Chapter 34

List due to bilging side compartments

When a compartment in a ship is bilged the buoyancy provided by that compartment is lost. This causes the centre of buoyancy of the ship to move directly away from the centre of the lost buoyancy and, unless the centre of gravity of the compartment is on the ship's centre line, a listing moment will be created, b = w.

Let the ship in Figure 34.1 float upright at the waterline WL. G represents the position of the ship's centre of gravity and B the centre of buoyancy.

Now let a compartment which is divided at the centre line be bilged on the starboard side as shown in the figure. To make good the lost buoyancy

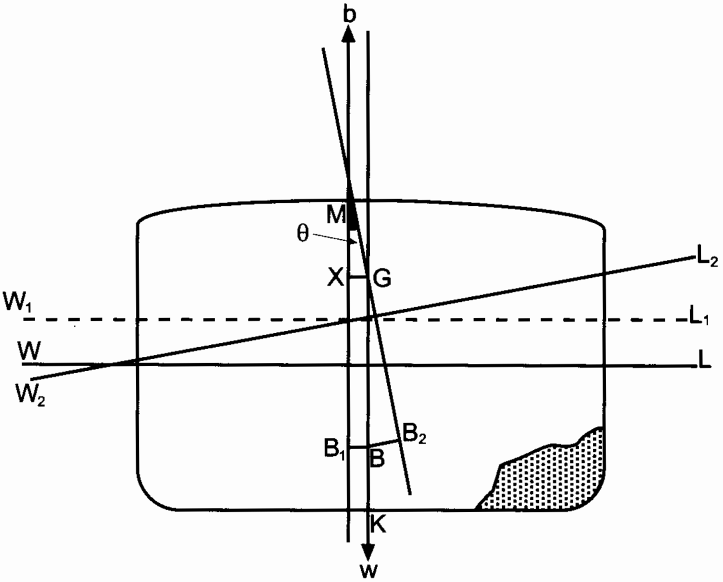


Fig. 34.1

the ship will sink to the waterline W_1L_1. That is, the lost buoyancy is made good by the layer between WL and W_1L_1.

The centre of buouancy will move from B to B_1, directly away from the centre of gravity of the lost buoyancy, and the distance BB_1 is equal to $\frac{w \times d}{W}$, where w represents the lost buoyancy and d represents the distance between the ship's centre of buoyancy and the centre of the lost buoyancy.

The shift in the centre of buoyancy produces a listing moment.

Let θ be the resultant list.

Then

$$\tan\theta = GX/XM$$

$$= BB_1/XM$$

where XM represents the initial metacentric height for the bilged condition.

Example 1

A box-shaped vessel of length 100 m and breadth 18 m, floats in salt water on an even keel at 7.5 m draft. KG = 4 m. The ship has a continuous centre line bulkhead which is watertight. Find the list if a compartment amidships, which is 15 m long and is empty, is bilged on one side.

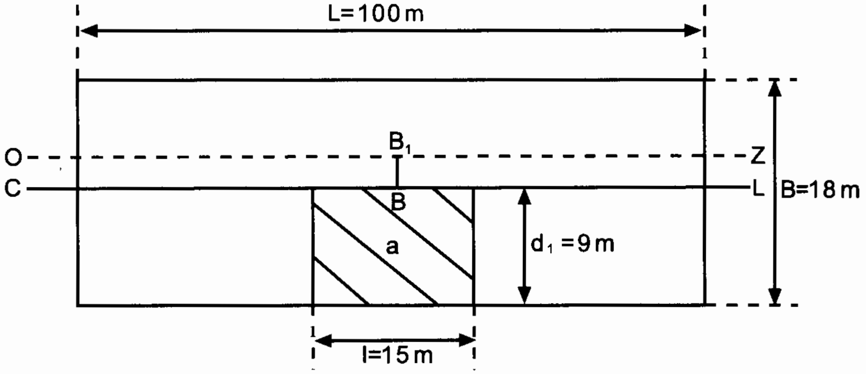


Fig. 34.2

(a) Find the New Mean Draft

$$\text{Bodily increase in draft} = \frac{\text{Volume of lost buoyancy}}{\text{Area of intact W.P.}}$$

$$= \frac{15 \times 9 \times 7.5}{100 \times 18 - 15 \times 9} = 0.61$$

$$\text{New draft} = 7.50 + 0.61$$

$$\therefore \text{New draft} = 8.11\,\text{m} = \text{draft } d_2$$

(b) Find the Shift of the Centre of Buoyancy

$$BB_1 = \frac{a \times B/4}{LB - a}$$

$$= \frac{15 \times 9 \times 18/4}{100 \times 18 - 15 \times 9} = \frac{607.5}{1665}$$

$$= 0.37\,\text{m}$$

(c) To Find I_{OZ}

$$I_{CL} = \left(\frac{B}{2}\right)^3 \cdot \frac{L}{3} + \left(\frac{B}{2}\right)^3 \cdot \frac{(L - l)}{3}$$

$$I_{CL} = \frac{9^3 \times 100}{3} + \frac{9^3 \times 85}{3} = 24\,300 + 20\,655$$

