Chapter 17

Ship squat in open water and in confined channels

What exactly is ship squat?

When a ship proceeds through water, she pushes water ahead of her. In order not to leave a 'hole' in the water, this volume of water must return down the sides and under the bottom of the ship. The streamlines of return flow are speeded up under the ship. This causes a drop in pressure, resulting in the ship dropping vertically in the water.

As well as dropping vertically, the ship generally trims for'd or aft (see Figure 17.1). Ship squat thus is made up of two components, namely mean bodily sinkage plus a trimming effect. If the ship is on even keel when

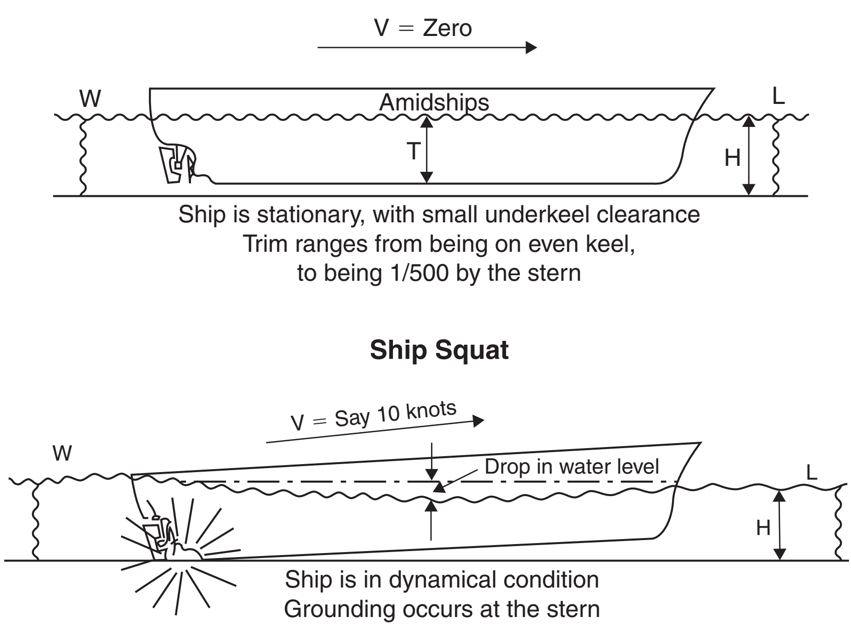


Fig. 17.1 Container vessel squatting at the stern.

static, the trimming effect depends on the ship type and C_B being considered. Also read later in this chapter, the detailed note on false drafts.

The overall decrease in the static underkeel clearance (ukc), for'd or aft, is called ship squat. It is *not* the difference between the draughts when stationary and the draughts when the ship is moving ahead.

If the ship moves forward at too great a speed when she is in shallow water, say where this static even-keel ukc is 1.0–1.5 m, then grounding due to excessive squat could occur at the bow or at the stern.

For full-form ships such as Supertankers or OBO vessels, grounding will occur *generally* at the bow. For fine-form vessels such as Passenger Liners or Container ships the grounding will generally occur at the stern. This is assuming that they are on *even keel* when stationary.

If C_B is >0.700, then maximum squat will occur at the bow.
If C_B is <0.700, then maximum squat will occur at the stern.
If C_B is very near to 0.700, then maximum squat will occur at the stern, amidships and at the bow. The squat will consist only of mean bodily sinkage, with no trimming effects.

It must be *generally*, because in the last two decades, several ship types have tended to be shorter in length between perpendiculars (LBP) and wider in Breadth Moulded (Br. Mld). This has lead to reported groundings due to ship squat at the bilge strakes at or near to amidships when rolling motions have been present.

Why has ship squat become so important in the last 40 years?

Ship squat has always existed on smaller and slower vessels when underway. These squats have only been a matter of centimetres and thus have been inconsequential.

