

THE ANALYSIS OF SQUAT AND UNDERKEEL CLEARANCE FOR DIFFERENT SHIP TYPES IN A TRAPEZOIDAL CROSS-SECTION CHANNEL

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This paper deals with ship squat phenomenon, which, in general, appears in shallow waters navigation, but with a more pronounced effect on canals passage.

Therefore, theoretical calculations of ship squat have been made for the main types of vessels used in shipping, transiting a canal with trapezoidal cross section. The results analysis showed that large ships can not navigate through the considered canal because of small underkeel clearance.

The paper can be useful for ship designers, naval architects and naval officers, who have to know squat's effects, in order to prevent any shipping accidents.

Keywords: squat, underkeel clearance, blockage factor, ship, canal.

1. Introduction

In the last decade it was observed a continuous increase of the main dimensions of certain ship, especially for container carriers, RO-RO vessels and LNG carriers. In opposition, the dimensions of access channels, rivers, canals, and harbors where these vessels operate do not increase at the same rate. Therefore, the behavior of ships flow in harbors will be influenced by waterways restrictions.

A phenomenon that occurs on vessels in these areas is **ship squat**, which may be defined as the sinkage and/or trimming of the ship due to pressure changes along the ship length in shallow waters. Large and fuller ships such as tankers and bulk carriers should pay extra attention when navigating in restricted waters. The squat effect is directly related to ship dimensions, its speed and water depth; therefore it interests port designers as much as masters and naval architects [1].

Current researches on this phenomenon are limited to experiments or model scale for an accurate mathematical expression of ship squat. The literature presents various formulas of ship squat, the most commonly used being those of Barrass (1979, 2004) [2], Millward (1990), Norrbin (1986) and Tuck (1970).

The objectives of this paper are to explain and calculate squat that occurs on ships transiting waterways. The article includes an analysis of the squat and

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underkeel clearance for different ship types in a trapezoidal cross-section channel, at different speeds and different values for the block coefficient.

2. Ship squat

Squat is the decrease of underkeel clearance caused by the movement of the submerged ship's body through water. Compared with the static position, the hull goes deeper into the water and trims for a few degrees.

A moving vessel pushes the water in front of her bow, which must flow back under and at the sides of the ship to replace the volume of water displaced by the ship's hull. In shallow and/or narrow waters the water particles' velocity of flow increases which results a pressure drop, according to Bernoulli's Law,

$$p + \rho \cdot g \cdot h + \frac{1}{2} \rho V^2 = \text{const.}, \quad (1)$$

where p is the static pressure, ρ - density, g - gravity, h - height and V - speed [3].

The pressure drop under the ship causes a vertical sinking of the ship's hull and depending on the vessel's block coefficient it will trim forward, aft or will sink deeper on even keel. The amount of all vertical sinking and trim is called **ship squat** (fig. 1).

When ships navigate in shallow water at too great speed, grounding may occur at the bow or at the stern due to excessive squat. Full-form ships such as Supertankers or Ore-Bulk-Oil ships may experience grounding generally at the bow. Fine-form vessels such as Passengers Liners or Container ships may experience grounding generally at the stern.

If block coefficient, C_B , is greater than 0.7, then maximum squat will occur at the bow. If C_B is less than 0.7, then maximum squat will occur at the stern. If C_B is very near to 0.7, then maximum squat will occur at the stern, amidships and at the bow. In this case, squat will consist only of mean bodily sinkage, with no trimming effects.

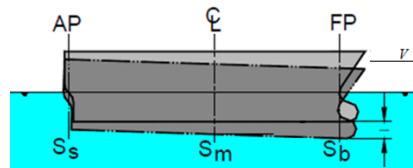


Fig. 1. Ship squat (S_b – squat at bow, S_m – squat amidship, S_s – squat at stern) [4]

Squat formulas have been developed for estimating maximum ship squat for vessels operating in restricted and open water conditions with satisfactory results. Some have been measured on ships and some on ship models.

