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On the modeling of car passenger ferryship design parameters with respect to selected sea-keeping qualities and additional resistance in waves

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ABSTRACT

This paper presents the modeling of car passenger ferryship design parameters with respect to such design criteria as selected sea-keeping qualities and additional resistance in waves. In the first part of the investigations approximations of selected statistical parameters of design criteria of ferryship were elaborated with respect to ship design parameters. The approximation functions were obtained with the use of artificial neural networks. In the second part of the investigations design solutions were searched for by applying the single- and multi-criterial optimization methods. The multi-criterial optimization was performed by using Pareto method. Such approach made it possible to present solutions in such form as to allow decision makers (shipowner, designer) to select solutions the most favourable in each individual case.

Keywords: sea-keeping qualities; roll-on - roll-off ferryship; rolling; motion sickness index; lateral accelerations, additional resistance in waves; ship design parameters; modeling; artificial neural networks; optimization; Pareto method

INTRODUCTION

In ship design process design solutions which fulfil both economic criteria and technical limitations are searched for. Economic criteria are consisted of a set of requirements imposed by shipowner, among which a suitable internal capacity and service speed of the ship can be numbered, that significantly influences operational profitability of the ship sailing on a given shipping line. Obtaining the assumed service speed by the ship depends a.o. on parameters and operational conditions of propulsion system as well as value of total hull resistance to motion. Since total resistance of ship hull consists of a.o. additional resistance in waves associated with ship sailing in heavy weather conditions, the additional resistance can be used as a design criterion for certain types of ships.

And, technical limitations are consisted of a.o. appropriate stability, unsinkability or hull structural strength. For certain types of ships insensibility to weather conditions, i.e. the so-called good sea-keeping qualities are more and more often used as a design criterion. In such case among sea-keeping qualities wave effects can be numbered in the form of rolling and secondary wave effects (resulting from waving and rolling) to which a.o. accelerations, slamming, shipping of water on the deck and sickness motion index, belong.

The presented investigations were aimed at determination of optimum values of ship design parameters with respect to assumed economic criteria and technical limitations. The investigations were performed on the example of preliminary design of a car passenger ferry ship. The type of ship is characteristic of specific operational and design problems such as internal capacity, stability (unsinkability), speed or insensibility to weather conditions. Therefore for the ship in question selected sea-keeping qualities and additional resistance in waves at a given ship capacity were assumed to be design criteria. In the first phase of the investigations approximation functions of the above mentioned criteria were determined on the basis of main geometrical parameters of ship hull. In the second phase values of the design parameters were determined for which the assumed design task were characterized by the best merits as regards the assumed criteria.

METHOD

The following design task was formulated in the investigations: to find the vector of independent variables, $X = X(X_1, X_2, \dots X_n)$, which minimizes or maximizes functions of partial targets under limitations given for car passenger ferry ship sailing in heavy weather conditions.

The following data were assumed:

- independent variables: L/B, B/d, CB, CWL, where: L, B, d - ship length, breadth and draught, CB - block coefficient of hull underwater part, CWL - waterplane coefficient;
- limitations:
  - theoretical volumetric displacement $V = 17500\ m^3$
  - L/B ratio within the range of $5.17 \div 7.64$
  - B/d ratio within the range of $3.22 \div 4.46$

  - CB within the range of 0.6 ÷ 0.64
  - CWL within the range of 0.8 ÷ 0.85
  - initial lateral metacentric height GM = 1 m
  - ship speed v = 5 kn;
- design criteria:
  - the motion sickness index MSI (acc. ISO 2631/3) [9] for the wave encounter angle $\beta = 120°$ (in the reference system of: 180° – head wave, 0° – following wave)
  - the additional resistance in waves R for $\beta = 180°$
  - the roll angle ϕ for $\beta = 30°$
  - the lateral acceleration on the car deck, at, acc. [11] for $\beta = 30°$.

In the investigations was assumed a conventional wave spectrum consisted of wave energy spectral density functions acc. ITTC for waves of the significant heights H = 6 m and characteristic periods T in the range from 6 to 14 s, (Fig.1). This made it possible to eliminate impact of the characteristic period on ship responses and to decrease number of independent variables in the design task.

