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SHIP SQUAT

ABSTRACT

Although a recognised phenomenon affecting a vessel, particularly in shallow and confined waterways, squat is difficult to calculate, quantify and apply.

Many different factors affect its impact. It is always a predicted figure, depending on factors that may at any given time be unknown or difficult to ascertain with any degree of accuracy.

It involves, but is not limited to the input of information from the vessel's particulars, as well as those of the limitations of the waterway to be transited, traffic interaction, factor of tides and tidal streams, currents and prevailing weather etc.

The knowledge of squat, its calculation and application of safe margins, and timely preventive action (reduction of speed) may save a vessel from grounding and its aftermath. Lack of appreciation of squat can prove to be very costly.

KEY WORDS

ship squat, ship trim, ship design, depth of influence, width of influence, squat prediction, prevention

INTRODUCTION

The paper begins with a description of what exactly ship squat is. Details are given on how squat predictions are very important for vessels with large DWT like supertankers or high-speed ships like container vessels.

The main factors or variables for estimating maximum squat are discussed in detail. Three formulae are given for estimating maximum squat and where along the ship's length it is likely to occur.

One of the three formulae is complicated. The other two formulae, however, are quick approximations giving answers that err on the high and therefore safe side.

Finally, a summary is given to show the advantages for shipowners, the ship's officer of the watch, the ship's pilot and the Port Authority, now that the maximum squat for the ships can safely be predicted.

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 pushed ahead of the ship must return down the sides and under the keel of the ship.

The streamlines of return flow are speeded up under the ship. This causes drop in pressure resulting in the ship dropping vertically in the water. As well as dropping vertically, the ship trims fore and aft. The overall decrease in the underkeel clearance fore or aft is called *ship squat*.

Ship squat can be caused in two ways. On most occasions squat is caused by the forward motion of a vessel.

Squat is the decrease in underkeel clearance caused by this forward motion. (1)

As the ship moves forward she develops a mean bodily sinkage together with a slight trimming effect. The algebraic sum of bodily sinkage and the trim ratio (forward or aft) is known as "ship squat".

It must be emphasised that for any draught, squat is NOT the difference in reading between the situation when a vessel is stationary and when she is underway. This misconception is inaccurate and misleading.

For example, the difference in bow draught readings due to forward motion might be 2m, whilst the decrease in underkeel clearance might only be 0.40m. (1).

The other occasion where squat will occur is with a moored vessel, in an ebb tide, alongside a jetty (3). Tide speed along the stationary vessel produces, as before, components of bodily sinkage and trimming effects. The two combined give *ship squat for a stationary vessel*.

Maritime personnel, taking draught readings, say for a draught survey, must be aware that the second situation could lead to underloading cargo aboard a vessel being loaded ready for departure.

Ship squat has always existed on smaller slower vessels. It only amounted to a few centimetres and was therefore inconsequential. (3)

In the 1960s and 1970s several new specialised ship types were developed. Two of these were the supertanker and the container ship.

Supertankers of 250,000 t DWT became common. They were almost too big for ports to accommodate them, resulting in static underkeel clearances as low as 1.0 m to 1.5m.

At the same time container ships were replacing many of the older general cargo ships. Service speeds for these container ships gradually increased from 16 knots up to as high as 27 knots. Passenger liners also followed this specification for higher and higher speeds up to 30 knots.

However, with oil fuel costs in mind, for the 1990s new orders for container ships tended to specify service speeds ranging from 18 to 22 knots. In 1995, even passenger liners like the new "Oriana" operated with a design service speed of 24 knots. Still high, but not as high as yesteryear.

As underkeel clearances decreased and design service speeds increased, maximum squats gradually increased until they could be in the order of 1.5m to 1-75m. These are by no means inconsequential.

Developments in ship design have, therefore, made the prediction of squat much more important from the safety point of view. Much more so in the 1990s than, say, 30 years ago. (3)

A vessel behaves differently in shallow water than she does when she is in deep water. (4)

It becomes necessary to know when a ship has entered shallow waters. This can be determined by using the depth of influence coefficient F_D in the following manner.

Let 'H' be the depth of water and let 'T' be the mean draught of the static ship, measured at or near to amidships. $^H/T$ is then worked out and compared (4) with the FD value for each ship type.