Barras's formula [2] is among the most simple and easy to use for all channel configurations. Based upon his research from 1979, 1981 and 2004, the

maximum squat formula is determined by block coefficient C_B , blockage factor S and ship speed V_K .

Maximum squat, δ_{max} is equal to [5, p. 327]:

$$\delta_{max} = \frac{C_B \cdot S^{0.81} \cdot V_K^{2.08}}{20} \text{ m.} \quad (2)$$

The main factor is ship speed V_K . Detailed analysis has shown that squat varies as speed to the power of 2.08. In this context, V_K is the ship's speed relative to water; therefore the effect of current/tide must be taken into account.

The value of the block coefficient C_B determines if the maximum squat occurs at bow or at stern. Full-form ships with C_B greater than 0.700 produce squat at bow. Fine-form ships with C_B less than 0.700 produce squat at stern. Ships with C_B near 0.700 produce a mean bodily sinkage equal to maximum squat.

Two simplified formulas relative to the previous equation are [5, p. 327]:

$$\delta_{max} = \frac{C_B \cdot V_K^2}{100} \text{ m,} \quad (3)$$

for open water conditions only, with the ratio H/T between water depth and ship draft, figure 2, ranging from 1.1 to 1.4, and

$$\delta_{max} = \frac{C_B \cdot V_K^2}{50} \text{ m,} \quad (4)$$

for confined channels where the blockage factor S has values between 0.100 and 0.265. An S value of 0.100 appertains to a very wide channel, almost in open water conditions, while a blockage factor of 0.265 appertains to a narrow channel.

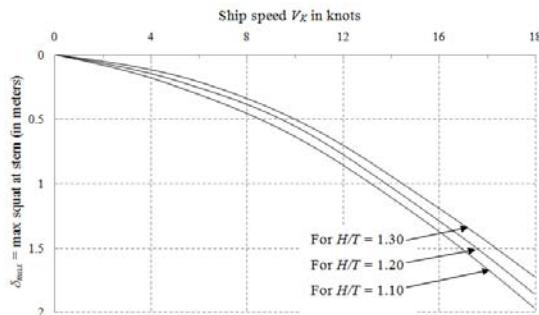


Fig.2. Squats for container vessels with $C_B = 0.600$ [5, p. 330]

For a medium width channel, maximum squat is [2, p. 153]

$$\delta_{max} = K \cdot \frac{C_B \cdot V_K^2}{100} \text{ m,} \quad (5)$$

where, K factor is a function of blocking factor S ,

$$K = (6 \cdot S) + 0.40 \quad (6)$$

The blockage factor S is an element to consider in ship squat calculation and it represents the immersed cross-section of the ship, A_S , divided by the cross-section of water within the canal, A_C , figure 3 [5, p. 329],

$$S = \frac{A_S}{A_C} = \frac{b \cdot T}{B \cdot H} . \quad (7)$$

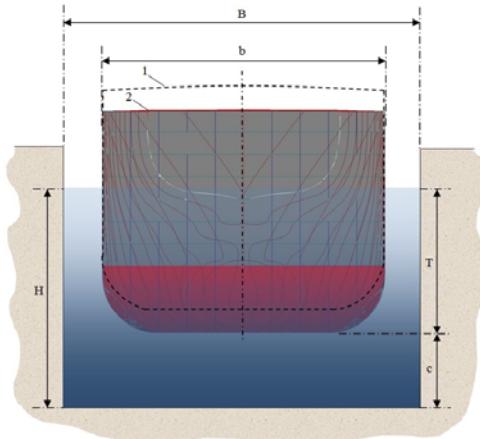


Fig. 3. Ship in a canal

B – canal breadth; H – water depth; b – ship's breadth; T – ship's draft; c – underkeel clearance
 1 – ship in static condition; 2 – ship at V_K speed

3. Ship squat and underkeel clearance analysis for different ship types in a canal

The problem of squat and underkeel clearance calculation is important for ships, especially in shallow waters and confined waterways. To see how ship squat varies depending on actual speed limit in channel navigation for different ship types, there have been made calculations.

