THE ANALYSIS OF SQUAT AND UNDERKEEL CLEARANCE FOR DIFFERENT SHIP TYPES IN A CANAL

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Abstract: *During the last decade researches in ship hydromechanics were directed to navigation problems in getting bigger ships into harbors. This issue is connected to navigation safety and correct determination of the hydrodynamic forces generated on the ship hull moving in confined waters. This paper's purpose is to explain what is squat, how is calculated and includes an analysis of squat for different ship types navigating through a canal. Following the results it was concluded that the ship squat depends on the block coefficient of the ship, its speed and the cross-sectional area of the canal.*
Key-words: *squat, underkeel clearance, block coefficient, blockage factor, ship, canal*

1. INTRODUCTION

In the past years 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.

One effect acting 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 the ship dimensions, its speed and water depth, therefore it interests port designers as much as masters and naval architects.

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:

$$p + \rho g h + \frac{1}{2}\rho V^2 = const \tag{1}$$

where: p – static pressure, ρ – density, g – gravity, h – height, V – speed [4].

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 **squat** (Figure 1).

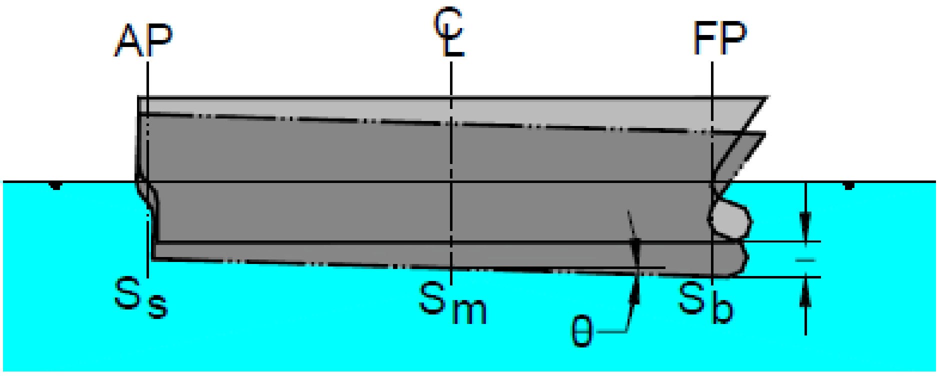


Figure 1. Ship squat (S_b –squat at bow, S_m –squat amidship, S_s –squat at stern) [3]

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 is bigger than 0.700, then maximum squat will occur at the bow. If C_B is smaller than 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. In this case, squat will consist only of mean bodily sinkage, with no trimming effects.

Squat formulas have been developed for estimating maximum ships squats 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 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, blockage factor and ship speed.

Maximum squat, δ_{max} is [1, p. 327]:

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

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 bigger then 0.700 produce squat at bow. Fine-form ships with C_B smaller then 0.700 produce squat at stern. Ships with C_B near 0.700 produce a mean bodily sinkage equal to maximum squat.

Two short-cut formulas relative to the previous equation are [1, p. 327]:

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

for open water conditions only with the ratio H/T between 1.1 and 1.4 and

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

for confined channels where the blockage factor has values between 0.100 and 0.266. An 'S' value of 0.100 appertains to a very wide channel, almost in open water conditions. An 'S' value of 0.266 appertains to a narrow channel.

