Chapter 25
True mean draft

In previous chapters it has been shown that a ship trims about the centre of flotation. It will now be shown that, for this reason, a ship's true mean draft is measured at the centre of flotation and may not be equal to the average of the drafts forward and aft. It only does when LCF is at average ⊕.

Consider the ship shown in Figure 25.1(a) which is floating on an even keel and whose centre of flotation is FY aft of amidships. The true mean draft is KY, which is also equal to ZF, the draft at the centre of flotation.

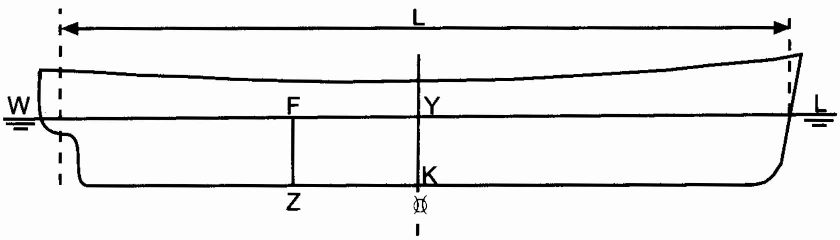

Fig. 25.1 (a)

Now let a weight be shifted aft within the ship so that she trims about F as shown in Figure 25.1(b).

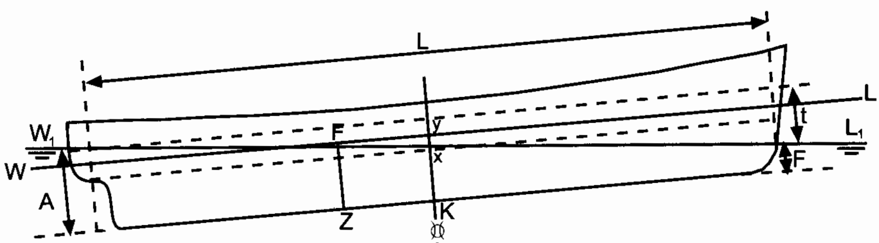

Fig. 25.1 (b)

The draft at the centre of flotation (ZF) remains unchanged.

Let the new draft forward be F and the new draft aft be A, so that the trim (A − F) is equal to 't'.

Since no weights have been loaded or discharged, the ship's displacement will not have changed and the true mean draft must still be equal to KY. It can be seen from Figure 25.1(b) that the average of the drafts forward and aft is equal to KX, the draft amidships.

Also

$$ZF = KY = KX + XY$$

or

$$\text{True mean draft} = \text{Draft amidships} + \text{correction}$$

Referring to Figure 25.1(b) and using the property of similar triangles:

$$\frac{XY}{FY} = \frac{t}{L} \qquad XY = \frac{t \times FY}{L}$$

or

$$\textit{Correction FY} = \frac{\textit{Trim} \times \textit{FY}}{\textit{Length}}$$

where FY is the distance of the centre of flotation from amidships.

It can also be seen from the figure that, when a ship is trimmed by the stern and the centre of flotation is aft of amidships, the correction is to be added to the mean of the drafts forward and aft. Also by substituting forward for aft and aft for forward in Figure 25.1(b), it can be seen that the correction is again to be added to the mean of the drafts forward and aft when the ship is trimmed by the head and the centre of flotation is forward of amidships.

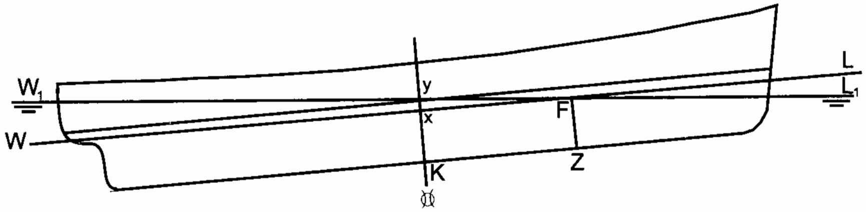

Fig. 25.1 (c)

Now consider the ship shown in Figure 25.1(c), which is trimmed by the stern and has the centre of flotation forward of amidships.

In this case

$$ZF = KY = KX - XY$$

or

$$\text{True mean draft} = \text{Draft amidships} - \text{correction}$$

The actual correction itself can again be found by using the above formula, but in this case the correction is to be subtracted from the mean of the drafts forward and aft. Similarly, by substituting forward for aft and aft for forward in this figure, it can be seen that the correction is again to be subtracted from the average of the drafts forward and aft when the ship is trimmed by the head and the centre of flotation is aft of amidships.

