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The influence of ship size and propeller parameters on engine workload during ship motion on regular wave

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Key words: ship motions on a regular wave, vertical relative motion, propeller emergence, decrease in torque value of a propeller

Abstract

While the ship is sailing on waves the relative motions occur which result in propeller emergence, and as a consequence – propeller thrust reduction which results in a decrease in the ship's speed. Propeller emergence is also accompanied by the decrease in torque values, with which the propeller affects the marine engine. The article presents a simplified method for calculating the decrease in torque of the propeller during ship motion on a regular wave together with the obtained results for various ship sizes and propellers.

Introduction

As direct result of a ship sailing on waves, ship motions can be observed, occurring in continuous way, like the wave inducing them. Other dangerous phenomena resulting from ship motions are also present, such as e.g. accelerations or relative motions, which also occur in a continuous way, as well as other phenomena occurring sporadically, for example: deck wetness, slamming or emergence of a propeller. The latter phenomena result among other from the ship's relative motions, and in this case frequency of their occurrence within one hour or per 100 waves is investigated. Emergence of a propeller is a dangerous phenomenon for the whole propulsion system: it is responsible for the propeller thrust reduction which results in effect in the reduction of the ship's speed on waves (the reduction of the ship's speed on waves is caused by other factors as well) [1]. When determining the value of the torque value it is not enough to know the frequency of propeller emergence e.g. per hour but it is also necessary to establish the value and duration of propeller emergence on a given navigation route.

Propeller thrust reduction while sailing on waves has been presented in numerous papers, e.g. [2], where the wave action on the stream wake velocity has been considered, however, without accounting for propeller emergence, [3] – thrust reduction with propeller emergence present, [4] – thrust reduction with emergence of the tunnel bow thruster. Papers [5, 6] discuss also the approximate effect of the propeller emergence on the decrease of a ship's speed. None of these works, however, provides information on the changes in torque value with a ship sailing on waves.

The articles [7, 8] present an algorithm and calculation results for propeller torque decrease on a ship sailing on regular and irregular wave.

The article presents an approximate method and calculation results of propeller emergence and torque reduction together with its duration for ship varying in size and different propellers. The method presented here can be useful for research into propelling system of a ship sailing in real weather conditions already at an early ship design stage.

Relative ship motion and propeller emergence on regular wave

Using the commonly applied linear theory of ship motions [9], vertical, absolute displacement of a ship resulting from its motions on a regular wave, equals:

$$S_{zP}(t) = Z(t) + y_P \Phi(t) - x_P \Theta(t) \qquad (1)$$

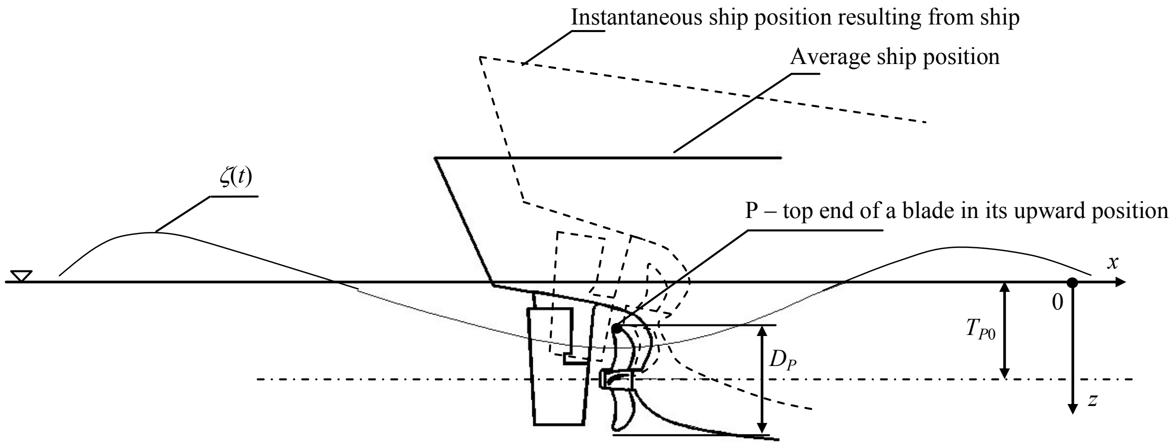

Fig. 1. The influence of a relative motion on the propeller emergence

while relative:

$$R_{zP}(t) = S_{zP}(t) - \zeta(t) \tag{2}$$

where:

