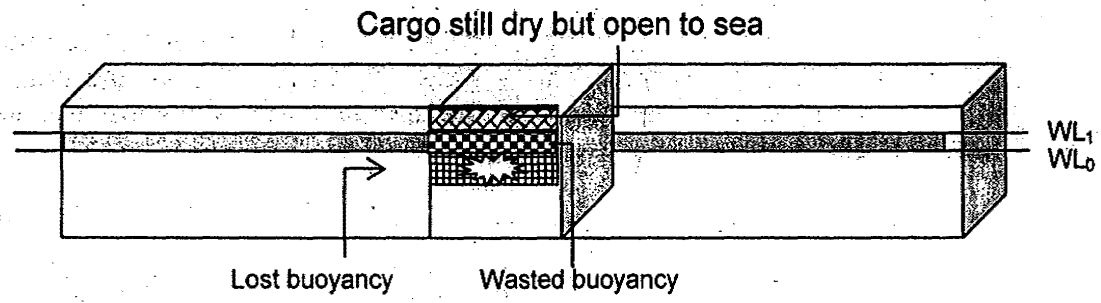


Fig. 4

Case: When the damage occurs above the level of a water tight flat that is below the initial draft level, the loss of buoyancy occurs in damage length above the flat only. The replenishing buoyancy comes from due to sinkage. Sinkage depends on intact water plane area.

Ex. 4 A box shaped vessel 80 m x 16 m at an even keel draft of 4.5 m has a mid compartment 12 m in length, extending from side to side, with a watertight flat 2.5 m above the keel, KG = 4.72 m. Calculate (a) her draft and (b) her GM after the compartment above the W/T flat with a permeability of 70% is bilged.

Sol^n : -

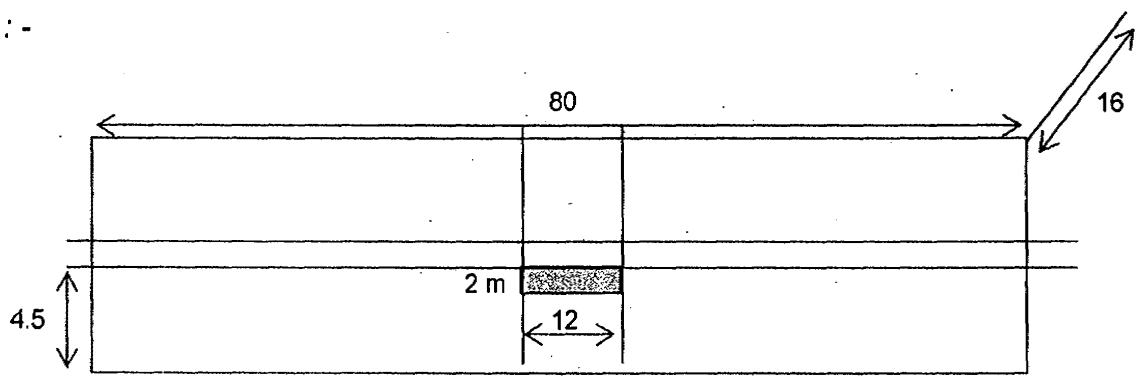


Fig. 5

GM_T before the damage = 2.271m.
Lost buoyancy = 12 x 16 x 2 x 0.7 = 268.8m^3
Intact WPA = Total – lost WPA = 80 x 16 - (12 x 16 x 0.7) = 1145.6m^2.
Sinkage = $\frac{\text{L.Buoyancy}}{\text{intact WPA}} = \frac{168.8}{1145.6}$ = .235m.
New draft = 4.735 m.
New KB is found by taking moments about the keel & is equal to;

$$= \frac{\text{Moment of total volume upto new WL} - \text{moment of volume not providing buoyancy}}{\text{Intact UW vol}}$$

$$= \frac{80\times16\times4.735\times\tfrac{1}{2}\times4.735 - [12\times16\times2.235\times(\tfrac{1}{2}2.235+2.5)]0.7}{80\times16\times4.5} = 2.302\text{ m.}$$

MI of intact WPA about C/L axis = MI of initial (unbroken) WPA about CL axis – Lost MI about same axis

$$BM_T = \frac{MI_{INTACT\,WPCL}}{Intact\ uw\ vol}$$

$$BM_T = \frac{\frac{80\times16^3}{12} - \frac{12\times16^3}{12}\times0.7}{80 \times 16 \times 4.5}$$

BM_T = 4.243 m, KB = 2.302 m

$KB + BM_T$ = KM_T = 6.545 m

$KM_T - KG$ = GM_T = 1.825 m

Draft = 4.71m, GM_T = 1.825 m. (Note: GM_T before the damage was 2.271m)

Note: Comparing Q3 & Q4 it can be seen that if there is a watertight flat below the final waterline, it limits the damage below the flat and prevents the damage to reach waterline and hence the loss of WPA. Also, GM_t normally would improve after bilging if WPA is not damaged.

Case: Damage to 'centre line compartment' that is located amidships, carries a solid cargo such as steel cargo. The vertical extent of damage is limited. The damage is contained below the watertight flat, which is slightly above the water line before the damage. The damaged length has intact buoyancy at DB level.

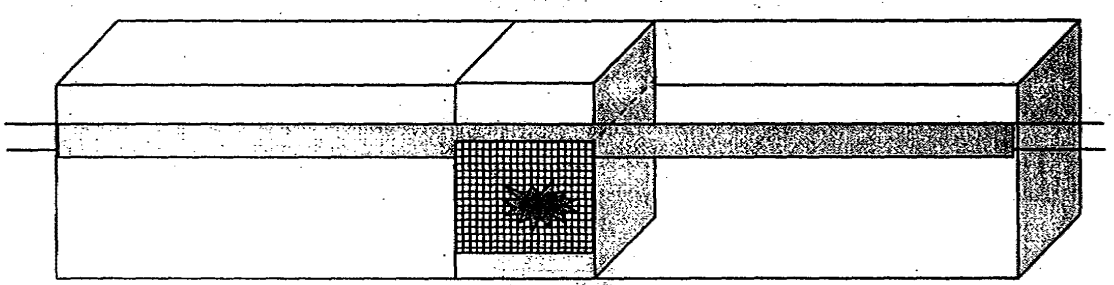


Fig. 6

Ex. 5 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship compartment of length 18m & extending over full breadth, containing a cargo of permeability 70%. This compartment was bilged. Find GM of the vessel after damage using the 'Constant displacement method'. Given; (a) There is a DB of height 1.8m below the damaged length. & (b) There is watertight flat at a draft of 7.4m. Initial KG = 8.501 m.

In present case the water plane at the final water line may or may not be sound. This is because at the initial draft the water plane area is damaged. This 'water plane area' will continue till the flat level beyond which the 'water plane area' is sound. The rate of sinkage will be different in the two regions. The ship will sink faster initially & slower later.

Lost buoyancy = 18 x 21 x 5.4 x 0.7 = 1428.84 m^3

Intact water plane area
(till the draft of w/tight flat) = Total water plane area – lost water plane area
= 140 x 21 – 18 x 21 x 0.70
= 2675.4 m^2

Buoyancy available till
The w/tight flat = 2675.4 x 0.2 = 535.08 m^3

Extra buoyancy required = 1428.84 – 535.08 = 893.76 m^3

∴ Extra sinkage = Extra buoyancy required / Intact Water plane area

$$= \frac{893.76}{140 \times 21}$$

= 0.304 m.

New Draft = 7.2 + 0.2 + 0.304 = 7.704 m.

Damaged area is not uniform over different drafts from keel till the final water line, hence the KB will have to be found by moments:

Taking Moments of volume about the keel:

$$KB = \frac{\text{Moment of total under water volume upto the new draft} - \text{Moment of wasted buoyancy}}{\text{Intact U/W volume}}$$

$$KB = \frac{140 \times 21 \times 7.704 \times \frac{1}{2}(7.704) - 0.7\{18 \times 215.6\,(\frac{1}{2} \times 5.6 + 1.8)\}}{21168} = 3.800 \text{ M.}$$

$$BM = \frac{140 \times 21^3}{12 \times 140 \times 21 \times 7.2} = 5.104 \text{m.}$$

KM = 3.800 + 5.104 = 8.904 m

KG = 8.501 m ∴ GM_T = 0.403 m.

Note: GM_t before damage was 0.203m

Case: Damage to 'centre line compartment' that is located amidships, carries a solid cargo such as steel cargo. The vertical extent of damage is limited. The damage is contained below the watertight flat, which is slightly above the water line before the damage. The damaged length does not have intact buoyancy at DB level.

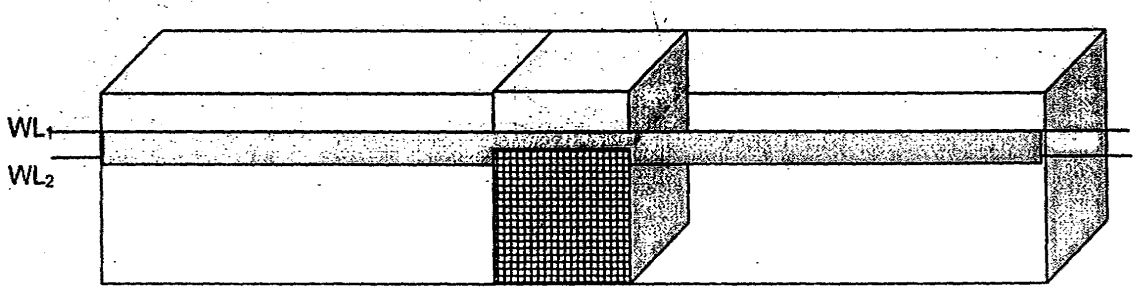


Fig. 7

Ex. 6 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship compartment of length = 18m & extending over full breadth, containing a cargo of permeability = 70%. This compartment was bilged. Find GM of the vessel after damage using the 'Constant displacement method'. Given; There is watertight flat at a draft of 7.4m. Initial KG = 8.501 m.

The water plane area at the final water line may or may not be sound. This is because at the initial draft the water plane area is damaged. This 'water plane area' will continue till the flat level. Beyond the flat level, the 'water plane area' is sound. The rate of sinkage will be different in the two regions. The ship will sink faster initially & slower later as was also stated under the last case.

Lost buoyancy = 18 x 21 x 7.2 x 0.7 = 1905.12 m^3

Intact water plane area
(till the draft of w/tight flat) = Total water plane area – lost water plane area
= 140 x 21 – 18 x 21 x 0.70
= 2675.4 m^2

Buoyancy available till

The w/tight flat = 2675.4 x 0.2 = 535.08 m^3
Extra buoyancy required = 1905.12 – 535.08 = 1370.04 m^3
$\therefore$ Extra sinkage = $\frac{\text{Extra buoyancy required}}{\text{Intact water plane area}}$
= $\frac{1370.0}{140 \times 21}$
= 0.466 m.
New Draft = 7.2 + 0.2 + 0.466 = 7.866 m.

Damaged area is not uniform over different drafts from keel till the final water line, hence the KB will have to be found by moments:
Taking Moments of volume about the keel:

$$KB = \frac{\text{Moment of total under water volume upto the new draft} - \text{Moment of wasted buoyancy}}{\text{Intact U/W volume}}$$

$$KB = \frac{140 \times 21 \times 7.866 \times \frac{1}{2}(7.866) - 0.7\left\{18 \times 21 \times 7.4\ (\frac{1}{2} \times 7.4\right\}}{21168} = 3.955\ M$$

$$BM = \frac{140 \times 21^3}{12 \times 140 \times 21 \times 7.2} = 5.104 m$$

KM = 3.955 + 5.104 = 9.059 m
KG = 8.501 m
$\therefore GM_T$ = 0.558 m.

Note: GM_t before damage was 0.203m.Comparing Q5 & Q6, it can be seen that intact buoyancy below the water level provides poorer GM_t

Case: Damage to 'centre compartment' that is located amidships, carries a solid cargo such as steel cargo. The vertical extent of damage is un-limited. Width of the centre compartment is half of the breadth.

Ex. 7 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship compartment of length = 18m subdivided in to port, starboard & centre compartment containing a cargo of permeability = 70%. The breadth of port & starboard compartment is 5.25 m each, the width of centre compartment is 10.5 m. centre compartment was bilged. Find GM of the vessel after damage using the 'Constant displacement method'. If initial KG was 8.501 m, find the change in GM_T.

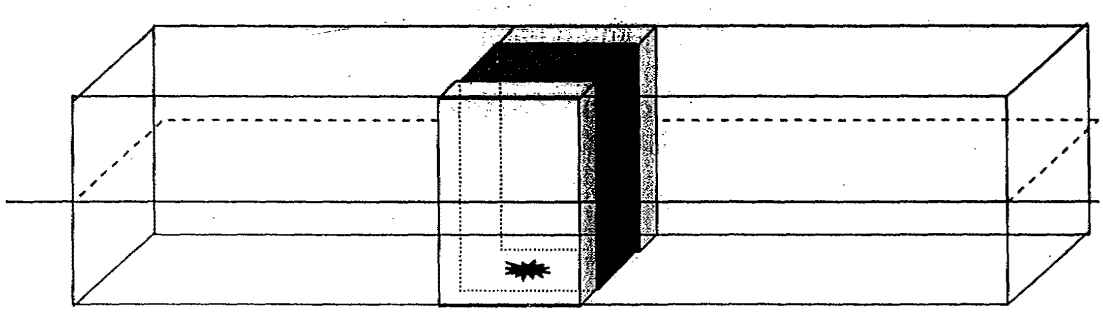


Fig. 8

Sol^n : -

Initial KM = 3.6 + 5.104 = 8.704 m.
Hence initial GM_T = 8.704 – 8.501 = 0.203 m.
lost buoyancy =18 x 10.5 x 7.2 x 0.70 = 952.56 m^3

In present case even the water plane at the final water line is damaged.

Intact water plane area = Total water plane area – lost water plane area
= 140 x 21 – 18 x 10.5 x 0.70
= 2807.7 m^2

$\therefore$ Sinkage $= \dfrac{\text{Lost Buoyancy}}{\text{Intaact water plane area}}$

$= \dfrac{952.56}{2807.7}$

= 0.339 m.

New Draft = 7.539 m
KB = ½ draft.
New KB = 3.770 m.

$$BM_T = \frac{\textit{Moment of Inertia of water plane area about the centre line}}{\textit{Intact under water volume}}$$

$$= \frac{\frac{140\times 21^3}{12} - \frac{18\times 10.5^3\times 0.7}{12}}{140\times 21\times 7.2} = 5.047 \text{ m}$$

KM = 8.817m
KG = 8.501m
GM_T = 0.316 m

Case: Damage to side compartment is symmetrical about C/L, located amidships, carry solid cargo such as steel cargo. The vertical extent of damage is un-limited. Total width of the side compartments is half of the breadth of ship.

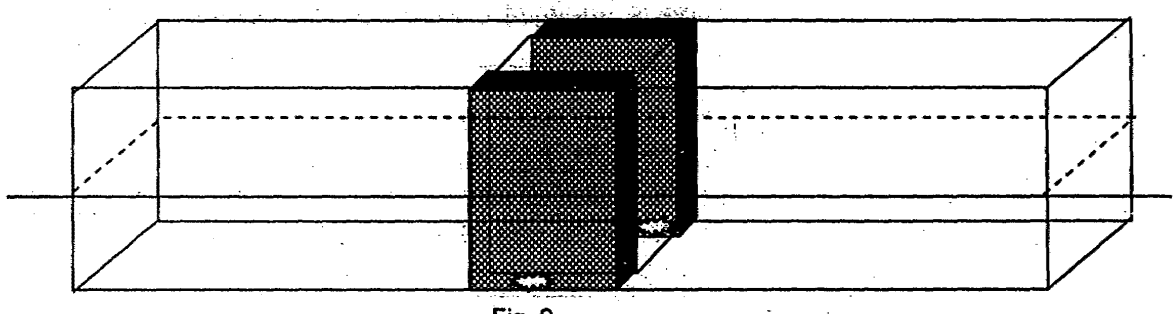


Fig. 9

Ex. 8 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship compartment of length = 18m subdivided in to port, starboard & centre compartment containing a cargo of permeability = 70%. The breadth of port & starboard compartment is 5.25 m each; the width of centre compartment is 10.5 m. Both the side compartments were bilged. Find GM of the vessel after damage using the 'Constant displacement method'. If initial KG was 8.501 m, find the change in GM_T.

Sol^n: -

Initial KM = 3.6 + 5.104 = 8.704 m. Hence initial GM_T = 8.704 – 8.501 = 0.203 m.
18 x 10.5 x 7.2 x 0.70 = 952.56 m^3 is the lost buoyancy.
In present case the water plane at the final water line is damaged.
Intact water plane area = Total water plane area – lost water plane area
= 140 x 21 – 18 x 10.5 x 0.70
= 2807.7 m^2

$\therefore$ Sinkage = $\frac{\text{Lost Buoyancy}}{\text{Intact water plane area}}$

= 952.56 /2807.7

= 0.339 m.

New Draft = 7.539 m

KB = ½ draft.

New KB = 3.770 m.

BM_T = Moment of Inertia of water plane area about the centre line / Intact under water volume.

$$= \frac{\frac{140\times21^3}{12} - \left\{\frac{18\times5.25^3}{12} + 18\times5.25\times7.875^2\right\}\times2\times0.7}{140\times21\times7.2} = 4.702m$$

KM = 8.472m

KG = 8.501m

GM_T = (-) 0.029 m

Note: Comparing Q7 & Q8 it can be seen that for the same loss of buoyancy and WPA but one involving loss of MI about an axis away from centre line causes higher loss of BM_T and hence GM_T.

Case: Damage to 'centre line compartment' that is located amidships, carries ballast. The vertical extent of damage is restricted by a watertight flat below the waterline hence is limited. Damage occurs below the flat level.

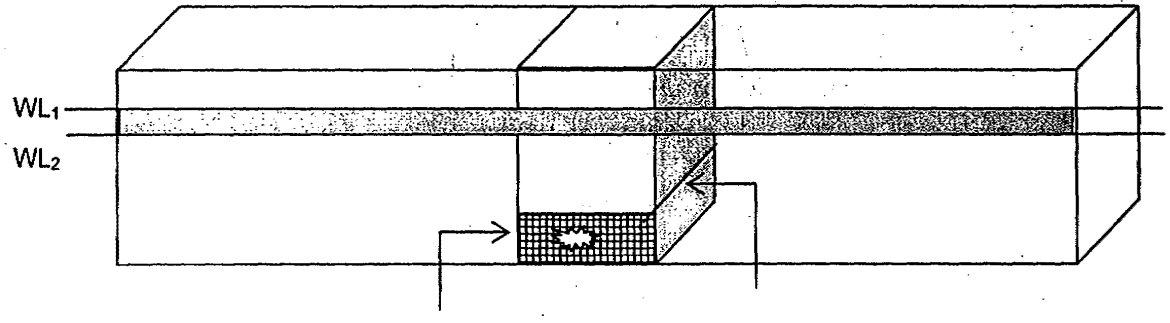


Fig. 10

Ex. 9 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship DB tank of length 18m & extending over full breadth, containing ballast (RD 1.025). This tank was bilged. Find GM of the vessel after damage using the 'Constant displacement method' & using 'Added weight method'. Given; Height of tank 2 m. Initial KG = 8.501 m.

Sol^n: -

Initial KM = 3.6 + 5.104 = 8.704 m. Hence initial GM_T = 8.704 – 8.501 = 0.203 m.

Constant Displacement Method:

Initial displacement = 140 x 21 x 7.2 x 1.025 = 21697.2 t.

Let us find the parameters assuming that the ballast water was pumped out before damage.

'w' = 18 x 21 x 2 x 1.025 = 774.9 t.

Taking moments:

Weights	KG	v. Moments
21697.2	8.501	184447.9
774.9	1	774.9
20922.3		183673

KG $= \frac{183673}{20922.3} = 8.779$ m

TPC of ship $= \frac{140 \times 21 \times 1.025}{100} = 30.135$

Bodily rise $= \frac{w}{100\,TPC} = 0.257$ m

New draft = 6.943 m.

New intact under water volume = 20412 m^3.

Let us assume that after the ballast is removed from the ship the bilging occurs, thus Lost buoyancy = 18 x 21 x 2 & intact water plane area = 140 x 21 m^2.

Sinkage $= \frac{LB}{IWPA} = 0.257$ m.

The new draft there fore = 6.9427 + 0.257 = 7.200 m.

The KB is found by taking the moments:

KB $= \frac{140 \times 21 \times 7.2 \times \frac{1}{2}7.2 - 18 \times 21 \times 2}{140 \times 21 \times 6.9428} = 3.696$

BM $= \frac{140 \times 21^3}{12 \times 140 \times 21 \times 6.943} = 5.293$m

KM = KB+ BM = 8.989 m

GM_T = KM – KG = 0.210 m.

Added Wight Method:

'w' the weight added = 0 ∴new KG = 8.501 m. KB = 3.6 m

BM $= \frac{21 \times 21}{12 \times 7.2} = 5.104$ GM = KB + BM – KG = 0.203.= 0.203 m.

Relating the GMs in the two methods

0.203 x 21697 = 0.210 x 20922.3.

Note:

The 'Added weight method' is very useful in quickly finding the GM_T, which is the initial GM_T only. The GM_T of 'Constant displacement method' can approximately be found as follows:

$GM_T = \frac{0.210 \times 20922.3}{21697} = 0.203$m

Case: Damage to 'centre line compartment' that is located amidships, carries oil. The vertical extent of damage is restricted by a watertight flat below the waterline hence is limited. Damage occurs below the flat level.

Ex. 10 A box shaped vessel of length 140m, breadth 21m, draft 7.2m has a midship DB tank of length = 18m & extending over full breadth, containing oil (RD 0.80). This tank was bilged. Find GM of the vessel after damage using the 'Constant displacement method'. Given; Height of tank 2 m. Initial KG = 8.501 m.

Sol^n: -

Initial KM = 3.6 + 5.104 = 8.704 m. Hence initial GM_T = 8.704 – 8.501 = 0.203 m.

Constant Displacement Method:

Initial displacement = 140 x 21 x 7.2 x 1.025 = 21697.2 t.

Let us find the parameters after hypothetical pump – out of oil.

'w' = 18 x 21 x 2 x 0.80 = 604.8 t.

Taking moments:

Weights	KG	v. Moments
21697.2	8.501	184447.9
- 604.8	1	604.8
21092.4		183843.1

KG = 183843.1/21092.4 = 8.7161 m

TPC of ship $= \frac{140 \times 21 \times 1.025}{100} = 30.135$

Bodily rise $= \frac{w}{100TPC}$

New draft = 6.999 m.

New intact under water volume = 20577.95 m^3.

Let us assume that after the oil is completely removed from the ship the bilging occurs, thus Lost buoyancy = 18 x 21 x 2 & intact water plane area = 140 x 21 m^2.

Sinkage $= \frac{LB}{IWPA} = 0.257$ m.

The new draft there fore = 6.999 + 0.257 = 7.256 m.

The KB is found by taking the moments:

$$KB = \frac{140 \times 21 \times 7.256 \times \frac{1}{2}7.256 - 18 \times 21 \times 2}{140 \times 21 \times 6.999} = 3.724m$$

$$BM = \frac{140 \times 21^3}{12 \times 140 \times 21 \times 6.999} = 5.251m$$

KM = KB+ BM = 8.975 m

GM_T = KM – KG = 0.259 m.

Case: Bilging of end compartment of box shaped vessels causing the vessel to trim.

Ex .11 A box shaped vessel 100 x 20m, KG = 5.2 m, floats at an even keel draft of 5 meters salt water. An end compartment forward, 10 m long and covering the full breadth of the vessel is bilged. Calculate the new drafts forward and aft.

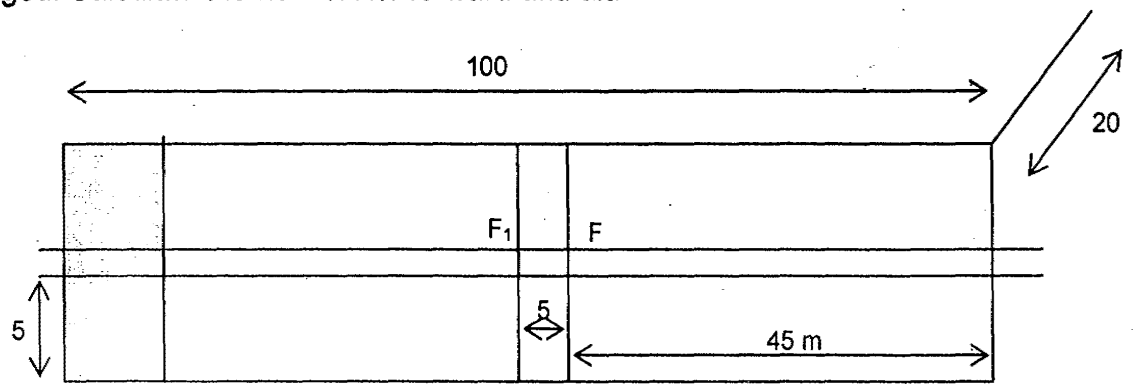


Fig. 11

Lost buoyancy = 10 x 20 x 5 = 1000m^3

Intact WPA = Total – lost WPA = 200 x 100 – 10 x 20 = 1800m^2.

Sinkage $= \frac{\text{Lost Buoyancy}}{\text{Intact water plane area}} = 0.555m$

New draft = 5.555m. KB = ½ new draft = 2.778m

To find longitudinal shift of COF: take moments about midships.

$$\frac{\text{Tot area} \times 0 - \text{lost WPA} \times 45}{\text{Intact WPA}} = \frac{-10 \times 20 \times 45}{1800} = -5\text{m}$$

MI of intact WP about athwartship axis through new COF

MI of initial (unbroken) WPA about ath axis thro' new COF – Lost MI about ath axis thro' new COF

$$BM_L = \frac{\text{Residual MI about ath axis through new COF}}{\text{Intact uw vol}}$$

$$= \frac{\left[\frac{20\times100^3}{12}+100\times20\left(5^2\right)\right]-\left[\frac{20\times10^3}{12}+10\times20\times50^2\right]}{100\times20\times5}$$

BM_L = 121.5 m KB = 2.778 m

$KB + BM_L$ = KM_L = 124.278 m

$KM_L - KG$ = GM_L = 119.07 m

To find new LCB_1, take moment of under water volume about A.P.

$$LCB_1 = \frac{100 \times 20 \times 5.555 \times 80 - 10 \times 20 \times 5.555 \times 95}{100 \times 20 \times 5l} = 45 \therefore BB = 5\text{m}.$$

(Note $FF_1 = BB_1$ in this case as damage is uniform at different drafts upto new water level)

$$\frac{t_{rc}}{LBP} = \frac{BB_1}{GM_L}$$

$\therefore t_{rc} = 4.199$m

T_{ra} =1.889m & t_{rf} = 2.310 m

Draft F = 5.000+0.555+2.310 =7.865m & Aft = 5.000+0.555-1.889 = 3.666 m.

Case: Bilging of intermediate compartment of box shaped vessels causing the vessel to trim.

Ex. 12 A box shaped vessel 120 m x 20 m at an even keel draft of 4.5 m has a compartment 15 m in length with its forward bulkhead 15 m abaft the forward end. The compartment extending the full width of the vessel and having a permeability of 70% is bilged. If the vessel had a KG of 4.5m before bilging, calculate her final drafts F & A.

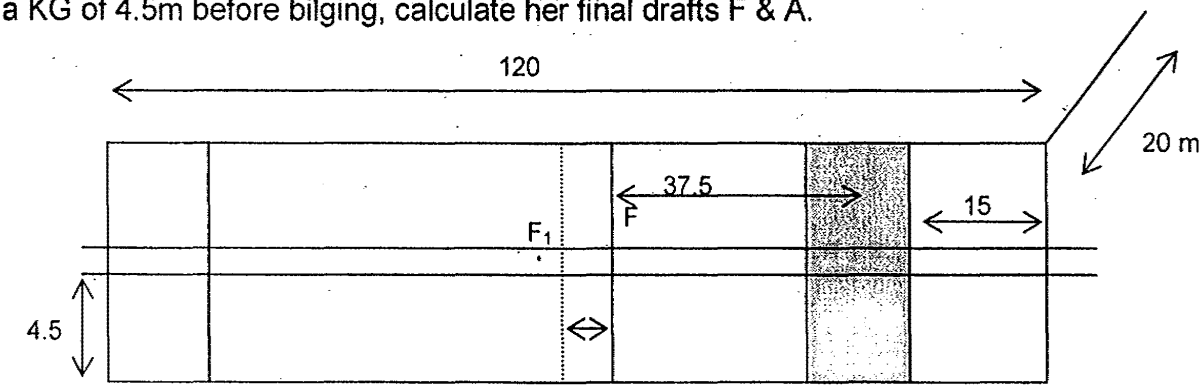


Fig. 12

Lost buoyancy = 15 x 20 x 4.5 x 0.7 = 945m^3

Intact WPA = Total – lost WPA = 120 x 20 – 15 x 20 x 0.7 = 2190m^2.

Sinkage = $\frac{\text{L.Buoyancy}}{\text{Intact WOA}} = 0.432\text{m}$

New draft = 4.932 m.

KB = ½ new draft = 2.466m

To find longitudinal shift of COF: take moments about midships.

$$\frac{\text{Tot area} \times 0 - \text{lost WPA} \times 37.5}{\text{Intact WPA}} = \frac{-15 \times 20 \times 37.5 \times 0.7}{2190} = -3.596\text{m}$$

MI of intact WPA about athwartship axis through new COF
MI of initial (unbroken) WPA about ath axis thro' new COF – Lost MI about ath axis thro' new COF

$$BM_L = \frac{\text{Residual MI about ath axis through new COF}}{\text{Intact uw vol}}$$

$$= \frac{\left[\frac{20\times120^3}{12} + 120\times20(3.596)^2\right] - \left[\frac{20\times15^3}{12} + 15\times20\times41.096^2\right]0.7}{120\times20\times4.5}$$

BM_L = 236.336m,
KB = 2.466m
$KB + BM_L = KM_L$ = 238.802m
$KM_L - KG = GM_L$ = 234.302m
BB_1 = 3.596m.
(Note $FF_1 = BB_1$ in this case as damage is vertically uniform at different drafts upto new water levels)

$$= \frac{t_{rc}}{LBP} = \frac{BB_1}{GM_L} \quad \therefore t_{rc} = 1.842\text{m}$$

t_{ra} = 0.866m & t_{rf} = 0.976m
Draft F = 5.908m & Aft = 4.066m.

Case: Bilging of intermediate compartment (with a horizontal flat & damage above the flat) of box shaped vessels causing the vessel to trim.

Ex. 13 A box shaped vessel 80m x 16m floats at an even keel draft of 4.5m with KG 6.8m. She has a compartment 12m in length, extending from side to side with its after bulkhead 20m. For'd of amidships. The compartment has a watertight flat 2.0m above the keel. Calculate the drafts f & aft if that compartment with permeability of 70% is bilged above the watertight flat.

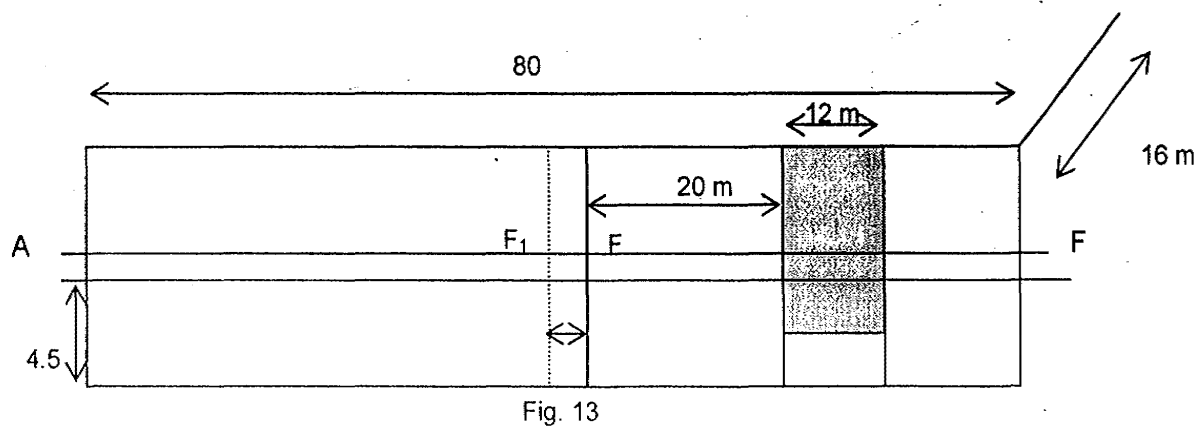


Fig. 13

Lost buoyancy = 12 x 16 x 2.5 x 0.7 = 336m^3
Intact WPA = Total – lost WPA = 1280 – 12 x 16 x 0.70 = 1145.6m^2.

Sinkage $= \frac{\text{L.Buoyancy}}{\text{Intact WPA}} = \frac{336}{1145.6} = 0.293\text{m}$

New draft = 4.793 m.

KB is found by taking moments about the keel.

$$= \frac{\text{Moments of total volume upto new WL} - \text{moments of volume not providing buoyancy}}{\text{Intact UW vol}}$$

$$= \frac{80\times16\times4.793\times\tfrac{1}{2}\times4.793-\left[12\times16\times2.793\times\left(\tfrac{1}{2}\times2.793+2\right)0.7\right]}{80\times16\times4.5} = 2.331\text{m.}$$

To find longitudinal shift of COF: take moments about midships.

$$= \frac{\text{Tot area}\times0-\text{lost WPA}\times26\times0.7}{\text{Intact WPA}} = \frac{-12\times16\times26\times0.7}{1145.6} = 3.050\text{m}$$

MI of intact WPA about athwartship axis through new COF

= MI of initial (unbroken) WPA about ath axis thro' new COF – Lost MI about ath axis thro' new COF

$BM_L = \frac{\text{Residual MI about ath axis through new COF}}{\text{Intact uw vol}}$

$$= \frac{\left[\frac{16\times80^3}{12}+16\times80\,(3.05)^2\right]-\left[\frac{16\times12^3}{12}+16\times12\times29.05^2\right]0.7}{80\times16\times4.5}$$

BM_L = 100.61m,

KB = 2.331m

$KB + BM_L = KM_L$ = 102.941m

$KM_L - KG = GM_L$ = 96.141m

To find new LCB_1, take moment of under water volume about A.P.

$$LCB_1 = \frac{80\times16\times4.793\times40-16\times12\times2.793\times66\times0.7}{80\times16\times4.5} = 38.303 \therefore BB = 1.697\text{m.}$$

(Note FF_1 not equal to BB_1 in this case as damage upto new water levels is not uniform at different drafts)

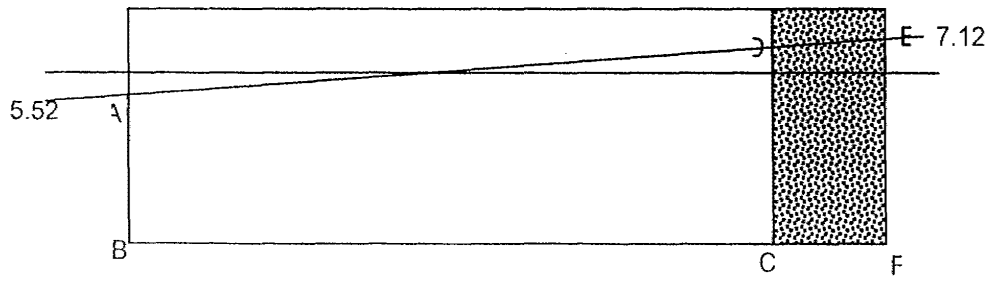
$$= \frac{t_{rc}}{LBP} = \frac{BB_1}{GM_L} \quad \therefore t_{rc} = 1.410\text{m}$$

t_{ra} = 0.651m & t_{rf} = 0.759m

Draft F = 5.552m & Aft = 4.142m.

Ex. 14 A box shaped vessel 100m x 12m is at an even keel draft of 6m has a forward compartment 10m in length containing general cargo. After this compartment is bilged, the drafts were 7.12m forward and 5.52m aft. Find permeability of cargo in forward compartment.

Hint:



Intact under water volume does not change after bilging. The under water volume is 7200m^3 before damage. Intact under water volume after damage = volume ABCD + volume DCFE x (1 – p), where p is permeability fraction. We get p = 0.45.
Ans. 45%.

Ex 15 A box shaped vessel 120 m-x 20 m has a compartment 12 m in length with forward bulkhead 30m from fore end of the vessel. The compartment extends from side to side and has a cargo of uniform permeability of 80%. The vessel with a KG 5.4m has a draft of 6.0m forward & 8 m aft. Calculate her draft F & A if the compartment is bilged.
Hint: Lost buoyancy is calculated as per the draft at the compartment that is damaged. The draft correction for the midlength of compartment = $\frac{2 \times 36}{120} = 0.6$. Draft = 6+0.6 = 6.6 m.
Lost buoy = 12x20x6.6x0.8 =1267.2m^3. Sinkage = 0.574m.
The FF_1, LCB_1, Residual MI, BM_L, will be done in the same way as is done for even keel vessel. t_{rf} & t_{ra} thereafter is applied to 6.574m & 8.574m respectively.

Ex 16 A box shaped vessel 120 m-x 20 m floating in SW has a compartment 12 m in length with forward bulkhead 30m from fore end of the vessel. The compartment extends from side to side and has ballast water (R.D. 1.025) filled to a height of 4 m. The vessel with a KG 5.4m is on EK draft of 6.0m. Calculate her draft F & A if the compartment is bilged.
Hint: Assume that the quantity of liquid in the compartment is pumped out prior getting bilged. The drafts forward & aft with empty compartment are found. Hereafter proceed as in the last question.

Exercise 20
Q. 1 A box shaped vessel 82 m x 15 m, at an even keel draft of 4.5 m has a midship compartment 10m in length with a watertight flat at. 4.7 m above the keel. Her KG is 5.1 m Calculate her drafts F & A and her GM if that compartment is bilged below the water level.
Ans. Draft 5.073 m. GM 1.626 m.

Q. 2 A box shaped vessel of length 80m, breadth 15m at an even keel draft of 4m has a midship compartment 12m in length with a water tight flat 3m above the keel. The midship compartment with a permeability of 70% is bilged below the water tight flat. Calculate her draft for'd & aft and GM after bilging if KG in initial condition is 5.1m.
Ans. Draft 4.315m, GM 1.798m
Q. 3 A box shaped vessel 80 m x 15 m, is at an even keel draft of 4.0 m, KG 4.1 m. An empty midship compartment 12 m in length with a watertight flat 4.2 m above the keel is holed 2 m above the keel. Calculate the F & A drafts at which she will settle. Also calculate her GM then.
Ans. Draft 4+0.2+0.43 = 4.63m KB 2.349m, BM 4.688 GM 2.937m

Q. 4 A box shaped vessel 90 m long and 20 m wide has a mid-ship compartment 12 m long 15m wide extending from ship's bottom with a watertight flat at a height of 5.2 m from bottom. Compartment has a cargo of permeability = 60%. If draft of the ship was 5m at even keel, find the new draft if the compartment described above gets bilged. Also find the change in KM if any.
Ans. New Draft = 5.312m BM unchanged but KM increases by 0.159m to 9.326m.

Q. 5 A box shaped vessel 100m long, 20m broad floats at an even keel draft of 6.0m in water of RD 1.005. A hold 10m long, 20m wide is full of cargo of RD 0.6 and SF 2.8 m^3/t. The forward bulkhead of this hold is 20m from the aft end of ship. Calculate the change in the KM_L of the ship if this compartment is bilged.

Hint: $1-\frac{1}{S.F \times S.G} = 0.4048$ *or* 40.48% Sinkage = 0.253m, new draft = 6.253 m.
KB = ½ draft = 2.331m. FF_1= 1.477m. BM_L = 130.219m, KB = 3.127 m.
KB + BM_L = KM_L = 133.346 m, Initial KM_L = 141.889 m, Change of KM_L = 8.543 m.

Q. 6 A box- shaped vessel of length 80m and breadth 15m floats in salt water at an even keel draft of 4.2 m. KG = 5.1 m. An amidships compartment of length 12 m with a permeability of 70% gets bilged below a water- tight flat located 3m above the keel. Find the GM and draft in this condition.
Ans. GM 1.678m Draft 4.515 m.

Q. 7 A box shaped vessel of length 80 m, breadth 18 m, at an even keel draft of 4 m has a KG of 3.5 m. A midship compartment extending the full width of the vessel and 10 m long has a watertight flat at a height of 3 m above the keel. If this compartment of permeability 40% is bilged below the watertight. flat, calculate the draft at which she will settle and her GM then.
Ans. 4.15m & 3.746m.

Q. 8 A box - shaped vessel 210 m long and 25 m wide floats in salt water at draft 10 m F&A. KG = 10.6 m. An empty amidships compartment 30 m long and 25 m wide has a water-tight flat 10.5 m above the keel. Find the GM if this compartment is bilged below the water-tight flat.
Ans. 0.433m. Final drafts 11.5m. KB 5.825m.

Q. 9 A box shaped vessel, 80 m x 15 m at an even keel draft of 3.6 m has a midship compartment 20 m in length, extending from side to side, with a watertight flat 1.8 rn above the keel. The KG of the vessel is 5.8 m. If that compartment is bilged, calculate (i) the draft at which she settles and (ii) her GM after bilging.
Ans. (i) 4.20 m Forward and aft. (ii) 1.358m KB 1.95m

Q. 10 A box - shaped vessel 80 m x 16 m at an even keel draft of 4.5 m, KG 5.8 m, has a midship compartment 22 m in length with a water-tight flat 3 m above the keel. If that compartment with permeability of 65% is bilged below the flat, calculate her drafts and GM.
Ans. Drafts forward & aft 5.034m, GM 0.056mm, KB 2.639 m.

Q. 11 A wall -sided vessel of constant water-plane area of length 105m has the following equally spaced half - ordinates of water plane; 1.7, 3.4, 5.6, 6.7, 6.7, 5.61 3.4 & 1.7 m. When floating at an even keel draft of 4.5 m, an empty compartment with transverse end bulkheads at the 6.7 m ordinates is bilged. Calculate the end drafts at which she would settle.
Ans. Final drafts Forward and aft 5.539m.

Q. 12 A box shaped vessel 72 m X 8 m floats at on even keel draft of 4 m. A Midship compartment 12 m long has a watertight flat 4 .5 m above the keel. If that compartment is bilged below the watertight flat, find her KM.
Ans. Draft 4.75m, KM 3.731m, KB 2398 m.

Q. 13 A vessel of constant triangular cross-section has a depth of 12m and a breadth at the deck of 15m. Calculate the draught at which the vessel will become unstable if the center of gravity is 6.675m above the keel.
Ans. Draft 7.2m.

Q. 14 A box shaped vessel 100m x 12m is at an even keel draft of 6 meters, has a forward compartment 10 m in length; containing general cargo. After this compartment is bilged, the drafts were found to be 7.03m fwd and 5.53m aft. Find the permeability of the cargo in the for'd compartment.
Ans. Permeability 40.26%.

Q. 15 A box shaped vessel 100m long and 12m wide floats at an even keel draft of 6m in SW. No.4 hold, 10m long and 12m broad, is empty. The after bulkhead of this hold is 10m from the after end of the ship. Find the drafts fwd and aft if this hold is bilged.
Ans. F 5.122m A 8.473m.

Q. 16 A box shaped vessel 120 m x 18 m, at an even keel draft of 6m has KG 5.2m. A compartment 15m in length with its forward bulkhead 20m abaft midlength contains cargo of RD 0.6 and stowage factor 2 m^3/t. Calculate the fore and after drafts if that compartment is flooded due to damage.

Ans. Permeability = $1 - \frac{1}{S.F \times S.G} = 0.167$

Draft = 6.128 m KB 3.064m BM_L 197.2 m, T_r 0.360m. Draft F'd, 5.822m Aft, 6.182m.

Q. 17 A box shaped vessel 115m x 20m, at an even keel draft of 4m has a forward compartment 18m in length, divided by two F and A bulkheads. The port and starboard compartments are 7m wide each and the centre compartment 6 m wide. The two side compartments of permeability 60% are bilged. Calculate her GM after bilging, if the original GM was 1.2 m.
Ans. Original KM 10.333 m, KG 9.133 m. Final GM 0.580 m.

Q. 18 A box shaped vessel of length 160 m, width 18m is at an even keel draft of 6.4 m. A compartment 15 m in length and 18 m in width, symmetrical about the ship's F & A centre line, with its CG 27.5 m for'd of midships, permeability 80% is bilged. Calculate the drafts for'd and aft at which she will settle. Initial KG was 4.7 m.
Ans. F 7.488m, Aft 6.381m.

Q. 19 A box shaped vessel 120m x 20m has a compartment 12m in length at the fore end of the vessel. The compartment extends from side to side and has a permeability of 60%. The vessel with a KG 5.8m is at an even keel draft of 6.0m. Calculate her drafts F & A if the for'd compartment is bilged.
Ans. H. Draft 6.383m New LCF 56.553m GM_L 166.25m trim change 2.488m Draft F 6.383m Draft Aft 5.210 m.

Q. 20 A box shaped barge 110m x 20m floating at an even keel draft of 6 m has a double bottom tank, 1.0 m deep, throughout her length. A compartment 24 m in length situated above the D.B., extending from side to side, with its after bulkhead amidships has a permeability of 60%. Calculate the end drafts if that compartment is bilged above the double bottom. The vessel's KG is 6.7 m.
Ans. F 7.288 m A 6.2522 m.

Q. 21 A box shaped vessel 132 m-x 20 m has a compartment 12 m in length at the fore end of the vessel. The compartment extends from side to side and has a permeability of 60%. The vessel with a KG 5.4m is at an even keel draft of 6.0m. Calculate her draft F & A if the for'd compartment is bilged.
Ans. Draft 6.346mt = 2.227m, FF_1 3.46m, BM_L 207.276m.Drafts f'd 7.518m Aft 5.291m.

Q. 22 A box shaped vessel 100 m x 20 m, KG = 5.2 m, floats at an even keel draft of 5 m in salt water. An end compartment forward, 10 m long and covering the full breadth of the vessel is bilged. Calculate the new drafts forward and aft.
Ans. F 7.865m, Aft 3.666m, H.D. 5.555, GML 119.078m.

Containership Damaged In Bad Weather: Container ships owing to their large windage area & the shape compatibility with parametric rolling are some times severely affected in the bad weather. In the picture M/V Xin Qing Dao can be seen with damage due to storm force 11, 30 m seas & severe rolling. She is 5,618 TEU capacity, LOA 279.90 m, beam 40.3 m and draft 14 m 2003 built container ship with a service speed of 26 knots. 31 laden 40' containers were lost overboard & another 29 damaged off Brittany, on the night of oct. 27, 2004.



Chapter 21 Concept of rolling in still water and influence of wave system, ARD

Still water rolling & factors affecting the rolling of ships:-

Still water rolling may be considered Simple Harmonic. In SHM the particles of the medium perform to & fro motion about the mean position with uniformly alternating velocity & acceleration vectors.

The differential equation of SHM is:

$$\frac{D^2x}{dt^2} + \omega^2 x = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The periodic time T is given by $T = \frac{2\pi}{\omega}$, 'ω' in the eq.1 is square root of coefficient of x. Thus

$$T = \frac{2\pi}{\sqrt{\text{coefficient of } x}}$$

The equation in terms of T is

$$\frac{D^2x}{dt^2} + \frac{4\pi^2 x}{T^2} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Mass moment of inertia is a criterion for rolling of the ship & is given by Mk^2, where M is the ship's mass and is equal to $\frac{\Delta}{g}$.

k = radius of gyration about longitudinal axis of roll through the COG of the ship. Thus $I = \frac{\Delta k^2}{g}$

Righting moment = Δ GM Sin θ = Δ GM θ (for small angles of heels)

The angular acceleration = $\frac{d^2\theta}{dt^2}$

$$\therefore\ I\frac{d^2\theta}{dt^2} = -\Delta GM\theta \quad \therefore \frac{\Delta k^2}{g} \times \frac{d^2\theta}{dt^2} + \Delta GM\theta = 0$$

Rearranging $\frac{d^2\theta}{dt^2} + \frac{g\,GM\,\theta}{k^2} = 0$ ..... (3)

From (3) & (2) it can be seen that (3) is a SHM equation having a period T, given by

$T = \frac{2\pi}{\sqrt{\text{coefficient of } \theta}}$ i.e. $T = \frac{2\pi}{\sqrt{\frac{(g.GM)}{K^2}}} = \frac{2\pi k}{\sqrt{(g.GM)}}$

Deductions: -

1. *T is independent of θ:* Time period of roll is independent of amplitude of roll for small angles.

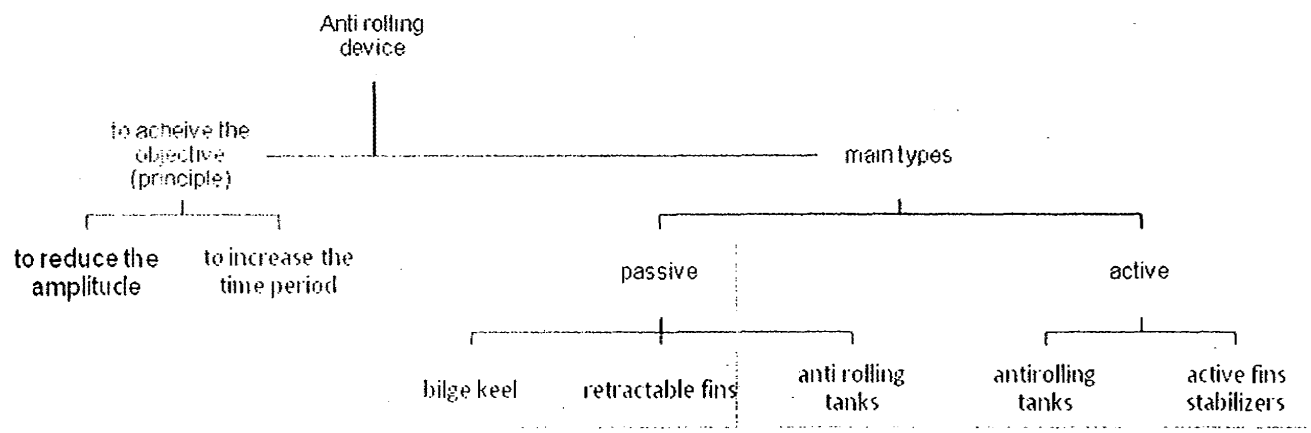
2. *Radius of gyration and MI:* Time period varies directly as k, the radius of gyration. Thus if weights are placed away from axis of oscillation, the time period will increase. On Ships like container vessels period may be large even if sometimes GM is not so small.

3. *GM_T:* T varies inversely as square root of initial metacentric height. This relationship is similar to that provided by the formula $GM_T = \left[\frac{f \times B}{T_r}\right]^2$ which gives GM_T varies inversely as square of true roll period.

4. *Loading / discharging / shifting:* T will change due to loading / discharging / shifting of weights as the same will affect radius of gyration & GM_T.
5. Period of piching: On similar lines as above, period of piching is given by $T = \frac{2\pi k_L}{\sqrt{(g.GM_L)}}$ where K_L is longitudinal radius of gyration in metres about transverse axis of piching.

6. *Effect of draft & displacement:* The slope of the wave becomes more & more flat with the increase of depth. With the increasing draft more and more of the underwater portion is in contact with the flatter sea. Moreover higher draft means higher displacement & therefore righting moment will be more.

Anti-rolling devices and their effect: -



Anti-rolling devices may be designed to:-

a. Reduce the amplitude of ship's roll and / or
b. To increase the period of ship's roll.

Reduction of roll amplitude may have a psychological consolation of having 'small angle of rolling' to the crew or passengers but the rolling will still be uncomfortable. This is because, if the rolling must be made comfortable then, 'roll period' must be increased. Increase of roll period is more sensible than 'reducing the roll angle'. The short roll period is also associated with large angular accelerations, which create severe stresses on certain large structures especially at their foundations. This is damaging for heavy masses situated away from roll axis.
Most anti rolling devices may involve both these functions viz. reduction of the amplitude of ship's roll & Increase of the period of ship's roll though primarily aiming for one of the two functions.
The ratio of the two would vary in different devices that are used. The control of roll in comparison with the cost factor, the space used & maintenance cost etc will decide as to how efficient or popular the device is.

Anti rolling devices from the automation point of view are primarily of two types viz.

a. Passive, which by the virtue of appropriate construction and location in respect of the type and form of ship creates opposite forces to alter the roll characteristics in the desired direction. In these types, there are no sensors, actuators etc. The power is not required while the device is operational.
b. Active devices incorporate sensors whose signals are used to create suitable anti heel moments. Control equipment is required to anticipate motion and activate the stabilizer to apply the necessary roll-reducing moments.

1. Bilge keels (passive):-

The fins or "keels" at or near the turn of the bilge has been on many ships and has proved its merits for years. Froude was the first, how-ever, to show their effectiveness experimentally, in1870. Longitudinally, bilge keels extend from 30 to 75 percent of the length and vary in depth from 30 cm to about 78cm. Although the bilge keels are more effective if more deep, practical considerations would not permit excess depth. The bilge keels have certain disadvantages too. Some of these are:

a. The necessity of keeping within the extreme depth and breath of the vessel,
b. Difficulties in dry docking,
c. Necessity of limiting the stress on the plating of the keel,
d. Reducing the probability of leaking due rusting where the keel is attached to the hull,
e. Increase in hull resistance.

It is worth noting that:-

1. Bilge keels virtually carry a body of water along and adjacent to the body of vessel. Which increases radius of gyration and hence virtual mass moment of inertia of the vessel.
2. Part of the roll causing energy is consumed in eddying of water behind the keel.
3. The pressures around leading & following sides of bilge keel is such that it creates a couple that opposes the rolling.

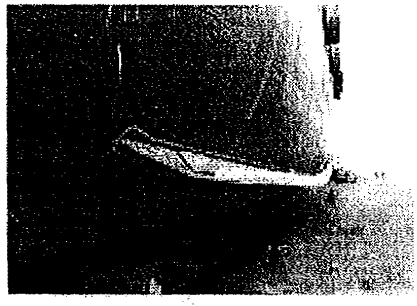


Fig. 1

The principal purpose of bilge keels is to reduce the amplitude of roll. Bilge keels also increase the period of roll slightly. Ordinary bilge keels produce a roll reduction of about 30 per cent and thus are about half as effective as passive tank systems and a 1/3rd or 1/4th as effective as activated fins. Bilge keels are fitted at the turn of the bilge.

2. *Antirolling tanks (passive):-*
In the earliest forms these tanks were used to create free surface at upper deck level. These were called "water chambers". FSE was for reducing the stability of ship but were dangerous in situations, where the period of the water moving in the tank and the period of roll of the ship were synchronized. For this reason, this type of antirolling tank was abandoned.

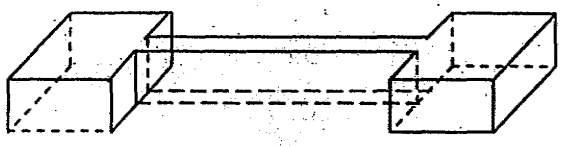


Fig. 2

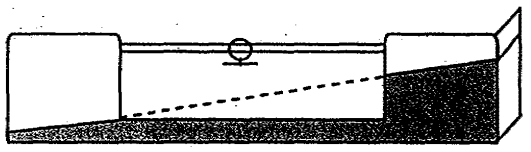


Fig. 3

Newer anti-rolling tanks were of two types:

a. Non-activated
b. Activated tanks.

The non-activated tanks are made of the dimension suited to the size of ship with the proportion of tank filled up to provide desired effect. System has horizontal and vertical ducts. In these non-activated tanks, the water moves along gravity but with a phase lag with rolling & the phase lag will depend on the size of connecting pipe. Whenever the ship rolls the water will move to the low side, achieving its maximum listing moment when maximum quantity of water has reached on low side. Let us consider a vessel at a certain instant, reaching the extreme position during starboard roll at say 8°.

1. Direction of rolling motion & roll amount, is to port.
2. Listing moment due to water in tank is to starboard.
3. Tendency of water to move is still port to starboard.

The above clearly shows that the listing moment is opposite to the roll motion at least for some time during the roll period. Care must be taken to provide proper dimensions to the ducts as well as proper venting at the top of the venting ducts.
One of the non-activated type of tanks were a pair of narrow tanks about 60m in length located around amidships. These were the flat tanks // to shipside with approximately half of the tank above the load waterline. The tanks are open to the sea at the bottom and vented at the top.

Thus as the ship rolls, the tank on the low side fills up. The idea is to create a listing moment in the direction opposite to roll.

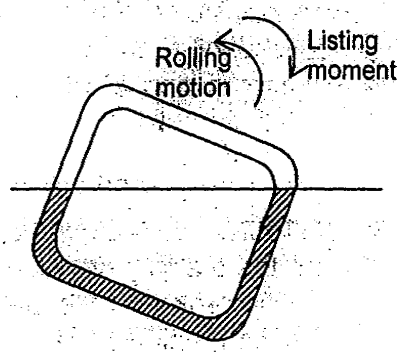


Fig. 4

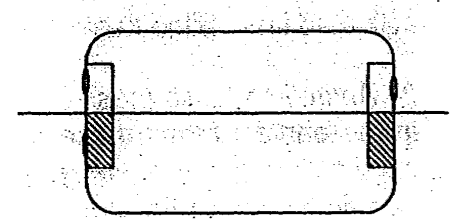


Fig. 5

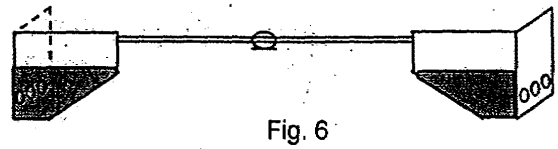


Fig. 6

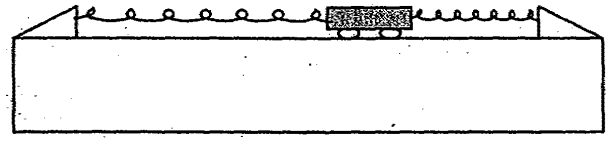


Fig. 7

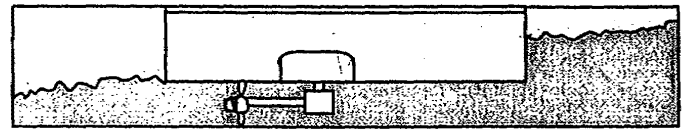


Fig. 8

To obtain satisfactory roll reduction the mass of the liquid in the tanks is generally about three percent of the displacement. Some loss of GM occurs due to the free-surface effect of the liquid, but the reduction is generally small. Some of the variations which have been tried out are:

a. Triangular tanks with the holes on shipside, the port and starboard tanks connected on top by equalizing duct.
b. A weight supported by port and starboard springs and moving to and fro with a phase lag with the roll of ship. This system has been abandoned on account of being impractical involving heavy mass moving and the maintenance / space required.

3. *Anti Roll Tanks (active):-* Port & starboard tanks are connected by a duct at bottom & an equalizing duct at top. In the duct at bottom a thruster in the form of an impeller throws or sucks water after the sensor & control system has directed it to do so.

4. *Activated fin (active):- The* activated fin is highly developed, very popular and the most widely used system used on many modern ships specially passenger ships. The first successful installation was made by Motora in Japan in the 1920s. Around the same time a similar system was being developed in the United Kingdom.

The fin is connected to a driving mechanism which rotates the fin to various angles. The purpose of fins may be understood by observing the turning moment provided by a rudder. By turning the rudder to port or starboard the turning moment is obtained about vertical axis. similarly changing the pitch upwards or downwards a vertical force in upward or downward direction and hence a moment about horizontal axis is provided on both the sides to oppose the

predicted roll motion. The fins are normally designed to give a roll reduction of about 80 to 90 per cent.

Rolling in waves:-

Wave motion follows Trochidal theory. Trochoidal theory can not be easily & readily used to discuss the oscillation of ship. Let us discuss the Oscillation of ship among a similar Sine wave, which means the height & length of Sine wave is equal to that of the Trochoid. To understand the Trochoid let us assume that a disc of radius R is rolled on a horizontal surface. A point at a distance 'r' will trace a Trochoid while the disc is made to roll.

The ship is considered to be broadside to the system and is assumed not to have any effect in modifying the system. The wave length is considered to be great enough for its profile across the ship to be regarded as a straight line.

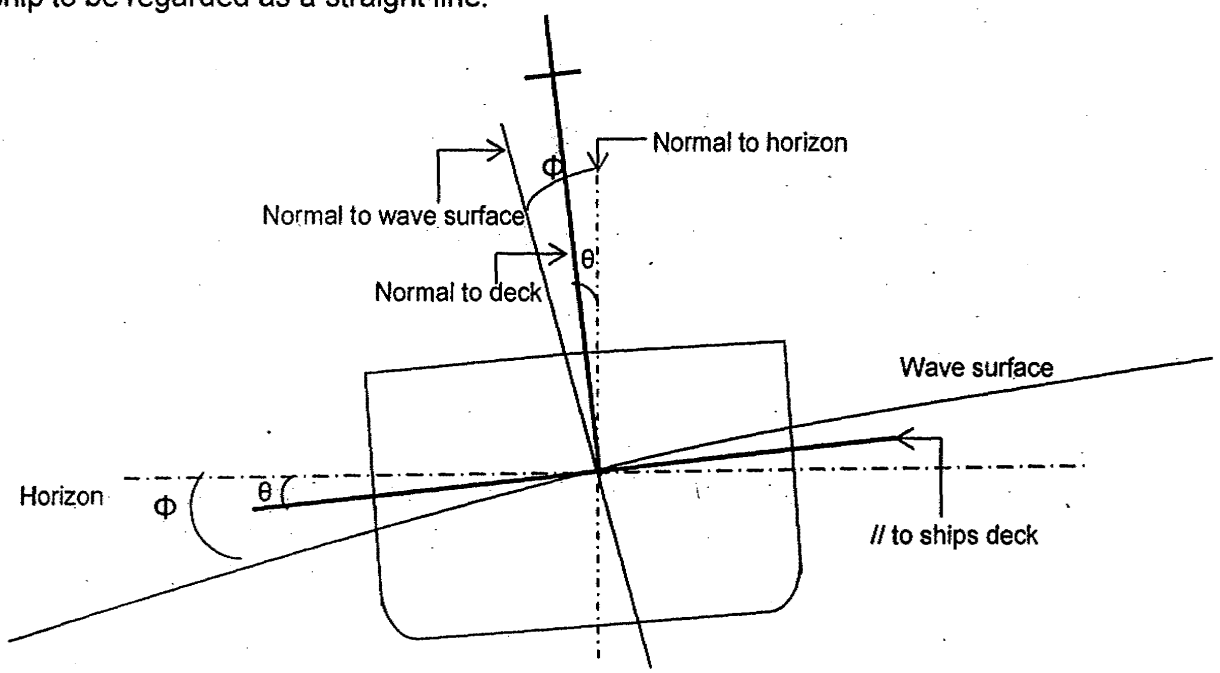


Fig. 9

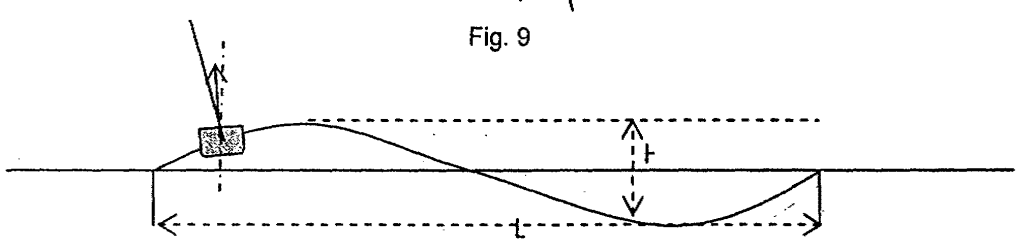


Fig. 10

H is the height of the wave from crest to trough;

L is the length of the wave;

T_1 is the period of the wave;

is the inclination of the surface wave contour to the horizontal;

is given by the formula $= \frac{\pi H}{L} \sin p_1 t$ where $p_1 = \frac{2\pi}{T_1}$

Thus is the angle between the wave surface & horizontal where as θ is the angle between ship's decks & the horizon i.e. heel wrt. true vertical. Thus the heel observe in an inclinometer is θ where as the righting moment will not be as per θ but as per virtual inclination i.e. (θ ~) the equation thus formed will give θ as follows.

$$\theta = A \sin (p_0 t + \lambda) + \frac{p_0^{\,2} \alpha}{p_0^{\,2} - p_1^{\,2}} \sin p_1 t$$

Where A and λ are constants.

α is the maximum value of slope of the wave and will occur when sin $p_1t = 1$ and $\alpha = \frac{\pi H}{L}$.

An excellent formula to give the resultant heel amount θ is has follows:

$$\theta = A \sin \frac{2\pi t + \lambda}{T_0} + \frac{\left(\frac{T_1}{T_0}\right)^2 \alpha}{\left(\frac{T_1}{T_0}\right)^2 - 1} \sin \frac{2\pi t}{T_1}$$

The first term on the right i.e. A Sin $\frac{2\pi t + \lambda}{T_0}$ is the natural oscillation of the ship as found when rolling without resistance in still water; the second term i.e. $\frac{\left(\frac{T_1}{T_0}\right)^2 \alpha}{\left(\frac{T_1}{T_0}\right)^2 - 1} \sin \frac{2\pi t}{T_1}$ is the rolling oscillation forced upon the ship by wave system. It is of value to study this second term; it's amplitude is: $\frac{\left(\frac{T_1}{T_0}\right)^2 \alpha}{\left(\frac{T_1}{T_0}\right)^2 - 1}$

The study of behaviour of the ship on waves is very interesting and also very important for master from the point of view of handling the vessel in waves. Vessels have the true rolling period governed by there GMs, weight distribution etc. The storms or depressions originated in different oceans or water body, depending on various factors such as depth of sea, distance travelled, intensity of depression have different time period. The wave encounter period will depend on the directions of travel of the waves and ship. The roll behaviour of ship in prevailing wavescan broadly be divided in three categories as explained below:

Case 1: wave encounter period less than ship's rolling period: ($T_1 < T_0$)

When the period of the wave system is less than the natural period of the ship, the denominator is negative and the amplitude is negative. This will make the second term & hence the contribution of the wave system negative.

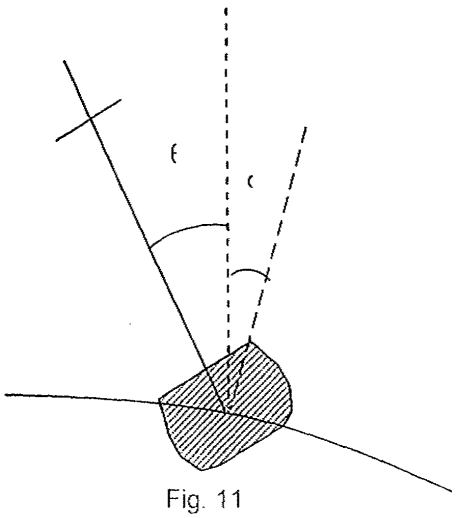


Fig. 11

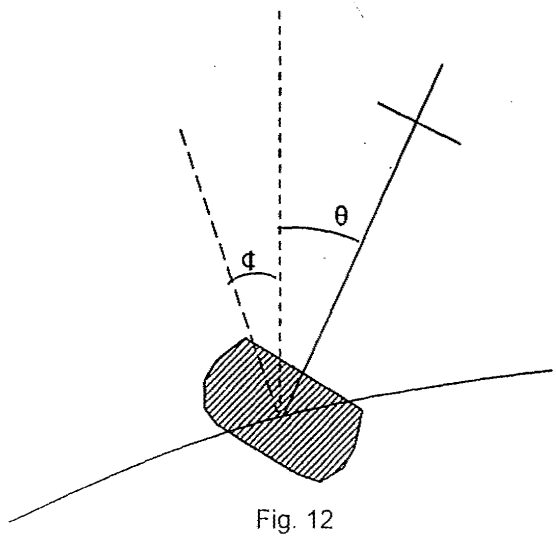


Fig. 12

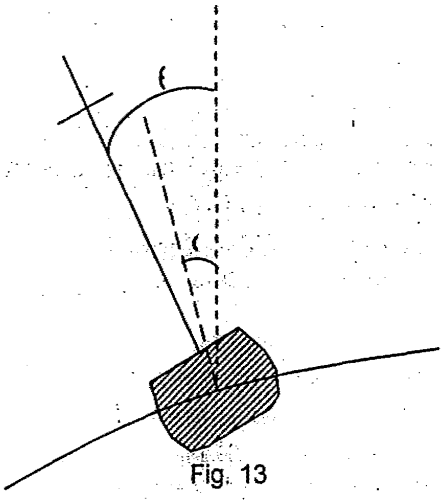


Fig. 13

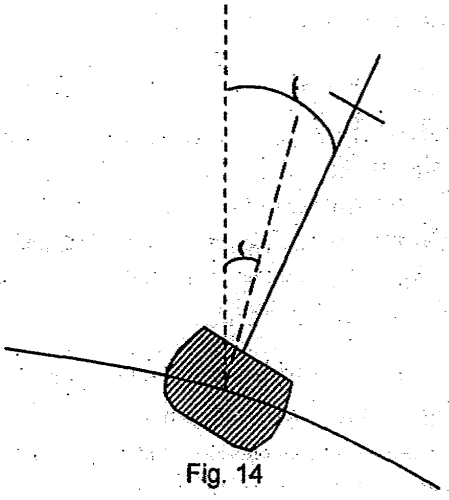


Fig. 14

The sea tries to make the ship roll as shown in the figure 11 & 12 (into the sea). Passengers and crew will tend to have an exaggerated impression of the angle of roll but a person watching and inclinometer will find the roll amplitude to be quite controlled as compared to the observed roll size. As T_1 (period of waves) gets less & less amplitude of forced oscillation, approaches zero.