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

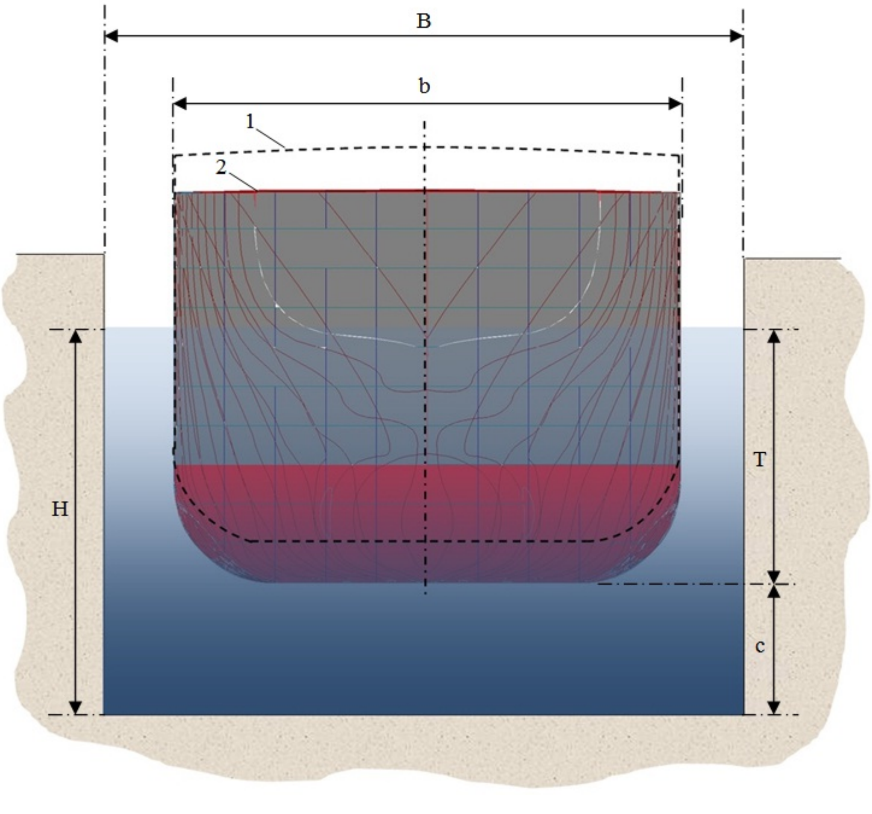
$$\delta_{max} = K \times \frac{C_B \times V_K^2}{100} \text{ m} \quad (5)$$

where,

$$K = (6 \times S) + 0.40 \quad (6).$$

The blockage factor 'S' is another factor to consider 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 2) [1, p. 327]:

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



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
Figure 2. Ship in a canal

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 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, like lenght between perpendiculars, breadth, draft, block coefficient or cruise speed, are listed in Table 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 rectangular cross section and the following dimensions *B* = 123 m, *H* = 24 m, where B represents canal breadth and H water depth (Figure 3).

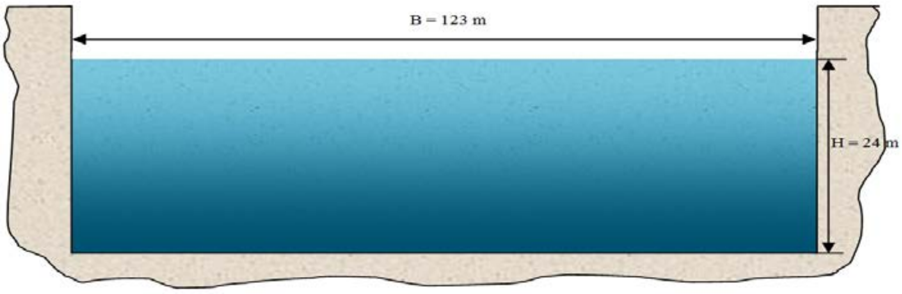


Figure 3. Rectangular cross section of the canal

The blockage factor formula is $S = \frac{A_N}{A_C}$, therefore it must be calculated the cross section area of the canal,

$$A_C = B \times H = 123 \times 24 = 2952 \text{ m}^2$$

and the area of the submerged amidship section with the formula $A_N = b \times T$. The results are listed in Table 2.

Tabel 2. Blockage factor 'S'

Ship type	A_N [m^2]	S
Ultra Large Crude Carrier	1495	0,506
Very Large Crude Carrier	1200	0,407
Oil Tanker	390	0,132
Bulk Carrier	426,56	0,144
General Cargo Ship	156	0,053
Passenger Liner	228	0,077
Container Ship	427,5	0,145
RO – RO Ship	228,49	0,077
Tug	68,75	0,023
		A_C = 2952 m^2

For this analysis of ship squat there have been considered speeds of 6, 8, 10 and 12 knots. The following charts contain the results of maximum squat calculated with formula (2) and the underkeel clearance calculated with formula (9):