$Z(t)$, $\Phi(t)$, $\Theta(t)$ – ship motions on a regular wave: heaving, rolling, pitching, respectively;

x_P, y_P – coordinates of a ship bound point P, for which the vertical relative motion is calculated, in this case it is a point situated on the top of a propeller blade in its upward position (Fig. 1).

On the basis of relative motion, the equation (2) and the propeller position (to be exact: the position of a top end of a propeller blade – point P, Fig. 1) are possible to calculate when, at what height and how long propeller will emerge. The height of propeller emergence h_{ws} is when:

$$h_{ws}(t) = R_{zP}(t) - T_{zS}(t) > 0 \tag{3}$$

where T_{zS} is the draught of the top end of a propeller blade in its upward position:

$$T_{zS} = T_{P0} - 0.5D_P \tag{4}$$

T_{P0} – draught of propeller shaft (Fig. 1),

D_P – diameter of a propeller.

Propeller emergence and torque reduction

Propeller emergence may occur during a vertical relative motion of a ship on wave (Fig. 1). An example of such emergence in time has been presented in figure 2. The figure shows also the number of a slow rotations propeller while it is emerging from water.

While the propeller is emerging from water, some parts of its blades will rotate in the air – hence the lift force of such blades, and consequently their thrust force and torque will be differ in value from the blades remaining in water, therefore practically zero.

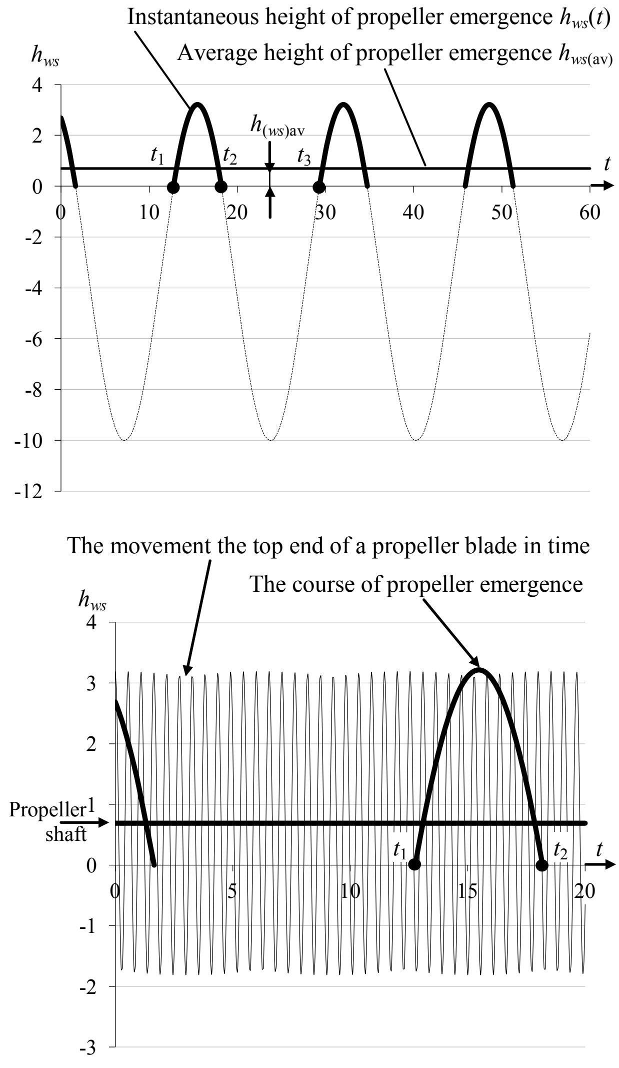

Fig. 2. An example of propeller emergence and the movement of the top end of propeller blade in time

On the basis of figure 2, a typical slow rotations propeller can be expected to fully rotate a dozen or even up to twenty times while emerging from water. Hence, it has been assumed that the surface of the propeller blades emerging from water will be proportional to the height of propeller emergence $h_{ws}(t)$.