Case 2: wave encounter period more than ship's rolling period: - ($T_1 > T_0$)

When T_1 (Wave system) > T_0 (natural roll period of ship). The denominator and hence the entire amplitude of forced oscillation is +ve. This causes the contribution of the wave system positive. A further increase of T_1 will make T_1^2 bigger so much so that –1 may be neglected from denominator & the amplitude would become equal to α. The value of amplitude prior to this stage is positive & greater than α. The sea tries to roll the ship as follows, (away from sea). Passengers and crew will tend to have a diminished impression of the angle of roll but a person watching and inclinometer will find the roll amplitude to be much larger as compared to the observed roll size. For T_1 greater than T_0, the amplitude of forced roll is, however, always greater than α whereas for T_1 less than $0.7T_0$, the amplitude of forced roll is always less than α.

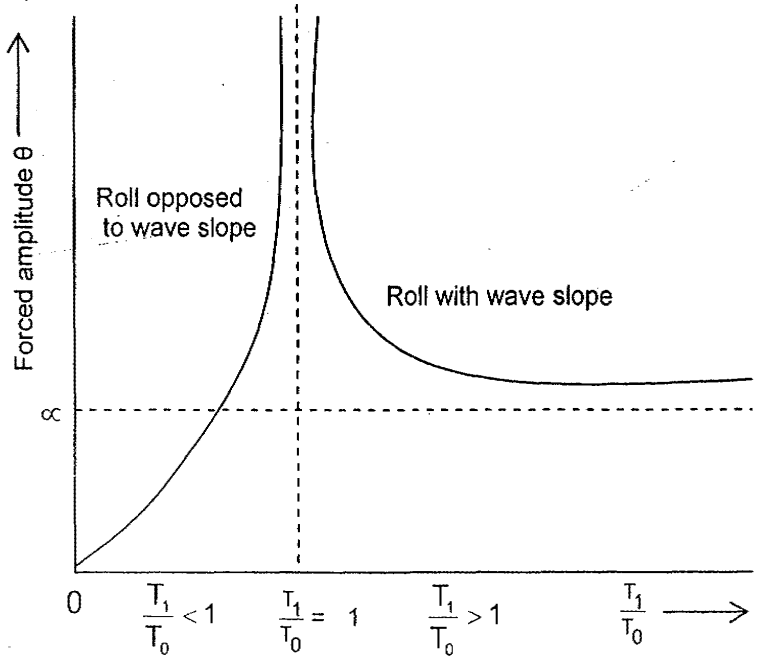


Fig. 15

In the graph of forced amplitude θ versus the ratio T_1 / T_0 the following observations can be made: -

1. When $T_1 / T_0 = 1$ the forced amplitude tends to become infinity.
2. When $T_1 / T_0 < 1$ the forced amplitude is equal to maximum wave slope α when the ratio is about 0.7. for the ratio is less than 0.7 the forced amplitude is less than α. The forced amplitude is more than α when the ratio is more than 0.7.
3. When $T_1 / T_0 > 1$ the forced amplitude is always more than α but when T_1 is sufficiently large in comparison with T_0, the forced amplitude is very slightly more than α, (nearly same as α).

Case 3: wave encounter period is same as ship's rolling period: - ($T_1 = T_2$)
When the wave train meets the ship in such a way that the wave encounter period is approximately equal to the ship's natural roll period the condition of resonance of synchronism is satisfied. Putting $T_1 = T_0$ in the expression for θ, we see that the denominator of forced oscillation becoming zero & thus the amplitude itself becoming infinite. This, however, cannot immediately occur and it can be shown that a modified "rolling equation" describes the new situation i.e.

$$\theta = A \sin\left(\frac{2\pi t}{T_0} + \lambda\right) + \frac{\pi \alpha t}{T_0} \sin\left(\frac{2\pi t}{T_0} - \frac{\pi}{2}\right)$$

Where the slope of the synchronous wave is given by $\Phi = \alpha \sin \frac{2\pi t}{T_0}$

If we substitute the value of t as 0, $\frac{T_0}{2}$, T_0, $\frac{3T_0}{2}$, $2T_0$..... the component of forced oscillation will become equal to 0, ½ πα, - πα , $^3/_2$ πα , -2πα ..... respectively and the values at $t = \frac{T_0}{4}$, $\frac{3T_0}{4}$, $\frac{5T_0}{4}$ etc., is zero. Hence the effect of the passage of each half wave length is to increase the forced amplitude of roll by $\frac{\pi \alpha}{2}$ and these increasing maxima occur in the successive crests and troughs of the wave system. The ship swings & dances in synchronism with the wave system of crests & troughs. The behaviour is similar to a live orchestra band on stage where every one is in synchronism to create the magical effect. Theoretically in the absence of resistance, the amplitude should build up until the ship capsizes. For example, if a synchronous wave train of maximum slope 6° is met, the forced amplitude of rolling will be 9.4°, 18.8°, 28.2°...., etc., in the successive crests and troughs.

Practically though situation may be some what different. Additional momentum is gained only once during each complete roll, i.e. during every other half roll. Rolls are asymmetric. The half roll contributing to excitation is of longer duration with greater roll angles, whereas the other half roll is determined by maximum stability and therefore is shorter with moderate roll angles.

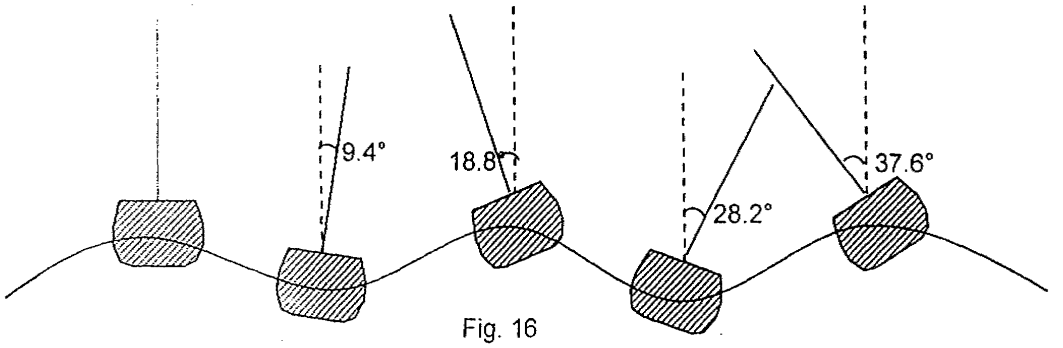


Fig. 16

So far it has been observed that excitation of roll motion caused by wave slope (which logically is understandable) can be dangerous and will normally occur when the ship is making way in beam seas. This excitation can lead to considerably greater roll angles in case of resonance, which means the wave period becoming approximately equal to the ship's period of roll. However for the latest container ships and passenger vessels, with their typical hull shape, a physically different cause of roll motion becomes more and more relevant to ship operation. This occurs in longitudinal seas where the wave slope is of negligible influence. It is parametric excitation of roll.

The meaning of "parametric": -
The GZ values available on ship are provided for static sea conditions. When vessel rests on a large longitudinal wave with the crest amidships the GZ values increase in size for all the angle of heel. The reverse happens when the trough is amidships.
Righting moment = Δ x GZ
Liquid displaced and GZ are important stability "parameters". In longitudinal waves (shipping seas and changing crest position) both these parameters oscillate. This causes a periodic variation of righting moment. This can trigger roll if it occurs with an appropriate period. Weight (virtually displaced) varies only within a limited range but the righting lever can undergo periodic variations to a large extent. This is the predominant cause of possible roll excitation. The excitation is originated due to cyclic fluctuation of stability parameters hence the name "parametric excitation" or "parametric roll".

With mono hull merchant ships a periodic variation of the righting lever in longitudinal waves is caused by the combined effects of two processes:

1. Waves moving along the hull, and
2. Periodic changes of trim during pitch.

Although these processes always occur simultaneously, they will be explained individually in order to get a clear idea of the different effects.

1. Waves moving along the hull : -
If the wave length of wave is 70% to 140% of the ship's length and the waves become high enough, the values of the effective righting levers depend on the position of the wave crest on the hull. This results from the usual form of monohull merchant ships, especially of modern design. The forward and aft parts of the ship contribute considerably to the development of righting levers owing to the flare (e.g. the forecastle). If the wave crest passes the midships part of the hull, both ends emerge in troughs. Righting levers are smaller, with a minimum when the crest is approximately amidships.
Once the crest moves towards one end of the ship and the following crest is approaching the other end, both ends immerse deeper than in still water. Righting levers are greater, with a maximum when a trough is approximately amidships. Variation of righting levers increases with the ships' dimensions as long as the proportion between ship and waves remains similar.
In case of small ships the righting levers at large heeling angles depend on the immersion of forecastle and poop. This is because the volume of these superstructures is large in proportion of the whole ship's volume. When the midship rests on a wave crest, the righting levers are considerably reduced at large heeling angles. Steep waves, the lengths of which are of the magnitude of the ship's length, are encountered more often by smaller ships.

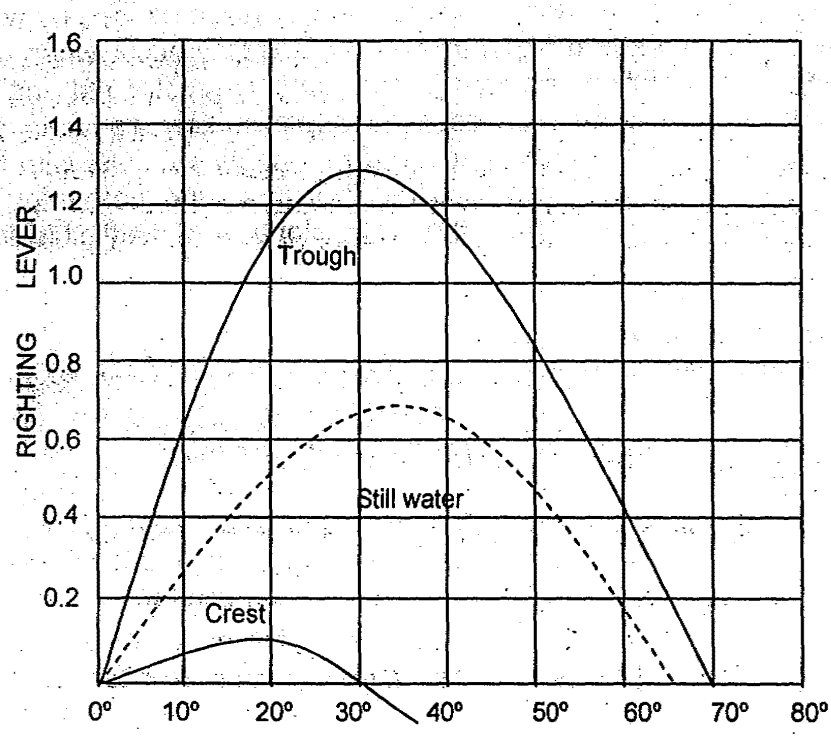


Fig. 17

2. *Periodic changes of trim during pitch: -*

Severe pitching in head seas causes a periodic change of trim and thus a change of righting levers. This applies specially to large container ships and passenger vessels which show *greatly different shape forward and aft*. In the fore body the breadth is sharply reduced whereas in the after body there is pronounced flare and the hull's full breadth extends up to the transom. Let us observe the piching motion in two steps.

1. When the slender fore body immerses the transom, with its greater breadth, emerges. The righting lever developed will be rather small. These become smaller and reach a minimum before the flare of the upper part forward at the level of the forecastle immerses in the oncoming wave. This makes the righting levers increase again till the reversal point of pitch motion.
2. When the transom immerses deeper than in still water, *righting levers are greater*, with a maximum at the aft reversal point of the pitch motion.

With ships of appropriate large dimensions, the scale effect renders the periodic variation of righting levers due to pitching great enough to contribute to parametric roll excitation.

Parametric resonance: -

The period of encounter between ship and waves determines the relative movement of waves along the hull as well as pitch motions, which are generally enforced oscillations. For these reasons, righting levers and consequently the ship's transverse stability fluctuate with the period of encounter. Parametric resonance occurs at certain relations between the period of variation of the transverse stability (period of encounter) on the one hand and the effective period of roll motions on the other.

For monohull merchant ships, only two cases of parametric resonance are important:

1. The encounter period approximately equals the period of roll when minimum stability occurs once during a complete roll (synchronized), or

2. The encounter period is approximately half the roll period and minimum stability occurs twice during a complete roll (Parametric).

Different stability in Inclining & Righting:-
In parametric resonance one can observe that the roll motion and periodic variation of stability coincide in a certain distinctive way. This relationship between the two is enforced by the fact that the *ship will of course incline when stability is reduced*, i.e. before and after its minimum. Thus inclining takes place under the condition of reduced stability. Before righting can begin, the ship's stability must sufficiently improve in the course of its periodic variation. During righting, stability continues to grow towards its maximum. Thus *righting takes place under the condition of increased stability.*

Wave encounter period = ½ Roll period:-
The fact that inclining at reduced stability alternates with righting at increased stability can only lead to excitation of roll if this alternation is repeated regularly and sufficiently often. This is only possible at parametric resonance, when the period of encounter approximately equals or is approximately half the effective roll period.

Difference between head & following waves:-
In following seas the effect of waves moving along the hull from stern to bow predominates. In head seas, the effect of steep waves moving from bow to stern can account for a considerable stability variation.

With Large vessels pitching what is the danger?
With large ships the effect of pitch motions alone can make stability oscillate with critical amplitudes even when the wave heights are comparatively small. Then, during a number of consecutive rolls, the momentum inherent in the rolling ship at the end of each righting is greater than it had been at the beginning of the preceding inclining, due to the surplus of effective stability gathered during righting. The additional momentum gained during righting will make roll angles increase as long as it is greater than the loss of momentum due to roll damping. The result can be dangerously great roll angles.

When the period of encounter is approximately half the period of roll the ship is in a very hazardous situation. Analysing carefully the following deductions are made:

1. The ship gains additional momentum during each righting and thus twice during a complete roll motion.
2. Stability changes at twice the rate relative to the roll motion.
3. This causes stability to shift closer to its maximum prior to and during righting.
4. The difference between effective stability during inclining on one hand and during righting on the other is intensified. This increases the additional momentum gained during each half roll.

Under these conditions moderate variations of transverse stability can trigger considerable roll motions which explain the occasional severe rolling of long container ships in head seas.

5. Before righting begins, there must be enough time to allow stability to shift to higher values. Therefore the ship must remain close to its maximum inclination for a certain period of time. This happens particularly when stability becomes small or even negative at its minimum. Such low stability minima occur when high and steep waves move along the hull and a crest is close to amidships.

6. The start of righting, and thus the whole course of the roll motion, is determined by the wave crest reaching a position relative to the hull which renders stability sufficiently effective again. Such wave crest positions are reached in regular intervals equal to the period of encounter

Risk and action to take: -

To assess the risk of being exposed to severe parametric roll it is not always sufficient to know the ship's natural period of roll at small roll angles. In addition, the periods of roll motions at roll angles of 30° and 40° are important.
If the righting lever curve rises considerably above its slope at zero inclination (tangent at its origin) it shows a pronounced non-linearity. The reason for this is mainly high freeboard. With a righting lever curve (GZ curve) of the character shown in figure the period of roll at 30°or 40°amplitude can be more than 30% smaller than the period at small angles. For example, a Panamax containership sailing with a GM of 0.80m has a natural period of roll at small angles of about 29s. Owing to the shape of its righting lever curve, the period at angles between 30° and 40° is only about 22s.

The suggested countermeasure is to alter course so that an angle of at least 50° is achieved between the ship's heading and the direction of the waves. A further reduction in speed may be necessary in certain cases; if the heading cannot be changed, a drastic reduction of speed is recommended.

In Head sea rolling mountainous roll motion can occur when the period of encounter is approximately half the period of roll at dangerous roll amplitudes such as 30° or 40°. This ratio becomes possible with large containerships in head seas when they are forced to reduce speed. Large containerships have a similar combination of breadth, freeboard and KG.

This combination leads to certain periods of roll at dangerous amplitudes. Owing to the similarity of hull shape, roll periods depend mainly on the breadth of a large modern containership--presently 32.20m, 40.00m and 42.80m. Periods of roll are a function of GM but at large angles variation of period is much less with a change of GM as compared to the 'Period-GM' relationship at small angles.

It can be concluded that periods of encounter which are half the period of roll at dangerous roll amplitudes are a function of GM as well. Such periods of encounter must be considered critical as they are a precondition for sudden severe roll motions.
In fact head seas with wavelengths of 180m and above yield just these critical periods of encounter. This holds true especially at low speeds.

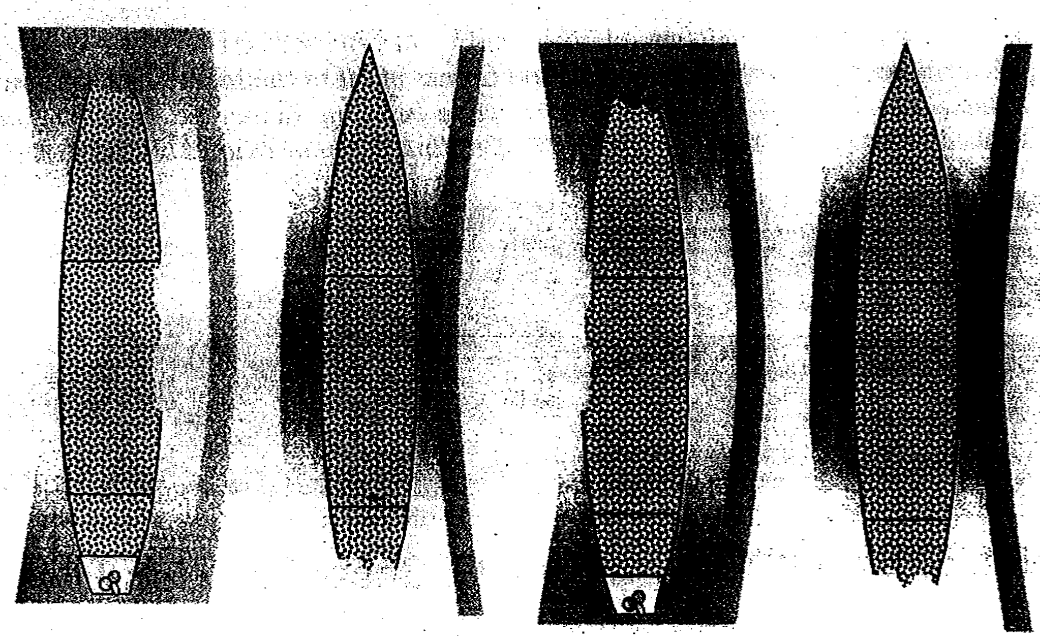


Fig. 18

	1	2	3	4
Pitch	Forward	Aft	Forward	Aft
Heel	Starboard	Port	Starboard	Port
Midship	Crest	Trough	Crest	Yrough

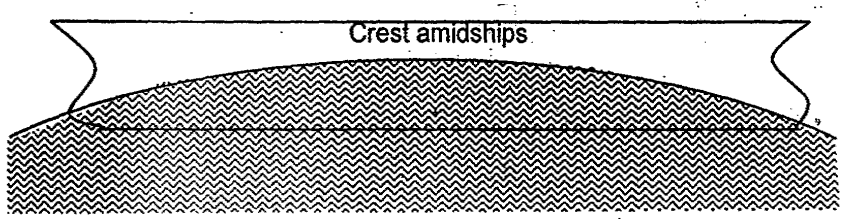
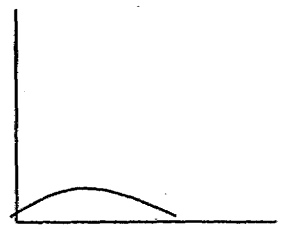


Fig. 19



Diminished curve

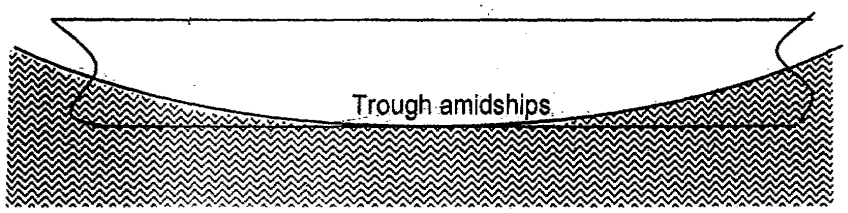
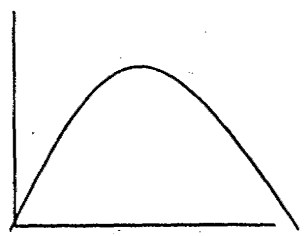


Fig. 20



Amplified curve

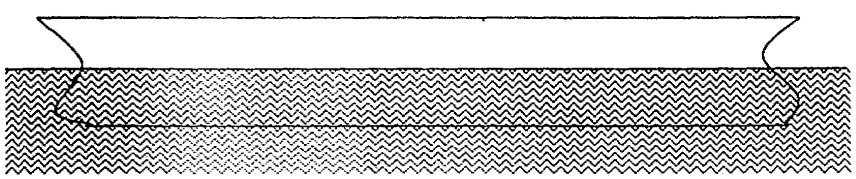
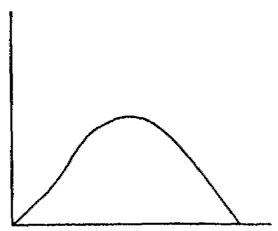
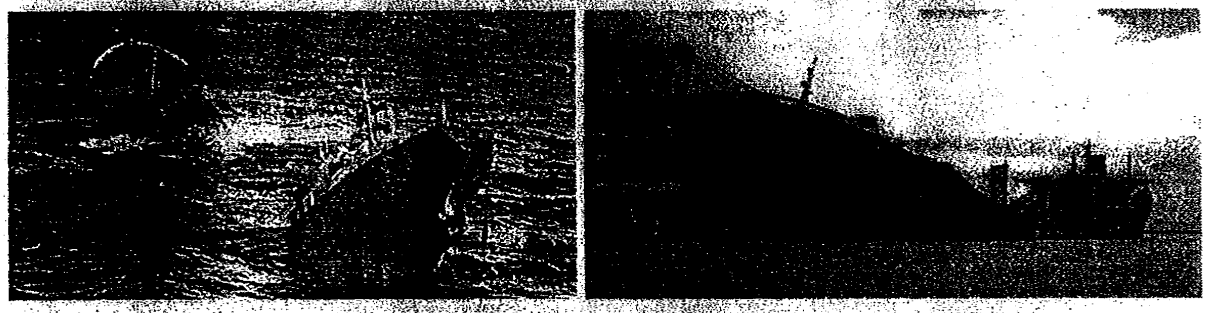


Fig. 21



Normal curve
for static level

Static & Wave Bending Moment: The leaking oil tanker Prestige sinks some 240km off Spain's north western coast, taking more than 70,000 tonnes of oil to the seabed 4 km below. The Prestige ran in trouble during a violent storm, where wave bending moments caused the breaking of the ship. A ship can also break due simply to static bending moment caused because of uneven loading.



Chapter 22 Strength of vessel, Shear Force and Bending Moment

When a weight is suspended by the hook of a crane by a rope, the weight suspended and the tension acting upwards in the opposite direction tend to stretch the rope as shown in the diagram. The rope is subjected to tensile stress. (Fig 1(a))



Fig 1(a)

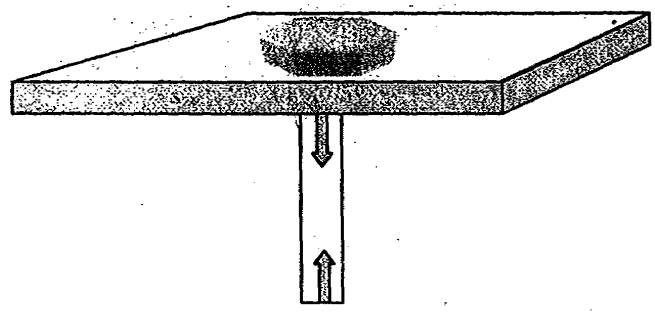


Fig. 1(b)

In the fig 1(b) we see a weight placed on the table on board a ship. The table has a single leg. The weight placed on the table acts down wards and the reaction from the deck works upwards on the table leg. The leg is subjected to compressive stress. In both the above cases we find two equal and opposite forces acting in same line tending to compress the member.

Stress: Materials undergo three types of stress viz. Tensile, Compressive & Shearing. If we observe a cross section of the wire rope or the table leg shown in above figures the two opposite forces cause stresses which are perpendicular to the section and are called direct stresses and are either tensile or compressive. The stress is force per unit area of the section. Tensile stress when applied to a material tends to pull the material apart. In fig. 1(a) let the weight lifted by crane be 5t and let the cross section area be 4.5cm^2. The tensile stress on the wire rope = $\frac{5}{4.5}$ = 1.11 t / cm^2. Compressive stress when applied to a material tends to compress the material. Buckling may occur when a material is placed under compression

Strain: Strain is the measure of the deformation produced in the member. If a rod of length L is in tension and the elongation resulted is x then the strain is defined as ratio:

$$\frac{\text{Elongation}}{\text{Original length}} \quad \therefore \text{Strain } \varepsilon = \frac{x}{l}$$

Hooke's law: - States that strain is proportional to the stress producing it within the elastic limits.

Modulus of elasticity (Young's Modulus): within the limits for which hook's law is obeyed, the ratio of the direct stress to the strain produced is called young's modulus or the modulus of elasticity.

Shear Stress: - When two equal and opposite parallel forces (not in the same line is applied on a body then there is tendency for one part of the body to slide over or shear from the other part across an intermediate section). The tendency of shearing stress is to tear the material between the two forces. The shear stress experienced by a rivet holding the plates together it shown by the diagram below.

Stress in a material may combine to resist force. Combined stress causes flexure (bending) & torsion (twisting).

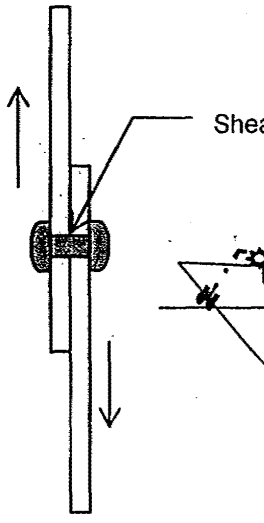


Fig. 2 a

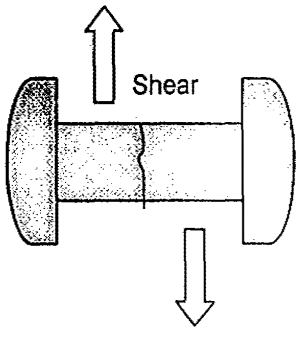


Fig. 2 b

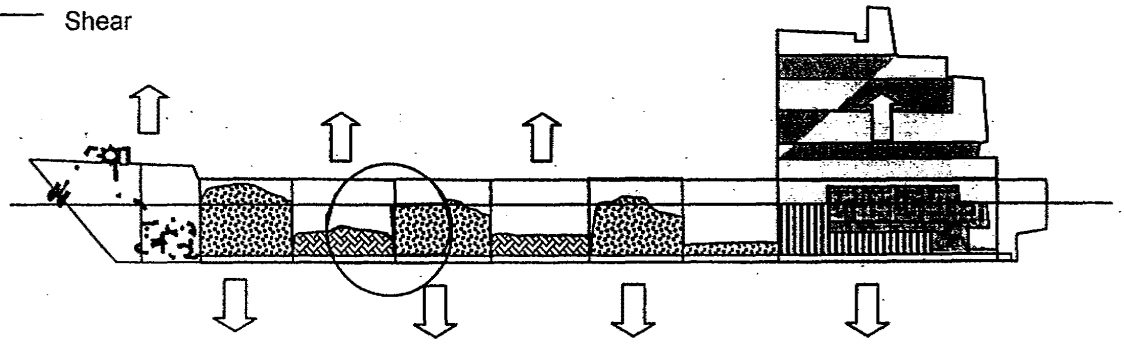


Fig. 3 a

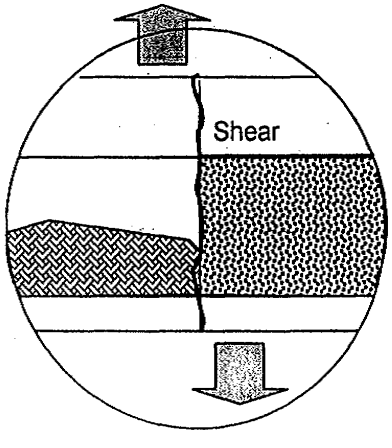


Fig. 3 b

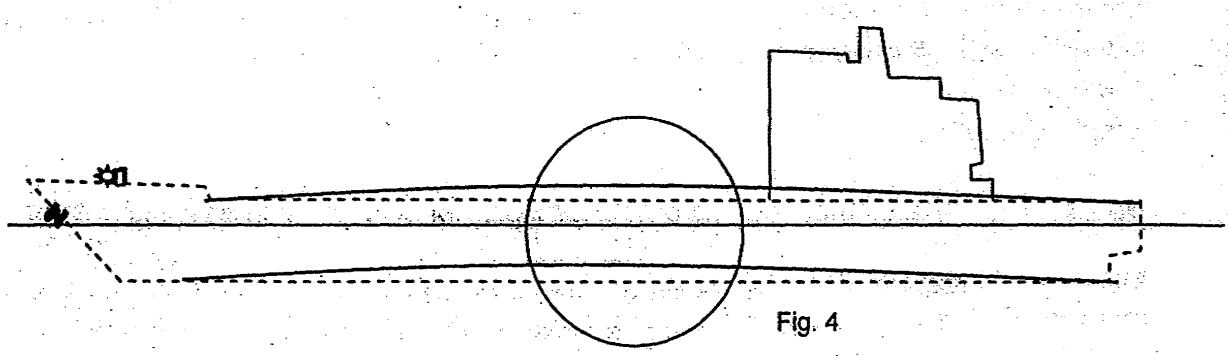


Fig. 4

Vessel hogging

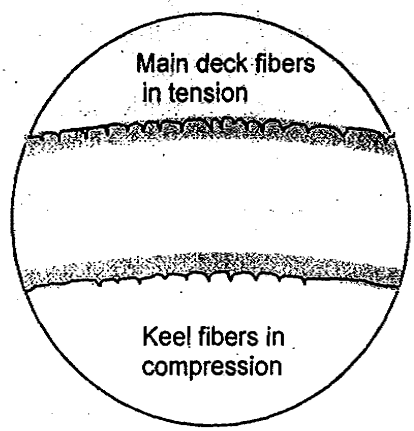


Fig. 5

Under the circumstances the neutral surface and neutral axis are halfway between the upper and lower surfaces of the beam. Above the neutral axis the fibers are in compression and below it they are in tension. The stresses of tension and compression increase in intensity with their distance from the neutral axis.

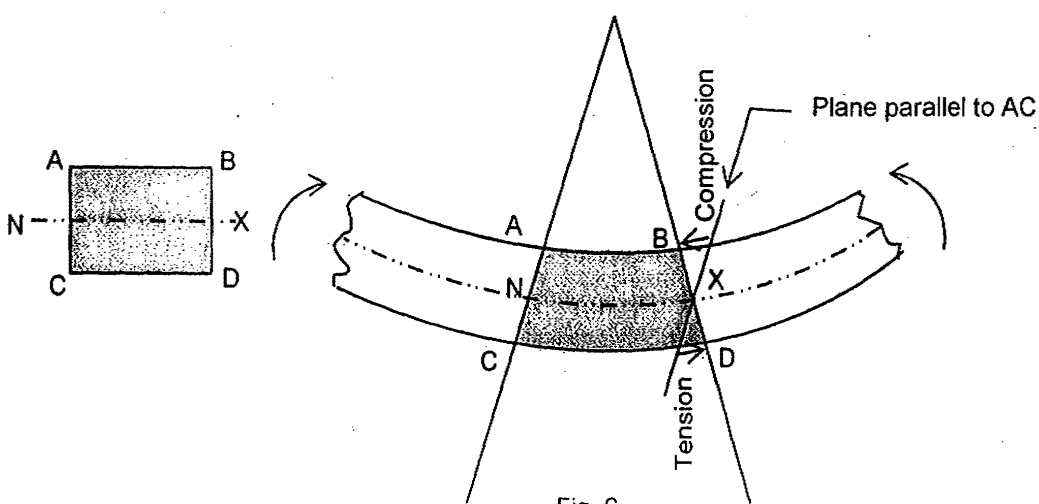


Fig. 6

Now it is necessary to find the stresses in the structure and the overall deflection. For a beam in which let the bending moment at some point x from one end be M.
The shearing stress f at a distance z from the neutral axis of the section is given by;

$$f = \frac{Mz}{I} = \frac{M}{Z}$$

Where I is the second moment of area about the neutral axis of the section at x and Z = I /z is called the section modulus.
The maximum stresses will occur when z is maximum, that is at the top and bottom of the section. The stresses at top and bottom will be equal if neutral axis is mid depth of the section.

Shear Force: - The shear force at any section of a beam is total load (difference between upward & downward forces) on either it's left hand side or the right hand side.

SF and BM acting on a ship in still water: -
When a vessel floats say in still water and is in equilibrium, the weight perfectly equals the buoyancy force.
Hence we can say that buoyancy force B = weight or gravity force Mg. if we compare these vertically opposite forces at different points along the ship's length or if we compare the buoyancy per unit length with weight per unit length we will find that for most ship shaped vessels these forces are not equal along most of the length.

Let the mass per unit length at a given point is 'm' and let the immersed cross sectional area at that point 'a' then the mass of unit under water length = δ.a.
Buoyancy force per unit length = δ.a.g
Weight per unit length = mg
At the given point net force per unit length or load per unit length = δ.a.g - mg

If this load is integrated along the length there will be a force tending to shear the structure so that,
Shearing force = $\int (\delta.a.g - mg)\, dx$
On integrating a second time the bending moment can be determined as follows:
Bending moment = $\iint (\delta.a.g - mg)\, dx\, dx$
A beam of finite cross section, when subjected to a bending moment has a plane of demarcation somewhere with in it. On one side of which the fibers are in tension and on the other side of which they are in compression. On this plane of demarcation there is neither compression nor tension. This surface of demarcation is normally referred to as neutral axis. Consider a beam of rectangular section loaded in pure bending that deforms as shown in fig. 6.

Still water weight calculation: -
Weight calculation is required for (1) use in strength curves & (2) to precisely know the displacement, for stability etc. For purposes of determining the strength curves, both the magnitude and the location of the weights must be accurately known & accounted for.
The weights can be classified into groups such as hull structure, propulsion plant, electric plant, auxiliary systems, anchors, chain, windlass, winches, hatch covers, deck equipment etc. The weights of such standard items as generators, pumps, and anchors are more or less known accurately. Other parts, such as frames, hull plating, and bulkheads, must be calculated item by item from the ship's plans. The weights of the various groups are summarized, along with their vertical and longitudinal axes, about the keel and aft perpendicular respectively. The weight curve is an extremely irregular one, reflecting the concentrations and non-uniformity of the ship's weight distribution. In a simpler form the weight curve could be a combination or series of rectangles, triangles and trapeziums. Thus if a rectangle of base length representing the length along the ship of 5m and a height representing weight per unit length along y axis (unit : t/m) equal to 31.6 t/m. This means the mass of the ship along with equipment and machinery etc. over the 5m length that is being considered is equal to 5 x 31.6 = 158t. Rectangle represents the uniformity of weight distribution during this 5m run.

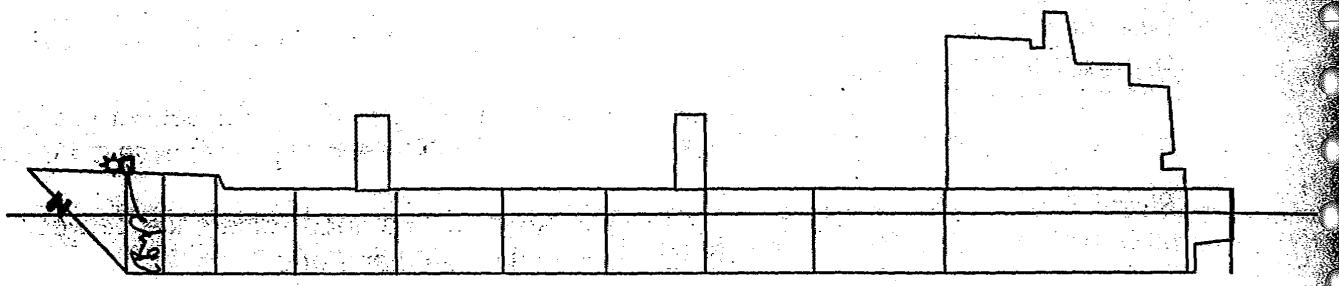


Fig. 7

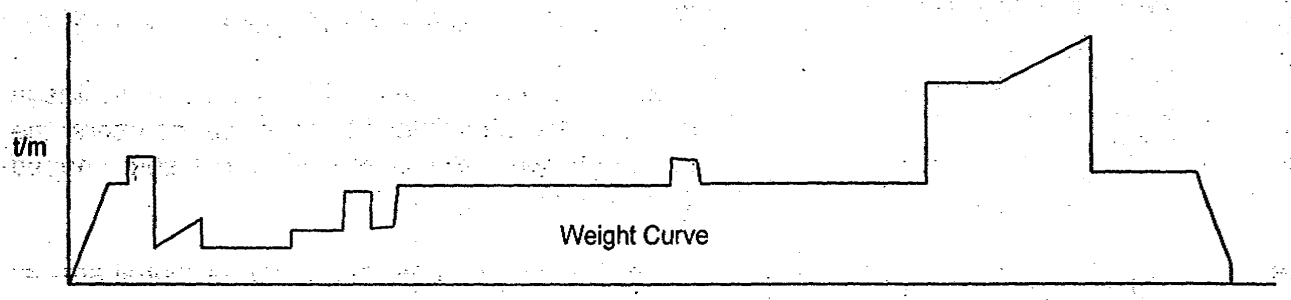


Fig. 8

Buoyancy calculations: - The calculations for buoyancy are relatively simpler compared to those for weight. These values are determined by computing the sectional areas below the waterlines corresponding to any draft & trim that is considered. For any given waterline or displacement condition, these sectional areas are plotted as ordinates to some convenient scale throughout the length of the ship. A smooth curve is drawn though these ordinate points, resulting in a curve that describes the buoyancy distribution longitudinally along the ship. The buoyancy curve is gradual and continuous with its maximum values near the midship section.

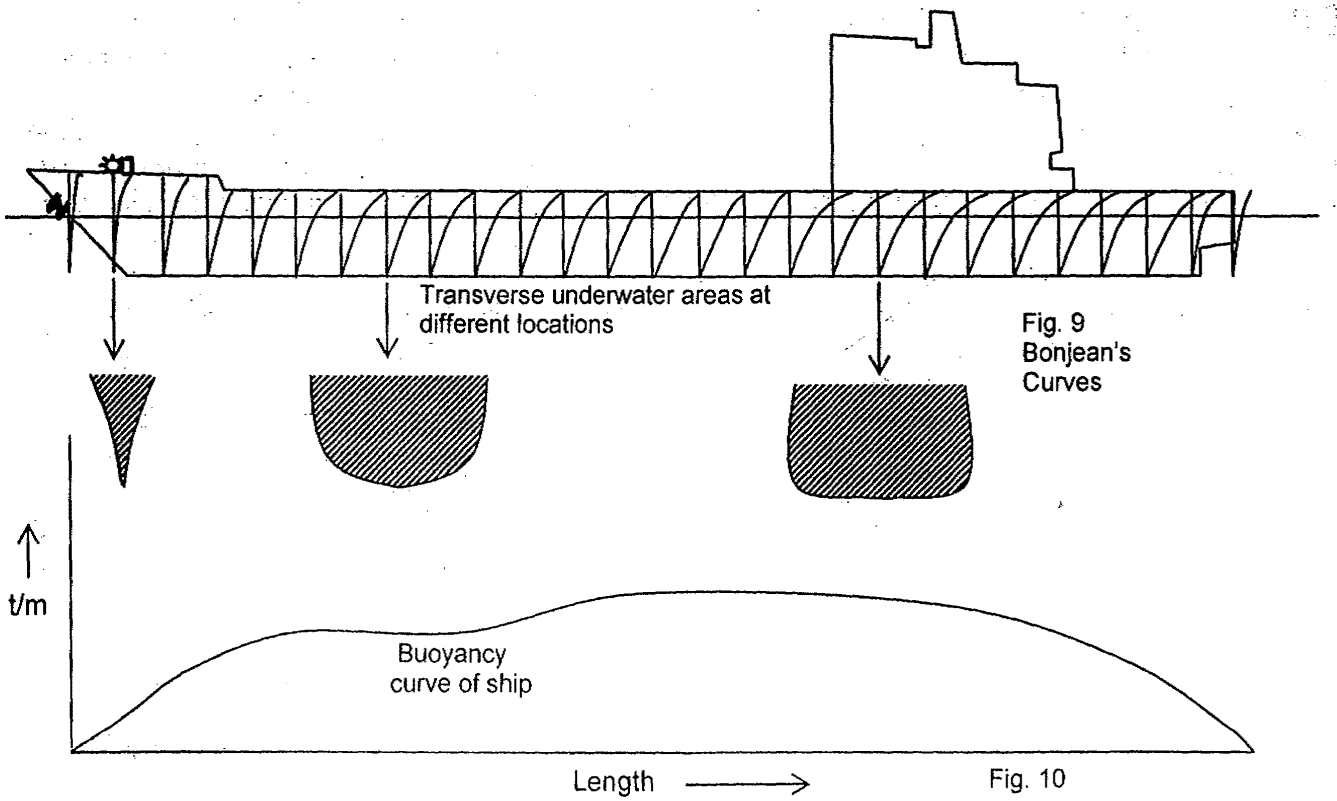


Fig. 9 Bonjean's Curves

Fig. 10

Load, shear, force and bending-moment curves. After the weight and buoyancy curves have been determined, the load curve is found by a simple procedure. The net-load curve ordinate at

any point is found by subtracting the weight per unit L value from the buoyancy per unit L value at that point. The load per unit L ordinates are then plotted at different locations. This curve is then integrated by various convenient means to obtain the SF curve. As per convention that is used in this book the area under load curve to the left of point under consideration will give SF values. SF curve when integrated in a similar manner gives the bending-moment curve. The positive sign of BM curve as per the convention used here indicates sagging and vice versa.

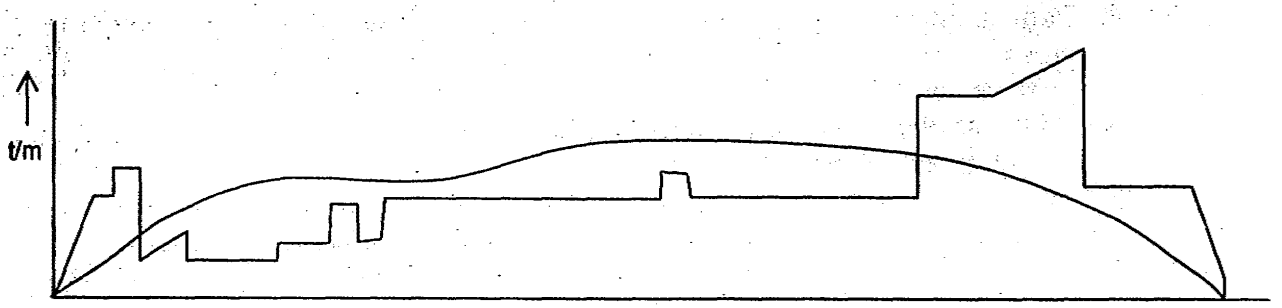


Fig. 11

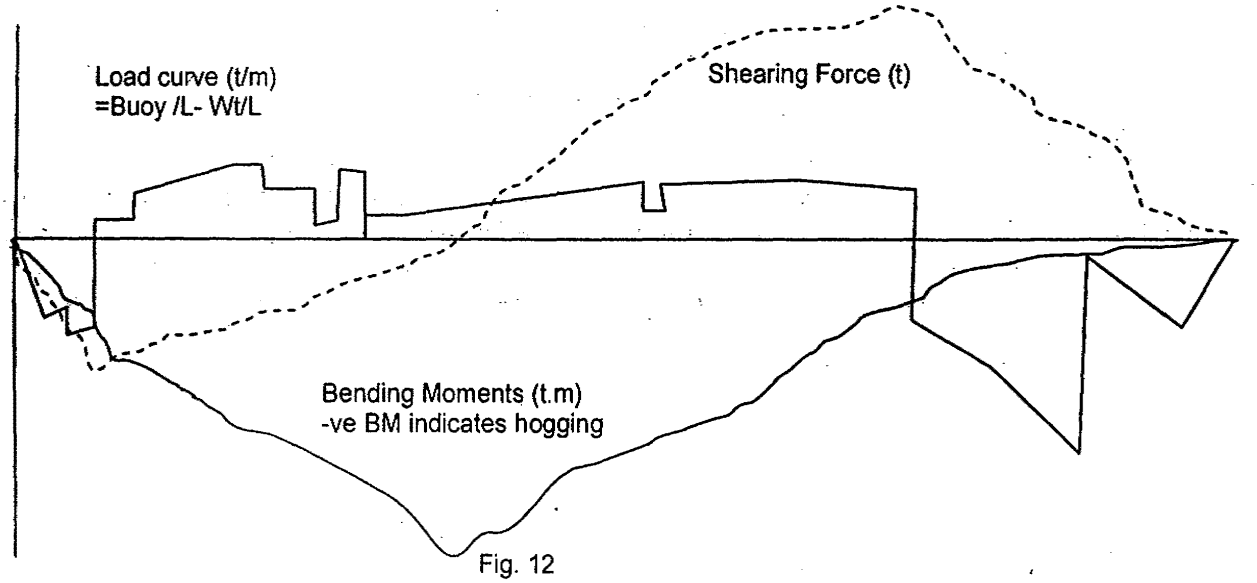


Fig. 12

Ship in a seaway: -

A ship among waves is alternately supported by the wave crest at the midship region or the ends; that is, the buoyancy distribution varies with the position of the wave crest passing under it. For the purpose of studying the stresses on the ship's girder among waves, certain values of a wave's size must be assigned in order that the corresponding buoyancy distribution may be calculated. One quasi-static method for such a study is to assume that the ship is supported by a trochoidal wave, whose length is equal to the length between the ship's perpendiculars and whose height is 1.1 L. The evaluation of the buoyancy distributions, in one case where the wave crest is amidships with the wave trough at the ends of the ship, and in another case where the wave trough is amidships with the wave crests at the ends of the ship, is assumed to approximate the most severe stresses to which the ship normally will be exposed.

Strength curves are normally developed for several displacements, considering both the hogging and sagging condition at each displacement originating from static load and then added with the hogging and sagging obtained from waves.

Relation among strength curves: -

The following relationship must be understood and applied by students when drawing the strength curves.

1. The area under the buoyancy curve must equal the area under the weight curve.
2. The centroids of the weight and buoyancy curves must be vertically in line.
3. The net area of the load curve must be equal to zero.
4. Peak shear force values will exist at those points along the length where the load curve crosses the x - axis. (The word maximum is not used, because there may be several peak values.)
5. Peak bending moment values occur where the SF curve changes direction from positive to negative or vice versa.
6. Points of inflection occur in the bending-moment curve where the ordinates of the shear curve have peak values (where the load curve intersects the base line).
7. The shearing force and bending-moment curves have zero values at their extremities.

Ex. 1 A light beam, 24 m in length, is supported at its ends. Weights are placed on it as follows:

5kg	4 m from one end,
6kg	8 m from one end,
7kg	12 m from one end,
8kg	16 m from one end.

Draw the SF and BM diagrams to scale. Calculate the maximum BM and state its location.

Hint: Whenever beam is standstill in position, it is in equilibrium. Forces are balanced or opposite forces are equal in magnitude & sum of all the moment calculated about a point are zero. Reaction forces act at the two supports. Let these forces be R_A & R_M.

Now, $R_A + R_M = 5+6+7+8 = 26kg$.....(1)

Taking moment about one of the supports i.e. A & since clock wise moments = anti clockwise moments we have,

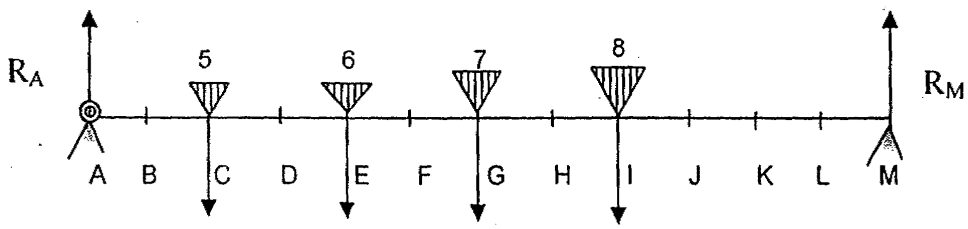


Fig. 13

$(5X4) + (6X8) + (7X12) + (8X16) = R_M \times 24$

$\therefore R_M = 11.67kg.$

$R_A = 26 - R_M = 14.33$ kg

Sign Convention for SF: - All the forces, only to the left of point under consideration are considered. Even if forces only on right are considered the magnitude will still be same as that on left side. Vertically upwards forces are positive and downward forces are negative. The algebraic sum is the SF at that point

If we place a vertical screen at a point slightly to the left of A, we find no vertical force to the left. But if the screen is placed slightly to the right of A, we find R_A = 14.33 kg acting upwards. We may say that at A SF changes from 0 to 14.33 kg. At B the algebraic sum of the forces to left is 14.33 kg so SF at B is 14.33. At C, G, E and I point forces are acting. The SF value will be different if found for position slightly to the left and slightly to the right. Or in other words the SF

at these points will vary from one value to other. Thus if we have to find SF at C, we proceed as follows:

SF at point slightly to the left of C = +14.33
SF at point slightly to the right of C = + 14.33 – 5 = 9.33 kg.
At C SF changes from + 14.33 kg to + 9.33 kg.

Similarly,
At E SF changes from + 9.33 kg kg to + 3.33 kg.
At G SF changes from + 3.33 kg to - 3.67 kg.
At I SF changes from - 3.67 kg kg to -11.67 kg.
At M SF changes from -11.67 kg to 0 kg.

Sign Convention for BM: - Moments are taken about point under consideration of the forces, only to the left of the point. Even if moments of forces to the right are taken the magnitude will be same as that on left side. Clockwise moments are positive and anticlockwise moments are negative. The algebraic sum is the bending moment and if positive would mean that there is sagging moment at the point. Negative would mean hogging moment. . (BM can also be found by calculating the area under SF curve upto the point under consideration. Area below x-axis is negative & vice versa.)

BM at ends is always 0, hence BM at A = 0.
At B BM = +(14.33 x 2) = +28.66 kg.m
At C BM = +(14.33 x 4) = +57.32 kg.m
At D BM = +(14.33 x 6) – (5 x 2) = +75.98 kg.m

St^{n}	SF Calculations	S.F. (kg)	B.M. calculations	BM values (kg.m)
A	0 to 14.33	0 to 14.33		0
B	14.33 + 0	14.33	+(14.33 x 2) = +28.66	+28.66
C	14.33 to (14.33 – 5)	14.33 to 9.33	+(14.33 x 4) = +57.32	+57.32
D	9.33 + 0	9.33	+(14.33 x 6) – (5 x 2) = +75.98	+75.98
E	9.33 to (9.33 – 6)	9.33 to 3.33	+(14.33 x 8) – (5 x 4) = +94.64	+94.64
F	3.33 + 0	3.33	+(14.33 x 10) – (5 x 6) – (6 x 2) = 101.3	+101.3
G	3.33 to (3.33 – 7)	3.33 to -3.67	+(14.33 x 12) – (5 x 8) – (6 x 4) = 107.96	+107.96
H	-3.67 + 0	-.3.67	+(14.33 x 14) – (5 x 10) – (6 x 6) – (7 x 2) = 100.62	+ 100.62
I	-3.67 to (-3.67- 8)	-3.67 to -11.67	+(14.33 x 16) – (5 x 12) – (6 x 8) – (7x 4) =93.28	+93.28
J	-11.67 + 0	-11.67	+(14.33 x 18) – (5 x 14) – (6 x 10) – (7 x 6) – (8 x 2) = 69.94	+69.94
K	-11.67 + 0	-11.67	+(14.33 x 20) – (5 x 16) – (6 x 12) – (7 x 8) – (8 x 4) = 46.6	+ 46.6
L	-11.67 + 0	-11.67	+(14.33 x 22) – (5 x 18) – (6 x 14) – (7 x 10) – (8 x 6) = 23.26	+ 23.26
M	-11.67 to (11.67 +11.67)	- 11.67 to 0	+(14.33 x 24) – (5 x 20) – (6 x 16) – (7 x 12) – (8 x 8) = - ≈0.08	0

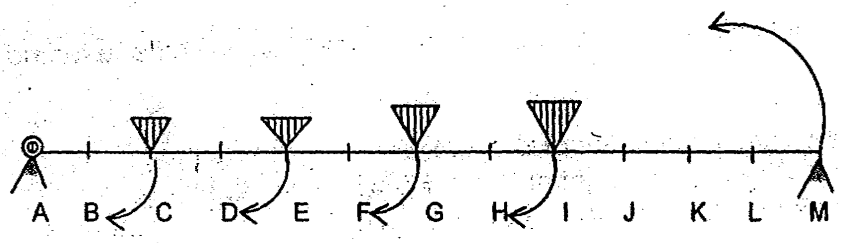


Fig. 14

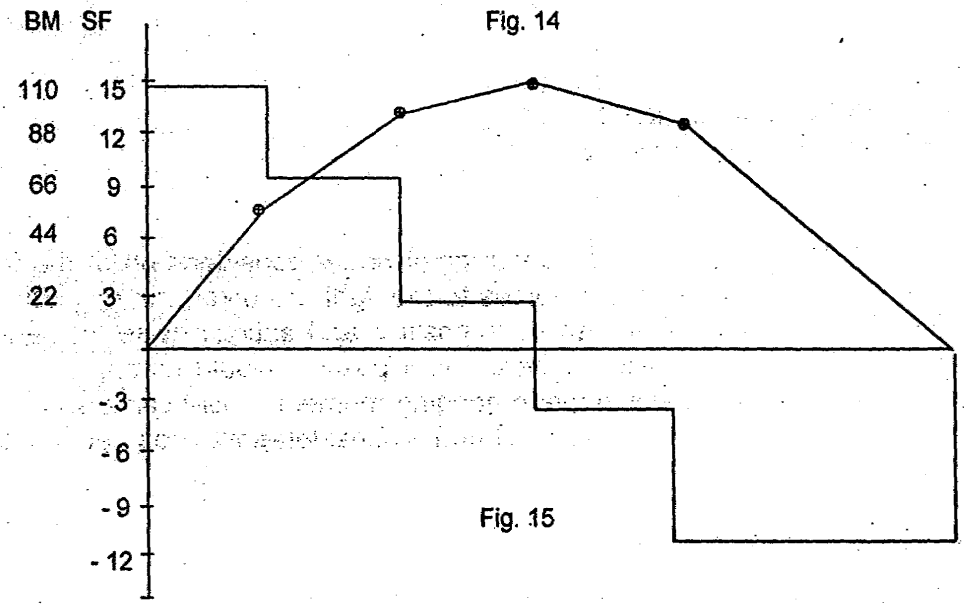


Fig. 15

In respect of above curves the following points must be noted: -

1. SF curve runs vertical at the points where there are point forces acting on beam.
2. Horizontal run of SF curve is characteristic of a weight less beam.
3. Area under SF curve till the point under consideration gives the ordinate for BM curve.
4. Peak bending moment values occur where the SF curve changes direction from positive to negative or vice versa.
5. Where the SF curve is horizontal straight line the BM curve is slant straight line.
6. The shearing force and bending-moment curves have zero values at their extremities.
7. Positive area under SF curves= negative area under SF curves.

BM curve rises in the segments of straight line runs to reach a max BM = 108 kg. m at middle of beam.

Ex. 2 A uniform beam 16 meters long, weighing 10kg/m run is supported at point's 3 meters from each end. Draw a SF and BM diagram and state the point at which the BM becomes nil.

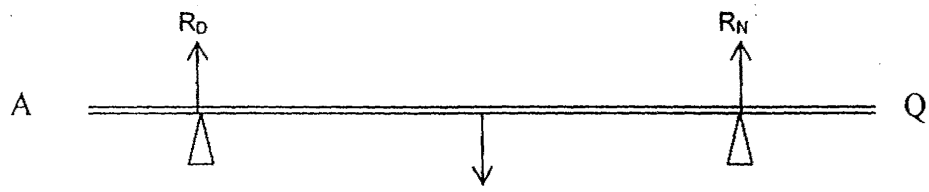


Fig. 16

Let AQ, be the beam 16m long supported at D and N. Let the reaction forces at these two points be R_D and R_N respectively.

Taking moments about D we have 160 x 5 = R_N x 10 giving R_N = 80 and R_D = 80.

Note: For taking moments we may assume that the weight 160kg acts from midlength but for calculating SF and BM the weight shall be considered as uniformly distributed all over.

Sign Convention: -
BM: Consider moments only on left side of point under consideration. CW-Moments are positive & ACW-Moments are negative. Or BM can also be found by calculating the area under SF curve upto the point under consideration. Area below x-axis is negative & vice versa.

Station	S.F. kg	BM by Moments. (CWM to left are +ve) (method 1)	B.M. kg.m	BM by Area under SF Curve (method 2)
A	0	0	0	0
B	-10	-10 x 0.5 = - 5	-5	Area of Δ:½ 1x10 =-5
C	- 20	-20 x 1 = - 20	- 20	½ 20 x 2 = -20
D	-30 to +50	- 30 x 1.5 + 0 = - 45	- 45	½ 30 x 3 = -45
E	40	- 40 x 2 + 80 x 1 = 0	0	- 45 + [½ (50+40)]x1= 0
F	30	- 50 x 2.5 + 50 x 2 = 35	35	0+[½ (40+30)]x1 =+35
G	20	- 60x3 + 80x3= +60	+60	35+[½ (30+20)]x1=+60
H	10	-70x3.5 + 80x4 = +75	+75	60+[½ (20+10)]x1=75
I	0	-80x4 + 80x5 = +80	+80	75+½ 10x1= 80
J	- 10	-90x4.5+ 80x6 = +75	+75	80-½ 10x1= 75
K	- 20	-100x5 + 80x7 = 60	+60	75-[½ (20+10)]x1=60
L	-30	-110x5.5 + 80x8 = 35	+35	60-[½ (30+20)]x1=+35
M	-40	-120x6 + 80x9 = 0	0	35-[½ (40+30)]x1 =+0
N	-50 to +30	-130x6.5 + 80x10 = -45	-45	0- [½ (50+40)]x1=-45
O	+20	-140x7 + 80x11 +80x1 = -20	-20	-45+[½ (30+20)]x1=-20
P	+10	-150x7.5+80x12+ 80x2 = -5	-5	-20+[½ (20+10)]x1=-5
Q	0	-160x8+ 80x13+ 80x3 = 0	0	-5+½ 10x1= 0

Scale SF Curve: 10kg = 1cm
BM Curve: 10kg.m = 1cm

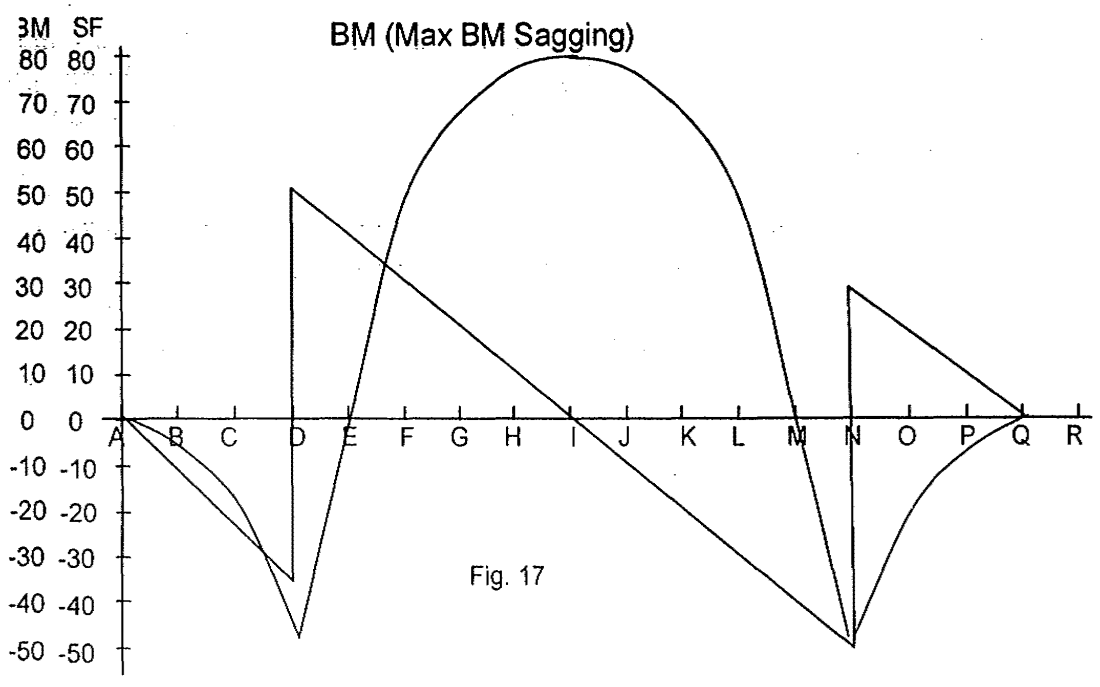


Fig. 17

To find the point at which BM will become 0.
Weight per unit length of beam = 10kg ∴weight of a segment of length x = 10x.
Method 1: By observation. Where the BM curve cuts the x-axis.

Method 2: CWM = ACWM (either to the left or to the right)
Thus if the position is x metre to the right of D then mass of the beam to the left of this point = 30 + 10x..... (1)
Distance of the centroid of this segment from this position = ½ (3+x).....(2)
ACWM = ½ (3+x) (30+10x)... (3)
CWM = 80x..... (4)
Equating (3) & (4) & simplifying we get $x^2 - 10x + 9 = 0$
Or (x – 9) (x – 1) = 0
Gives x = 1 or x = 9m

Method 3: Positive area under the SF curve = negative area under the SF curve to the left of point under consideration.
Negative area = ½ 30 x 3 = - 45..... (1)
Positive area = ½ {50 + (50 – 10x)}. x..... (2)
x is the distance of zero BM position from station D & 10x is the weight of segment x.
(1) + (2) = 0
Simplifying we get $x^2 - 10x + 9 = 0$
Or (x – 9) (x – 1) = 0
Gives x = 1 or x = 9m

Ex. 3 A uniform beam AB 16 m long weights 160 kg. It is supported at points two meters from each end. A weight of 15 kg is placed at a point 6m from end A. Draw the SF and BM diagrams for the beam. What is the maximum value of BM and the position on the beam where it occurs? Calculate the point on the beam, between the weight and end B, where the BM is nil.
Hint:-
Let AQ, be the beam 16m long supported at C and O. the weight of 15kg is placed at G. by taking moments about C we get R_O = 85kg and R_C = 90kg. the SF at different points at 1m apart will then be 0, -10, -20 to +70, +60, +50, +40, +30 to +15, 5, -5, - 15, -25, -35, -45, -54, -65 to +20, +10, 0 respectively.

To find the point (other than 2nd & 14th metre pt) at which SF becomes 0, SF is 0 between 7th metre & 8th metre point. Let the O'SF point be X metre from 7th metre point.
Weight per unit length of beam = 10kg ∴weight of a segment of length x = 10x.
Sum of upward forces to the left of point = sum of downward forces to the left.
∴90 = 70 + 15 + 10x
∴10x = 5
∴ x = 0.5m
∴ SF = 0 at 7.5m from left end. The position can also be found by similar Δ principles using ordinates H + F on SF curve.

$$\frac{\text{SF at H}}{\text{SF at I}} = \frac{x}{(x-1)}$$

At this point BM has a maximum positive value = Area under SF curve to the left.
= - ½ 20 x 2 + ½ [70 + 30] x 4 + ½ 15 x 1.5
= - 20 + 200 + 11.25 = 191.25 kgm.

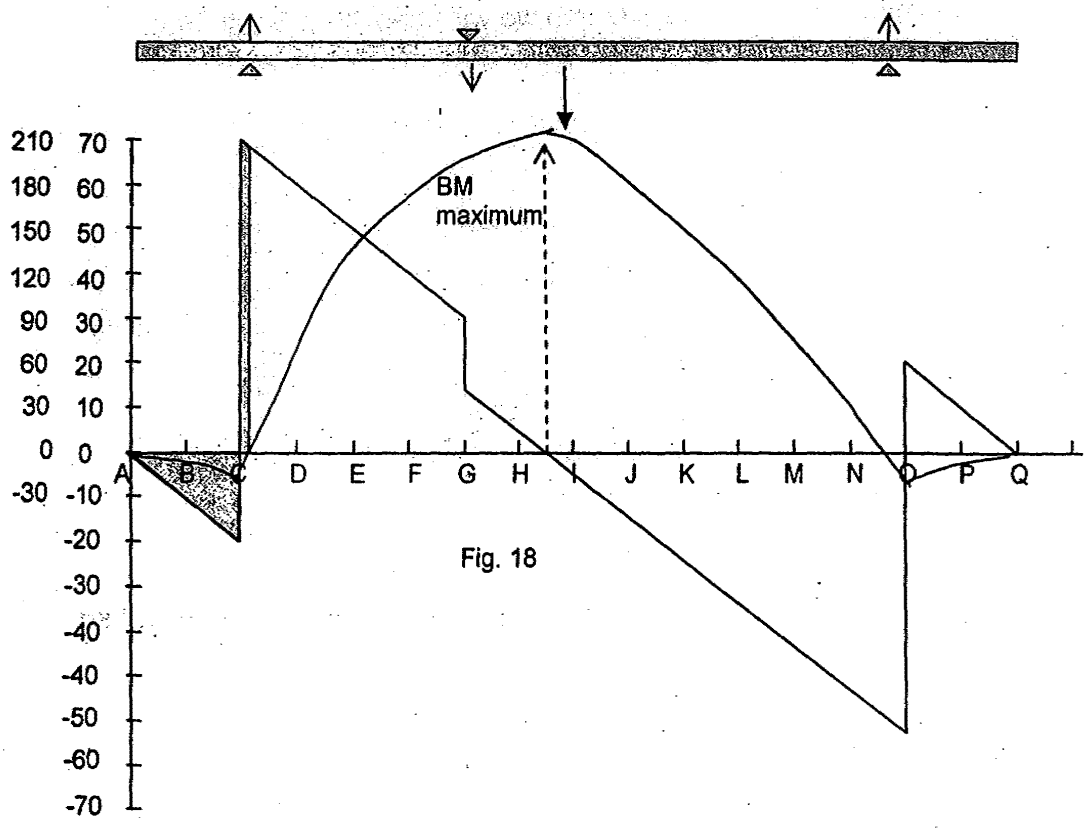


Fig. 18

To calculate the point on the beam, between the load and end B, where the BM is nil.