$$= 44\,955\,\text{m}^4$$

$$I_{OZ} = I_{CL} - A \cdot BB_1^2$$

$$= 44\,955 - (100 \times 18 - 15 \times 9) \times 0.365^2$$

$$= 44\,955 - 222$$

$$= 44\,733\,\text{m}^4$$

(d) To Find GM

$$BM = \frac{I_{OZ}}{V}$$

$$= \frac{44\,733}{100 \times 18 \times 7.5}$$

$$= 3.31\,\text{m}$$

$$+$$

$$KB = \frac{d_2}{2} \quad \therefore\ KB = 4.06\,\text{m}$$

$$KM = 7.37\,\text{m}$$

$$-$$

$$KG = 4.00\,\text{m as before bilging}$$

$$\text{After bilging, } GM = \underline{3.37\,\text{m}}$$

(e) To Find the List

$$\tan \text{List} = \frac{BB_1}{GM}$$

$$= \frac{0.37}{3.37} = 0.1098$$

Ans. List = 6° 16′

Example 2

A box-shaped vessel, 50 m long × 10 m wide, floats in salt water on an even keel at a draft of 4 m. A centre line longitudinal watertight bulkhead extends from end to end and for the full depth of the vessel. A compartment amidships on the starboard side is 15 m long and contains cargo with permeability 'μ' of 30 per cent. Calculate the list if this compartment is bilged. KG = 3 m.

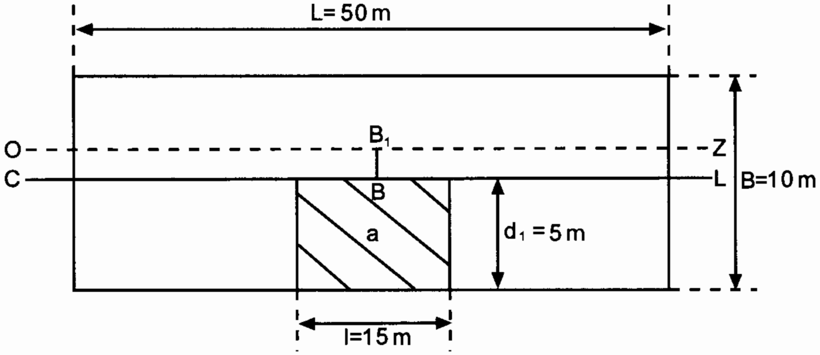


Fig. 34.3

(a) Find the New Mean Draft

$$\text{Bodily increase in draft} = \frac{\text{Volume of lost buoyancy}}{\text{Area of intact W.P.}}$$

$$= \frac{\frac{30}{100} \times 15 \times 5 \times 4}{50 \times 10 - \frac{30}{100} \times 15 \times 5} = \frac{90}{477.5}$$

$$= 0.19\,\text{m}$$

$$\therefore \text{ New draft} = 4.00 + 0.19 = 4.19\,\text{m say draft } d_2$$

(b) Find the Shift of the Centre of Buoyancy

$$BB_1 = \frac{\mu a \times \frac{B}{4}}{LB - \mu a}$$

$$= \frac{\frac{30}{100} \times 15 \times 5 \times \frac{10}{4}}{50 \times 10 - \frac{30}{100} \times 15 \times 5} = \frac{56.25}{477.5}$$

$$= 0.12\,\text{m}$$

(c) To Find I_{OZ}

$$I_{CL} = \frac{LB^3}{12} - \frac{\mu l b^3}{3}$$

$$= \frac{50 \times 10^3}{12} - \frac{30}{100} \times \frac{15 \times 5^3}{3}$$

$$= 4166.7 - 187.5$$

$$= 3979\,\text{m}^4$$

$$
\begin{aligned}
I_{OZ} &= I_{CL} - A \cdot BB_1^2 \\
&= 3979 - 477.5 \times 0.12^2 \\
&= 3979 - 7 \\
&= 3972\,\text{m}^4
\end{aligned}
$$

(d) To Find GM

$$
\begin{aligned}
BM_2 &= \frac{I_{OZ}}{V} \\
BM_2 &= \frac{3972}{50 \times 10 \times 4} \\
\therefore BM_2 &= 1.99\,\text{m} \\
&\quad + \\
KB_2 &= 2.10\,\text{m} \\
KM_2 &= 4.09\,\text{m} \\
&\quad - \\
\text{as before bilging, } KG &= 3.00\,\text{m} \\
GM_2 &= \underline{1.09\,\text{m}}
\end{aligned}
$$

(e) To Find the List

$$
\begin{aligned}
\tan \text{List} &= BB_1/GM \\
&= \frac{0.12}{1.09} = 0.1101
\end{aligned}
$$

Ans. List = 6° 17′ to starboard

Note: When $\mu = 100$ per cent then:

$$I_{CL} = \left(\frac{B}{2}\right)^3 \cdot \frac{L}{3} + \left(\frac{B}{2}\right)^3 \left(\frac{L-l}{3}\right) \text{m}^4$$

or

$$I_{CL} = \frac{LB^3}{12} - \frac{lb^3}{3}\,\text{m}^4$$

Both formulae give the same answer

Summary

1 Make a sketch from the given information.
2 Calculate the mean bodily increase in draft.
3 Calculate the ship in the centre of buoyancy.
4 Estimate the second moment of area in the bilged condition with the use of the parallel axis theorem.
5 Evaluate the new KB, BM, KM and GM.
6 Finally calculate the requested angle of list.