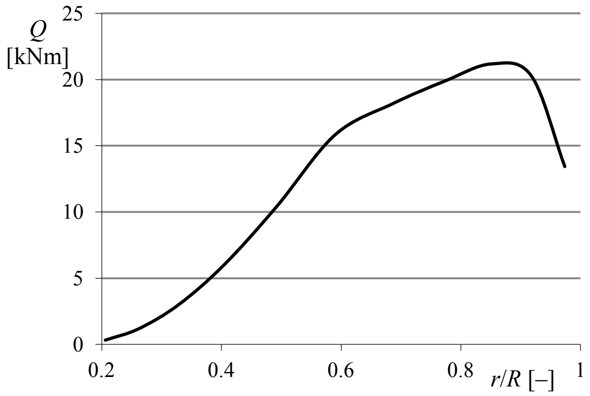

Fig. 3. Torque distribution on a blade of a propeller fully submerged in water in the relative radius function r/R

An algorithm for calculating thrust force and torque on a section of a propeller blade in various propeller angle positions has been presented in [10], which enables us to calculate torque distribution along propeller radius (Fig. 3). This algorithm has been used for approximate torque calculations on a propeller partially above water.

During propeller emergence, the basic thrust forces and torque equal zero on propeller blade parts emerging from water (Fig. 4).

With propeller rotation (Fig. 4), the surface of a propeller blade above water will be changing depending on the height of emergence.

Calculations of the propeller thrust reduction – an example

Calculations of the propeller thrust decrease have been performed for:

- 5 ships (various displacement) with a 4-blade propeller;
- 2 ships (various displacement) with a 5-blade propeller.

Basic parameters for the analysed ships are given in table 1. Full geometry of ship hull (to calculate ship relative motions on a regular wave) and full geometry of propeller (to calculate hydrodynamic characteristics and torque distribution on a propeller blade) was available.

Calculations of torque distribution on propeller fully submerged in water (Fig. 5) have been

