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Modeling of ship seakeeping properties by descriptive variables at the preliminary design stage

Modelowanie właściwości morskich statku za pomocą zmiennych opisowych na etapie wstępnego projektowania

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Abstract
The article describes a method of ship seakeeping characteristics modeling that are represented by descriptive variables. The research aimed at checking the possibility of using artificial neural networks for building models based on descriptive values of seakeeping properties and finally, developing design guidelines. The article reports an experiment of modeling a situation of shipping green water by a container vessel. The experiment verifies the theoretically adopted method.

Słowa kluczowe: wstępne projektowanie statku, właściwości morskie, zalewanie pokładu, kontenerowiec, sztuczne sieci neuronowe

Abstrakt
W artykule przedstawiono metodę modelowania właściwości morskich przedstawionych za pomocą zmiennych opisowych. Celem badań było sprawdzenie możliwości wykorzystania sztucznych sieci neuronowych do budowania modeli bazujących na wartościach opisowych właściwości morskich i na tej podstawie opracowywanie wskazówek projektowych. W artykule przeprowadzono przykładowy eksperyment numeryczny modelowania zalewania pokładu kontenerowca, weryfikujący wstępnie przyjętą metodę.

Modeling seakeeping properties by descriptive variables

The term seakeeping properties is defined by effects of waves acting on the ship. These effects include ship motions and their secondary effects such as accelerations, shipping water (green water), slamming, etc. The need to take these phenomena into account is of increasing importance in ship design and operation.

Various methods are available for determining seakeeping properties of a ship:

- full-scale tests of real object (ship),
- testing of ship's hull model in a test basin,
- analytical (numerical) methods generally based on planar flow and linear theory of motions.

The first method is the most reliable but costly, so it is very rarely used, and then, mainly to verify computational methods. For this reason tests on a real vessel are performed on few ships, mostly in limited operational and environmental conditions.

Various properties of the ship can be represented descriptively. For example, in the study [1] linguistic variables are used for the description of ship's behavior in calm water. Another study [2] makes use of fuzzy logic to determine the centre of gravity of a ro-ro ferry.

Similarly, seakeeping characteristics can be modeled descriptively. In the studies [3] and [4] seakeeping properties are presented as linguistic variables of the intensity of ship motions and accompanying phenomena, while the author in [5] uses elements of fuzzy logic for choosing the optimal hull shape of a ro-ro ferry.

Figure 1 presents a method of modeling seakeeping properties by descriptive variables referring to the intensity of each phenomenon.

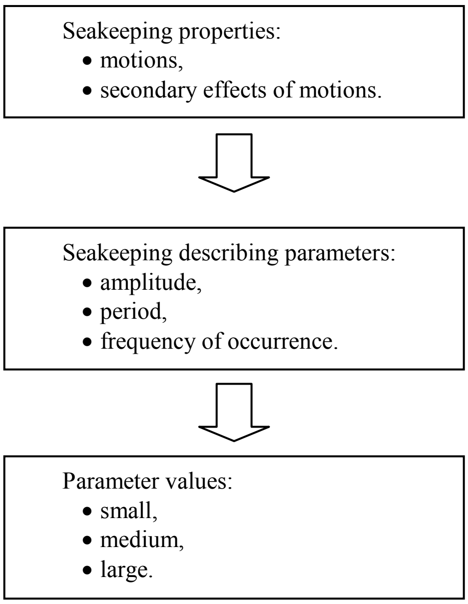

Fig. 1. Modeling of seakeeping properties by descriptive variables
Rys. 1. Modelowanie właściwości morskich za pomocą zmiennych opisowych

By utilizing the classification abilities of artificial neural networks functions approximating seakeeping properties in the descriptive form that would utilize ship's operational parameters or design parameters can be developed. Data needed to build such functions can be gathered by observation or using records in the ship's logbook (Fig. 2). These records generally include statements whether any ship motion occurred (e.g. rolling, pitching, or heaving) in specific weather conditions, the date and ship's positions. Although information is rather scarce, a hypothesis can be made that the information can be used for building approximating models based on linguistic variables. In such models:

- independent variables could be some motions of the ship in the form of two- or multiple state variable, e.g. no motions, slight motions, substantial motions;
- dependent variables could be ship movemnent parameters, wave parameters (determined from ship's position and date), hydromechanical parameters of the hull – these could have a descriptive or calculable form.

The fundamental problem connected with the use of logbook entries is their reliability.