Exercise 34

1 A box-shaped tanker barge is 100 m long, 15 m wide and floats in salt water on an even keel at 5 m draft. KG = 3 m. The barge is divided longitudinally by a centre line watertight bulkhead. An empty compartment amidships on the starboard side is 10 m long. Find the list if this compartment is bilged.

2 A box-shaped vessel, 80 m long and 10 m wide, is floating on an even keel at 5 m draft. Find the list if a compartment amidships, 15 m long is bilged on one side of the centre line bulkhead. KG = 3 m.

3 A box-shaped vessel, 120 m long and 24 m wide, floats on an even keel in salt water at a draft of 7 m. KG = 7 m. A compartment amidships is 12 m long and is divided at the centre line by a full depth watertight bulkhead. Calculate the list if this compartment is bilged.

4 A box-shaped vessel is 50 m long, 10 m wide and is divided longitudinally at the centre line by a watertight bulkhead. The vessel floats on an even keel in salt water at a draft of 4 m. KG = 3 m. A compartment amidships is 12 m long and contains cargo of permeability 30 per cent. Find the list if this compartment is bilged.

5 A box-shaped vessel 68 m long and 14 m wide has KG = 4.7 m, and floats on an even keel in salt water at a draft of 5 m. A compartment amidships 18 m long is divided longitudinally at the centre line and contains cargo of permeability 30 per cent. Calculate the list if this compartment is bilged.

Chapter 35

The Deadweight Scale

The Deadweight Scale provides a method for estimating the additional draft or for determining the extra load that could be taken onboard when a vessel is being loaded in water of density less than that of salt water. For example, the vessel may be loading in a port where the water density is that of fresh water at 1.000 t/cu.m.

This Deadweight Scale (see Figure 35.1) displays columns of scale readings for:

Freeboard (f).
Dwt in salt water and in fresh water.
Draft of ship (mean).
Displacement in tonnes in salt water and in fresh water.
Tonnes per cm (TPC) in salt water and in fresh water.
Moment to Change Trim 1 cm (MCTC).

On every dwt scale the following constants must exist:

$$\text{Any Freeboard (f)} + \text{Any draft (d)} = \text{Depth of ship (D)}$$

hence $f + d = C1$.

$$\text{Any Displacement (W)} - \text{Any Dwt} = \text{Lightweight (L wt)}$$

hence $W - Dwt = C2$.

The main use of the Dwt Scale is to observe Dwt against Draft. Weight in tonnes remains the same but the volume of displacement will change with a change in density of the water in which the ship floats. The salt water and fresh water scales relate to these changes.

On many ships this Dwt Scale has been replaced by the data being presented in tabular form. The officer onboard only needs to interpolate to obtain the information that is required. Also the Dwt Scale can be part of a computer package supplied to the ship. In this case the officer only needs to key in the variables and the printout supplies the required data.

The following worked example shows the use of the Dwt Scale:

Question:

Determine the TPC at the fully loaded draft from the Dwt Scale shown in Figure 35.1 (on page 304) and show the final displacement in tonnes remains similar for fresh and salt water.

From Figure 35.1 TPC is 31.44 and the permitted fresh water sinkage as shown on the freeboard marks is 19 cm with displacement in salt water being almost 23 900 t.

Consequently, the approximate load displacement in fresh water is given by:

$$\text{FW sinkage} = W/\text{TPC} \times 40\,\text{cm}$$

So

$$W = \text{TPC} \times \text{FW sinkage} \times 40 = 31.44 \times 19 \times 40 = 23\,894 \text{ tonnes}$$

Hence this vessel has loaded up an extra 19 cm of draft in fresh water whilst keeping her displacement at 23 894 t (equivalent to salt water draft of 9.17 m).