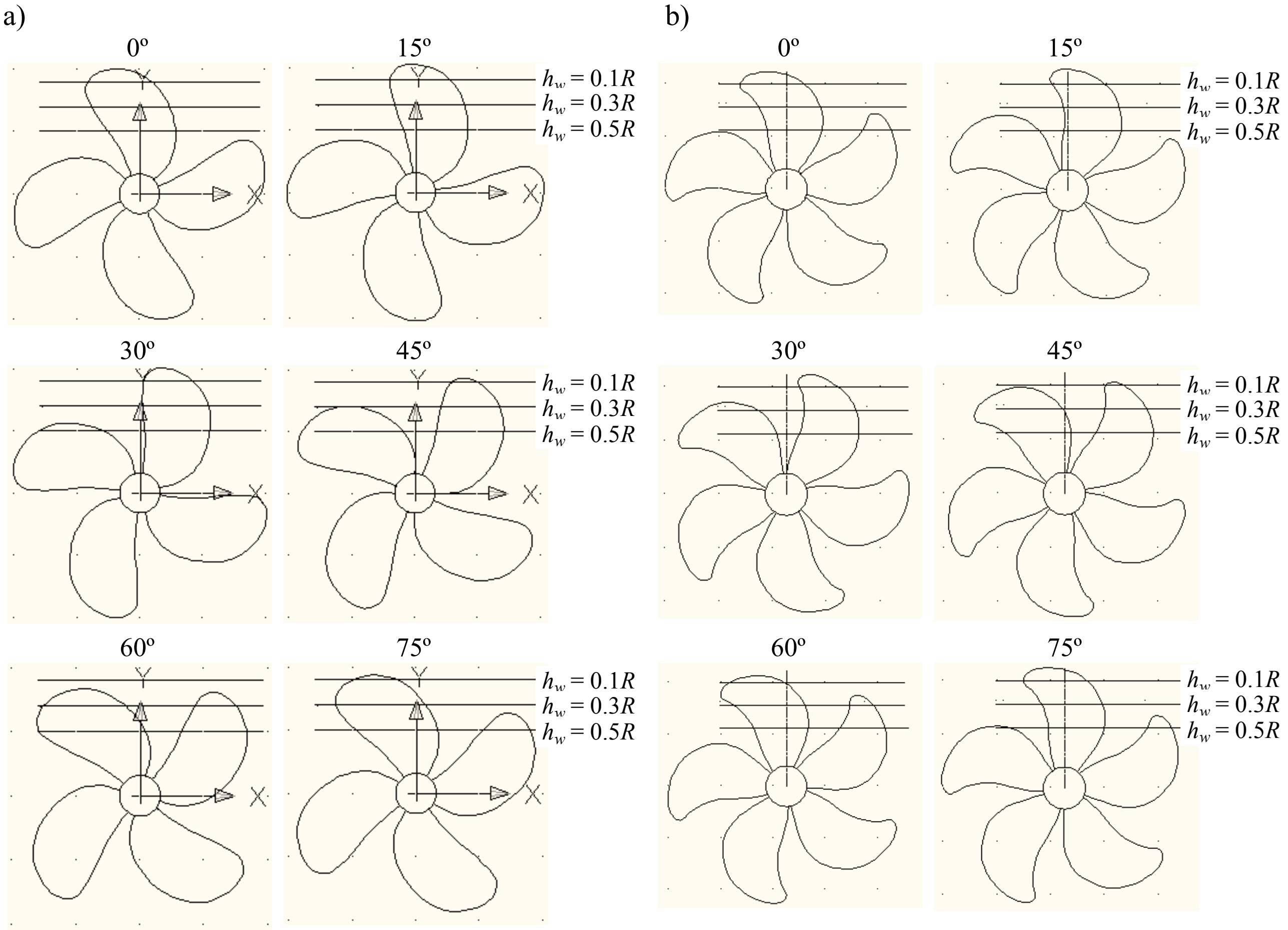

Fig. 4. Changes in propeller surface emerging from water during rotating propeller emergence (propeller emergence h_w is related to propeller radius R); a) 4-blade propeller, b) 5-blade propeller

performed for propellers mounted on analysed ships (Table 1). Torque decrease for the whole propeller depending on relative (h_w/D_p) propeller blade emergence above water (Fig. 6) has been calculated on the basis of torque distribution on a propeller blade and blade surface above water (Fig. 4).

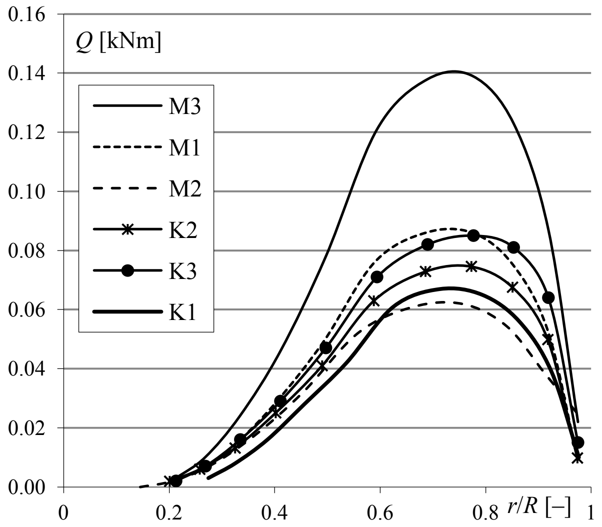

Fig. 5. Torque distribution on a propeller blade fully submerged in water for propellers on ships (Table 1)

Propeller emergence above water and torque decrease result from vertical relative motion (3), depending on wave parameters ζ_A, ω, μ, ship velocity V and course ψ, as well as propeller diameter and submersion in water (4). Figure 7 shows instantaneous changes in propeller torque in the time function during propeller emergence on a regular wave, as well as mean value of torque decrease. The influence of wave height and direction relative to the ship on mean torque decrease for such ship has been presented in figure 8.