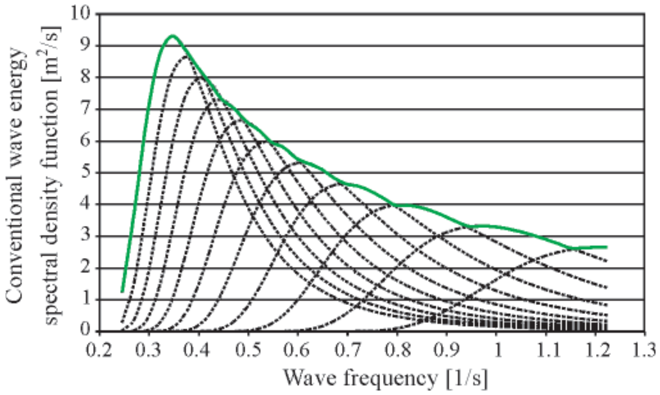

Fig. 1. *Conventional wave energy spectral density function, ITTC spectrum, H = 6 m, T = 6 ÷ 14 s*

In the first phase of the investigations functions of partial targets were determined depending on independent variables.

APPROXIMATION OF DEPENDENT VARIABLES

Functions of partial targets, which are necessary to solve the design task, are to be expressed in the form of analytical functions approximating the assumed dependent variables (i.e.: motion sickness index, additional resistance in waves, roll angles and lateral accelerations). To perform approximations the method presented in Fig. 2 was assumed.

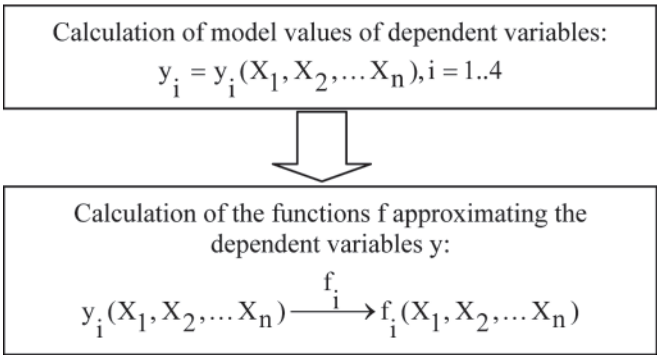

Fig. 2. *Algorithm of approximation of the dependent variables y_i, where: X_1, X_2, ... X_n – independent variables (design parameters), y_i – model values of dependent variables, f_i – searched for approximating functions, i=1..4.*

To determine the functions f_i in the equation (1) it is possible to make use of statistical methods or those based on artificial neural networks. The application of artificial neural networks to approximation of unknown relations belongs to mathematical numerical methods dealing with the so-called „artificial intelligence" and finds wider and wider use in shipbuilding [1, 2, 5, 6].

To calculate model values the set of 24 design variants of car passenger ferry ship of different hull forms shown in Tab. 1, was assumed. Model values were presented in the form of irregular wave statistical values of the wave energy spectral density function shown in Fig. 1.

Tab. 1. *Model set of independent and dependent variables appearing in the above assumed parameters of ship motions and waving, where: CB – block coefficient of hull underwater part, CWL – waterplane coefficient, L – ship length, B – ship breadth, d – ship draught, MSI – motion sickness index, a_t – lateral acceleration on car deck, ϕ – significant amplitude of ship roll angles, R – additional resistance in waves*