A general rule may now be derived for the application of the correction to the draft amidships in order to find the true mean draft.

Rule

When the centre of flotation is in the *same direction* from amidships as the maximum draft, the correction is to be *added* to the mean of the drafts. When the centre of flotation is in the *opposite direction* from amidships to the maximum draft, the correction is to be *subtracted.*

Example 1

A ship's minimum permissible freeboard is at a true mean draft of 8.5 m. The ship's length is 120 m, centre of flotation being 3 m aft of amidships. TPC = 50 tonnes. The present drafts are 7.36 m F and 9.00 m A. Find how much more cargo can be loaded.

$$\text{Draft forward} = 7.36\text{ m}$$

$$\text{Draft aft} = 9.00\text{ m}$$

$$\text{Trim} = 1.64\text{ m by the stern}$$

$$\text{Correction} = \frac{t \times FY}{L} = \frac{1.64 \times 3}{120}$$

$$\text{Correction} = 0.04\text{ m}$$

$$\text{Draft forward} = 7.36\text{ m}$$

$$\text{Draft aft} = 9.00\text{ m}$$

$$\text{Sum} = 16.36\text{ m}$$

$$\text{Average} = \text{Draft amidships} = 8.18\text{ m}$$

$$\text{Correction} = +0.04\text{ m}$$

$$\text{True mean draft} = 8.22\text{ m}$$

$$\text{Load mean draft} = 8.50\text{ m}$$

$$\text{Increase in draft} = 0.28\text{ m or } 28\text{ cm}$$

$$\text{Cargo to load} = \text{Increase in draft required} \times \text{TPC}$$

$$= 28 \times 50$$

Ans. Cargo to load = 1400 tonnes

Effect of hog and sag on draft amidships

When a ship is neither hogged nor sagged the draft amidships is equal to the mean of the drafts forward and aft. In Figure 25.1(d) the vessel is shown in hard outline floating without being hogged or sagged. The draft forward is F, the draft aft is A, and the draft amidships (KX) is equal to the average of the drafts forward and aft.

Now let the vessel be sagged as shown in Figure 25.1(d) by the broken outline. The draft amidships is now K_1X, which is equal to the mean of the drafts forward and aft (KX), plus the sag (KK_1). The amount of hog or sag must therefore be taken into account in calculations involving the draft amidships. The depth of the vessel amidships from the keel to the deck line (KY or K_1Y_1) is constant being equal to the draft amidships plus the freeboard.

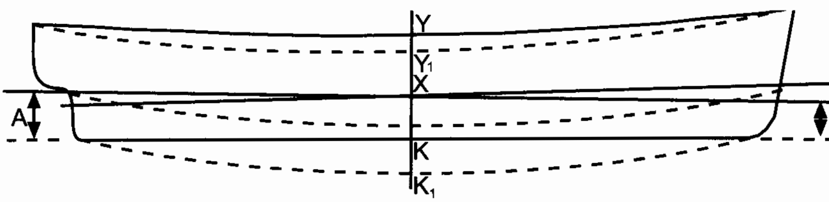

Fig. 25.1 (d)

Example

A ship is floating in water of relative density 1.015. The present displacement is 12 000 tonnes, KG 7.7 m, KM 8.6 m. The present drafts are F 8.25 m, A 8.65 m, and the present freeboard amidships is 1.06 m. The Summer draft is 8.53 m and the Summer freeboard is 1.02 m FWA 160 mm TPC 20. Assuming that the KM is constant, find the amount of cargo (Kg 10.0 m) which can be loaded for the ship to proceed to sea at the loaded Summer draft. Also find the amount of the hog or sag and the initial GM on departure.