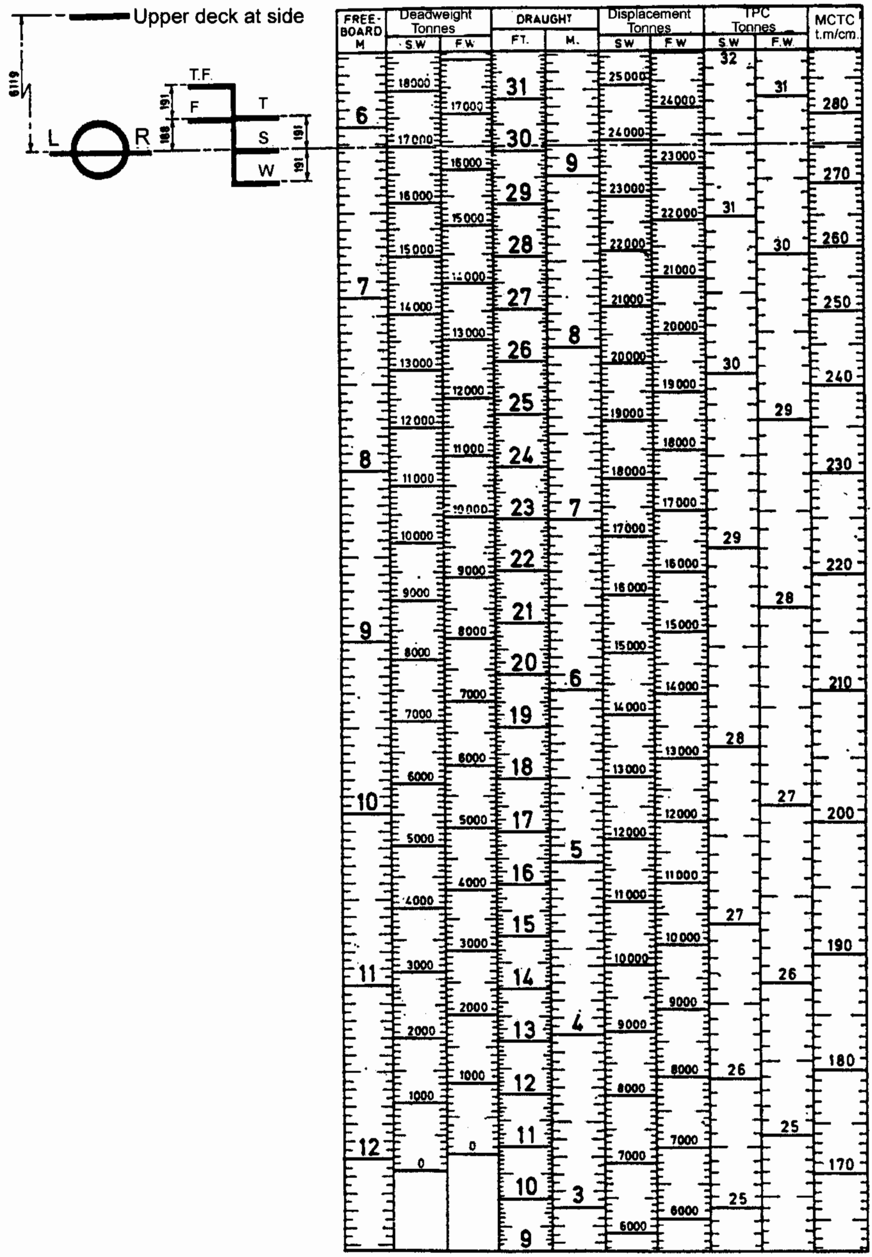


Fig. 35.1. Deadweight Scale

Chapter 36
Interaction

What exactly is interaction?

Interaction occurs when a ship comes too close to another ship or too close to, say, a river or canal bank. As ships have increased in size (especially in Breadth Moulded), Interaction has become very important to consider. In February 1998, the Marine Safety Agency (MSA) issued a Marine Guidance note 'Dangers of Interaction', alerting Owners, Masters, Pilots, and Tug-Masters on this topic.

Interaction can result in one or more of the following characteristics:

1 If two ships are on a passing or overtaking situation in a river the squats of both vessels could be doubled when their amidships are directly in line.
2 When they are directly in line each ship will develop an angle of heel and the smaller ship will be drawn bodily towards the larger vessel.
3 Both ships could lose steerage efficiency and alter course without change in rudder helm.
4 The smaller ship may suddenly veer off course and head into the adjacent river bank.
5 The smaller ship could veer into the side of the larger ship or worse still be drawn across the bows of the larger vessel, bowled over and capsized.

In other words there is:

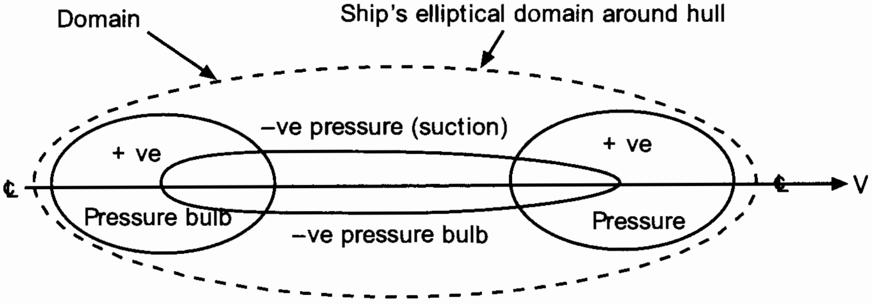
(a) a ship to ground interaction;
(b) a ship to ship interaction;
(c) a ship to shore interaction.

What causes these effects of interaction? The answer lies in the pressure bulbs that exist around the hull form of a moving ship model or a moving ship. See Figure 36.1. As soon as a vessel moves from rest, hydrodynamics produce the shown positive and negative pressure bulbs. For ships with greater parallel body such as tankers these negative bulbs will be comparatively longer in length. When a ship is stationary in water of zero current speed these bulbs disappear.

Note the elliptical Domain that encloses the vessel and these pressure bulbs. This Domain is very important. When the Domain of one vessel interfaces with the Domain of another vessel then interaction effects will occur. Effects of interaction are increased when ships are operating in shallow waters.

Ship to ground (squat) interaction

In a report on measured ship squats in the St Lawrence seaway, A. D. Watt stated: 'meeting and passing in a channel also has an effect on squat. It was found that when two ships were moving at the low speed of five knots that squat increased up to double the normal value. At higher speeds the squat when passing was in the region of one and a half times the normal value.' Unfortunately, no data relating to ship types, gaps between ships, blockage factors etc. accompanied this statement.



Note: Ship is moving ahead at velocity V

Fig. 36.1. Pressure distribution around ship's hull (not drawn to scale).

Thus, at speeds of the order of five knots the squat increase is +100 per cent whilst at higher speeds, say ten knots, this increase is +50 per cent. Figure 36.2 illustrates this passing manoeuvre. Figure 36.3 interprets the percentages given in the previous paragraph.