Design variants	**Independent variables**				**Dependent variables**			
	CB	**CWL**	**L/B**	**B/d**	**MSI [%]**	**ϕ [°]**	**a_t [m/s²]**	**R [kN]**
1	0.599	0.809	5.68	3.22	97.20	10.82	1.71	878.50
2	0.599	0.809	6.74	3.84	88.40	9.56	1.76	1150.60
3	0.599	0.809	5.17	4.46	93.90	7.98	1.32	1164.00
4	0.644	0.828	6.17	3.58	91.50	9.61	1.67	856.60
5	0.644	0.828	6.74	3.22	92.30	11.60	1.81	796.40
6	0.644	0.828	5.17	4.46	91.40	7.50	1.31	985.90
7	0.637	0.811	5.71	3.40	88.20	9.62	1.58	712.00
8	0.637	0.811	6.74	3.84	66.80	9.57	1.60	893.00
9	0.637	0.811	5.17	4.46	81.30	6.32	1.33	933.60
10	0.616	0.828	5.17	4.46	79.50	6.27	1.30	1068.10
11	0.616	0.828	6.74	3.22	80.00	8.69	1.82	843.80
12	0.616	0.828	5.96	3.84	79.30	7.66	1.52	970.30
13	0.620	0.831	6.74	3.90	78.20	8.73	1.90	1108.90
14	0.620	0.831	5.96	3.22	92.80	10.51	1.91	852.50
15	0.620	0.831	5.17	4.46	85.80	7.54	1.45	1116.00
16	0.634	0.852	5.57	3.77	80.80	7.84	1.57	956.30
17	0.634	0.852	6.74	3.22	78.70	10.01	1.84	879.10
18	0.634	0.852	5.17	4.46	75.20	6.80	1.35	1106.20
19	0.626	0.850	5.64	3.50	87.30	7.31	1.49	878.90
20	0.626	0.850	6.74	3.22	79.60	9.07	1.69	882.10
21	0.626	0.850	5.17	4.46	79.00	6.30	1.25	1090.00
22	0.610	0.804	6.74	4.04	71.20	5.54	1.55	798.90
23	0.610	0.804	5.96	3.22	90.70	7.96	1.59	595.80
24	0.610	0.804	5.17	4.46	82.40	4.70	1.25	775.50

The values of dependent variables given in Tab. 1 were calculated by means of exact numerical methods with the use of SEAWAY software which is based on planar flow theory. Exactness tests of the software, presented in [4], indicate a high accuracy of calculations. For calculations of additional resistance in waves the Gerritsma-Beukelman method was used [3].

Approximation functions of the dependent variables: MSI, ϕ, R and a_t were determined by using artificial neural networks and presented analytically in the form of Eqs. (1), (2), (3) and (4):

$$MSI = \frac{\left(\frac{1}{1+e^{-(([CB,CWL,CB/CWL,L/B,B/d]\times S+P)\times A-B)}}\times C-\alpha_0\right)-\alpha_1}{\alpha_2} \qquad (1)$$

where:
MSI – motion sickness index [%]
L – ship length
B – ship breadth
d – ship draught
CB – block coefficient of hull underwater part
CWL – waterplane coefficient
A – matrix of weight values:

$$\begin{bmatrix} -0.581 & 1.019 & -2.326 & -0.015 & 1.460 & -0.044 \\ 0.379 & -0.268 & -0.469 & -0.021 & 0.310 & -1.453 \\ -0.924 & 0.480 & -1.928 & -1.033 & 1.071 & 0.487 \\ -0.321 & 0.842 & 1.699 & -0.686 & -0.422 & 0.652 \\ -0.283 & -0.254 & 2.564 & 1.254 & 1.030 & 0.340 \end{bmatrix}$$

S – matrix of coefficients:

$$\begin{bmatrix} 22.22 & 0 & 0 & 0 & 0 \\ 0 & 20.83 & 0 & 0 & 0 \\ 0 & 0 & 20.41 & 0 & 0 \\ 0 & 0 & 0 & 0.64 & 0 \\ 0 & 0 & 0 & 0 & 0.81 \end{bmatrix}$$

B – vector of threshold values: [-1.583 -0.131 -1.882 0.366 0.508 -2.022]
C – column vector of weight values: [1.15 -0.71 -2.80 1.59 -1.88 1.75]
P – vector of displacement values: [-13.31 -16.75 -15.02 -3.29 -2.60]
$\alpha_0, \alpha_1, \alpha_2$ – coefficients of the following values: $\alpha_0 = -1.62$, $\alpha_1 = -2.74$, $\alpha_2 = 0.04$

$$R = \frac{\left(\frac{1}{1+e^{-(([CWL,CB/CWL,L/B,B/d]\times S+P)\times A-B)}}\times C-\alpha_0\right)-\alpha_1}{\alpha_2} \qquad (2)$$

where:
R – additional resistance in waves [kN]
A – matrix of weight values:

$$\begin{bmatrix} 0.726 & 2.897 & -2.504 & 0.570 & 1.932 & -0.365 & -0.164 \\ 3.661 & -4.110 & 0.244 & 0.431 & 3.790 & 0.275 & -0.070 \\ -1.219 & -0.517 & 1.854 & -0.481 & 0.820 & -0.656 & -0.492 \\ -0.423 & -0.886 & 1.422 & 0.046 & -0.087 & -1.134 & -0.560 \end{bmatrix}$$