- for a supertanker $F_D = 5.68 \times T$
- for a general cargo ship $F_D = 7.07 \times T$
- for a passenger vessel $F_D = 8.25 \times T$
- for a RO-RO vessel $F_D = 9.20 \times T$

If H/T is above the respective F_D value, the vessel's resistance will not alter, her speed will remain constant, her propeller revs will remain steady and her squat will remain unchanged. She is in fact operating in deep water conditions. (8)

Below the corresponding value of F_D for each vessel, each ship will be in shallow water conditions. Below this F_D value, the vessel's resistance will increase, her speed will decrease despite the same input of engine power, her propeller revs will decrease and her squat will increase as H/T approaches 1.10 (4)

Other indications that a ship has entered shallow waters are:

a) wave making increases at the forward end of the ship;
b) vessel becomes more sluggish to manoeuvre;
c) ship may start to vibrate suddenly because of entrained water effects causing resonance;
d) rolling, pitching and heaving motions decrease due to the cushion of water beneath the vessel.

The main factors affecting ship squat are:

a) the forward speed V_K which is the speed of the ship over the ground. This is the most important factor because ship squat varies directly as V_K^2. If the speed is halved then the squat is quartered.
b) the block coefficient C_B. This also is important. Squat varies directly with the C_B.

In other words, oil tankers and OBOs will have comparatively more squat than passenger liners and container ships. This is shown graphically in Figure 3.

c) the relationship between the depth of water (H) and the static mean draught of the ship (T).
d) the presence of river or canal banks. The closer banks are to the sides of a moving vessel, the greater are the squats.
e) the presence of another ship in a river in a crossing or passing manoeuvre.

The presence of the second ship increases the squats on both vessels.

In open water conditions, having no adjacent banks, it is possible to calculate an artificial width of water to represent the riverbanks. This is known as the "*width of influence*" (4)

Practical calculations for squat

An important factor is the blockage factor 'S', where S = b x T / B x H as shown in Figure 1. From this we obtain the velocity-return factor S_2 where

S_2= S / I-S as shown in Figure 1.

Method 1:

Maximum squat =

$$'\int_{max}' = C_B/30 \text{ x } S_2^{2/3} \text{ x } V_K^{2{,}08} \text{ metres,}$$

for open water and confined channel conditions.

Method 2:

Maximum squat =

$$'\int_{max}' = C_B \text{ x } V_K^2 / 100 \text{ metres}$$

in open water only

Method 3:

Maximum squat =

$$'\int_{max}' = \text{'K' x } (C_B \text{ x } V_K^2 / 100) \text{ metres}$$

in open water and confined channels, where 'K' (6 x S) + 0.400. (5)

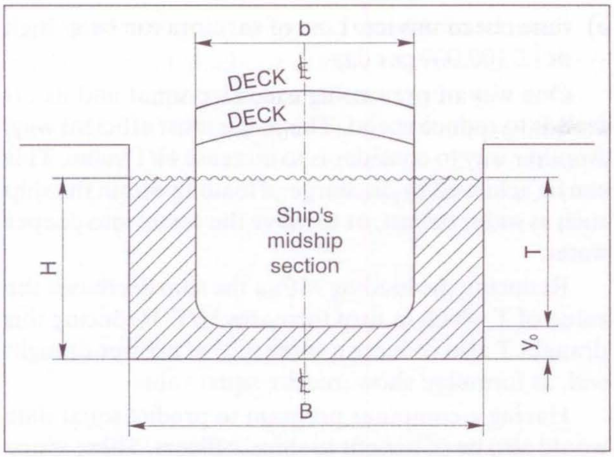

Figure 1- Ship in a canal in static condition

A_s – Cross-section of ship at amidships = b × T.

A_c – Cross-section of canal = B × H.

$\text{Blockage factor} = S = \frac{A_S}{A_C} = \frac{b \times T}{B \times H}.$

y_0 – Static underkeel clearance.

$\text{Velocity-return factor} = S_2 = \frac{S}{1-S}.$

H/T range is 1.10 to 1.40.

Blockage factor range is 0.100 to 0.265.

$\text{Width of influence} = F_B = \frac{\text{Equivalent 'B'}}{b}$ in open water.

V_K – Speed of ship over the ground, in knots.

$A_W = A_c - A_s$.

Hence S_2 also $= \frac{A_s}{A_w}$

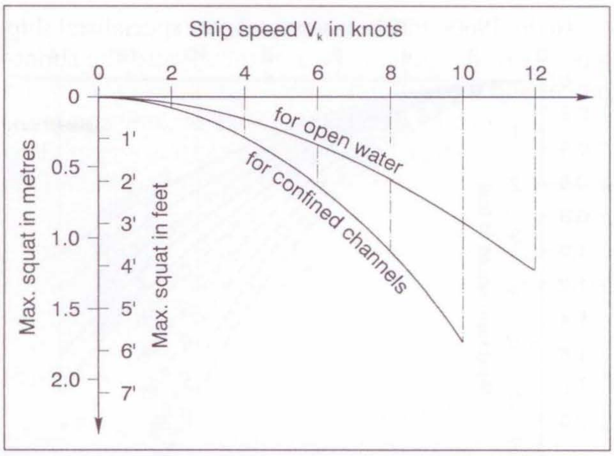

Figure 2 - Maximum squats against ship speed for a 250,000 t vlcc

H – Water depth.

