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Design guidelines for predicting wave resistance of ro-ro ferries at the initial designing stage

Wskazówki projektowe do prognozowania dodatkowego oporu na fali promów ro-ro na wstępnym etapie projektowania

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Key words: added wave resistance, ro-ro ferries, design guidelines, regression, design parameters

Abstract
Design guidelines are presented for predicting added wave resistance useful at the early stage of designing ro-ro ferries. The guidelines were prepared on the basis of regression analysis of model values of added wave resistance. The model values were calculated by means of 448 ferry shape variants assuming conventional waving parameters and ferry movement parameters. Such approach permitted the replacement of a complicated numerical model with a simple regression model based on basic design parameters.

Słowa kluczowe: dodatkowy opór na fali, prom ro-ro, wskazówki projektowe, regresja, parametry projektowe

Abstrakt
W pracy przedstawiono wskazówki projektowe dotyczące prognozowania dodatkowego oporu na fali przydatne na wstępnym etapie projektowania promów ro-ro. Wskazówki opracowano w oparciu o analizę regresji wartości wzorcowych dodatkowego oporu na fali. Wartości wzorcowe obliczono za pomocą dokładnych metod numerycznych dla 448 wariantów kształtu promu, przyjmując umowne parametry falowania oraz parametry ruchu promu. Takie podejście pozwoliło zastąpić skomplikowany model numeryczny prostym modelem regresyjnym bazującym na podstawowych parametrach projektowych.

Introduction

In the process of ship design naval architects seek solutions for fulfilling both economical criteria and technical limitations. Economical criteria consist of a number of requirements set by the ship -owner, among which there are desired internal capacity and operational speed, which significantly affect the profitability of the vessel's operation on a given shipping line. Whether a ship reaches the assumed operational speed depends *inter alia* on the parameters and work conditions of the propulsion system and the values of total hull resistance. One factor of this resistance is added wave resistance connected with vessel's sailing in stormy conditions. It can constitute even up to 30–50% of the vessel's total resistance [1, 2]. Predicting the vessel's added wave resistance is an essential challenge to naval architects due to the economical aspect of propulsion system's parameter selection, fuel consumption and estimation of voyage time.

Wave added resistance is significantly affected by the hull's shape and dimension, which is why it should be modelled as early as the stage of initial design. An essential feature of the vessel's initial designing is that the hull's exact shape is presented by means of 'main dimensions' and certain general coefficients characterising hull shape, e.g. block coefficient. This modest amount of information does not permit using known methods of determining added wave resistance based on the classical linear or non-linear theory. Another problem is that the selection of improper values of main dimensions and block coefficients may cause large wave resistance, as the change of any ship's dimension after construction is economically unprofitable.

This study was aimed at working out design guidelines permitting the reduction of the ro-ro ferry's added wave resistance at the initial stage of its designing.

The method

The aim of research was achieved by an analysis of results obtained from numerical calculations of vessel's motions in waves. The research methods consisted of the following stages:

1) preparing a list of ferries in a wide scope of shapes and sizes;
2) simplification and idealisation of connections in the physical model:
   a) replacing the hull's real shape with shape parameters;
   b) assuming a conventional operational scenario in which, among other things, real wave conditions were replaced with statistical conditions;
3) preparing a mathematical symbolic model of the phenomenon or feature;
4) using a numerical calculation model;
5) selection of functions approximating the set of discrete results of numerical model;
6) verification and assessment of determined modelling methods;

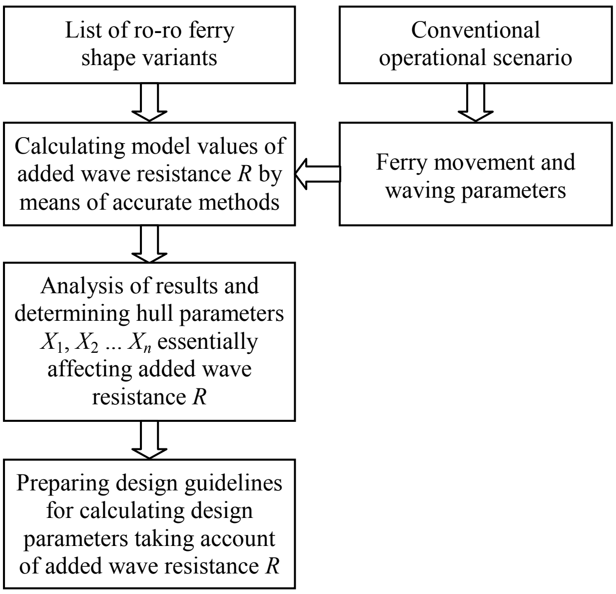

Fig. 1. Algorithm presenting the research method, where: X_1, X_2 … X_n – vessel's design parameters, R – added wave resistance