S – matrix of coefficients:

$$\begin{bmatrix} 20.83 & 0 & 0 & 0 \\ 0 & 20.41 & 0 & 0 \\ 0 & 0 & 0.64 & 0 \\ 0 & 0 & 0 & 0.81 \end{bmatrix}$$

B – vector of threshold values: [2.220 -2.108 1.688 -0.967 -0.410 -1.842 0.633]
C – column vector of weight values: [2.665 2.431 1.836 0.373 -2.001 -2.197 -0.728]
P – vector of displacement values: [-16.75 -15.02 -3.29 -2.60]
$\alpha_0, \alpha_1, \alpha_2$ – coefficients of the following values: $\alpha_0 = -0.939$, $\alpha_1 = -1.575$, $\alpha_2 = 0.0022$

$$a_t = \frac{\left(\frac{1}{1+e^{-(([CB,CWL,CB/CWL,L/B,B/d]\times S+P)\times A-B)}}\times C-\alpha_0\right)-\alpha_1}{\alpha_2} \qquad (3)$$

where:
a_t – maximum lateral acceleration on the car deck [m/s^2]
A – matrix of weight values:

$$\begin{bmatrix} -0.874 & 0.408 & 0.046 & 0.313 & 0.001 & 0.863 & -0.096 & 0.041 & 0.368 & 0.265 & 0.732 & -0.753 & -0.471 \\ 1.062 & -0.014 & -0.680 & 0.739 & 0.903 & -0.981 & -0.583 & -0.089 & -0.835 & 0.239 & 0.035 & -0.380 & -0.550 \\ 0.955 & -0.358 & -0.392 & 0.412 & -0.270 & 0.704 & -0.467 & 0.149 & -0.867 & 0.060 & 0.801 & -0.202 & 0.736 \\ -0.755 & 0.616 & -0.266 & 0.527 & 0.320 & 0.507 & -0.968 & -0.821 & 0.870 & 0.378 & 0.261 & -0.480 & -0.089 \\ 0.810 & -0.399 & -0.822 & 0.233 & 0.480 & 0.903 & -0.424 & 0.241 & -0.655 & 0.385 & 0.301 & -0.656 & 0.420 \end{bmatrix}$$

S – matrix of coefficients:

$$\begin{bmatrix} 22.22 & 0 & 0 & 0 & 0 \\ 0 & 21.47 & 0 & 0 & 0 \\ 0 & 0 & 20.41 & 0 & 0 \\ 0 & 0 & 0 & 0.64 & 0 \\ 0 & 0 & 0 & 0 & 0.81 \end{bmatrix}$$

B – vector of threshold values:
[0.368 -0.043 -0.045 -0.231 -0.109 0.821 -0.289 0.924 0.776 0.683 1.025 -0.397 -0.121]
C – column vector of weight values:
[-0.923 0.021 -0.562 0.617 0.171 -0.052 0.356 -0.773 0.798 0.786 0.628 1.003 -0.989]
P – vector of displacement values: [-13.31 -17.48 -15.02 -3.29 -2.60]
$\alpha_0, \alpha_1, \alpha_2$ – coefficients of the following values: $\alpha_0 = 0.193$, $\alpha_1 = -2.18$, $\alpha_2 = 1.67$

$$\phi = \frac{(([CB, CWL, CB/CWL, B/d] \times S + P) \times A + 6.96) + 1.049}{0.189} \tag{4}$$

where:
ϕ – significant amplitude of roll angles [°]
A – column vector of weight values: [38.14 -30.37 -33.83 -0.54]
S – matrix of coefficients:

$$\begin{bmatrix} 22.22 & 0 & 0 & 0 \\ 0 & 20.83 & 0 & 0 \\ 0 & 0 & 20.41 & 0 \\ 0 & 0 & 0 & 0.81 \end{bmatrix}$$

P – vector of displacement values: [-13.31 -16.75 -15.02 -2.60]

In Tab. 2 the above presented networks are described together with their selected statistical parameters. From the above given sheets it results that the functions (1), (2), (3) and (4) are characterized by a simple structure and relatively high accuracy.