However, from the mid-1960s to this new millennium, ship size steadily has grown until we have Supertankers of the order of 350 000 tonnes deadweight (dwt) and above. These Supertankers have almost out-grown the Ports they visit, resulting in small static even-keel ukc of only 1.0–1.5 m.

Alongside this development in ship size has been an increase in service speed on several ships, e.g. Container ships, where speeds have gradually increased from 16 up to about 25 kt.

Ship design has seen tremendous changes in the 1980s and 1990s. In Oil Tanker design we have the 'Jahre Viking' with a dwt of 564 739 tonnes and an LBP of 440 m. This is equivalent to the length of five football pitches.

In 2002, the biggest Container ship to date, namely the 'Hong Kong Express' came into service. She has a dwt of 82 800 tonnes, a service speed of 25.3 kt, an LBP of 304 m, Br. Mld of 42.8 m and a draft moulded of 13 m.

As the static ukc have decreased and as the service speeds have increased, ship squats have gradually increased. They can now be of the order of 1.50–1.75 m, which are of course by no means inconsequential.

Recent ship groundings

To help focus the mind on the dangers of excessive squat one only has to recall the grounding of these nine vessels in recent years.

Herald of Free Enterprise	RO-RO vessel at Zeebrugge	06/03/1987
QE11	Passenger Liner at New Orleans	07/08/1992
Sea Empress	Supertanker at Milford Haven	15/02/1996
Heidrun	Supertanker at Nantes	10/09/1996
Diamond Grace	260 000 tonnes dwt Very Large Crude Carrier (VLCC) at Tokyo Harbour	02/07/1997
Napoleon Bonaparte	Passenger Liner at Marseille	05/02/1999
Treguier	31 950 tonnes dwt Oil Tanker at Bordeaux	04/08/1999
Don Raul	37 000 tonnes Bulk Carrier at Pulluche, Chile	31/03/2001
Tasman Spirit	87 500 tonnes Oil Tanker at Karachi Harbour	27/07/2003

Department of Transport 'M' notices

In the UK, over the last 20 years the UK Department of Transport have shown their concern by issuing *four* 'M' notices concerning the problems of ship squat and accompanying problems in shallow water. These alert all Mariners to the associated dangers.

Signs that a ship has entered shallow water conditions can be one or more of the following:

1. Wave-making increases, especially at the forward end of the ship.
2. Ship becomes more sluggish to manoeuvre. A pilot's quote … 'almost like being in porridge.'
3. Draught indicators on the bridge or echo sounders will indicate changes in the end draughts.
4. Propeller rpm indicator will show a decrease. If the ship is in 'open water' conditions, i.e. without breadth restrictions, this decrease may be up to 15% of the Service rpm in deep water. If the ship is in a confined channel, this decrease in rpm can be up to 20% of the service rpm.
5. There will be a drop in speed. If the ship is in open water conditions this decrease may be up to 30%. If the ship is in a confined channel such as a river or a canal then this decrease can be up to 60%.
6. The ship may start to vibrate suddenly. This is because of the entrained water effects causing the natural hull frequency to become resonant with another frequency associated with the vessel.

7. Any rolling, pitching and heaving motions will all be reduced as ship moves from deep water to shallow water conditions. This is because of the cushioning effects produced by the narrow layer of water under the bottom shell of the vessel.
8. The appearance of mud could suddenly show in the water around the ship's hull say in the event of passing over a raised shelf or a submerged wreck.
9. Turning circle diameter (TCD) increases. TCD in shallow water could increase 100%.
10. Stopping distances and stopping times increase, compared to when a vessel is in deep waters.
11. Rudder is less effective when a ship is in shallow waters.

What are the factors governing ship squat?

The main factor is ship speed V. Detailed analysis has shown that squat varies as speed to the power of 2.08. However, squat can be said to vary approximately with the speed squared. In other words, we can take as an example that if we halve the speed we quarter the squat. Put another way, if we double the speed we quadruple the squat!!