How may these squat increases be explained? It has been shown in the chapter on Ship Squat that its value depends on the ratio of the ship's cross-section to the cross-section of the river. This is the blockage factor 'S'. The presence of a second ship meeting and crossing will of course increase the blockage factor. Consequently the squat on each ship will increase.

Maximum squat is calculated by using the equation:

$$\delta_{\max} = \frac{C_b \times S^{0.81} \times V_k^{2.08}}{20} \text{ metres}$$

Consider the following example.

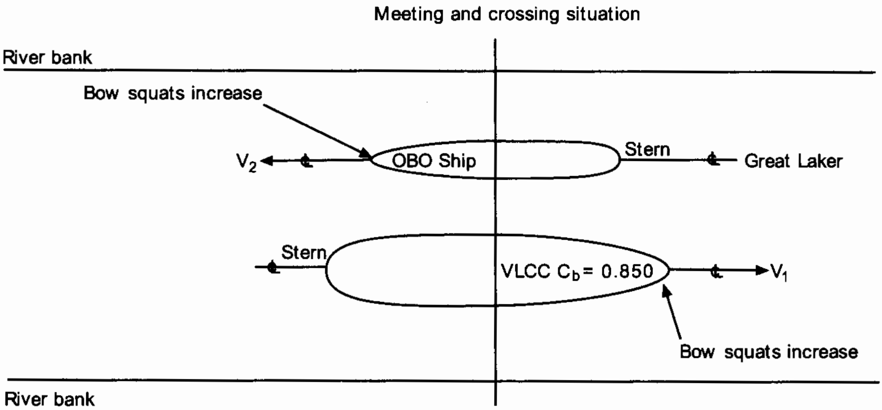


Fig. 36.2. Amidships (⊕) of VLCC directly in line with amidships of OBO ship in St Lawrence seaway.

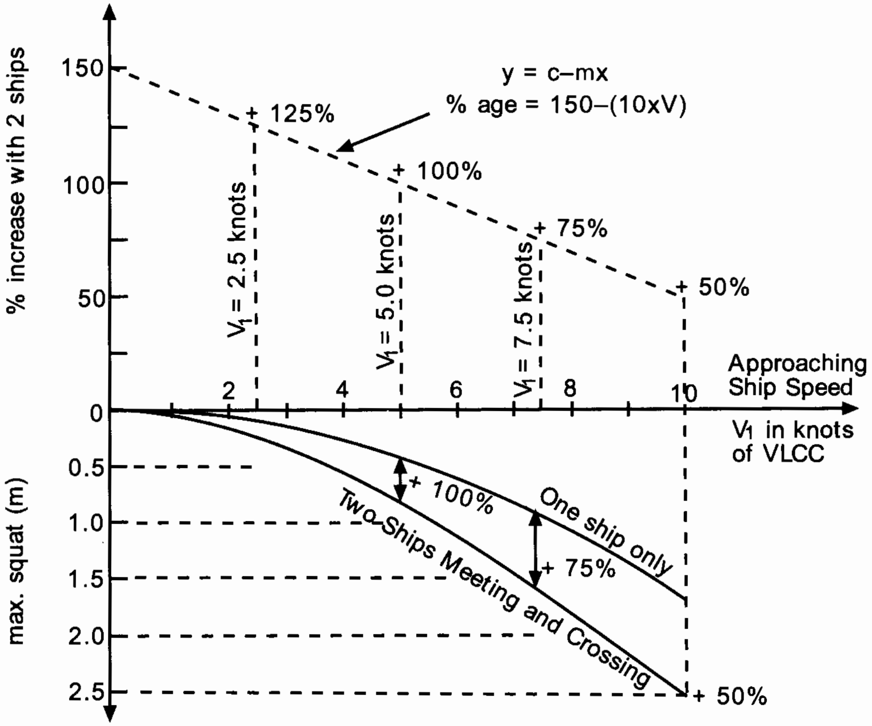


Fig. 36.3. Maximum squats for one ship, and for the same ship with another ship present.

Example 1

A supertanker has a breadth of 50 m with a static even-keel draft of 12.75 m. She is proceeding along a river of 250 m and 16 m depth rectangular cross-section. If her speed is 5 kts and her C_B is 0.825, calculate her maximum squat when she is on the centre line of this river.

$$S = \frac{b \times T}{B \times H} = \frac{50 \times 12.75}{250 \times 16} = 0.159$$

$$\delta_{\max} = \frac{0.825 \times 0.159^{0.81} \times 5^{2.08}}{20} = \underline{0.26\,\text{m}}$$

Example 2

Assume now that this supertanker meets an oncoming container ship also travelling at 5 kts. See Figure 36.4. If this container ship has a breadth of 32 m a C_b of 0.580, and a static even-keel draft of 11.58 m calculate the maximum squats of both vessels when they are transversely in line as shown.

$$S = \frac{(b_1 \times T_1) + (b_2 \times T_2)}{B \times H}$$

$$S = \frac{(50 \times 12.75) + (32 \times 11.58)}{250 \times 16} = 0.252$$

Supertanker:

$$\delta_{\max} = \frac{0.825 \times 0.252^{0.81} \times 5^{2.08}}{20}$$

$$= \underline{0.38\,\text{m at the bow}}$$

Container ship:

$$\delta_{\max} = \frac{0.580 \times 0.252^{0.81} \times 5^{2.08}}{20}$$

$$= \underline{0.27\,\text{m at the stern}}$$

The maximum squat of 0.38 m for the supertanker will be at the bow because her C_b is greater than 0.700. Maximum squat for the container ship will be at the stern, because her C_b is less than 0.700. As shown this will be 0.27 m.