Figures 9–13 show examples of calculations of the mean torque decrease at given wave heights for ships varying in size (Table 1). The influence of ship size (more precisely its seakeeping) on torque decrease on a regular wave can easily be seen here.

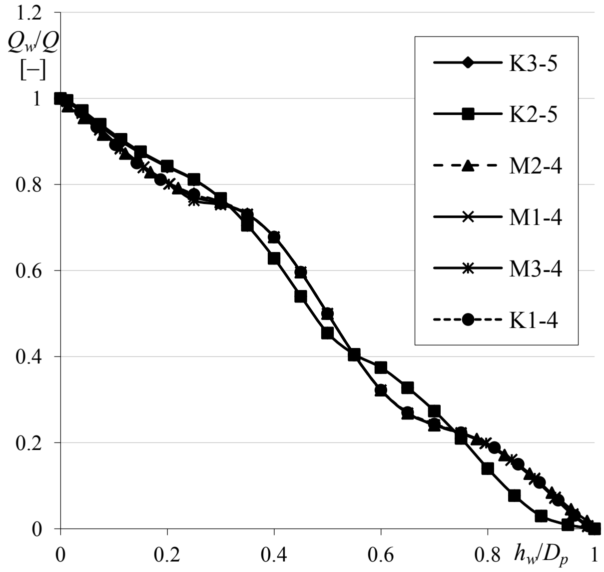

Fig. 6. Relative torque decrease for propellers emerging above water in ships given in table 1, depending on relative height above water h_w/D_p (Q_w – torque on a propeller emerging from water)

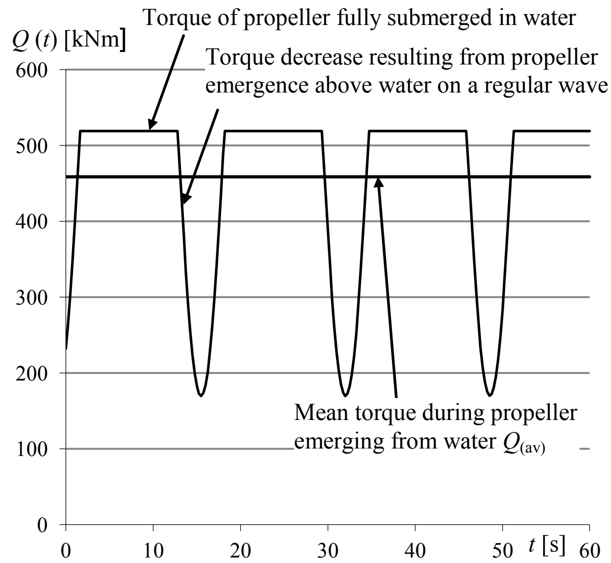

Fig. 7. Instantaneous torque decrease during propeller emergence from water on regular wave for M1 ship (frequency $\omega = 0.6$ 1/s, amplitude $\zeta_A = 6$ m, wave direction $\beta_w = 0°$ relative to ship ($V = 6$ m/s))

Table 1. Ship and propeller parameters

Parameter	K1	K2	K3	M1	M2	M3	M5
Length between perpendiculars L_{PP} [m]	140.14	171.94	210.20	138.0	189.9	180.0	160.0
Ship breadth B [m]	22.3	25.3	32.24	23.0	25.3	32.2	25.3
Draught T [m]	8.25	9.85	10.5	8.5	10.6	12.0	10.0
Displacement ∇ [m^3]	17290	29900	47250	21441	40831	56396	27202
Ship speed V [m/s]	9.31	10.08	11.37	7.33	7.51	8.69	10.08
Propeller diameter D_P [m]	5.196	6.15	7.42	5.0	5.8	6.2	6.2
Number of blades z [–]	4	5	5	4	4	4	4
Propeller rotational speed n [1/s]	2.33	1.82	1.73	1.85	2.03	1.64	1.87
Distance between the propeller and midship section [m]	–67.07	–82.57	–101.1	–66.4	–89.5	–76.4	–76.4