For this, it is necessary to know the main dimensions of various vessels used in modern navigation. Therefore, *Significant Ships* catalog represents a source of reference for ship design, being annually published by The Royal Institution of Naval Architects in London.

The most representative vessels in shipbuilding have been selected and their average dimensions, such as length between perpendiculars, breadth, draft, block coefficient or cruise speed, have been listed in table 1 [1].

Tabel 1

Average dimensions for common ship types

Ship type	L_{pp} [m]	b [m]	T [m]	C_B	V_K [kn]
Ultra Large Crude Carrier (ULCC)	350	65	23	0,850	14,5
Very Large Crude Carrier (VLCC)	318	60	20	0,825	15,5
Oil Tanker	212,5	32,5	12	0,800	15,5
Bulk Carrier	212,5	34,4	12,4	0,775	14,5
General Cargo Ship	125	20	7,8	0,700	14,5
Passenger Liner	230	30	7,6	0,625	25
Container Ship	250	37,5	11,4	0,575	23
RO – RO Ship	179,5	31,3	7,3	0,560	21
Tug	36,5	12,5	5,5	0,500	10

In this case study it was selected a theoretical navigation canal with a trapezoidal cross-section, similar to Suez Canal, with following dimensions: water line breadth, $W_0 = 313$ m, bottom breadth, $B = 121$ m and water depth, $H = 24$ m (fig. 4).

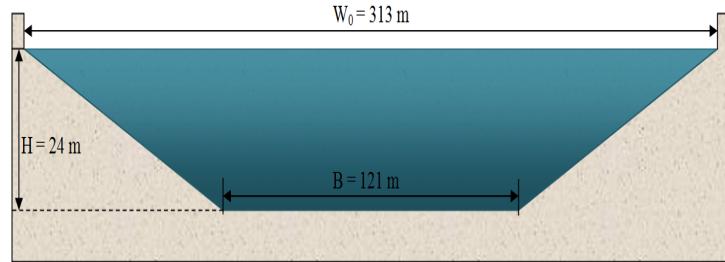


Fig. 4. Trapezoidal cross-section of the canal

The blockage factor formula is $S = A_S / A_C$, therefore it must be calculated the cross section area of the canal, A_C ,

$$A_C = \frac{(W_0 + B) \cdot H}{2} = \frac{(313 + 121) \cdot 24}{2} = 5208 \text{ m}^2.$$

and the area of the submerged amidship section with the formula $A_S = b \cdot T$. The results are listed in table 2 [1].

Table 2

Blockage factor S

Ship type	A_S [m ²]	S
Ultra Large Crude Carrier	1495	0,287
Very Large Crude Carrier	1200	0,230
Oil Tanker	390	0,075
Bulk Carrier	426,56	0,082
General Cargo Ship	156	0,030

Passenger Liner	228	0,044
Container Ship	427,5	0,082
RO – RO Ship	228,49	0,044
Tug	68,75	0,013
$A_C = 5208 \text{ m}^2$		

For this analysis of ship squat there have been considered speeds of 6, 8, 10 and 12 knots (approximately equal to 3, 4, 5 and 6 m/s). The following charts contain the results of maximum squat calculated with relation (2) and the underkeel clearance calculated with formula (9),

$$c = H - T - \delta_{\max} \text{ m} . \quad (9)$$

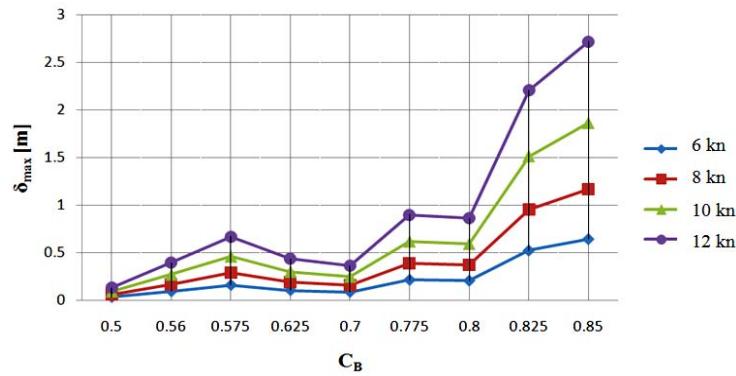


Fig. 5. Maximum ship squat against block coefficient at considered speeds

The graph in figure 5 shows that for ships with block coefficient over 0.800, the greater the speed the bigger the squat is. On the other side, vessels with C_B equal to 0.500 have small differences in squat dimensions for considered speeds.