Summer freeboard	1.02 m	Present mean freeboard	1.06 m
Summer draft	+ 8.53 m	Depth Mld	9.55 m
Depth Mld =	9.55 m	Present draft amidships	8.49 m
		Average of drafts F and A	8.45 m
		Ship is sagged by	0.04 m

$$\text{Dock water allowance (DWA)} = \frac{(1025 - \rho_{DW})}{25} \times \text{FWA} = \frac{10}{25} \times 160 = 64\text{ mm}$$

$$= 0.064\text{ m}$$

$$\text{TPC in dock water} = \frac{RD_{DW}}{RD_{SW}} \times TPC_{SW} = \frac{1.015}{1.025} \times 20$$

$$= 19.8\text{ tonnes}$$

$$\text{Summer freeboard} = 1.020\ \text{m}$$

$$\text{DWA} = \underline{0.064\ \text{m}}$$

$$\text{Min. permissible freeboard} = 0.956\ \text{m}$$

$$\text{Present freeboard} = \underline{1.060\ \text{m}}$$

$$\text{Mean sinkage} = 0.104\ \text{m or } 10.4\ \text{cm}$$

$$\text{Cargo to load} = \text{Sinkage} \times TPC_{dw} = 10.4 \times 19.8$$

$$\text{Cargo to load} = \underline{205.92\ \text{tonnes}}$$

$$GG_1 = \frac{w \times d}{W + w} = \frac{205.92 \times (10 - 7.7)}{12\,000 + 205.92} = \frac{473.62}{12\,205.92}$$

$$\therefore \text{Rise of G} = 0.039\ \text{m}$$

$$\text{Present GM } (8.6 - 7.7) = 0.900\ \text{m}$$

$$\underline{\text{GM on departure} = 0.861\ \text{m}}$$

and ship has a sag of 0.04 m.

Exercise 25

1 The minimum permissible freeboard for a ship is at a true mean draft of 7.3 m. The present draft is 6.2 m F and 8.2 m A. TPC = 10. The centre of flotation is 3 m aft of amidships. Length of the ship 90 m. Find how much more cargo may be loaded.

2 A ship has a load salt water displacement of 12 000 tonnes, load draft in salt water 8.5 m, length 120 m, TPC 15 tonnes, and centre of flotation 2 m aft of amidships. The ship is at present floating in dock water of density 1015 kg per cu. m at drafts of 7.2 m F and 9.2 m A. Find the cargo which must yet be loaded to bring the ship to the maximum permissible draft.

3 Find the weight of the cargo the ship in Question 2 could have loaded had the centre of flotation been 3 m forward of amidships instead of 2 m aft.

4 A ship is floating in dock water of relative density 1.020. The present displacement is 10 000 tonnes, KG 6.02 m, KM 6.92 m. Present drafts are F 12.65 m, A 13.25 m. Present freeboard 1.05 m. Summer draft 13.10 m and Summer freeboard is 1.01 m. FWA 150 mm. TPC 21. Assuming that the KM is constant find the amount of cargo (KG 10.0 m) which can be loaded for the ship to sail at the load Summer draft. Find also the amount of the hog or sag and the initial metacentric height on departure.

Chapter 26
The inclining experiment

It has been shown in previous chapters that, before the stability of a ship in any particular condition of loading can be determined, the initial conditions must be known. This means knowing the ship's lightweight, the VCG or KG at this lightweight, plus the LCG for this lightweight measured from amidships. For example, when dealing with the height of the centre of gravity above the keel, the initial position of the centre of gravity must be known before the final KG can be found. It is in order to find the KG for the light condition that the Inclining Experiment is performed.

The experiment is carried out by the builders when the ship is as near to completion as possible; that is, as near to the light condition as possible. The ship is forcibly inclined by shifting weights a fixed distance across the deck. The weights used are usually concrete blocks, and the inclination is measured by the movement of plumb lines across specially constructed battens which lie perfectly horizontal when the ship is upright. Usually two or three plumb lines are used and each is attached at the centre line of the ship at a height of about 10 m above the batten. If two lines are used then one is placed forward and the other aft. If a third line is used it is usually placed amidships. For simplicity, in the following explanation only one weight and one plumb line is considered.

The following conditions are necessary to ensure that the KG obtained is as accurate as possible:

1 There should be little or no wind, as this may influence the inclination of the ship. If there is any wind the ship should be head on or stern on to it.
2 The ship should be floating freely. This means that nothing outside the ship should prevent her from listing freely. There should be no barges or lighters alongside; mooring ropes should be slacked right down, and there should be plenty of water under the ship to ensure that at no time during the experiment will she touch the bottom.
3 Any loose weights within the ship should be removed or secured in place.

4 There must be no free surfaces within the ship. Bilges should be dry. Boilers and tanks should be completely full or empty.
5 Any persons not directly concerned with the experiment should be sent ashore.
6 The ship must be upright at the commencement of the experiment.
7 A note of 'weights on' and 'weights off' to complete the ship each with a VCG and LCG.