If this container ship had travelled alone on the centre line of the river then her maximum squat at the stern would have only been 0.12 m. Thus the presence of the other vessel has more than doubled her squat.

Clearly, these results show that the presence of a second ship does increase ship squat. Passing a moored vessel would also make blockage effect and squat greater. These values are not qualitative but only illustrative of this phenomenon of interaction in a ship to ground (squat) situation. Nevertheless, they are supportive of A. D. Watt's statement.

Ship to ship Interaction

Consider Figure 36.5 where a tug is overtaking a large ship in a narrow river. Three cases have been considered:

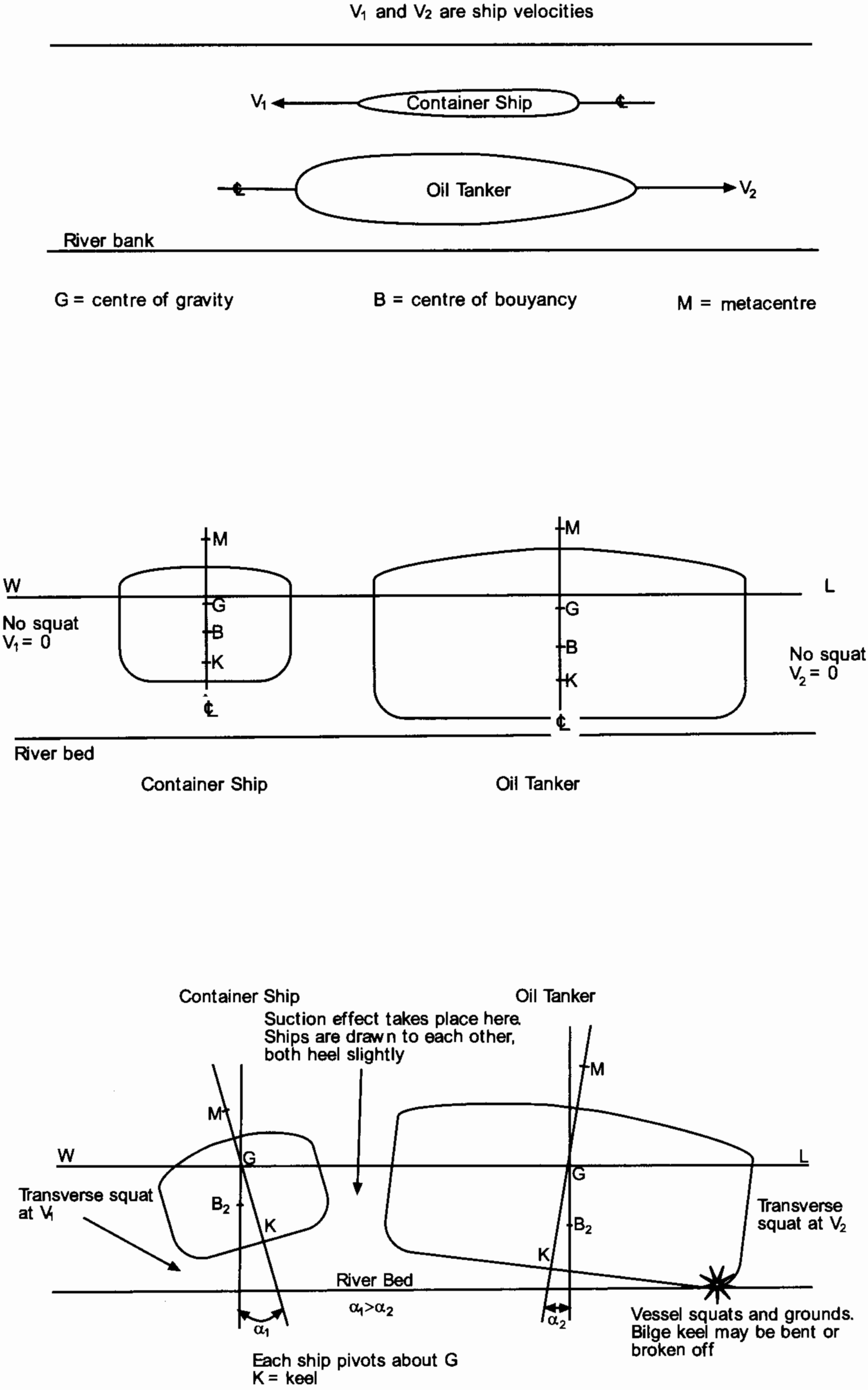


Fig. 36.4. Transverse squat caused by ships crossing in a confined channel.