Let the point be y m to the left of 14 m station.
For BM to be 0 the negative area between this point and 14th metre station = positive area between 14th & 16th metre station.
∴ ½ [65 + (65 – 10y). y = ½ 20 x 2
∴ $130y - 10y^2 = 40$ or $y^2 - 13y + 4 = 0$

Solution to quadratic eq. = $y = \frac{-b +/- [b^2 - 4ac]^{\frac{1}{2}}}{2a}$

Solving & choosing the appropriate solution we get y = 0.32m. Similarly the point to the right of 2nd station is 0.58m from it.

Ans. Maximum BM 191.25tm occurs at a point 7.5m from end A. This being on positive side implies a sagging moment. BM is nil at a point 2.32m from end B.

Ex. 4 Draw SF & BM curve for a weightless cantilever 6m long with a weight of 50 kg placed at free end.
Soln: Cantilever is a beam with 1 end free & the other rigidly fixed on say a wall.

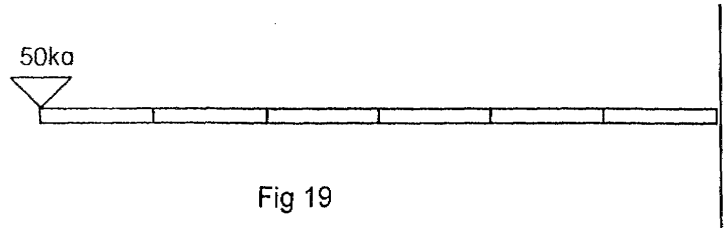


Fig 19

To have compatibility with sign convention we will keep the left side free.

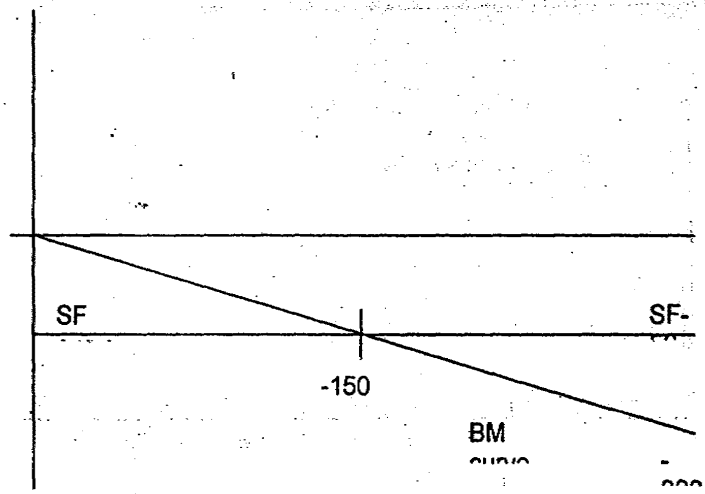


Fig 20

BM at the rigid end is 300 kg.m, hogging

Ex. 5 Draw SF & BM curve for a uniformly weghted cantilever 6m long of weight 60 kg.

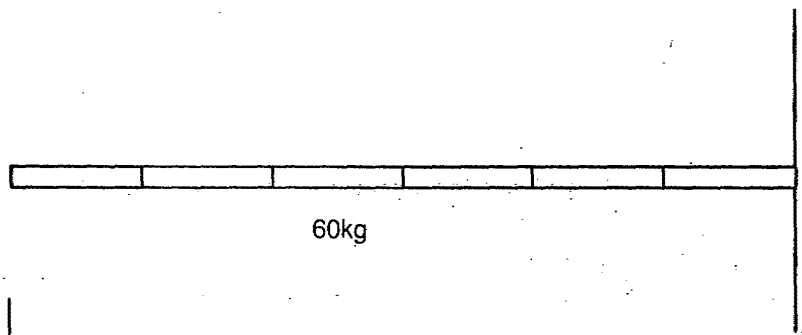


Fig 21

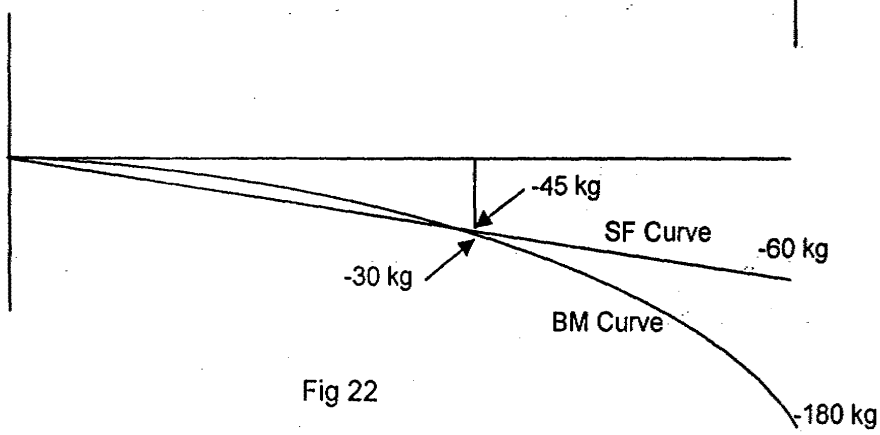


Fig 22

Ex. 6 A box vessel of light weight 200t of uniform weight distribution is 40m long and has 4 compartments equal in length. Quantity of bulk cargo loaded in the holds 1, 2, 3, 4 is 160, 280, 280 and 160 respectively. Draw the SF and BM curves.

Light ship weight per unit length = $\frac{200}{40}$ = 5 t/m

For cargo in hold 1 & 4 (weight per unit length) = $\frac{160}{10}$ = 16 t/m

For cargo in hold 2 & 3 (weight per unit length) = $\frac{280}{10}$ = 28 t/m

Total buoyancy force = total weight = 200 + 880 = 1080t

Since weight is symmetrical about midships draft will be even keel and buoyancy per unit length will be uniform and will be $\frac{1080}{40}$ = 27 t/m

Load per unit length = (buoyancy per unit length – weight per unit length)
Load /L at: Hold 1 & 4 = 27 – (16+5) = +6 t/m, Hold 2 & 3 = 27 –(28 +5) = -6 t/m

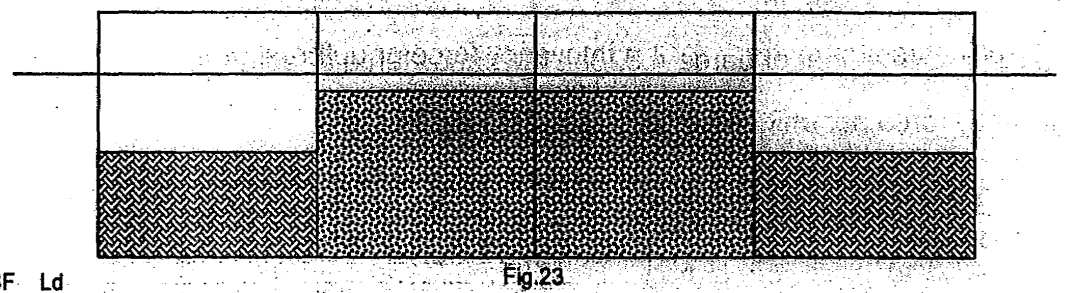


Fig.23

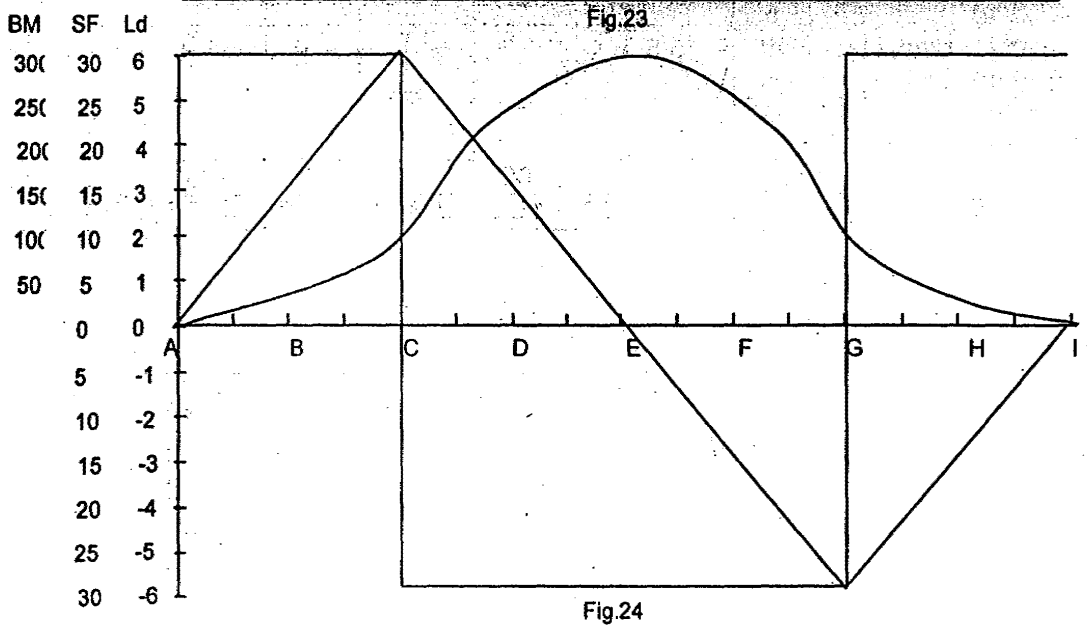


Fig.24

Stations	SF calculations	SF(t)	BM calculations	BM (tm)
A	0	0	0	0
B	5 x 6 = 30	30	½ 30 x 5 = 75	75
C	10 x 6 = 60	60	$75 + \left(\frac{30+60}{2}\right) x5 = 300$	300
D	60 - 30 = 30	30	300 + 225 - 525	525
E	30 – 30 = 0	0	525 + 75 = 600	600
F	0 – 30 = - 30	- 30	600 – 75 = 525	525
G	-30 – 30 = - 60	- 60	525 – 225 = 300	300
H	-60 + 30 = - 30	- 30	300 – 225 = 75	75
I	-30 + 30 = 0	0	75 – 75 = 0	0

Ex. 7 A box shaped vessel of length 80 m and light displacement 280 t is loaded with 640 t of iron ore to equal heights at the ends and sloping uniformly to nil at mid length. Draw the SF and BM diagrams for the barge indicating their values at appropriate positions.

Sol^{n}: - Light weight = 280t. Weight per unit length of Lt Wt = $\frac{280}{80}$ = 3.5t/m

If cargo was evenly trimmed in the hold it would have caused Wt per met length = $\frac{640}{80}$ = 8. This W/L of cargo at C&E.
It also means that the weight of cargo per unit metre at ends in presently loaded condition = 16 t/m.
This is because weight per unit length is proportional to the height of cargo.

Loaded displacement of barge = 920t = buoyancy force or upthrust.

Buoyancy force per unit length of ship = $\frac{920}{80}$ = 11.5t/m

St^n	A	B	C	D	E	F	G	H	I
Buoyancy / L (t/m)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Wt/L = Cgo / L +lt wt / L (t/m)	19.5	15.5	11.5	7.5	3.5	7.5	11.5	15.5	19.5
Load / L = Buoy/L –Wt / L (t/m)	-8	-4	0	4	8	4	0	-4	-8
SF (t)	0	-60	-80	-60	0	+60	+80	+60	0
BM (tm)	0	-333.3	-1066.6	-1800	-2133.2	-1800	-1066.6	-333.3	0

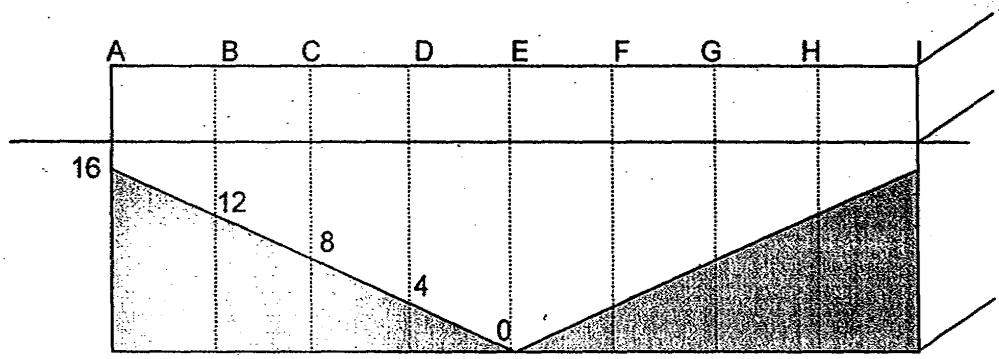


Fig. 25

Scale
Length: 5m = 1 cm
Load curve: 2 t/m = 1cm

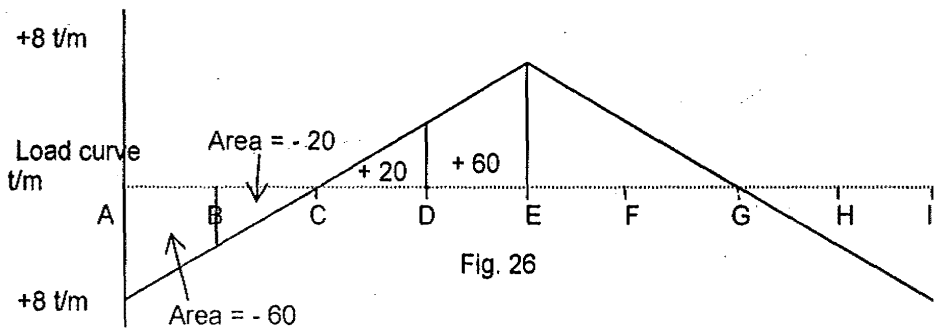


Fig. 26

SF ordinates at any point are found by totalling area under Load curve till the point under consideration. Thus SF at A = 0. Till B it is – 60 & till C it is – 60 – 20 = - 80. Since Load curve is slant straight line SF curve will be curvilinear.
Similarly BM ordinate at any point is found by totalling up area under SF curve till the point under consideration. BM curve is also curvilinear.

Note: The centre of curvature of a curvilinear portion is on the upper side if previous curve is running upwards (has upward slope) & is on the lower side if the previous curve is running downwards.

Ordinates	SM	Product	SM	Product
0	1	0	5	0
60	4	240	8	480
80	1	80	-1	-80
	SOP = 320		SOP = 400	

Area under SF curve from A to C = $\frac{10}{3}$ x 320 = 1066.7 t

Area under SF curve from A to B = $\frac{10}{12}$ x 400 = 333.33 t

Hence Area under SF curve from B to C = 1066.7 – 333.3 = 733.4 t.

Thus area under the SF curve upto A = 0, upto B = - 333.3tm, upto C = - [333.3 + 733.3] = -1066.6tm, upto D = - [1066.6 + 733.3] = 1800tm, upto E = -[1800 + 333.3] = 2133.3tm

Scale
Length: 5m = 1 cm
Load curve: 2 t/m = 1cm
SF curve: 20 t = 1cm
BM curve: 500tm = 1 cm

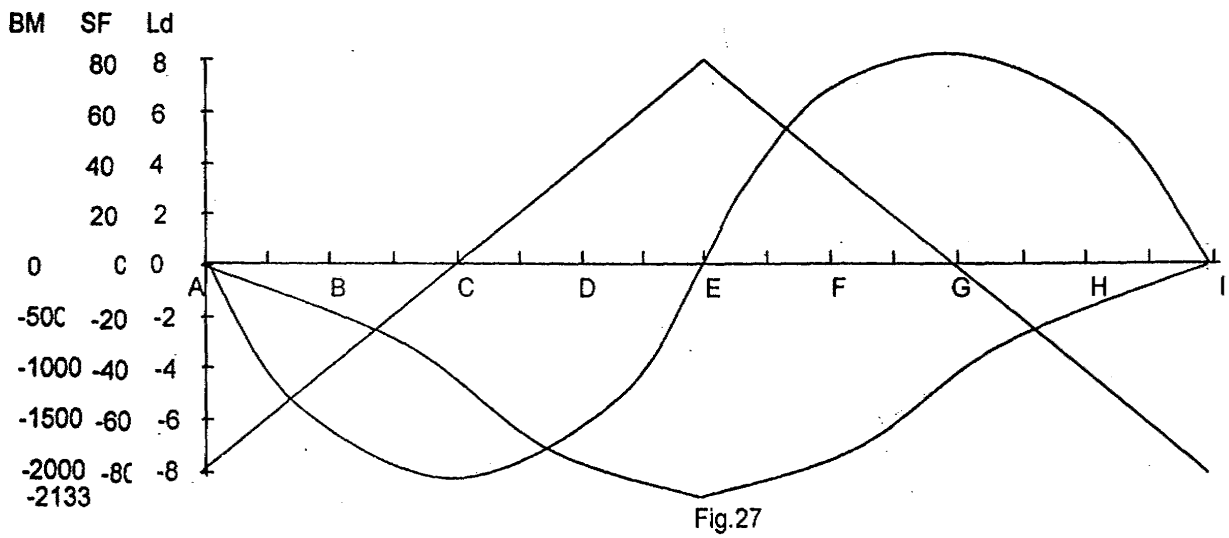


Fig.27

Max. SF at 20m from each end = 80t; SF = 0 at mid length
Max BM at mid length =2133.36 tm at mid length (hogging as BM on negative side)

Ex. 8 A box shaped barge 40m X 6m floats at an even keel draft of 3 meters in fresh water with a cargo of ore, SF $\frac{2}{3}$ cubic meter / tonne, stored to a height of 3 metres at the ends, uniformly sloping to nil at mid-length. Draw the SF & BM diagrams.

Hint: If cargo was evenly trimmed in the hold it would have had a uniform height of 1.5m.
$\therefore$ vol of cargo = 40 x 6 x 1.5 m^3 Weight = vol / SF = 540t.

Load Displ = 40 x 6 x 3 x 1.000 = 720t
Light weight = 720t – 540t = 180t. Length / met of Lt Wt = 180/40 = 4.5t/m.
Wt/m length of uniform height cargo = 540 / 40 = 13.5 t/m
It means that the weight of cargo per unit metre at ends in presently loaded condition = 27 t/met.
This is because weight per met length is proportional to the height of cargo.
The Load curve can be plotted at 5m interval.
Total weight of the barge = 720t = buoyancy force or upthrust. Buoyancy force per metre length of ship = 720/40 = 18t/m

St^{n}	A	B	C	D	E	F	G	H	I
Wt/m	27	20.25	13.5	6.75	0	6.75	13	20.25	27
Total wt/m =Cgo+4.5	31.5	24.75	18	11.25	4.5	11.25	18	24.75	31.5
Buoy/m -Wt/m t/m	-13.5	-6.75	0	+6.75	+13.5	+6.75	0	-6.75	-13.5
SF (t)	0	-50.62	-67.5	-50.62	0	+50.62	+67.5	+50.62	0
BM (t.m)	0	-140.6	-450	-759	-900	-759	-450	-140.6	0

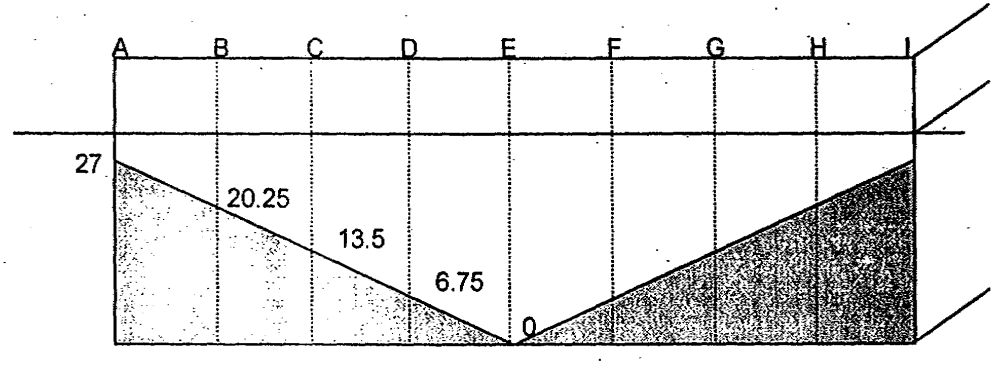


Fig. 28

Length: 2.5m = 1 cm
Load Curve: 3 t/m = 1cm
SF Curve: 15 t = 1cm
BM Curve: 180 t.m = 1cm

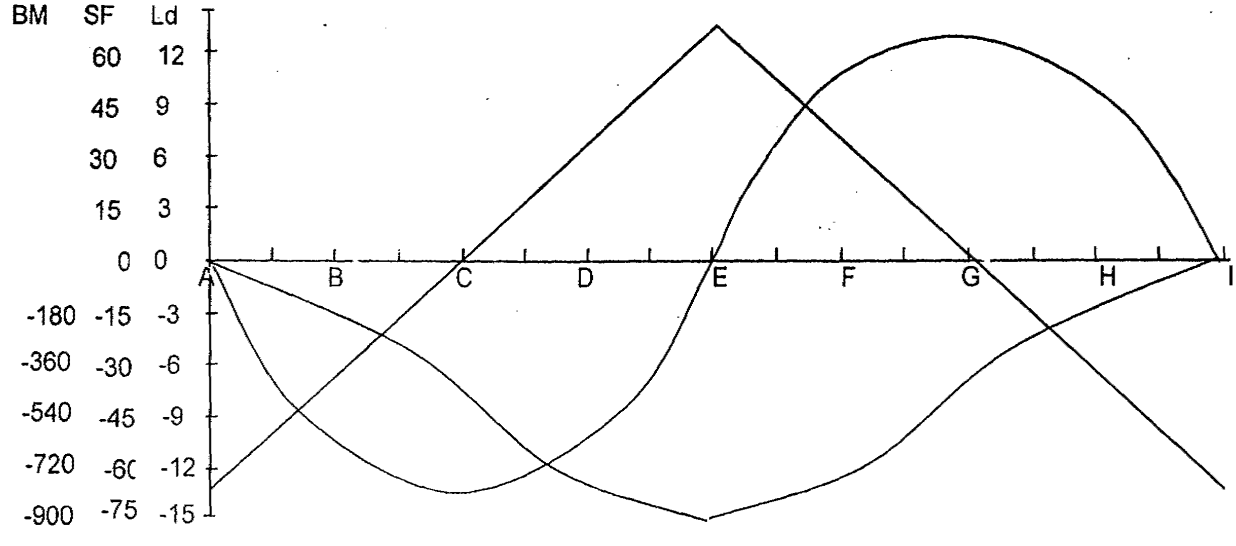


Fig.29

BM curve is negative through out , vessel hogging all along her length. Maximum bending moment is amidships and is equal to 900tm.

Ex. 9 A box shaped barge of length 60m and light displacement 600t is loaded with iron ore level stowed as follows: - 150t each over a length of 15m at each end and 210t over a length of 15m at midlength. Draw the curves of Load & SF for the barge.

Sol^{n}: -

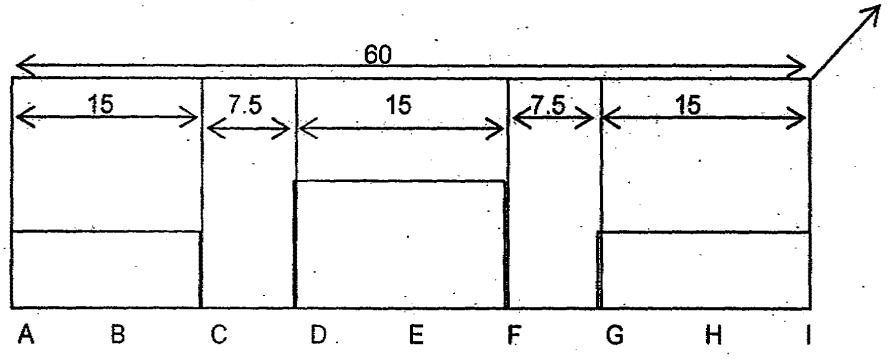


Fig. 30

Light weight = 600t. Cargo = (150 x 2) + 210 = 510t. Tot displacement = 1110t.

Buoyancy force per metre length = $\frac{110}{60} = 18.5$ t/m (This is constant for the entire length as the draft fore & aft is same.

Light ship weight per metre length = $\frac{600}{60} = 10$ t/m

In hold 1 & 3 cargo weight per metre length = 10 t/m, In hold 2 cargo it is = 14 t/m.

Station	A	B	C	C	D	D	E	F	F	G	G	H	I
Buoy/m	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5
Wt/m	20	20	20	10	10	24	24	24	10	10	20	20	20
Load/m	-1.5	-1.5	-1.5	+8.5	+8.5	-5.5	-5.5	-5.5	8.5	8.5	-1.5	-1.5	-1.5
SF	0	-11.25	- 22.5	- 22.5	41.25	41.25	0	- 41.25	- 41.25	22.5	11.25	11.25	0

Scales:
Length: 3.75m = 1cm
Load: 2 t/m = 1cm
SF: 9 t = 1cm

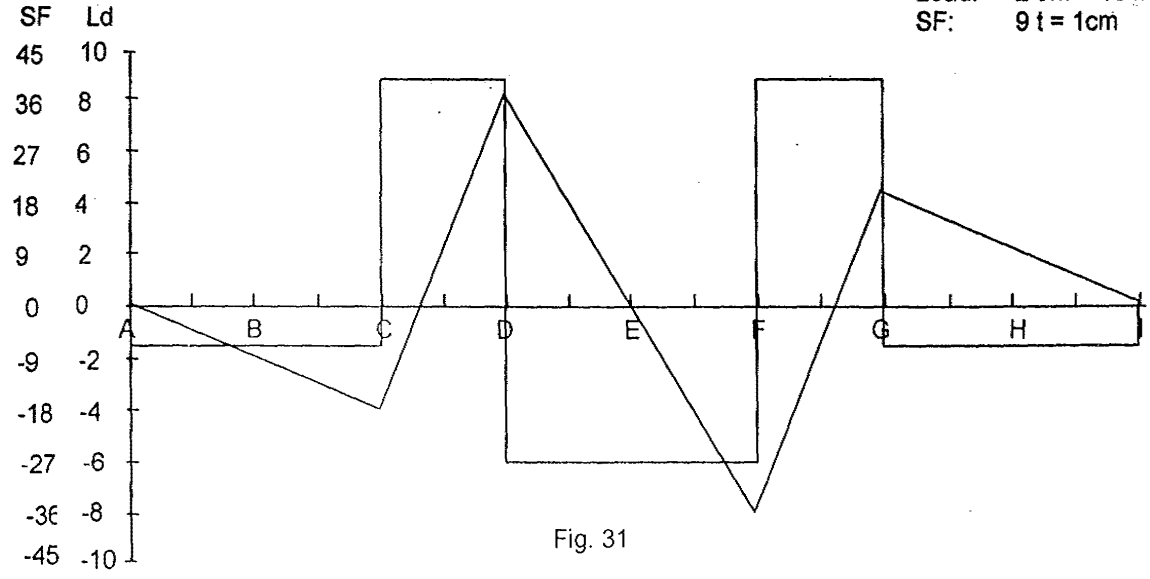


Fig. 31

Ex. 10 A rectangular barge 60m long has 6 identified holds & is loaded with Rock phosphate that is symmetrical about midships hold 1 & 6 has 240t each even timed cargo. Hold 2 & 5 has 200t of cargo loaded in prism fashion with peak at mid length of hold & tapering to zero at F & A ends of hold. In hold 3 & 4 150t of cargo is loaded with peak at F & A end of holds & tapering to 0 at mid length. Find SF & BM at end of hold 2 & 3 mid length of hold 3. Given Lt weight of barge is 300t and there is no athwartship slope of cargo in any hold.

Sol^{n}:

Lt Weight = 300t

Light weight per unit length $= \frac{300}{60} = 5$ **t/m**

Total cargo = (240 +200 + 150) 2 = 1180t loaded displacement = 1180 + 300 = 1480t

Since displacement = buoyancy.

Total buoyancy = 1480t

Since the loading & barge is symmetrical about mid length the vessel will be on even keel.

∴Buoyancy at any point is dependent on draft at that point the buoyancy all along length of vessel will be uniform.

Buoyancy per unit length of vessel $= \frac{1480}{60} = 24.7$ **t/m**

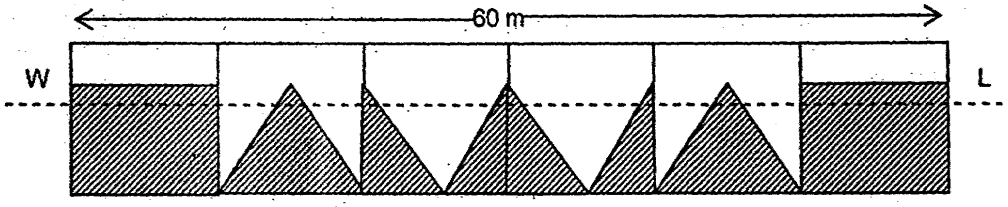


Fig. 32

SF at any point may be found by algebraically adding vertical forces to the left of point under consideration (upward forces can be called positive forces and vice-versa)

SF at end of hold 2 = + (24.7 x 20) –[(5 x 20) + (240 + 200)]
= 494 – [100 + 440]
= - 46t

SF at mid length of hold 3
= + (24.7 x 25) – [(5 x 25) – (240 + 200 + 75)]
= 617.5 – (125 + 515) = - 22.5t

SF at end of hold 3
= (24.7 x 30) – [(5 x 30) – (240 + 200 + 150)]
= 741 – (150 + 590) ≈ 0

BM at any point may be found by adding algebraically the moments of forces which are acting at the left of point under consideration (clock wise moment to left of point can be considered positive & vice versa)

BM at end of hold 2
= + (494 x 10) – [(100 x 10) + (240 x 15) + (200 x 5)]
= + 4940 – (1000 + 3600 + 100)
= 4940 – 5600
= -660t (hogging)

BM at midlength of holds 3

$$+ (617.5 \times 12.5) - [(125 \times 12.5) + (240 \times 20) + (200 \times 10) + (75 \times \frac{10}{3})]$$

$$+ 7718.8 - [1562.5 + 4800 + 2000 + 250]$$

$$= 77188 - 8612.5 = -893.7t \text{ (hogging)}$$

BM at end of hold 3

$$+ (714 \times 15) - [(150 \times 15) + (240 \times 25) + (200 \times 15) + (150 \times 5)]$$

$$11115 - [2250 + 6000 + 3000 + 750]$$

$$11115 - 12000 = -885t \text{ (hogging)}$$

Exercise 25

Q. 1 A uniform log of square cross section each side 50 cms and 20 meters long, weighting 700 kg/m^3, floats in water of relative density 1.020. When a load uniformly distributed over 4 m of it's mid length is placed on the log; the log just submerges uniformly. Draw the SF & BM diagrams for the log, stating their maximum values.
Ans. +/-0.64t at each edge of distributed load. Max BM is at mid length = 3.20t.m.

Q. 2 A box shaped barge 40m x 5m has light SW draft of 0.8m fwd and aft. It has four identical holds, each 10m long. Cargo is loaded level as follows:
No.1 hold: 200 t, No.2 hold: 98 t,
No.3 hold: 98 t, No.4 hold: 200 t
Draw the SF and BM curves to scale.
Ans. MAX, SF values –51 & +51 BM Max 510 tm Hogging

Q. 3 A box shaped vessel 24m long and 6m wide has light displacement of 120t. Iron ore (SF 0.6) is loaded, 3m high at the forward and after ends, sloping steadily to zero at the centre. Draw the SF and BM diagrams to scale.
Note: The cargo has no slope in the athwart ships direction.
BM (max) = -272tm at mid point (hogging)

Q. 4 A box shaped barge of length 30 m and light displacement 120 to be loaded with 180 t of ore, peaked at mid length and sloping uniformly to nil at ends. Draw the curves of weights, buoyancy, loads, SF and BM to scale, indicating their values.
Ans. BM max = +223 tm at mid point (sagging)

Q. 5 A box shaped vessel of length 120 m, light displacement 1440 t is divided into six compartments of equal lengths, the compartments are level stowed with cargo as follows:
Nos. 1 and 6 500 tonnes each
Nos. 3 and 4 400 tonnes each
Nos. 2 and 5 Empty
Draw curves of Shearing Forces and Bending Moments for the vessel, indicating their values at different positions along length.
Ans. BM max = -3400 tm (hogging)

Q. 6 A uniform beam 10 m in length weighing 1200 kg is supported on two level platforms extending 2 m from each end of the beam. A load of 600 kg is applied at the mid-length of the beam. Draw the SF and BM diagrams for the beam, showing the necessary calculations and indicating their values at appropriate positions on the diagrams.
Ans. BM max midway = 2100 kg.m SF 0, +660, +300, -30, -660, 0

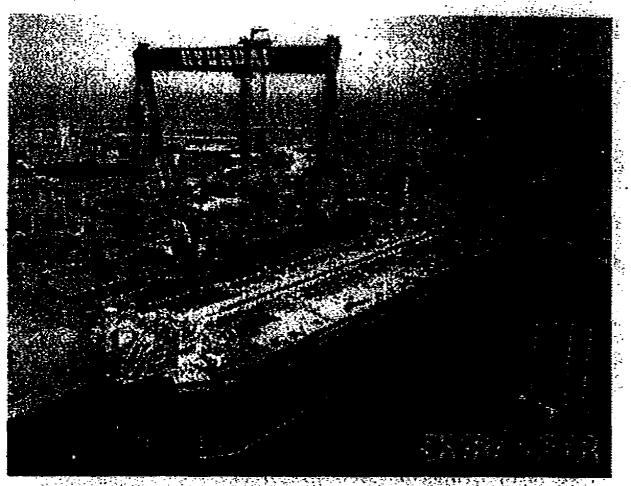
Q. 7 Define the following: (i) Stress (ii) Strain (iii) Shearing Force (iv) Bending Moment Distinguish between Shearing Forces and Bending Moments in ships. Briefly explain the causes of these and show how they are graphically represented on ships.

Q. 8 Describe Hog and Sag as static and dynamic stresses. How does framing system of a large tanker resist these stresses?

Q. 9 Describe the various dynamic stresses a vessel at sea can encounter. State which structural members counter the effects of these stresses.

Q. 10 Discuss the problem of vertical shear and longitudinal bending moments in ships of different types, showing how this determines the type of framing system to be used.

Largest Shipyard: Hyundai Heavy Industries Ulsan Shipyard, in South Korea, is currently the largest in the world and has the capability to build a variety of vessels including Commercial Cargo, Offshore and Naval vessels. Groundbreaking was done in 1972. Hyundai's Ulsan shipyard sprawls over 7,200,000 square meters. Facilities include nine dry docks. Shanghai on the other hand has agreed to allow the nation's leading shipbuilder to construct the world's largest shipyard on one of its islands. The US$3 billion scheme aims to turn the China State Shipbuilding Corp (CSSC), as well as the nation, into the largest shipmaker in the world by 2015.



Chapter 23 Stability by Inclining Experiment & Rolling Period tests

Inclining Experiment:

Before a ship officer can begin stability calculations he must know the position of the center of gravity of the vessel in a light condition. This light ship KG is found by performing the inclining experiment. The inclining experiment is performed at the shipyard when the ship is built or by a naval architect in a dock after an alteration to the ship's structure is caused (which could change the value of the light ship KG.)

The determination of light ship displacement & COG must be done to:

- Every passenger ship (any size) every cargo ship ≥ 24m (as defined in LL 66).
- Any ship who underwent material alterations.
- Every passenger ship at interval of 5y. (light weight survey)

A ship may be dispensed with re inclining test, if required data is available from the test of sister ship. Administration may allow dispensation to specially designed bulkers and liquid carriers if data of similar ships clearly indicates sufficient GM will always be there.

Principle of Inclining Test:-

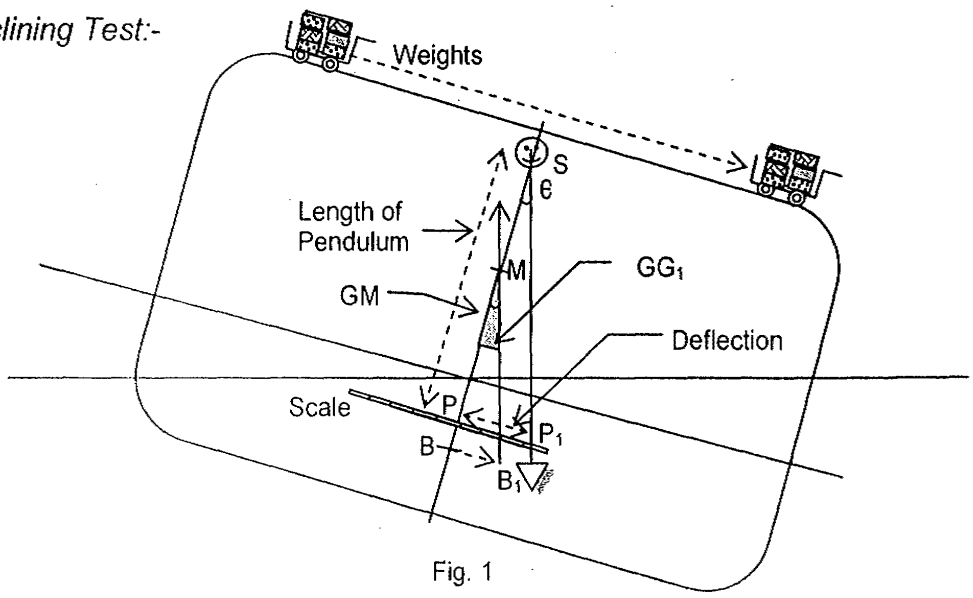


Fig. 1

Triangle GG_1M is similar to triangle SPP_1

$$\therefore \tan\theta = \frac{GG_1}{GM} = \frac{\text{Deflection in met}}{\text{Length of pendulum}}$$

$$\text{BUT } GG_1 = \frac{w \times d}{\Delta} \therefore GM = \frac{LOP}{Defl^n} \times \frac{w \times d}{\Delta}$$

This way the GM & hence KG at the time of experiment can be found out & from this data the KG of light ship can be determined.

Preparation for inclining test: -

The intact stability code provides for procedure & preparations to be done in respect of inclining experiment. The pre experiment preparations may be divided in various parts as follows:

(a) *Notification to Administration and responsibility of preparation: -*

2. Due written notice is given to administration.
3. Representative of Administration witnesses the test.
4. Responsibility of preparation lies with shipyard, owner or naval architect.
5. Procedure is outlined in the document submitted to the Administration. If one has any alternate method then details of method is given to Administration for review (before inclining)

(b) *Information to be provided with notification:-*

The notification must include the important information in respect of the vessel such as,

1. Identification of ship,
2. Date, time, location of test,
3. Details regarding Inclining weight e.g. type of weights, amount, whether and how are the weights certified, the method of moving the weights,
4. Pendulums or alternate arrangements, maximum heel anticipated arrangements for one or two pendulums,
5. Trim,
6. Details of tanks,
7. Weights on board over & above light ship,
8. Description of computer,
9. Name /s of a person responsible for test.

(c) *General condition of ship: -*

1. Ship must be as complete as possible.
2. Temporary material, debris etc should be removed off the ship or minimum.
3. There should be no trapped water.
4. The vessel should be moored in quiet or sheltered area.
5. Tide, trim, depth, specific gravity etc must be accurately checked. Ship must not touch bottom when heeled.
6. Ship must be as up right as possible
7. Draft must be sufficient [At low draft change of WPA is abrupt]
8. Trim should not be more than 1% different from designed trim so that stability parameters for the condition are known accurately.
9. Weights must be certified & sufficient to provide 2° to 4° heel to each side 1° for large ships. (Water ballast transfer may be acceptable)

10. There should be at least 3 Pendulums, located as far apart as practical Deflection of at least 15 cm ensured thus should be long enough. It is recommended that pendulum lengths of 4 to 6 m be used. Usually, the longer the pendulum the greater the accuracy of the test. But very long pendulums are used on a tender ship the pendulums may not settle down and the accuracy of the pendulums would then be questionable. Pendulums should be unobstructed through the entire length. It should be of piano wire of monofilament, trough provided to dampen vibrations. Inclinometer or other devices must only be in conjunction with at least 1 pendulum.

11. Efficient 2 way communication must be available.

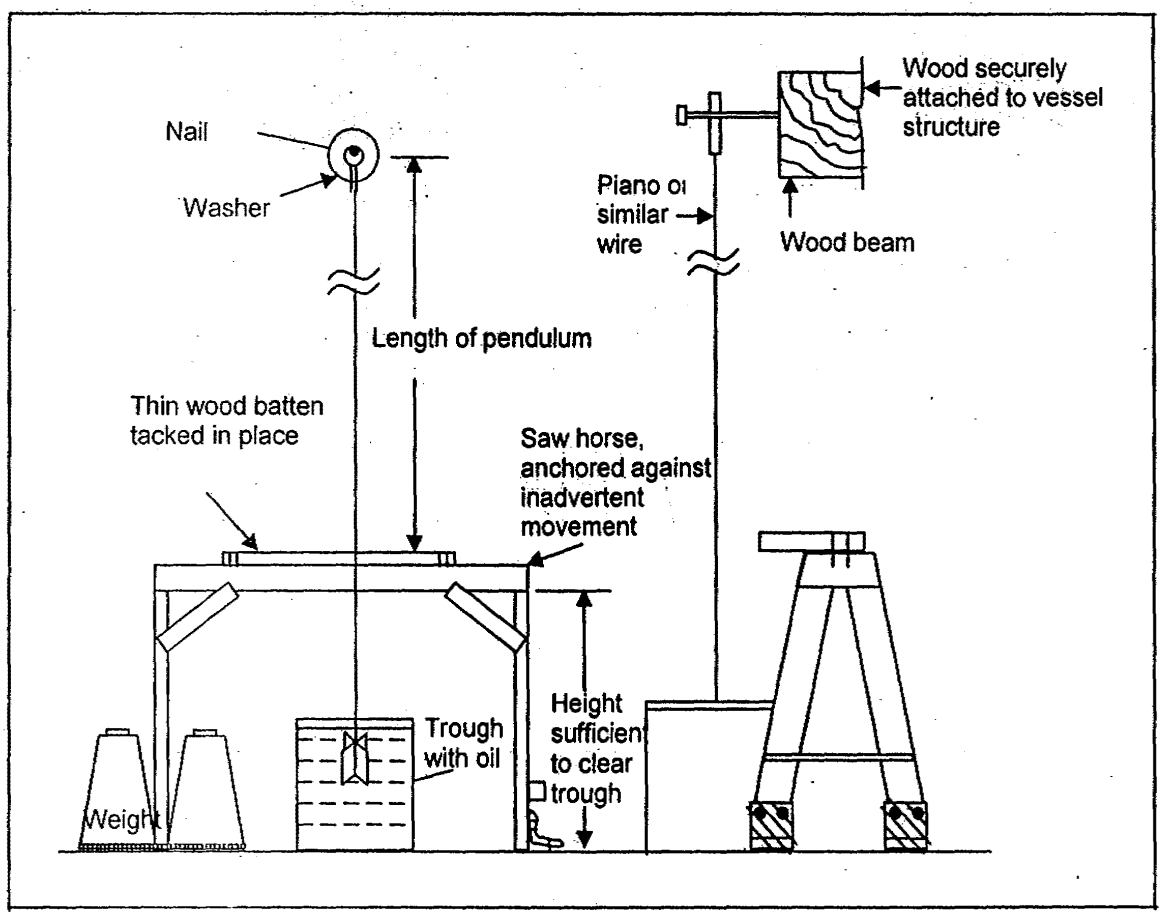


Fig. 2

(d) *Plans Required:* - The important plans which must be submitted are lines plan, curve of form plan (hydrostatic), G.A. plan, capacity plan, tank sounding plan, draft mark location plan, docking plan.

(e) *Equipment:* - The various equipment needed for the experiment are weights, pendulum, small boat, engineering (graduated) scale, sharp pencil, chalks, measuring tape, sounding tape, sea hydrometer (.999 to 1030), liquid hydrometer for ships liquids, graph, explosion proof testing device, thermometer draft tubes.

Precautions to be taken: -

Following are some of the important precautions which must not be taken in order to ensure the accuracy:

a) Draft / free board marks are accurately taken to determine displacement. At least 5 readings at equally spaced interval are used. All six side drafts are read accurately. Moulded depth at each location found from ship's lines. (Moulded dimensions given in plans). Readings must be taken immediately before or after test as some times density is likely to change Copy of test fist is then forwarded to Administration with calculated results in acceptable format.
b) Preparations done so far must be carefully checked. At least two persons should do initial walk through. All compartments must be open and clean. Tanks must be ventilated. All equipments must be in appropriate place.
c) Weather, water level fluctuations, superimposed (additional) heeling moments must be considered.
d) All empty tanks must be entered. Ensure that they are dry. Other tanks are accurately sounded.
e) Some weights may have to be added or removed or shifted. Allow KG appropriately depending on the position on ship viz. (high or low).
f) Specific Gravity of sample taken just before or after test, from 3 positions,viz forward, midship, aft. Sample is taken from sufficient depth temp correction considered if temp different at time of test.
g) Shift of any liquid will exaggerate heel. This is minimized by ensuring decks, tanks, bilges dry or completely filled up. The tanks which must have part liquid preferably must have wall sided sides & should be of regular shape so the FSM can be found easily.

$$FSM = \frac{lb^3}{12} \times d_i$$

Slack tanks should normally be limited in pair e.g. 1 port / 1 stbd etc. For certain liquids viz. F.W., Fuel, D.O., Lubs Potable Water slack deep tanks can be 20 – 80% full. Slack D.B can be 40 to 60% full. This is to avoid non-uniform rate of heel change due to liquid. If change of trim expected longitudinal shift of liquid considered. Communication of liquid between tanks is avoided.

h) On pier if off shore winds prevail moorings must be slack. Moorings must be close to centreline as well as water line. If on shore winds prevail moorings to be slack If floating crane is used it should not be moored to ship.
i) Ensure weights are accurate and values are not changed due to moisture or damage after being certified.
j) Transfer of Liquid may be acceptable for large ships with high GM. If Ballast transfer is adopted instead of weights.
   1. Tanks to be of regular shape, wall sided, free of air pockets.
   2. Tanks to be placed in pair & opposite.
   3. S.G. of liquid within the tank to be checked.
   4. Pipe lines to be full & all ballast valves closed.
   5. Accurate sounding and calculations are done after each shift.
k) A graph is plotted of tan θ against heeling moment as shown. The graph must pass through origin & must be straight line. Otherwise the change is caused due to external moments, excessive liquids, insufficient depth etc.

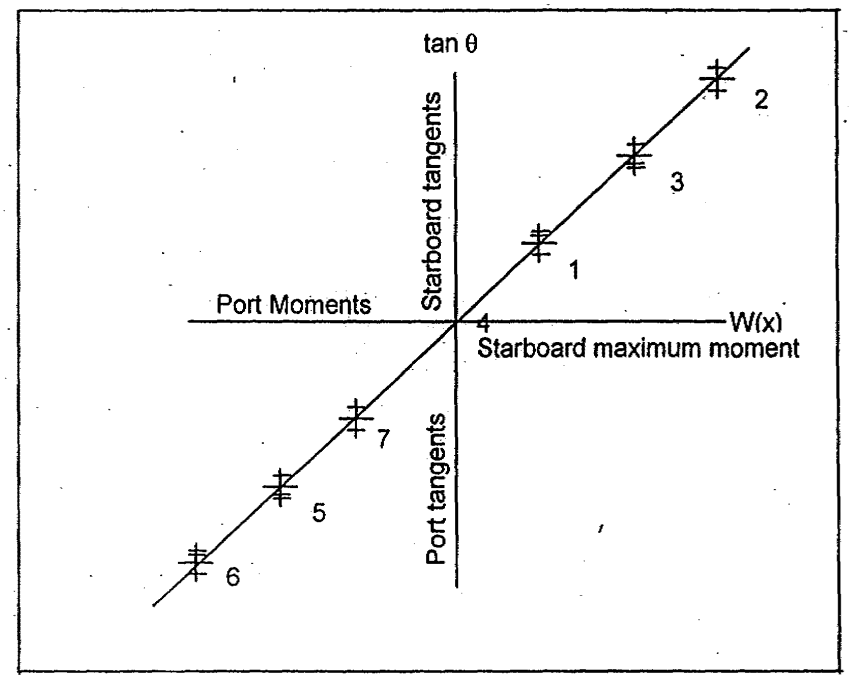


Fig. 3

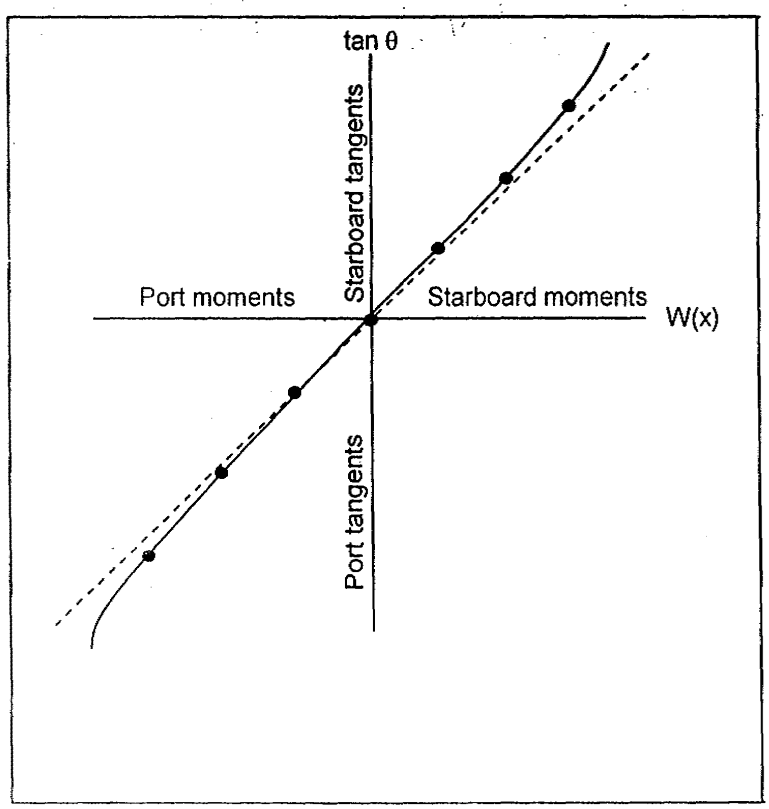


Fig. 4

Excessive free liquids (re-check all tanks and voids and pump out as necessary: Re-do all weight movements and re-check freeboard and draught readings)

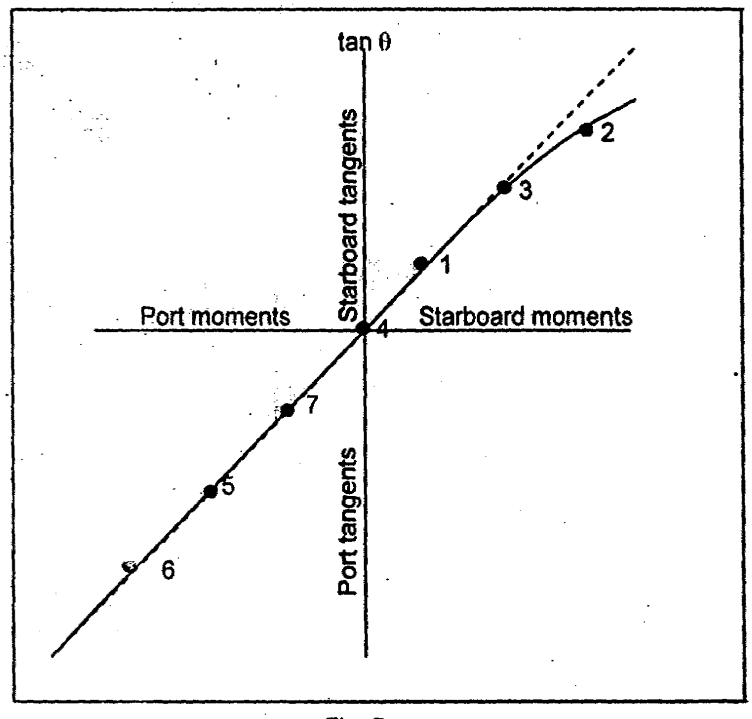


Fig. 5

Ship touching bottom or restrained by mooring lines
(Take water soundings and check lines: re-do weight movements 2 and 3)

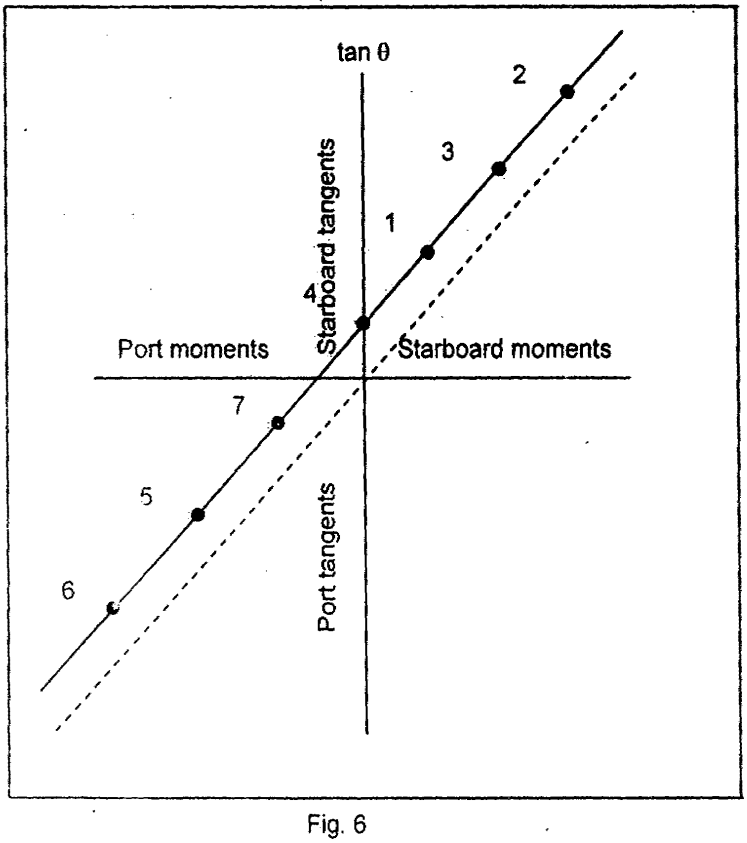


Fig. 6

Steady wind from port side came up after initial zero point taken

(plot acceptable)

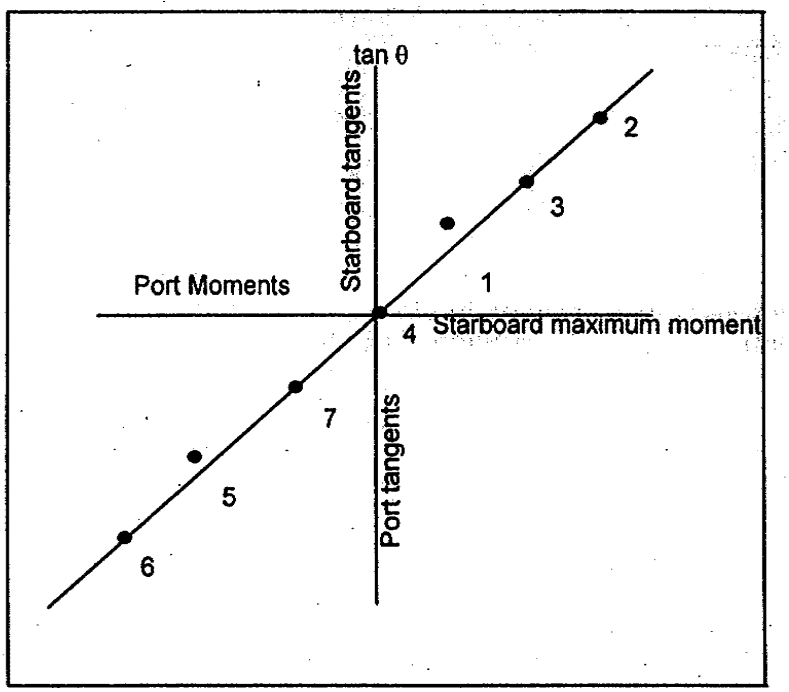


Fig. 7
Gusty wind from port side
(Re-do weight movements 1 and 5)

Q. M V ALPHASHIP was floating in sea water with all compartments empty except the following:

1. DB tank with 200 t of HFO (KG 1.1 m, FSM 700 t.m)
2. No. 3 DBT port and starboard full of ballast
3. Drinking water tank port and starboard with 20 t each at KG 10.5 m each and a total FSM of 130 t/m.

An inclining experiment was carried out. A weight of 18 tonnes Kg. 12.2 m, shifted transversely through a distance of 13 m, caused a deflection of 8.5 cms in a plum line 9.2 in length. Calculate the GM (solid) and the KG of the light ship.

Sol^{n}: -

Light displacement of M V ALPHASHIP	= 7211.6 t
HFO in No. 1	= 200 t
Water ballast in No. 3 DB (P&S)	= 683.47 t
FW in drinking water tanks	= 40 t
Inclining weight	= 18.0 t
Δ at the time of inclining experiment	= 8153.07 t
KM for displacement of 6024.72 t	= 15.158 m

$$\text{GM (fluid)} = \frac{w \times d}{\Delta \times \tan\theta} = \frac{w \times d}{\Delta \times \frac{\text{deflection}}{\text{length}}} = \frac{18 \times 13}{8153.07 \times \frac{0.085}{9.2}} = 3.106 \text{ m}$$

KG (fluid) at the time of experiment =15.158 – 3.106 = 12.052 m

Total FSM = 700 + 130 = 830 t.m. $FSC = \frac{830}{8153.07} = 0.102$ m

KG (solid) at the time of experiment = 12.052 – 0.102 = 11.95 m

To find KG of light ship we proceed as follows:

Total displacement	8153.07	11.95	97429.2
No. 1 DB tank (-)	200	1.1	(-) 220.0
No. 3 DB tanks (-)	683.47	0.70	(-) 478.4
Dr. wtr. Tanks (-)	40	10.5	(-) 420
Inclining Wt (-)	18.0	12.2	(-) 219.6
Light Wt.	7211.6	13.324	96091.2

KM for light displacement = 16.263 m
Light GM (solid) = 16.263 – 13.324 = 2.939 m

Rolling period tests: -
Determination of ship's stability by means of the rolling period tests (for ships up to 70m)

Rolling Period Test may be useful in getting approximate initial GM where it is not practicable to give approved loading conditions or other detailed stability Information.

$GM_0 = \left(\frac{f.B}{T_r}\right)^2$ where f is the rolling coefficient, B the moulded breadth & T_r is true rolling period.

Rolling coefficient 'f' is dependent on distribution of mass & is found from experiments. In coasters (excluding tankers), the 'f' is found to be varying from 0.88 to 0.73 when carrying different ballast quantities. 'f' therefore will be different in loaded condition. It will depend on distribution of masses from rolling axis.
Following precautions must be taken when carrying out rolling period tests for determining 'f':

1. 'f' must be found from tests in restricted areas. Water disturbance due to wind action & tide must be minimum.
2. The liquid in tanks should be at normal working levels.
3. Depth or under keel clearance should be enough so that the rolling is not restricted.
4. Mooring line should be slack & vessel should roll as freely as practicable.
5. There must be no loose weights, slack water should be minimum.
6. Rhythmetic lifting & lowering of weights by port & starboard derricks can initiate the roll but at the time of measuring the period everything must be standstill.
7. T, the time period is interval between two similar roll phases. For timing a roll take a set of 5 rolls. A stop watch is used for this purpose.
8. 'f' may be different in open sea than the one found in sheltered waters. A suitable correction therefore may be needed. Administration must re-examine the value of 'f' in light of different circumstances.

Following precautions must be taken by a user in noting down rolling period in order to find the GM:

a. Discard odd or vague reading.
b. Avoid forced oscillation.
c. Ensure that the sea action is least.
d. Take average from the set of observations.

Precautions when using the relationship: -

1. For GM of 20cm & below, results are less reliable.

2. The formula is more suitable for dry cargo ships. In case of liquid carrier or with excessive unaccounted free surface the results may not be correct.

GM_0 from monogram: Nomogram that is provided consists of 2 scales with a line placed in between the two scales in order to provide the desired result without having to use the calculator. The values of breadth & rolling coefficient are joined by a straight line. This line joins the intermediate line at a point say M. Now draw a line joining rolling period & M. This line extended till the left side scale will give the GM_0 of the vessel.

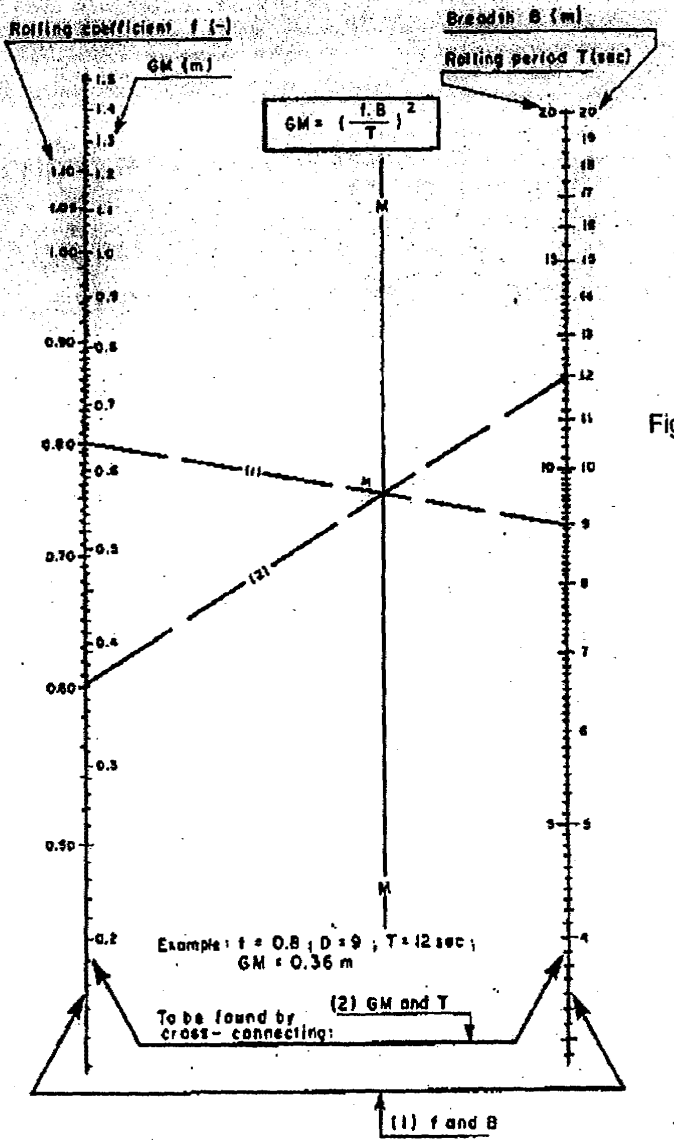


Fig. 8

MS Estonia: MS Estonia, previously MS Viking Sally (1980-1990 was a cruise ferry built in 1980 at the German shipyard Meyer Werft in Papenburg. The ship's sinking in the Baltic Sea on September 28, 1994, claimed 852 lives and was one of the deadliest maritime disasters of the late 20th century. Estonia is one of the several Ro-Ro ferries which displayed poor stability subsequent to the hull breach.



Chapter 24 Damaged stability criteria of different ships

Deterministic Damage Stability Adopted By SOLAS & Probabilistic Damage Stability for Passenger Ships:-

In 1948, the British government invited all the States that had signed the SOLAS Convention to attend an international conference, in order to revise the provisions on safety of life at sea. A new version was adopted in June by twenty-seven states that came into effect on 19 November 1952. The damage stability requirements were first introduced internationally in the third SOLAS conference held in 1948 and were deterministic.

In 1960 SOLAS conference, many countries suggested substantial changes to the damage stability rules. But due to lack of time, an agreement on major changes was not possible. Continued study of passenger ship subdivision was recommended. As a result of above recommendation.

IMCO established a subcommittee on subdivision & safety in April, 1961, which was later renamed sub-committee on stability, load lines and fishing vessels safety (SLF). The work of SLF committee resulted in the probabilistic damage stability rules for passenger ships. These rules were given in resolution a.265 (viii) and were said to be the equivalent rule to deterministic rules mentioned above.

The Res 265(VIII) contains "regulations on subdivision and stability of passenger ships as an equivalent to part 'B' of chapter II of international convention for the safety of life at sea,1960' PART B of 1960, SOLAS is subdivision and stability (applicable to passenger ships only, except reg 19 regarding stability information, which also applies to cargo ships.)

1966, 1st Introduction Of Subdivision & Damage Stability Requirements For Cargo Ships:- Subdivision & Damage Stability requirements for cargo ships were introduced for the first time in 1966 by the International Conference on Load Lines. IMO by resolution MSC.19(58) introduced

a probabilistic damage stability rule for cargo ships (different from probabilistic rules of A265(VIII), which is now included in SOLAS convention as part B-1 of chapter ii-i.
Subdivision & Damage Stability rules are also included in the following instruments. Ships shown to comply with the following regulations may be exempted from the application of part B-1:

1. Annex 1 to MARPOL 73/78, for tankers
2. International Bulk Chemical Code, A212(VII)
3. International Gas Carrier Code, A328(IX)
4. Guidelines for the design and construction of offshore supply vessels (resolution A 469(XII)),.
5. Code of Safety for Special Purpose Ships (resolution A.534(13), as amended);
6. Damage stability requirements of regulation 27 of the 1966 Load Line Convention is applied in compliance with resolutions A.320(IX) and A.514(13), provided that in the case of ships to which regulation 27(9) applies, main transverse watertight bulkheads, to be considered effective, are spaced according to paragraph (12)(f) of resolution A.320(IX).
7. Safety for Nuclear Merchant Ships, A491 (XII)
8. Safety for Dynamically Supported Craft, A373(X)
9. Code of construction of MODU,A414.
10. Torremolinos Convention for fishing vessels.

Some damage stability rules are deterministic and others are on the basis of probability theory. IMO has been trying to establish probabilistic rules for all kinds of ships abandoning the deterministic rules.

SOLAS Ch. II-1 Part B provides deterministic requirements for subdivision of passenger ships, Res. A.265(VIII) is probabilistic alternative for passenger ships.
SOLAS reg.II-1/8-1 covers probabilistic subdivision and damage stability of ro-ro passenger ships.
SOLAS Ch.II-1 Part B-1 provides for probabilistic subdivision & damage stability for dry cargo ships of L>80m unless covered by deterministic criteria.
MARPOL Annex I specifies oil tanker subdivision & damage stability requirements incl. double-hulls.
International Bulk Chemical (IBC) Code gives requirements for chemical carriers.
It must be noted that where a chemical carrier can carry petroleum grades in addition to noxious liquid substances in bulk, MARPOL Annex I also applies.
International Gas Carrier (IGC) Code gives damage stability requirements for liquefied gas carriers.

SOLAS:
Deterministic rules found place in SOLAS right in the beginning covering the passenger vessels and are still there in chapter II-I Part B of the Convention. At present these rules are only for passenger vessels, although passenger vessels can also comply with probabilistic rules as given in IMO resolution A 265(VIII) as discussed before. Following are relevant terms.

- Floodable Length. The floodable length at any point in the length of the ship (as previously defined) is the maximum portion of the length, having its center at the point in question, that can be symmetrically flooded at the prescribed permeability, without immersing the margin line.

- Criterion of Service. The criterion of service is a numeral intended to express the degree to which a vessel is a passenger vessel. In principle, a numeral of 23 corresponds to a vessel engaged primarily in carrying cargo, with accommodations for a small number of passengers, while a numeral of 123 is intended to apply to a vessel engaged solely, or very nearly so, in the carriage of passengers.
- Factor of Subdivision. The factor of subdivision is a factor prescribed by the applicable regulations and by international convention that depends on ship length and criterion of service.
- Permissible Length. The permissible length at any point is obtained by multiplying the floodable length at that point by the factor of subdivision.
- Curve of Floodable Length. This is a curve which, at every point in its length, has an ordinate representing the length of the ship which may be flooded with the centre of the length at that point, without the margin line being submerged. There are several methods of determining the position and length of a space which when flooded will cause sinkage to a waterline touching the margin line, including the system prescribed by the International Convention for the Safety of Life at Sea. The principles involved can be demonstrated by what is called a direct method in which only the basic hydrostatic data of the ship is required.

Stability of passenger ships in damaged condition: -

Regulation 8 of part B of Chapter II-I of SOLAS is a very important regulation & deals with Stability of passenger ships in damaged condition. RORO passenger ships in damaged condition also shall comply with this regulation except that RORO passenger ships built before July 97, may have some relaxation as on today but sooner or later during the dry docking subsequent to the stipulated relevant dates they must comply with 'passenger ship – damaged stability requirements'.