When all is ready and the ship is upright, a weight is shifted across the deck transversely, causing the ship to list. A little time is allowed for the ship to settle and then the deflection of the plumb line along the batten is noted. If the weight is now returned to its original position the ship will return to the upright. She may now be listed in the opposite direction. From the deflections the GM is obtained as follows.

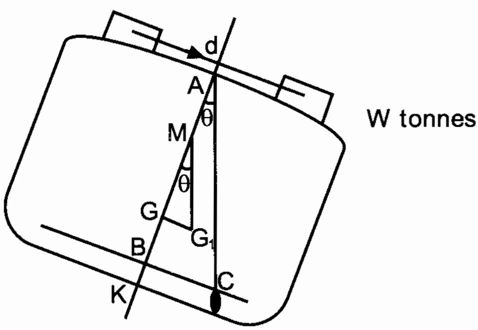

Fig. 26.1

In Figure 26.1 let a mass of 'w' tonnes be shifted across the deck through a distance 'd' metres. This will cause the centre of gravity of the ship to move from G to G_1 parallel to the shift of the centre of gravity of the weight. The ship will then list to bring G_1 vertically under M, i.e. to θ degrees list. The plumb line will thus be deflected along the batten from B to C. Since AC is the new vertical, angle BAC must also be θ degrees.

In triangle ABC,

$$\cot\theta = \frac{AB}{BC}$$

In triangle GG_1M,

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

$$\therefore \frac{GM}{GG_1} = \frac{AB}{BC}$$

Or

$$GM = GG_1 \times \frac{AB}{BC}$$

But

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

$$\therefore\ GM = \frac{w \times d}{W} \times \frac{AB}{BC}$$

Hence

$$GM = \frac{w \times d}{W \tan\theta}$$

In this formula AB, the length of the plumb line and BC, the deflection along the batten can be measured. 'w' the mass shifted, 'd' the distance through which it was shifted, and 'W' the ship's displacement, will all be known. The GM can therefore be calculated using the formula.

The naval architects will already have calculated the KM for this draft and hence the present KG is found. By taking moments about the keel, allowance can now be made for weights which must be loaded or discharged to bring the ship to the light condition. In this way the light KG is found.

Example 1

When a mass of 25 tonnes is shifted 15 m transversely across the deck of a ship of 8000 tonnes displacement, it causes a deflection of 20 cm in a plumb line 4 m long. If the KM = 7 m, calculate the KG.

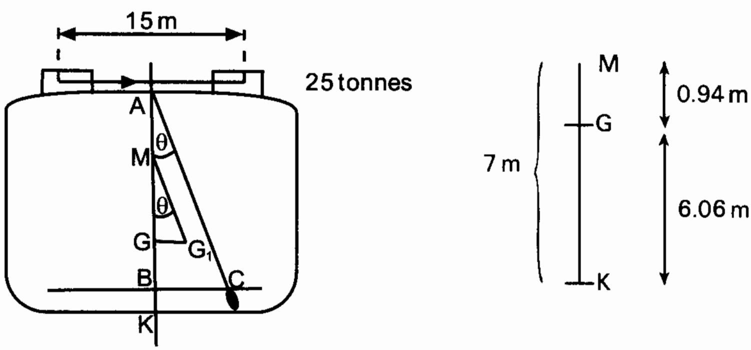

Fig. 26.2

$$\frac{GM}{GG_1} = \frac{AB}{BC} = \frac{1}{\tan\theta}$$

$$\therefore\ \tan\theta\ GM = GG_1$$

$$GM = \frac{w \times d}{W} \times \frac{1}{\tan\theta}$$

$$= \frac{25 \times 15}{8000} \times \frac{4}{0.2}$$

$$GM = 0.94\,m$$

$$KM = 7.00\,m$$

Ans. KG = 6.06 m as shown in sketch on page 240.

Example 2

When a mass of 10 tonnes is shifted 12 m, transversely across the deck of a ship with a GM of 0.6 m it causes 0.25 m deflection in a 10 m plumb line. Calculate the ship's displacement.