T – Ship's even keel static draft.

Assume static H/T = 1.10 for graphs.

Method 3:

Maximum squat =

$\text{'}\int_{max}\text{'} = 2 \times (C_B \times V_K^2 / 100)$ metres

in confined channels when the blockage factor ranges from 0.100 to 0.265.

Methods 2, 3 and 4 will give approximate squats. These will err slightly on the high side and contain, therefore, a small margin of safety.

Knowing how to predict maximum squat is important. Equally important is knowing whereabouts on the moving vessel it will occur. It all depends on how each ship is trimming when static.

Trim is the difference between the aft draught and the forward draught.

Consider first of all ships that are on even keel when stationary. In other words, their trim is zero. As soon as each ship moves she will:

a) trim by the head if her C_B is greater than 0.700;

b) trim by the stem if her C_B is less than 0.700;

c) usually not trim if her C_B is 0.700.

Thus,

- for full-form vessels, '$\int_{max}$' will occur at the bow;
- for fine-form vessels, '$\int_{max}$' will occur at the stem;
- for medium form vessels, '$\int_{max}$' will occur at the stem, bow and amidships, i.e. all along the bottom shell of the ship.

However, if each vessel is trimming (2) when stationary, then the following applies:

a) if a vessel is static and trimming **by the head**, then when she is underway bodily sinkage will occur plus a slight trimming effect also **by the head**;

b) if a vessel is static and trimming **by the stern** then when she is underway bodily sinkage will occur plus a slight trimming effect also **by the stern**.

In both cases, any static trim on a ship will be **increased in the same direction** when she is at forward speed. '$\int_{max}$' will occur and be added onto the larger of the two static end drafts. (2)

The width of influence 'F_B' is an artificial width of water used in squat calculations. (4) It is used for a ship operating in open water conditions. It is dependent on the type of ship being considered.

- for a supertanker $F_B = 8.32 \times B$
- for a general cargo ship $F_B = 9.50 \times B$
- for a tug (coastal) $F_B = 12.69 \times B$

where 'B' is the ship's maximum breadth, at or very near amidships.

If H/T ranges from 1.10 to 1.4, the width of influence F_B can be evaluated using:

$$F_B = B/b = 7.7 + 45(1 - C_W)$$

For merchant ships, we can assume that the 2-dimensional coefficient C_W can be related approximately to the 3-dimensional coefficient C_B using:

$$C_w = 2/3C_B + 1/3$$

By using this width of influence, one can place the ship in an artificial channel/canal and then proceed; calculating the maximum squat as though the vessel was operating in a river or canal.

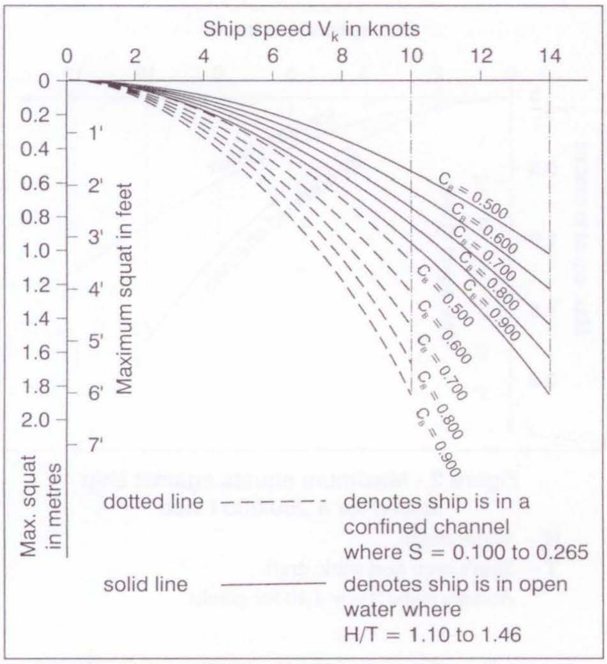

Figure 3 - Maximum ship squats in confined channels and in open water conditions

Ship type	Typical C_B, fully loaded
ULCC	0.860
Supertanker	0.825
Oil tanker	0.800
Bulk carrier	0.750
General cargo	0.700
Passenger liner	0.625
Container ship	0.565
Coastal tug	0.500

Any width of water beyond F_B will give identical squat values. This is why it is termed the "width of influence".(4)

Any width of water less than F_B will produce increased resistance, loss of speed, loss of prop revs and increases in ship squat. (6)

Several authors such as Yamaguchi(2), Baker(3), Todd(4), Lackenby(5) and Rawson & Tupper (6) have all suggested values for 'F_B' for particular ship types.