In this context, speed V is the ship's speed relative to the water. Effect of current/tide speed with or against the ship must therefore be taken into account.

Another important factor is the block coefficient C_B. Squat varies directly with C_B. Oil Tankers will therefore have comparatively more squat than Passenger Liners.

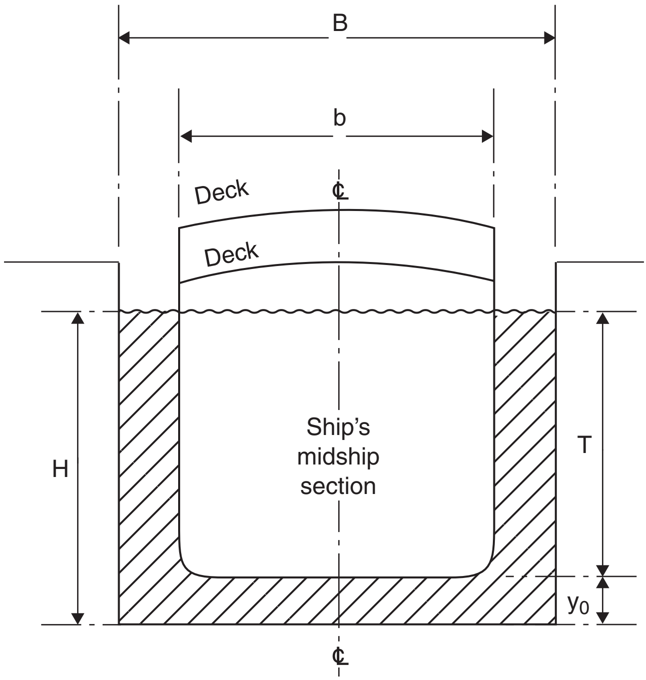
The Blockage Factor 'S' is another factor to consider (see Figure 17.2). This is the immersed cross-section of the ship's midship section divided by the cross-section of water within the canal or river. If the ship is in open water the width of influence of water can be calculated. This ranges from about 8.25 breadths for Supertankers, to about 9.50 breadths for General Cargo ships, to about 11.75 ship breadths for Container ships. See Chapter 18 for detailed notes on the 'width of influence.'

Water depth (H)/ship's draft (T) also affects ship squat. When H/T is 1.10–1.40, then squat varies as the reciprocal of H/T. Hence squat will vary as T/H.

The presence of another ship in a narrow river (passing, overtaking or simply moored) will also affect squat, so much so, that squats can *double in value* as they pass/cross the other vessel.

Squat formulae

Formulae have been developed that will be satisfactory for estimating maximum ships squats for vessels operating in confined channels and in open water conditions. These formulae are the results of analysing about 600 results. Some have been measured on ships and some on ship models. Some



A_S = cross-section of ship at amidships = b × T
A_C = cross-section of canal = B × H *or* 'B' × H
$A_W = A_C - A_S$
y_0 = static underkeel clearance

$$\text{Blockage factor} = \frac{A_S}{A_C} = S$$

$$\text{'B'} = \frac{7.04}{C_B^{0.85}} \times b$$

$$\text{'Width of influence'} = \frac{\text{equivalent 'B'}}{\text{ship's breadth 'b'}} \text{ in open water conditions}$$

V = speed of ship relative to water in knots
Blockage factor covers range of 0.10–0.266

Fig. 17.2 Ship in a canal in static condition.

of the empirical formulae developed are as follows:

Let:

b = breadth of ship
H = depth of water
C_B = block coefficient

CSA = cross-sectional area
B = breadth of river or canal
T = ship's even-keel static draft
V = ship speed relative to the water or current

$$\text{Let Blockage factor} = S = \frac{\text{CSA of ship}}{\text{CSA of river or canal}}$$

If ship is in open water conditions, then the formula for B becomes:

$$B = \frac{7.04}{C_B^{0.85}} \text{ ship breadths} \qquad \text{known as the 'width of influence'}$$