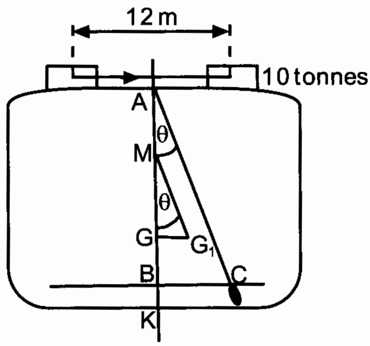

Fig. 26.3

$$GM = \frac{w \times d}{W} \times \frac{1}{\tan\theta}$$

$$W = \frac{w \times d}{GM} \times \frac{1}{\tan\theta}$$

$$= \frac{10 \times 12 \times 10}{0.6 \times 0.25}$$

$$W = 8000.$$

Ans. Displacement = 8000 tonnes

Summary

Every new ship should have an Inclining Experiment. However, some shipowners do not request one if their ship is a sister-ship to one or more in the company's fleet.

If a ship has undergone major repair or refit, she should then have an Inclining Experiment to obtain her modified Lightweight and centre of gravity (VCG and LCG).

Exercise 26

1 A ship of 8000 tonnes displacement has KM = 7.3 m and KG = 6.1 m. A mass of 25 tonnes is moved transversely across the deck through a distance of 15 m. Find the deflection of a plumb line which is 4 m long.

2 As a result of performing the inclining experiment it was found that a ship had an initial metacentric height of 1 m. A mass of 10 tonnes, when shifted 12 m transversely, had listed the ship $3\frac{1}{2}$ degrees and produced a deflection of 0.25 m in the plumb line. Find the ship's displacement and the length of the plumb line.

3 A ship has KM = 6.1 m and displacement of 3150 tonnes. When a mass of 15 tonnes, already on board, is moved horizontally across the deck through a distance of 10 m it causes 0.25 m deflection in an 8 m long plumb line. Calculate the ship's KG.

4 A ship has an initial GM = 0.5 m. When a mass of 25 tonnes is shifted transversely a distance of 10 m across the deck, it causes a deflection of 0.4 m in a 4 m plumb line. Find the ship's displacement.

5 A ship of 2304 tonnes displacement has an initial metacentric height of 1.2 m. Find the deflection in a plumb line which is suspended from a point 7.2 m above a batten when a mass of 15 tonnes, already on board, is shifted 10 m transversely across the deck.

6 During the course of an inclining experiment in a ship of 4000 tonnes displacement, it was found that, when a mass of 12 tonnes was moved transversely across the deck, it caused a deflection of 75 mm in a plumb line which was suspended from a point 7.5 m above the batten. KM = 10.2 m. KG = 7 m. Find the distance through which the mass was moved.

7 A box-shaped vessel 60 m × 10 m × 3 m is floating upright in fresh water on an even keel at 2 m draft. When a mass of 15 tonnes is moved 6 m transversely across the deck a 6 m plumb line is deflected 20 cm. Find the ship's KG.

8 The transverse section of a barge is in the form of a triangle, apex downwards. The ship's length is 65 m, breadth at the waterline 8 m, and the vessel is floating upright in salt water on an even keel at 4 m draft. When a mass of 13 tonnes is shifted 6 m transversely it causes 20 cm deflection in a 3 m plumb line. Find the vessel's KG,

9 A ship of 8000 tonnes displacement is inclined by moving 4 tonnes transversely through a distance of 19 m. The average deflections of two pendulums, each 6 m long, was 12 cm 'Weights on' to complete this ship were 75 t centred at Kg of 7.65 m 'Weights off' amounted to 25 t centred at Kg of 8.16 m.

(a) Calculate the GM and angle of heel relating to this information, for the ship as inclined.

(b) From Hydrostatic Curves for this ship as inclined, the KM was 9 m. Calculate the ship's final Lightweight and VCG at this weight.

Chapter 27
Effect of trim on tank soundings

A tank sounding pipe is usually situated at the after end of the tank and will therefore only indicate the depth of the liquid at that end of the tank. If a ship is trimmed by the stern, the sounding obtained will indicate a greater depth of liquid than is actually contained in the tank. For this reason it is desirable to find the head of liquid required in the sounding pipe which will indicate that the tank is full.

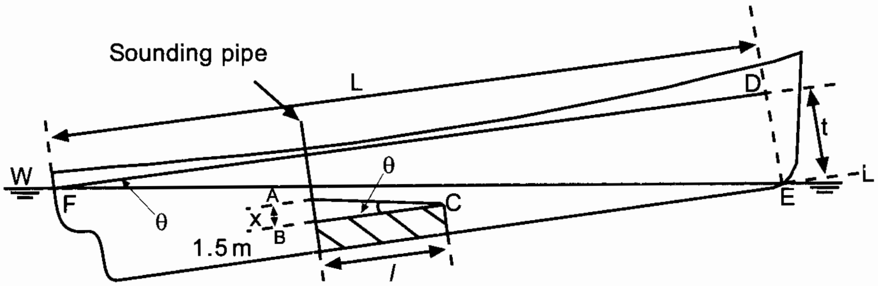

Fig. 27.1

In Figure 27.1, 't' represents the trim of the ship, 'L' the length of the ship, 'l' the length of a double bottom tank, and 'x' the head of liquid when the tank is full.