Rys. 1. Algorytm przedstawiający metodę badań, gdzie: X_1, X_2 … X_n – parametry projektowe statku, R – dodatkowy opór na fali

7) determining the applicability scope and restrictions of particular methods.

A detailed research algorithm has been presented in figure 1.

Modelling added wave resistance

List of ro-ro ferry hull shape variants

For preparing a list of ro-ro ferry hull shape variants, guidelines were used contained in the report [3]. A list of 448 variants was made in the research, prepared on the basis of the following ranges of the ferry's design parameters:

- *LBd* (*L* – waterplane length, *B* – waterplane breadth, *d* – vessel draft) = 19 000, 28 000, 37 000, 46 000 m^3;
- *L*/*B* = 5.8, 6.6, 7.4, 8.2;
- *B*/*d* = 3, 3.5, 4, 4.5,

and a set of 7 ro-ro ferry shape variants (Table 1).

Table 1. Ro-ro ferry shape variants, where: CB – block coefficient, CM – frame section coefficient, CB(L) – longitudinal block coefficient, CB(V) – vertical prismatic coefficient, CWL – waterplane block coefficient, XF – distance of waterline's geometric centre from after perpendicular, XB – distance of buoyancy centre from after perpendicular, Lpp – vessel's length between perpendiculars

Tabela 1. Warianty kształtu promu ro-ro, gdzie: CB – współczynnik pełnotliwości podwodzia, CM – współczynnik pełnotliwości owręża, CB(L) – wzdłużny współczynnik pełnotliwości podwodzia, CB(V) – pionowy współczynnik pełnotliwości podwodzia, CWL – współczynnik pełnotliwości wodnicy, XF – odległość środka geometrycznego wodnicy od pionu rufowego, XB – odległość środka wyporu od pionu rufowego, Lpp – długość statku pomiędzy pionami

CB [–]	CM [–]	CB(L) [–]	CB(V) [–]	CWL [–]	XF/Lpp [%]	XB/Lpp [%]
0.609	0.954	0.639	0.759	0.803	46.00	47.61
0.614	0.963	0.638	0.743	0.826	45.34	48.00
0.618	0.955	0.647	0.762	0.811	45.64	47.24
0.585	0.971	0.642	0.734	0.797	43.59	47.16
0.629	0.958	0.657	0.743	0.847	45.04	46.62
0.614	0.984	0.645	0.786	0.781	45.44	48.11
0.642	0.977	0.657	0.777	0.826	44.44	48.79

Model values of added wave resistance

For calculating model values of wave resistance the Gerritsma-Beukelman method was applied [1, 4]. This method is restricted to, first of all, the determination of resistance increment on the opposite wave. Of methods used for determining added wave resistance, the Gerritsma-Beukelman method is the simplest and yields results most consistent with the experiment. It is based on comparing energy discharged from a rolling vessel in the form of back wash with the work performed by the added resistance force [5]. The Gerritsma-Beukelman method permits a fairly accurate determination of added resistance for vessels of any shape, although the accuracy of this method is lower for vessels with low values of block coefficient [6].

Calculations were made by means of the SEAWAY program. SEAWAY accuracy tests shown in [4, 7] point to a fairly high calculation accuracy.

Calculations of added wave resistance were made on "statistical wave" with a conventional operational scenario assumed:

1) the ferry is proceeding at a progressive speed $v = 10$ m/s in head waves,
2) wave spectrum conforms with JONSWAP,
3) significant wave height $H_S = 1–6$ m at one metre interval,
4) wave reaches characteristic period T, for which there is a maximum value of added wave resistance.