General Requirements: -

- Sufficient intact stability shall be provided in all service conditions so as to enable the ship to withstand the final stage of flooding of any one main compartment, which is required to be within the floodable length.
- Where two adjacent main compartments are separated by a bulkhead, which is stepped, the intact stability shall be adequate to withstand the flooding of those two adjacent main compartments.
- Where the required factor of subdivision is 0.5 or less but more than 0.33 intact stability shall be adequate to withstand the flooding of any two adjacent main compartments.
- Where the required factor of subdivision is 0.33 or less the intact stability shall be adequate to withstand the flooding of any three adjacent main compartments.

Note

- The above requirements shall be determined by calculations, which are in accordance with the assumed values of permeabilities & assumed values of the extent of damage given in the tables below.
- The GM must be calculated by the constant displacement method.
- The margin line should not be submerged in the final stages of flooding.
- In making these calculations the ship is to be assumed in the worst anticipated service condition as regards stability.

Assumed values of volume and surface permeabilities shall be in general as follows:

Spaces	Permeability
Appropriated to cargo, coal or stores	60
Occupied by accommodation	95
Occupied by machinery	85
Intended for liquids	0 or 95*

Higher surface permeabilities are to be assumed in respect of spaces, which, in the vicinity of the damage waterplane, contain no substantial quantity of accommodation or machinery, and spaces, which are not generally occupied, by any substantial quantity of cargo or stores.

Assumed values of the extent of damage:-

- Longitudinal extent: 3 m plus 3% of the length of the ship, or 11 m, whichever is less. Where the required factor of subdivision is 0.33 or less the assumed longitudinal extent of damage shall be increased as necessary so as to include any two consecutive main transverse watertight bulkheads;
- Transverse extent (measured inboard from the ship's side, at right angles to the centreline at the level of the deepest subdivision load line): a distance of one fifth of the breadth of the ship, as defined in regulation 2; and
- Vertical extent: from the base line upwards without limit;
- If any damage of lesser extent than that indicated above would result in a more severe condition regarding heel or loss of metacentric height, such damage shall be assumed in the calculations.

The stability required in the final condition after damage, and after equalization where provided, shall be determined as follows:

The positive residual righting lever curve shall have a minimum range of 15° beyond the angle of equilibrium. This range may be reduced to a minimum of 10°, in the case where the minimum required area under the righting lever curve i.e. 0.015 m^c is increased in the similar ratio:

$$\text{Thus } \frac{\text{New aea under curve}}{\text{minimum requred area}} = \frac{15°}{\text{range of curve (10°to15°)}}$$

The area under the righting lever curve shall be at least 0.015 metrer.radians, measured from the angle of equilibrium to the lesser of:

- The angle at which progressive flooding occurs,
- 22° (measured from the upright) in the case of one-compartment flooding, or
- 27° (measured from the upright) in the case of the simultaneous flooding of two or more adjacent compartments.

A residual righting lever is to be obtained within the range of positive stability, taking into account the greatest of the following heeling moments:

- The crowding of all passengers towards one side;

- The launching of all fully loaded davit-launched survival craft on one side;
- Due to wind pressure as calculated by the formula:

$$GZ \text{ (in metres)} = \frac{\text{heelingmoment}}{\text{displacement}} + 0.04$$

However, in no case is this righting lever to be less than 0.1 m.

For the purpose of calculating the heeling moments the following assumptions shall be made:

- Moments due to crowding of passengers:
- Four persons per square metre;
- A mass of 75 kg for each passenger;
- Passengers shall be distributed on available deck areas towards one side of the ship on the decks where muster stations are located and in such a way that they produce the most adverse heeling moment.

Moments due to launching of all fully-loaded davit-launched survival craft on one side:

- All lifeboats and rescue boats fitted on the side to which the ship has heeled after having sustained damage shall be assumed to be swung out fully loaded and ready for lowering;
- For lifeboats which are arranged to be launched fully loaded from the stowed position, the maximum heeling moment during launching shall be taken;
- A fully loaded davit-launched liferaft attached to each davit on the side to which the ship has heeled after having sustained damage shall be assumed to be swung out ready for lowering;
- Persons not in the life-saving appliances which are swung out shall not provide either additional heeling or righting moment;
- Life-saving appliances on the side of the ship opposite to the side to which the ship has heeled shall be assumed to be in a stowed position.

Moments due to wind pressure:-

- A wind pressure of 120 N/m^2 is to be applied;
- The area applicable shall be the projected lateral area of the ship above the waterline corresponding to the intact condition;
- The moment arm shall be the vertical distance from a point at one half of the mean draught corresponding to the intact condition to the centre of gravity of the lateral area.

GZ Requirement in the Intermediate Stage:-
In intermediate stages of flooding, the maximum righting lever shall be at least 0.05m and the range of positive righting levers shall be at least 7°. In all cases, only one breach in the hull and only one free surface need be assumed.

Unsymmetrical flooding & Equalization Arrangements:-
Unsymmetrical flooding is to be kept to a minimum consistent with efficient arrangements. Where it is necessary to correct large angles of heel, the means adopted shall, where practicable, be self-acting, but in any case where controls to cross- flooding fittings are provided they shall be operable from above the bulkhead deck. These fittings together with their controls shall be acceptable to the Administration. The maximum angle of heel after flooding but before equalization shall not exceed 15°. Where cross-flooding fittings are required the time for

equalization shall not exceed 15 min. Suitable information concerning the use of cross-flooding fittings shall be supplied to the master of the ship.

Damage Stability Criteria:-

Damaged stability in the final conditions of the ship after damage and, in the case of unsymmetrical flooding, after equalization measures have been taken shall be as follows:

1. In the case of symmetrical flooding there shall be a positive residual metacentric height of at least 50 mm as calculated by the constant displacement method;
2. In the case of unsymmetrical flooding, the angle of heel for one-compartment flooding shall not exceed 7°. For the simultaneous flooding of two or more adjacent compartments, a heel of 12° may be permitted by the Administration;
3. In no case shall the margin line be submerged in the final stage of flooding. If it is considered that the margin line may become submerged during an intermediate stage of flooding, the Administration may require such investigations and arrangements, as it considers necessary for the safety of the ship.

Annex to IMO Resolution A .265(VIII):
The degree of subdivision is determined by the required Subdivision Index R, as follows:

$$R = 1 - \frac{1000}{(4L_s + N + 1500)} m$$

W here:
$N = N_1 + 2N_2$
N_1 = number of persons for whom life-boats are provided.
N_2 = number of persons (including officers and crew) that the ship is permitted to carry in excess of N_1.

Where the conditions of service are such that compliance with paragraph above on the basis of $N = N_1 + 2 N_2$ is impracticable and where the Administration considers that a suitably reduced degree of hazard exists, a lesser value of N may be taken but in no case less than $N = N_1 + N_2$.
In the final stage of flooding:

(1) There shall be a positive metacentric height, GM, calculated by the constant displacement method and for the ship in upright condition, of atleast
$GM = 0.003(B_2^2(N_1 + N_2)/ F_1)$ or
$GM = 0.049(B_2/F_1)$ (in feet)
$GM = 0.015(B_2/F_1)$ (in metres) or
GM =0.05m whichever is the greater
Where: Δ = displacement of the ship in the undamaged condition (in long tons or metric tons respectively);

(2) the angle of heel in the case of one compartment flooding shall not exceed 7 degrees. For the simultaneous flooding of two or more adjacent compartments a heel of 12 degrees may be permitted unless the Administration considers a lesser heel necessary to ensure an adequate amount and range of residual stability;

(3) except in way of the flooded compartment or compartments no part of the relevant bulkhead deck at side shall be immersed.
(ii) Unsymmetrical flooding shall be kept to a minimum consistent with efficient arrangements. If any equalizing arrangements are necessary to ensure that the angle of heel in the final stage of

flooding does not exceed the limits specified in sub-paragraphs (i) (2) and (3) of this paragraph, these arrangements shall, where practicable, be self acting. However, if controls are necessary, they shall be operable from above the highest relevant bulkhead deck. All such arrangements shall be acceptable to the Administration.
(iii) The Administration shall be satisfied that stability prior to equalization is sufficient. However, in no case shall the maximum heel before equalization exceed 20 degrees nor shall it result in progressive flooding. Additionally, the time for equalization of cross-connected spaces to atleast the limits specified in sub-paragraphs(i) (2)and (3)of this paragraph shall not exceed ten minutes.
(iv)The Administration shall be satisfied that the residual stability is sufficient during intermediate flooding and that progressive flooding will not take place. Calculations relative thereto shall be in accordance with the provisions of sub-paragraph (b)(iii) of this Regulation, respecting the assumed extent of damage and resulting extent of flooding. Heel during intermediate flooding due either to negative metacentric height alone or in combination with unsymmetrical flooding shall not exceed 20 degrees.
Attained Subdivision Index A

(a). (i) In addition to complying with Regulation 5 the attained Subdivision Index A shall be determined for the ship by formula (II):

$A = \Sigma aps$..... (II)

Where:

"a" accounts for the probability of damage as related to the position of the compartment in the ship's length,

"p" evaluates the effect of the variation in longitudinal extent of damage on the probability that only the compartment or group of compartments under consideration may be flooded, and

"s" evaluates the effect of freeboard, stability and heel in the final flooded condition for the compartment or group of compartments under consideration.

Probability Concept for Cargo Ships (SOLAS): The probabilistic concept was introduced into SOLAS for cargo ships in 1990, applicable to cargo ships of 100 metres or more in length built on or after 1 February 1992; and in 1996 to cargo ships between 80 metres and 100 metres.
The degree of subdivision to be provided shall be determined by the required subdivision index R a follows:

$$R = \sqrt[3]{(0.002 + 0.009L_s)_s}$$ *Where L_s is meters.*

$$R = 1 - \left[\frac{1}{\left(1 + \frac{L_s}{100} \times \frac{R_0}{1 - R_0}\right)} \right]$$

R_0 is the value R as calculated in accordance with the 1st formula above.

Regulation 25-4 is regarding the Attained subdivision index A. In the first para it states that *the Subdivision index 'A' calculated in accordance with this regulation, shall not be less than the required subdivision index R.*

It is clear that damage may be assumed on either the port or starboard sides, each producing the same value of A. If port & starboard give different 'A' then the calculated A value may be

taken as that which evidently gives the less favourable result. Otherwise the mean value obtained from calculations involving both sides is to be used.
Second para gives formula for A:

Subdivision index $A = \sum p_i s_i$

P_i *Accounts for the probability that only the compartment or group of compartments under consideration may be flooded disregarding any horizontal subdivision.*

S_i *Accounts for the probability of survival after flooding the compartment or group of compartments under consideration, including the effects of any horizontal subdivision.*

In the formula $A = \Sigma p_i s_i$ it should be noted that:
p_i is independent of the draught but includes the factor r;
s_i is dependent on the draught and includes the factor v; and is a weighted average of s-factors calculated at draughts of d_i and d_p.
It is recommended that the product $p_i s_i$ should be calculated using five decimal places, while the final results, i.e. the indices A and R, should be to at least three decimal places. *In calculating A, level trim shall be used.*

What is the meaning of probabilistic approach?

If a coin is tossed the probability of any of the two sides coming is ½ or 50% or o.5. Similarly when a dice is rolled probability of any number out of the 6 faces is 1/6 or 16.67% or 0.167. In a lighter way it can be said that the possibility of breaking the law is inversely proportional to the probability of getting caught for penalty or punishment. Thus what are the chances that you will respond to a red traffic signal on a lonely road at 2 AM?

If there is a high probability of damage in bow area, say 90% or 0.9, then there must be close spacing of bulkheads & hence higher chances of survivability say 96% or 0.96. If the probabilities instead of 0.9 & 0.96 were 0.9 & 0.1 respectively there would be inadequate safety. In considering the chances of survival instead of considering laws of physics (stability & floatation) alone, the practical hurdles, weather (waves), loss of strength, type of action taken, past incidents are also considered. All this in addition to the ship already complying with the ILLC's freeboard related regulations makes a vessel safer.

The philosophy behind the probabilistic concept is that two different ships with the same index of subdivision are of equal safety and therefore there is no need for special treatment for specific parts of the ship. The forward and bottom regions are given special attention & are dealt with by special rules concerning subdivision, provided for the cases of ramming and grounding.

In order to develop the probabilistic concept of ship subdivision, it is assumed that the ship is damaged. Since the location and size of the damage is random, it is not possible to state which part of the ship becomes flooded. The probability of flooding a space is equal to the probability of occurrence of all such damages, which just open the considered space.

When a particular space is assumed flooded, in addition to some inherent characteristics of the ship there are various factors, which influence whether the ship can survive such flooding; they include the initial draught and GM, the permeability of the space and the weather conditions, all of which are random (can have varying & unpredictable value) at the time when the ship is damaged. It means none of this initial data can be considered as fixed for a given ship.

Therefore it is necessary to take data from past accidents to know some set of above data which were present when accident occurred.
The probability of survival is determined by a formula as follows: The probability of a space getting flooded & probability of not capsizing if that space is flooded are multiplied. Such a product is found for all compartments & even sets of compartments taken 2, 3, 4, 5 etc at a time. The sum of all such product id found. The sum of all such products is found. The final figure is called Acquired subdivision index. (A.S.I.). Although the ideas outlined above are very simple, their practical application in an exact manner would give rise to several difficulties. For example, for an extensive but still incomplete description of the damage, it is necessary to know its longitudinal and vertical location as well as its longitudinal, vertical and transverse extent. Such a five-dimensional random variable is difficult to work on & hence simplifications are necessary. The accuracy provided may not be high but it is possible to develop a useful comparative scale to understand the benefits of the longitudinal, transverse and horizontal subdivision of the ship.

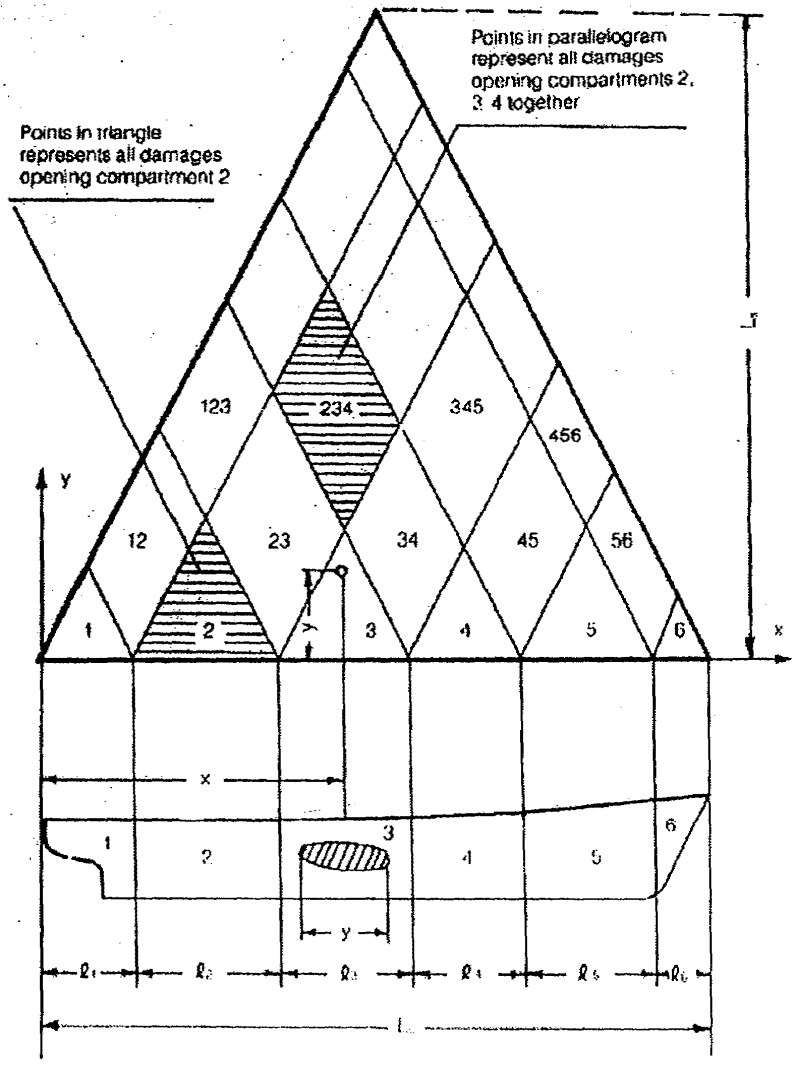


Fig 1
M Points in the parallelogram represent all damages opening compartments 2,3,4 together.
N Points in this parallelogram represent damages which open both 2 & 3.
P Points in this triangle represent all the damages which open compartment 2.
X Damage location
Y Damage length

We will consider various probability aspects, initially

A. Considering the longitudinal extent or athwart ship bulkheads & then
B. Considering horizontal subdivision & lastly
C. Considering the athwart ship penetration for longitudinal damages.

A Consideration of longitudinal damage location and extent only:

The simplest case is to consider the location and length of damage in the longitudinal direction. This would be sufficient for ships with no longitudinal and horizontal watertight structural divisions. With the damage location x and damage length y as defined in figures below, all possible damages can be represented by points in a triangle.

Neither the position of damage (damage location) 'x' is fixed, nor the longitudinal extension or damage length 'y' is fixed. The location can be any where along the ship's length. It is not dependent on type of ship & extent of damage or any other logical cause. We may say that probability of a damage occurring at a certain location is literally random & variable. Hence we say 'x' which is distance of damage from say aft perpendicular is 'Random Variable'. How big the damage is also a random variable for the same reason. At a certain location possibility of a certain type of damage may be more than certain other type of damage. If we consider a large number of past accidents then such a probability graph can be drawn. Such information can be called 'Distribution Density'.

Distribution density represented as f(x,y) can be derived from damage statistics. The meaning of f(x,y) is as follows: The total volume between the x-y plane and the surface given by f(x,y) equals one and represents the probability that there is damage (probability of one means that the damage is certain). The volume above a triangle corresponding to damage which opens a compartment represents the probability that this compartment is opened. The probability that a compartment or a group of adjacent compartments is opened is expressed by the factor p_i as calculated according to regulation 25-5.

Consideration of damage location x and damage length y only would be fully correct in the case of ships with pure transverse subdivision. However, there are very few, if any, such ships – all normally have a double bottom, at least.

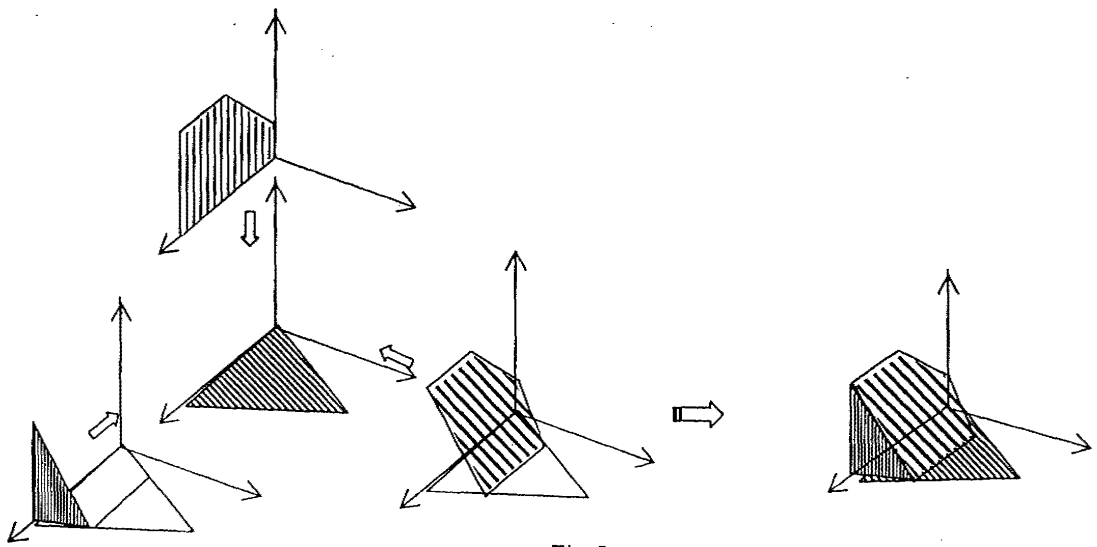


Fig 2

The diagram is broken in 4 parts to give idea of its 3 dimensional shape. The 4 parts are then joined together showing the shape & outer surface of the shape.

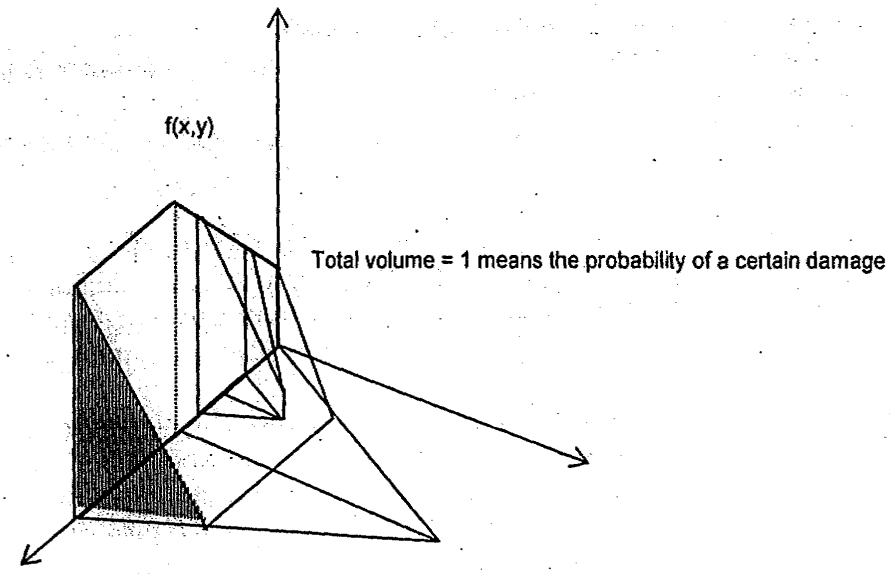
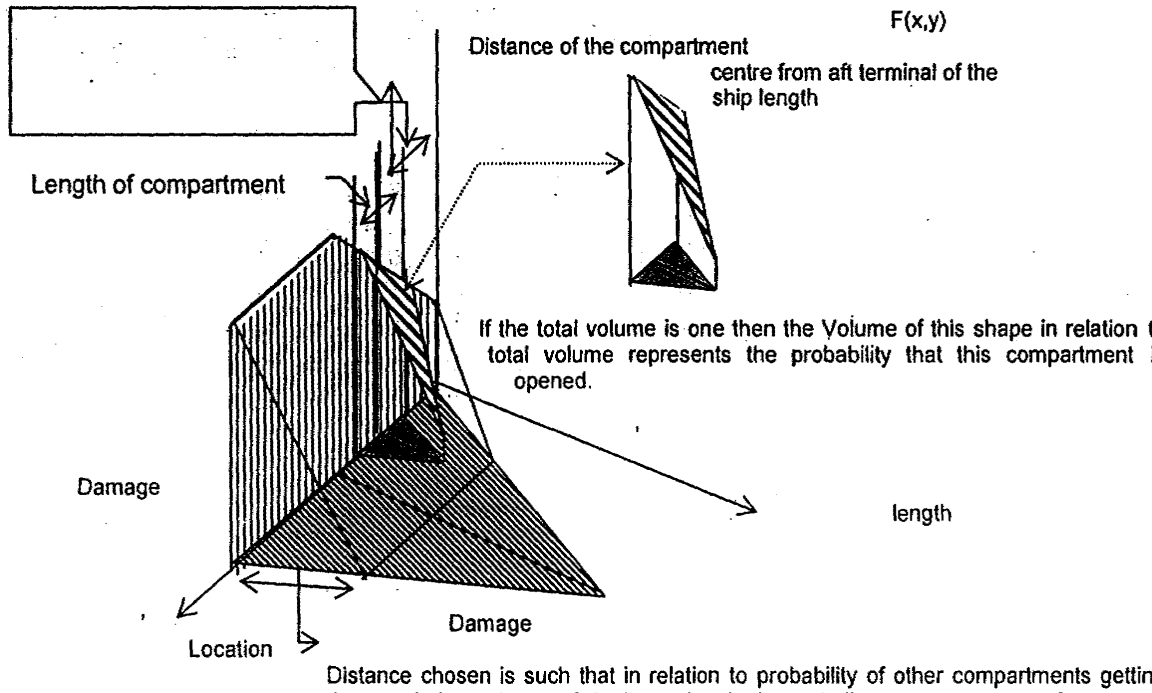


Fig 3



Distance chosen is such that in relation to probability of other compartments getting damaged the volume of 3 dimensional shape indicates occurrence of a certain damage.

Fig 4



Fig 5

In such a case, the probability of flooding a compartment should be considered into the following three ways:

a. Probability of flooding the double bottom only,

b. Probability of flooding the space above the double bottom only and
c. Probability of flooding both the space above and the double bottom itself. For each of these cases there may be a different probability that the ship will survive in the flooded condition.

A way out of this dilemma, which may be used in applying these new regulations, is as follows: Assume that the most unfavourable vertical extent of a damage (out of the three possibilities) or select the situation in which the probability of survival is least. Thus the favourable effect of placing horizontal subdivision is neglected. This does not cause any significant error. The importance of length of compartment & the longitudinal location is still maintained.

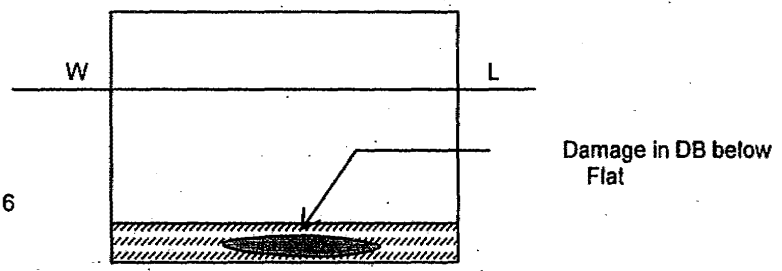


Fig 6

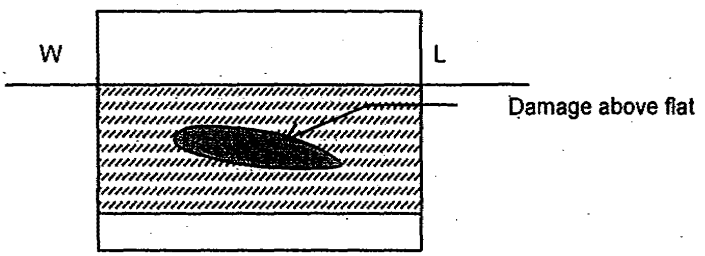


Fig 7

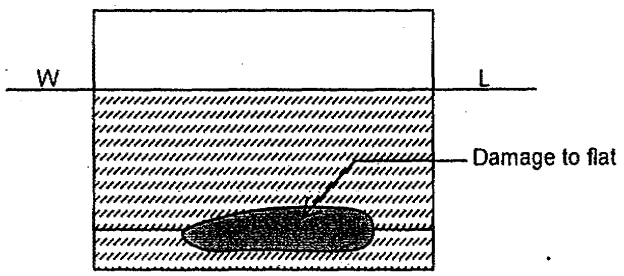


Fig 8

B. Considering horizontal subdivision:

Let us consider that a watertight subdivision exists in one of the compartment under consideration. We will discuss regarding the chances of the water tight subdivision getting damaged. We will also discuss as to, what is the effect of vertical positioning of this division on the probability or the chance of damage.

Case 1, w/t subdivision at waterlevel:-

For an under water damage, we shall suppose that this subdivision will surely get damaged. Or the probability of the subdivision not getting damaged (V_i) is zero. This means that the subdivision will not be able to limit the damage below it & the vertical extent of damage will be unlimited.

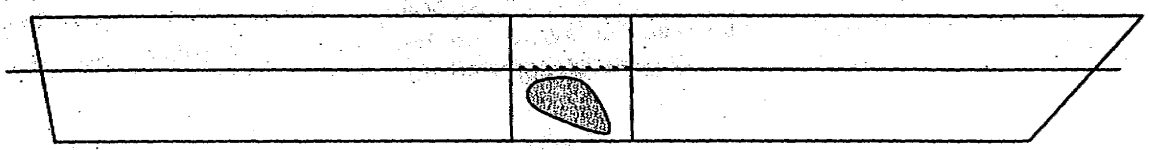


Fig 9

Case 2, w/t subdivision at the level of maximum bow height (according to the 1966 Load Line Convention):-

For a damage that is mainly under water there is no chance of this w/t division getting damaged. In the language of probability, we say $V_i = 1$. Or probability of w/t division not getting damaged is 100%.

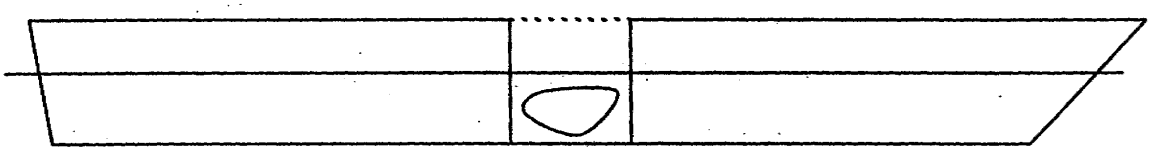


Fig 10

Case 3, w/t subdivision at some intermediate level:-

Let the draft be 10m, the w/t division be at 12m & the maximum bow height be at 15m. The probability of the flat not getting damaged, V_i is given by the following formula:

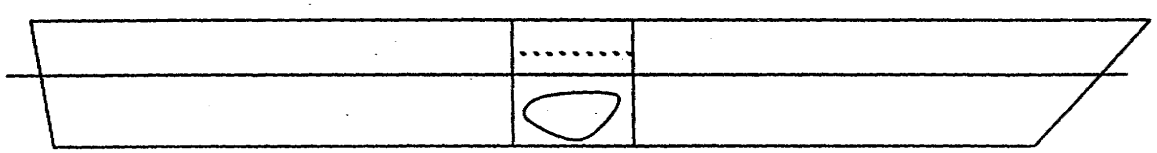


Fig 11

$$V_i = \frac{\text{Draft of subdivision - ships draft}}{\text{Draft of Maximum bow height - ships draft}}$$

$$\therefore V_i = \frac{12-10}{15-10} = 0{,}4 \text{ or } 40\ \%$$

This factor V_i represents the assumed distribution function of the vertical extent of damage and varies from zero for subdivision at the level of the waterplane, linearly upwards to the value of one at the level conforming to the minimum bow height.

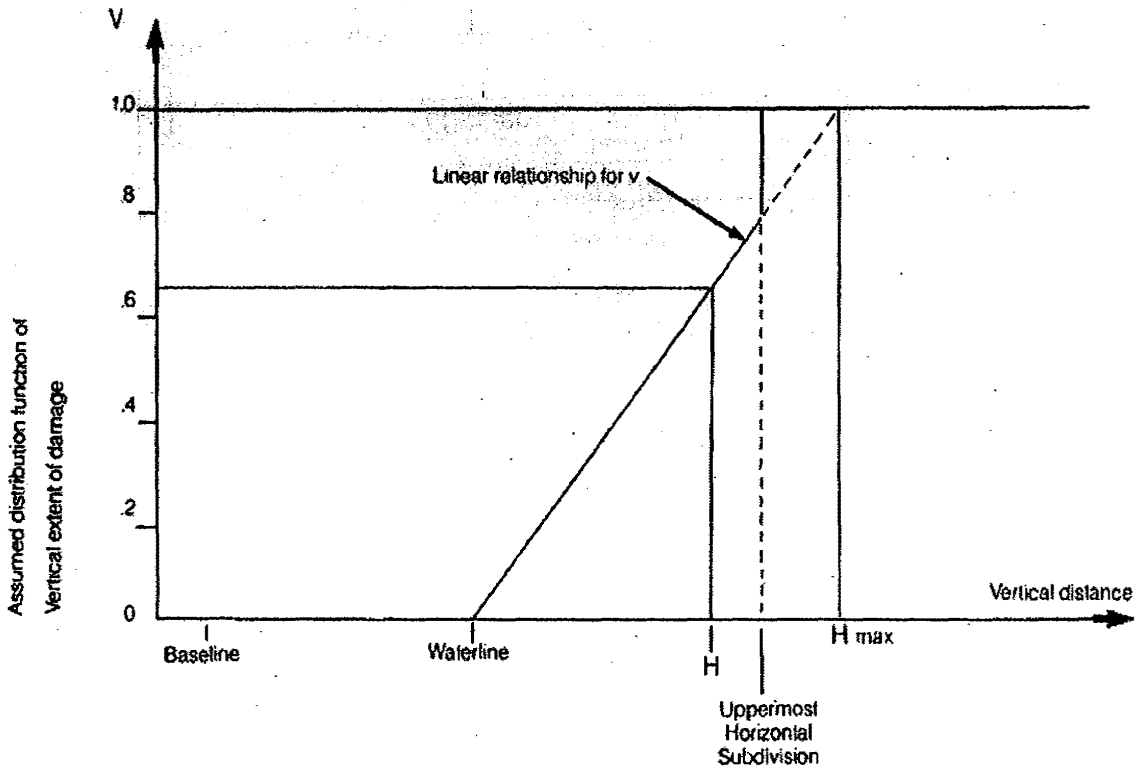


Fig 12

To use the curve proceed as follows:
On x-axis start at a point indicating the position of flat or subdivision and move upwards till the slant line is met. Then move to left till the y-axis is met giving probability V. V is probability of horizontal subdivision not getting damaged or assumed distribution function of vertical extent of damage.

C *Consideration of damage penetration in addition to longitudinal damage location and extent:-*

Let us assume that the damaged compartment & hence the damage is rectangular. Let the vertical extent of damage be according to B, the damage can be described by

i) the damage location x (the distance from reference position say aft perpendicular),
ii) the damage length y (the longitudinal extension) and
iii) the damage penetration z (which is the distance between the shipside & the fore & aft longitudinal bulkhead which would restrict the damage)

These variables can be represented in a three-dimensional co-ordinate system. We see a prism whose base is equal to L_s . The damage can occur any where along the length of ship & can thus be located anywhere on the base line.

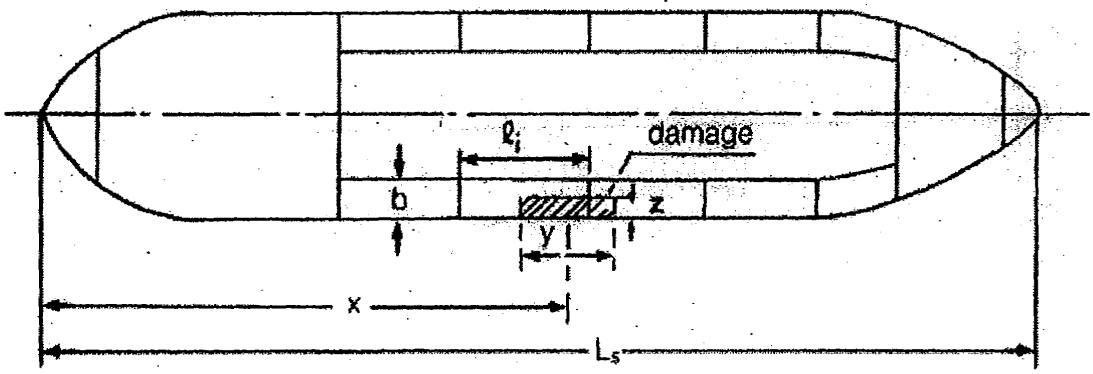


Fig 13

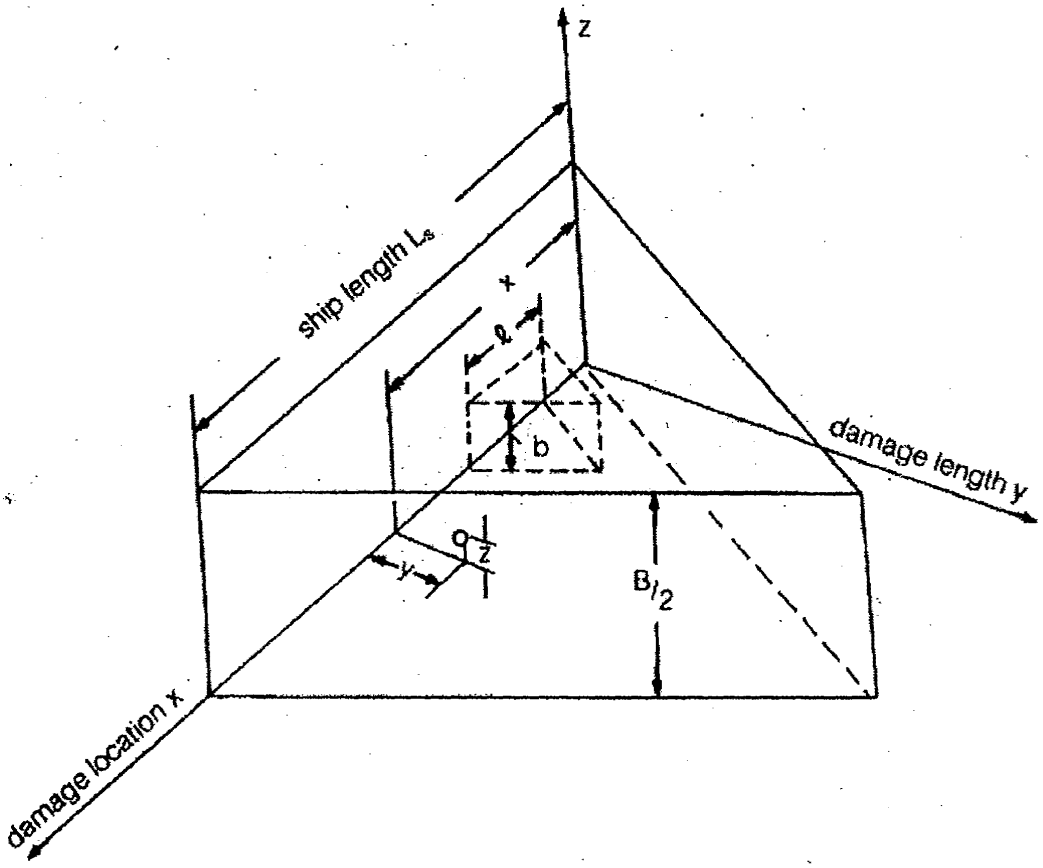


Fig 14

The length of prism is also L_s, which means that even if the damage is as long as the ship's length itself, it can still be represented by the prism. The thickness of the prism is ½B which is the maximum penetration possible from each side. Thus each point in the prism represents damage.

All damages, which open a side compartment, correspond to the points of a smaller prism. In the fig such a small prism is shown.

i) b is equal to height or thickness of smaller prism & is also the distance of the longitudinal bulkhead from the ship's side,

ii) l_i is equal to the length of the side compartment under consideration. It represents the length of the damaged compartment.

Damage location x, damage length y and damage penetration z are random variables. The distribution density f(x,y,z) can be derived from damage statistics. This distribution density can be illustrated by assuming it to be a density, which varies from point to point of the volume shown.The "weight " of the total volume (total volume of bigger prism) is one and represents the probability that there is a (certain) damage. The "weight" of a partial volume or the volume of smaller prism (representing the flooding of certain spaces) represents the probability that the space / spaces under consideration is / are opened.

The probability that a side compartment is opened can be expressed as p_i r, where p_i is to be calculated according to regulation 25-5.1 and r according to regulation 25-5.2. The probability that a centre compartment (extending at least to the ship's centreline) is opened, in addition to the adjacent side compartment, can be expressed as p_i (1-r).

Meaning of p_i & r:
p_i is the probability that only the compartment or group of compartment under consideration may be flooded.
Whenever the compartment is divided in wing & centre compartments then the p_i value for a wing compartment is found by multiplying the value by a reduction factor r. Thus p_ir means that only the wing compartment will be damaged & not the centre. The probability that a centre compartment is opened, in addition to the adjacent side compartment, can be expressed as p_i (1-r).
Again, it must be stated that the probability calculated on the basis of the simplifying assumptions mentioned above is not exact. Nevertheless, it gives a comparative measure of how the probab of opening spaces depends on transverse and longitudinal structural subdivisions.

International Loadlines Convention 66
Extracts from the Regulation 27 are..
A type "A" ship is one which:
(a) is designed to carry only liquid cargoes in bulk;
(b) has a high integrity of the exposed deck with only small access openings to cargo compartments, closed by watertight gasketed covers of steel or equivalent material; and
(c) has low permeability of loaded cargo compartments.
A type "A" ship if over 150 m in length to which a freeboard less than type "B" has been assigned, when loaded in accordance with the requirements of the next paragraph below, shall be able to withstand the flooding of any compartment or compartments, with an assumed permeability of 0.95, consequent upon the damage assumptions and shall remain afloat in a satisfactory condition of equilibrium as specified below. In such a ship the machinery space shall be treated as a floodable compartment, but with a permeability of 0.85. A type "A" ship shall be assigned a freeboard not less than that based on table A. All ships which do not come within the provisions regarding type "A" ships in paragraphs (2) and (3) shall be considered as type "B" ships.

The initial condition of loading before flooding shall be determined as follows:
(a) The ship is loaded to its summer load waterline on an imaginary even keel.
(b) When calculating the vertical centre of gravity, the following principles apply:
(i) Homogeneous cargo is carried.
(ii) All cargo compartments, except those referred to under (iii), but including compartments intended to be partially filled, shall be considered fully loaded except that in the case of fluid cargoes each compartment shall be treated as 98% full.

(iii) If the ship is intended to operate at its summer load waterline with empty compartments, such compartments shall be considered empty provided the height of the centre of gravity so calculated is not less than as calculated under (ii).
(iv) 50% of the individual total capacity of all tanks and spaces fitted to contain consumable liquids and stores is allowed for. It shall be assumed that for each type of liquid, at least one transverse pair or a single centreline tank has maximum free surface, and the tank or combination of tanks to be taken into account shall be those where the effect of free surfaces is the greatest; in each tank the centre of gravity of the contents shall be taken at the centre of volume of the tank. The remaining tanks shall be assumed either completely empty or completely filled, and the distribution of consumable liquids between these tanks shall be effected so as to obtain the greatest possible height above the keel for the centre of gravity.
(v) At an angle of heel of not more than 5deg. in each compartment containing liquids, as prescribed in (ii) except that in the case of compartments containing consumable fluids, as prescribed in (iv), the maximum free surface effect shall be taken into account.
Alternatively, this actual free surface effects may be used, provided the methods of calculation are acceptable to the Administration.
(vi) Weights shall be calculated on the basis of the following values for specific gravities:

salt water 1.025	fresh water 1.000
oil fuel 0.950	diesel oil 0.900
lubricating oil 0.900	

Damage assumptions
The following principles regarding the character of the assumed damage apply:
(a) The vertical extent of damage in all cases is assumed to be from the base line upwards without limit.
(b) The transverse extent of damage is equal to B/5 or 11.5 m, whichever is the lesser, measured inboard from the side of the ship perpendicularly to the centreline at the level of the summer load waterline.
(c) If damage of a lesser extent than specified in subparagraphs (a) and (b) results in a more severe condition, such lesser extent shall be assumed.
(d) Except where otherwise required by paragraph (10)(a), the flooding shall be confined to a single compartment between adjacent transverse bulkheads provided the inner longitudinal boundary of the compartment is not in a position within the transverse extent of assumed damage. Transverse boundary bulkheads of wing tanks which do not extend over the full breadth of the ship shall be assumed not to be damaged, provided they extend beyond the transverse extent of assumed damage prescribed in subparagraph (b).
If in a transverse bulkhead there are steps or recesses of not more than 3 m in length located within the transverse extent of assumed damage as defined in subparagraph (b), such transverse bulkhead may be considered intact and the adjacent compartment may be floodable singly. If, however, within the transverse extent of assumed damage there is a step or recess of more than 3 m in length in a transverse bulkhead, the two compartments adjacent to this bulkhead shall be considered as flooded. The step formed by the afterpeak bulkhead and the afterpeak tank top shall not be regarded as a step for the purpose of this regulation.
(e) Where a main transverse bulkhead is located within the transverse extent of assumed damage and is stepped in way of a double bottom or side tank by more than 3 m, the double bottom or side tanks adjacent to the stepped portion of the main transverse bulkhead shall be considered as flooded simultaneously. If this side tank has openings, into one or several holds, such as grain feeding holes, such hold or holds shall be considered as flooded simultaneously. Similarly in a ship designed for the carriage of fluid cargoes, if a side tank has openings into adjacent compartments, such adjacent compartments shall be considered as empty and as being flooded simultaneously. This provision is applicable even where such

openings are fitted with closing appliances, except in the case of sluice valves fitted in bulkheads between tanks and where the valves are controlled from the deck. Manhole covers with closely-spaced bolts are considered equivalent to the unpierced bulkhead except in the case of openings in topside tanks making the topside tanks common to the holds.

(f) Where the flooding of any two adjacent fore and aft compartments is envisaged, main transverse watertight bulkheads shall be spaced at least $1/3\ L^{2/3}$ or 14.5 m, whichever is the lesser, in order to be considered effective. Where transverse bulkheads are spaced at a lesser distance, one or more of these bulkheads shall be assumed as non-existent in order to achieve the minimum spacing between bulkheads.

Conditions of equilibrium

The condition of equilibrium after flooding shall be regarded as satisfactory provided:

(a) The final waterline after flooding, taking into account sinkage, heel and trim, is below the lower edge of any opening through which progressive downflooding may take place. Such openings shall include air pipes, ventilators and openings which are closed by means of weathertight doors (even if they comply with regulation 12) or hatch covers (even if they comply with regulation 16 or regulation 19(4)), and may exclude those openings closed by means of manhole covers and flush scuttles (which comply with regulation 18), cargo hatch covers of the type described in regulation 27(2), remotely operated sliding watertight doors, and sidescuttles of the non-opening type (which comply with regulation 23). However, in the case of doors separating a main machinery space from a steering gear compartment, watertight doors may be of a hinged, quick-acting type kept closed at sea, whilst not in use, provided also that the lower sill of such doors is above the summer load waterline.

(b) If pipes, ducts or tunnels are situated within the assumed extent of damage penetration as defined in paragraph (12)(b), arrangements shall be made so that progressive flooding cannot thereby extend to compartments other than those assumed to be floodable in the calculation for each case of damage.

(c) The angle of heel due to unsymmetrical flooding does not exceed 15deg.. If no part of the deck is immersed, an angle of heel of up to 17deg. may be accepted.

(d) The metacentric height in the flooded condition is positive.

(e) When any part of the deck outside the compartment assumed flooded in a particular case of damage is immersed, or in any case where the margin of stability in the flooded condition may be considered doubtful, the residual stability is to be investigated. It may be regarded as sufficient if the righting lever curve has a minimum range of 20deg. beyond the position of equilibrium with a maximum righting lever of at least 0.1 m within this range. The area under the righting lever curve within this range shall be not less than 0.0175 m. rad. The Administration shall give consideration to the potential hazard presented by protected or unprotected openings which may become temporarily immersed within the range of residual stability.

(f) The Administration is satisfied that the stability is sufficient during intermediate stages of flooding.

The following tables provide a comparison of deterministic type of damage stability requirements for cargo ships in various IMO conventions and codes at one glance.

Table A-1

IMO Instrument	*Type of ship*	*Length / Freeboard*	*Ship must withstand flooding of which compartment?*
LLC		**L <Table B tabular freeboard if > 100 m (or 150 m where Table A applies)**	**Should, be capable of withstanding the flooding of one or more of their main watertight compartments when loaded to the summer load waterline, depending on the date of build.**
	Type A ships built before 8 June 2000	Ships > 150 m but not exceeding 225 m.	Must be capable of withstanding the flooding of anyone compartment, other than the mach space, designed to be empty in the summer load condition. ('p' of the empty compartment is 95%.
		Ships > 225 m	Must be capable of withstanding the flooding of any one compartment, designed to be empty, in the summer load condition or the mach space. The 'p' of the mach space and other compartments: 85% & 95% resp.
	Type A ships built on or after 8 June 2000	Ships > 150 m	Must be capable of withstanding the flooding of anyone compartment with an assumed 'p' of 0.95. In such a ship the mach space shall be treated as a floodable compartment but with a permeability of 0.85.
	Type B ships built before 8 June 2000	*Tabular freeboard <B but not < B-60* (Ships > 100 m but not > 225 m)	Must be capable of withstanding the flooding of any one compartment, other than the mach space when loaded to the summer load waterline. 'p' 95%.
		Ships > 225 m	Must be capable of withstanding the flooding of any one compartment (including the mach space) when loaded to the summer load waterline. The 'p' of the mach space, and other compartments 85% & 95% resp.
		Tabular Freeboard < B-60 but not < B-100 Ships > 100 m but not > 225 m	Must be capable of withstanding the flooding of any two adjacent fore and aft compartments, neither of which is the machinery space, when loaded to the summer load waterline. 'p' 95%.
		Ships > 225 m	Must be capable of withstanding the flooding of the machinery space alone or any two other adjacent fore and aft compartments. 'p' 85% & 95% resp.
	Type B ships built on or after 8 June 2000	*Tabular freeboard <B but not < B-60* (Ships > 100 m but not > 150 m)	Must be capable of withstanding the flooding of any one compartment, other than the mach space when loaded to the summer load waterline. 'p' 95%.
		Ships > 150m	Must be capable of withstanding the flooding of any one compartment (including the mach space) when loaded to the summer load waterline. The 'p' of the mach space, and other compartments 85% & 95% resp.
		Tabular Freeboard < B-60 but not < B-100 (Ships > 100 m but not > 150 m)	Must be capable of surviving damage to anyone transverse bulkhead throughout the length of the ship such that two adjacent fore and aft compartments are flooded simultaneously, neither of which is the machinery space.
		Ships > 150m	Must be capable of withstanding the flooding of the machinery space alone or the damage specified in block above.

For more details a student must refer to the 'International Convention on Load Lines 1966.

Table A-2

IMO Instrument	Limiting Size	Location of damage	Extent of damage
MARPOL	Every oil tanker delivered after 31 December 1979, > or = 150 gross	*1. Tankers > 225 m,* Anywhere in the ship's length; *2. Tankers* > 150 m but not > 225 m Anywhere in the ship's length except involving either after or forward bulkhead bounding the mach space located aft. (The machinery space shall be treated as a single floodable compartment) *3. Tankers not > 150 m,* Anywhere in the ship's length between adjacent transverse bulkheads with the exception of the machinery space. *4.For tankers of 100 m or less* where all requirements of damage stab criteria cannot be fulfilled without materially impairing the operational qualities of the ship, Administrations may allow relaxations from these requirements.	As per table B

Table A-3

Type of Gas Carrier	*Type of Chemical Tanker*
Ships subject to these Rules shall be designed to one of the following standards. 1 A Type 1G Ship is a gas carrier intended to transport products which require maximum preventative measures to preclude the escape of such cargo. 2 A Type 2G Ship is a gas carrier intended to transport products which require significant preventative measures to preclude the escape of such cargo. 3 A Type 2PG Ship is a gas carrier of 150 m in length (Lc) or less intended to transport products which require significant preventative measures to preclude escape of such cargo, and where the products are carried in independent tanks type C designed for a MARVS of at least 7 bar gauge and a cargo containment system design temperature of – 55 °C or above. Note that a ship of this description but over 150 m in length is to be considered a Type 2G ship. 4 A Type 3G Ship is a gas carrier intended to carry products which require moderate preventative measures to preclude the escape of such cargo. Thus a Type 1G ship is a gas carrier intended for the transportation of products considered to present the greatest overall hazard and Types 2G/2PG and Type 3G for products of progressively lesser hazards. Accordingly, A Type 1G ship shall survive the most severe standard of damage and its cargo tanks should be located at the maximum prescribed distance inboard from the shell plating.	1.A Type 1 ship is a chemical tanker intended to transport products with very severe environmental and safety hazards which require maximum preventive measures to preclude an escape of such cargo. 2 A Type 2 ship is a chemical tanker intended to transport products with appreciably severe environmental and safety hazards which require significant preventive measures to preclude an escape of such cargo. 3 A Type 3 ship is a chemical tanker intended to transport products with sufficiently severe environmental and safety hazards which require a moderate degree of containment to increase survival capability in a damaged condition. Thus, a Type 1 ship is a chemical tanker intended for the transportation of products considered to present the greatest overall hazard and Type 2 and Type 3 for products of progressively lesser hazards. Accordingly, a Type 1 ship shall survive the most severe standard of damage and its cargo tanks shall be located at the maximum prescribed distance inboard from the shell plating.

Table A-4

IMO Instrument	*IBC code / IGC code*
Type 1/ type 1G	Any where along ships length irrespective of the length of the ship.
Type 2 / type 1G: L > 150 m	Anywhere along the length.
L ≤ 150m	Anywhere along the length except involving aft machinery space and bulkheads.
Type 2PG: L ≤ 150m'	Any where along the length except involving transverse bulkheads. spaced apart more than the stipulated length of the damage.
Type 3: L ≤ 225 m	Anywhere along the length.
L ≥ 125 m	Anywhere along the length except involving either of aft machinery space end bulkheads.
L < 125 m;	Except aft machinery space flooding which may be considered by the administration.
Type 3G: L ≥ 125 m	Anywhere along the length except involving transverse bulkheads speed further apart than the stipulated length of damage.
L < 125 m;	In addition to above aft machinery space flooding may be excluded which may be considered by the administration.

Table B

IMO regulation (damage stability) – extent damage		
ILLC	MARPOL	IBC code / IGC code
Side damage: Longitudinal: 1/3 $(L)^{2/3}$ or 14.5 m Transverse : B/5 or 11.5 m vertical : full depth	Side damage: Longitudinal : 1/3$(L)^{2/3}$ or 14.5 m Transverse : B/5 or 11.5 m vertical : full depth	*Side damage:* Longitudinal: 1/3$(L)^{2/3}$ or 14.5 m which ever is less. Transverse : B/5 or 11.5 m which ever is less. Vertical : Full depth.
Bottom damage: Not considered	*Bottom damage:* Longitudinal : 1/3$(L)^{2/3}$ or 14.5 m (0.3L from FP) 1/3$(L)^{2/3}$ or 5 m (aft of above). Transverse : B/6 or 10 m (0.3L from FP) B/6 or 5 m (aft of above). Vertical : B/15 or 6m *Add^{nal} raking damage* requirement: i. 20,000 t ≤ dwt < 75000 t Longitudinal : 0.4L from FP Transverse : B/3 Vertical : breach of outer hull ii. dwt ≥ 75000 t Longitudinal : 0.6L from FP Transverse : B/3 Vertical : breach of outer hull	*Bottom damage:* Longitudinal : 1/3$(L)^{2/3}$ or 14.5 m (0.3L from FP) 1/3$(L)^{2/3}$ or 5 m (aft of above). Transverse : B/6 or 10 m (lesser value) (over 0.3L from FP) B/6 or 5m(aft of above) Vertical : B/15 or 6m (IBC code) B/15 or 2m (IGC code) Location of cargo tanks is limited beyond the side and bottom damage in type 1 ship and beyond only the bottom damage in type 2 ship.

Table C

: IMO regulations (damage stability) – survival criteria			
	Criteria	ILLC	MARPOL, IBC, IGC code
1	Final W.L	Below any opening through which progressive flooding can occur	
2	Angle of heel:		
	a) deck edge immersed	15°	25°
	b) deck edge not immersed	17°	30°
3	Range of stability	≥ 20° beyond the equilibrium location	
4	Maximum residual arm	≥ 0.1 m within the range	
5	Area under the curve	≥ 0.0175 m radians in the range	
6	Intermediate stage of flooding	Required to be satisfied	

Concept of Floodable length (Deterministic):-

In the earlier phase of the research work in respect of subdivision, the effect upon floodable length of variation in block coefficient, freeboard, sheer and permeability was studied. Diagrams were prepared based on a standard form to give the floodable lengths as percentages of L. This was generally done for twelve stations and for two permeabilities. The curves representing freeboard ratio (FR) & sheer ratio (SR) are placed appropriately as shown in the diagram, the relationship was analyzed. Freeboard ratio is the ratio between 'f' &'d' or is equal to f/d.

'f' being the vertical distance amidships between subdivision loadline & margin line & 'd' the vertical distance between moulded baseline amidships & subdivision loadline.)

The sheer ratio is the ratio between the sheers of margin line at fore perpendiculars & aft perpendiculars wrt draft. e.g. sheer ratio at FP = sheer wrt lowest part of margin line ÷ draft.

Let us determine the floodable length from this diagram. In the diagram we see the curves of freeboard ratio & sheer ratio. Let the freeboard ratio & the sheer ratio be 0.22 & 0.34 respectively & let the block coefficient be 0.63. A vertical line is drawn through C_b point on the x axis to meet FBR curve. From this intersection point draw horizontal line to meet SR curve & then drop perpendicular to get the floodable length as % of 'L'.

The floodable lengths so obtained were for 60 per cent and 100 per cent permeability. It is assumed that floodable length is inversely proportional to the permeability for the intermediate values of permeabilities. Thus for a given set of values of C_b, FR & SR the floodable length at a particular station could be found.

The most likely cause of sinking would be a breaching of the hull intactness by collision. The consequences of the resulting flooding are minimized by subdividing of the hull into compartments by watertight bulkheads. The extent to which such bulkheads are fitted is determined by IMO standards that are based on the size and type of ship. The ships that must have a high probability of surviving a collision are built to the "one-compartment" standard as a minimum standard, meaning that at least one compartment bounded by watertight bulkheads must be floodable without sinking the ship. A two-compartment standard is common for larger passenger-carrying ships--a measure that presumably protects the ship against a collision at the boundary between two compartments. The *Titanic,* the victim of the most famous sinking in the North Atlantic, was built to the two-compartment standard, but its collision with an iceberg just before midnight on April 14, 1912, perforated at least five compartments. The *Titanic* could not survive such damage, but its many watertight bulkheads did retard the flooding so that the ship required two hours and forty minutes to sink.

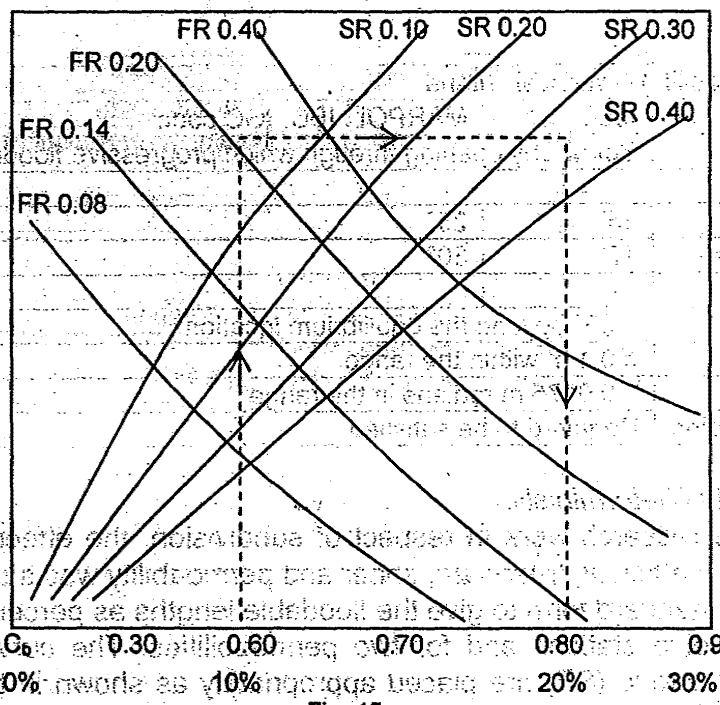


Fig. 15

Factor of subdivision introduced:-

Concept of Factor of subdivision introduced the idea of permissible length and the floodable length. The factor relating floodable lengths to permissible length is called factor of subdivision (F). The maximum permissible length between bulkheads is obtained by multiplying the floodable length for a point at the centre of the compartment by the factor of subdivision.

By this factorial system a factor of subdivision of 1.0 means that the ratio between the compartment length & floodable length is one & therefore to cause flooding over floodable length, the flooding of one compartment is good enough. Such a ship is said to correspond to a 'one-compartment standard' (i.e., any one compartment can be flooded without the ship sinking under assumed conditions). Similarly a factor of subdivision of 0.5 would give rise to a two-compartment standard, etc. An intermediate factor such as 0.7, 0.8 etc may also be given to ships which will positively corresponding to one-compartment standard. But under certain conditions viz. favorable drafts prior damage (less than maximum), smaller permeabilities etc., the ship would survive with two or even more number of compartments flooded.

The factor (F) depends on the length of the ship and the nature of its service as measured by a Criterion of Service Numeral (Cs). This numeral is based on the relation between the volume of the spaces allotted to passengers and machinery and the total volume. The greater the volume for passengers and machinery the larger the value of Cs and the lower the value of F.

Passenger vessels on international voyages in the past years have been constructed either as cruise ships, or as combination car / passenger ferries. The spaces below the freeboard deck can be subdivided with ample bulkheads to permit them to meet a two compartment standard without it becoming a very expensive affair. A vessel carrying passengers below the freeboard deck may require a few more bulkheads, a few more sliding watertight doors and a few more stairways, but the costs of these in comparison with the overall safety which they provide is very small. Car cum passenger ferries may easily meet a two compartment standard with car decks extending below the freeboard deck.

The loss of the *Mohawk* by collision and the *Morro Castle* by fire drew a lot of public attention. These resulted in improvements to the standards of subdivision and stability and thus a positive improvement to the 1929 convention.
Later International Conferences on Safety of Life at Sea (SOLAS) took place in 1948 and 1960, resulting in gradually, adopting higher standards for vessels carrying large number of passengers on short voyages and increasing the proportion of ships required to meet a 2-compartment standard.
In fig below we find a typical set of curves of floodable and permissible lengths, with the actual subdivisions indicated. All the triangles marking the actual lengths of compartments lie below the curves of permissible length and thus satisfy the regulations.All the triangles have same slope to base line & are isosceles.

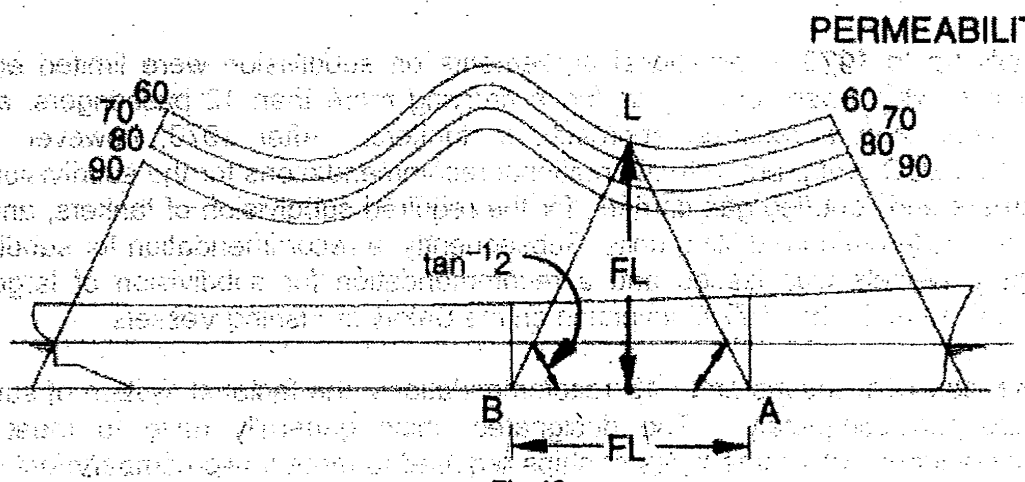


Fig 16

Concept of Probability:-
At the 1960 SOLAS Conference, new concepts were proposed for future discussion.

1. Thus a ship which can sustain more damage & still survive is safer than the vessel which cannot survive. Probability of survival was related to safety of ship after damage.
2. In fact while these new concepts were under discussion the capsizing of the liner *Andrea Doria*, which had been built to the 1948 Standards, showed up the short comings of stability provisions of the 1948 convention. This further caused the maritime nations to pursue a continued study of this subject under the auspices of the then-called Inter-Governmental Maritime Consultative Organization (IMCO).

During the 1960's there were three significant developments.

1. *Regularity in Study:* Technical Subcommittee of IMCO on Subdivision and Stability from world-over met on a regular basis.
2. *Exchange of knowledge & Experience:* The exchange of information on casualty data and accident experience of all individual countries pushed the members to look for better method / criteria of subdivision.
3. *Computerisation:* There was a simultaneous development throughout the world in the field of computers for the calculation of vessel characteristics and subdivision capabilities. Thus where on one hand, the calculation of floodable length curves and damage stability characteristics used to take weeks of manual calculations, better results could now be obtained by relatively few manhours of naval architect's labor and a few minutes of modern computers.

Parallel studies were done in the areas of environmental protection due to marine pollution. The 1954 Conference on Marine Pollution (MARPOL), incorporated subdivision along with marine pollution. This resulted in the inclusion of a permissive standard for tanker subdivision.

1973: IMO Finally Yields To Probability Concept: -
The proponents of the probabilistic approach to subdivision continued to discuss and project their point of view in a rigorous way at IMCO until IMCO responded vide a Resolution in 1973. IMCO accepted this new approach to subdivision and adopted new standards based on the probabilistic approach, as a permissive alternative to the 1960 SOLAS convention requirements.

The 1974 Conference on Safety of Life At Sea, which came in to force in 1980, also endorsed this approach as an as alternative, but continued to permit the basic factorial provisions of the 1960 Convention.

Thus generally up to 1970, international agreements on subdivision were limited entirely to passenger ships, which were defined as those carrying more than 12 passengers, and as a permissive rather than a required approach, to tankers. After 1970, however, in rapid succession, the IMCO group put forth international recommendations for the subdivision of bulk chemical carriers and liquefied gas carriers, for the required subdivision of tankers, and for the subdivision of mobile offshore drilling units. Subsequently, a recommendation for subdivision of offshore supply vessels was issued and a recommendation for subdivision of large fishing vessels was contained in the 1977 Convention on the Safety of Fishing Vessels.

In all of these later conventions and IMO recommendations, the factorial system of subdivision has been dropped completely. The designated ships generally have to meet a one-compartment standard, with some types of ships required to meet a two-compartment standard at certain locations along their lengths. The approach to subdivision has also changed from the previous preoccupation with sinkage and trim to a more realistic treatment, whereby the damaged ship is analyzed for its floodability and stability in both the longitudinal and transverse directions. SOLAS had probabilistic concept (Acquired subdivision index $\sum p_i s_i \geq$ Required Subdivision Index)for cargo vessels & deterministic concept (Margin line, floodable length, permissible length, factor of subdivision etc)
A revised SOLAS chapter II-1 was adopted vide May 2005 amendments scheduled to enter into force on 1 January 2009. The revision of SOLAS chapter II-1 is intended to harmonize the provisions on subdivision and damage stability for passenger and cargo ships. The revised provisions in parts A, B and B-1 will be applicable to new ships built after the expected entry into force date of 1 January 2009.
The amendments, which have been intensively developed over the past decade, are based on the "probabilistic" method of determining damage stability, which is itself based on the detailed study of data collected by IMO relating to collisions. Because it is based on statistical evidence concerning what actually happens when ships collide, the probabilistic concept is believed to be far more realistic than the previously-used "deterministic" method. The deterministic method had hidden dangers such as 1.Effect of waves 2. Loss of strength 3. Subsequent changes in scenario due to cargo shift/action taken etc unaddressed. Probabilistic concept in a way takes account of these areas also.

The revision has taken into account the results of the HARDER (Harmonization of Rules and Design Rational) research project: a project undertaken by a consortium of European industrial, research and academic institutions to study the probabilistic approach for assessing a ship's damage stability and to develop new criteria and indexes for subdivision based on probability of

survival, taking into account effects from waves, heeling moments, cargo shift, transient effects and equalization arrangements.

Harder project:-

The project HARDER means Harmonisation of Rules and Design Rational. It concluded its work in May 2003 and developed a fully validated concept of probabilistic damage stability for all types of ships according to the project plan.

The project has studied all relevant aspects related to stability of a damaged vessel in a probabilistic framework, including new and updated damage statistics and rational formulation of probability of survival, where the effects from waves, heeling moments, cargo shift, transient effects and equalization arrangements are taken into account in an all-embracing way. The concept has been thoroughly validated and different proposals for required index have been worked out to ensure equivalency with the current regulations. These proposals were submitted to IMO-SLF for consideration and were accepted as a basis for the new damage stability harmonised rules developed by IMO SLF 46 (September 2003).

New and updated damage distributions have been established, by searching 'old' IMO data as well as more recent data from United States, Greek and German sources, and Norwegian data. The database contains 2946 casualties collected from 7 different sources (in all, 1851 collisions, 930 groundings and 165 other incidents). Studies of bow heights of the world fleet have been done in order to attain an updated formulation of the probability distribution of the vertical extent of damage. This vertical extent of damage has been verified and validated by comparison between bow height studies, casualty information and theoretical calculations.