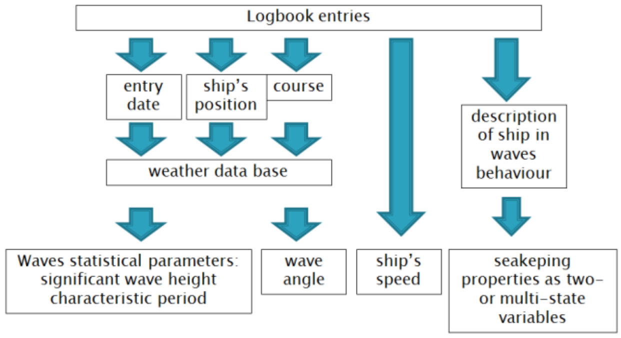

Fig. 2 The use of logbook entries for the modeling of seakeeping properties
Rys. 2. Wykorzystanie zapisów w dzienniku okrętowym do modelowania właściwości morskich

The descriptive modeling of seakeeping properties has some advantages and disadvantages:

– mathematical model is a weak point as it takes into account the evaluation of seakeeping properties and has limited possibilities of application (only as a restricting function);
– advantages:
  - low research costs;
  - less time consuming research;
  - research can include a large number of ships in real operational and environmental conditions.

The research method aimed at developing design guidelines based on models with descriptive variables can consist of the following stages:

Stage 1: Approximation of functions indicating seakeeping properties in the descriptive form making use of design parameters of selected ships;
Stage 2: Prediction of seakeeping properties for other ships through approximations;
Stage 3: Development of design guidelines.

Further presented in the article is a numerical experiment performed to verify the method.

Numerical experiment: modeling of shipping water by a container ship using descriptive variables at the preliminary design stage

The experiment was aimed at verifying the proposed method. To this end the assumption was made that entries in the logbook will be replaced by results obtained from numerical calculations. The practical aim of the research was to:

– verify possibilities of employing artificial neural networks for seakeeping property classification;
– develop design guidelines for container ships that would account for green water.

The seakeeping properties were modelled by the adopted research method.

Numerical tests covered a series of container ships with the following parameters:

- length between perpendiculars: L_{pp} = 99÷277 m;
- moulded breadth B = 16÷37 m;
- moulded draft d = 4.3÷12.81 m;
- freeboard f_B = 0÷10 m;
- block coefficients of:
  - underwater hull CB = 0.53÷0.7;
  - waterplane CWL = 0.66÷0.85;
  - midship CM = 0.92÷0.98.

The data on green water frequency used in the research were obtained from numerical calculations by SEAWAY software. The solutions worked out allowed to select ships characterized by major and minor shipping of water on deck. The phenomenon was evaluated by adopting operating / constraint criteria presented in [6]. The linguistic variable Ω_{zp} describing the frequency of green water assumed these values:

- minor flooding of deck,
- major flooding of deck.

In the first stage of research a function approximating deck flooding depending on design parameters of the ship was developed. The function was represented as a multilayer perceptron with a 3×5×1 structure:

$$\Omega_{zp} = f(\text{CB}, \text{CM}, f_B) \tag{1}$$

where

W_{zp} – two-state nominal variable describing the probability of shipping water:
  1 – shipping water exceeding the dangerous threshold;
  2 – shipping water not exceeding the dangerous threshold;

CB – underwater hull block coefficient;

CM – midship block coefficient;

f_B – freeboard [m] calculated from this equation:

$$f_B = H - d \tag{2}$$

where

H – depth to main deck [m];

d – draft [m].

Classification statistics shown in table 1 indicate that the network has a high prediction capability. The weight values show that block coefficients have a significant influence on the recognition of shipping water on deck.

In the second stage of research seakeeping properties were predicted in the full range of adopted design parameters, i.e.:

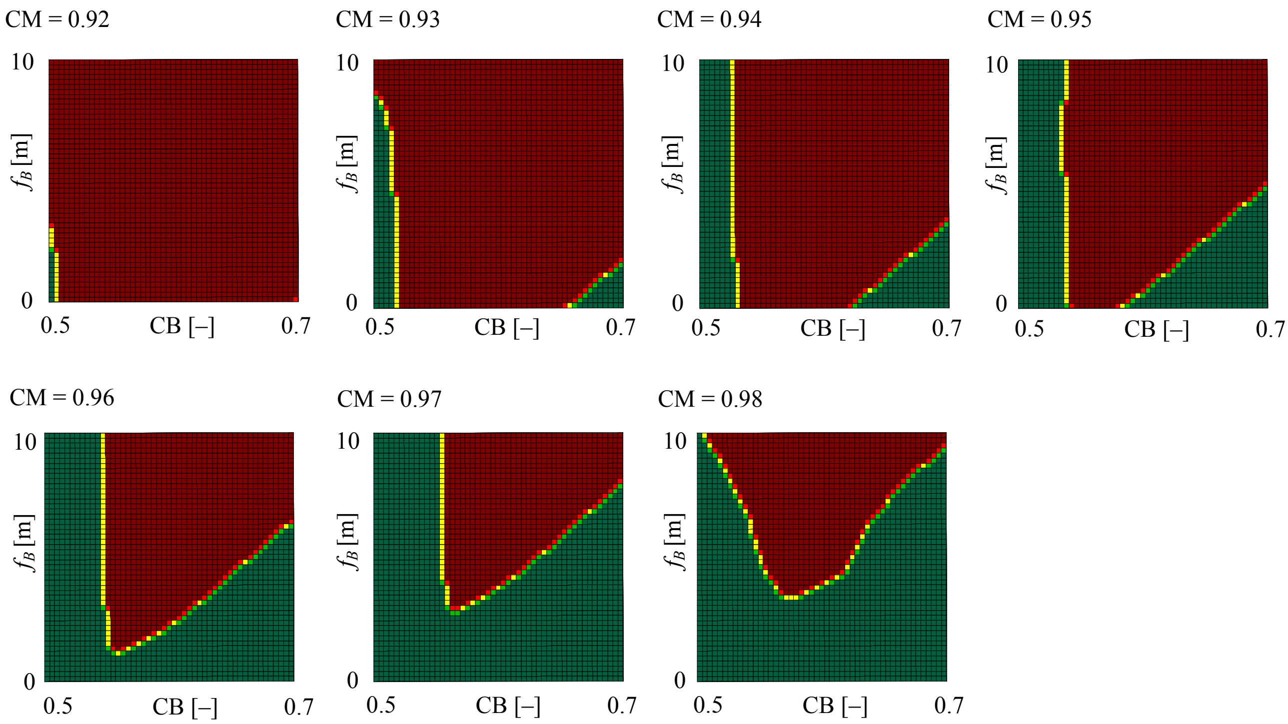

Fig. 3. Design guidelines concerning shipping water by container ships, where: CB – underwater hull block coefficient, CM – midship block coefficient, f_B – freeboard, green – shipping water exceeding the dangerous threshold, red – shipping water not exceeding the dangerous threshold

Rys. 3. Wskazówki projektowe dotyczące zalewania pokładu kontenerowców, gdzie: CB – współczynnik pełnotliwości podwodzia, CM – współczynnik pełnotliwości owręża, f_B – wysokość wolnej burty, kolor zielony – zalewanie pokładu przekraczające niebezpieczny próg, kolor czerwony – zalewanie pokładu nieprzekraczające niebezpiecznego progu

– freeboard f_B = 0÷10 m,
– block coefficient of:
  - underwater hull CB = 0.53÷0.7,
  - midship CM = 0.92÷0.98.

On this basis in the third stage of research design guidelines were formulated (Fig. 1).

Table 1. Statistics for classification problems of the artificial neural network predicting values of the function Ω_{zp}
Tabela 1. Statystyki dla problemów klasyfikacyjnych sztucznej sieci neuronowej przewidującej wartości funkcji Ω_{zp}

Number of occurrences	Teaching set		Validation set		Test set	
	$\Omega_{zp}=1$	$\Omega_{zp}=2$	$\Omega_{zp}=1$	$\Omega_{zp}=2$	$\Omega_{zp}=1$	$\Omega_{zp}=2$
Total	11429	7571	4468	2928	4494	2902
Right	10802	7024	4207	2725	4235	2696
Wrong	627	547	261	203	259	206
Wrong [%]	5.5	7.2	5.8	6.9	5.8	7.1

Conclusions

The presented modeling method is based on data that can be obtained without substantial costs as compared to costs related with measurements done on the ship.

Thanks to the availability of logbook entries, data from a large group of ships can be used that presently are not utilized.

The research shows that the classification capabilities of artificial neural networks can be used in building models of seakeeping properties based on descriptive variables. However, it is not known:

– what the results will be when logbook entries are used;
– to what extent logbook entries are reliable.

It is of key importance for the proposed research to determine the data reliability. When this issue is settled, the results of research obtained through an analysis of logbook entries may be used for ship design and operational purposes.

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