The outcome of this part of research was a set of 2568 model values of added wave resistance calculated for the assumed ferry shapes and accepted wave parameters.

Hull parameters essentially affecting added vessel resistance in waves

On the basis of statistical analysis of the set of model values relationship (1) was formulated permitting the prediction of added resistance in waves R:

$$R = (114.74 + 0.76 \cdot B - 117.34 \cdot C_M) \cdot H_S^2 \quad (1)$$

where: R – significant value of added wave resistance [kN], B – waterplane breadth [m], C_M – midship section coefficient [–], H_S – wave significant height [m].

Relation (1) is characterised by:

1) high Pearson correlation coefficient $R = 0.99$,
2) low value of standard deviation $\sigma = 32$ kN,

which proves high interrelationship of the above variables and high approximation accuracy. Figures 2–5 compare the model values calculated by means of accurate numerical methods with values approximated by equation (1). Equation (1) is characterised by trends in conformance with [5, 6, 8].

As the values of coefficient C_M are not always known in the initial stage of designing, relation (1) was simplified to this formula (2):

$$R = 0.81 \cdot B \cdot H_S^2 \quad (2)$$

Relation (2) is characterised by:

1) high Pearson correlation coefficient $R = 0.98$,
2) standard deviation $\sigma = 41$ kN,

which also confirms a fairly high approximation accuracy.

Figure 6 presents a comparison of model values with values calculated by means of equation (2). It follows from the graph that relation (2) is characterised by proper trend.

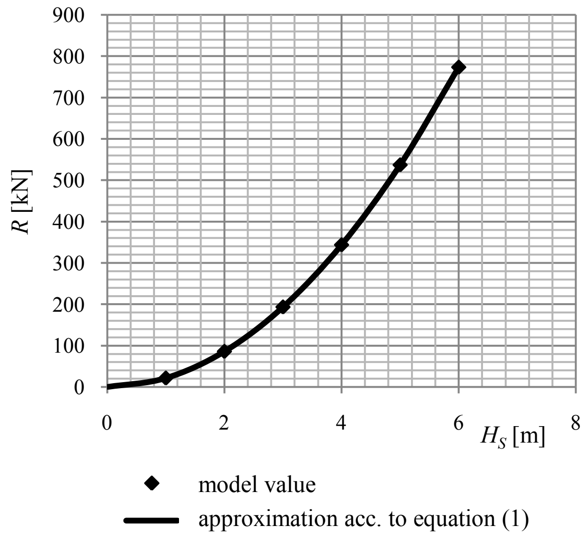

Fig. 2. Significant values of added resistance in bow waves R calculated by means of accurate numerical methods and equation (1), H_S = var, $CM = 0.97$, $B = 27.14$ m, wave spectrum – JONSWAP, vessel speed $v = 10$ m/s

Rys. 2. Wartości znaczące dodatkowego oporu na fali dziobowej R obliczone za pomocą dokładnych metod numerycznych oraz równania (1), H_S = var, $CM = 0.97$, $B = 27.14$ m, spectrum falowania JONSWAP, prędkość statku $v = 10$ m/s

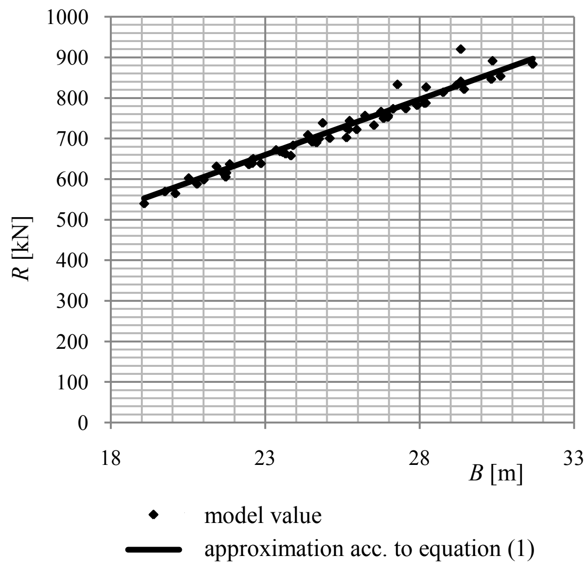

Fig. 3. Significant values of added resistance in bow waves R calculated by means of accurate numerical methods and equation (1), B = var, $CM = 0.97$, $H_S = 6$ m, wave spectrum – JONSWAP, vessel speed $v = 10$ m/s