Based on the ship characteristics for the world fleet, distributions of ship types and lengths, as well as empirical relations for length versus breadth, draught, displacement, service speed, etc., have been developed. This information has been used to calculate the external dynamics in order to derive distributions for the energy to be absorbed during a collision between a given struck ship and a ship of the world fleet. Furthermore, traffic route data (e.g. for the Strait of Dover) has been acquired and analysed to make a comparison between the world fleet distribution and the distribution in specific waters. Based on the distribution on collision energy, the expected size of damage has been calculated by simulation with computer models.

Model tests of different ship types have been performed in order to study their behaviour after a damage case in a real seaway. These results have been used to test numerical simulation models with the view to develop generic models for assessing the capsizing resistance and survival capability for any vessel type and internal compartmentation.

The outcomes of these studies have then been exploited to propose a static equivalent method, which has been applied for the development of rational survival criteria to be used in a probabilistic damage stability framework. Validation and verification of the concept have been carried out by a systematic study of the proposed regulations on different types of vessels. A databases for test ships covering a wide range of ship types have been established.

A sample of vessels, consisting of all ship types covered by SOLAS, with representative size and arrangement lay-out, making it possible to calculate a required subdivision index representative of the existing SOLAS standard, has been established, and systematic calculations of attained indices carried out for the purpose of establishing the required subdivision index ensuring equivalence with the current regulations. The proposed probabilistic

concept has been applied to 12 different design concepts, and a systematic study of the possible impact of the new rules on new ship designs has been carried out.
The recommendations from the project have been summarized in regulatory format and communicated via the IMO-SLF-SDS Inter-sessional Correspondence Group in preparation of the work of SLF 46.

The probability of a ship's surviving after a collision incident is expressed by the Attained Index, A. This index requires calculations of a series of different damage scenarios in predefined initial loading conditions. The general formulation of Attained Index is given next:

$$A = \sum_i wf_i A_i$$

Where A_i attained index for each specified loading condition (draught)
wf_i weighting factor of each A_i

The method of calculating the attained index for a loading condition is expressed by the following formula:

$$A = \sum_{i=1}^{i=t} p_i v_i s_i$$

Where,

i expresses each investigated compartment or a group of compartments.
t is the number of investigated damages for the calculation of the A-Index for the particular loading condition
p is the probability that a compartment or a group of compartments may be flooded.
v is the probability that the space above a horizontal subdivision may not be flooded.
s is the probability that the ship may survive after flooding the compartment or group of compartments under consideration in the defined loading condition.

The attained index, A, should be obviously greater than a Required Subdivision Index, R, specified by the regulations.

Considering that the currently in-force damage stability regulations for new buildings can be assumed corresponding to a satisfactory level of safety, it follows that a harmonization of relevant rules on the basis of the probabilistic damage stability concept should aim at keeping these levels of safety on the *average* unchanged. Thus, the determination of the new Required Index, R_{new}, has been based on the concept of "equivalence of safety".

In order to achieve "equivalent level of safety" between the existing regulatory body and the new proposed one, with respect to the evaluation of ships' damage stability, the following working assumption was taken:

$$(A/R)_{NEW} = (A/R)_{EXISTING}$$

The way of implementation of the particular assumption to the Dry Cargo ships is expressed as follows:

$$\frac{Anew}{Rnew} \approx \frac{A_{EXISTING}}{R_{EXISTING}} \Rightarrow Rnew = Anew. \frac{R_{EXISTING}}{A_{EXISTING}} = Anew. \frac{R_{B-1}}{A_{B-1}}$$

where R_{B-1}, A_{B-1}: to be determined according to SOLAS B-1 (IMO (1997)).

With respect to the Passenger ships that were built under the probabilistic concept of Resolution A.265, the following has been considered:

$$\frac{Anew}{Rnew} \approx \frac{A_{EXISTING}}{R_{EXISTING}} \Rightarrow Rnew = Anew. \frac{R_{EXISTING}}{A_{EXISTING}} = Anew. \frac{R_{A.265}}{A_{A.265}}$$

where $R_{A.265}$, $A_{A.265}$: calculated values according to Resolution A.265.

For passenger ships that were built under deterministic rules (SOLAS 90), the values of the new required indices are calculated according to the following formulation:

$$\frac{Anew}{Rnew} \approx \frac{A_{EXISTING}}{R_{EXISTING}} \Rightarrow Rnew = Anew. \frac{R_{EXISTING}}{A_{EXISTING}}$$

Herein it can be assumed for passenger ships that $R_{EXISTING}/A_{EXISTING} = 1$ and is noted that the limit damage GM curve has to be taken into account at all specified loading conditions.

The general formulation of Required Subdivision Index, R is given next:

$$R = 1 - \frac{C_1}{L + C_2 N + C_3}$$

Where,

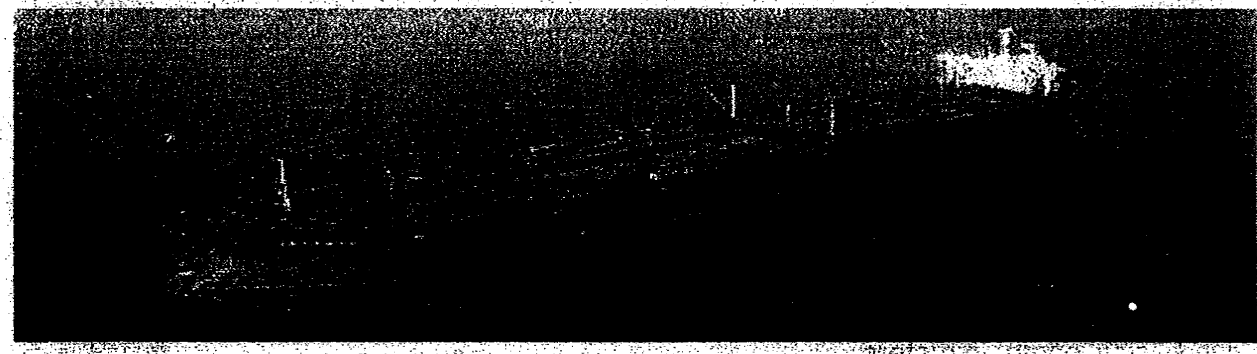
L is subdivision length, in meters

N is related to the persons on board and the extent of life saving equipment, $N = N1+2N2$, where N1 is the number of persons for whom lifeboats are provided and N2 the number of persons the ship is permitted to carry in excess of N1.

As far as the Dry Cargo Ships are concerned, the C_2 coefficient was assumed equal to zero due to the fact that cargo ships have a relatively small number of persons on board, namely only officers and crew. As this number is relatively small, its significance on the formulation of the Required Subdivision Index is negligible.

In practice, "equivalence of safety" can be only achieved 'on average', within practical limitations, by proper determination of the R-formula for the addressed ships, following a regression analysis of data of collected and newly calculated Attained Indices of a statistically sufficient sample of ships. These data correspond to various dry cargo and passenger ship types, relevant sizes and loading conditions assumed marginally meeting existing SOLAS damage stability criteria, pertaining to new buildings of the specific ship category.

Largest Tanker: Knock Nevis, or T.T. Jahre Viking is the biggest ship ever built. It is a class ULCC (Ultra Large Crude Carrier) super tanker. 485 meters long, draft 25 m she can stand taller than the Petronas Twin Towers of Malaysia. Due to this enormous size, Jahre Viking cannot pass the Panama, Suez, or English channel.
She has a cargo capacity of 564,763 tons and can carry about 650,000 m³ of crude oil. Initially built with a displacement of 480,000 tons it was then known as the Seawise Giant. 87,000 tonnes dwt was added later.



Chapter 25 Stability & damage stability management of vessel

Guidelines on the management of ship's stability: -
These Guidelines are prepared by the IMO to minimize accidents and losses caused by improper ship operation. Though the general stability characteristics & design must be as per relevant IMO – instruments, there is an urgent need for additional care for stability by the ship's master and officers during cargo operations, navigation and emergency procedures.

A. Documentation and recording:-
Proper management of ship's stability should therefore be addressed to as a shipboard key operation in the light of ISM Code. Specific guidance for particular ship type should be provided in the company's approved SMS-Manual.
The following items regarding stability are common to all ships and should therefore be addressed to in the SMS-Manual:

1. Care for and monitoring of the ship's water tight integrity;
2. Control of KG in the course of cargo, ballast or bunker operation;
3. Avoidance of transverse shifting of masses, like cargo or heavy items of equipments, and the avoidance of large liquid free surfaces;
4. Preparedness for corrective measures in the event of intolerable loads or threats on stability;
5. Keeping of records for control and references.

The Guidelines on the Management of Ship's Stability are intended as in aid to focus on problems of shipboard stability management rather than presenting a comprehensive manual.

Each ship should be provided with a loading and Stability Manual, approved by the Administration. It should be drawn up in the "working language" of the masters and his officers. If the working language is neither English, French nor Spanish, the text should include a translation into one of these languages. The arrangements for responsibility, authority and

competence on board with regard to cargo operations and tank operations should be clearly laid down in the company's SMS.

Records: -
Records on ship's stability should be filled and kept in a suitable way. Some of the items which must be recorded are:
Voyage number, port, date and time,
Cargo and tank status,
Actual stability parameters and Flag State minimum parameters,
Result of ships draught survey (if applicable),
Result of stability measurement (if applicable) &
Final assessment of stability for the forthcoming voyage.

During the voyage daily and at arrival, an update of tank status and actual stability parameters should be established and recorded. The records may consist of appropriate printouts of the ship's loading and stability computer or tank monitoring system.
Data on actual longitudinal and torsional stress parameters should be included (if applicable).

B. Control of stability during loading and unloading: -
Minimum stability requirement in port
The stability criteria as lined out in the IMO Intact Stability Code or in similar instruments of the Flag State should be observed while the ship is at sea. In port, particularly during loading and unloading operations a deviation from those criteria is generally acceptable provided the metacentric height is positive at all times and not less than 0.15m.
It should be noted however that certain types of cargo operations like loading or unloading containers, Ro/Ro-vehicles and any other heavy units may require a metacentric height well above 0.15 m in order to avoid unsuitable heeling of the ship. The company's SMS-Manual should contain specific guidance regarding the minimum GM during the cargo operations. Heeling restrictions of the ship with regard to the operation of ship's cranes should be observed.

Risks to stability during loading and unloading: -
A careful planning of the sequence of loading and unloading, particularly with both operations to be undertaken simultaneously. A close review of the operations plan should be carried out before the operation starts.
In order to avoid undue risks to stability the planned procedure should be divided into suitable steps with check points or mile stones which provide for an effective control.
Incorrect figures of cargo unit masses in cargo documents may foil the operations plan. It is therefore recommended to take draught readings at suitable intervals and check the cargo intake appropriately.
Co-ordination between tank operations and cargo operations is of utmost importance.
The loading or unloading of heavy cargo units by lifts-on/lift-off or roll-on/roll-off operation may require the movement of large quantities of ballast water for avoiding excessive heel or trim. This can be a threat to stability depending mainly on the vertical location of the ballast tanks. A properly calculated balance of heeling levers and righting levers should be made up for critical situations. Cargo and any loose equipment should be secured before heavy lift operations are started.
Liquid free surfaces in ballast and/or cargo tanks during loading or unloading may cause negative initial stability with unexpected list and loll behaviour of the ship. This may happen particularly to OBO-Carriers loading or unloading oil and to tankers of the "single tank across" design. The approved operations plan for loading or unloading those types of ships should be strictly observed.

Measures of control:-

The company's SMS-Manual should contain general instructions with regard to the control stability during loading and unloading cargo, appropriate to the type of ship and her cargo particular covering:

The proper planning of cargo loading and unloading sequences including ballast and bunk operations.
Suitable checks of cargo mass intake. Specific advice as may be necessary for loading unloading special cargoes like heavy lift units or liquid bulk cargoes.

The company's SMS-Manual should require a suitable documentation of cargo loading and unloading operations.

Assessment of stability before departure:-

Defining stability limits for departure:-

Minimum stability requirements as determined by Flag State should be well understood complied with. The same checked in respect of the following:
Relevant information in the Loading and Stability Manual, i.e. Limiting curves or tables of maximum KG or minimum GM.
Additional criteria as may be applicable for certain cargoes or certain modes of operation.

The stability criteria generally specify minimum values but no maximum values. It is advisable to avoid excessive values of metacentric height, since these might lead to acceleration forces to sea which may cause undue strain to the securing of cargo and thus endanger the ship's stability by the risk of cargo shifting.

Reduction of stability during the forthcoming voyage due to consumption and other foreseeable reasons should be well assessed and taken into account when defining limits of departure stability. This should include, if applicable:
Water soaking of deck cargo,
Icing,
Having a haul of fish on deck.

Methods of assessment of stability

Stability should be assessed before departure or whenever deemed necessary by either:

1. Comparing the intended loading plan or the existing loading condition with similar conditions of known stability parameters.
2. Individual calculation of masses and moments of allocated or existing cargo distribution and tank fillings,
3. Measurement of stability by in-service inclining test or by evaluation of the observed natural period of roll.

The last method generally provides the most accurate and reliable results, but can only be used in a close to final state of loading and needs further adaptations to arrive at the result for departure condition or worst condition during the voyage.

Special considerations:-

Ships carrying grain cargo should comply with the requirements of Grain Code. Ships loaded with timber on deck should comply with the provisions of Timber Code. Ships carrying certain

solid bulk cargoes other than grain may require a defined effort of transverse cargo trimming before commencement of the voyage, according to the Solild Bulk Code.
Before a voyage commences, the cargo and equipment must be properly stowed & secured.

D. Control of stability while at sea

Fuel consumption

- The order of fuel tanks to be used during the voyage should be agreed between the master and the chief engineer wrt stability.
- Consumed bunkers should be replaced by ballast at pre-defined stages following an appropriate plan.
- The number of partially filled or slack tanks should be kept to a minimum because of their adverse effect on stability.
- If a tank is kept slack deliberately in order to reduce a large metacentric height care should be taken to avoid dangerous sloshing. Sloshing effects are under control if tanks are filled to above 90% or below 10% of the tank capacity.

Ballast exchange at sea:-

A preplanned procedure should be followed however with regard to longitudinal strength aspects which may become critical on certain ships although this should not be critical in case of bulk – carriers or tankers.
The exchange of ballast at sea on container ships or Ro/Ro-vessels may be critical for the stability of the ship. A careful preplanning of this operation, preferably with the use of the loading computer, is a stringent requirement.
The company's SMS-Manual should contain specific guidance on this procedure.

Water soaking of deck cargo and icing:-

Certain deck cargoes like timber, open pipes, open barges, cork, coke and others may assume added mass by heavy rain or overcoming sea water. Care should be taken to provide a good drainage in order to limit the reduction of stability to the anticipated value.
SMS-Manual should contain appropriate advice on dealing with the risk of icing with guidance from Intact Stability Code.

Measures in case of negative GM:-

Experience has shown that due to extreme water absorption or icing or failures in tank management a negative GM can develop.
Depending on the existing sea conditions this may not be detected until the ship shows a slight list. This situation is critical in a way that a first attempt may be correct this list by a transverse re-arrangement of bunkers or ballast. Hence the ship would loll to the opposite side and resume a list greater than before.
Although the observed list may be a combined result of negative GM and eccentric masses it is strongly recommended that with any corrective action the possible consequences of negative GM should be borne in mind. Flooding of double bottom tanks or reducing weight on deck are to be considered.
As flooding a double bottom tank will produce another liquid free surface until the tank is full, a narrow center line tank should be chosen if possible. If a transverse pairs of tanks has to be flooded the tank on the low side should be flooded first. This will in fact increase the ship's list but avoid a possible loll to opposite side.

E. Measures before and in heavy weather:-

Weather tight and watertight hatches, doors, etc., should be kept closed during navigation, except when necessarily opened for the working of the ship, and should always be ready for immediate closure and be clearly marked to indicate that these fittings are to be kept closed except for access. All doorways and other openings through which water can enter into the hull or deck-house, forecastle, etc., should be suitably closed in adverse weather conditions and accordingly all appliances for this purpose should be maintained on board and in good conditions.

Vent pipe covers to be secured in bad weather. Although in principle all cargo should be properly stowed and secured before the ship commences a sea passage it is advisable to re-inspect all cargo in holds and on deck before the ship enters a heavy weather.

Sailing in heavy weather:-

- In severe weather, the speed of the ship should be reduced if excessive rolling, propeller emergence, shipping of water on deck or heavy slamming occurs. As a thumb rule six heavy slamming or 25 propeller emergences during 100 pitching motions should be considered dangerous.
- Water trapping in deck wells should be avoided. If freeing ports are not sufficient for the drainage of the well, the speed of the ship should be reduced or the course changed, or both. Freeing ports with closing appliances should always be capable of functioning and are not to be locked.
- Masters should be aware that steep breaking waves may occur in certain areas. These waves are particularly dangerous, especially for small ships.
- Special attention should be paid when a ship is sailing in following or stern quartering sea, because dangerous phenomena such as parametric resonance, broaching to, reduction on stability on the wave crest, and excessive rolling may occur singularly, in sequence or simultaneously in a multiple combination, creating a threat of capsize.
- Steering must be taken on hand or manual mode.

The SMS Manual should contain general advice on "entering heavy weather" with regard to:
water tight integrity of the ship,
re-assuring proper stowage and securing of cargo and equipment,
ship handling in heavy weather.

F. Control of stability in damaged condition

Compliance to the stability criteria and ready reckoning stability information: -

- Master must make use of al the rapidly usable simplified information to have a complete control over the stability status of the ship. One of such information may be the one provided to the master in the form of diagrams, tables or suitable computer programs prescribing the observation of a value of minimum GM or maximum KG related to actual condition of loading. This value would guarantee the survival of the ship which means the vessel will not to capsize, under a specified condition of damage and fair weather condition.
- Generally damage stability criteria require a higher initial stability than the intact stability criteria. Damage stability criteria on tankers need not to be observed in pure ballast conditions.
- Compliance with damage stability criteria does not ensure immunity against capzising in any damaged condition.

Effects of damage on stability: -
Water entering in the damaged ships will generally assemble in the lower parts of the hull which is in favor for the ship's stability; the amount of the water able to enter the ship depends on the permeability of the flooded space.

Water entering a damaged ship causes a draught to increase and thus changes relevant stability parameters like KM and cross-curve values. In fully loaded conditions KM is likely to increase slightly while cross-curve values decrease with the draught. The latter is unfavorable if a list develops.

Asymmetrical flooding causes the immediate development of a list. This is the most serious effect as it lowers the water inlet and increases the rate of flooding.
If the flooded space has a large surface area the negative effect of liquid free surface will affect the stability seriously. Most commonly the initial ingress of water will heel the ship which will fail to upright because of negative GM. Subsequently the ship will either capsize or upright again when the amount of water taken in is sufficient to restore a positive GM.

Assessment and control of damage: -
Due regard must be made for rescue and safety of persons on board when any action is taken in respect of damage stability. A reasonably clear picture of the affected parts of the hull must be made when accessing the damage. For this purpose the following issues should be surveyed.

- Locations and extent of damage.
- Estimated rate of flooding
- Size and permeability of flooded place,
- Neighboring spaces liable to be affected by breaching of bulkheads.

In order to avoid capsizing of the ship. The following aspects should be taken into account:

- Any intolerable list of the ship may be counteracted by deliberate counter flooding.
- Breaching of bulkheads to adjacent spaces may be prevented by shoring with timber or other suitable means. Small holes or cracks may be secured by wooden wedges or plugs. If the casualty has happened alongside or close to a jetty a good mooring of the damaged vessel may prevent capsizing. The support of tugs pressing the vessel to the jetty may be useful too.
- In the case of collision bow to side with another vessel it may be useful to secure the bow of the one vessel to the breached side of the other in order to prevent capsizing. Using the ship's pumps and/or pumps supplied by other vessels may control the flooding, at least to an extent to save time for other useful measures.
- Deliberate breaching or standing may save a damaged vessel from capsizing.
- The damage may have affected the longitudinal strength of the ship by weakening the structure (mainly the deck which acts as an upper girder). The damage may additionally increase any existing shear forces and bending moments by the effect of the incoming water. These aspects should be borne in mind when taking deliberate actions to secure the stability of the ship.

- A damaged vessel sitting on the ground should not be towed off or allowed to refloat until sufficient stability and a close to upright floating condition is confirmed by thorough investigation.

G. Control of stability in special situations

Control of stability after a major shift of cargo:

A major transverse shift of cargo will cause the ship to heel and reduces the righting levers at the immersed side. A suitable action is must. As the amount of shifted cargo and distance of shifting will be unknown until the cargo space has been inspected it may be useful to estimate the residual stability at the immersed side by the following method:

Take the actual righting lever curve for the upright ship from the last record statement.
Indicate the observed angle of heel after cargo shifting and draw a horizontal line through the intersection of the heeling angle ordinate with the righting lever curve.
Measure the residual righting lever curve (shaded area) in terms of range, area and value of maximum lever against usual minimum stability requirements and prevailing weather conditions.
If remedial actions are deemed necessary to secure the stability of the ship the following aspects should be considered:
Change the course and/or speed to reduce further rolling of the ship may be useful as a quick reaction.
Securing of the shifted cargo to its new position may be advisable before righting the ship up by counter flooding with ballast or by transfer of bunkers.
As securing a shifted bulk cargo may be impractical any measures to upright the vessel should be restricted to a moderate reduction of the heel in order to avoid a re- shifting of cargo with a possibly larger heel to the other side.

Towing operations :-

A ship, when engaged in towing operations, should possess an adequate reserve of stability to withstand the anticipated heeling moment arising from the low line without endangering the towing ship. Thus the ships shifting berths within the port area may have stability less than for seagoing condition. If a tugboat is used for this purpose the tug master should be warned accordingly to pull or push at reduced power.

Fire fighting:-

1. Fire fighting on board in port or at sea may involve the use to large quantities of water especially if access to the fire is restricted and a more or less flooding action is the only way to control the fire. Free surface effect may endanger the ship by capsizing.
2. In particular with fire fighting alongside a jetty and developing list may not be noticed until the mooring ropes give way. Additionally shore fire brigades may not be fully aware of the risk of capsizing due to the free surface effect.
3. In order to control the risk of capsizing the bilge pumps should be run to get rid of the water appropriately.

Dry-docking: -

Ships being dry-docked should have ample stability and as little trim as possible in order to have adequate safety during the critical period.

During the docking period ballast tanks may have to be emptied and bunkers shifted depending on the work program. Therefore, before the ship is being refloated again a full survey of all tanks and a subsequent stability and trim calculation should be carried out to make sure that after refloating

- The ship has sufficient stability.
- The ship will float without list.
- The trim is within reasonable limits.

H. Miscellaneous issues

Equipment for stability management:-

Equipment and instrumentation for stability management should ideally consist of:

- An approved computer and software supporting the documentation of cargo and tank operations, statical calculations with regard to stability, draught, trim and stress, andthe evaluation o
  f draught readings (shipboard draught survey),
- An approved system for carrying out a fast and reliable stability measurement,
- An approved remote draught gauging system,
- An approved remote tank gauging system.

A simple and straight forward instruction manual written in the working language of the master and officers should be provided with the equipment. It is desirable that the input/output form in the computer screen presentation be similar to the one in the loading and stability manual so that the operators will easily gain familiarity with the computer and the manual. In order to validate the proper functioning of the equipment test conditions should be run periodically at intervals specified in SMS-Manual.

Other considerations: -

The company should, when addressing the management of ship's stability in the SMS-Manual, must , provide attention to safe ship operation. This may include:

- Longitudinal strength in terms of permissible bending moments and shear forces or torsional moments.
  Vertical sequence of masses in container stacks on deck Observation of deck loading restrictions due to sight line requirements,
- Suitable trim of the ship with regard to steering and handling in heavy weather,
- Load line requirements.

I. Specific shipboard training & guidelines

Deck officer, designated to assume the duties of a cargo officer, should be given proper familiarization with the ship and the documentation and equipment regarding the management of ship's stability and related aspects.

The master should verify the appropriate ability of the particular deck officer and provide supervision if and as long as deemed necessary.

Aspects of stability management within the contingency planning scheme should be appropriately addressed to in shipboard drills or paper exercises on damage control issues. This applies to deck officers ad engineers on board.

Advice on the dangers of flooding of forward compartments: -

The recommendations give here are as per an MSC circular & based on of the re-opened Formal Investigation of Derbyshire intend that masters of bulk carriers should be made fully aware of the possible dangerous consequences of water entry into forward spaces and consequent reduction of freeboard, and approved the Advice on the dangers of flooding of forward compartments.

Derbyshire sank off Okinawa in Typhoon ORCHID in September 1980 with the loss of 44 lives. Flooding of the fore peak and the forward ballast tank through air pipes caused the ship to trim by the head and reduce the effective bow height. Statistical analysis of tank test results

indicated that, although there was a low probability of the ship meeting a hatch-breaking wave in her intact condition, a reduction in bow height of as little as 1.1m could lead to a 70% probability of encountering a hatch-breaking wave (depending on speed, etc). The hatch covers of Nos.1 and 2 cargo holds subsequently failed allowing rapid flooding of those spaces. The ship was then in a condition beyond its survival capability. The evidence considered by the investigation indicated that these events took place rapidly. There was no evidence that any attempt to abandon ship had been possible.

Masters - particularly those who sail on large ships where the bridge is remote from the forward spaces - need to be especially vigilant that the weather tight integrity of their ship is fully maintained. After initial battening down, regular checks should be made to detect any reduction in the integrity of the closing arrangements. In particular:

- Spaces that are entered on routine basis should be subject to a careful check after their use to ensure that watertight integrity is fully restored.
- Bilges and tanks should be regularly sounded and any ingress of water investigated.
- Where bilge alarms are fitted, they should be regularly tested.
- Pumping arrangements in forward spaces should be regularly checked for operational effectiveness. Owners of ships without bilge alarms in remote forward spaces should consider fitting such devices with audible and visual indication on the bridge.
- Masters should consider early evasive action whenever approach of severe depression is anticipated. Ship handling characteristics and any limitations of control may lead to dangerous situation in extreme weather.
- Masters should keep owners or managers advised when weather conditions deteriorate. Communication regarding position, course and speed and should be made more frequently.

Guidelines for damage control plans & booklet: -

These guidelines are intended as advice on the preparation of damage control plans for passenger and cargo ships to which SOLAS regulations in chapter II-1 apply.

The damage control plan and damage control booklet are intended to provide ship's officers with clear information on the ship's watertight compartmentation and equipment related to maintaining the boundaries and effectiveness of the compartmentation so that, in the event of damage to the ship causing flooding, proper precautions can be taken to prevent progressive flooding through openings therein and effective action can be taken quickly to mitigate and, where possible, recover the ship's loss of stability. These documents therefore should be clear and easy to understand. It should not include information which is not directly relevant to damage control, and should be provided in the working language of the ship. Translation in English or French should be available if none of these is the language of document.

What must a damage control plans show?

The damage control plan should be of a scale adequate to show clearly the required content of the plan, but not less than a 1:200 scale. Isometric drawings are recommended for special purposes. The plan should include inboard profile, plan views of each deck and transverse sections to the extent necessary to show the following:

1 The watertight boundaries of the ship.
2 The locations and arrangements of cross-flooding systems, blow-out plugs and any mechanical means to correct list due to flooding, together with the locations of all valves and remote controls, if any.
3 The locations of all internal watertight closing appliances including on ro-ro ships, internal

ramps or doors acting as extension of the collision bulkhead and their controls and the locations of their local and remote controls, position indicators and alarms. The locations of those watertight closing appliances which are not allowed to be opened during the navigation and of those watertight closing appliances which are allowed to be opened during navigation, according to SOLAS regulation II-1/15, should be clearly indicated.

4 The locations of all doors in the shell of the ship, position indicators, leakage detection and surveillance devices.
5 The locations of all weather tight closing appliances in local subdivision boundaries above the bulkhead deck and on the lowest exposed weather decks, together with locations of controls and position indicators, if applicable.
6 The locations of all bilge and ballast pumps, their control positions and associated valves.
7 Pipes, ducts or tunnels, if any, through which limited progressive flooding has been accepted by the Administration.

For passenger ships, the damage control plan should be permanently exhibited on the navigation bridge, as well as in the ship's control station, or equivalent.
For cargo ships, the damage control plan should be permanently exhibited or readily available on the navigation bridge. Furthermore, the damage control plan should be permanently exhibited or readily available in the cargo control room.

How the damage control booklets must be?
The information listed above should be repeated in the damage control booklet. The damage control booklet should include general instructions for controlling the effects of damage, such as:

1. Immediately closing all watertight and weather tight closing appliances. Though a general alarm must always sounded & head count always taken before closing & isolating any damaged portion, duct keel etc.
2. Establishing the locations and safety of persons on board, sounding tanks and compartments to ascertain the extent of damage and repeated soundings to determine rates of flooding; and
3. Cautionary advice regarding the cause of any list and of liquid transfer operations to lessen list or trim, and the resulting effects of creating additional free surfaces and of initiating pumping operations to control the ingress of water.
4. The booklet should contain additional details to the information shown on the damage control plan, such as the locations of all sounding devices, tank vents and overflows which do not extend above the weather deck, pump capacities, piping diagrams, instructions for operating cross-flooding systems, means of accessing and escaping from watertight compartments below the bulkhead deck for use by damage control parties, and alerting ship management and other organizations to stand by and to co-ordinate assistance, if required.
5. If applicable to the ship, locations of non-watertight openings with non-automatic closing devices through which progressive flooding might occur should be indicated as well as guidance on the possibility of non-structural bulkheads and doors or other obstructions retarding the flow of entering seawater to cause at least temporary conditions of unsymmetrical flooding.
6. If the results of the subdivision and damage stability analysis are included, additional guidance should be provided to ensure that the ship's officers referring to that information are aware that the results are included only to assist them in estimating the ship's relative survivability.
7. The guidance should identify criteria on which the analyses were based and clearly indicate that the initial conditions of the ship's loading extents and locations of damage,

permeabilities, assumed for the analyses may have no correlation with the actual damaged condition of the ship.

Damage control plans and damage control booklets should be in printed form. The use of on-board computers[1], with damage stability software developed for the specific ship, and familiar to properly trained ship's officers can provide a rapid means to supplement the information in the planned booklet for effective damage control. Simple, clear and concise guidance, such as damage consequence diagrams, can provide the master with a rapid means to evaluate the consequence of damage to the ship.

Guidelines on early assessment of hull damage and possible need for abandonment of bulk carriers

Following recommendations for decision-making emanating from various formal safety assessment (FSA) studies on bulk carrier safety & are based on relevant IMO circular. The guidelines in particular address bulk carriers which may not withstand flooding of any one cargo hold and containing information on the action to be taken in case of flooding of such holds, making sure that the professional judgment of the master is not undermined. These guidelines, aim towards improving the precautionary measures and procedures for emergencies on board their ships. This ship specific guidance should be brought to the attention of all crew members during familiarization training.

As a result of the disappearance and loss of a number of bulk carriers a lot of literature has come out & which have given positive results too. Apparently in a large proportion of the cases the ship's masters often appeared to be unaware of the imminent danger they were in. Ship losses were frequently so rapid that the ship did not have time to send a distress signal.
The records studied show that in the event of loss of hull integrity, in many cases, bulk carriers should be evacuated as quickly as possible. Early assessment of the situation is therefore imperative, combined with alerting a maritime rescue co-ordination centre, alerting all personnel onboard and making preparations for evacuation. This is of particular importance for single skin bulk carriers which may not be capable of withstanding flooding of any cargo hold.
Companies should take due action setting appropriate precautionary measures and procedures for emergencies. The advice applies equally to ships other than bulk carriers when carrying dense cargoes.

Heavy cargoes such as iron ore occupy small volume in the ships holds resulting in a large unoccupied space. This provides potential in a flooding scenario for large volumes of water to rapidly consume the ship's residual buoyancy and, in the case of smaller vessels, its stability. Larger vessels are also highly susceptible to structural failure due to increases of weights.

Deterioration of structure through corrosion, fatigue and damage is identified as a principal factor in the loss of many bulk carriers. Failing to identify such deterioration may lead to sudden and unexpected failure. Bulk carrier crews may be unaware of the vulnerability of these vessel types.

Flooding of spaces forward of the collision bulkhead will, in the event of flooding, significantly affect the trim of the ship and reduce freeboard at the bow. Freeboard (which is so instrumental in discouraging the green seas from boarding the decks and causing impact on hatch covers and other fittings that protect the water or weathertight integrity of the ship) should be protected all along at any cost especially forward. If air pipes and ventilators forward are damaged the ship's ability to resist further escalation of flooding is compromised.

Masters should quickly assess damage to their ships by being alert to water ingress and its consequences. Hatch covers may be dislodged by pressure and/or sloshing from within a hold if flooding occurs through side shell or bulkhead. Sudden pressurization of compartments adjoining those that are damaged or flooded will indicate failure of internal subdivision, most notably bulkheads. The bulkheads although watertight are not really built or exposed to regular carriage of liquids especially on a dry ship. In past, many ships have experienced a collapse of bulkheads under dynamic sloshing, just like pack of cards.

Personally I am of the opinion that if there was an early detection of ingress, a large number of casualties and loss of life could have been prevented. Master & other officers must carefully read the following & be guided by them when required on their ships.

Various methods of detecting ingress water: -

- On medium sized and smaller ships, slowing of the ship's roll period may indicate excessive water within the hull - a serious threat to stability. Ships fitted with GM meters should be able to identify any unexpected changes in GM. Master must keep a regular check on the roll period especially when soundings can not be taken.
- *Unusual motion or attitude* such as and unusual trim or heel, her changed motions, breach of the hull envelope should be suspected immediately:
- Unusual collections of water on decks may be indicating trim or heel abnormality.
- Sudden changes of heel or trim will indicate flooding or in smaller ships with lighter cargoes it may indicate cargo shift.
- Jerky lateral motions can be indicative of large scale sloshing as would be the case if a hold were flooded.
- Increases of water boarding forward decks may indicate flooding of a forward compartment. Trim and freeboard changes are notoriously difficult to assess from an after bridge.
- Spaces may be monitored, either using gauging or bilge/water level alarms. Forward store spaces can also be monitored audibly using "talkback" telephones that may be fitted in forward spaces.
- Anchor impacts and water in the space can be detected using telephones of the type that remain active until switched off from the bridge.
- Hull Stress Monitors, where fitted, may be able to detect unexpected longitudinal hull girder bending. Torsional stresses may also be detected through differential changes between port and starboard strain gauges.
- Visual monitoring from the bridge using binoculars, where fitted, by closed circuit television, can give indication of abnormal water on deck and local damage. However, assessment of trim or freeboard using this method is difficult.
- Assessment of trim changes can in certain conditions be detected by noting the level of the horizon, when visible, against a known reference point on the foremast.
- Draught and trim can be assessed using draught gauges. Changes are much more discernible using this method than by visual means from above decks.

Early readiness for evacuation and communication:

A lot many mishaps can be avoided if,

1. There is early detection of damage.
2. All the concerned parties (shore, shipboard people, ships in neighborhood) are informed at earliest.
3. Correct actions in correct order are taken without loss of valuable time.

In the event of identifying or *even suspecting* that the ship may have sustained damage, ship's personnel should immediately be called to their emergency stations. This will not do any harm and may even avert loss of lives. A high priority should be placed on preparing equipment for evacuation. Abandonment should however only be invoked on the spoken orders of the master following assessment of the risk.
Contact with a Maritime Rescue Co-ordination Centre (MRCC) and/or owners should be made early if the master has any suspicion that the ship is damaged. An URGENCY signal is justified and this should be upgraded to DISTRESS if the ship is confirmed as damaged.
Masters should place a strong emphasis on evacuation training so that donning of protective suits and lifejackets, launching of survival craft, and operation of EPIRBs and SARTs is a familiar process to all ships' personnel. Also included should be shutdown procedures for main and auxiliary machinery, which can, if left running, hinder launching of survival craft.

Preparations should be concurrent with any investigation:-
Masters may wish to investigate any suspected water ingress more closely but preparations for evacuating the ship should be made without delay and concurrent with any investigation. Remote methods of observation are preferable to sending personnel onto decks, particularly in bad weather and/or at night. Deck floodlights should be used if necessary to try and identify abnormalities. Detrimental effects on watchkeepers' night vision are of secondary importance in such circumstances.

Safety of personnel:-
In circumstances deemed justifiable for sending personnel onto decks at least two personnel should go to investigate. They should wear harnesses that attach them to a lifeline and to each other and should be in constant (radio) communication with the bridge. Each harness should be provided with two easily operated clips so that wearers are always attached to the ship's structure, even when passing across from one lifeline or structural attachment to another. Lifelines on both sides of the deck should be rigged at all times and progress along the deck should always be via the lee or sheltered side. When weather conditions deteriorate is not the time to begin rigging such measures. Fencing or shipside rails alone should not be relied upon without attachment by harness.
When a loss of hull integrity is known or suspected, personnel should not be sent onto decks that are being regularly submerged or deeply awash. In such circumstances the ship should be regarded as in imminent danger and priority should be given to preparations for evacuation.

In the event of a collision: -
Masters should call the ship's personnel to emergency stations with a strong emphasis on preparing to evacuate the ship. This is particularly important and urgent in cases where a ship is loaded with dense bulk cargo. Older designs of bulk carriers and small ships with fewer holds are particularly prone to sudden progressive flooding if the damage occurs abaft any strengthened bulkheads in the forward part of the ship. This type of damage is more probable resulting from collisions in dense traffic or overtaking manoeuvres.

Ship is the best lifeboat:-
There may be cases where abandonment may be the worst option and for bulk carriers as with other ship types this is most probably true in the event of grounding. In close proximity to shore, and especially in bad weather, life-saving craft launched from the ship are unlikely to save the occupants from the perils of the shoreline and the process of launching the craft probably carries much greater danger than remaining on board. Again, early contact with a Maritime Rescue Co-ordination Centre is important and the master should not hesitate to broadcast an Urgency or Distress message. When aground and although the ship may be severely damaged

or broken in two, the accommodation blocks in such strandings usually survive long enough for helicopter evacuation.

Company's Role:
Companies are reminded that the Master is the one who decides on whether or not the ship is to be abandoned. This guidance is provided to assist the master in making that decision and is based on the over riding principle that human life is more important than property.
Companies are also reminded that emergency contingency planning forms an integral part of the International Safety Management Code required by SOLAS chapter IX. They should therefore assess the actual risk to their ships with consideration of the information given in these Guidelines and provide in their Safety Management System appropriate advice to assist the master in assessing the action to take in a situation involving flooding of the ship.

Simplified stability information: -
In part B-1 of chapter II-1 of SOLAS the thought that is reflected aims towards providing a ship with a simplified document that will provide reliable information and will enable Master to obtained accurate guidance in respect of stability of the vessel by rapid and simple means. Apparently the Masters on many ships do not ensure the compliance to minimum statutory standards of stability. Undue traditional reliance is being placed on the value of GM alone, while other important criteria which govern the righting lever GZ curve are not being assessed as they should be. It should be understood that GM is one of the most valuable feature of stability but not the only one. Plotting and evaluating GZ curves is often difficult and time consuming hence it is strongly felt that simplified stability information be incorporated into ships stability booklets. This will not only ensure a good control of master on stability status of vessel but also a cross check on Mate's stability calculations.
A quick check using a single table or graph can indicate whether the vessel complies with adequate stability standards or not. In different stability booklets this information may be in different forms. Some of these are as given below:

- The maximum deadweight moment diagram or table
- The minimum permissible GM diagram or table
- The maximum permissible KG diagram or table

(The limiting values in above tables are related to salt water displacement or draft).

Maximum permissible deadweight moment diagram:-
Displacement in tonnes on the y-axis and deadweight moment in tonnes metres on the x- axis is a very handy information. The total deadweight moment at any displacement must not under any circumstances exceed the maximum permissible deadweight moment at that displacement.

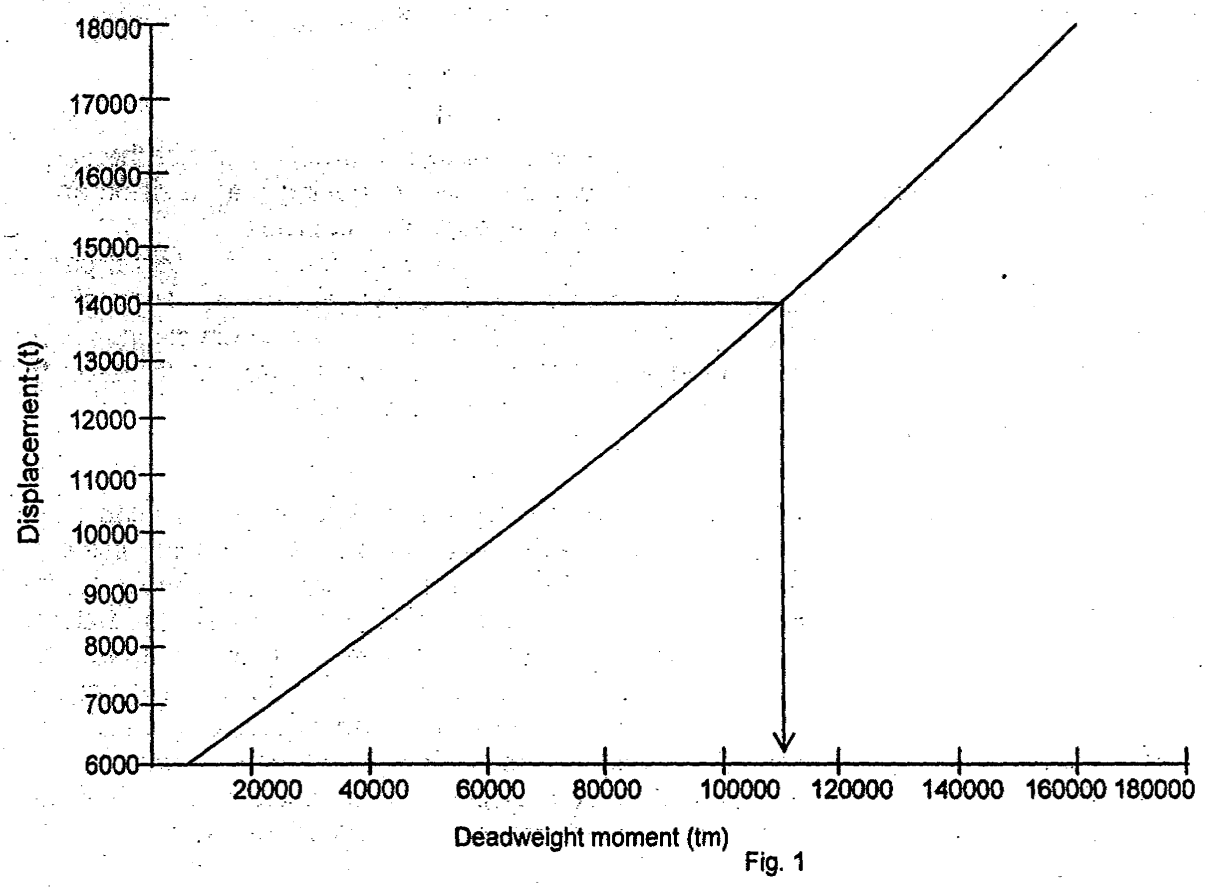


Fig. 1

Let the light ship displacement be 5000t.
Let the present displacement be 14000t.
∴ The deadweight = 14000 – 5000 = 9000t.
The equivalent limiting value of deadweight moment = 110000tm

$$\text{Maximum Kg} = \frac{\text{deadweight moment}}{\text{deadweight}} = \frac{110000}{9000} = 12.22\text{m}.$$

The other such information / tables provided in loading and stability manual for making a quick assessment are:

1. Standard loading / service conditions providing KG calculations, evaluation of GZ curve to check the compliance with intact stability criteria and severe wind criteria.
2. Calculation of various damaged conditions for different cargo / drafts / location to check the compliance with damage stability criteria.
3. A table or curve of transverse GM versus rolling period of the ship.
4. 'Trim tables', to find new drafts forward and aft after say 100t is loaded or discharge at any location.
5. Maximum allowable heeling moment tables in grain stability booklet.

Some of the above stated information can be found in chapter 26 where selected pages of loading and stability manual are given.

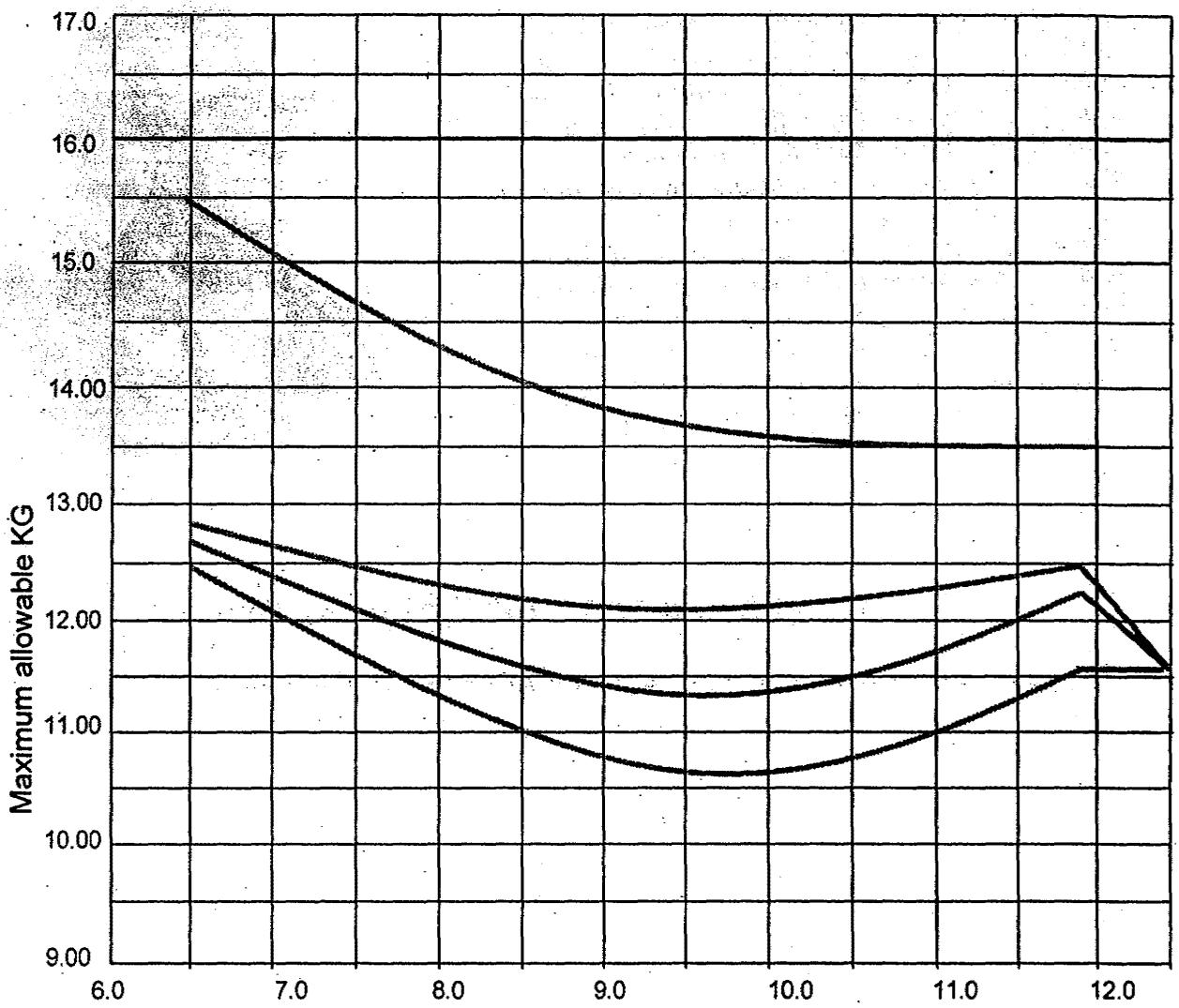

17.0
16.0
15.0
14.00
13.00
12.00
11.00
10.00
9.00
Maximum allowable KG
6.0
7.0
8.0
9.0
10.0
11.0
12.0
Draft in metre

Fig. 2

Charles Babbage, (1791-1871) was an English mathematician, philosopher, inventor and mechanical engineer who originated the concept of a programmable computer. In 1991 a perfectly functioning difference engine was constructed from Babbage's original plans. Built to tolerances achievable in the 19th century, the success of the finished engine indicated that Babbage's machine would have worked. Nine years later, the Science Museum completed the printer Babbage had designed for the difference engine, an astonishingly complex device for the 19th century. Babbage is credited with inventing the first mechanical computer that eventually led to more complex designs.



Chapter 26 Layout of a typical Stability manual

A: Selected pages from stability booklet of MV ALPHASHIP (Multipurpose General Cargo ship)

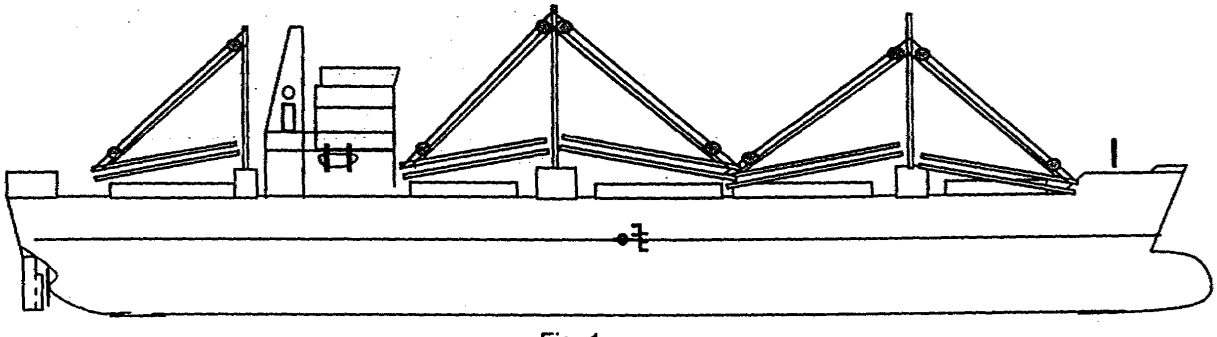


Fig. 1

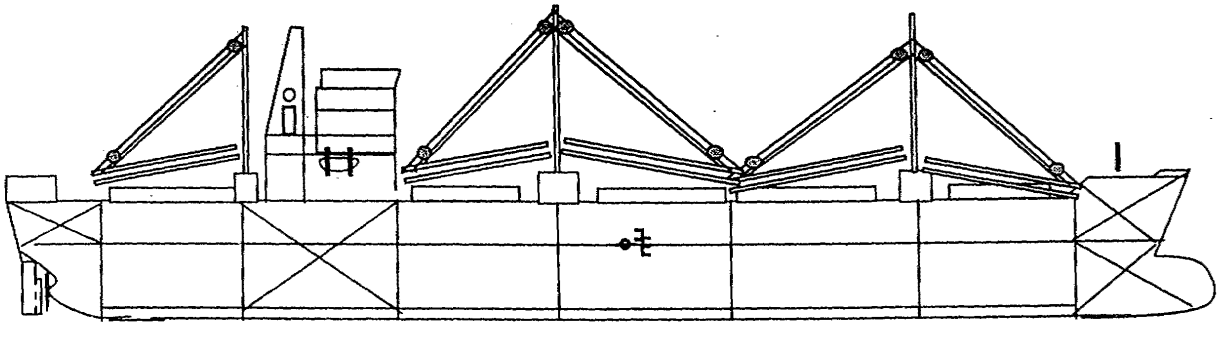


Fig. 2

GENERAL PARTICULARS

Moulded dimensions:

Length overall to extreme point on bulb:	184.758 m
Length overall to extreme point on stem:	184.17 m
Length between perpendiculars	171.792 m
Breadth moulded	24 m
Depth moulded to upper deck	12.999 m
Depth moulded to second deck	9.700 m
Summer load draught	10.156 m
Block coefficient	0.720
Light Weight	7211.6 tonnes
Displacement (summer)	30634.2 tonnes
Deadweight	22422.6 tonnes
Gross tonnage	15113.42
Net tonnage	7637.72

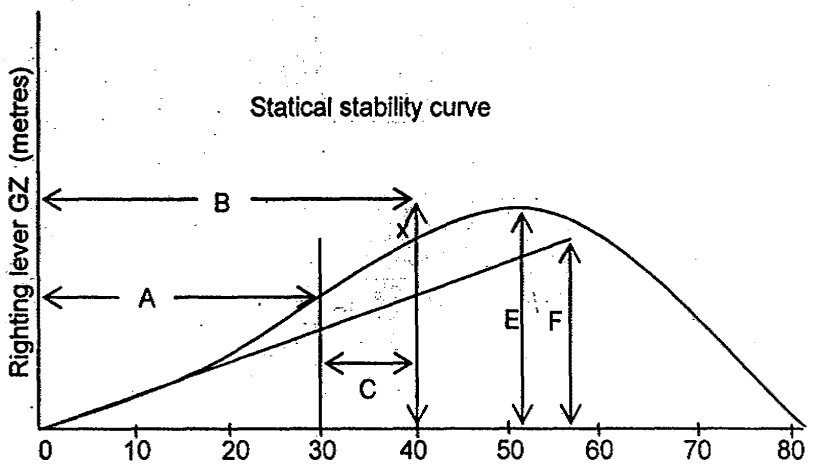


Fig. 3

Angle of inclination (degrees)

A –area under curve up to 30° to be not less than 0.055 metre radians

B - do X° -do- 0.09 -do-

C - area between 30°and X° -do- 0.03 -do-

X – 40° or lesser angle at which water could enter hull

E – Max. GZ to occur at angle not less than 30° and to be at least 0.20 metres in height.

F – initial GM to be not less than 0.15 metres (0.49 ft)

Hydrostatic particulars (in salt water) (S.G. 1.025)								
Draught B.K (metres)	Displacement (metric tonnes) i.e. 1000 Kilograms	T.P.C.I (tonnes per cm immersion)	M.C.T.C. (moment to change trim one cm)	L.C.B. F.W.D Of AP (metres)	L.C.F. F.W.D Of AP (metres)	V.C.B. Above base (metres)	K.M.(T) Transverse Metacentre A.B (metres)	K.M (L) Longl. Metacentre A.B. (metres)
2.80	7088.2	29.00	203.28	87.535	87.744	1.496	16.414	581.56
3.00	7669.2	29.26	207.2	87.549	87.757	1.604	15.702	547.82
3.20	8255.8	29.52	210.98	87.564	87.774	1.712	15.042	516.88
3.40	8848	29.736	214.48	87.577	87.774	1.822	14.438	489.3
3.60	9444.4	29.93	217.28	87.590	87.774	1.930	13.897	465.5
3.80	10043.6	30.1	219.94	87.6	87.774	2.038	13.400	443.8
4.00	10647.	30.26	222.46	87.612	87.757	2.146	12.951	424.62
4.20	11253.2	30.40	224.98	87.61	87.723	2.256	12.551	406.14
4.40	11862.2	30.54	227.36	87.620	87.672	2.366	12.194	389.76
4.60	12474.	30.674	229.32	87.622	87.620	2.472	11.885	374.5
4.80	13087.2	30.786	231.56	87.627	87.568	2.576	11.614	360.22
5.00	13703.2	30.91	233.52	87.619	87.500	2.684	11.372	346.78
5.20	14322.	31.02	235.48	87.615	87.415	2.88	11.126	334.32
5.40	14943.6	31.13	237.44	87.606	87.313	2.892	10.972	323.26
5.60	15568	31.24	239.4	87.590	87.21	2.998	10.81	312.62
5.80	16196.6	31.34	241.36	87.574	87.108	3.102	10.662	302.96
6.00	16826.6	31.83	243.6	87.554	86.971	3.204	10.531	294.84
6.20	17460.8	31.58	245.98	87.529	86.799	3.308	10.414	287
6.40	18097.8	31.72	248.5	87.499	86.611	3.412	10.311	280
6.60	18736.2	31.85	251.02	87.466	86.406	3.516	10.219	274.12
6.80	19376.	31.99	253.96	87.429	86.167	3.620	10.144	268.24
7.00	20018.6	32.13	257.32	87.385	85.927	3.724	10.071	263.2
7.20	20665.4	32.29	260.96	87.337	85.671	3.828	10.010	258.58
7.40	21316.4	40.86	264.6	87.284	85.431	3.934	9.959	254.38
7.60	21970.2	32.60	268.52	87.228	85.174	4.040	9.917	250.46
7.80	22625.4	32.77	272.44	87.169	84.936	4.144	9.878	247.24
8.00	23289.	32.95	276.36	87.105	84.714	4.252	9.849	243.74
8.20	23962.4	33.12	280.28	87.038	84.490	4.356	9.835	240.8
8.40	24637.2	33.29	284.34	86.967	84.285	4.460	9.824	238.28
8.60	25313.4	33.46	288.4	86.895	84.080	4.566	9.818	235.48
8.80	25991.	33.62	292.6	86.821	83.893	4.674	9.823	232.82
9.00	26671.4	33.79	296.52	86.745	83.721	4.782	9.830	230.44
9.20	27351.8	33.96	300.3	86.667	83.533	4.892	9.842	228.06
9.40	28033.6	34.10	304.36	86.590	83.379	5.000	9.855	225.54
9.60	28715.6	34.24	308	86.511	83.226	5.108	9.876	222.88
9.80	29408.4	34.39	311.64	86.432	83.089	5.216	9.900	220.36
10.00	30097.2	34.56	315	86.354	82.952	5.324	9.935	218.12
10.20	30785.7	34.56	319	86.351	82.770	5.436	9.960	215.68
10.40	31475.2	34.57	323.2	86.342	82.586	5.545	9.981	213.12
10.60	32166.1	34.59	327.5	86.303	82.384	5.657	10.003	210.74
10.80	32859.4	34.61	331.1	86.246	82.380	5.762	10.037	208.31
11.00	33553.1	34.65	335.4	86.208	82.200	5.871	10.064	205.87

Compartment No.	Location (frame Nos.)	Capacities		Centres of gravity			
		Bale Cu. M	Grain Cu. M	Vertical Above base	Vertical Moments m.tonnes	Long. From A.P. (m)	Long Moments about A.P m.tonnes
1 hold	212-179	1977.3	2149.1	6.14	13195.47	148.2	318496.6
2 hold	179-140	5226.8	5681.3	5.47	31076.71	123.7	702776.8
3 hold	140-109	4570.3	4967.7	5.5	27322.35	96.7	480376.6
4 hold	109-74	4532.6	4918.0	5.48	26950.64	70.3	345735.4
5 hold	13-39	2496.81	2683.4	7.60	20393.84	20.7	55546.38
Total in holds		18803.81	20399.5	5.83	118939	93.28	1902932
No. 1 Tween deck	212-179	1627.5	1769.0	12.28	21723.32	149.6	264642.4
No. 2 Tween deck	179-140	2703	2938.1	11.79	34640.2	124.6	366087.3
No. 3 Tween deck	140-109	2119.3	2303.7	11.40	26262.18	96.9	223228.5
No. 4 Tween deck	109-74	2505.5	2716.3	11.83	32133.83	68.9	187153.1
No. 5 Tween deck	13-39	1508	1689.3	11.75	19849.28	20.6	34799.58
Total in tween deck		10463.3	11416.4	11.79	134608.8	94.242	1075911
Grand total		29267.11	31815.9	7.969	253547.8	93.627	2978843

Density D.O.: 0.88 t/m^3. H.F.O.: 0.95 t/m^3

Capacities centres of gravity and free surface moment of oil and other tanks							
Compartment	Location Frame No	Capacities			Centres of gravity		Free surface moment AR S.G 1.0 (ton.m)
		100% full Cubic metres	98% full				
			Cubic metres	Tonnes AT. SG. 1.0	Vertl. A.B	Longl. From A.P	
Oil fuel tanks / ballast tanks / FW tanks							
Bulbous bows		280	274.4	274.4	3.52	167.5	28
Fore Peak	212 - FE	159	155.8	155.8	6.94	164.6	40
No . 1 D.B tank	212-179	249.6	244.6	244.6	1.19	149.5	779.3
No . 2 D.B tank P.	179-40	320.6	314.1	314.1	0.68	122.6	1335.4
No . 2 D.B tank S.	179-40	320.6	314.1	314.1	0.68	122.6	1335.4
No . 3 D.B tank P.	140-109	333.4	326.7	326.7	0.70	96.7	422.2
No . 3 D.B tank S.	140-109	333.4	326.7	326.7	0.70	96.7	422.2
No . 4 D.B tank P.	109-71	403.9	395.8	395.8	0.71	69.7	504.0
No . 4 D.B tank S.	109-71	403.9	395.8	395.8	0.71	69.7	504.0
No . 5 D.B tank S	56-72	77.2	75.7	75.7	0.91	45.2	176.7
Setting tank P.	39-43	54.4	53.3	53.3	6.3	30.0	16.7
Setting tank S.	39-43	54.8	53.7	53.7	6.45	30.0	16.7
Service tank P.	39-43	6.9	6.8	6.8	6.41	30.1	11.1
Service tank S.	39-43	54.4	53.3	53.3	6.41	30.1	11.1
Total		3052.1	2990.8	2990.8			5602.8
Diesel oil tanks / FW tanks							
No . 5 D.B tank P.	47.70	132.2	129.6	129.6	0.89	45.8	319.9
No. 6 tank P.	34-43	181.5	177.8	177.8	0.65	27.5	93
No. 6 tank S.	34-43	161.4	158.1	158.1	0.61	27.5	61.3
Service tank M.E.$_1$.	43-48	23.1	22.6	22.6	13	33.5	5.5
Service tank M.E $_2$	43-48	16.3	15.9	15.9	13	33.4	5.5
No . 7 DB tank P.	23-32	117.3	115.0	115.0	2.89	19.4	27.9
No . 7 DB tank S.	23-32	100.4	98.4	98.4	2.90	19.4	14.8
Dr W. tank P.	8-13	54	77.1	77.1	11.74	6.8	68.8
Dr W. tank S.	8-13	54	67.8	67.8	11.79	6.8	78.1
Aft peak tank	0-12	186.5	182.8	182.8	9.40	4.2	33.4
Total		1026.7	1045.1	1045.1			708.2

Right arm in metres								
Displacement In tonnes	5°	10°	15°	20°	25°	30°		Deck edge immersed
						A	B	
7000	1.504	2.958	4.347	5.519	6.432	7.663	7.663	40.4
7700	1.414	2.799	4.138	5.316	6.209	7.395	7.395	39.8
8400	1.343	2.657	3.939	5.115	5.988	7.130	7.130	39.1
9100	1.282	2.545	3.769	4.943	5.799	6.903	6.903	38.4
9800	1.230	2.436	3.616	4.777	5.616	6.684	6.684	37.7
10500	1.190	2.357	3.492	4.634	5.459	6.495	6.495	36.9
11200	1.159	2.284	3.373	4.499	5.310	6.317	6.317	36.2
11900	1.130	2.224	3.285	4.388	5.188	6.170	6.170	35.5
12600	1.104	2.172	3.209	4.285	5.075	6.034	6.034	34.9
13300	1.078	2.129	3.142	4.191	4.972	5.910	5.910	34.1
14000	1.055	2.085	3.077	4.100	4.872	5.790	5.790	33.3
14700	1.036	2.051	3.021	4.031	4.796	5.528	5.699	32.5
15400	1.022	2.025	2.982	3.977	4.736	5.459	5.628	31.7
16100	1.003	1.991	2.929	3.905	4.657	5.367	5.533	30.8
16800	0.988	1.966	2.894	3.855	4.602	5.302	5.467	30.2
17500	0.967	1.944	2.862	3.816	4.559	5.253	5.415	29.5
18200	0.960	1.923	2.834	3.779	4.518	5.205	5.366	28.7
18900	0.953	1.901	2.803	3.737	4.472	5.151	5.311	27.8
19600	0.946	1.883	2.780	3.705	4.437	5.110	5.269	27
20300	0.942	1.870	2.759	3.673	4.402	5.069	5.226	26.2
21000	0.939	1.859	2.743	3.645	4.371	5.034	5.189	25.4
21700	0.937	1.852	2.728	3.633	4.358	5.018	5.173	24.5
22400	0.936	1.841	2.716	3.617	4.340	4.998	5.152	23.6
23100	0.927	1.832	2.706	3.603	4.325	4.980	5.134	22.7
23800	0.921	1.828	2.701	3.598	4.319	4.973	5.127	21.9
24500	0.916	1.822	2.696	3.586	4.306	4.958	5.111	20.9
25200	0.917	1.823	2.700	3.585	4.305	4.957	5.110	20.2
25900	0.914	1.820	2.692	3.557	4.274	4.921	5.073	19.3
26600	0.917	1.827	2.694	3.537	4.252	4.895	5.047	18.4
27300	0.919	1.833	2.688	3.505	4.217	4.854	5.005	17.5
28000	0.920	1.844	2.68	3.476	4.185	4.817	4.966	16.7
28700	0.921	1.843	2.666	3.445	4.151	4.778	4.925	15.8
29400	0.923	1.843	2.648	3.411	4.114	4.734	4.880	14.9
30100	0.924	1.843	2.636	3.405	4.107	4.726	4.873	14.0
30800	0.926	1.842	2.628	3.395	4.096	4.714	4.859	13.1
31500	0.927	1.844	2.420	3.390	4.091	4.707	4.853	12.2

Cross curves of stability particulars								
Displacement In tonnes	Righting arm in metres							
	40°		45°		60°		75°	
	A	B	A	B	A	B	A	B
7000	9.530	9.530	9.805	9.805	9.883	9.911	9.082	9.138
7700	9.208	9.208	9.500	9.500	9.659	9.724	8.886	8.979
8400	8.890	8.890	9.197	9.197	9.408	9.526	8.691	8.837
9100	8.617	8.617	8.938	8.938	9.189	9.376	8.51	8.725
9800	8.354	8.354	8.689	8.689	8.954	9.21	8.332	8.616
10500	8.128	8.128	8.473	8.473	8.761	9.089	8.181	8.537
11200	7.914	7.914	8.270	8.270	8.597	8.957	8.076	8.464
11900	7.738	7.738	8.103	8.103	8.459	8.841	7.994	8.404
12600	7.575	7.575	7.948	7.948	8.331	8.73	7.925	8.352
13300	7.426	7.426	7.807	7.807	8.204	8.622	7.863	8.309
14000	7.282	7.282	7.670	7.670	8.086	8.518	7.805	8.265
14700	6.886	7.173	7.188	7.566	7.987	8.433	7.757	8.231
15400	6.804	7.087	7.111	7.485	7.923	8.381	7.719	8.205
16100	6.694	6.973	7.008	7.376	7.835	8.301	7.677	8.171
16800	6.618	6.894	6.936	7.301	7.769	8.244	7.643	8.146
17500	6.559	6.832	6.88	7.242	7.709	8.195	7.61	8.124
18200	6.503	6.774	6.827	7.187	7.651	8.146	7.58	8.103
18900	6.439	6.707	6.767	7.124	7.585	8.098	7.54	8.081
19600	6.390	6.656	6.722	7.075	7.532	8.064	7.503	8.063
20300	6.341	6.606	6.676	7.027	7.481	8.031	7.472	8.05
21000	6.299	6.561	6.636	6.985	7.434	7.999	7.446	8.039
21700	6.281	6.542	6.619	6.967	7.393	7.971	7.426	8.032
22400	6.256	6.517	6.596	6.943	7.337	7.93	7.4	8.021
23100	6.235	6.495	6.576	6.922	7.279	7.891	7.3	8.012
23800	6.227	6.487	6.569	6.914	7.227	7.858	7.277	8.008
24500	6.209	6.468	6.552	6.896	7.169	7.817	7.254	8.002
25200	6.208	6.466	6.550	6.895	7.119	7.783	7.239	8.003
25900	6.165	6.422	6.510	6.853	7.049	7.727	7.222	8.000
26600	6.135	6.390	6.481	6.823	6.997	7.689	7.215	8.007
27300	6.086	6.34	6.436	6.775	6.93	7.635	7.208	8.013
28000	6.042	6.294	6.394	6.731	6.866	7.587	7.203	8.024
28700	5.995	6.244	6.350	6.684	6.94	7.667	7.196	8.023
29400	5.943	6.191	6.301	6.633	6.776	7.488	7.211	8.023
30100	5.934	6.181	6.293	6.624	6.754	7.458	7.219	8.023
30800	5.919	6.165	6.278	6.609	6.743	7.453	7.212	8.022
31500	5.911	6.157	6.271	6.601	6.769	7.448	7.245	8.024

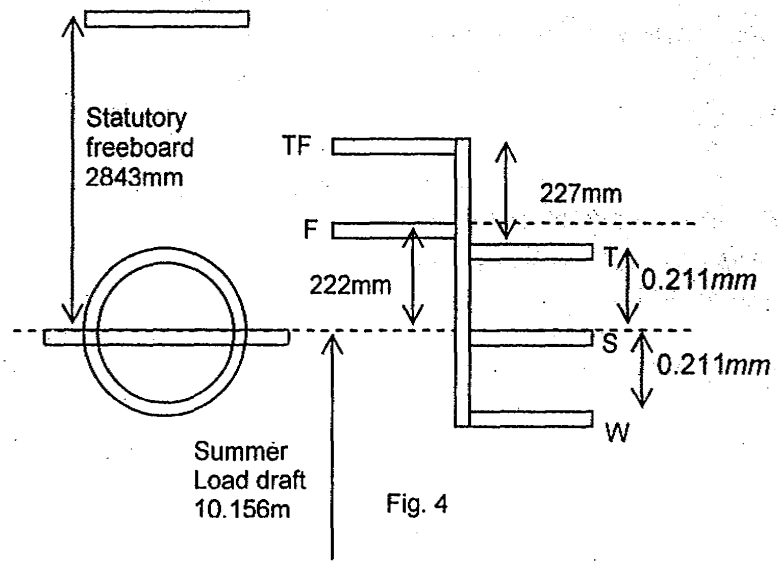


Fig. 4

Loadlines	Drafts (m)	Free board (m)	Displacement (t)	Deadweight (t)
Summer	10.156	2.843	30634.2	23422.6
Winter	9.945	3.054	29890.6	22679
Tropical	10.367	2.632	31361	24149.4
Fresh Water	10.378	2.621	30634.2	23422.6
Tropical F.W.	10.594	2.405	31361	24149.4

Following data is usable for the calculation require to be done to check whether 'severe wind criteria' are satisfied.
The wind heeling levers (l_{w1}) and (l_{w2}) are constant values at all angle of inclination and should be calculated as follows:

$$l_{w1} = \frac{PAZ}{1000g\,\Delta} \text{ m and}$$

$$l_{w2} = 1.5\, l_{w1} \text{ (m)}$$

Where,

P = 504 N/m^2. The value of P used for ships in restricted service may be reduced subject to the approval of the administration;

A = projected internal area of the portion of the ship and deck cargo above the waterline (m^2);

Z = vertical distance from the centre of A to the centre of the underwater lateral area or approximately to a point at one half the draught (m);

Δ = displacement (t)

g = 9.81 m/s^2

The angle of roll (θ_1) should be calculated as follows

$\theta_1 = 109k\, X_1\, X_2\, \sqrt{rs}$ (degrees)

where,

X_1 = factor as shown in table 1

X_2 = factor as shown in table 2

k = factor as follows:

k = 1.0 for a round bilged ship having no bilge or bar keels
k = 0.7 for a ship having sharp bilges
k = as shown in table 3 for a ship having bilge keels a bar keel or both.