Tab. 2. *Type, structure and selected statistical parameters of the elaborated neural networks*

Variable	**Type of network**	**Structure of neural network**	**Correlation coefficient R**	**Root mean square error, RMS, of:**	
				learning	**testing**
MSI	MLP	5x6x1	0.998	2.08	4.29
R	MLP	4x7x1	0.999	11.3	38.67
a_t	MLP	5x13x1	0.998	0.12	0.07
ϕ	linear	4x1	0.984	0.65	0.25

SELECTION OF OPTIMUM DESIGN PARAMETERS OF SHIP HULL

In this part of the experiment hull form parameters of car passenger ferry ship were searched for with respect to the assumed criteria, i.e.:

- maximum of MSI
- minimum of the additional resistance in waves, R
- minimum of the acceleration on the car deck, a_t
- minimum of the roll angle φ.

The functions (1), (2), (3), (4) were used to solve the problem. To find a design solution which satisfies the assumed criteria the single- and multi-criterial optimization methods were applied.

SINGLE-CRITERIAL OPTIMIZATION

In this part of the investigations minimum values of the functions (1), (2), (3) and (4) were determined. In the first phase the GRG2 (Generalized Reduced Gradient) program of linear optimization was used [7]. The results are presented in Tab. 3 and Fig. 3 and 4.

The main disadvantage of optimization methods of both kinds (single- and multi-criterial) is that they provide only information on location of an optimum point. They do not give information on shape of objective function and it is not certain whether the achieved optimum solution is global [3]. Hence in the next phase of the investigations a set of all possible design solutions was determined and the results were analyzed against the assumed criteria. To the calculations the following increments of the design parameters were assumed:

- $\Delta L/B = 0.01$ m
- $\Delta B/d = 0.01$ m
- $\Delta CB = 0.01$
- $\Delta CWL = 0.01$.

Tab. 3. Optimum design solutions with respect to the assumed criteria

Variant	CB	CWL	L/B	B/D	MSI [%]	R [kN]	ϕ [°]	a_t [m/s^2]	Criterion
A	0.636	0.804	6.74	4.46	53.7	1141.9	4.32	1.49	min. of MSI
B	0.617	0.804	6.15	3.22	88.1	551.30	8.29	1.59	min. of R
C	0.599	0.852	6.74	4.46	97.2	1164.2	0.26	1.67	min. of ϕ
D	0.650	0.800	5.17	4.46	97.2	1164.2	2.11	1.19	min. of a_t

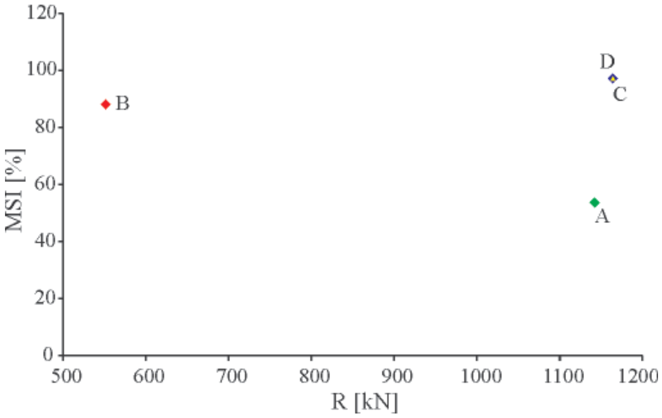

Fig. 3. Comparison of the design solutions with respect to the additional resistance in waves, R, and the motion sickness index MSI