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

$$\text{Maximum squat} = \delta_{max} = \frac{C_B \times S^{0.81} \times V^{2.08}}{20} \text{ m} \quad \text{for open water and confined channels}$$

Two short-cut formulae relative to the previous equation are:

$$\delta_{max} = \frac{C_B \times V^2}{100} \text{ m} \quad \text{for open water conditions only} \quad \text{with } \frac{H}{T} = 1.1\text{–}1.4$$

$$= \frac{C_B \times V^2}{50} \text{ m} \quad \text{for confined channels} \quad \text{where } S = 0.100\text{–}0.266$$

An 'S' value of 0.100 appertains to a very wide river, almost in open water conditions. An 'S' value of 0.226 appertains to a narrow river.

For a medium width of river,

$$\delta_{max} = K \times \frac{C_B \times V^2}{100} \text{ m} \qquad \text{for medium width rivers}$$

$$K = (6 \times \text{'S'}) + 0.40 \qquad \text{S is the blockage factor}$$

A worked example, showing how to predict maximum squat and how to determine the remaining ukc is shown later in this chapter. It illustrates the use of the more detailed formula and then compares the answer with the short-cut method.

These formulae have produced several graphs of maximum squat against ships speed V. One example of this is in Figure 17.3, for a 250 000 tonnes dwt Supertanker. Another example is in Figure 17.4, for a Container vessel having shallow water speeds up to 18 kt.

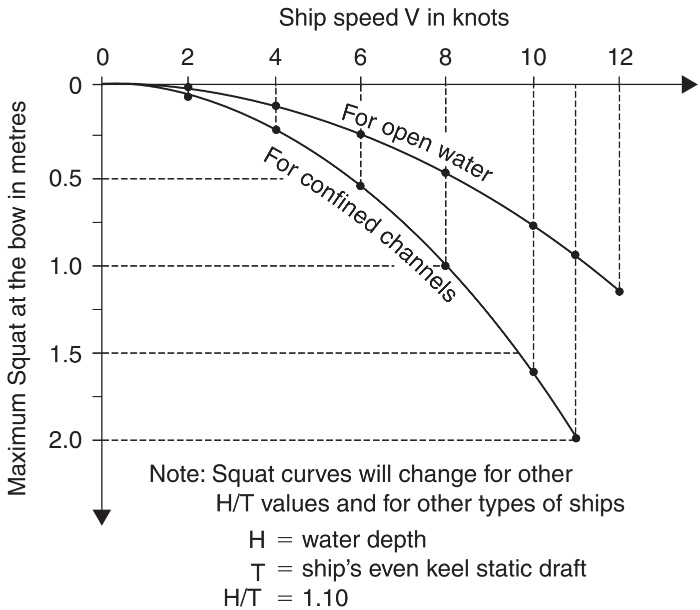


Fig. 17.3 Maximum squats against ship speed for a 250 000 tonnes dwt Supertanker.