Rys. 3. Wartości znaczące dodatkowego oporu na fali dziobowej R obliczone za pomocą dokładnych metod numerycznych oraz równania (1), B = var, $CM = 0.97$, $H_S = 6$ m, spectrum falowania JONSWAP, prędkość statku $v = 10$ m/s

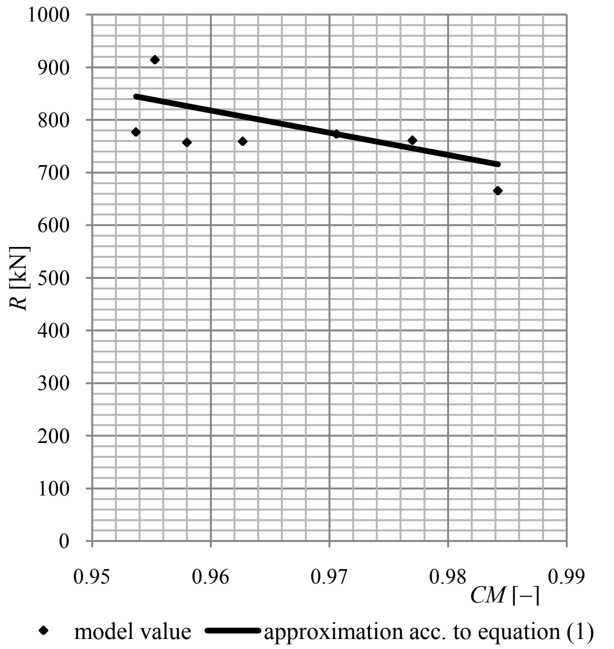

Fig. 4. Significant values of added resistance in bow waves R calculated by means of accurate numerical methods and equation (1), CM = var, B = 27.1 m, H_S = 6 m, wave spectrum – JONSWAP, vessel speed v = 10 m/s

Rys. 4. Wartości znaczące dodatkowego oporu na fali dziobowej R obliczone za pomocą dokładnych metod numerycznych oraz równania (1), CM = var, B = 27.1 m, H_S = 6 m, spectrum falowania JONSWAP, prędkość statku v = 10 m/s

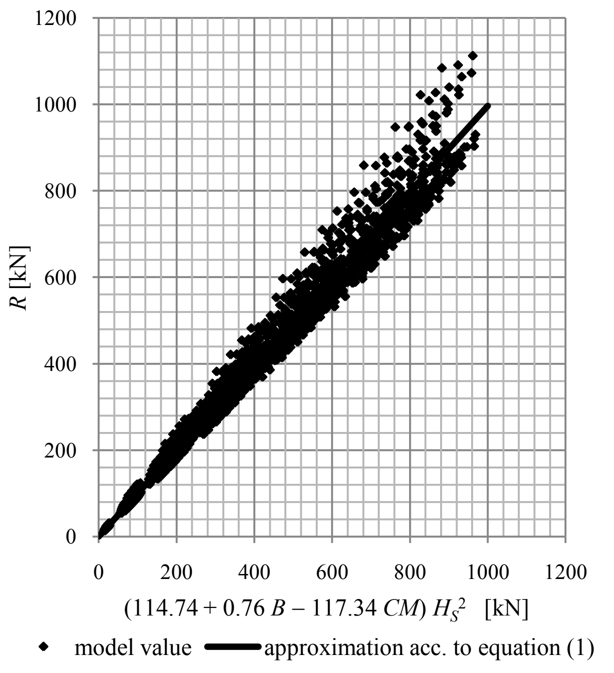

Fig. 5. Significant values of added resistance in bow waves R calculated by means of accurate numerical methods and equation (1), B = var, CM = var, H_S = var, wave spectrum – JONSWAP, vessel speed v = 10 m/s