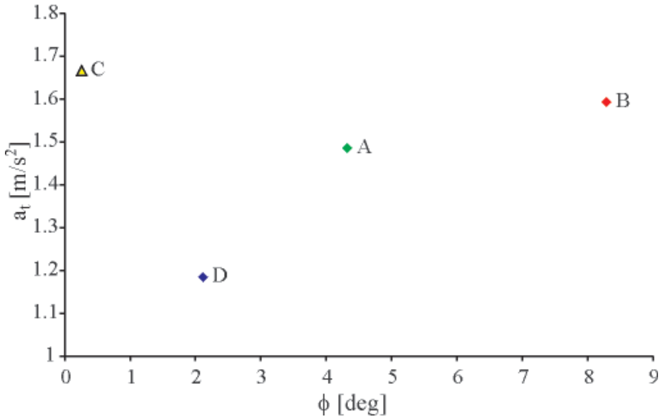

Fig. 4. Comparison of the design solutions with respect to the roll angle ϕ and the lateral acceleration a_t

The analysis results are illustrated in Fig. 5 through 11. In Fig. 5, 7, 9, 11 are presented the sets of minimum values of the variables (design criteria) dependent on a given criterion. From the sets merits of the design solutions result with respect to the assumed criteria. For instance from Fig. 5 it results that the design solutions characterized by small values of MSI index are also characteristic of large values of additional resistance and small values of roll angles and lateral accelerations. And, the design solutions characterized by large values of MSI index are also characteristic of a.o. small values of mean additional resistance in waves. In Fig. 6, 8, 10, 12 values of design parameters are presented depending on selected design criteria. On the basis of both groups of the diagrams the car passenger ferryship design parameters which satisfy decision maker with respect to assumed criteria, can be determined.

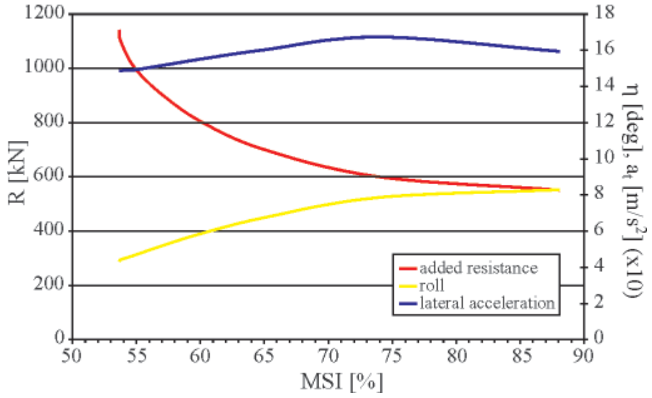

Fig. 5. Minimum values of dependent variables within the range of MSI = 53 ÷ 88 %

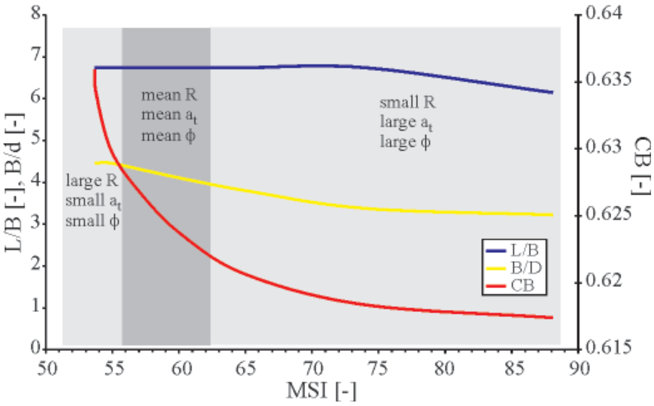

Fig. 6. Values of design prameters in function of MSI index, CWL = 0.80

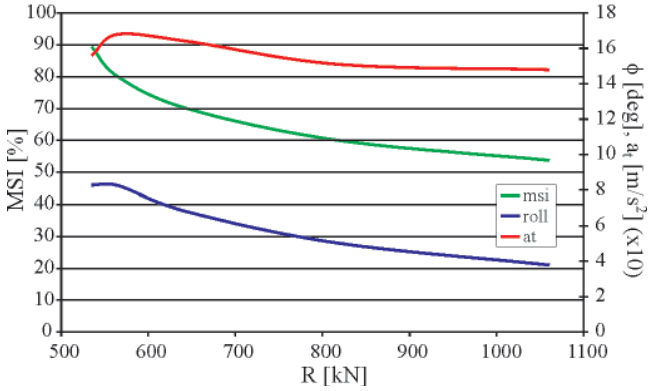

Fig. 7. Minimum values of dependent variables within the range of R = 530 ÷ 1060 kN