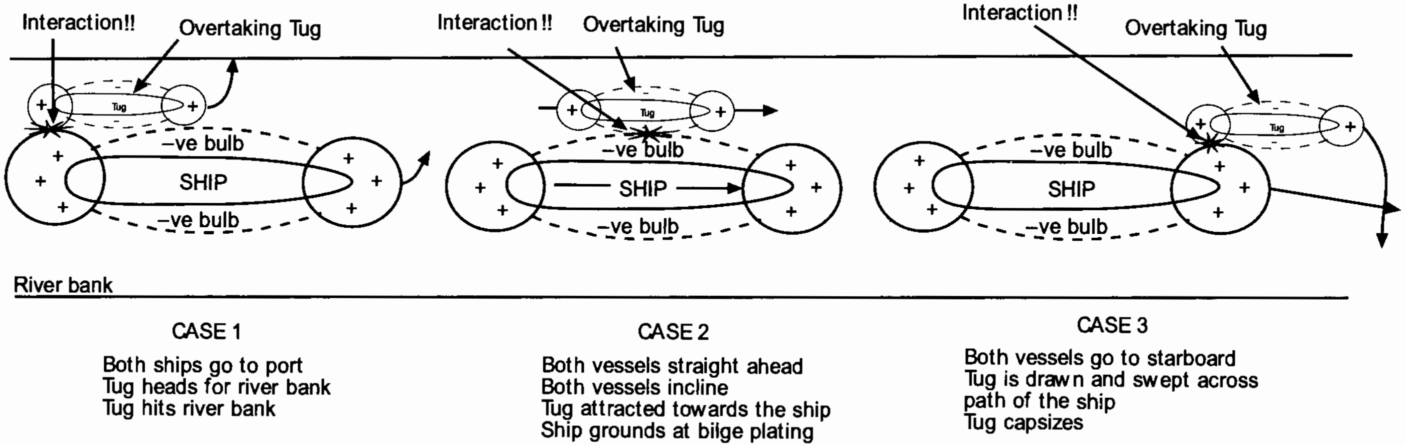


Fig. 36.5. Ship to ship interaction in a narrow river during an overtaking manoeuvre.

Case 1. The tug has just come up to aft port quarter of the ship. The Domains have become in contact. Interaction occurs. The positive bulb of the ship reacts with the positive bulb of the tug. Both vessels veer to port side. Rate of turn is greater on the tug. There is a possibility of the tug veering off into the adjacent river bank as shown in Figure 36.5.

Case 2. The tug is in danger of being drawn bodily towards the ship because the negative pressure (suction) bulbs have interfaced. The bigger the differences between the two deadweights of these ships the greater will be this transverse attraction. Each ship develops an angle of heel as shown. There is a danger of the ship losing a bilge keel or indeed fracture of the bilge strakes occurring. This is 'transverse squat', the loss of underkeel clearance at forward speed. Figure 36.4 shows this happening with the tanker and the container ship.

Case 3. The tug is positioned at the ship's forward port quarter. The Domains have become in contact via the positive pressure bulbs. Both vessels veer to the starboard side. Rate of turn is greater on the tug. There is great danger of the tug being drawn across the path of the ship's heading and bowled over. This has actually occurred with resulting loss of life.

Note how in these three cases that it is the smaller vessel, be it a tug, a pleasure craft or a local ferry involved, that ends up being the casualty!!

Figures 36.6 and 36.7 give further examples of ship to ship Interaction effects in a river.

Methods for reducing the effects of Interaction in Cases 1 to 5

Reduce speed of both ships and then if safe increase speeds after the meeting crossing manoeuvre time slot has passed. Resist the temptation to go for the order 'increase revs' This is because the forces involved with Interaction vary as the *speed squared*. However, too much a reduction in speed produces a loss of steerage because rudder effectiveness is decreased. This is even more so in shallow waters, where the propeller rpm decrease for similar input of deep water power. Care and vigilance are required.

Keep the distance between the vessels as large as practicable bearing in mind the remaining gaps between each ship side and nearby river bank.

Keep the vessels from entering another ship's Domain, for example crossing in wider parts of the river.

Cross in deeper parts of the river rather than in shallow waters, bearing in mind those increases in squat.

Make use of rudder helm. In Case 1, starboard rudder helm could be requested to counteract loss of steerage. In Case 3, port rudder helm would conteract loss of steerage.

Ship to shore interaction

Figures 36.8 and 36.9 show the ship to shore Interaction effects. Figure 36.8 shows the forward positive pressure bulb being used as a pivot to bring a ship alongside a river bank.

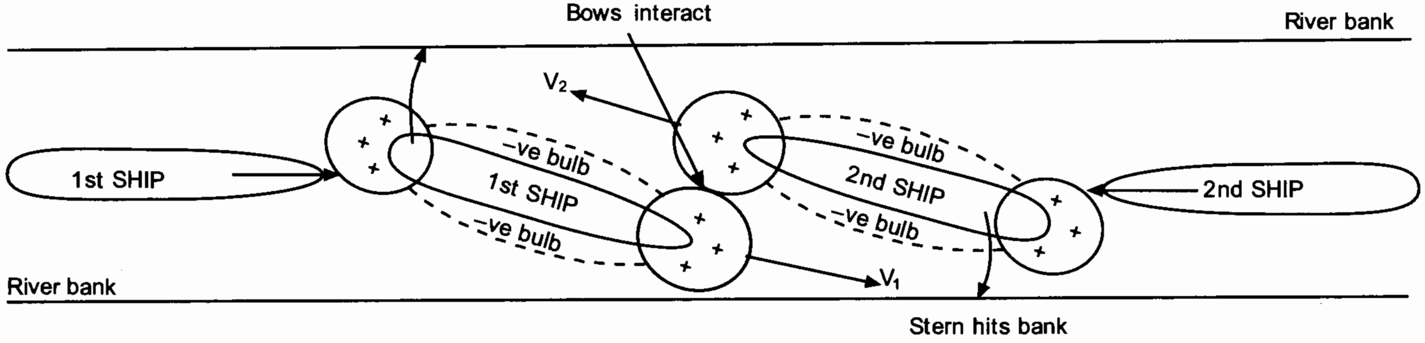


Fig. 36.6. Case 4. Ship to ship interaction. Both sterns swing towards river banks. The approach situation.