In triangles ABC and DEF, using the property of similar triangles:

$$\frac{x}{l} = \frac{t}{L}$$

or

$$\frac{\textit{Head when full}}{\textit{Length of tank}} = \frac{\textit{Trim}}{\textit{Length of ship}}$$

Example 1

A ship 100 m long is trimmed 1.5 m by the stern. A double bottom tank 12 m × 10 m × 1.5 m has the sounding pipe at the after end. Find the sounding which will indicate that the tank is full.

$$\frac{\text{Head}}{l} = \frac{\text{Trim}}{\text{L}}$$

$$\therefore \text{ Head when full} = \frac{1.5 \times 12}{100}$$

$$\text{X or AB} = 0.18\,\text{m}$$

$$\text{Depth of tank} = 1.50\,\text{m}$$

Ans. Sounding when full = 1.68 m

Example 2

A ship 100 m long is trimmed 2 m by the stern. A double bottom tank 15 m × 20 m × 1.5 m, which has the sounding pipe situated at the after end, is being filled with fuel oil of relative density 0.8. The present tank sounding is 1.6 m. Find the sounding when the tank is full, and also how much more oil is required to fill the tank.

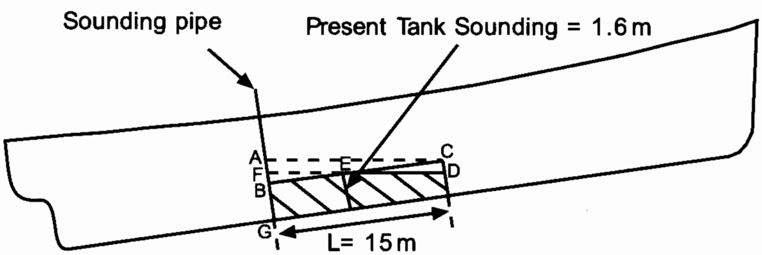

Fig. 27.2

In Figure 27.2 the right-angled triangles ABC, CDE, and BEF are similar. BG = 1.5 m. FG = the present sounding (1.6 m).

$$\frac{\text{Head}}{l} = \frac{\text{Trim}}{\text{L}}$$

$$\text{Head} = \frac{2 \times 15}{100}$$

$$\text{Head of oil full} = 0.30\,\text{m}$$

$$\therefore \text{ The sounding when full} = 1.80\,\text{m (AG)}$$

Also:

$$\text{CD} = \text{Head of oil full} - \text{present tank sounding}$$

$$= 1.80\,\text{m} - 1.60\,\text{m}$$

$$\text{CD} = 0.20\,\text{m}$$

In triangles CED and ABC:

$$\frac{CE}{CD} = \frac{BC}{AB}$$

$$CE = \frac{CD \times BC}{AB}$$

$$= \frac{0.20}{0.30} \times 15$$

$$CE = 10 \text{ metres}$$

$$\text{Volume of oil yet required} = \text{Area triangle CED} \times \text{Breadth of tank}$$

$$= \tfrac{1}{2} \times CE \times CD \times 20$$

$$= \tfrac{1}{2} \times 10 \times 0.20 \times 20$$

$$= 20 \text{ cu. m}$$

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

$$= 20 \times 0.8$$

$$= 16 \text{ tonnes}$$

Ans. Sounding when full 1.8 m. Oil yet required 16 tonnes

Exercise 27

1 A ship 120 m long is trimmed 1.5 m by the stern. A double bottom tank is 15 m × 20 m × 1 m and has the sounding pipe situated at the after end of the tank. Find the sounding which will indicate that the tank is full.

2 A ship 120 m long is trimmed 2 m by the stern. A double bottom tank 36 m × 15 m × 1 m is being filled with fuel oil of relative density 0.96. The sounding pipe is at the after end of the tank and the present sounding is 1.2 m. Find how many tonnes of oil are yet required to fill this tank and also find the sounding when the tank is full.