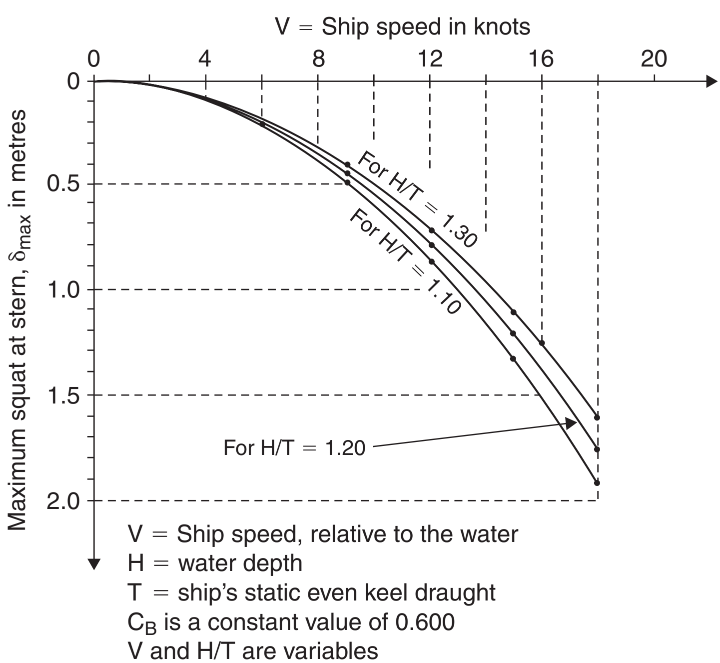
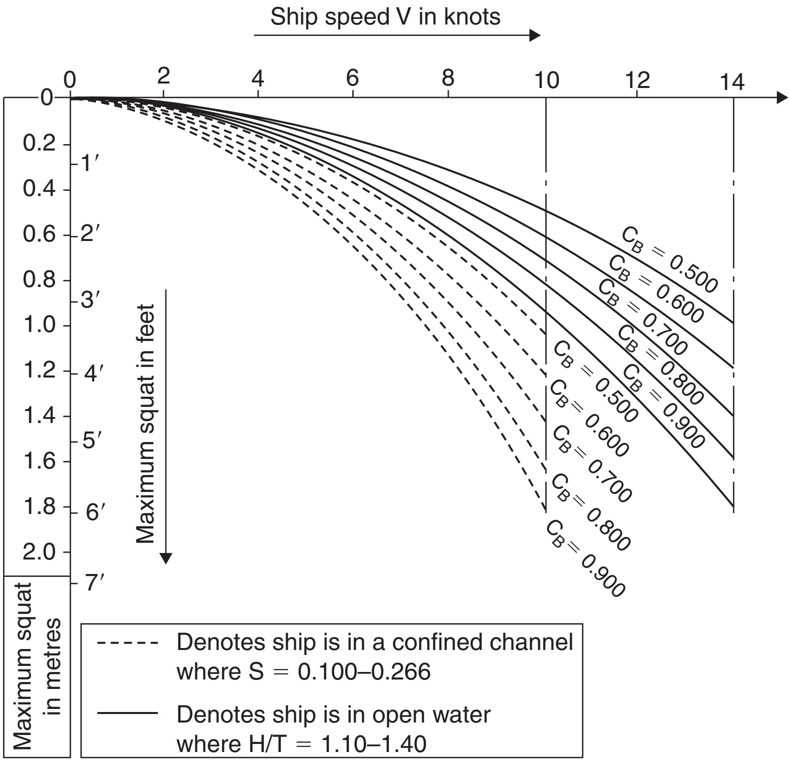


Fig. 17.4 Squats for Container vessels in open water when C_B is 0.600.



Ship type	Typical C_B, fully-loaded	Ship type	Typical C_B, fully-loaded
ULCC	0.850	General Cargo	0.700
Supertanker	0.825	Passenger Liner	0.625
Oil Tanker	0.800	Container ship	0.565
Bulk carrier	0.775–0.825	Coastal tug	0.500

Fig. 17.5 Maximum ship squats in confined channels and in open water conditions.

Figure 17.5 shows the maximum squats for Merchant ships having C_B values from 0.500 up to 0.900, in open water and in confined channels. Three items of information are thus needed to use this diagram.

First, an idea of the ship's C_B value, secondly the selected speed V and thirdly to decide if the ship is in open water or in confined river/canal conditions. A quick graphical prediction of the maximum squat can then be made. The final decision to be made is whether the remaining ukc at the bow or the stern is safe enough. If it is not safe, then the selected speed prior to the ship's transit should be reduced.