PREVENTION

When a ship grounds due to excessive squat the ship-owners may be faced with the following costs:

a) repair costs for the ship;

b) repair costs for repairs to lock sills;

c) compensation claims for oil spillage;

d) dry-dock charges for inspection of a ship;

e) time out of service. Loss of earnings can be as high as ∫ £ 100,000 per day.

One way of preventing excessive squat and its effects is to reduce speed. This is the most efficient way. Another way to consider is to increase H/T value. This can be achieved by discharge of loading within the ship such as water ballast, or to move the vessel into deeper water.

Reducing the loading within the ship decreases the value of T which in turn increases H/T' Reducing this draught T also reduces q value. C,3 at a lower draught will, as formulae show, reduce squat value.

Having a computer program to predict squat data would also be of benefit to ships' officers. There is one that prints out the following:

1. whether the ship is in open waters or in a confined channel;
2. gives maximum squats and where they occur;
3. gives the remaining underkeel clearances at bow and stern;
4. gives the speed required for the vessel to go aground at the bow and at the stern.

This computer program covers all types of ships, for all relevant speeds, and is able to predict for both open water and confined channel conditions.

Shipboard personnel such as the master and deck officers need to know about the theory and possible dangers resulting from excessive squat.

Ship pilots also need a detailed appreciation of this topic when assisting with the passage of ships along narrow rivers and through canals

A third group of personnel needing to know about ship squat is the Port Authorities. Some of them, aware of possible grounding problems "request" a static minimum underkeel clearance of 1.0 m to 1.25 m before allowing entry of a vessel into their river. Maximum transit speed is also "requested".

In the past there existed a tendency to overestimate squat on certain routes and to underload the cargo accordingly. Now that squat can be predicted more accurately, the ship can sometimes be loaded up an extra few centimetres giving the vessel extra earning capacity. Load-line limits, of course, always have to be adhered to.

In the past, the ships' pilots have used 'trial and error', 'rule of thumb' and years of experience to bring their vessels safely into and out of port.

The positioning of a simple graph of ship speed against maximum squat placed on the bridge may be all that is required. See Figure 2 for such an example.

The pilot can observe quickly from this graph a speed that could cause problems and then a speed that would give a squat which would leave the ship with a safe dynamical underkeel clearance.

CONCLUSION

If we can predict the ship squat for a given situation the following advantages are gained:

1. The ship operator knows up to which speed he must reduce to ensure the safety of the vessel and he may prevent some damage which would otherwise occur in shallow waters.
2. The ship officers can load the ship up to the load-line limits. If a 100,000 tons DWT oil tanker is being loaded by an extra 30 centimetres, the effect is an extra 3% DWT, thus giving the ship extra earning capacity.
3. If the ship does not ground, there is no repair bill to pay. Neither will the ship be out of service, which could be very costly indeed, as her owner's loss of earnings could be as high as £ 10,000.00 per day.

In the past, ship pilots have used trial-and-error, rule-of-thumb and years of experience to bring their vessels safely into the port. It can now be stated that ship squat can be predicted and a great deal of grey area of ignorance surrounding the phenomenon has been removed.

The formulae give the pilots firm guidelines which contribute to the efficiency of the ports as well as to that of the ship-owners by safeguarding ship, crew and cargo.

Thus, by maintaining the ships' availability for trading, pilots will, in particular, help to increase the shipowners' earnings.

After all, prevention is better than cure and a lot CHEAPER!!

POVZETEK

LADIJSKI POČEP

Ladijski počep,čeprav je poznani fenomen, ki vpliva na ladjo, še posebej v plitkih vodah ter v utesnjenih plovnih poteh, je težavno izračunat, izmerit ter ga uporabit v praksi.

Zaradi vpliva mnogo različnih faktorjev, ki vplivajo na ta fenomen,

se ga lahko vedno predstavi kot napovedna številka, odvisna od faktorjev, ki so v določenem času nam nepoznani ali težko preverljivi s stopnjo točnosti.

Za točni izračun ni samo potrebna vhodna informacija ladijskih podatkov, ampak prav tako tudi omejitve določene plovne poti, vpliv prometa, faktor morskih men ter njihova smer, tokovi in sedanje vreme, kar pa je seveda težko dosegljivo v določenem času.

Znanje ladijskega počepa, njegov izračun ter njegova uporaba v mejah varnosti in pravočasen preventiven ukrep (zmanjšanje hitrosti) lahko obvaruje ladjo pred nasedanjem in posledicami.

Potreba po oceni ladijskega počepa se lahko izkaže za izredno dragoceno informacijo.

Navsezadnje boljše je preprečiti kot zdraviti.

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