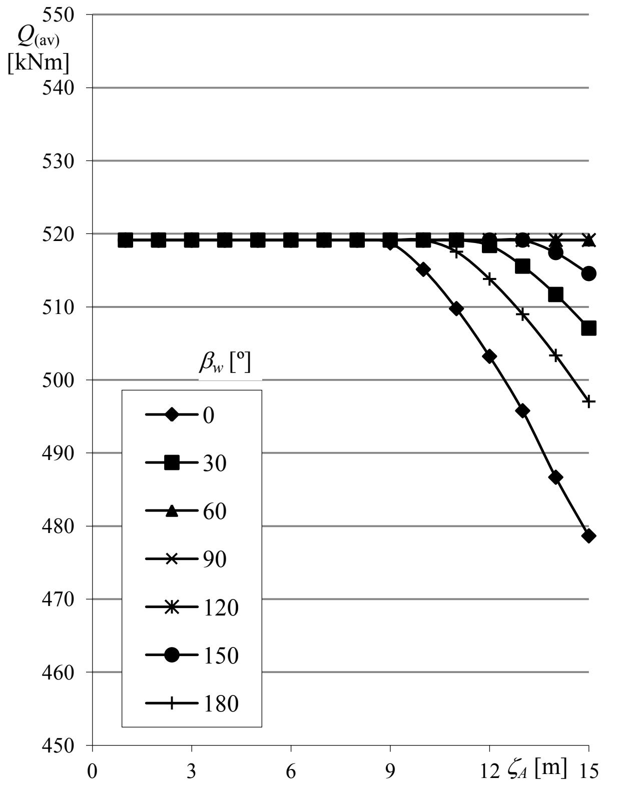

Fig. 8. Instantaneous torque decrease during propeller emergence from water on regular wave $\omega = 0.4$ 1/s various wave amplitudes ζ_A and wave directions β_w relative to ship ($V = 6$ m/s) for M1 ship

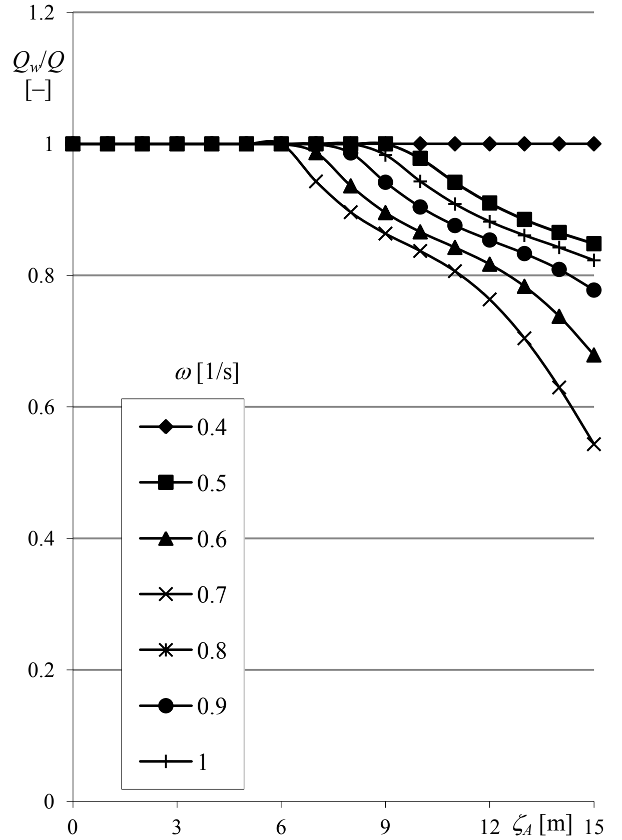

Fig. 10. Relative decrease in torque of a 4-blade propeller (M3 ship, $V = 7.2$ m/s, $\beta_w = 0º$) for various heights of regular waves