Worked example 17.1

In shallow water conditions, for a fully loaded condition, a vessel has a C_B of 0.750. She was on even keel when static. Estimate the maximum squat at the bow when she has a speed of 10 kt in open water and when she is in a confined channel.

$$\delta_{max} = \frac{C_B \times V^2}{100} \text{ m} \qquad \text{for open water conditions only}$$

$$= \frac{0.750 \times 10^2}{100} = 0.75 \text{ m at the bow, because } C_B > 0.700$$

$$\delta_{max} = \frac{C_B \times V^2}{50} \text{ m} \qquad \text{for confined channels only}$$

$$= \frac{0.750 \times V^2}{50} = 1.50 \text{ m at the bow, because } C_B > 0.700$$

Worked example 17.2

If the ship in Worked example 17.1 was operating in a river giving a blockage factor of 0.175, then estimate the maximum squat as she proceeds at a forward speed of 10 kt.

For a medium with of river,

$$\delta_{max} = K \times \frac{C_B \times V^2}{100} \text{ m} \qquad \text{medium width rivers}$$

$$K = (6 \times \text{'S'}) + 0.40 \qquad \text{hence} \quad K = (6 \times 0.175) + 0.40 = 1.45$$

$$\text{Therefore} \quad \delta_{max} = 1.45 \times \frac{0.750 \times 10^2}{100}$$

$$= 1.09 \text{ m at the bow, because } C_B > 0.700$$

Worked example 17.3

A Supertanker is operating in open water conditions. Her Br. Mld is 55 m. Her C_B is 0.830, static even-keel draft (T) is 13.5 m and forward speed is 11 kt. The water depth (H) is 16 m. Calculate the maximum squat for this vessel by *two* methods and her minimum remaining ukc at this speed of 11 kt.

$$\text{Width of influence} = B = \frac{7.04}{C_B^{0.85}} \text{ ship breadths}$$

$$= \frac{7.04}{0.830^{0.85}} \times 55 = 8.248 \times 55$$

$$= 453.6 \text{ m}$$

This is an equivalent artificial width of river in open water conditions. Any greater width of water will give the same values for maximum squats for this vessel only.

$$\text{Blockage factor} = S = \frac{b \times t}{B \times H} = \frac{55 \times 13.5}{453.6 \times 16} = 0.102$$

Method 1 (more detailed method)

$$\text{Max squat} = \delta_{max} = \frac{C_B \times S^{0.81} \times V^{2.08}}{20}\ \text{m} \qquad \text{for open water}$$

$$= \frac{0.830 \times 0.102^{0.81} \times 11^{2.08}}{20}$$

$$= 0.96\ \text{m at the bow, because } C_B > 0.700$$

Method 2 (short-cut method)

$$\delta_{max} = \frac{C_B \times V^2}{100}\ \text{m} \qquad \text{for open water}$$

$$= 0.830 \times \frac{11^2}{100}$$

$$= 1.00\ \text{m at the bow, because } C_B > 0.700$$

This is slightly above the first answer, so is erring on the high and therefore safe side.

$$\text{Average maximum squat is } \frac{0.96 + 1.00}{2} = 0.98\ \text{m}$$

$$\text{Hence remaining ukc at the bow} = H - T - \delta_{max}$$

$$= 16.00 - 13.50 - 0.98$$

$$= 1.52\ \text{m @ } V = 11\ \text{kt}$$

Worked example 17.4

Use Figure 17.5 to estimate the maximum squats for Cargo–Passenger ship having a C_B of 0.650 and a forward speed of 8.00 kt, when she is in open water and when she is in a confined channel.

Procedure

Open water: At a speed of 8 kt, drop vertically down from the 'x' axis until midway between the *solid curves* for C_B values of 0.600 and 0.700. At this point move left to the 'y' axis and lift off the maximum squat value of 0.42 m.

Confined channel: At a speed of 8 kt, drop vertically down from the 'x' axis until midway between the *dotted curves* for C_B values of 0.600 and 0.700. At this point move left to the 'y' axis and lift off the maximum squat value of 0.84 m.

Both of these maximum squats will occur at the stern, because C_B is <0.700.