$r = 0.73 +/- 0.6 \frac{OG}{d}$

OG = distance between the centre of gravity and the waterline (m) (+if the centre of gravity is above the waterline, - if it is below)
d = mean moulded draught of the ship (m)
s = factor as shown in table 4

Table 1 – values of factor X_1

B/d	X_1
≤ 2.4	1.0
2.5	0.98
2.6	0.96
2.7	0.95
2.8	0.93
2.9	0.91
3.0	0.90
3.1	0.88
3.2	0.86
3.4	0.82
≥ 3.5	0.80

Table 2 values of factor X_2

C_b	X_2
≤ 0.45	0.75
0.50	0.82
0.55	0.89
0.60	0.95
0.65	0.97
≥ 0.70	1.0

Table 3 – values of factor k

$A_k \times 100 / L \times B$	k
0	1.0
1.0	0.98
1.5	0.95
2.0	0.88
2.5	0.79
3.0	0.74
3.5	0.72
≥ 4. 0	0.70

table 4 = values of factors

T	s
≤ 6	0.100
7	0.098
8	0.093
12	0.065
14	0.053
16	0.044
18	0.038
≥ 20	0.035

(Intermediate values in these tables should be obtained by linear interpolation)

Rolling period $T = \frac{2CB}{\sqrt{GM}}$ (s)

Where: C = 0.373 + 0.023 (/b/d) – 0.043 (L/100)
The symbols in the above tables and formula for the rolling period are defined as follows
L = waterline length of the ship (m)
B = moulded breadth of the ship (m)
d = mean moulded draught of the ship (m)
C_B = block coefficient
A_k = total overall area of bilge keels, or area of the lateral projection of the bar keel or sum of these areas (m^2).
GM = metacentric height corrected for free surface effect (m).

Condition No-1 ship in ballast departure calculation of displacement, K.G / L.C.G condition.							
Items	Con-tent	Weight tonnes	K.G. (m).	Vert. Moments m.t	L.C.G Ford (A.P)	Long. Moments m.t	Free surface m.t
Fore peak tank	W.B	20	6.94	138.8	164.6	3292	41
No. 1 D.B. tank	H.F.O	237.1	1.19	282.1	149.5	42173.95	-
No. 2 D.B. tank P & S	H.F.O	300.0	0.68	204	122.6	36780	2537.4
No. 3 D.B. tank P. S	H.F.O	633.5	0.70	443.4	96.7	42876.78	-
No. 4 D.B. tank P & S	W.B	300	0.71	213	69.7	20910	1033.8
No. 5 D.B. tank P.	D.O	116.3	0.89	103.5	45.2	4678.2	-
No. 5 D.B. tank S.	-	-	-	-	-		-
HFO settling & Ser Tks. P & S	H.F.O	196.5	6.4	1257.6	30.1	37853.76	32.3
D.O settlg & Ser tks	D.O	24	13	312.0	33.5	10452	9.7
No. 7 tanks P & S	D.O.	100	2.9	290.0	23.2	6728	37.8
Dr W tanks P & S	F.W.	90	11.8	1062.0	5.8	6159.6	147
No. 1 Hold	-						
No. 2 Hold	-	-	-	-	-	-	-
No. 3 Hold	-	-	-	-	-	-	-
No. 4 Hold	-	-	-	-	-	-	-
No. 5 Hold	-	-	-	-	-	-	-
No. 1 Tween deck	-	-	-	-	-	-	-
No. 2 Tween deck	-	-	-	-	-	-	-
No. 3 Tween deck	-	-	-	-	-	-	-
No. 4 Tween deck	-	-	-	-	-	-	-
No. 5 Tween deck	-	-	-	-	-	-	-
Bulbus bow	W.B.	287	3.52	1010.2	167.5	48072	
Deck cargo							
Crew and effects		14	16	224	45.6	638.4	
Stores spares & provisions		96	13.2	1267.2	78.4	7526.4	
Dead weight		2414.4					
Light ship		7211.6	9.123	65791.4	66.5	479571.4	
Displacement		9626	7.542	72599.2	77.676	747712.5	3839

Displacement = 9626 tonnes
L.C.G from A.P = 77.676 m.
L.C.B from A.P = 87.6 m.
L.C.F from A.P = 87.774
M.C.T.C. = 218.08 m.t

trim by stern = 4.380
hydrostatic draft = 3.660
draft at F.P = 1.150
draft at A.P = 5.530

KM = 13.476
KG = 7.542
GM (solid) = 5.934
FSC = 0.399
GM (fluid) = 5.535 m
KG_{FL} 7.941m

θ	5°	10°	15°	20°	25°	30°	35°	40°
Sin θ	0.087	0.174	0.259	0.342	0.423	0.500	0.574	0.643
KN from curve	1.243	2.463	3.654	4.818	5.661	6.738	7.582	8.419
- KG_{FL} Sin θ	0.691	1.382	2.057	2.716	3.359	3.970	4.558	5.106
GZ = (KN-KG_{FL} sin θ	0.552	1.081	1.597	2.102	2.302	2.768	3.024	3.313
Simpson multipliers	4	2	4	2	4	1	Sum	
products	2.208	2.162	6.388	4.204	9.208	2.768	26.938	

1	4	1	sum
2.768	12.096	3.313	18.177

Area under GZ curve upto 30° = $\frac{5}{3} \times \frac{1}{57.3}$ x 26.938 = 0.784 m-rad

Between 30° and 40° = $\frac{5}{3} \times \frac{1}{57.3}$ x 18.177 = 0.529 m-rad

Total area to 40° = 1.313 m-rad

Heel	5°	10°	15°	20°	25°	30°	35°	40°	45°	60°	75°
GZ	0.552	1.081	1.597	2.102	2.302	2.768	3.024	3.313	3.135	2.374	0.973

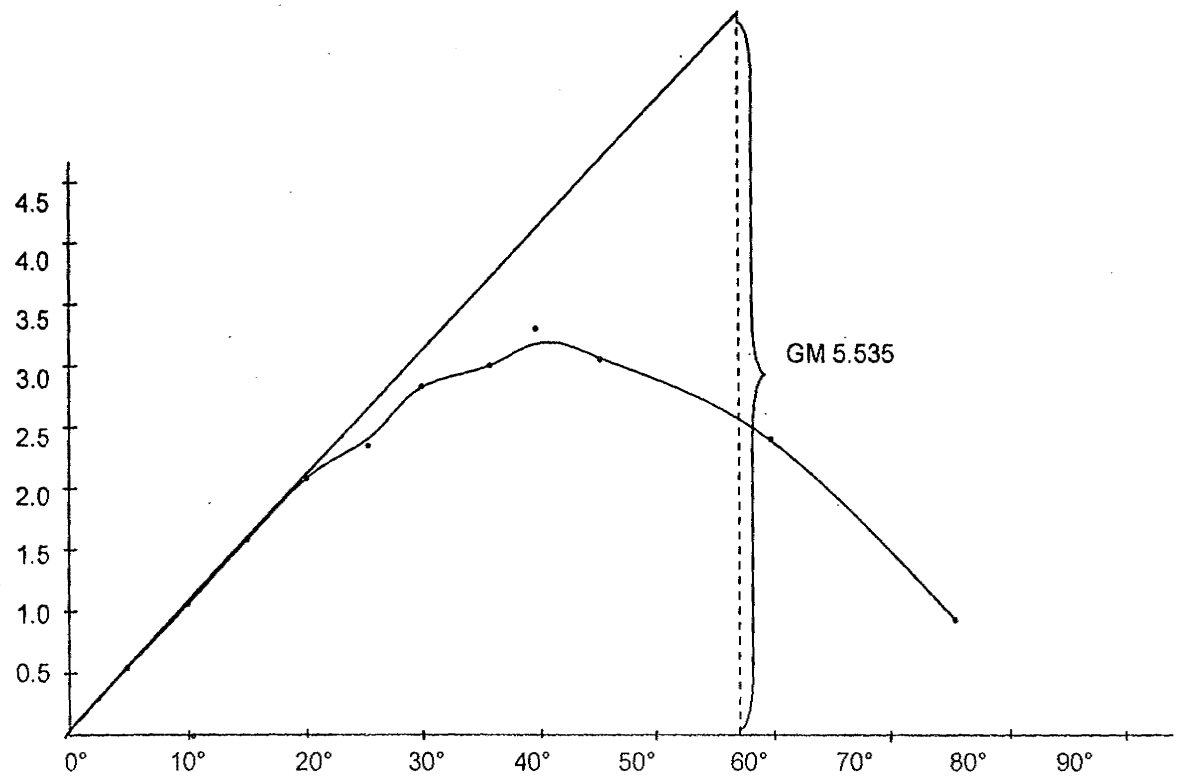


Fig. 5

The data of M V ALPHA SHIP required for the severe wind criterion is as follows in condition 1. A = area 1860 m^2, centre of Windage 8.2 m above water level. k = 1 as the ship has no bilge keels. Hydrostatic draft considered as moulded draft. Moulded breadth 24m, C_b = 0.71, length at waterline 179 m Angle of flooding 44°.

KB = 1.962 ∴vertical distance from COB to waterline = 3.66 – 1.962 = 1.698m.
∴Z = 8.2 + 1.698 = 9.898m

$$l_{w1} = \frac{PAZ}{1000g\Delta} = \frac{504 \times 1860 \times 9.898}{1000 \times 9.81 \times 9626} = 0.098\,m$$

l_{w2} = 0.098 x 1.5 = 0.147m

$\theta_1 = 109k\,X_1\,X_2\,\sqrt{rs}$ (degrees)
k = 1 (from table 3)
$\frac{B}{d} = \frac{24}{3.66} = 6.56 \therefore X_1 = 0.8$ (from table 1)
X_2 = 1 (from table 2)
$r = 0.73 +/- 0.6\,\frac{OG}{d}$
OG = KG – draft = 7.542 – 3.66 = 3.882 m

$$\therefore r = 0.73 + 0.6 \times \frac{3.882}{3.66} = 1.366\text{ m}$$

Rolling period $T = \frac{2CB}{\sqrt{GM}}$ (s)
Where: C = 0.373 + 0.023 (/b/d) – 0.043 (L/100)

$$\therefore C = 0.373 + 0.023 \times \frac{24}{3.66} - 0.043 \times \frac{179}{100} = 0.601$$

$$T = \frac{2CB}{\sqrt{GM}} = \frac{2 \times 0.601 \times 24}{\sqrt{5.535}} = 12.262$$

∴ s = 0.063 (from table 4)

$$\therefore \theta_1 = 109 \times 1 \times 0.8 \times 1 \times \sqrt{1.366 \times 0.063} = 25.5°$$

For the area a the ordinates at 2° (lee ward side), at 11° & 24° (to wind ward side) are 0,1.3m and 2.6 m respectively. The uniform distance between the ordinates is 13°. Using the Simpson's 1st rule the area $a = \frac{13}{3} \times \frac{1}{57.3}(0 + 3 \times 1.3 + 2.6) = 0.492\ m^c$.

For the area b the ordinates of the curve on lee ward side at 2°, 23° and 44° are 0, 2.5m and 2.75 respectively with uniform distance between the ordinates as 21°.

Using the Simpson's 1st rule the area $b = \frac{21}{3} \times \frac{1}{57.3}(0 + 3 \times 2.5 + 2.75) = 1.252 m^c$.

It is found that area b > area a and steady wind equilibrium angle is not large. (Large angle means 16° or 80 % of deck edge immersion)

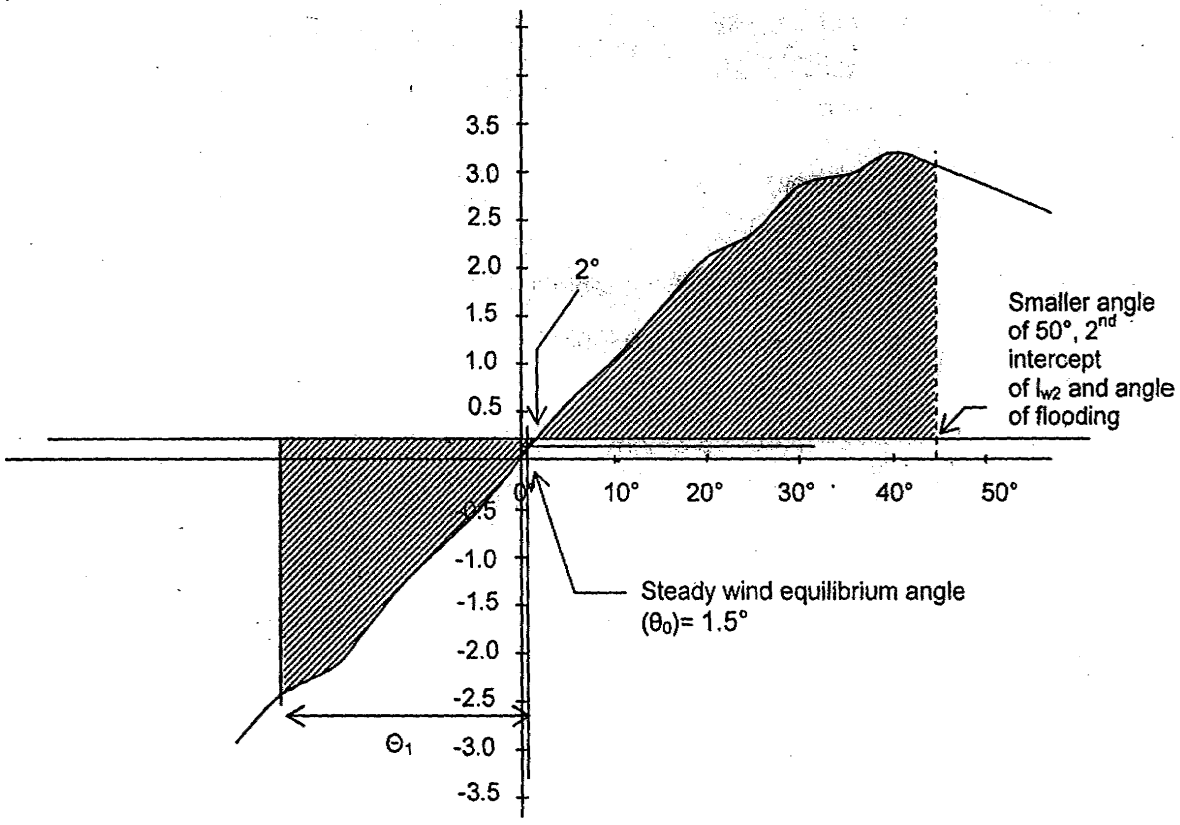

3.5
3.0
2.5
2.0
1.5
1.0
0.5
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
2°
0°
10°
20°
30°
40°
50°
Smaller angle of 50°, 2nd intercept of l_{w2} and angle of flooding
Steady wind equilibrium angle (θ_0)= 1.5°
Θ_1

Fig. 6

Condition No-2 Summer load Calculation of displacement, K.G / L.C.G condition.							
Items	Con-tent	Weight tonnes	K.G.(m).	Vert. Moments m.t	L.C.G Ford (A.P)	Long. Moments m.t	Free surface m.t
Fore peak tank							
No. 1 D.B. tank	H.F.O	237.1	1.19	282.1	149.5	42173.95	-
No. 2 D.B. tank P & S							
No. 3 D.B. tank P. S	H.F.O	633.5	0.70	443.45	96.7	42876.78	-
No. 4 D.B. tank P & S	H.F.O	300	0.71	213	69.7	20910	957.6
No. 5 D.B. tank P.	D.O	116.3	0.89	103.507	45.2	4678.2	-
No. 5 D.B. tank S.	H.F.O	60	0.91	54.6	45.2	2712	167.9
HFO settling & Ser Tks. P & S	H.F.O	196.5	6.4	1257.6	30.1	37853.76	32.3
D.O settling & Ser tanks	D.O	24	13	312	33.5	10452	9.7
No. 7 tanks P & S	D.O.	100	2.9	290	23.2	6728	37.8
Dr W tanks P & S	F.W.	90	11.8	1062	5.8	6159.6	147
No. 1 Hold		1109	6.14	8037.26	148.2	164353.8	
No. 2 Hold		4394	5.47	24035.18	123.7	543537.8	-
No. 3 Hold		3488	5.5	19184	96.7	337289.6	-
No. 4 Hold		3918	5.48	21470.64	70.3	275435.4	-
No. 5 Hold		1804	7.60	12190.4	20.7	37342.8	-
No. 1 Tween deck		942	12.28	11567.76	149.6	140923.2	-
No. 2 Tween deck		1563	11.79	18427.77	124.6	194749.8	-
No. 3 Tween deck		1620	11.40	18468	96.9	156978	-
No. 4 Tween deck		1347.2	11.83	15937.38	68.9	92822.08	-
No. 5 Tween deck		1370	11.75	16097.5	20.6	28222	-
Bulbus bow							
Deck cargo							
Crew and effects		14	16	224	45.6	638.4	
Stores spares & provisions		96	13.2	1267.2	78.4	7526.4	
Dead weight		1867.4					
Light ship		7211.6	9.123	65791.43	66.5	479571.4	
Displacement		30634.2	7.727	236716.8	85.98	2633929	1352.3

Cargo = 21555.2t

LCB = 86.352m

$$Tr = \frac{(85.98 \sim 86.352) \times 30634.2}{100 \times 318.12} = 0.358m$$

Displacement	=	30634.2 tonnes	trim by stern	= 0.358 m
L.C.G from A.P	=	85.98 m	hydrostatic draft	= 10.156 m
L.C.B from A.P	=	86.352 m	draft at F.P	= 9.971 m
L.C.F from A.P	=	82.810 m	draft at A.P	= 10.328 m
M..C.T.C.	=	317.34 m. t		

TRIMMING MOMENT = 11395.9m. t
KM = 9.955 m
KG = 7.727 m
GM (solid) = 2.228 m
FSC = 0.044 m
GM (fluid) = 2.184 m

Sin θ	5°	10°	15°	20°	25°	30°	35°	40°	
Sin θ	0.087	0.174	0.259	0.342	0.423	0.500		0.643	
KN from curve	0.925	1.842	2.63	3.397	4.099	4.863		6.17	
- KG Sin θ	0.672	1.344	2.001	2.642	3.268	3.863		4.968	
GZ = (KN-KG sin θ	0.253	0.498	0.629	0.755	0.833	1.000	1.105	1.203	
Simpson multipliers	4	2	4	2	4	1	Sum		
products	1.012	0.996	2.516	1.51	3.332	1.000	10.366		
						1	4	1	sum
						0.812	4.42	1.203	6.435

Area under

GZ curve upto 30° = $\frac{5}{3} \times \frac{1}{57.3} \times 10.366 = 0.302$ m-rad

Between 30° and 40° = $\frac{5}{3} \times \frac{1}{57.3} \times 6.435 = 0.187$ m-rad

Total area to 40° = 0.489 m-rad

Heel	5°	10°	15°	20°	25°	30°	35°	40°	45°	60°	75°
GZ	0.253	0.498	0.629	0.755	0.833	1.000	1.105	1.203	1.148	0.762	0.558

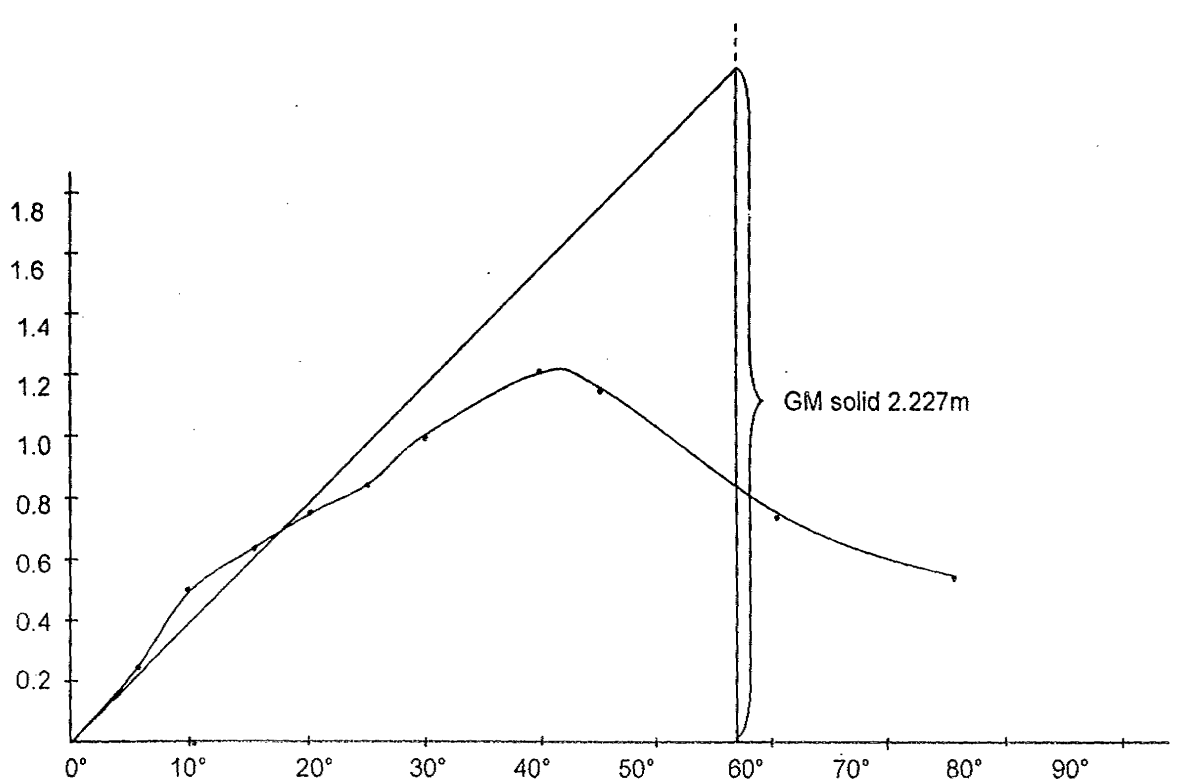


Fig. 7

The data of M V ALPHA SHIP required for the severe wind criterion is as follows in condition 2. A = area 1120 m^2, centre of Windage 5.2 m above water level. k = 1 as the ship has no bilge keels. Hydrostatic draft considered as moulded draft. Moulded breadth 24m, C_b = 0.72, length at waterline 172 m Angle of flooding 26°.

KB = 5.408 ∴vertical distance from COB to waterline = 10.156 – 5.408 = 4.748 m.

∴Z = 5.2 + 4.748 = 9.948m

$$l_{w1} = \frac{PAZ}{1000g\Delta} = \frac{504 \times 1120 \times 9.948}{1000 \times 9.81 \times 30634.2} = 0.019\,m$$

Steady wind heel = 0.9°

l_{w2} = 0.019 x 1.5 = 0.028m

k = 1 (from table 3)

$\frac{B}{d} = \frac{24}{10.156} = 2.36$ $X_1 = 1$ (from table 1)

$X_2 = 1$ (from table 2)

$r = 0.73 +/- 0.6 \frac{OG}{d}$

OG = KG – draft = 7.727 – 10.156 = -2.429 m

$\therefore r = 0.73 - 0.6 \times \frac{2.429}{10.156} = 0.586$ m

Rolling period $T = \frac{2CB}{\sqrt{GM}}$ (s)

Where: C = 0.373 + 0.023 (/b/d) – 0.043 (L/100)

$$\therefore C = 0.373 + 0.023 \times \frac{24}{10.156} - 0.043 \times \frac{172}{100} = 0.353$$

$$T = \frac{2CB}{\sqrt{GM}} = \frac{2 \times 0.353 \times 24}{\sqrt{2.184}} = 11.465$$

∴ s = 0.069 (from table 4)

$\theta_1 = 109k\,X_1\,X_2\,\sqrt{rs}$ (degrees)

$\therefore \theta_1 = 109 \times 1 \times 1 \times 1 \times \sqrt{0.586 \times 0.069} = 21.9°$

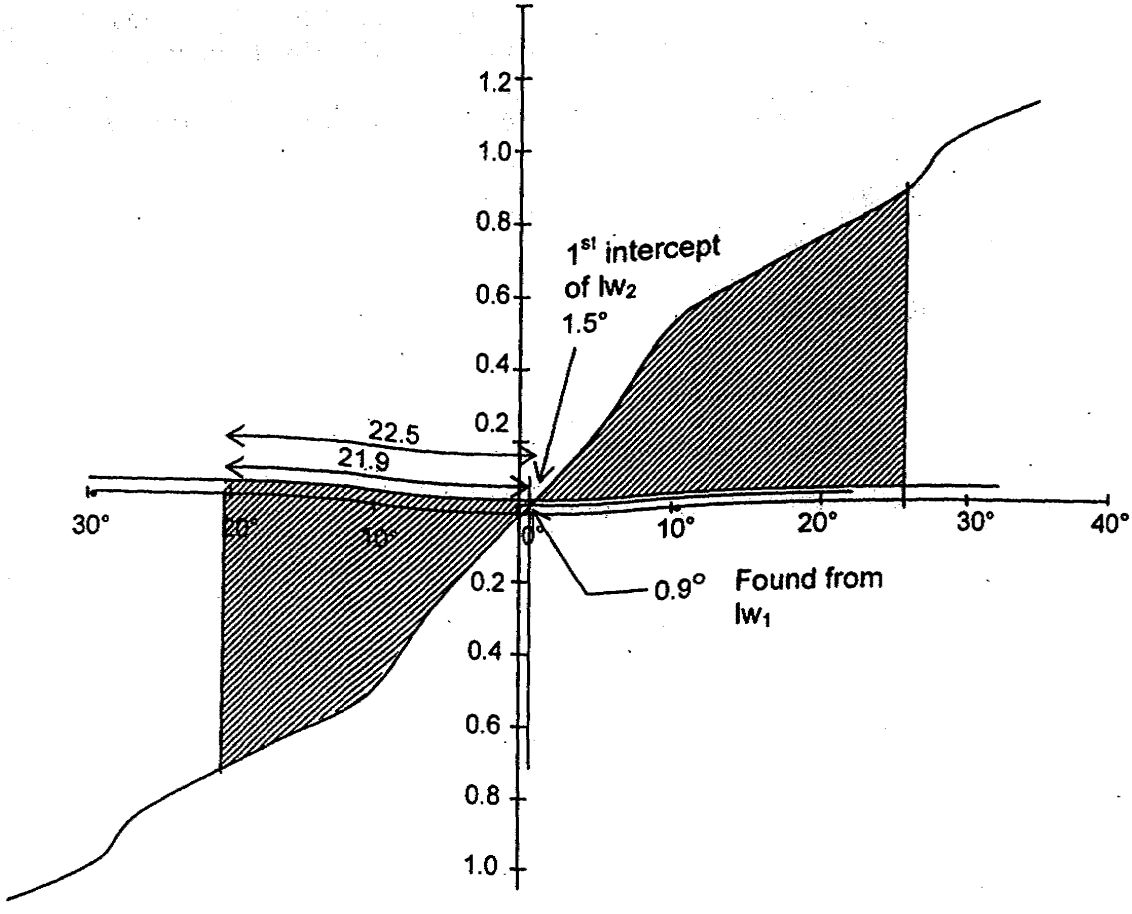


Fig. 8

To find areas a and b:

For the area a the ordinates at 1.5° (lee ward side), at 9.75° & 21° (to wind ward side) are 0,0.58 m and 0.82 m respectively. The uniform distance between the ordinates is 11.25°. Using the Simpson's 1st rule the area a = $\frac{11.25}{3} \times \frac{1}{57.3}(0 + 3 \times 0.58 + 0.82) = 0.168\ m^c$.

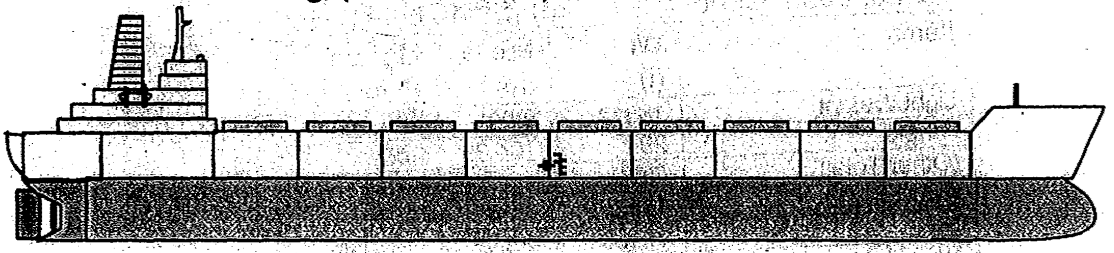
For the area b the ordinates of the curve on lee ward side at 1.5°, 13.75° and 26° are 0, 0.58 m and 0.81respectively with uniform distance between the ordinates as 12.25°.

Using the Simpson's 1st rule the area b = $\frac{12.25}{3} \times \frac{1}{57.3}(0 + 3 \times 0.58 + 0.81) = 0.182 m^c$.

It is found that area b > area a and steady wind equilibrium angle is not large. (Large angle means 16° or 80 % of deck edge immersion)

Note: A student must answer the following question to get some idea in respect of trim and stability calculations of a bulk carrier

B: MV Bravo 269 m long (bulk carrier)



DIMENSIONS:-

Length (over all)	269.00 m
Length (between perpendiculars)	258.00 m
Breadth (molded)	46.000 m
Depth (molded)	23.900 m
Draft on summer freeboard	16.858 m

Air pipe (AP) and access hatch (AH) etc

Name	Length (From AP.)	OFF C/L.	Height (Above BL)
F.P.Tk. A/P	248.700	17.500	25.890
Bosun Store Vent	249.700	16.800	25.990
No.1 Tst. A.P.(F)	247.500	10.730	26.230
No.1 Tst. A.P.(A)	201.200	10.730	25.500
No.2 Tst. A.P.(F)	200.800	10.730	25.500
No.2 Tst. A.P.(A)	154.500	10.730	25.500
No.3 Tst. A.P.(F)	154.100	10.730	25.500
No.3 Tst. A.P.(A)	107.800	10.730	25.500
No.1 Hold A.H.(F)	247.800	8.400	28.190
No.2 Hold A.H.(F)	225.100	9.500	25.400
No.3 Hold A.H.(F)	201.800	9.500	25.400
No.3 Hold A.H.(A)	178.400	8.000	25.430
No.5 Hold A.H.(F)	155.100	8.000	25.430
No.4 Tst. A.P.(F)	107.385	10.730	25.500
No.4 Tst. A.P.(A)	61.095	10.730	25.500
No.5 Tst. A.P.(F)	60.895	10.730	25.500
No.5 Tst. A.P.	37.750	10.730	25.500
Deep Fot. A.P.	25.750	13.810	25.320
D.O.T.K. A.P.	21.750	13.810	25.320
F.V.Tk. A.P.	12.950	12.190	25.420
A.P.Tk. A.P.	12.550	13.600	25.330
No.5 Hold A.H.(F)	155.100	8.000	25.430
No.6 Hold A.H.(F)	131.800	9.500	25.400
No.7 Hold A.H.(F)	108.400	9.500	25.400
No.8 Hold A.H.(F)	85.100	9.500	25.400
No.9 Hold A.H.(F)	61.700	8.000	25.430

Note:-
Coaming height (On upper deck)
Air pipe 760m/m
Access trunk 600m/m

Cond.No.1 Homo. Load. Cond. (D=17.6m) (Sf=40.6cf/Lt) Half Bunker Departure

Items	Wt (t)	Mid G (m)	Moment (t.m)	Kg (m)	Moment (t.m)	Fsm. (t.m)
Light Weight	18812	9.00	169308	12.51	235338	0
Others	294	104.29	30661	9.83	2890	142
(Other Total)	(294)		(30661)		(2890)	(142)
No.1 Hold	14828	-105.92	-1570581	13.95	206851	0
No.2 Hold	17123	-83.16	-1570581	13.44	230133	0
No.3 Hold	16871	-60.02	-1012597	13.44	226746	0
No.4 Hold	16674	-36.53	-609101	13.43	223932	0
No.5 Hold	16947	-13.00	-220311	13.43	227598	0
No.6 Hold	17143	10.21	175030	13.44	230402	0
No.7 Hold	17143	33.55	575147	13.44	230402	0
No.8 Hold	17070	56.87	970771	13.47	229933	0
No.9 Hold	15569	80.12	1247388	14.30	222637	0
(Cargo Total)	(149368)		(-1868202)		(2028634)	(0)
Fore Peak Tank	0					
No.1 T&B S.Tk. (P)	0					
No.1 T&B S.Tk. (S)	0					
No.2 T&B S.Tk. (P)	0					
No.2 T&B S.Tk. (S)	0					
No.3 T&B S.Tk. (P)	0					
No.3 T&B S.Tk. (S)	0					
No.4 T&B S.Tk. (P)	0					
No.4 T&B S.Tk. (S)	0					
No.5 T&B S.Tk. (P)	0					
No.5 T&B S.Tk. (S)	0					
Aft Peak Tank	0					
No.2 Hold (P.U.)	0					
No.4 Hold (W.B.)	0					
No.6 Hold (P.U.)	0					
N0.7 Hold (P.U.)	0					
No. Hold (P.U.)	0					
(W.B. Total)	0					
Slop Tank (P)	0					
Slop Tank (S)	0					
(Slop Total)	0					
No.1 Fuel Oil Tank	0					
No.2 Fuel Oil Tank	0					
No.3 Fuel Oil Tank, 12	38	59.04	2244	0.14	5	495
No.4 Fuel Oil Tank, 95	282	81.57	23003	1.09	307	486
Deep Fuel O.Tk.(P), 95	849	97.91	83126	17.42	14790	415
Deep Fuel O.Tk.(S), 95	795	98.05	77950	17.20	13674	315
Fuel O.Serv.Tk.(S), 76	20	94.05	1881	19.96	399	1
Fuel O.Sett.Tk.(S), 78	19	97.25	1848	19.85	377	1
(F.O. Total),	(2003)		(190052)		(29552)	(1693)
Diesel Oil Tk. (P), 52	46	106.80	4913	18.82	866	49
Diesel Oil Tk. (S), 52	46	106.80	4913	18.82	866	49
(D.O. Total)	(92)		(9826)		(1732)	(98)
Fr Water Tk.(P), 55	154	112.76	17365	19.42	2991	135
Fr Water Tk.(S), 55	154	112.76	17365	19.42	2991	135
(F.W. Total)	(308)		(34730)		(5982)	(270)
Total	170877	-8.39	-1433625	13.48	2304128	2203

Displacement (t)	170877	Mid G (m)	-8.39	KM (m)	19.15
Corresp. Draft (m)	16.796	Mid B (m)	-8.232	K G (m)	13.48
Fore Draft (m)	16.861	MCTC (T-M)	2041.5	G M (m)	5.67
Aft Draft (m)	16.729	Mid F (m)	-0.222	Go_g (m)	0.013
Trim (m)	-0.132	TPC	111	Go_m (m)	5.657
				Kg_o (m)	13.493

θ \ θ	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	70.0	80.0	90.0
KN	1.673	3.354	5.050	6.726	8.180	9.442	10.55	11.51	12.29	12.89	13.33	13.63	13.81	13.50	12.75
Sin θ	0.087	0.173	0.258	0.342	0.422	0.5	0.573	0.642	0.707	0.766	0.819	0.866	0.939	0.984	1
KG_f Sin θ	1.176	2.342	3.491	4.614	5.702	6.746	7.739	8.673	9.540	10.33	11.05	11.68	12.67	13.28	13.49
GZ	0.496	1.011	1.558	2.111	2.478	2.696	2.811	2.838	2.755	2.563	2.284	1.947	1.133	0.213	-0.742

Go_m (m) = 5.657m
GZ maximum = 2.838 m

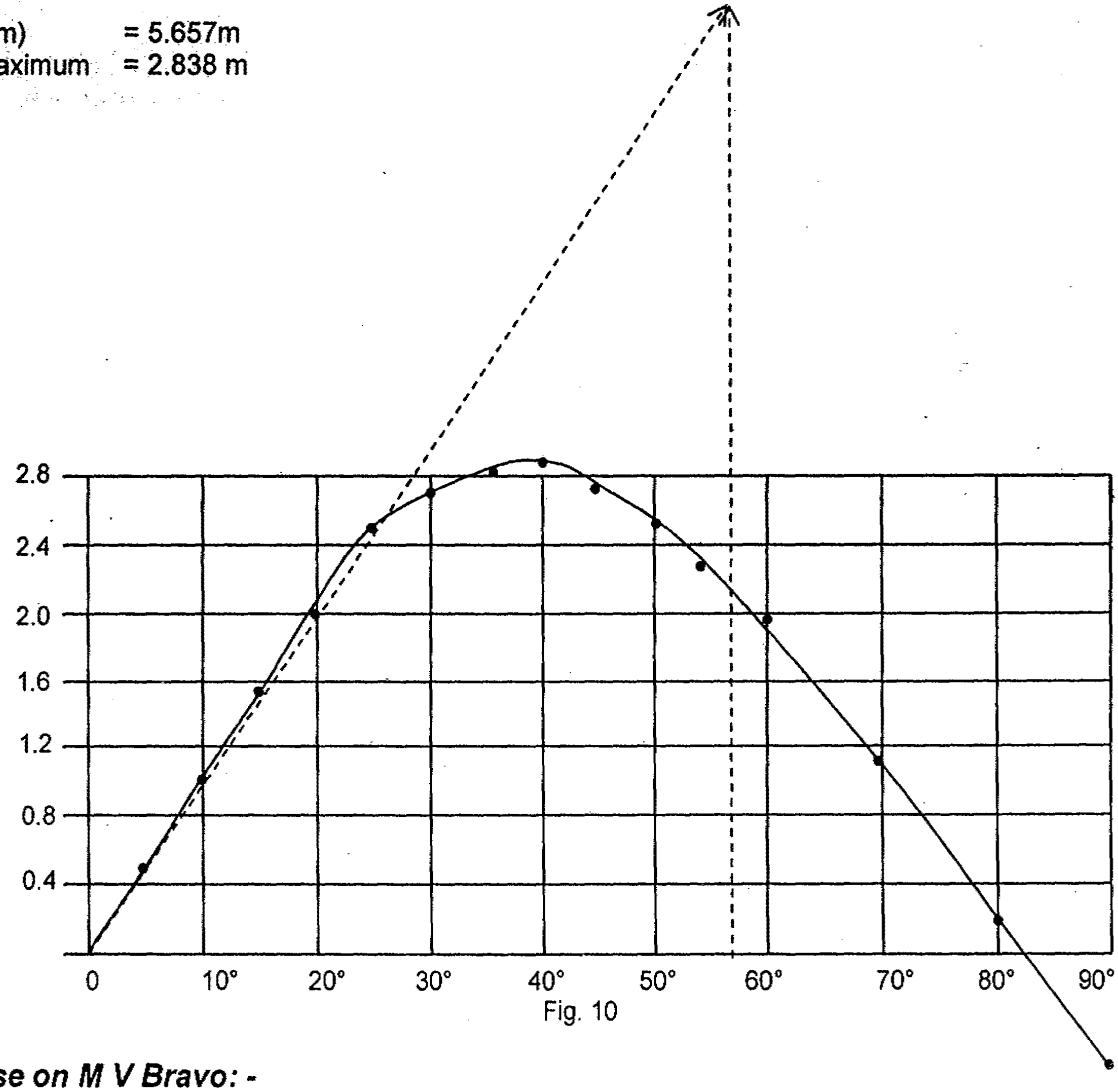


Fig. 10

Exercise on M V Bravo: -

Q. 1 State the details about the air pipes of No 4 top side tank.

Q. 2 State the details about the access hatch of hold No 7.

Q. 3 Calculate the drafts forward and aft of M V Bravo if 2000t are discharged from hold No 3 and 7 each and 500t are discharged from hold nr. 9. Also find the GM_T after above operation is carried out.

Q. 4 Calculate the draft forward and aft if the cargo distribution in holds 1 to 9 is 12000t, 16500t, 16300t, 17000t, 17904t, 16800t, 17100t, 17200t,15700t total bunkers and fresh water location and weights are same as condition 1.

Q. 5 Number 5 top side tank is filled up completely with sea water ballast. Capacity of the tank is 1800t and has a KG of 19m, LCG 37.8m and has CG 16.5m off centreline. Find the resultant list and drafts forward and aft.

Q. 6 M V Bravo has drafts forward 14.8m aft 16.00m, midships 15.2m. Find the displacement and the cargo on board if constant, stores, fresh water, bunkers total up to 3400t.

Q. 7 The following drafts were read on gauges of M V Bravo. Forward 13.64m, aft 14.36m and midships 14.20m find the displacement, LCG and GM_f if the KG is 14.2m.

Q. 8 M V Bravo is floating in salt water and has a displacement of 150000t and COG is 6m forward of midships. Find the drafts forward and aft and also the new draft when the vessel moves to a fresh water dock.

Q. 9 M V Bravo is floating at a hydrostatic draft 13.25m, KG 14m. With the help of the hydrostatic curve provided draw the GZ curve and confirm whether the intact stability criteria are being satisfied.

Q. 10 M V Bravo floating at a fresh water dock at even keel draft of 16.9m. What will be the drafts and GM upon entering salt waters?

Q. 11 M V Bravo loading concentrates is at an intermediate draft forward 12.76 and aft 14.42. The loadings to be done in the next run are 4000t in hold 5, 3000t in hold 2 and 4000t in hold 7. During this run 2000t each is removed from DB tanks 2 port, starboard and 4th port, starboard. Find the approximate drafts at the end of run. (Use the following trim table)

Trim Table (for 100 m. tonnes loading) (unit = cm)

Items	Mean Draft	12.0 m	13.0 m	14.0 m	15.0 m
No.1 D.B T. (P/S)	F.P.	3.25	3.22	3.20	3.18
	A.P.	-1.48	-1.44	-1.41	-1.37
No.2 D.B T. (P/S)	F.P.	2.44	2.43	2.42	2.40
	A.P.	-0.65	-0.63	-0.62	-0.60
No.3 D.B T. (P/S)	F.P.	1.64	1.65	1.65	1.62
	A.P.	0.16	0.15	0.15	0.15
No.4 D.B T. (P/S)	F.P.	0.85	0.87	0.88	0.89
	A.P.	0.98	0.94	0.92	0.90
No.5 D.B T. (P/S)	F.P.	0.06	0.09	0.11	0.13
	A.P.	1.79	1.73	1.69	1.65
No.6 D.B T. (P/S)	F.P.	-0.72	-0.68	-0.65	-0.62
	A.P.	2.59	2.51	2.45	2.39
No.2 hold	F.P.	2.44	2.43	2.42	2.40
	A.P.	-0.65	-0.63	-0.62	-0.60
No.5 hold	F.P.	0.85	0.87	0.88	0.39
	A.P.	0.97	0.94	0.92	0.90
No.8 hold	F.P.	-0.80	-0.75	-0.72	-0.69

Note: A student must answer the following question to get some idea in respect of trim and stability calculations of a tanker

C: Selected pages from stability booklet of M. T. T A N G O (Tanker)

Principle Particulars & Dimensions

Ship's Name	M.T. Tango
Keel Laid	July 94
Kind of Cargo	Crude Oil Carrier, Flush Decker, Ocean Going.
Length (O.A.)	269.00 m
Length (P.P.)	258.00 m
Breadth (Mld.)	46.000 m
Depth (Mld)	23.900 m
Draft (Summer FB)	16.858 m (Preliminary)

Trim Table (for 100 m. tons loading)
(Unit = cm)

Item	Mean Draft	11.0 m	12.0 m	13.0 m	14.0 m	15.0 m
Aft Peak Tank	F.P.	-2.62	-2.52	-2.42	-2.32	-2.23
	A.P.	4.91	4.69	4.49	4.30	4.14
No.1 Deep F.O.T (P)	F.P.	-1.63	-1.54	-1.46	-1.39	-1.32
	A.P.	3.81	3.63	3.48	3.33	3.21
No.1 Deep F.O.T (S)	F.P.	-1.63	-1.54	-1.46	-1.39	-1.32
	A.P.	3.81	3.63	3.48	3.33	3.21
No.2 Deep F.O.T. (P)	F.P.	-1.88	-1.79	-1.71	-1.62	-1.55
	A.P.	4.09	3.90	3.74	3.58	3.45
No.2 Deep F.O.T (S)	F.P.	-1.90	-1.81	-1.73	1.64	-1.57
	A.P.	4.11	3.93	3.76	3.60	3.47
H.F.O. Sett.Tank	F.P.	-1.81	-1.72	-1.64	-1.56	-1.49
	A.P.	4.01	3.83	3.66	3.51	3.38
H.F.O. Serv. Tank	F.P.	-1.69	-1.61	-1.52	-1.45	-1.38
	A.P.	-3.88	3.70	3.54	3.39	3.27
No.1 Diesel O.Tk.	F.P.	-1.99	-1.90	-1.81	-1.73	-1.66
	A.P.	4.21	4.02	3.85	3.69	3.55
No.2 Diesel O.Tk.	F.P.	-2.00	-1.91	-1.82	-1.74	-1.67
	A.P.	4.23	4.03	3.86	3.70	3.56
D.O. Serv.Tank	F.P.	-2.05	-1.96	-1.87	-1.78	-1.71
	A.P.	4.28	4.08	3.91	3.75	3.61
Fresh Water Tk.(P/S)	F.P.	-2.47	-2.36	-2.26	-2.17	-2.09
	A.P.	4.74	4.52	4.33	4.15	4.00
No.1 Dist.W.Tk.	F.P.	-2.23	-2.13	-2.04	-1.95	-1.87
	A.P.	4.47	4.27	4.09	3.92	3.77
No.2 Dist. W.Tk.	F.P.	-2.34	-2.24	-2.14	-2.05	-1.97
	A.P.	4.60	4.39	4.20	4.03	3.88

Trim Table (for 100 m. tonnes loading) (unit = cm)

Items	Mean Draft	15.0 m	16.0 m	17.0 m	18.0 m
No.1 Cargo T. (P/S)	F.P.	3.25	3.22	3.20	3.18
	A.P.	-1.48	-1.44	-1.41	-1.37
No.2 Cargo T. (P/S)	F.P.	2.44	2.43	2.42	2.40
	A.P.	-0.65	-0.63	-0.62	-0.60
No.3 Cargo T. (P/S)	F.P.	1.64	1.65	1.65	1.62
	A.P.	0.16	0.15	0.15	0.15
No.4 Cargo T. (P/S)	F.P.	0.85	0.87	0.88	0.89
	A.P.	0.98	0.94	0.92	0.90
No.5 Cargo T. (P/S)	F.P.	0.06	0.09	0.11	0.13
	A.P.	1.79	1.73	1.69	1.65
No.6 Cargo T. (P/S)	F.P.	-0.72	-0.68	-0.65	-0.62
	A.P.	2.59	2.51	2.45	2.39
Slop Tank (P/S)	F.P.	-1.18	-1.13	-1.09	-1.06
	A.P.	3.07	2.97	2.90	2.83
Fwd.W.B.Tank	F.P.	3.85	3.82	3.79	3.76
	A.P.	-2.11	-2.04	-1.99	-1.95
No.1 W.B.Tk. (P/S)	F.P.	3.36	3.34	3.31	3.29
	A.P.	-1.60	-1.56	-1.52	-1.48
No.2 W.B.Tk. (P/S)	F.P.	2.44	2.43	2.42	2.40
	A.P.	-0.65	-0.63	-0.62	-0.60
No.3 W.B.Tk. (P/S)	F.P.	1.64	1.65	1.65	1.65
	A.P.	0.16	0.15	0.15	0.15
No.4 W.B.Tk. (P/S)	F.P.	0.85	0.87	0.88	0.39
	A.P.	0.97	0.94	0.92	0.90
No.5 W.B.Tk. (P/S)	F.P.	0.06	0.09	0.12	0.13
	A.P.	1.79	1.73	1.68	1.65
No.6 W.B.Tk. (P/S)	F.P.	-0.80	-0.75	-0.72	-0.69
	A.P.	2.67	2.58	2.52	2.46

Tank Capacity Table (1 cub. m = 6.28978 barrel)

CARGO OIL TANKS							
Tank Name		Frame No.	Capacity (100%) Cub.m	U.S. Barrel (100%)	Center of Gravity Mid.G m	Center of Gravity Kg m	Max. Free Surface (m4)
No.1 Cargo Tank	P	86-95	13435.5	84506	-94.57	13.72	17746
	S	86-95	13435.5	84506	-94.57	13.72	17746
No.2 Cargo Tank	P	79-86	13811.6	86872	-62.30	13.65	21992
	S	79-86	13811.6	86872	-62.30	13.65	21992
No.3 Cargo Tank	P	72-79	13811.6	86872	-30.80	13.65	21992
	S	72-79	13811.6	86872	-30.80	13.65	21992
No.4 Cargo Tank	P	65-72	13811.6	86872	0.70	13.65	21992
	S	65-72	13811.6	86872	0.70	13.65	21992
No.5 Cargo Tank	P	58-65	13811.6	86872	32.20	13.65	21992
	S	58-65	13811.6	86872	32.20	13.65	21992
No.6 Cargo Tank	P	51-58	13161.2	86872	63.31	14.04	21992
	S	51-58	13161.2	86872	63.31	14.04	21992
Slop Tank	P	50-51	1650.0	10378	81.68	14.91	3142
	S	50-51	1650.0	10378	81.68	14.91	3142
Total			166986.2	1050306			

Water Ballast Tanks (Specific Gravity = 1.025)							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center Of Gravity		Max. Free Surface (m4)
					Mid.G	Kg	
			Cub.m	m.tons	m	m	
Fwd. W.B. Tank	C	95-98	2824.9	2895.5	-118.74	10.27	11015
No.1 W.B. Tank	P	86-95	5686.6	5828.8	-99.13	9.82	27446
	S	86-95	5686.6	5828.8	-99.13	9.82	27446
No.2 W.B. Tank	P	79-86	3762.2	3856.7	-62.31	7.09	31921
	S	79-86	3762.2	3856.7	-62.31	7.09	31921
No.3 W.B. Tank	P	72-79	3763.2	3857.3	-30.81	7.09	31939
	S	72-79	3763.2	3857.3	-30.81	7.09	31939
No.4 W.B. Tank	P	65-72	3763.2	3857.3	0.69	7.09	31939
	S	65-72	3763.2	3857.3	0.69	7.09	31939
No.5 W.B. Tank	P	58-65	3725.9	3819.0	32.09	7.14	31240
	S	58-65	3725.9	3819.0	32.09	7.14	31240
No.6 W.B. Tank	P	50-58	4154.2	4258.1	66.21	7.91	22588
	S	50-58	4154.2	4258.1	66.21	7.91	22588
Aft Peak Tank	C	A.E. -17	2272.8	2329.6	123.46	18.11	12888
Total			54809.1	56179.5			

Fresh Water Tanks Specific Gravity = 1.000							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center Of Gravity		Max. Free Surface (m4)
					Mid.G	Kg	
			Cub.m	m.tons	m	m	
Fresh Water Tank	P	13-17	218.9	218.9	117.71	21.15	378
	S	13-17	218.9	218.9	117.71	21.15	378
No.1 Dist. Water Tank	S	24-28	* 69.0	69.0	108.99	21.33	61
No.2 Dist. Water Tank	S	17-24	* 73.9	73.9	113.11	21.33	33
Total			580.7	580.7			
Cooling Water Tank	C	11-17	37.4	37.4	117.58	3.38	4

Fuel Oil Tanks (Specific Gravity = 0.950)							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center Of Gravity		Max. Free Surface (m4)
					Mid.G	Kg	
			Cub.m	m.tons	m	m	
No.1 Deep F.O. Tank	P	48-50	1222.6	1161.4	87.10	15.08	904
	S	48-50	*1274.9	1211.2	87.19	15.35	941
No.2 Deep F.O. Tank	P	32-48	*872.9	829.3	96.43	16.54	529
	S	32-48	*1161.1	1093.5	97.18	17.75	634
H.F.O. Sett. Tank	P	42-48	*41.4	39.3	83.85	21.08	16
H.F.O. Serv. Tank	P	48-49	*37.5	35.6	89.50	21.32	13
Total			4600.3	4370.3			
F. O. Overflow Tank	C	40-48	119.4	113.4	93.76	1.53	1079

Diesel Oil Tanks (Specific Gravity = 0.880)							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center of Gravity		Max. Free Surface (m4)
					Mid. G	Kg	
			Cub. m	m. t	m	m	
No.1 Diesel Oil Tank	P	32-40	* 72.9	64.2	100.62	21.48	14
No.2 Diesel Oil Tank	P	32-40	* 121.4	106.8	100.88	21.56	53
D.O. Serv. Tank	P	32-36	* 22.8	19.9	102.55	21.30	1
Total			216.3	190.9			

Note: The capacities with * mark shows the value to overflow pipe.

Lub. Oil Tanks Specific Gravity = 0.900							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center Of Gravity		Max. Free Surface (m4)
					Mid.G	Kg	
			Cub.m	m.t	m	m	
Btm. L.O.Sump Tank	C	26-40	33.2	29.9	105.08	1.68	16
Btm. L.O. Reserve Tank	C	26-40	33.7	30.3	37.60	0.99	14
No.1 Cyl. O.Stor. Tank	P	48-49	37.9	34.1	88.93	21.24	9
No.2 Cyl. O.Stor. Tank	P	46-48	37.9	34.1	91.68	21.24	9
No.1 M/E L.O. Stor. Tank	S	48-49	20.1	18.1	85.53	21.25	3
No.2 M/E L.O. Stor. Tank	S	48-49	20.1	18.1	90.48	21.25	3
M/E L.O. Sett. Tank	S	40-42	5.7	6.1	97.15	20.35	1
G/E L.O. Stor. Tank	S	41-46	4.5	4.1	94.15	20.35	1
G/E L.O. Stor. Tank	S	42-14	4.5	4.1	95.55	20.35	1
Total			197.6	177.9			

Other Tanks							
Tank Name		Frame No.	Capacity (100%)	Weight (100%)	Center Of Gravity		Max. Free Surface (M4)
					Mid.G	Kg	
			Cub.M	M.t	M	M	
Clean Drain Tank	S	32-40	39.4	-	100.70	1.69	27
Waste Oil Tank	P	32-40	39.4	-	100.70	1.69	27
Bilge Tank	C	17-25	63.5	-	112.32	1.49	73

Cargo Tanks No.1 Cargo Tank (P or S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
2500.0	-94.48	4.83	8.63	17746
5000.0	-94.49	6.86	8.63	17746
7500.0	-94.49	8.89	8.64	17746
10000.0	-94.49	10.92	8.64	17746
12500.0	-94.50	12.95	8.64	17746

No.2 Cargo Tank (P or S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	9.4	-	-
2500.0	-62.28	4.77	10.14	21992
5000.0	-62.29	6.73	10.15	21992
7500.0	-62.29	8.69	10.15	21992
10000.0	-62.29	10.66	10.15	21992
12500.0	-62.30	12.62	10.15	21992

NO.3 Cargo Tank (P or S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
2500.0	-30.78	4.77	10.14	21992
5000.0	-30.79	6.73	10.15	21992
7500.0	-30.79	8.69	10.15	21992
10000.0	-30.79	10.66	10.15	21992
12500.0	-30.80	12.62	10.15	21992

NO.4 Cargo Tank (P or S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
2500.0	0.72	4.77	10.14	21992
5000.0	0.71	6.73	10.15	21992
7500.0	0.71	8.69	10.15	21992
10000.0	0.71	10.66	10.15	21992
12500.0	0.70	12.62	10.15	21992

NO.5 Cargo Tank (P or S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
2500.0	32.22	4.77	10.14	21992
5000.0	32.21	6.73	10.15	21992
7500.0	32.21	8.69	10.15	21992
10000.0	32.21	10.66	10.15	21992
12500.0	32.20	12.62	10.15	21992

NO.6 CARGO TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
2500.0	62.30	5.23	8.69	17544
5000.0	62.71	7.42	9.19	20953
7500.0	63.01	9.50	9.50	21991
10000.0	63.19	11.51	9.66	21991
12500.0	63.29	13.51	9.74	21991

SLOP TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	1.94	-	-
250.0	81.67	5.37	5.65	898
500.0	81.66	7.50	6.58	1705
750.0	81.66	9.35	7.37	2681
1000.0	81.67	11.00	8.03	3142
1250.0	81.68	12.55	8.46	3142
1500.0	81.68	14.04	8.74	3142

FWD. W.B. TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	0.0	-	-
500.0	-118.73	2.64	0.0	6707
1000.0	-118.76	4.46	0.0	9753
1500.0	-118.78	6.10	0.0	10680
2000.0	-118.78	7.66	0.0	9903
2500.0	-118.76	9.24	0.0	10071

NO.1 W.B. TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	0.0	-	-
1000.0	-94.37	0.81	9.09	24370
2000.0	-95.06	1.55	9.95	2003
3000.0	-96.97	3.25	12.48	2202
4000.0	-98.00	5.54	13.75	2202
5000.0	-98.64	8.06	14.52	2287

NO.2 W.B. TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	0.0	-	-
500.0	-62.29	0.36	11.10	30415
1000.0	-62.29	0.72	11.26	31744
1500.0	-62.30	1.07	11.34	31562
2000.0	-62.32	1.42	11.49	51
2500.0	-62.32	2.34	13.53	51
3000.0	-62.31	3.94	14.88	51
3500.0	-62.31	5.93	15.85	51

NO.3 W.B. TANK (P OR S)

Volume(m^3)	Mid.G(m)	Kg (m)	Cr. Line G (m)	I (m^4)
0.0	-	0.0	-	-
500.0	-30.80	0.36	11.10	30455
1000.0	-30.80	0.72	11.26	31772
1500.0	-30.81	1.07	11.34	31573
2000.0	-30.82	1.42	11.49	51
2500.0	-30.82	2.33	13.53	51
3000.0	-30.82	3.94	14.88	51
3500.0	-30.81	5.93	15.35	51

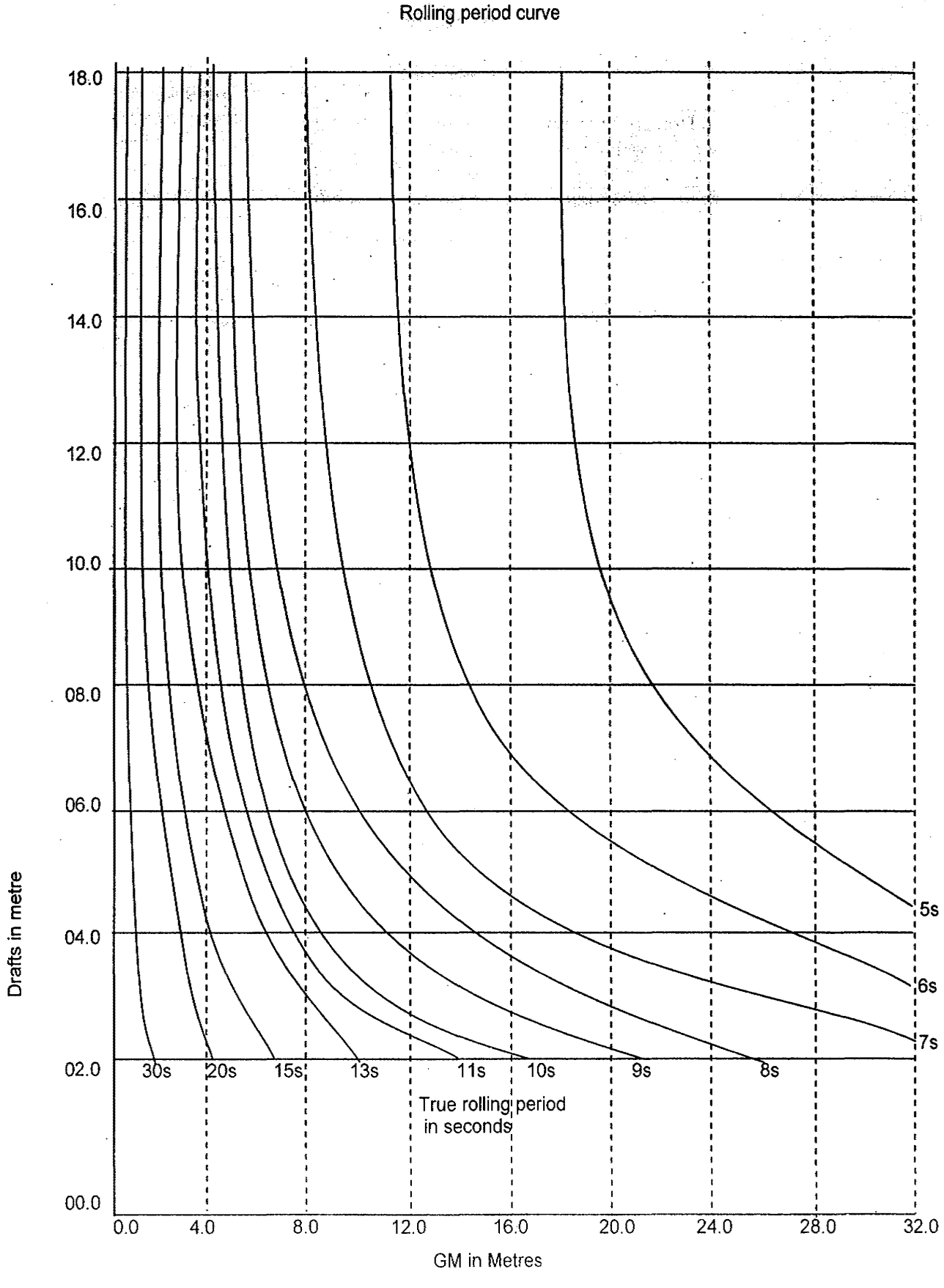

Rolling period curve
18.0
16.0
14.0
12.0
10.0
08.0
06.0
04.0
02.0
00.0
Drafts in metre
30s
20s
15s
13s
11s
10s
9s
8s
5s
6s
7s
True rolling period
in seconds
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
GM in Metres

Fig. 11

FREEBOARD MARK

	Freeboard Mm	Draft (m)	Deadweight (mt)
Tropical fresh water	6,341	17,595	
Fresh water	6,692	17,244	
Tropical	5,727	17,209	
Summer	7,078	16,858	
Winter	7,429	16,507	

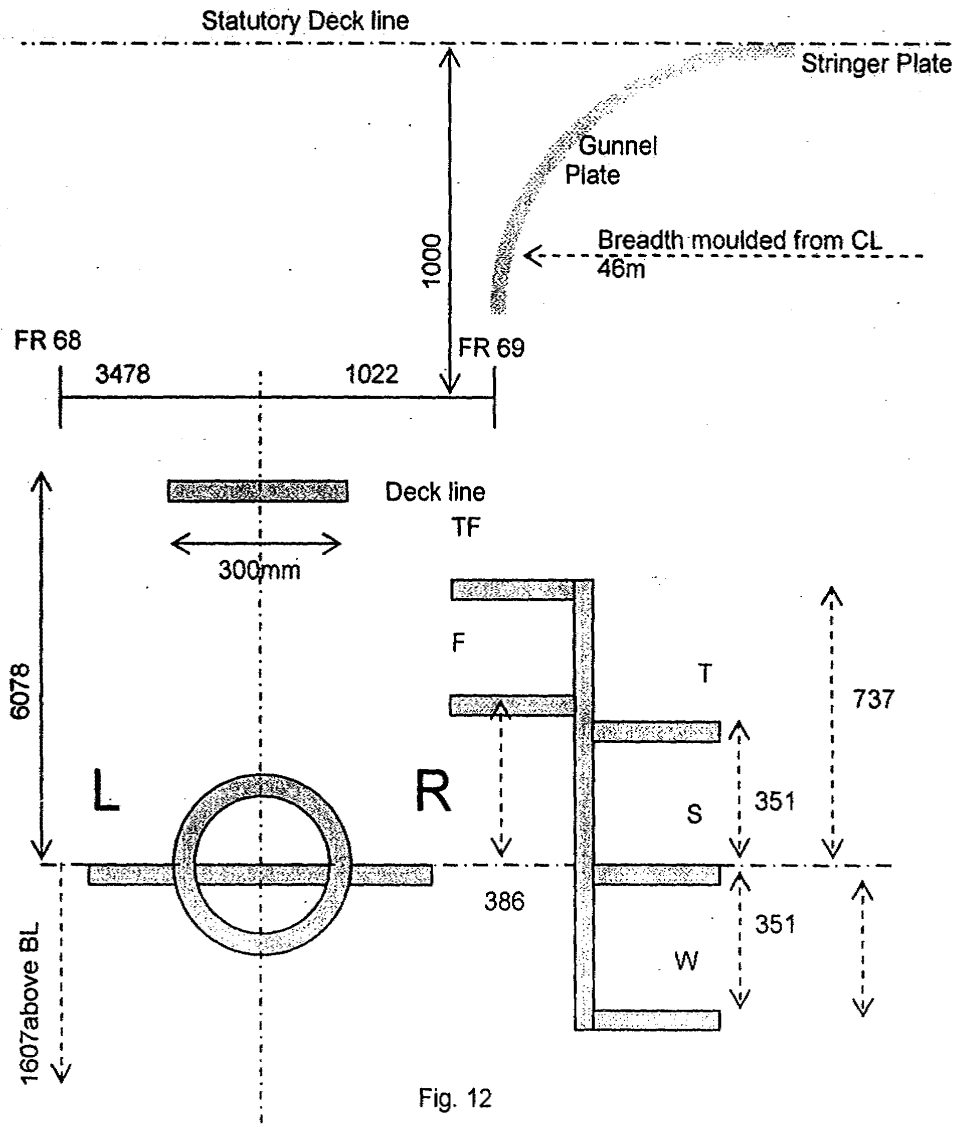


Fig. 12

Cond. No. 1 Homogenous. Load. Condition
(Design Draft) Sg = 0.8165
Half Bunker Departure