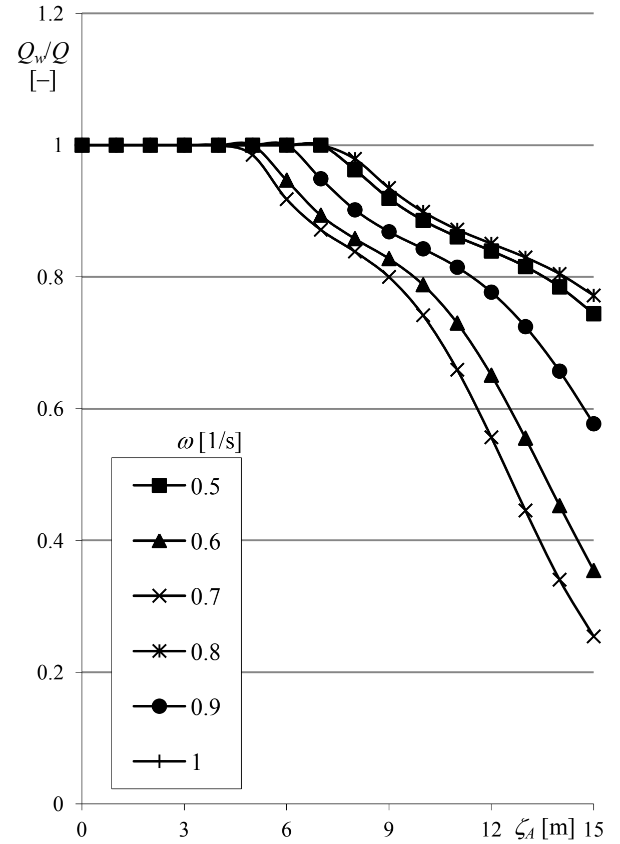

Fig. 9. Relative decrease in torque of a 4-blade propeller (M2 ship, $V = 7.2$ m/s, $\beta_w = 0º$) for various heights of regular waves

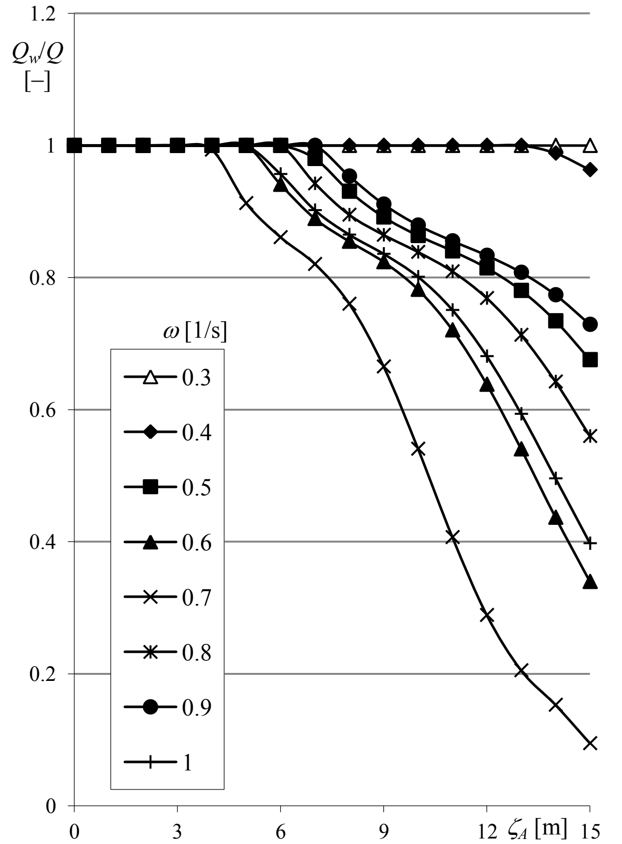

Fig. 11. Relative decrease in torque of a 4-blade propeller (K2 ship, $V = 7.2$ m/s, $\beta_w = 0º$) for various heights of regular waves