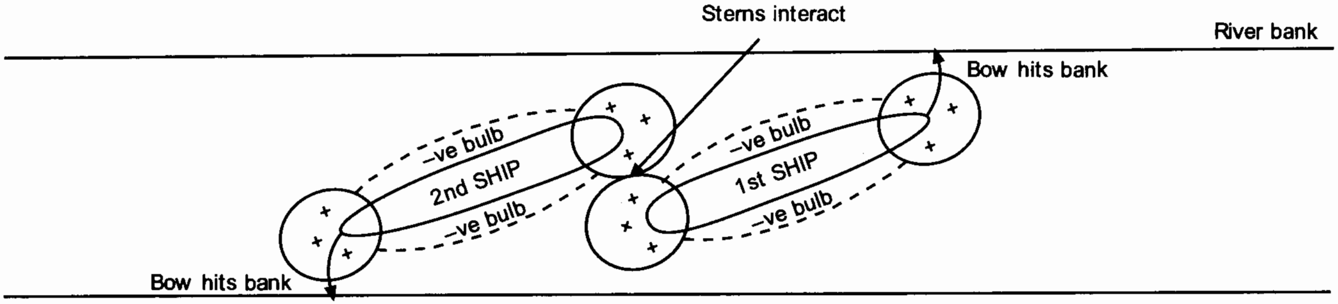


Fig. 36.7. Case 5. Ship to ship interaction. Both bows swing towards river banks. The leaving situation.

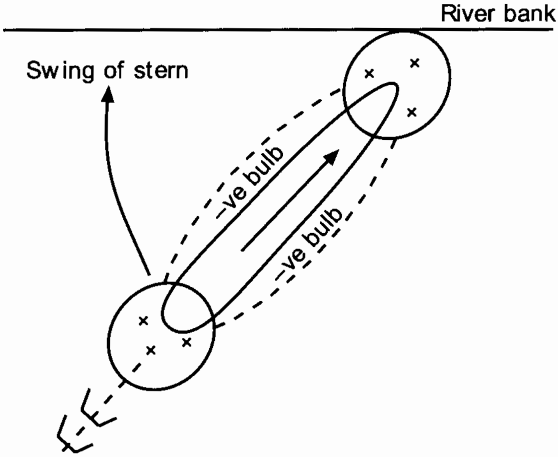


Fig. 36.8. Ship to bank interaction. Ship approaches slowly and pivots on forward positive pressure bulb.

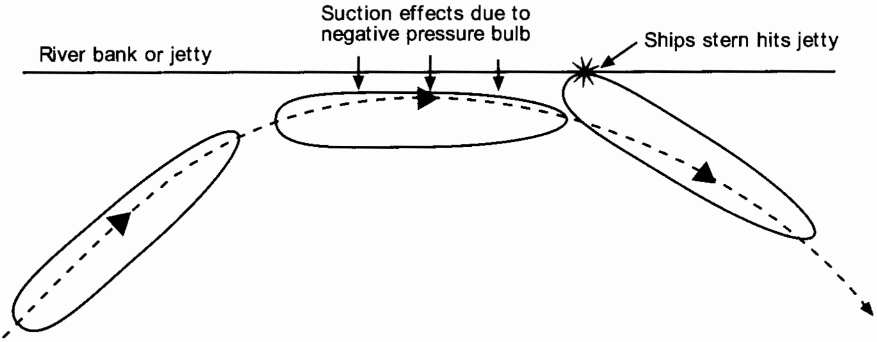


Fig. 36.9. Ship to bank interaction. Ship comes in at too fast a speed. Interaction causes stern to swing towards river bank and then hits it.

Figure 36.9 shows how the positive and negative pressure bulbs have caused the ship to come alongside and then to veer away from the jetty. Interaction could in this case cause the stern to swing and collide with the wall of this jetty.

Summary

An understanding of the phenomenon of Interaction can avert a possible marine accident. Generally a reduction in speed is the best preventive procedure. This could prevent on incident leading to loss of sea worthiness, loss of income for the shipowner, cost of repairs, compensation claims and maybe loss of life.

Exercise 36

1 A river is 150 m wide and has 12 m depth of water. A passenger liner having a breadth of 30 m a static even-keel draft of 10 m and a C_b of 0.625 is proceeding along this river at 8 kts. She meets an approaching general cargo vessel having a breadth of 20 m, a static even-keel draft of 8 m and a C_b of 0.700 moving at 7 kts.

Estimate the maximum squats of each vessel when their amidships are transversely in line.

2 With the aid of sketches, define Interaction and list how its effects may be limited. Show clearly how Interaction and transverse squat are inter-related.