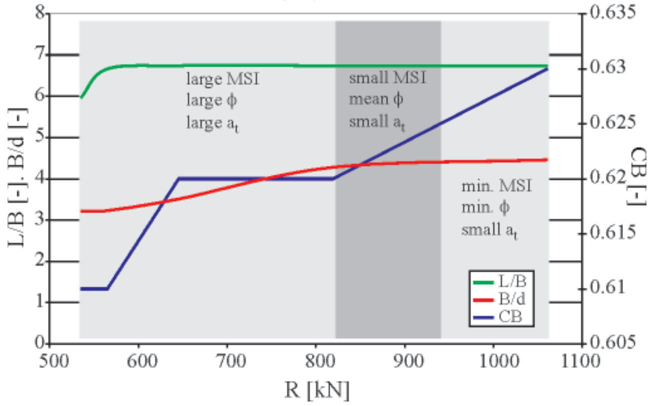

Fig. 8. Values of design parameters in function of the additional resistance in waves R, CWL = 0.80

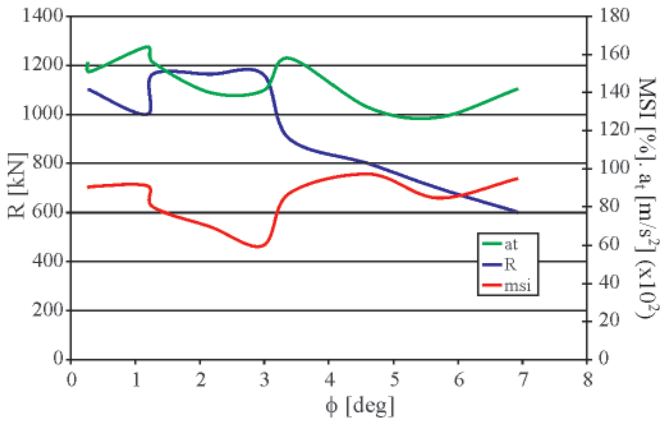

Fig. 9. *Minimum values of dependent variables within the range of ϕ = 0.26 ÷ 6.93°*

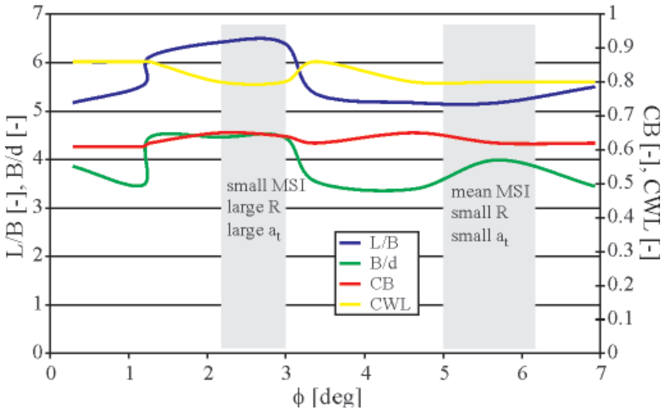

Fig. 10. *Values of design parameters in function of the roll angle ϕ*

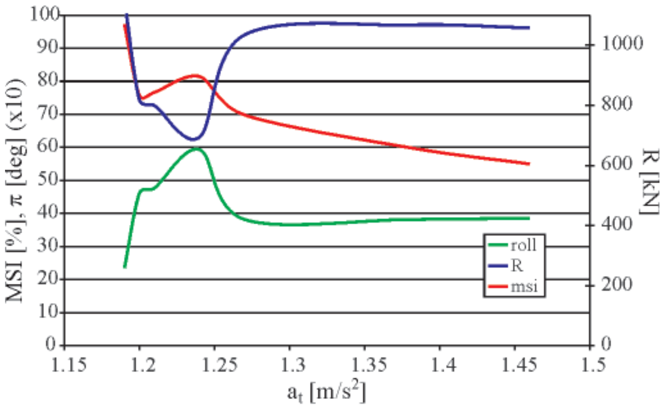

Fig. 11. *Minimum values of dependent variables within the range of a_t = 1.19 ÷ 1.46 m/s^2*