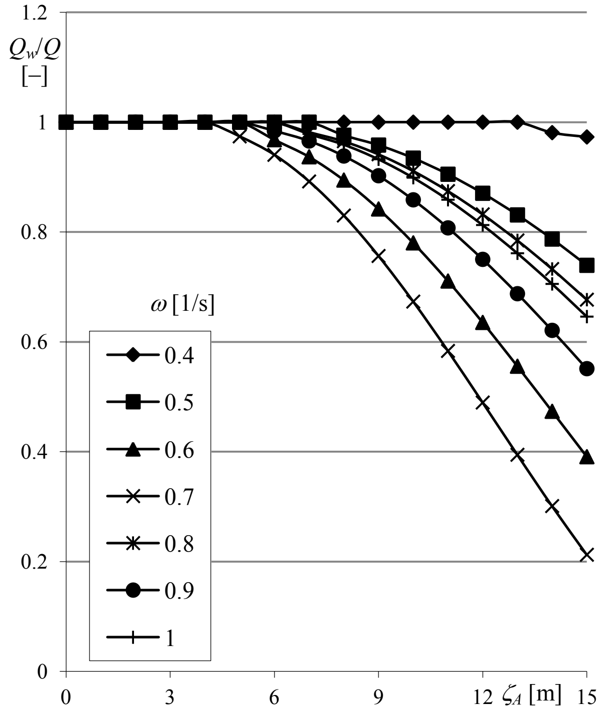

Fig. 12. Relative decrease in torque of a 5-blade propeller (K2 ship, V = 7.2 m/s, β_w = 0º) for various heights of regular waves

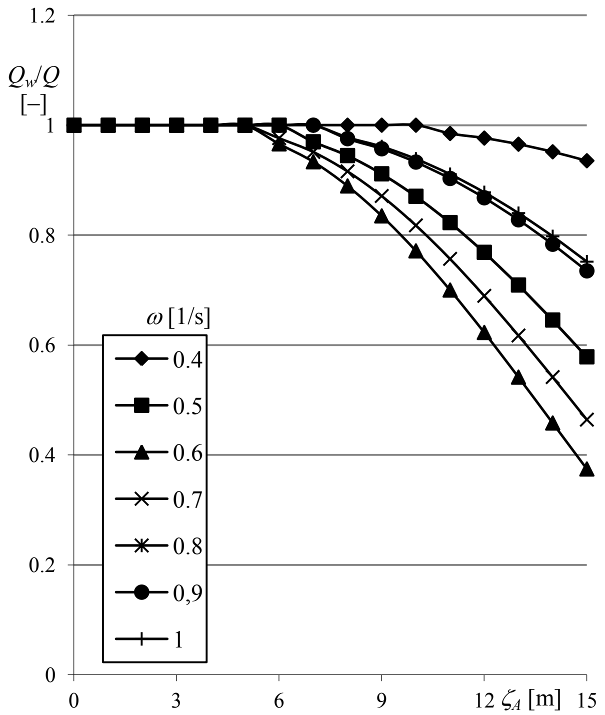

Fig. 13. Relative decrease in torque of a 5-blade propeller (K3 ship, V = 7.2 m/s, β_w = 0º) for various heights of regular waves

Conclusions

Calculations performed for a propeller emergence on a regular wave in course of time indicate that for one cycle of a propeller emergence, especially in the case of a following wave, such propeller can rotate fully over a dozen times with parts of the propeller blades emerging from water. A decrease in torque on various ship (Table 1) propellers emerging from water has been calculated with the aid of a computer programme using a simplified algorithm. Calculations performed lead us to make the following conclusions:

– geometry of a propeller and number of blades exert only a minimum influence on relative torque dependent on relative propeller emergence above water (Fig. 6);
– relative motions of a ship play decisive role on relative (or absolute) torque decrease for a ship sailing on a regular wave – it means that mainly ship sailing properties determine the work of a propelling system during ship motions on rough sea;
– sailing properties depend on ship geometry and size (dimensions), which can be seen on presented examples of calculations of torque decrease on emerging propeller (Fig. 9–13);
– calculations obtained here will be used further in research on the work of the ship propelling system while sailing in real weather conditions on a given shipping route.

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