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

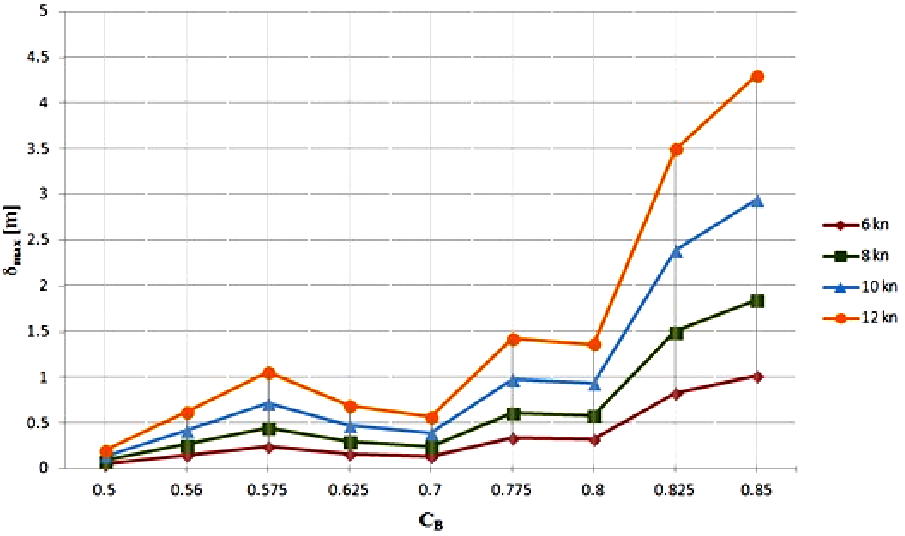


Figure 4. Maximum ship squat against block coefficient at considered speeds

The graph in Figure 4 shows that for ships with block coefficient 0.850 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.

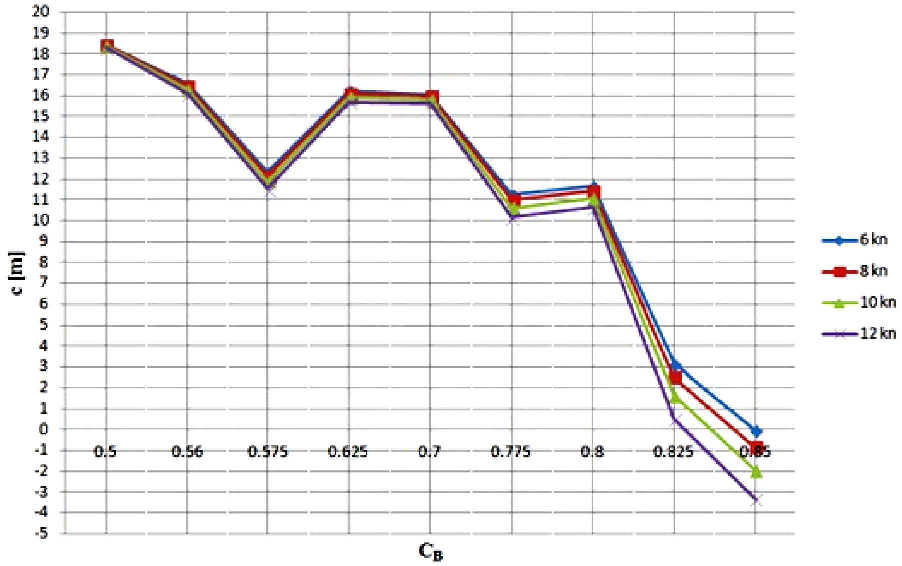


Figure 5. Underkeel clearance against block coefficient at considered speeds

In contrast, the underkeel clearance chart (Figure 5) shows that bigger vessels like ULCC or VLCC could not navigate through the canal because of their major drafts and the danger of grounding. However, the ships with block coefficient smaller 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 ULCC, VLCC, Oil Tankers or Bulk Carriers have the fineness block coefficient greater than 0.700. In shallow waters, for these ships, squat will occur at the bow. On the other hand, vessels such as Passenger Liners, Container Ships, RO-RO Ships and Tugs have the fineness 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.

Maximum squat when the ship's speed is 6 knots is measured in centimeters and can be neglected, ranging from 5 to 100 centimeters. Underkeel clearance is big enough for all ship types, except ULCC vessels due to their high draft.

For 8 knots, ship squat increases by 82 % compared to 6 knots values. Underkeel clearance ranges from -0.8 to 18 meters, so ULCC and VLCC vessels can not navigate with this speed in the considered canal. At 10 knots, maximum squat falls bellow 1 meter, except ULCC and VLCC ship types.

If the speed is 12 knots, maximum squat increses by 46 % compared to 10 knots values and by 322 % compared with 6 knots results. In this case the larger ships' underkeel clearance do not allow these vessels to transit the canal.

To summarize, ULCC and VLCC vessels can not navigate through the considered canal, regardless their speed. Even if the underkeel clearance is positive at low speeds, ship handling can be lost.

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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