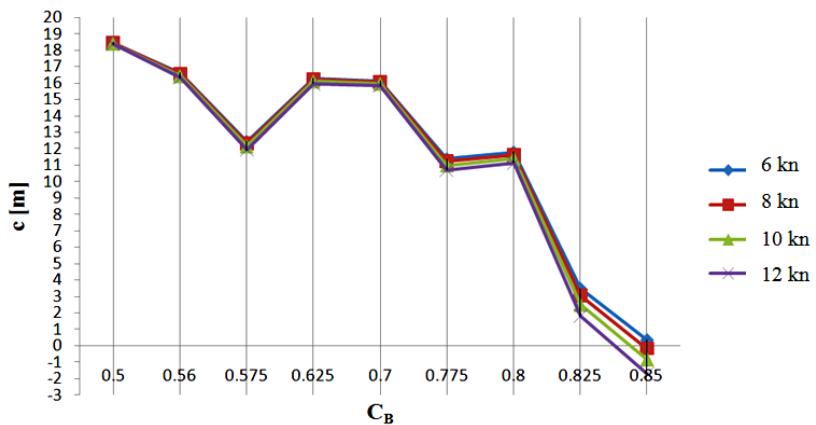


Fig. 6. Underkeel clearance against block coefficient at considered speeds

In contrast, the underkeel clearance chart (fig. 6) shows that bigger vessels, such as ULCC or VLCC, could not navigate through the canal because of their major draft and the danger of grounding. However, the ships with a block coefficient less than 0.800 are allowed to go through the canal thanks to their underkeel clearance, greater than nine meters.

4. Conclusions

Analyzing the technical data of various types of vessels from *Significant Ship* catalog and calculating their averages there were obtained the results listed in table 1, where it can be seen that large vessels like Ultra Large Crude Carrier (ULCC), Very Large Crude Carrier (VLCC), Oil Tankers or Bulk Carriers have the block coefficient greater than 0.700. In shallow waters, for these ships, squat occurs at the bow.

On the other hand, vessels such as Passenger Liners, Container Ships, RO - RO Ships and Tugs have the block coefficient less than 0.700. Thus, in shallow waters, these ships will trim to the aft. Only General Cargo Ships characterized by a block coefficient equal to 0.700 will produce a mean bodily sinkage equal to maximum squat.

When the ship's speed is 6 knots, maximum squat does not exceed 0.7 m, and the underkeel clearance is positive. However, for ULCC vessels, it is only 35 cm, a very low value, dangerous for canal navigation.

At 8 knots, maximum squat is below 1 m, except for ULCC vessels which have a 1.17 m squat and a negative underkeel clearance that doesn't allow navigation. For other ships, water depth is sufficient, even for a VLCC vessel, which has an underkeel clearance of 3 m.

At 10 knots, squat is still below 1 m for vessels smaller than ULCC and VLCC. For these ships, squat values are 1.8 m and 1.5 m, corresponding to an underkeel clearance of 0 m and 2.48 m.

At 12 knots, the maximum squat and underkeel clearance trend values are kept. ULCC and VLCC vessels don't have sufficient depth of water, while the other ships can sail smoothly.

Following the results, it has been shown that the ULCC ship type can not navigate without grounding in the considered trapezoidal cross-section canal. Other ships can transit such channel even at 12 knots speeds [1].

Maximum squat determination for shallow and/or narrow waters remains an important issue for safety of navigation. Masters should know before entering such areas, where and how much the draft will increase to take actions to combat the squat effect.

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