Items	%	Weight (m)	Mid. G (m)	Moment (t.m)	Kg (m)	Moment (t.m)	FSM (t.m)
Light Weight		228000	10.30	234840	13.20	300960	0
Others		300	95.00	28500	15.00	4500	200
(Other Total)		(300)		(28500)		(4500)	(200)
No.1 Cargo T. (P+S)	98	23446	-94.50	-2215647	13.50	316521	31599
No.2 Cargo T. (P+S)	98	24101	-62.30	-1501492	13.43	323676	39159
No.3 Cargo T. (P+S)	98	24101	-30.80	-742311	13.43	323676	39159
No.4 Cargo T. (P+S)	98	24101	0.70	16871	13.43	323676	39159
No.5 Cargo T. (P+S)	98	24101	32.20	776052	13.43	323676	39159
No.6 Cargo T. (P+S)	98	22967	63.30	1453810	13.83	317634	39157
Slop Tank (P+S)	98	2879	81.68	235157	14.72	42379	5595
(Cag Total)		(145696)		(-1977560)		(1971238)	(232987)
Fwd. W.B.Tank		0					
No.1 W.B.Tk. (P)		0					
No.1 W.B.Tk. (S)		0					
No.2 W.B.Tk. (P)		0					
No.2 W.B.Tk. (S)		0					
No.3 W.B.Tk. (P)		0					
No.3 W.B.Tk. (S)		0					
No.4 W.B.Tk. (P)		0					
No.4 W.B.Tk. (P)		0					
No.5 W.B.Tk. (S)		0					
No.5 W.B.Tk. (P)		0					
No.6 W.B.Tk. (S)		0					
No.6 W.B.Tk. (S)		0					
Aft. Peak Tank		0					
(W.B. Total)		(0)		(0)		(0)	(0)
No.1 Deep F.O.T.(P)	19	211	86.61	18275	7.03	1483	821
No.1 Deep F.O.T.(S)	18	211	86.61	18275	7.03	1483	894
No.2 Deep F.O.T.(P)	96	796	96.50	76814	16.25	12935	503
No.2 Deep F.O.T.(S)	96	1050	97.16	102018	17.50	18375	595
H.F.O. Sett.Tank	96	38	93.85	3566	21.04	800	15
H.F.O.Serv.Tank	96	34	89.50	3043	21.16	719	12
(F.O. Total)		(2340)		(221991)		(35795)	(2840)
No.1 Diesel O.Tk	73	45	100.52	4523	20.78	935	12
No.2 Diesel O.Tk	45	46	100.86	4640	20.26	932	47
D.O.Serv. Tank	96	19	102.65	1950	21.21	403	1
(D.O. Total)		(110)		(11113)		(2270)	(60)
Fresh Water Tk.(P)	55	121	117.71	14243	19.61	2373	378
Fresh Water Tk.(S)	55	121	117.71	14243	19.61	2373	378
No.1 Dist.W.Tk.	55	38	108.99	4142	20.41	776	51
No.2 Dist.W.Tk.	55	41	113.09	4637	20.37	835	33
(F.W. Total)		(321)		(37265)		(6357)	(840)
Total		171567	-8.42	-1443851	13.53	2321120	236927

Displacement (t)	171567	Mid. G (m)	-8.42	Tkm (m)	19.15
Corresp. Draft (m)	16.86	Mid. B (m)	-8.20	Kg (m)	13.53
Fore Draft (m)	16.95	MTC (t.m)	2043.9	Gm (m)	5.62
Aft. Draft (m)	19.77	Mid. F (m)	-0.18	Gog (m)	1.38
Mean Draft (m)	16.86	TPC (t)	111.1	Gom (m)	4.24
Trim (m)	-0.18	I/D (%)	145.3	Kgo (m)	14.91

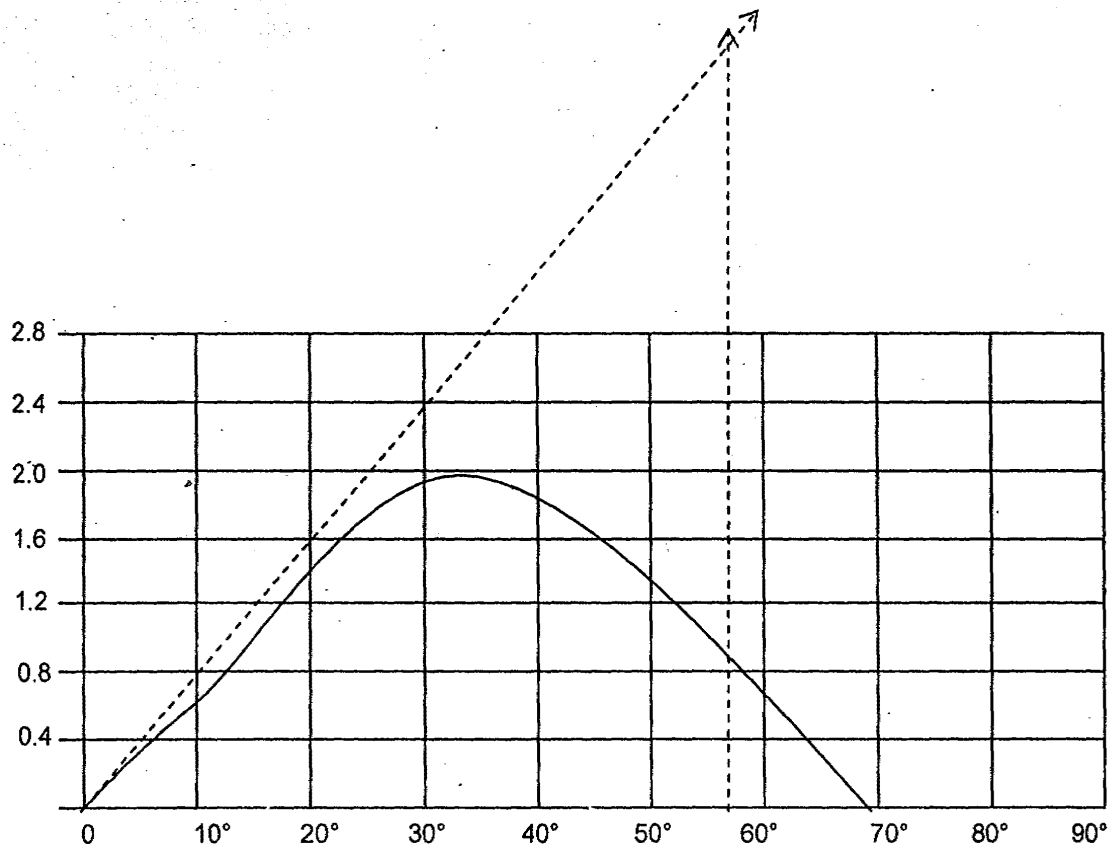


Fig. 13

To Check	Criteria	Required	Attained	Unit	Status
AREA 30	Area under GZ curve up to 30 deg.	0.055	0.652	m.rad	OK
AREA 40	Area under GZ curve up to 40 deg.	0.090	1.080	m.rad	OK
AREA 3040	Area under GZ curve between 30 and 40 deg	0.030	0.428	m.rad	OK
GZ 0.2	Max GZ > 0.2	0.200	2.48	m	OK
MAX GZ 25	Max. GZ at an angle > 25 deg	25.000	36.3	Deg	OK
GM_0.15	GM > 0.15 m	0.150	4.37	m	OK
Angle of flooding			57°		

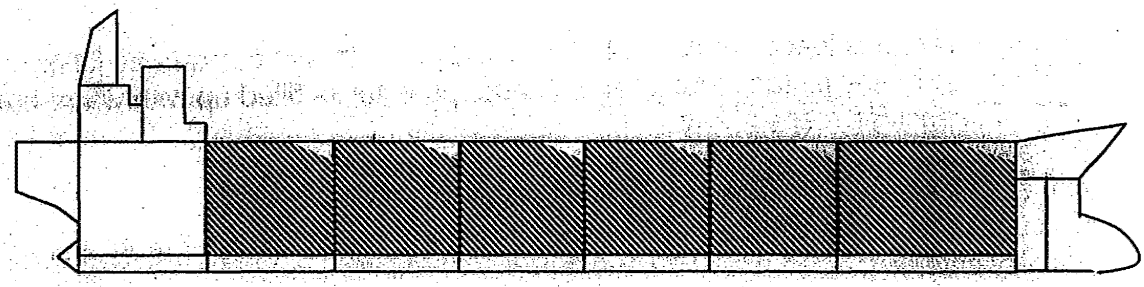


Fig. 14

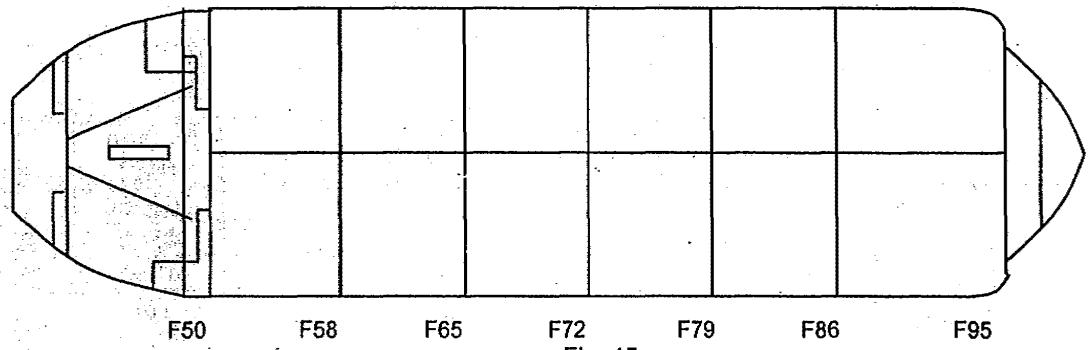


Fig. 15

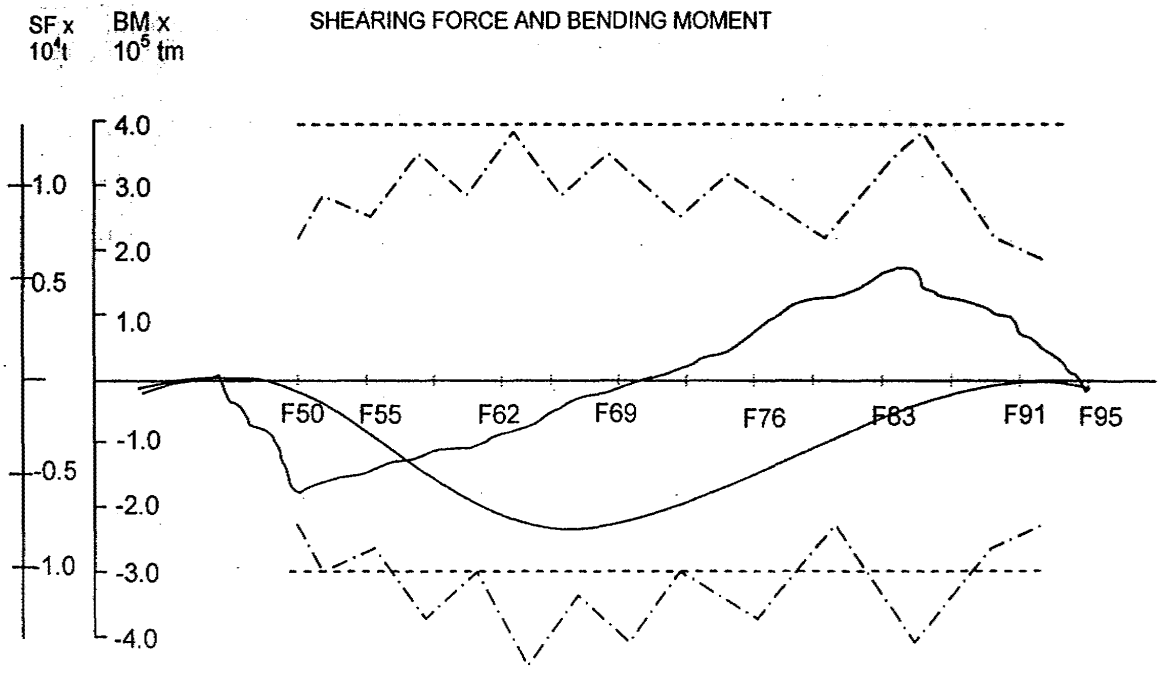


Fig. 16

Exercise on M T Tango:

Q. 1 The following drafts were read on gauges of M T Tango. Forward 14.60m, aft 15.38m and midships 15.08m find the displacement, LCG and GM_f if the KG is 11.2m.

Q. 2 M T Tango is floating in salt water and has a displacement of 154000t and COG is 4.6m forward of midships. Find the drafts forward and aft.

Q. 3 M T Tango is floating at a hydrostatic draft 16.77m, KG 12m. With the help of the hydrostatic curve provided draw the GZ curve and confirm whether the intact stability criteria are being satisfied.

Q. 4 M T Tango is loaded in heavy ballast condition with half bunkers as follows:
a. No cargo in any oil tank fore peak and after peak tanks filled up with water ballast to 53% and 41% of capacities respectively.
b. water ballast filled up in tanks 1 to 6 with 100% capacity.
c. fuel oil, diesel oil, fresh water as in condition 1.
Calculate the displacement, drafts forward and aft and confirm if the vessel satisfies the intact stability criteria.

Items	%	Weight (m)	Mid.G (m)	Moment (t.m)	Kg (m)	Moment (t.m)	FSM (t.m)
Light Weight		22800	10.30	234840	13.20	300960	0
Others		300	95.00	28500	15.00	4500	200
(Other Total)		(300)		(28500)		(4500)	(200)
(Cargo Total)		(.0)		(0)		(0)	(0)
Fwd. W.B.Tank	53	1375	-118.77	-163309	5.59	7686.25	8496
No.1 W.B.Tk. (P)	100	5829	-99.13	-577829	9.82	57240.78	
No.1 W.B.Tk. (S)	100	5829	-99.13	-577829	9.82	57240.78	
No.2 W.B.Tk. (P)	100	3857	-62.31	-240330	7.09	27346.13	
No.2 W.B.Tk. (S)	100	3857	-62.31	-240330	7.09	27346.13	
No.3 W.B.Tk. (P)	100	3857	-30.81	-118834	7.08	27307.56	
No.3 W.B.Tk. (S)	100	3857	-30.81	-118834	7.08	27307.56	
No.4 W.B.Tk. (P)	100	3857	0.69	2661.33	7.08	27307.56	
No.4 W.B.Tk. (P)	100	3857	0.69	2661.33	7.08	27307.56	
No.5 W.B.Tk. (S)	100	3819	32.09	122551.7	7.14	27267.66	
No.5 W.B.Tk. (P)	100	3819	32.09	122551.7	7.14	27267.66	
No.6 W.B.Tk. (S)	100	4258	66.21	281922.2	7.91	33680.78	
No.6 W.B.Tk. (S)	100	4258	66.21	281922.2	7.91	33680.78	
Aft. Peak Tank	41	950	122.00	115900	14.46	13737	13210
(W.B. Total)		(53279)		(-1107125)		(421727)	(21706)
(F.O. Total)		(2340)		(221991)		(35795)	(2840)
(D.O. Total)		(110)		(11113)		(2270)	(60)
(F.W. Total)		(321)		(37265)		(6357)	(840)
Total		79150	-7.24	-573416	9.75	771609	25646

Displacement (t)	79150	Mid. G (m)	-7.24	TKM (m)	24.88
Corresp. Draft (m)	8.22	Mid. B (m)	-12.41	KG (m)	9.75
Fore Draft (m)	7.04	Mtc (t.m)	1598.10	Gm (m)	15.13
Aft. Draft (m)	9.59	Mid. F (m)	-9.55	Gog (m)	0.32
Mean Draft (m)	8.31	TPC (t)	102.4	Gom (m)	14.81
Trim (m)	2.56			Kgo (m)	10.00

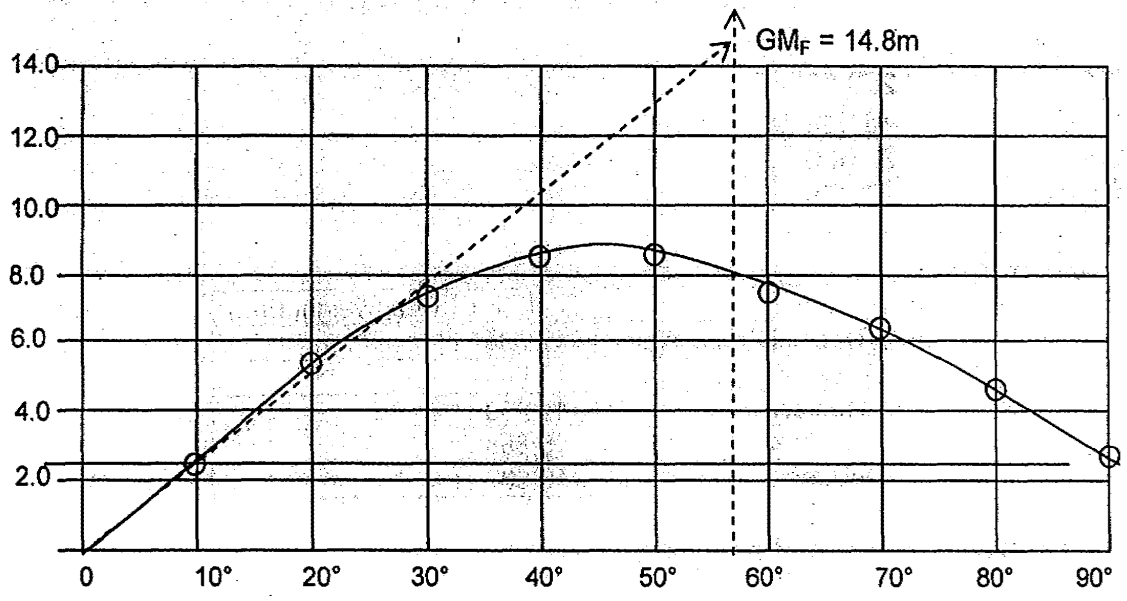


Fig. 9

To Check	Criteria	Required	Attained	Unit	Status
AREA 30	Area under GZ curve up to 30 deg.	0.055	2.052	m.rad	OK
AREA 40	Area under GZ curve up to 40 deg.	0.090	3.438	m.rad	OK
AREA 3040	Area under GZ curve between 30 and 40 d	0.030	1.386	m.rad	OK
GZ 0.2	Max GZ > 0.2	0.200	6.53	m	OK
MAX GZ 25	Max. GZ at an angle > 25 deg	25.000	45.2	Deg	OK
GM_0.15	GM > 0.15 m	0.150	14.61	m	OK
Angle of floodin			90°		

Stability Information to be used for M.V. Bravo & M.T. Tango

Principal dimensions:

Length BP	258,000 m
Breadth mld	46,000 m
Depth mld	23,900 m
Draft full ext	16,858 m

Deadweight & Draft:-

	Draft (m)	Deadweight (m.t)
Tropical Fresh Water	17,595	
Fresh Water	17,244	
Tropical	17,209	
Summer	16,858	
Winter	16,507	

Correction Table for fore & aft draft marks

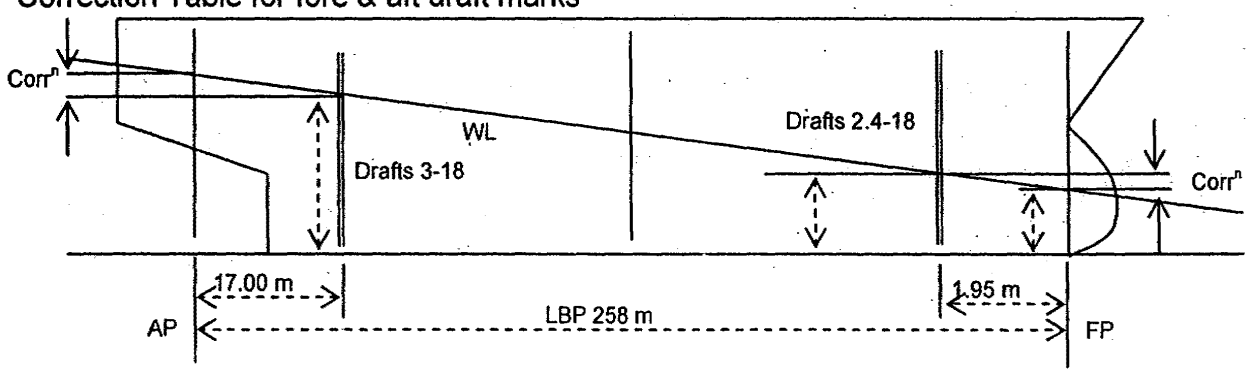


Fig. 17

Fore & Aft Correction (Unit: mm)

Trim by the stern											
Apparent Trim		0.0m	0.1m	0.2m	0.3m	0.4m	0.5m	0.6m	0.7m	0.8m	0.9m
0m	Aft	+0	+7	+14	+21	+28	+36	+43	+50	+57	+64
	Fore	+0	-1	-2	-2	-3	-4	-5	-6	-7	-7
1m	Aft	+71	+78	+85	+92	+100	+107	+114	+121	+128	+135
	Fore	-8	-9	-10	-11	-11	-12	-13	-14	-15	-15
2m	Aft	+142	+149	+156	+164	+171	+178	+185	+192	+199	+206
	Fore	-16	-17	-18	-19	-20	-20	-21	-22	-23	-24
3m	Aft	+213	+220	+228	+235	+242	+249	+256	+263	+270	+277
	Fore	-24	-25	-26	-27	-28	-29	-29	-30	-31	-32
4m	Aft	+284	+292	+299	+306	+313	+320	+327	+334	+341	+348
	Fore	-33	-33	-34	-35	-36	-37	-38	-39	-39	-40
5m	Aft	+356	+363	+370	+377	+384	+391	+398	+405	+412	+420
	Fore	-41	-42	-42	-43	-44	-45	-46	-46	-47	-48
6m	Aft	+427	+434	+441	+448	+455	+462	+469	+476	+484	+491
	Fore	-49	-50	-51	-51	-52	-53	-54	-55	-55	-56

NOTE: 1. DRAFT at F.P. = (Reading at fore draft mark)
+ (Correction for fore draft mark)
DRAFT at A.P. = (Reading at aft draft mark)
+ (Correction for aft draft mark)

When the ship has trimmed by the stem, the plus and minus signs are taken vice versa.

Example: df (at fore draft mark) = 8.000 m
da (at aft draft mark) = 9.500 m
Apparent trim (da – df) = 1.500 m (By the stern)
Fore corr. = -0.012 m, Aft corr. = +0.107 m

dF = 8.000 + (-0.012) = 7.988 m
dA = 9.500 + (+0.107) = 9.607 m

Correction Table for draft mark gauges

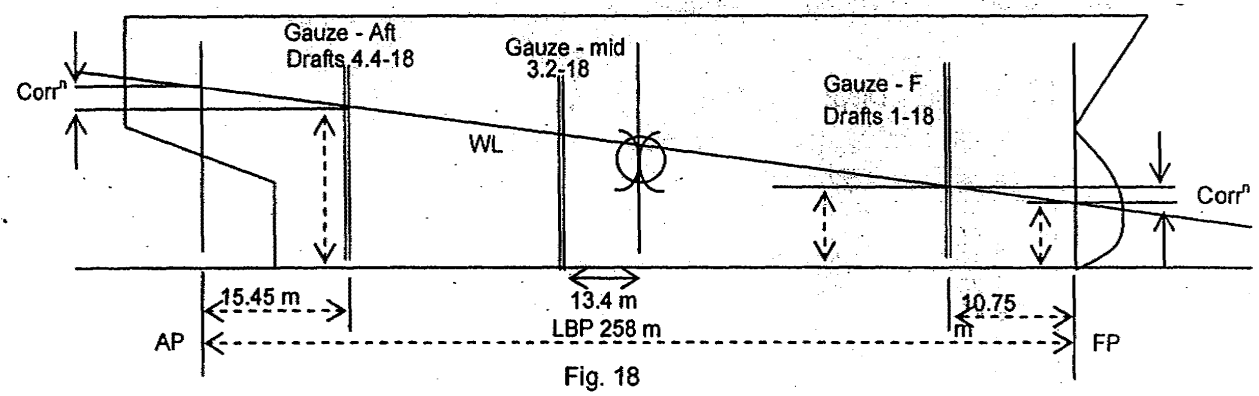


Fig. 18

Correction Table - For Draft Gauge (Fore Midship and Aft)

Trim correction (Unit: mm)

Apparent Trim (M)		Trim By The Stern (M)									
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	Fore	0	-5	-9	-14	-19	-23	-28	-32	-37	-42
	Mid	0	-6	-12	-17	-23	-29	-35	-40	-46	-52
	Aft	0	7	13	20	27	33	40	47	53	60
1.0	Fore	-46	-51	-56	-60	-65	-70	-74	-79	-83	-88
	Mid	-58	-64	-69	-75	-81	-87	-92	-98	-104	-110
	Aft	67	73	80	87	93	100	107	113	120	127
2.0	Fore	-93	-97	-102	-107	-111	-116	-121	-125	-130	-134
	Mid	-116	-121	-127	-133	-139	-145	-150	-156	-162	-168
	Aft	133	140	147	153	160	167	173	180	187	193
3.0	Fore	-139	-144	-148	-153	-158	-162	-167	-172	-176	-181
	Mid	-173	-179	-185	-191	-197	-202	-208	-214	-220	-225
	Aft	200	207	213	220	227	233	240	247	253	260
4.0	Fore	-186	-190	-195	-199	-204	-209	-213	-218	-223	-227
	Mid	-231	-237	-243	-249	-254	-260	-266	-272	-277	-283
	Aft	267	273	280	287	293	300	307	313	320	327
5.0	Fore	-232	-237	-241	-246	-250	-255	-260	-264	-269	-274
	Mid	-289	-295	-301	-306	-312	-318	-324	-330	-335	-341
	Aft	333	340	347	353	360	367	373	380	387	393
6.0	Fore	-278	-283	-288	-292	-297	-301	-306	-311	-315	-320
	Mid	-347	-353	-358	-364	-370	-376	-382	-387	-393	-399
	Aft	400	407	413	420	427	433	440	447	453	460

Note: 1. Draft at F.P. (dF) = (Reading at fore draft gauge) + (Correction for fore draft gauge)
2. Draft at Midship (dM) = (Reading at mid draft gauge) + (Corrn. for mid draft gauge)
3. Draft at A.P. (dA) = (Reading at aft draft gauge) + (Correction for aft draft gauge)

When the ship has trimmed by the stem, the plus and minus signs are taken vice versa.

Example: d_f (at fore draft gauge) = 8.000 m & d_a (at aft draft gauge) = 9.500 m
dop (at midship of P. side gauge) = 8.900 m
dos (at midship od S. side gauge) = 8.800 m
Apparent trim (da – df) = 1.500 m
Apparent midship draft ((dop+dos)/2) = 8.850 m
Fore corr. = -0.070 m. Midship corr. = -0.087 m, Aft corr. = +0.100 m.

dF = 8.000 +(-0.070) = 7.930 m Trim = 9.600 – 7.930 = 1.670 m
dA = 9.500 +(+0.100) = 9.600 m Mean draft = (9.600 + 7.930)/2 = 8.765 m
dM = 8.850 +(-0.087) = 0.763 m Deflection = 8.763 – 8.765 = -0.002m (Hogg.)

Draft (m)	Dispt (t)	Mid.b (m)	Mid.f (m)	MCTC (t – m)	TPC (t)	KM (m)
8.00	76897	-12.49	-9.76	1588.9	102.2	25.31
8.05	77409	-12.47	-9.71	1590.9	102.2	25.21
8.10	77921	-12.45	-9.66	1593.0	102.3	25.11
8.15	78433	-12.44	-9.62	1595.1	102.3	25.02
8.20	78946	-12.42	-9.57	1597.2	102.4	24.92
8.25	79458	-12.40	-9.52	1599.3	102.4	24.82
8.30	79971	-12.38	-9.47	1601.4	102.5	24.73
8.35	80484	-12.36	-9.43	1603.5	102.5	24.64
8.40	80998	-12.34	-9.38	1605.6	102.6	24.55
8.45	81512	-12.32	-9.33	1607.8	102.6	24.46
8.50	82026	-12.33	-9.20	1609.9	102.7	24.37
8.55	82540	-12.28	-9.23	1612.1	102.7	24.28
8.60	83054	-12.26	-9.18	1614.3	102.8	24.20
8.65	83569	-12.24	-9.13	1616.5	102.8	24.11
8.70	84084	-12.22	-9.08	1618.7	102.9	24.03
8.75	84599	-12.20	-9.03	1620.9	102.9	23.95
8.80	85115	-12.18	-8.98	1623.1	103.0	23.87
8.85	85630	-12.16	-8.93	1625.4	103.0	23.79
8.90	86146	-12.14	-8.88	1627.6	103.1	23.71
9.00	87179	-12.10	-8.78	1632.1	103.2	23.56
9.05	87696	-12.08	-8.73	1634.5	103.2	23.49
9.10	88213	-12.06	-8.67	1636.8	103.3	23.41
9.15	88730	-12.04	-8.62	1639.1	103.3	23.34
9.20	89248	-12.02	-8.57	1641.5	103.4	23.27
9.25	89765	-12.00	-8.51	1643.8	103.4	23.20
9.30	90283	-11.98	-8.46	1646.2	103.5	23.13
9.35	90802	-11.96	-8.40	1648.6	103.5	23.06
9.40	91320	-11.93	-8.35	1650.9	103.6	22.99
9.45	91839	-11.91	-8.29	1653.3	103.6	22.93
9.50	92358	-11.89	-8.24	1655.7	103.7	22.86
9.55	92877	-11.87	-8.18	1658.1	103.1	22.80
9.60	93397	-11.85	-8.13	1660.5	103.8	22.73
9.65	93917	-11.83	-8.07	1662.9	103.8	22.68
9.70	94437	-11.81	-8.02	1665.3	103.9	22.61
9.75	94957	-11.79	-7.96	1667.7	103.9	22.55
9.80	95478	-11.76	-7.91	1670.1	104.0	22.49
9.85	95998	-11.74	-7.85	1672.5	104.0	22.43
9.90	96519	-11.72	-7.80	1674.9	104.1	22.37

9.95	97041	-11.70	-7.74	1677.3	104.1	22.32
10.00	97562	-11.68	-7.69	1679.7	104.2	22.26
10.05	98084	-11.66	-7.64	1681.9	104.2	22.20
10.10	98606	-11.63	-7.59	1684.2	104.3	22.15
10.15	99128	-11.61	-7.53	1686.4	104.3	22.09
10.20	99650	-11.59	-7.48	1688.6	104.4	22.04
10.25	100173	-11.57	-7.43	1690.8	104.4	21.99
10.30	100695	-11.55	-7.38	1693.0	104.5	21.94
10.35	101218	-11.53	-7.33	1695.2	104.5	21.89
10.40	101742	-11.50	-7.28	1697.5	104.6	21.84
10.45	102265	-11.48	-7.23	1699.7	104.6	21.79
10.50	102789	-11.46	-7.17	1702.0	104.7	21.74
10.55	103313	-11.44	-7.12	1704.2	104.7	21.69
10.60	103837	-11.41	-7.07	1706.5	104.8	21.64
10.65	104362	-11.39	-7.01	1708.8	104.8	21.60
10.70	104887	-11.37	-6.96	1711.2	104.9	21.55
10.75	105412	-11.35	-6.90	1713.5	104.9	21.51
10.80	105937	-11.33	-6.85	1715.9	105.0	21.46
10.85	106463	-11.30	-6.79	1718.3	105.0	21.42
10.90	106989	-11.28	-6.74	1720.7	105.1	21.37
10.95	107515	-11.26	-6.68	1723.2	105.1	21.33
11.00	108042	-11.23	-6.62	1725.7	105.2	21.29
11.50	113323	-11.00	-5.94	1754.5	105.7	20.90
11.55	113853	-10.97	-5.87	1757.6	105.8	20.87
11.60	114383	-10.95	-5.80	1760.6	105.8	20.83
11.65	114913	-10.92	-5.73	1763.6	105.9	20.80
11.70	115443	-10.90	-5.66	1766.7	106.0	20.76
11.75	115974	-10.87	-5.5	1769.8	106.0	20.73
11.80	116505	10.85	-5.52	1772.9	106.1	20.69
11.85	117036	-10.82	-5.45	1776.0	106.1	20.66
11.90	117568	-10.80	-5.38	1779.1	106.2	20.63
11.95	118100	-10.77	-5.31	1782.2	106.3	20.60
12.00	118632	-10.75	-5.24	1785.3	106.3	20.57
12.05	119164	-10.62	-5.17	1788.3	106.4	20.54
12.10	119697	-10.70	-5.11	1791.3	106.4	20.51
12.15	120230	-10.67	-5.05	1794.3	106.5	20.48
12.20	120763	-10.65	-4.99	1797.3	106.5	20.45
12.25	121297	-10.63	-4.94	1799.7	106.6	20.42
12.30	121831	-10.60	-4.86	1803.3	106.7	20.39
12.35	122365	-10.57	-4.80	1806.3	106.7	20.36
12.40	122899	-10.55	-4.74	1809.3	106.8	20.33
12.45	123434	-10.52	-4.68	1812.3	106.8	20.31
12.50	123969	-10.50	-4.61	1815.3	106.9	20.28
12.55	124504	-10.47	-4.55	1818.3	106.9	20.25
12.60	125039	-10.45	-4.49	1821.3	107.0	20.23
12.65	125575	-10.42	-4.43	1824.3	107.1	20.20
12.70	126111	-10.40	-4.37	1827.3	107.1	20.18
12.75	126647	-10.37	-4.31	1830.3	107.2	20.15
12.80	127184	-10.34	-4.35	1833.4	107.2	20.13
12.85	127720	-10.32	-4.19	1836.4	107.3	20.10
12.90	128257	-10.29	-4.13	1839.4	107.3	20.08
12.95	128795	-10.27	-4.07	1842.4	107.4	20.06
13.00	129332	-10.24	-4.01	1845.4	107.5	20.03

13.05	129870	-10.21	-3.95	1848.5	107.5	20.01
13.10	130408	-10.19	-3.89	1851.5	107.6	19.99
13.15	130947	-10.16	-3.83	1854.6	107.6	19.97
13.20	131485	-10.14	-3.77	1857.7	107.7	19.95
13.25	132024	-10.11	-3.71	1860.8	107.7	19.93
13.30	132563	-10.08	-3.65	1863.8	107.8	19.91
13.35	133102	-10.06	-3.59	1866.9	107.9	19.89
13.40	133642	-10.03	-3.53	1870.0	107.9	19.87
13.45	134182	-10.01	-3.47	1873.0	108.0	19.85
13.50	134722	-9.98	-3.40	1876.1	108.0	19.83
13.55	135263	-9.95	-3.34	1879.2	108.1	19.81
13.60	135803	-9.93	-3.28	1882.2	108.1	19.79
13.65	136344	-9.90	-3.22	1885.3	108.2	19.77
13.70	136886	-9.88	-3.16	1888.3	108.2	19.75
13.75	137427	-9.85	-3.11	1891.3	108.3	19.74
13.80	137969	-9.82	-3.05	1894.3	108.4	19.72
13.85	138511	-9.80	-2.99	1897.4	108.4	19.70
13.90	139053	-9.77	-2.93	1900.4	108.5	19.69
13.95	139596	-9.74	-2.87	1903.3	108.5	19.67
14.00	140138	-9.72	-2.81	1906.3	108.6	19.65
14.05	140682	-9.69	-2.75	1909.3	108.6	19.64
14.10	141225	-9.66	-2.70	1912.2	108.7	19.62
14.15	141769	-9.64	-2.65	1914.6	108.7	19.61
14.20	142313	-9.61	-2.58	1918.1	108.8	19.59
14.25	142857	-9.58	-2.53	1921.0	108.8	19.58
14.30	143401	-9.56	-2.47	1923.9	108.9	19.56
14.35	143946	-9.53	-2.41	1926.7	108.9	19.55
14.40	144491	-9.50	-2.36	1929.6	109.0	19.54
14.45	145036	-9.48	-2.30	1932.4	109.0	19.52
14.50	145582	-9.45	-2.25	1935.2	109.1	19.51
14.55	146127	-9.42	-2.19	1938.0	109.2	19.50
14.60	146673	-9.40	-2.14	1940.8	109.2	19.48
14.65	147220	-9.37	-2.09	1943.6	109.3	19.47
14.70	147766	-9.34	-2.03	1946.3	109.3	19.46
14.75	148313	-9.32	-1.98	1949.1	109.4	19.45
14.80	148860	-9.29	-1.93	1951.8	109.4	19.44
14.85	149407	-9.26	-1.88	1954.5	109.5	19.42
14.90	149954	-9.24	-1.83	1957.1	109.5	19.41
14.95	150502	-9.21	-1.78	1959.8	109.5	19.40
15.00	151050	-9.18	-1.72	1962.4	109.5	19.39
15.05	151598	-9.16	-1.68	1965.0	109.6	19.38
15.10	152147	-9.13	-1.63	1967.5	109.7	19.37
15.15	152696	-9.10	-1.58	1970.0	109.7	1936
15.20	153245	-9.08	-1.53	1972.5	109.8	19.35
15.25	153794	-9.05	-1.48	1975.0	109.8	19.34
15.30	154343	-9.02	-1.44	1977.4	109.9	19.33
15.35	154893	-9.00	-1.39	1979.9	109.9	19.32
15.40	155443	-8.97	-1.34	1932.3	110.0	19.31
15.45	155993	-8.94	-1.30	1984.6	110.0	19.31
15.50	156543	-8.92	-1.25	1987.0	110.0	19.30
15.55	157094	-8.89	-1.21	1989.3	110.1	19.29
15.60	157645	-8.86	-1.17	1991.7	110.1	19.28
15.65	158195	-8.84	-1.12	194.0	110.2	19.27

15.70	158747	-6.81	-1.08	1996.3	110.2	19.27
15.75	159298	-8.78	-1.03	1998.5	110.3	19.26
15.80	159850	-8.76	-0.99	2000.8	110.3	19.25
15.85	160402	-8.73	-0.95	2003.0	110.3	19.25
15.90	160954	-8.70	-0.91	2005.2	110.4	19.24
15.95	161506	-8.68	-0.87	2007.4	110.4	19.23
16.00	162058	-8.65	-0.83	2009.5	110.5	19.23
16.05	162611	-8.62	-0.78	2011.7	110.5	19.22
16.10	163164	-8.60	-0.74	2013.8	110.5	19.21
16.15	163717	-8.57	-0.70	2015.9	110.6	19.21
16.20	164270	-8.54	-0.66	2017.9	110.6	19.20
16.25	164823	-8.52	-0.62	2020.4	110.6	19.20
16.30	165377	-8.49	-0.58	2022.0	110.7	19.19
16.35	165930	-8.46	-0.55	2024.1	110.7	19.19
16.40	166484	-8.44	-0.51	2026.1	110.8	19.18
16.45	167038	-8.41	-0.47	2028.1	110.8	19.18
16.50	167593	-8.39	-0.43	2030.0	110.8	19.17
16.55	168147	-8.36	-0.39	2032.0	110.9	19.17
16.60	168702	-8.33	-0.36	2034.0	110.9	19.16
16.65	169257	-8.31	-0.32	2035.9	110.9	19.16
16.70	169812	-8.28	-0.29	2037.9	111.0	19.16
16.75	170367	-8.25	-0.25	2039.8	111.0	19.15
16.80	170922	-8.23	-0.22	2041.7	111.0	19.15
16.85	171478	-8.20	-0.18	2043.6	111.1	19.15
16.90	172034	-8.18	-0.15	2045.5	111.1	19.14
16.95	172590	-8.15	-0.11	2047.4	111.1	19.14
17.00	173146	-8.13	-0.08	2049.3	111.2	19.14
17.05	173702	-8.10	-0.05	2051.2	111.2	19.13
17.10	174259	-8.07	-0.02	2053.2	111.2	19.13
17.15	174815	-8.05	0.01	2055.1	111.3	19.13
17.20	175372	-8.02	0.05	2057.0	111.3	19.13
17.25	175929	-8.00	0.08	2058.	111.3	19.13
17.30	176486	-7.97	0.11	2060.8	111.4	19.12
17.35	177043	-7.95	0.13	2062.6	111.4	19.12
17.40	177601	-7.92	0.16	2064.5	111.4	19.12
17.45	178158	-7.90	0.19	2066.4	111.5	19.12
17.50	178716	-7.87	0.22	2068.3	111.5	19.12
17.55	179274	-7.84	0.25	2070.1	111.5	19.12
17.60	179832	-7.82	0.27	2072.0	111.6	19.12
17.65	180390	-7.79	0.30	2073.9	111.6	19.12
17.70	180949	-7.77	0.32	2075.7	111.6	19.12
17.75	181507	-7.74	0.35	2077.6	111.7	19.12
17.80	182066	-7.72	0.37	2079.4	111.7	19.12
17.85	182625	-7.69	0.40	2081.2	111.7	19.12
17.90	183184	-7.67	0.42	2083.1	111.8	19.12
17.95	183744	-7.65	0.44	2084.9	111.8	19.12
18.00	184303	-7.62	0.46	2086.7	111.8	19.12

Selected portions of tables for correction of displacement for trim

Correction Table of Displacement by Trim (Unit in t)

Draft (m)	------- Trim (m) -------							
	-2.00	-1.90	-1.80	-1.70	-1.60	-1.50	-1.40	-1.30
2.0	1067	1011	954	88	842	787	732	677
2.5	1046	990	936	881	827	773	719	666
3.0	1026	972	919	866	813	760	708	655
3.5	1008	955	903	851	799	748	696	645
4.0	989	938	887	836	786	735	685	635
4.5	971	921	871	821	771	722	673	623
5.0	951	902	853	805	756	708	659	611
5.5	930	882	834	787	740	692	645	598
6.0	907	860	814	768	722	676	630	584
6.5	882	837	792	747	702	657	612	568
7.0	855	811	768	724	680	637	594	550

Correction Table of Displacement by Trim (Unit In t)

Draft (M)	------ Trim (m) -------							
	2.90	3.00	3:10	3.20	3.30	3.40	3.50	3.60
2.0	-1265	-1301	-1337	-1372	-1406	-1440	-1473	-1505
2.5	-1289	-1326	-1367	-1405	-1442	-1449	-1516	-1552
3.0	-1300	-1340	-1380	-1420	-1459	-1498	-1536	-1574
3.5	-1302	-1343	-1384	-1424	-1464	-1504	-1544	-1583
4.0	-1296	-1337	-1373	-1419	-1460	-1500	-1540	-1580
4.5	-1284	-1326	-1367	-1408	-1448	-1489	-1529	-1569
5.0	-1267	-1308	-1349	-1389	-1430	-1470	-1510	-1549
5.5	-1245	-1285	-1325	-1265	-1405	-1445	-1484	-1523
6.0	-1217	-1257	-1296	-1335	-1374	-1413	-1452	-1490
6.5	-1184	-1223	-1261	-1299	-1337	-1375	-1412	-1450
7.0	-1147	-1184	-1221	-1258	-1294	-1331	-1367	-1403

Correction Table of Displacement by Trim (Unit In t)

Draft (m)	------- Trim (m) -------							
	-0.60	-0.50	-0.40	-0.30	-0.20	-0.10	0.0	0.10
12.0	133	110	88	65	43	21	0	-21
12.5	118	97	77	58	38	19	0	-19
13.0	103	85	68	50	33	16	0	-16
13.5	88	73	52	43	28	14	0	-14
14.0	74	61	48	36	24	11	0	-11
14.5	61	50	39	29	19	9	0	-9
15.0	48	39	31	23	15	7	0	-7
15.5	36	30	23	17	11	5	0	-5
16.0	26	21	16	12	8	4	0	-3
16.5	16	13	10	7	4	2	0	-2
17.0	7	5	4	3	1	0	0	0

Correction Table of Displacement by Trim (Unit In t)

Draft (M)	------- Trim (m) -------							
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
12.0	-21	-42	-64	-84	-105	-126	-146	-166
12.5	-19	-37	-56	-74	-92	-110	-128	-146
13.0	-16	-32	-48	-64	-80	-95	-111	-126
13.5	-14	-27	-41	-55	-68	-81	-94	-106
14.0	-11	-23	-34	-45	-56	-67	-77	-88
14.5	-9	-18	-28	-37	-45	-54	-62	-71
15.0	-7	-14	-22	-29	-35	-42	-49	-55
15.5	-5	-11	-16	-21	-26	-31	-36	-40
16.0	-3	-7	-11	-14	-18	-21	-24	-27
16.5	-2	-4	-6	-8	-10	-12	-13	-15
17.0	0	-1	-2	-3	-3	-3	-4	-4

Correction Table of Displacement by Trim (Unit In t)

Draft (m)	TRIM (m)							
	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
12.0	-166	-186	-206	-225	-244	-263	-282	-301
12.5	-146	-163	-180	-197	-207	-230	-246	-262
13.0	-126	-140	-155	-169	-183	-197	-211	-225
13.5	-106	-119	-131	-143	-155	-166	-177	-189
14.0	-88	-98	-108	-118	-127	-136	-146	-155
14.5	-71	-79	-87	-94	-102	-109	-116	-123
15.0	-55	-61	-67	-73	-78	-84	-89	-94
15.5	-40	-45	-49	-53	-57	-61	-64	-68
16.0	-27	-30	-32	-35	-37	-39	-41	-43
16.5	-15	-16	-17	-18	-19	-20	-21	-21
17.0	-4	-4	-3	-3	-3	-2	-1	-1

Correction Table of Displacement by Trim (Unit in T)

Draft (m)	Trim (m)							
	-0.60	-0.50	-0.40	-0.30	-0.20	-0.10	0.0	0.10
17.0	7	5	4	3	2	1	0	0
17.5	0	0	0	0	0	0	0	0
18.0	-4	-4	-3	-3	-2	-1	0	1

Correction table of displacement by trim (unit in t)

Draft (m)	Trim (m)							
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
17.0	0	-1	-2	-3	-3	-3	-4	-4
17.5	0	0	1	2	2	3	4	6
18.0	1	2	4	6	8	10	12	14

Correction Table of Displacement by Trim (Unit In T)

Draft (m)	Trim (m)							
	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
17.0	-4	-4	-3	-3	-3	-2	-1	-1
17.5	6	7	8	10	12	13	15	17
18.0	14	16	19	22	24	27	30	33

Correction of displacement by 1 cm deflection

Mean Draft (m)	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
2.00	70.2	70.4	70.7	70.8	71.0	71.3	71.4	71.6	71.6	71.9
3.00	72.1	72.2	72.4	72.5	72.7	72.8	72.9	73.1	73.2	73.3
4.00	73.4	73.5	73.7	73.7	73.8	74.0	74.0	74.1	74.3	74.3
5.00	74.4	74.5	74.6	74.6	74.8	74.9	74.9	75.0	75.1	75.2
6.00	75.2	75.3	75.4	75.5	75.5	75.6	75.7	75.7	75.8	75.8
7.00	75.9	76.0	76.1	76.1	76.2	76.3	76.4	76.4	76.5	76.6
8.00	76.7	76.7	76.8	76.9	77.0	77.0	77.1	71.2	77.3	77.3
9.00	77.4	77.5	77.6	77.6	77.7	77.8	77.9	77.9	78.0	78.1
10.00	78.2	78.2	78.3	78.4	78.5	78.5	78.6	78.7	78.8	78.8
11.00	78.9	79.0	79.1	79.1	79.2	79.3	79.4	79.5	79.6	79.7
12.00	79.7	79.8	79.9	80.0	80.1	80.1	80.2	80.3	80.4	80.5
13.00	80.6	80.7	80.8	80.9	80.9	81.0	81.1	81.2	81.3	81.4
14.00	81.5	81.5	81.6	81.7	81.8	81.8	81.9	82.0	82.1	82.1
15.00	82.2	82.2	82.3	82.4	82.5	82.5	82.6	82.7	82.7	82.8
16.00	82.9	82.9	83.0	83.0	83.1	83.1	83.2	83.3	83.3	83.3
17.00	83.4	83.4	83.5	83.6	83.6	83.6	83.7	83.7	83.8	83.8

Example : 1. Measured d_f = 13.00 m, d_a = 14.00 m, d_{mid} = 13.70 m
2. Calculated mean draft, d_m = 13.50 m
3. Calculated deflection = 13.70 – 13.50 = 0.20 m (sagging)
4. Correction of displacement for sagging = 81.0 x 2.0 = 1620 m.tonnes

Note:
1. Deflection = $d_{mid} - d_m$
when sagging use + sign
when hogging use - sign

2. Specific gravity of sea water is assumed to be 1.025

This table is obtained as follows:
The correction = ¾ x TPC x def
TPC: tons per 1 cm immersion
Def: deflection of ship in centimeter.

Heel ° (θ) / Sin θ / Disp(t)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
	0.0872	0.1736	0.2588	0.3420	0.4226	0.5000	0.5736	0.6428
20000	6.228	10.631	12.908	14.330	15.243	15.798	16.103	16.211
30000	4.451	8.573	11.196	12.892	14.088	14.943	15.530	15.905
40000	3.526	7.005	9.867	11.786	13.177	14.232	15.039	15.642
50000	2.966	5.934	8.755	10.871	12.433	13.647	14.617	15.399
60000	2.598	5.209	7.815	10.081	11.799	13.157	14.266	15.191
70000	2.343	4.702	7.085	9.383	11.244	12.735	13.971	15.023
80000	2.158	4.334	6.543	8.766	10.749	12.365	13.719	14.851
90000	2.023	4.063	6.137	8.256	10.301	12.033	13.49	14.613
100000	1.922	3.860	5.832	7.853	9.894	11.731	13.247	14.321
110000	1.846	3.708	5.600	7.542	9.538	11.451	12.944	13.991
120000	1.790	3.593	5.426	7.305	9.247	11.155	12.602	13.630
130000	1.748	3.506	5.294	7.124	9.017	10.824	12.228	12.247
140000	1.717	3.445	5.198	6.989	8.827	10.479	11.831	12.845
150000	1.696	3.401	2.128	6.891	8.630	10.136	11.416	12.426
160000	1.682	3.372	5.081	6.821	8.422	9.800	10.998	11.992
170000	1.673	3.355	5.052	6.737	8.201	9.472	10.586	11.550
180000	1.673	3.347	5.039	6.618	7.968	9.140	10.190	11.113
190000	1.673	3.347	5.015	6.467	7.721	8.827	9.812	10.693
200000	1.677	3.355	4.942	6.283	7.458	8.506	9.448	10.295
210000	1.686	3.360	4.817	6.067	7.178	8.182	9.094	9.920
220000	1.693	3.301	4.639	5.815	6.879	7.856	8.746	9.557

KN Curves

Heel ° (θ) / Sin θ / Disp(t)	45.0	50.0	55.0	60.0	70.0	80.0	90.0
	0.7071	0.7660	0.8192	0.8660	0.9397	0.9848	1.0000
20000	16.158	15.982	15.717	15.405	14.886	14.140	12.806
30000	16.114	16.201	16.201	16.163	15.723	14.535	12.784
40000	16.075	16.376	16.586	16.621	16.004	14.663	12.774
50000	16.024	16.518	16.769	16.751	16.065	14.683	12.766
60000	15.973	16.505	16.731	16.700	16.012	14.647	12.768
70000	15.850	16.349	16.567	16.542	15.884	15.586	12.774
80000	15.634	16.108	16.323	16.312	15.726	14.506	12.778
90000	15.360	15.818	16.035	16.049	15.540	14.411	12.781
100000	15.048	15.501	15.732	15.769	15.331	14.304	12.782
110000	14.708	15.170	15.418	15.478	15.114	14.187	12.779
120000	14.350	14.826	15.095	15.184	14.895	14.065	12.770
130000	13.975	14.468	14.764	14.887	14.680	13.946	12.760
140000	13.583	14.098	14.425	14.586	14.469	13.835	12.751
150000	13.177	13.717	14.079	14.282	14.259	13.728	12.747
160000	12.760	13.329	13.728	13.972	14.048	13.621	12.747
170000	12.334	12.934	13.370	13.661	13.832	13.511	12.750
180000	11.903	12.532	13.007	13.340	13.610	13.400	12.753
190000	11.471	12.125	12.638	13.014	12.384	13.285	12.756
200000	11.053	11.716	12.261	12.680	13.152	13.168	12.759
210000	10.658	11.314	11.880	12.339	12.914	13.046	12.759
220000	10.287	10.937	11.508	11.996	12.672	12.921	12.758

D: Selected pages from stability booklet of MV Charlie (chemical tanker)

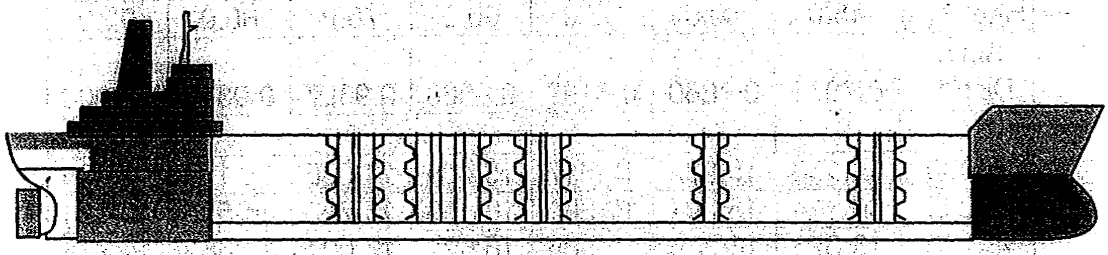


Fig. 19

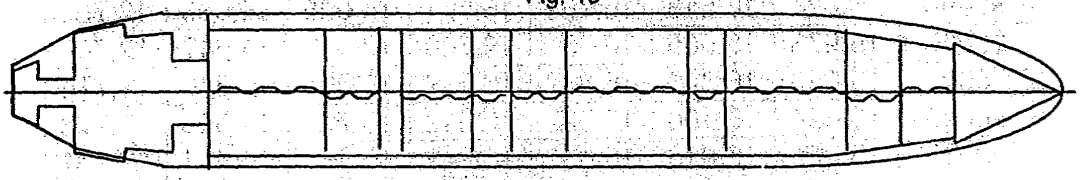


Fig. 20

Loading Conditions LOAD O2 – Ballast condition dep.

Description	Load	Dens T/m³	Weight T	Fill %	LCG M	TCG M	VCG M	FRSM Tm
Ballast Tk. N.1 ST	BW	1.025	529.1	100.0	109.87	6.28	4.77	0.00
Ballast Tk. N.1 PS	BW	1.025	529.1	100.0	109.87	-6.28	7.77	0.00
Ballast Tk. N.2 ST	BW	1.025	520.4	100.0	92.34	7.35	3.77	0.00
Ballast Tk. N.2 PS	BW	1.025	520.4	100.0	92.34	-7.35	3.77	0.00
Ballast Tk. N.3 ST	BW	1.025	670.1	100.0	73.15	7.35	3.77	0.00
Ballast Tk. N.3 PS	BW	1.025	670.1	100.0	73.15	-7.35	3.77	0.00
Ballast Tk. N.4 ST	BW	1.025	521.2	100.0	53.95	7.35	3.77	0.00
Ballast Tk. N.4 PS	BW	1.025	521.2	100.0	53.95	-7.35	3.77	0.00
Ballast Tk. N.5 ST	BW	1.025	579.4	100.0	36.12	7.30	3.85	0.00
Ballast Tk. N.5 PS	BW	1.025	579.4	100.0	36.12	-7.30	3.85	0.00
Fore Peak Ballast TK	BW	1.025	598.9	80.0	123.71	0.02	5.57	527.18
SUBTOTAL	BW		6239.2		77.35	0.00	4.13	527.18
D.O. Service TK PS	DO	0.870	7.7	98.0	15.85	-9.10	10.77	0.00
D.O. Storage TK PS	DO	0.870	70.8	98.0	12.95	-8.96	8.90	0.00
M.D.O. GG.E. TK	DO	0.870	2.1	98.0	7.23	5.60	19.54	0.00
SUBTOTAL	DO		80.6		13.08	-8.59	9.36	0.00
Crew & Effects	DOT	1.000	3.2	0.0	13.00	0.00	20.00	0.00
Effects	DOT	1.000	10.0	0.0	8.00	0.00	28.00	0.00
Provisions	DOT	1.000	5.0	0.0	13.00	0.00	20.00	0.00
SUBTOTAL	DOT		18.2		10.26	0.00	24.39	0.00
Pot. Water Tk. St	FW	1.000	98.6	100.0	0.30	5.56	10.97	0.00
Pot. Water Tk. Ps	FW	1.000	98.6	100.0	0.30	-5.56	10.97	0.00
SUBTOTAL	FW		197.1		0.30	-0.00	10.97	0.00
Hfo Storage Tk N.1 PS	HFO	0.950	63.8	98.0	23.65	-2.00	0.70	0.00
Hfo Storage Tk N.2 ST	HFO	0.950	110.1	98.0	24.85	6.38	6.97	0.00
Hfo Storage Tk N.3 PS	HFO	0.950	110.1	98.0	24.85	-6.38	6.97	0.00
Hfo Storage Tk N.4 ST	HFO	0.950	146.5	98.0	20.67	8.85	7.87	0.00

Hfo Storage Tk N.6 PS	HFO	0.950	60.1	98.0	19.90	-8.96	6.32	0.00
HFO Storage Tk N.5 ST	HFO	0.950	78.5	98.0	13.51	8.99	9.07	0.0
HFO Storage Tk N.7 PS	HFO	0.950	29.5	98.0	5.19	-6.37	10.84	0.00
HFO Settling Tk PS	HFO	0.950	34.1	98.0	22.98	-8.95	8.90	0.00
HFO Service Tk PS	HFO	0.950	30.6	98.0	20.73	-9.10	8.74	0.00
SUBTOTAL	HFO		663.2		20.86	0.85	7.11	0.00
M.E. L.O. Stor. Tk St	LO	0.900	10.3	98.0	8.38	8.88	10.13	0.00
D.G. L.O. Stor. Tk ST	LO	0.900	4.6	98.0	6.87	8.86	10.50	0.00
Red.Gear L.O. Stor. Tk PS	LO	0.900	4.6	98.0	6.87	-8.86	10.50	0.00
M.E. Serv. Lub. Oil	LO	0.900	7.0	98.0	14.35	0.00	1.01	0.00
Stern Tube Lub.Oil Tk	LO	0.900	1.9	98.0	6.95	0.00	0.89	0.00
SUBTOTAL	LO		28.4		9.26	3.22	7.39	0.00
Diath.Oil Stor.Tk PS	MIS	1.000	7.9	68.0	8.38	-8.80	9.49	1.11
Dist. Water Tk	MIS	1.000	11.1	59.7	6.86	3.22	6.62	4.01
Total			7245.7		68.75	-0.01	4.72	532.31

Lightweight	4815.3	55.29	0.00	8.73
Deadweight	7245.7	68.75	-0.01	4.72
Total weight	12061.0	63.37	-0.00	6.32

Floating condition and initial stability

Draught LBP / 2	5.51 m	KM	9.19 m
Trim	-2.03 m	GMO	9.87 m
Draught AFT	6.53 m	GMCORR	0.04 m
Draught FORE	4.50 m	GM	2.83 m

MINIMUM FREEBOARD

FRB m	XFRB m	YFRB m	ZFRB m	IMMA degrees	XIMM m	REDPO m
5.594	-3.923	7.443	12.18	31.2	8.13	0.132

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degrees	IMMR m	REDPO m
OPEO1	Aft. opening comp. R2009	28.350	9.10	12.95	40.2	6.873	0.161
OPEO2	Fwd.opening comp.R2009	45.150	9.10	12.95	40.8	7.138	0.161
OPEO3	Aft. opening comp. R2007	47.550	9.10	12.95	40.9	7.176	0.161
OPEO4	Fwd.opening comp.R2007	61.950	9.10	12.95	41.4	7.403	0.161
OPEO5	Aft. opening comp. R2005	63.550	9.10	12.95	41.5	7.428	0.161
OPEO6	Aft. opening comp. R2003	85.150	9.10	12.95	42.7	7.769	0.161
OPEO7	Aft. opening comp. R2003	100.350	9.10	12.95	42.7	8.009	0.161
OPEO8	Aft. opening comp. R2001	101.950	9.10	12.95	42.7	8.034	0.161
OPEO9	Fwd. opening comp.R2001	117.400	1.35	13.26	-	8.580	0.026

Righting lever curve

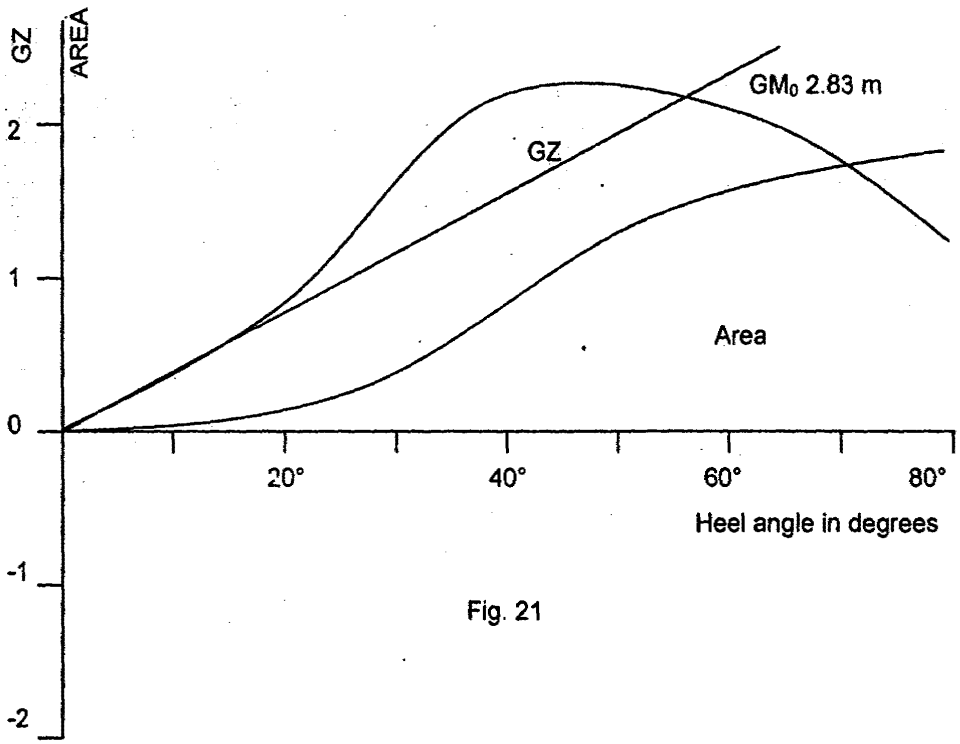


Fig. 21

HEEL Degree	MS m	GZ m	AREA rad*m	FSMOM tm	DGZ m
-30	-0.393	-1.81	0.433	-2.68.2	-0.022
-20	-0.123	-1.09	0.181	-1.95.7	-0.016
-10	-0.016	-0.51	0.044	-96.3	-0.008
0	0.000	0.00	0.000	0.0	0.000
10	0.015	0.51	0.044	96.2	0.008
20	0.125	1.09	0.181	195.6	0.016
30	0.393	1.81	0.434	268.2	0.022
40	0.485	2.31	0.799	325.5	0.027
50	0.133	2.30	1.207	387.8	0.032
60	-0.423	2.03	1.589	455.1	0.038
70	-1.132	1.53	1.901	516.3	0.043
80	-1.854	0.93	2.116	570.8	0.047

NOTE: GZ = GM_0 * SIN (heel) + MS – DGZ

Check of stability criteria

RCR	TEXT	REQ	ATTV	UNIT	STAT
Area 30	Area under GZ curve up to 30 deg.	0.055	0.434	m.rad	OK
Area 40	Area under GZ curve up to 40 deg.	0.090	0.799	m.rad	OK
Area 3040	Area under GZ curve between 30 and 40 deg	0.030	0.366	m.rad	OK
GZ 0.2	Max GZ > 0.2	0.200	2.355	m	OK
Max Gz 25	Max. GZ at an angle > 25 deg	25.000	44.484	Deg	OK
Gm_o 15	GM > 0.15 m	0.150	2.830	m	OK
Wind Roll	Wind & Rolling criterion	1.000	4.707		

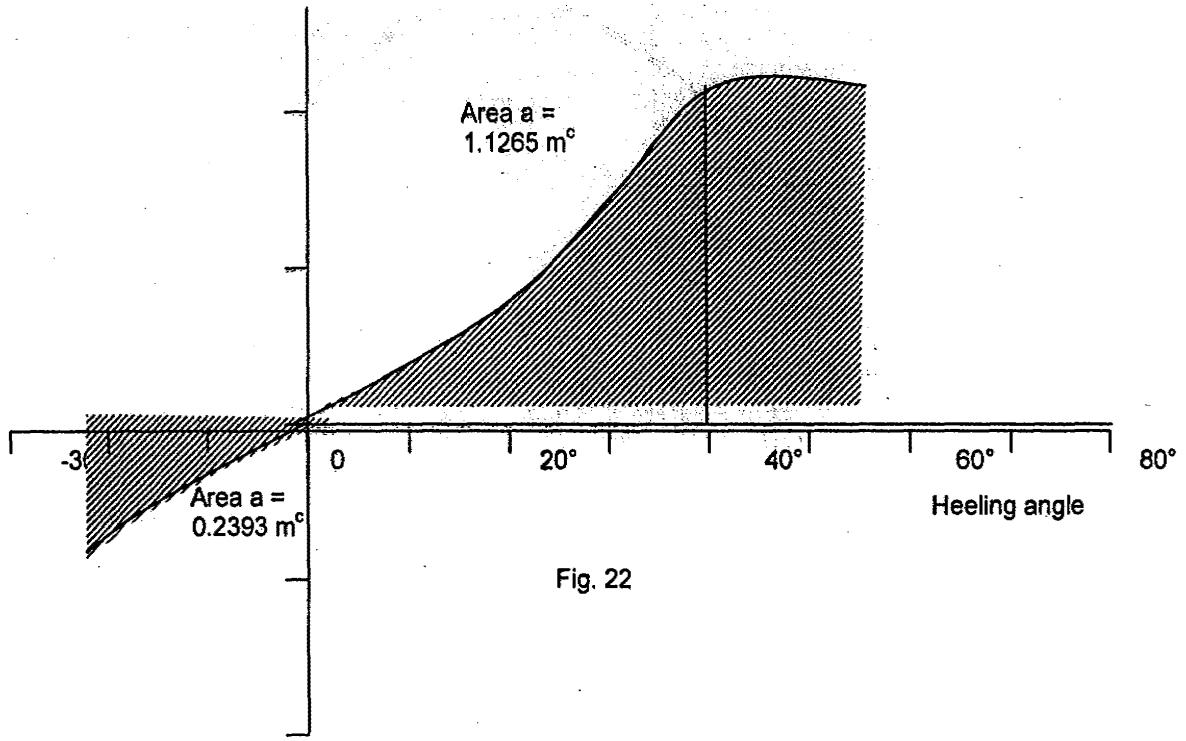


Fig. 22

LONGITUDINAL STRENGTH

				X	FRAME
SHEAR FORCE (MIN)	-7733.4	kN	POSITION:	112.4 m	145
SHEAR FORCE (MAX)	9290.7	kN		25.6 m	36
SAGGING MOMENT	-43.7	kNm		132.4 m	175
HOGGING MOMENT	321021.6	kNm		58.2 m	77

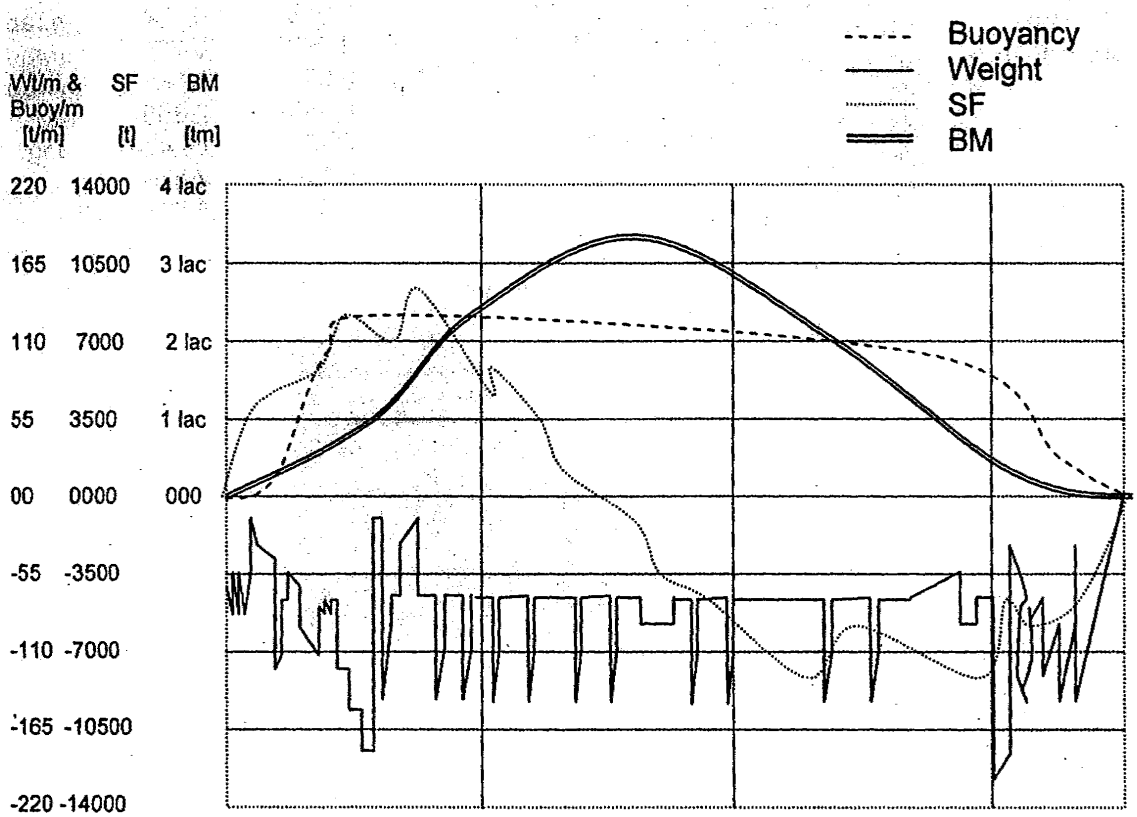
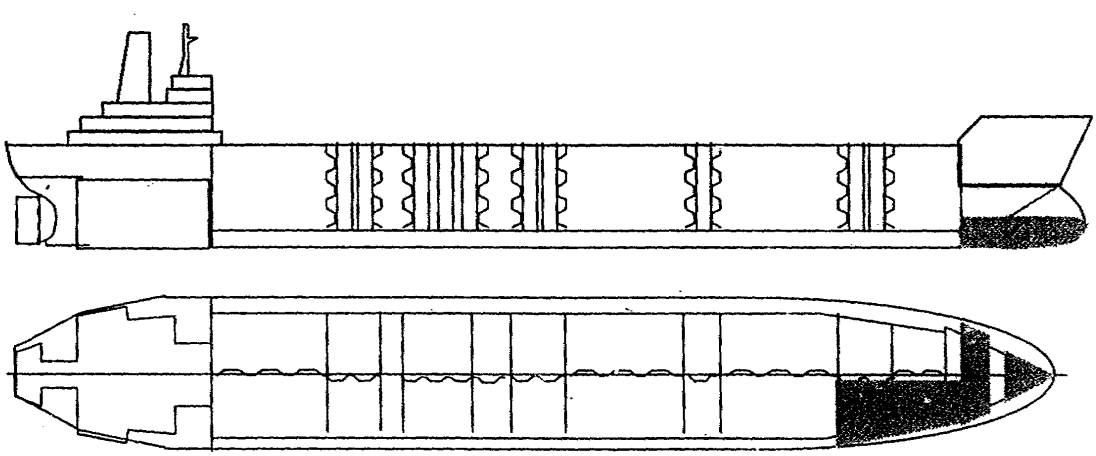


Fig. 23

Case: INI02 / DAM01 (Ballast water dep. / Side damage n.1)



FLOATING POSITION
T = 5.319m. TR = -3.225m. Heel = -2.4°
(T: draught, moulded (m) TR: trim (m) HEEL: heeling angle)

FREEBOARD DECK EDGE

CASE	initial cond / damage case	(INI02 / DAM01)
FRB	freeboard	(4.829 m)
XYRB	x where min. freeboard	(-1.6 m)
YFRB	y of min. freeboard	(-8.428 m)
ZFRB	z of min. freeboard	(12.144 m)
IMMA	immersion angle	(28.6°)
XIMM	x where immersion occurs	(7.412 m)
REDPD	reduction per 1 degree	(0.157 m)

DAMAGED COMPARTMENTS

NAME	DES	PERM	VOL (m^3)	XCG(m)	YCG(m)	Z CG(m)
R1001	C. TANK N.1 ST	0.95	169.0	111.79	3.18	2.79
R2001	BALLAST TK. N.1 ST	0.95	250.8	108.78	4.98	1.29
CLKST	CHAIN LOKER ST	1.00	0.0	-	-	-
R5000	INDUSTRIAL WATER TK	1.00	51.3	118.45	-0.16	2.18
R2000	FORE PEAK BALLAST TK	0.95	159.8	123.18	-0.07	2.12
FC	castello	1.00	0.0	-	-	-
MANO	TRUSTER ROOM	1.00	41.7	123.17	-0.15	3.10

Abbreviations

CASE	initial cond / damage case		
DES	comp. description	PERM	permeability
VOL	volume	XCG	x of center of gravity
YCG	y of center of gravity	ZCG	z of center of gravity

STABILITY CRITERIA

CASE	RCR	TEXT	REQ	ATTV	UNIT	STAT
INI02 / DAM01	PROGR.M	No progr. flooding	0.000	7.095	m	OK
INI02 / DAM01	MAXHEEL.M	Maximum heel	25.000	2.366	deg	OK
INI02 / DAM01	RANGE2.M	Range of pos. stab	20.000	77.634	deg	OK
INI02 / DAM01	MAXGZ2.M	Max. Righting lever 0.1 m	0.100	1.131	m	OK
INI02 / DAM01	MINAREA2.M	Minarea of GZ-curve	0.018	0.186	mrad	OK

Abbreviations

CASE	initial cond / damage case		
RCR	relevant criteria	TEXT	descriptive name
REQ	required value	ATTV	attained value
UNIT	unit	STAT	status of stability criteria.