Rys. 5. Wartości znaczące dodatkowego oporu na fali dziobowej R obliczone za pomocą dokładnych metod numerycznych oraz równania (1), B = var, CM = var, H_S = var, spectrum falowania JONSWAP, prędkość statku v = 10 m/s

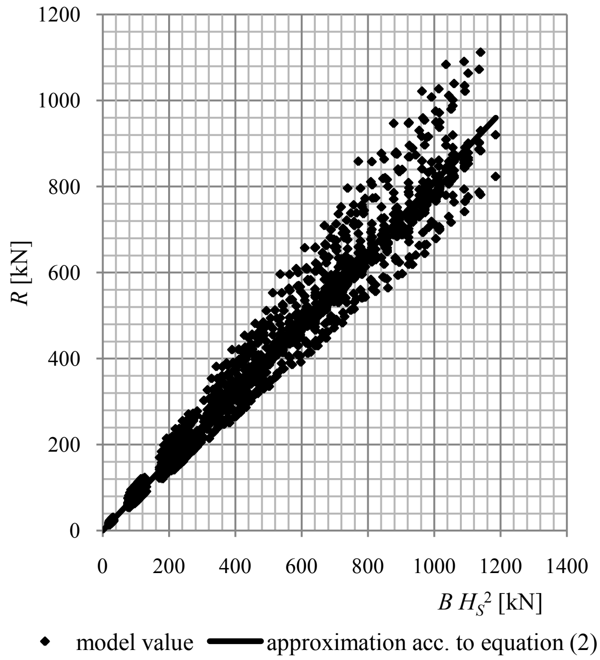

Fig. 6. Significant values of added resistance on bow wave R calculated by means of accurate numerical methods and equation (2), B = var, H_S = var, wave spectrum – JONSWAP, vessel speed v = 10 m/s

Rys. 6. Wartości znaczące dodatkowego oporu na fali dziobowej R obliczone za pomocą dokładnych metod numerycznych oraz równania (2), B = var, H_S = var, spectrum falowania JONSWAP, prędkość statku v = 10 m/s

Conclusions

Analytical tools for predicting added wave resistance are presented. They can be used as design guidelines for initial designing of ro-ro ferries. The relations worked out are characterised by fairly high accuracy in relation to the model values and proper trends.

The approach proposed enables the replacement of a complicated numerical model with a simple linear model characterised by high accuracy within the assumed restrictions.

The model values, on the basis of which approximations (1) and (2) were prepared, were calculated with certain assumptions described in the article. Therefore, approximations (1) and (2) have limitations resulting from the assumptions made and they concern:

- limitations of Gerritsma-Beukelman method,
- assumed waves spectrum JONSWAP,
- parameters and uprush directions of the statistical wave: bow wave of significant height H_S = 1–6 m and characteristic period causing the emergence of maximum values R,
- vessel speed v = 10 m/s,
- hull parameters and block coefficients conforming to assumptions, in particular B = 19–33 m, CM = 0.954–0.985.

References

1. ARRIBAS F. PÉREZ: Some methods to obtain the added resistance of a ship advancing in waves. Ocean Engineering 34, 2007, 946–955.
2. PAYNE S., DALLINGA R.P., GAILLARDE G.: Queen Mary 2 seakeeping assessment: the owner's requirements, the design verification and operational experience. Cruise & Ferry, 2005.
3. Sea Highways Ltd: Future trends in the design of ro-ro and ro-pax vessels operating in the southern Baltic. BALTIC GATEWAY Report, 2005.
4. GERRITSMA J., BEUKELMAN W.: Analysis of the Resistance Increase in Waves of a Fast Cargo-ship. International Shipbuilding Progress, 1972, 19(217).
5. DUDZIAK J.: Teoria okrętu. FPPOiGM, Gdańsk 2008.
6. NABERGOJ R., JASNA PRPIFI-ORŠIFI: A comparison of different methods for added resistance prediction. 22nd IWWWFB, Plitvice, Croatia 2007.
7. JOURNÉE J.M.J.: Verification and Validation of Ship Motions Program SEAWAY. Report 1213a, Delft University of Technology, The Netherlands 2001.
8. SCHNEEKLUTH H., BERTRAM V.: Ship Design for Efficiency and Economy. Butterworth-Heinemann, 1998.

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