RELEVANT OPENINGS

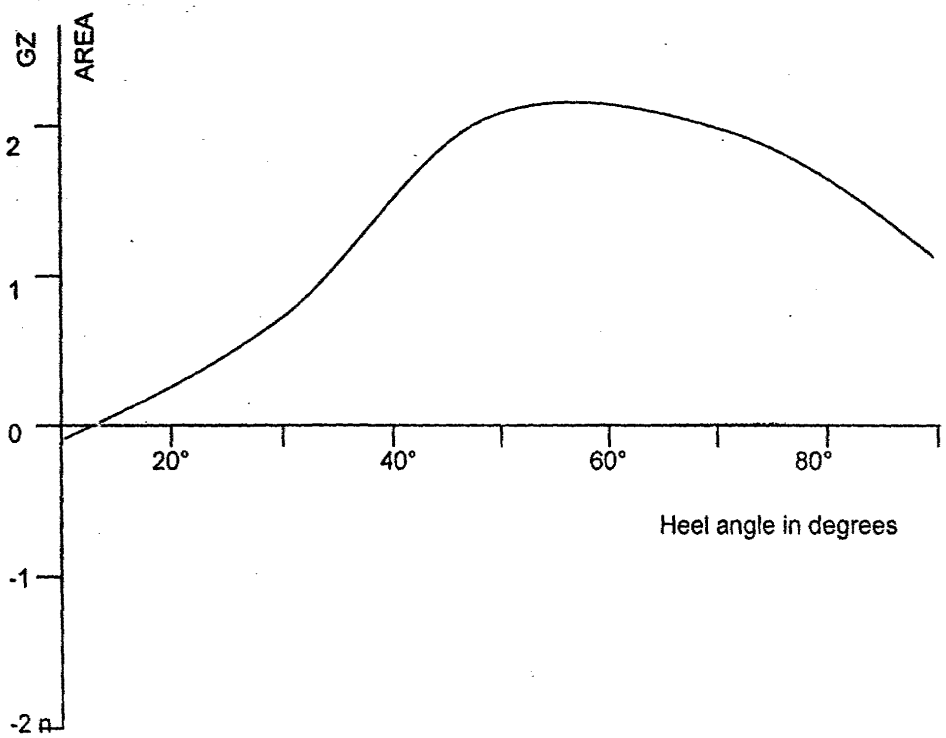
NAME	TEXT	X	Y	Z	IMMR
OPR01	Aft. Opening comp. R2009	39.50	9.100	12.954	7.095

Abbreviations

NAME	name	TEXT	descriptive name
X	x-coordinate in met	Y	y-coordinate in met
Z	z-coordinate in met	IMMR	reserve to immersion

HEEL	GZ	AREA	T	TR
degree	m	rad*m	m	m
0.0	0.115	0.000	5.335	-3.173
-1.0	0.067	-0.002	5.330	-3.197
-3.0	-0.031	-0.002	5.313	-3.237
-5.0	-0.130	0.001	5.289	-3.267
-7.0	-0.231	0.007	5.257	-3.287
-10.0	-0.387	0.023	5.197	-3.298
-12.0	-0.495	0.038	5.147	-3.29
-15.0	-0.664	0.069	5.059	-3.267
-20.0	-0.972	0.140	4.876	-3.176
-30.0	-1.646	0.369	4.329	-2.194
-40.0	-2.090	0.700	3.418	-2.789
-50.0	-2.191	1.078	2.265	-2.625
-60.0	-2.125	1.455	0.972	-2.053
-70.0	-2.052	1.820	-0.410	-0.970
-80.0	-1.793	2.159	-1.754	0.531

Righting lever curve



Question on M T Charlie:

Q. 1 What is the quantity of ballast, HFO, DO, FW in the given 'Loading Conditions LOAD O2 – Ballast condition dep'?

Q. 2 What is the deadweight and FSM in above condition? What is the light weight of M T Charlie?

Q. 3 What are x, y and z coordinates of minimum freeboard position in above intact condition?

Hint: - XFRB is the x coordinates of minimum freeboard position

Q. 4 What is immersion angle for above intact condition?
Q. 5 What is x coordinate of position where immersion occurs in above intact condition?
Hint : - XIMM
Q. 6 What is reduction of freeboard per degree of heel in above intact condition?
Hint : - REDPD
Q. 7 What are the various openings through which the progressive flooding may occur are stated for above condition? What details are provided?
Q. 8 What are the peak value are SF and BM reached in above loaded condition?
Q. 9 What is the maximum GZ and the angle of heel at which it occurs in above loaded condition?
Q. 10 What are the areas a and b in the severe wind criteria diagram of above loaded condition?
Q. 11 What are the compartments damaged in the given damaged condition?
Q. 12 state the values of various parameters obtained in the given damaged condition which are compared with the required criteria of damage stability for chemical tankers?

E: Selected pages from stability booklet of M.V. ROMEO

(Vehicle Carrier)

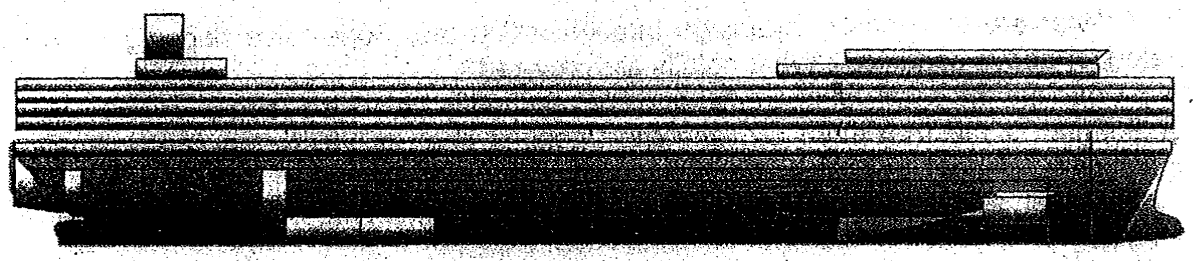


Fig. 24

LOAD / STAB MANUAL RORO

This is to certify that this Loading Manual has been approved in accordance with the requirements of Regulation 10(1), Annex 1 to the International Convention on Load Line 1966, and this ship is capable of complying with the requirement of IMO Resolution A.167 as amended by A.206 and in conjunction with A.562 when loaded in accordance with the approved stability information incorporated in this document.

Contents

Sr. Nr	Subject	Page Nr
1	Preface	
2	Principal Particulars of the Vessel	
3	Freeboard Marks and Corresponding Deadweights	
4	Car Deck and Tank Arrangement	
5	Tanks Capacity Table	
6	Dimensions / Clearance / VCG of VEHICLES & STOWAGE.	
7	Nr. of land Cruisers (Deck & Zone wise) with MG, KG & CLG.	
8	Nr. of STANDARD CAR (Deck & Zone wise) with MG, KG & CLG.	
9	Car load uniform deck load / axle load and deck area	
10	Standard loading conditions	
11	Trim and stability calculation for typical loading condition	
12	Special notes regarding the stability and loading of the ship	
13	Summary of Trim and Stability Conditions	
14	Simplified longitudinal strength calculation	
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GENERAL

PREFACE

This guidance to the Master has been prepared for loading cargoes, ballast, fuel, etc., in viewpoint of avoiding the excessive stress in hull structure and having enough stability.
The typical loading conditions are shown for the possible intended service of the vessel.
It is emphasized that a separate calculation is necessary for all other conditions of loading to meet the requirement of Government and Classification Society by this manual.
For all calculations in this guidance, the Light Ship Condition is based on the results of Inclining Experiment which was carried out in the dock of the builder's yard in the presence of surveyors for NK and also representative for the Owner, on 12th Feb., 2000.
The results are summarized as follows:

Light Weight	*14,623 t*
L.C.G. after Midship	*7.35 m*
Long. Moment	*107,445 tm*
V.C.G. above Base Line	16.75 m
Vertical Moment	244,921 *tm*

Warning Note:

1. This stability information shows that the ship complies with definite intact stability requirements in all designed conditions and gives the data deemed necessary for the calculation and evaluation of stability to the master in order that he can take measures for securing the stability in any service condition

2. The strengthening of the bottom forward has been approved on the basis that a draught forward not less than 5.60 meters can be achieved in ballast on part loaded conditions. If, in the option of the master, sea conditions are likely to cause regular slamming, than other appropriate measures such as change in speed, heading or an increase in draught forward may also need to be taken.

3. Instructions to the master concerning stability
   Compliance with the required minimum stability criteria does not insure immunity against capsizing, regardless of the circumstances, or absolve the Master from his responsibilities. Masters should therefore exercise prudence and good seamanship, having regard to the season of the year, weather forecasts, the navigational zone, and should take appropriate action as to speed and course warranted by the prevailing circumstances.
   Care should be taken to ensure that cargo, allocated to the ship is capable of being stowed, so that compliance with the stability criteria can be achieved. If necessary, the amount of cargo should be limited to the extent that ballast weight may be required.
   In determining the sequence of tanks from which fuel oil and fresh water is to be consumed and those into which water ballast may be admitted during the voyage the Master must ensure, prior to departure, that the required minimum stability criteria will be maintained throughout the voyage after making due to allowance for free surface effect as may be appropriate.
   Before a voyage commences, care should be taken to ensure that the cargo and sizeable pieces of equipment have been properly stowed or lashed, so as to minimize the possibility of both longitudinal and lateral shifting at sea, under the effect of acceleration caused by rolling and pitching.

Principal particulars of the vessel

Ship's Name	:	Romeo
Official Number	:	123456
Signal Letters	:	hytn
Nationality	:	INDIAN
Port of Registry	:	Zulu
Shipbuilder	:	Tango SHIPBUILDING CO., LTD.
Keel Laid	:	2ND AUG., 1999
Launched	:	24TH NOV, 1999
Delivered	:	17TH MARCH,2000
Type of Ship	:	MULTIPLE DECKER
Kind of vessel	:	VEHICLE CARRIER
Class	:	ZR, Vehicles Carrier (Equipped for Carriage of Containers),
Length (O.A.)	:	179.90 m
Length (P.P)	:	170.00 m
Breadth (mld.)	:	32.20 m
Depth (mld.)	:	15.07 / 34.50 m (fbd.Dk. / Strength Dk.)
Summer Draft (ext.)	:	9.622 m
Displacement (ext.)	:	31,984 mt
Deadweight	:	17,361 mt
Tonnage (TM69)		
Gross	:	51,259
Net	:	15,378
Speed (Sea Speed)	:	19.3 knots

Freeboard marks & corresponding deadweights

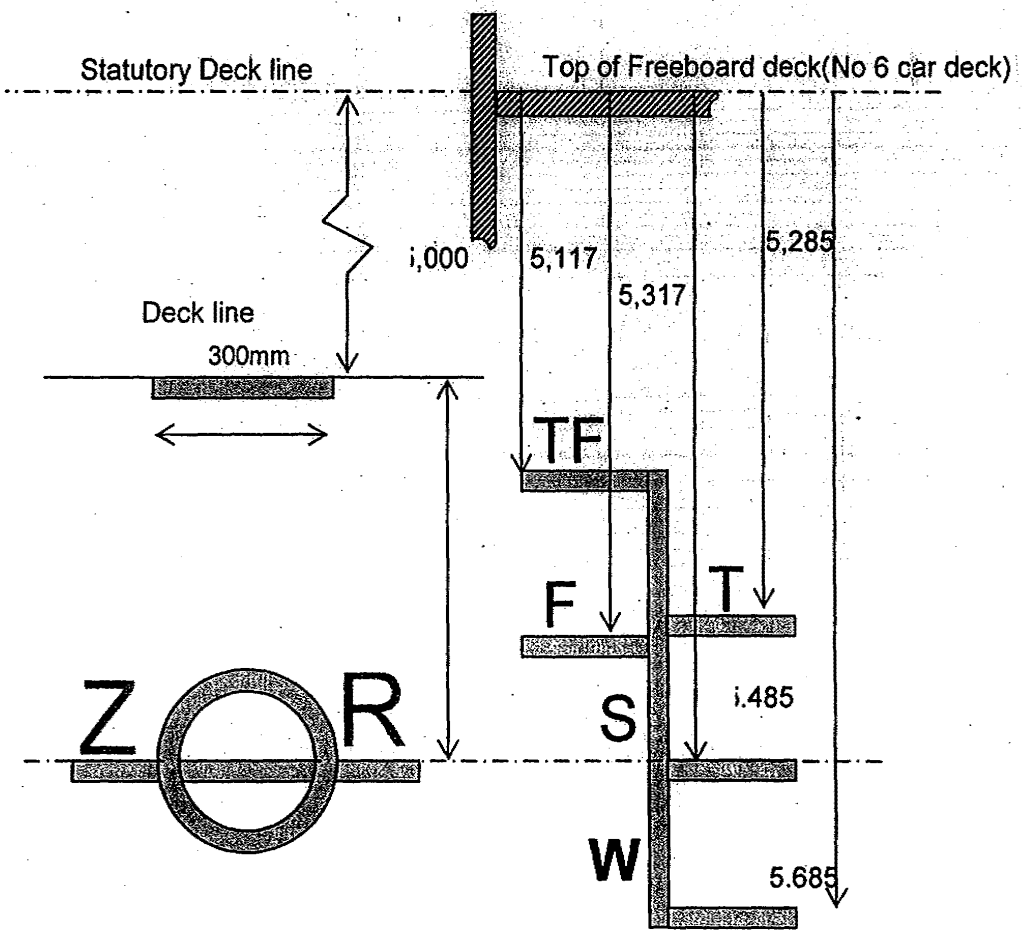


Fig. 25

Deadweights

Freeboard Lines		Freeboard Assigned By ZR (m)	Draft (Ext.) (m)	Full Dispt. (mt)	Full Dispt. (lt)	Dead-Weight (mt)	Dead-Weight (lt)
Tropical Fresh	Tf	5.117	9.990	32,397	32,397	18,294	18,005
Fresh	F	5.317	9.790	31,479	31,479	17,361	17.087
Tropical	T	5.285	9.822	32,416	32,416	18,313	18,024
Summer	S	5.485	9.622	31,479	31,479	17,361	17,087
Winter	W	5.685	9.422	30,546	30,546	16,413	16,154

CAR DECKS & TANK ARRANGEMENTS

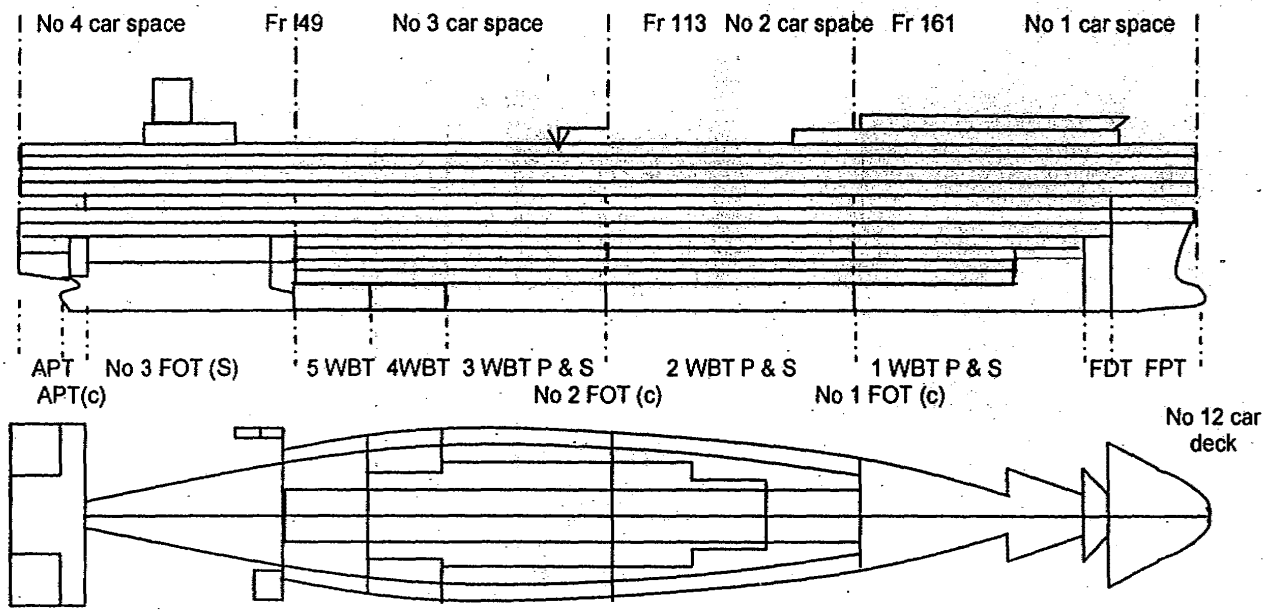


Fig. 26

Tank Capacity Table

TANK CAPCITY TABLE (Hull Part)								
Compartment		Location (Fr.No.)	Capacity (M³) 100%	Wt (mt)	Centre Of Gravity (m)			Max. Inertia (m^4)
					m g	kg	clg	
Water Ballast Tank (S.G.=1.025)				100%				
Fore Peak Tk.		201 – F.E	942.2	966	-80.52	12.87	-0.02	5,843
Fore Deep Tk.		193 – 201	358.3	367	-70.54	9.04	0	1,175
No.1 W.B.Tk.	P	161 – 193	706.4	724	-56.46	4.05	2.45	605
	S	161 – 193	706.4	724	-56.46	4.05	-2.45	605
No.2 W.B.Tk.	P	113 – 161	825.8	846	-22.46	2.26	8.78	2,350
	S	113 – 161	846.5	868	-22.31	2.27	-8.79	2,380
No.3 W.B.Tk	P	81– 113	374.3	384	7.75	2.64	12.76	319
	S	81– 113	374.3	384	7.75	2.64	-12.76	319
No.4 W.B.Tk	P	65 –81	175.5	180	26.13	2.75	10.49	272
	S	65 –81	187.2	192	26.50	2.82	-10.50	330
No.5 W.B.Tk.	P	49 –65	231.4	237	39.27	2.68	6.79	538
	S	49 – 65	231.4	237	39.27	2.68	-6.79	538
Aft Peak Tk.	P	A.E. – 13	706.8	724	83.46	12.04	10.08	1,253
	C	A.E. - 13	374.0	383	81.40	9.60	0.01	1,004
	S	A.E. - 10	459.2	471	82.54	11.17	-9.91	1,066
Water Ballast Total			7,499.7	7,686	-			
Fresh Water Tank (S.G.=1.000)								
Fr W Tk.	P	9 – 13	221.1	221	76.74	11.73	10.18	358
Dr W Tk.	S	9 – 13	219.8	220	76.73	11.72	-10.17	346
Fresh Water Total			440.9	441	-			

Note: 1. Minus (-) Signs in MG indicate forward midship.
2. Minus (-) Signs in CLG indicate starboard side off center line.

Tank capacity table (Machinery Part)									
Compartment		Location (F.R.No.)	Capacity (m^3)		Weight (mt)	Center Of Gravity (m)			Max. Inertia (m^4)
			100% Full	90%,95% Full		m g	k g	c l g	
Fuel Oil Tank <Double Bottom T.K.> (S.G.=0.970)					90% F_l				
No.1 Fuel Oil Tk.	C	113 – 161	841.4	757.3	735	-27.14	1.63	0	1,664
No.2 Fuel Oil Tk.	P	65 – 113	377.3	339.6	329	12.55	1.27	6.84	690
	C	47 – 113	1,080.8	972.7	944	25.32	1.52	0.01	2,281
	S	65 – 112	372.3	335.1	325	12.78	1.27	-6.78	707
<Deep Tk.>					95% F_l				
No.3 Fuel Oil Tk.	P	37 – 44	133.9	127.2	123	53.22	10.72	14.37	16
	S	41 – 49	458.5	435.6	423	49.60	10.30	-11.78	278
H.F.O. Sett. Tk.	P	21 – 25	* 25.3	24.0	23	67.25	11.23	13.63	9
H.F.O. Serv.Tk.	P	25 – 29	* 29.2	27.7	27	64.05	11.32	13.63	9
Fuel Oil Total			3,318.7	3,019.2	2,929				
Diesel Oil Tank < Deep Tk. > (S.G. = 0.860)					95% F_l				
Diesel Oil Tk.	P	44 – 49	100.9	95.9	82	48.43	10.52	14.38	11
Lub. Oil Tank (S.G. = 0.900)					90% F_l				
M/E L.O. Sump Tk.	C	28 – 40	25.5	23.0	21	59.15	1.18	-0.10	17
M/E L.O.Stor.Tk.	P	14 – 17	26.7	24.0	22	73.23	12.14	9.98	4
Miscellaneous Tank									
F.O.Overflow Tk.		45 – 47	35.2			48.86	1.32	0.34	192
Bilge Sep.Oil Tk.	P	33 – 45	33.5			53.42	1.55	3.55	19
Clean Draink Tk.	S	33 – 45	33.5			53.42	1.55	-3.56	19
Bilge Tk.		13 – 27	50.7			68.78	1.16	-0.04	33
Cool W.Tk.		8 – 13	17.5			76.58	3.08	0	1
Cyl.Oil Stor.Tk.	P	14 – 20	67.4			72.08	12.09	13.39	18
M/E L.O.Sett.Tk.	P	14 – 17	26.7			73.23	12.14	7.04	4
F.O.Sludge Tk.	P	23 – 25	3.0			66.45	8.54	8.45	2
L.O.Sludge Tk.	P	21 – 23	3.0			68.05	8.54	8.45	2

Note: 1. Minus (-) Signs in MG indicate forward midship.
2. Minus (-) Signs in CLG indicate starboard side off center line.
3. Weight of F.O., D.O. and L.O. are corresponding to 90% (Double

Bottom Tk.) or 95% (Deep Tk.) full capacity.
4. (*) Marks in capacity mean full of overflow position.

Dimensions / Clearance / Vcg of Vehicles & Stowage.

Kind of Car	Length (mm)		Width (mm)		Height (mm)	Weight (kg)	VCG (m)
Standard car	4,500	x	1,700	x	1,420	1,100	0.57
Land cruiser	3,970	x	1.690	x	1,850	1,720	0.80

Clearance of Car Stowage	Distance between Cars Front and Rear (mm)	Distance between Car Sides (mm)
Standard Car	300	100
Land Cruiser	300	100

Number of Car Stowage / Area, Deck wise

Item	Standard car (no. of cars)	Land cruiser (no. of cars)	UI (dk. area m^2)
No.12 Car Deck	500	-	-
No.11 Car Deck	497	560	-
No.10 Car Deck	496	556	-
No.9 Car Deck (Liftable)	508	572	* 4,470
No.8 Car Deck	433	482	
No.7 Car Deck (Liftable)	417	472	* 4,370
No.6 Car Deck	388	436	
No.5 Car Deck (Liftable)	284	316	* 2,980
No.4 Car Deck	265	297	
No.3 Car Deck	266	-	-
No.2 Car Deck	228	-	-
No.1 Car Deck	97	-	-
Total	4,379	3,691	11,820

Note : 1) (*) Marks at lift able deck stowage position.

Nr. of land Cruisers (Deck & Zone wise) with MG, KG & CLG.
Land Cruiser (Self Weight = 1.72 t)

	NO. 4 CAR SPACE				NO. 3 CAR SPACE				NO. 2 CAR SPACE			
Decks	Cars	M G (m)	KG (m)	CLG (m)	Cars	MG (m)	KG (m)	CLG (m)	Cars	MG (m)	KG (m)	CLG (m)
NO.11	123	65.36	30.52	1.92	162	21.52	30.52	0.19	126	-23.59	30.52	0.65
NO.10	123	65.35	27.99	1.92	178	21.70	27.99	-0.20	111	-23.00	27.99	1.04
NO. 9	123	65.55	25.25	1.97	178	21.71	25.25	-0.20	129	-23.45	25.25	-0.50
NO. 8	98	59.26	22.42	0.83	160	20.98	22.42	-0.28	117	-23.94	22.42	-0.45
NO. 7	114	65.61	19.31	1.28	135	19.45	19.31	-1.34	123	-23.7	19.31	-0.29
NO. 6	110	64.57	15.87	1.40	141	20.14	15.87	-0.05	123	-24.95	15.87	-0.59
NO. 5	-	-	-	-	153	21.72	12.36	-0.09	120	-24.01	12.36	0.10
NO. 4	-	-	-	-	162	21.14	9.74	-0.25	102	-2308	9.74	0.50
TOTAL	691	64.44	23.80	1.59	1,269	21.11	20.74	-0.17	951	-23.74	20.65	0.04

Decks	No. 1 Car Space				Total			
	Cars	M G (m)	K G (m)	CLG (m)	Cars	M G (m)	K G (m)	CLG (m)
NO.11	149	-63.23	30.52	0.00	560	-1.55	30.52	0.83
NO.10	144	-62.63	27.59	-0.19	556	0.59	27.99	0.52
NO. 9	142	-64.03	25.25	-0.29	572	-0.33	25.25	0.18
NO. 8	107	-58.85	22.42	-0.23	482	0.14	22.42	-0.19
NO. 7	109	-58.17	19.31	0.01	472	2.89	19.31	-0.15
NO. 6	62	-55.82	15.87	0.79	436	7.83	15.87	0.29
NO. 5	43	-54.47	12.36	0.07	316	-6.01	12.36	0.01
NO. 4	33	-53.49	9.74	-0.03	297	-2.34	9.74	0.03
TOTAL	780	-60.53	23.50	0.00	3,691	0.41	21.87	0.24

NOTE : Minus (-) signs in MG indicate forward midship, CLG indicate starboard side off center line.

Nr. of Standard Car (Deck & Zone wise) with MG, KG & CLG.
Standard Car (Self Weight = 1.10 t)

Decks	No. 4 Car Space				No. 3 Car Space				No. 2 Car Space			
	Cars	MG (m)	KG (m)	CLG (m)	Cars	MG (m)	KG (m)	CLG (m)	Cars	MG (m)	KG (m)	CLG (m)
NO.12	109	64.38	32.81	1.58	144	19.97	32.18	0.94	122	-23.21	32.81	0.11
NO.11	112	64.48	30.29	3.49	143	20.63	30.29	0.96	112	-24.05	30.29	0.72
NO.10	112	65.55	27.76	1.35	155	21.07	27.76	0.24	105	-23.79	27.76	0.96
NO. 9	112	65.58	25.02	1.43	156	20.99	25.02	0.05	118	-24.47	25.02	-0.12
NO. 8	80	60.46	22.19	1.40	151	22.18	22.19	-0.72	108	-24.00	22.19	-0.41
NO. 7	100	65.54	19.08	1.23	120	20.65	19.08	-1.22	111	-23.91	19.08	-0.38
NO. 6	96	65.29	15.64	1.23	120	20.15	15.64	0.02	106	-22.41	15.64	-0.14
NO. 5	-	-	-	-	141	20.80	12.13	0.88	107	-23.54	12.13	0.06
NO. 4	-	-	-	-	145	22.67	9.51	-0.30	93	-22.79	9.51	0.54
NO. 3	-	-	-	-	153	21.21	6.92	0.31	97	-22.46	6.92	0.01
NO. 2	-	-	-	-	125	19.01	4.80	0.39	90	-21.91	4.80	-0.03
NO. 1	-	-	-	-	-	-	-	-	58	12.17	2.74	0.28
TOTAL	721	64.61	25.05	1.70	1,553	20.90	19.01	0.16	1,227	-21.69	18.65	0.12

Dk	No. 1 Car Space				Total			
	Cars	MG (m)	KG (m)	CLG (m)	Cars	MG (m)	KG (m)	CLG (m)
NO.12	125	-62.90	32.81	0.09	500	-1.60	32.81	0.67
NO.11	130	-63.61	30.29	-0.12	497	-1.59	30.29	1.19
NO.10	124	-64.46	27.76	-0.27	496	0.23	27.76	0.52
NO. 9	122	-64.91	25.02	-0.31	508	-0.37	25.02	0.23
NO. 8	94	-58.82	22.19	-0.29	433	0.15	22.19	-0.16
NO. 7	86	-57.88	19.08	-0.21	417	3.36	19.08	-0.20
NO. 6	66	-54.20	15.64	0.52	38	7.04	15.64	0.36
NO. 5	36	-55.06	12.13	0.00	284	-5.52	12.13	0.45
NO. 4	27	-51.83	9.51	-0.02	265	-0.88	9.51	0.02
NO. 3	16	-48.90	6.92	-0.14	266	1.07	6.92	0.17
NO. 2	13	-48.97	4.80	-0.09	228	-1.02	4.80	0.20
NO. 1	39	-17.54	2.74	-0.10	97	0.22	2.74	0.13
TOTAL	878	-58.78	23.08	-0.11	4,379	0.18	20.72	0.35

No. Of Deck	Uniform Deck Load (KG / m²)	Axle Load On Voyage (Mt / Wheel)	Clear Height (mm)	Deck Area (m²)
No. 12 Car Deck	200	1.6 mt / 2 – W	1,800	5,050
No. 11 Car Deck	300	1.8 mt / 2 – W	2,100	5,090
No. 10 Car Deck	300	1.8 mt / 2 – W	2,100	5,150
No. 9 Car Deck (Liftable)	300	1.8 mt / 2 – W	1,700 / 2,300	5,110
No. 8 Car Deck	2,000	20.0 mt / 2 – W 50.0 mt / 2 – W	2,300 / 2,900 /4,500	4,470
No. 7 Car Deck (Liftable)	300	1.8 mt / 2 – W	1,800 / 2,300	4,680
No. 6 Car Deck	3,000	35.0 mt / 2 – W 50.0 mt / 2 – W	2,900 / 3,400 /5,100	4,370
No. 5 Car Deck (Liftable)	300	1.8 mt / 2 – W	2,300	3,060
No. 4 Car Deck	2,000	20.0 mt / 2 – W 50.0 mt / 4 – W	2,100 / 4,300	2,980
No. 3 Car Deck	200	1.6 mt / 2 – W	1,800	2,730
No. 2 Car Deck	200	1.2 mt / 2 – W	1,700	2,450
No. 1 Car Deck	200	1.2 mt / 2 - W	1,700	1,100
			TOTAL	46,240

Note: 1) Height of car lashing fittings on deck shall not be considered for deck clear height.
2) d/w to be less than given by load line and cars to be as evenly distributed as practically possible.
3) When containers (24 t) are loading longitudinally, clearance of containers to be more than 1.5m (only for no. 6 car deck).

Car deck area (deck & zone wise) with mg, kg & clg

Decks	No. 4 Car Space			No. 3 Car Space			No. 2 Car Space			No. 1 Car Space		
	Area (m^2)	MG (m)	CLG (m)	Area (m^2)	MG (m)	CLG (m)	Area (m^2)	M G (m)	CLG (m)	Area (m^2)	MG (m)	CLG (m)
NO.12	1,120	65.91	1.36	1,500	21.00	0.41	1,170	-23.95	0	1,260	-64.20	-0.09
NO.11	1,120	65.83	1.39	1,540	21.09	0	1,110	-23.90	0.61	1,320	-64.83	-0.08
NO.10	1,120	65.83	1.39	1,540	21.09	0	1,170	-23.95	0	1,320	-64.85	-0.08
NO.9	1,090	66.69	2.33	1,540	21.09	0	1,170	-23.95	0	1,310	-64.82	-0.08
NO.8	800	60.11	0.92	1,540	21.10	0	1,170	-23.95	0	960	-59.01	-0.11
NO.7	1,080	66.18	1.80	1,550	21.07	0	1,160	-23.95	0	890	-58.20	0
NO.6	1,050	65.14	1.38	1,490	21.20	0.01	1,160	-23.95	-0.05	670	-56.19	0
NO.5	-	-	-	1,540	21.22	0.02	1,080	-24.06	-0.07	440	-53.44	0
NO.4	-	-	-	1,560	21.01	-0.04	1,080	-23.33	-0.04	340	-53.48	0
NO.3	-	-	-	1,520	20.49	-0.02	1,030	-22.73	-0.04	180	-49.08	0
NO.2	-	-	-	1,360	18.61	-0.08	950	-21.99	-0.08	140	-49.30	0
NO.1	-	-	-	670	13.48	-0.15	430	-17.34	-0.04	-	-	-
TOTAL	7,380	65.30	1.53	17,350	20.55	0.07	12,680	-23.43	0.03	8,830	-61.21	-0.06

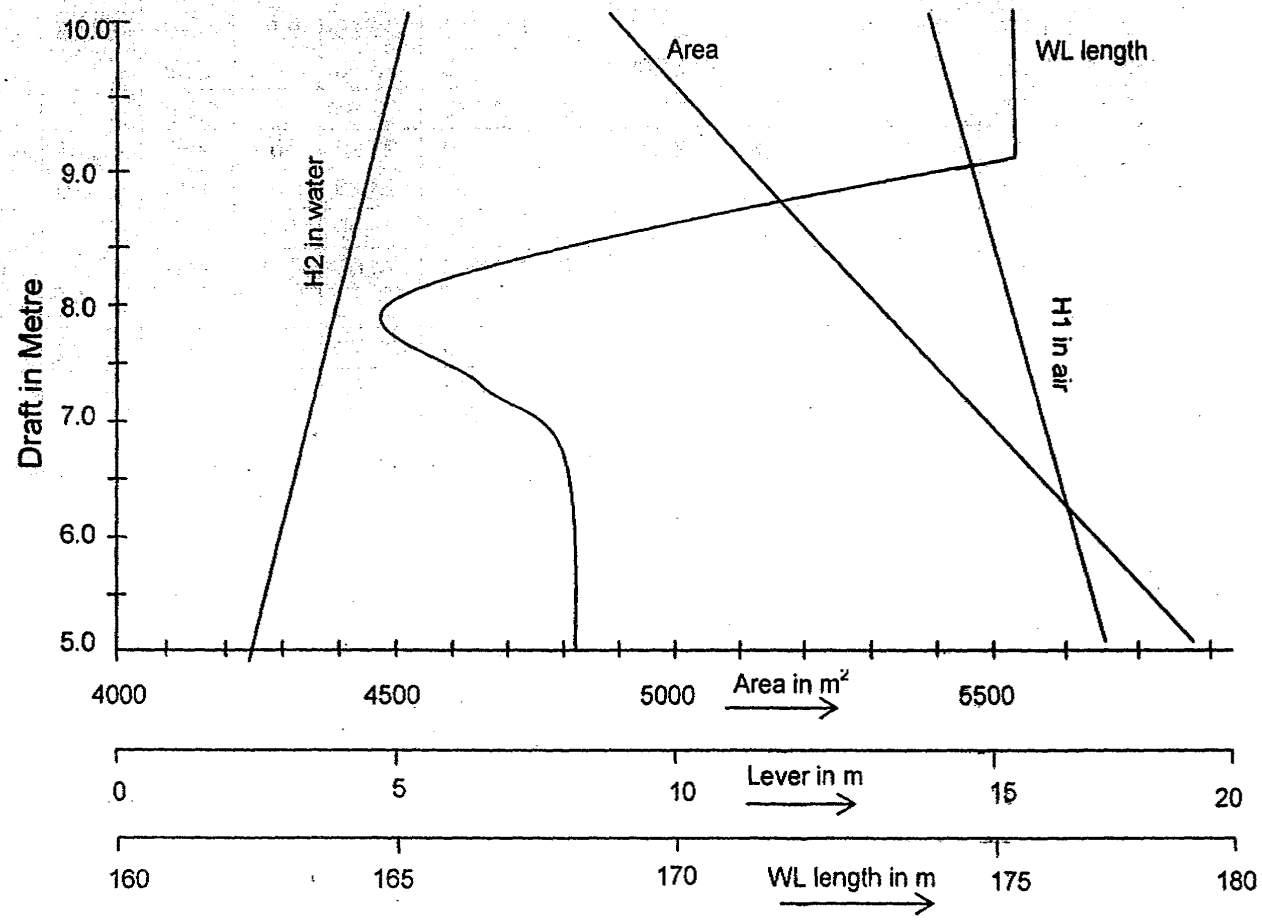
Decks	TOTAL		
	Area (m^2)	MG (m)	CLG (m)
NO.12	5,050	-0.71	0.40
NO.11	5,090	-1.16	0.45
NO.10	5,150	-1.44	0.32
NO.9	5,110	-1.52	0.51
NO.8	4,470	-0.91	0.18
NO.7	4,680	5.25	0.43
NO.6	4,370	7.91	0.32
NO.5	3,060	-5.50	-0.01
NO.4	2,980	-3.56	-0.03
NO.3	2,730	-0.40	-0.03
NO.2	2,450	-1.01	-0.08
NO.1	1,100	1.43	-0.11
TOTAL	46,240	0.02	0.27

Note: Deck areas are calculated as inside at trans. web or still of partial BHD. and incl. slope way.

Note: Minus (-) signs in MG indicate forward midship, CLG indicate starboard side off center line

Curves of Windage Area

A is Projected lateral area of vessel above water line
Z, the Vertical distance from centre of windage area to one half draft point is H1 + H2



Standard loaded cond. (cond. no. 7 – 9)

Item	No.	Weight (t)	Mg (m)	Kg (m)	Clg (m)
No.12 Dk. (Standard Car)	500	550	-1.60	32.81	0.67
No.11 Dk. (Standard Car)	497	547	-1.59	30.29	1.19
No.10 Dk. (Standard Car)	496	546	0.23	27.76	0.52
No. 9 Dk. (Standard Car)	508	559	-0.37	25.02	0.23
No. 8 Dk. (Standard Car)	433	476	0.15	22.19	-0.16
No. 7 Dk. (Standard Car)	417	459	3.36	19.08	-0.20
No. 6 Dk. (Standard Car)	388	427	7.04	15.64	0.36
No. 5 Dk. (Standard Car)	284	312	-5.52	12.13	0.46
No. 4 Dk. (Standard Car)	265	292	-0.88	9.51	0.02
No. 3 Dk. (Standard Car)	266	293	1.07	6.92	0.17
No. 2 Dk. (Standard Car)	228	251	-1.02	4.80	0.20
No. 1 Dk. (Standard Car)	97	107	0.22	2.74	0.13
Total		4,819	0.18	20.72	0.35

Mixed car loaded cond. (cond. no.10 – 12)

Item	No.	Weight (mt)	MG (m)	KG (m)	CLG (m)
No.12 Dk. (Standard Car)	500	550	-1.60	32.81	0.67
No.11dk. (Land Cruiser)	560	963	-1.55	30.52	0.83
No.10dk. (Land Cruiser)	556	956	0.59	27.99	0.52
No. 9 Dk. (Land Cruiser)	572	984	-0.33	25.25	0.18
No. 8 Dk. (Land Cruiser)	482	829	0.14	22.42	-0.09
No. 7 Dk. (Land Cruiser)	472	812	2.89	19.31	-0.15
No. 6 Dk. (Land Cruiser)	436	750	7.83	15.87	0.29
No. 5 Dk. (Land Cruiser)	316	544	-6.01	12.36	0.01
No. 4 Dk. (Land Cruiser)	297	511	-2.34	9.74	0.03
No. 3 Dk. (Land Cruiser)	266	293	1.07	6.92	0.17
No. 2 Dk. (Land Cruiser)	228	251	-1.02	4.80	0.20
No. 1 Dk. (Land Cruiser)	97	107	0.22	2.74	0.13
Total		7,550	0.24	21.25	0.26

Standard Car: (Self Weight = 1.10mt)
Land Cruiser: (Self Weight = 1.72mt)
U. L. : Assumed average load per square meters (t/m²)
Trim and stability calculation for typical loading condition:

A Displacement calculation from draft reading:
1. *Calculate the mean of the drafts on both sides at fore, midship and aft draft marks respectively (df, d^m, da).*

df : mean of fore drafts
d^m : mean of midship drafts
da : mean of aft drafts

2. *Correct the drafts df and da to the drafts at F.P. and A.P. by using data no. 3 "correction table for fore & aft draft marks".*

dF : draft at fore perpendicular (F.P.) = df + δ df.
d^M : draft at midship = $d^m + \delta d^m$ ($\delta d^m = 0$ in this ship).
dA : draft at aft perpendicular (A.P.) = da + δ da.

3. Trim (t), Mean draft (dm) and Deflection (def) are calculated as follows.
t = dA – dF & dm = ½ (dF + dA)
def = d^M - dm ; if def < 0 : Hogging, def > 0 : Sagging

4. Find the displacement (Δm) corresponding to dM from "HYDROSTATIC TABLES"
dM = dm + ¾ x def

5. The correction due to trim (Δt) are made to the above displacement (Δt), by using DATA NO.2 "CORRECTION TABLE OF DISPT. BY TRIM"

6. Actual displacement (Δ) is calculated by the following formula.

$$\Delta = (\Delta m + \Delta t) \times \frac{\rho}{1.025}$$ where ρ = Actual specific gravity

B. Calculations of L.C.G & drafts:

$$MG = MB + \frac{100 \times MCTC \times t}{\Delta} \times \frac{\rho}{1.025}$$

(MB & MG positive for abaft midship, negative for forward of midship).

1. Enter the value of variable loads and its L.C.G. (MG) into the item of WEIGHT and MG, respectively.
2. Enter the value of WEIGHT x L.C.G. (MG) into the item of LONG, MOMENT.
3. Sum up the items of WEIGHT and LONG. MOMENT, and enter into the item of TOTAL.

The all total weight is the vessel's DISPLACEMENT.
L.C.G. (MG) corresponding to displacement is determined by dividing the Total long. moment by the displacement

$$\text{L.C.G. (MG)} = \frac{\text{total long moment}}{\text{displ.}} \ldots\ldots \text{in meter}$$

4. Obtain the M.T.C., L.C.F. (MF) and L.C.B. (MB) corresponding to displacement from "HYDROSTATIC TABLES".

5. Calculate the vessel's TRIM and DRAFTS as follows.

$$\text{TRIM t} = \frac{\textit{trim moment}}{100 \times \textit{MCTC}} = \frac{\textit{Displ} \times \textit{BG}}{100 \times \textit{MCTC}} \ldots\ldots \text{in meter}$$

Drafts for'd & aft are calculated thereafter.

C. Stability calculation:

The explanation is made as reference for trim and stability calculation for typical loading condition.
Explanation follows for KG calculations...

$$\text{V.C.G. (KG)} = \frac{\textit{total vert. moment}}{\textit{displ}} \ldots\ldots \text{In meter}$$

The free surface correction (GGo) is obtained by diving the TOTAL F.S. moment by the displacement.

$$\text{GGo} = \frac{\textit{total F.S moment}}{\textit{displ}} \ldots\ldots\ldots\ldots\ldots \text{In meter}$$

KGo = V.C.G. (KG) + GGo
GoM = TKM – KGo

Notes on use of free surface moments:

Provided a tank is completely filled with liquid no movement of the liquid is possible and the effect on the shop's stability is precisely the same as if the tank contained solid material. Immediately a quantity of liquid is withdrawn from the tank the situation changes completely and the stability of the ship is adversely affected by what is known as the "free surface effects". This adverse affect on the stability is referred as a "loss in GM" or as a "virtual rise in VCG" and is calculated as follows.

Loss in GM due to Free surface effects

$$= \frac{\text{Sum of Free Surface Moments x S.G. of liquid in tank}}{\text{Displacement of vessel in tons}}$$

NB The "free surface effects" of all fuel oil, fresh water, feed water and service tanks should be taken into account in both the Arrival and Departure Conditions.

Note: When it is intended to introduce or discharge ballast water during a voyage the master should, prior to departure, ensure that the required criteria will be maintained at all times.

D: Intact Stability Criteria:

For ships without timber deck cargoes, the stability curves are to comply with the following requirements:

1) A_1 is to be not less than 0.055 m-rad.
2) A_2 is to be not less than 0.03 m-rad.
3) (A_1 + A_2) is to be not less than 0.09 m-rad.
4) GZ is to be not less than 0.20 m at the range of heeling angle from 30* upward.
5) The maximum righting lever to occur at angle of heel preferably exceeding 30* but not less than 25*.
6) GoM is to be not less than 0.15 m.

Where:

A_1 = Area under stability curve between 0° and 30° (m-rad)

A_2 = Area under stability curve between 30° and θ u (m-rad)

θ_u = Heeling angle (°) to be taken of whichever is less, down flooding angle in relevant loading condition or 40° *See Data for Down – Flooding Angle (θ f) Curve.

GZ_{max} = Maximum righting lever (m).

θ_{max} = Heeling angle at which righting arm reaches maximum (°).

GoM = Initial metacentric height corrected by free surface effect (m).

Stability Requirements in Wind and Waves. Stability curves and wind-heeling moment lever curves of ships are to comply with the following requirements:

1) Heeling angle caused by steady wind is to be less than 16° or an angle corresponding to 80% of immersing angle of deck edge, whichever is less.
2) Area "b" is to be less than area "a".

Where l_{w1} = Heeling moment lever caused by steady wind (m) given by the formula : $l_{w1} = \frac{0.0514 \times A \times Z}{\Delta}$ m

A = Projected lateral area of hull above water line (m^2)

Z = Vertical distance between the centre of "A" and the centre of underwater projected lateral area of hull (m).

Δ = Displacement (mt)

l_{w2} = Heeling moment lever caused by gust (m) given as 1.5 l_{w1} (m)

E. Subdivision and damage stability requirement:

This stability information booklet is to be prepared in application of 1990 AMENDMENTS to Chapter II – I, Part B – 1, Reg. 25 – 8 of the SOLAS 1974. The following information is to be supplied for the master of the ship to enable by rapid and simple way to obtain accurate guidance as to the stability of the ship under varying conditions of service.

Min. Permissible gom curve (provided in this booklet)

Damage control plan & damage control booklet (provided on board)

F: Assumptions on trim and stability calculations:

1) Consumption

All tanks (F.O., D.O., F.W., DR. W.) filled as follows,

	Departure (Full Bunker)	Departure (Half Bunker)	Arrival (20% Bunker)
Fuel Oil	Full	55%	10%
Diesel Oil	Full	55%	10%
Fresh Water	Full	100%	100%
Drink Water	Full	55%	10%

Consumable on board

Unit in mt

Cond. / Item	Departure		Arrival
	Full Bunker	Half Bunker	10% Bunker
Fuel Oil	2,879	1,583	288
Diesel Oil	82	45	8
Fresh Water	221	221	221
Drink Water	220	121	22
Provisions	10	5	1

2) Specific gravity and expansion margin of liquids

	Specific gravity	Expansion margin
Fuel Oil	0.970	10% (Double Bottom Tk) 5% (Deep Tk)
Diesel Oil	0.860	10%
Lub. Oil	0.900	10%
Fresh Water	1.000	0
Drink Water	1.000	0
Salt Water	1.025	0

3) Free surface effects of liquids in tanks.
For tanks containing consumable liquid, a free surface moment is to be assumed always present for one tank or pair of tanks, with the greater value of free surface moment for each liquid group. For other slack tank, the free surface moment is to be used at each level.

For tanks containing Ballast Water, where ballast tanks are full on departure and on arrival, no free surface correction is needed, however the Master is to ensure that those tanks are "pressed up" throughout the voyage. Where ballast tanks which are filled or emptied on voyage are assumed to have max. free surface moment in the departure and arrival condition

4) Stability
Statical stability curves (GoZ) and metacentric height (GoM) are calculated for ship on even keel.

5) Weight item "CONSTANT" in calculation sheet includes the followings.

Item		Weight (mt)	M G (m)	Long. Moment (mt-m)		K G (m)	Vert. Moment (mt-m)	Trans. Moment (mt-m)	F.S.M. (mt-m)
				Fore	Aft				
Crew & their effect		5	-55.00	275		37.00	185	-	-
Stores	Bon's Str.	5	-82.00	413		19.70	99	-	-
	Acc.Str.	5	-45.00	225		35.70	179	-9	-
	Eng./ El.Str.	10	51.25		513	10.00	100	101	-
	Rope Str.	5	77.50		388	18.50	93	-77	-
Oil & Water in E/R		180	66.20		11,916	9.31	1,676	1,055	41
M/E L.O. Sump Tk.		14	59.05		827	0.97	14	-1	15
Cool.W.Tk.		18	76.58		1,378	3.08	55	-	-
Car Lashing Equipment		27	0.25		7	20.70	559	8	-
Lift Care (2 - sets)		30	61.79		1,546	13.08	392	396	-
TOTAL		299	53.41	913	16,883	11.21	3,352	1,472	56
					15,970				

6) Permission Immersion

Propeller Immersion

$$\frac{dA - 3.342 \times 100(\%)}{6.100}$$

Standard Car Loaded Cond. Arrival. 10% Bunker < Total 4,379 Cars >
Summary of Hydrostatic Particulars

Displacement	(mt)	24354
Correspond Draft	(m)	7.94
Fore Draft	(m	7.94
Aft Draft	(m)	7.94
Mean Draft	(m)	7.94
Trim	(m)	0.00
MB	(m)	2.10
MG	(m)	2.10
BG	(m)	0.00
MTC	tm	355.8
MF	(m)	9.41
TPC	(mt)	42.1
TKM	(m)	17.21
KG	(m)	14.91
GM	(m)	2.30
GC	(m)	0.16
KGo	(m)	15.07
GoM	(m)	2.14
Propeller Immersion	(%)	75.4
CLG	(M)	0.00

Summary of Weight Distribution

Item	Weight (m)	MG (m)	Long Moment (mt-m)	KG (m)	Vert. Moment (mt-m)	F.S.M Nt (mt-m)	Clg (m)	Heel Moment (mt-m)
L.W.	14653	7.35	107445	16.75	244921	0	-0.06	-857
Prov.	1	-60.50	-61	35.60	36	0	0.00	0
Const	299	53.41	15970	11.21	3352	56	4.92	1472
Cargo	4819	0.18	891	20.72	99844	0	0.35	1683
W.B.	4073	-24.18	-98498	2.97	12083	1206	-1.11	-4519
F.W.	243	76.73	18646	11.44	2780	346	8.48	2060
F.O. & D.O.	296	22.44	6641	0.60	178	2223	0.39	115
(Total)	(24354)	2.10	(51034)	14.91	(363194)	(3831)	0.00	(-46)

## Cargo ##				## Water Ballast ##			
No.12 Car Dk.	(Std.Car)	550		Fore Peak Tk.			0
No.11 Car Dk.	(Std.Car)	547		Fore Deep Tk.	(C)	1	4
No.10 Car Dk.	(Std.Car)	546		No.1 W.B. Tk.	(P)	100	724
No. 9 Car Dk.	(Std.Car)	559		No.1 W.B. Tk.	(S)	100	724
No. 8 Car Dk.	(Std.Car)	476		No.2 W.B. Tk.	(P)	100	846
No. 7 Car Dk.	(Std.Car)	459		No.2 W.B. Tk.	(S)	100	868
No. 6 Car Dk.	(Std.Car)	427		No.3 W.B. Tk.	(P)	13	49
No. 5 Car Dk.	(Std.Car)	312		No.3 W.B. Tk.	(S)	100	384
No. 4 Car Dk.	(Std.Car)	292		No.4 W.B. Tk.	(P)		0
No. 3 Car Dk.	(Std.Car)	293		No.4 W.B. Tk.	(S)		0
No. 2 Car Dk.	(Std.Car)	251		No.5 W.B. Tk.	(P)	100	237
No. 1 Car Dk.	(Std.Car)	107		No.5 W.B. Tk.	(S)	100	237
(Sub Total)		(4819)		Aft.Peak Tk.	(P)		0
				Aft. Peak Tk.	(S)		0
## Fuel Oil & Diesel Oil ##				Aft.Peak Tk.	(C)		0
No.1 F.O.Tk.	(C)		0	(Sub Total)			(4073)
No.2 F.O.Tk.	(P)		0				
No.2 F.O.Tk.	(S)		0	## Fresh Water ##			
No.2 F.O.Tk.	(C)	27	288	Fresh W.Tk. (P)		100	221
No.3 F.O.Tk.	(P)		0	Drink W.Tk.(S)		10	22
No.3 F.O.Tk.	(S)		0	(Sub Total)			(243)
Diesel O.Tk.		9	8				
(Sub Total)			(296)				

Summary of GZ curve & Intact Stability Criteria

Range of stability (deg). .	71.0
Maximum go z (m)	3.10
Angle of max go z (deg). .	71.0
Residual dynamical stability (m – rad)	
area – a (up to 30.Deg)	0.259
area – b (up to 40. Deg)	0.417
area – c (area – a ~ area – b)	0.158
Flooding angle (deg) . .	71.0

Summary of KG Calculations

Items	Full (%)	Weight (mt)	M G (m)	Long. Mom. (mt-m)	K G (m)	Vert. Moment (mt-m)	F.S. M. (mt-m)	Clg (m)	Heel Mom (t-m)
Light Weight		14623	7.35	107445	16.75	244921	0	-0.06	-857
Provisions		1	-60.50	-61	35.60	36	0	0.00	0
Constant		299	53.41	15970	11.21	3352	56	4.92	1472
(Sub Total)		14923		123354		248309	56		615
Cargo									
No.12 Car Dk. (Std)		550	-1.60	-880	32.81	18046	0	0.67	369
No.11 Car Dk.(Std)		547	-1.59	-870	30.29	16569	0	1.09	651
No.10 Car Dk.(Std)		546	0.23	126	27.76	15157	0	0.52	284
No. 9 Car Dk.(Std)		559	-0.37	-207	25.02	13986	0	0.23	129
No. 8 Car Dk.(Std)		476	0.15	71	22.19	10562	0	-0.16	-76
No. 7 Car Dk.(Std)		459	3.36	1542	19.08	8758	0	-0.20	-92
No. 6 Car Dk.(Std)		427	7.04	3006	15.64	6678	0	0.36	154
No. 5 Car Dk.(Std)		312	-5.52	-1722	12.13	3785	0	0.46	144
No. 4 Car Dk.(Std)		292	-0.88	-257	9.51	2777	0	0.02	6
No. 3 Car Dk,(Std)		293	1.07	314	6.92	2028	0	0.17	50
No. 2 Car Dk.(Std)		251	-1.02	-256	4.80	1205	0	0.20	50
No. 1 Car Dk.(Std)		107	0.22	24	2.74	293	0	0.13	14
(Sub Total)		4819		891		299844	0		1683
Water Ballast									
Fore Peak Tk.		0					0		
Fore Dp Tk. (C)	1	4	-71.70	-287	0.33	1	3	0.00	0
No.1 W.B. Tk. (P)	100	724	-56.46	-40877	4.05	2932	0	2.45	1774
No.1 W.B. Tk. (S)	100	724	-56.46	-40877	4.05	2932	0	-2.45	-1774
No.2 W.B. Tk. (P)	100	846	-22.46	-19001	2.26	1912	0	8.78	7428
No.2 W.B. Tk. (S)	13	868	-22.31	-19365	2.27	1970	0	-8.79	-7630
No.3 W.B. Tk. (P)	100	49	6.51	319	1.06	52	101	11.89	583
No.3 W.B. Tk. (S)		384	7.75	2976	2.64	1014	0	-12.76	-4900
No.4 W.B. Tk. (P)		0					0		
No.4 W.B. Tk. (S)	100	0					0		
No.5 W.B. Tk. (P)	100	237	39.27	9307	2.68	635	551	6.79	1609
No.5 W.B. Tk. (S)		237	39.27	9307	2.68	635	551	-6.79	-1609
Aft.Peak Tk. (P)		0					0		
Aft.Peak Tk. (S)		0					0		
Aft.Peak Tk. (C)		0					0		
(Sub Total)		4073		-98498		12083	1206		-4519
Fresh Water									
Fresh W.Tk. (P)	100	221	76.74	16960	11.73	2592	0	10.18	2250
Fresh W.Tk. (S)	10	22	76.65	1686	8.55	188	346	-8.54	-190
(Sub Total)		243		18646		2780	346		2060
Fuel Oil & D. Oil									
No.1 F.O.Tk. (C)		0					0		
No.2 F.O.Tk. (P)		0					0		
No.2 F.O.Tk. (S)		0					0		
No.2 F.O.Tk. (C)	27	288	21072	6255	0.43	124	2213	0.01	3
No.3 F.O.Tk. (P)		0					0		
No.3 F.O.Tk. (S)	9	0					0		
Diesel O.Yk.		8	48.29	386	6.76	54	10	13.99	112
(Sub Total)		296			178		2223		115

(Summary of Severe Weather Criteria)

Area		(M * * 2)	5233.
H1 (In Air)		(M)	14.87
H2 (In Water)		(M)	3.94
Steady Wind Heeling Lever	(Lw1)	(M)	0.208
Gust Wind Heeling Lever	(Lw2)	(M)	0.312
Angle Of Deck Edge Immersion		(Deg)	26.5
Heel Angle Under Steady Wind	(Theta-0)	(Deg)	5.5
Angle Of Roll Due To Wave Action	(Theta-1)	(Deg)	15.1
Angle Of Windward	(Theta-R)	(Deg)	-9.6
Angle Of Min. (50, Theta-F, Theta-C)	(Theta-2)	(Deg)	50.0
Angle Of Downflooding	(Theta-F)	(Deg)	71.0
Angle-A (Potential Energy Due To Weather)		(M-Rad)	0.105
Angle-B (Dynamical Stability In Reserve)		(M-Rad)	0.347
Ration-C (Area-B / Area-A)			3.292

Righting lever (KN) tables (unit in meter)

Δ	Heel angle (deg)									
(MT)	5.	10.	20.	30.	40.	50.	60.	70.	80.	90.
15000	1.59	3.19	6.25	8.76	10.81	12.58	14.06	15.51	18.23	20.70
15500	1.58	3.16	6.21	8.73	10.79	12.58	14.11	15.61	18.33	20.68
16000	1.57	3.14	6.18	8.71	10.77	12.59	14.16	15.70	18.41	20.66
16500	1.56	3.12	6.15	8.68	10.75	12.59	14.20	15.80	18.50	20.65
17000	1.55	3.10	6.12	8.65	10.74	12.60	14.24	15.89	18.58	20.63
17500	1.54	3.09	6.09	8.63	10.72	12.60	14.28	15.98	18.65	20.61
18000	1.54	3.07	6.06	8.61	10.71	12.61	14.32	16.07	18.72	20.60
18500	1.53	3.06	6.04	8.59	10.70	12.61	14.36	16.16	18.78	20.58
19000	1.53	3.05	6.01	8.57	10.69	12.62	14.40	16.24	18.84	20.57
19500	1.52	3.04	5.99	8.55	10.68	12.63	14.44	16.33	18.90	20.56
20000	1.52	3.03	5.97	8.53	10.67	12.63	14.47	16.41	18.96	20.54
20500	1.51	3.02	5.95	8.51	10.66	12.64	14.51	16.49	19.01	20.53
21000	1.51	3.01	5.93	8.49	10.65	12.65	14.55	16.57	19.06	20.51
21500	1.51	3.01	5.91	8.48	10.64	12.65	14.58	16.65	19.10	20.50
22000	1.51	3.00	5.89	8.46	10.64	12.66	14.62	16.73	19.14	20.49
22500	1.51	3.00	5.87	8.45	10.63	12.67	14.65	16.81	19.19	20.48
23000	1.50	2.99	5.86	8.43	10.63	12.68	14.69	16.88	19.23	20.46
23500	1.50	2.99	5.84	8.42	10.63	12.68	14.72	16.96	19.26	20.45
24000	1.50	2.98	5.83	8.41	10.62	12.69	14.75	17.03	19.03	20.44
24500	1.50	2.98	5.81	8.39	10.62	12.70	14.78	17.10	19.33	20.42
25000	1.50	2.98	5.80	8.38	10.62	12.71	14.81	17.18	19.36	20.41
25500	1.50	2.97	5.79	8.37	10.62	12.72	14.85	17.25	19.39	20.40
26000	1.50	2.97	5.77	8.36	10.62	12.73	14.88	17.32	19.42	20.39
26500	1.50	2.96	5.76	8.35	10.63	12.74	14.91	17.38	19.45	20.38
27000	1.49	2.96	5.75	8.34	10.63	12.75	14.93	17.45	19.47	20.36
27500	1.49	2.95	5.74	8.33	10.63	12.76	14.96	17.51	19.50	20.35
28000	1.49	2.95	5.73	8.32	10.64	12.77	14.99	17.57	19.52	20.34
28500	1.49	2.94	5.72	8.31	10.64	12.78	15.02	17.63	19.54	20.33
29000	1.49	2.94	5.71	8.31	10.65	12.79	15.05	17.68	19.56	20.32
29500	1.48	2.93	5.70	8.30	10.65	12.81	15.08	17.73	19.57	20.31
30000	1.48	2.93	5.69	8.29	10.66	12.82	15.11	17.77	19.59	20.30
30500	1.48	2.92	5.69	8.29	10.66	12.83	15.13	17.82	19.60	20.29
31000	1.48	2.92	5.68	8.28	10.67	12.84	15.16	17.86	19.62	20.28
31500	1.47	2.91	5.67	8.28	10.67	12.86	15.19	17.90	19.63	20.27
32000	1.47	2.90	5.66	8.27	10.68	12.87	15.22	17.94	19.64	20.26
32500	1.46	2.90	5.65	8.27	10.68	12.89	15.25	17.98	19.65	20.25
33000	1.46	2.89	5.65	8.26	10.69	12.90	15.28	18.01	19.66	20.24
33500	1.46	2.88	5.64	8.26	10.70	12.92	15.30	18.04	19.67	20.23
34000	1.45	2.88	5.63	8.26	10.70	12.93	15.33	18.07	19.68	20.22
34500	1.45	2.87	5.63	8.25	10.71	12.95	15.36	18.10	19.69	20.21

Question on M V Romeo:

Q. 1 What are the 'stability wise instructions' given to master in the stability manual for M V Romeo?

Q. 2 What is the position of deck line with respect to statutory free board deck?

Q. 3 Describe nr. 4 DB tank wrt. its capacity, maximum moment of inertia, reference frame numbers, position wrt. CL, midships & keel.

Q. 4 What are the standard dimensions of the vehicles carried by M V Romeo? What is the prescribed clearance in between vehicles?

Q. 5 How many land cruisers can be accommodated on deck 6? How many standard cars may be accommodated on deck 8?

Q. 6 How many land cruiser can be accommodated on deck 8, car space 3? Describe the position of CG of these cars wrt. CL, midships and keel.

Q. 7 How many land cruisers can be accommodated in car space 1, 2, 3, 4 respectively?

Q. 8 How many standard cars can be accommodated on deck 6, car space 4? Describe the position of CG of these cars wrt. CL, midships and keel.

Q. 9 State load density, deck area, axle load for deck 11.

Q. 10 What are the decks and respective deck area available in car space 4?

Q. 11 From the curve of windage area, find length along waterline, windage area, the value of z (H1 + H2).

Q. 12 Describe the procedure in brief of calculating the hydrostatic draft in this manual.

Q. 13 What is the percentage propeller immersion if the aft draft is 7.5m?

Q. 14 Study the KG calculations and draw the GZ curve for the loading condition and compare the parameters with intact stability and severe wind criteria. Compare your result with the values provided.

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