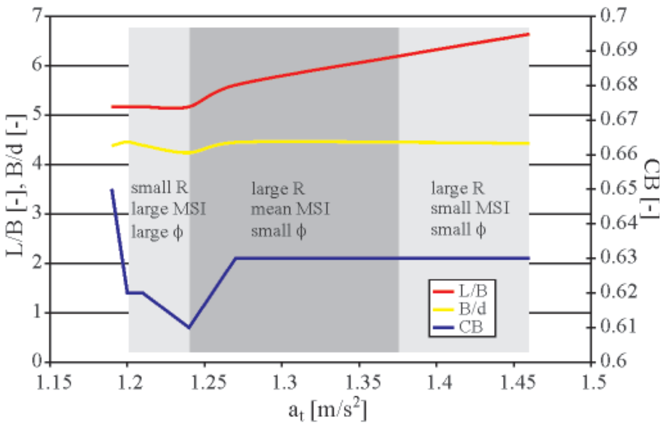

Fig. 12. *Values of design parameters in function of the lateral acceleration a_t, CWL = 0.80*

MULTI-CRITERIAL OPTIMIZATION

The next step in the investigations was an attempt of using the mult-criterial optimization methods in order to determine an optimum design solution of ro-ro ferry ship. In such case the notion of optimum solution is not simple as in the case when one does not accept to compare different criteria to each other and then must propose such definition of optimality which respects integrity of each of the criteria [5]. In order to select an optimum solution in the analyzed case when sets of partial solutions do not have any common part, it is necessary to find an acceptable compromise between partial targets. Importance of particular partial targets can be expressed by means of the weight coefficient [3] and hence obtained design solutions depend on values of the weights. In such case a verdict is automatically given and relations between partial solutions are unknown. This is disadvantageous as decision maker has no possibility to assess all variants (or only a part of them) before a verdict is given.

In the case of the ship hull parametric modeling for the offer design purposes it is sometimes important to know influence of partial criteria on design solutions. Then in the offer design its merits can be proposed from the point of view of different criteria and decision maker (shipowner) is able to choose the best variant from his point of view. Therefore in the assumed design task the notion of optimality in the sense of Pareto was used. The Pareto optimality concept does not provide any indications as to making choice of a final solution (out of P-optimum ones) . Decision on choice of optimum solution has to be taken by decision maker himself [5].

The optimality condition in the Pareto sense can be presented as follows: *the vector x will be consider (partly) smaller than the vector y, if and only if the relation* [5] *is satisfied:*

$$(\forall i)(x_i \le y_i) \wedge (\exists i)(x_i \le y_i) \qquad (5)$$

Then it is also said that the vector y is dominated by the vector x. If a given vector is not dominated by no other one then it is called the non-dominated vector. By analyzing Fig. 3 one can state that the solutions A and B are not dominated and the solutions C and D are dominated by the solutions A and B (with respect to MSI index and additional resistance R). And, from Fig. 4 results that the soultions A and B are dominated by the solution D with respect to the criteria of the roll angle φ and lateral acceleration a_t. From the fact it results that in the assumed design task no single optimum solution with respect to all the criteria can be obtained but only the set of four solutions which are not mutually dominated, and any decision on choice of a solution is compromise.

In Fig. 13 is presented the set of values of the dependent variables of all the optimum solutions - in the sense of Pareto - (i.e. those non-dominated) of the considered design task. The set is presented in function of the MSI index. As it turned out, in the obtained design solution the dependent variables achieved the following values:

- the motion sickness index, MSI = 55 ÷ 90 %
- the additional resistance in waves, R = 614 ÷1164 kN
- the significant amplitude of roll angles ϕ = 0.26 ÷ 8.91°
- the lateral accelerations a_t = 1.22 ÷ 1.91 m/s^2.

From the above given set optimum solutions can be selected with respect to arbitrary assumed criteria. In Tab. 4, 5 and 6 are presented example design solutions with respect to:

- all the criteria which achieve maximum mean values, i.e.: MSI < 85.5%, R < 889 kN, $\phi < 4.59°$, $a_t < 1.57$ m/s² (Tab. 4)
- MSI and R values smaller than mean ones, as well as ϕ and a_t values greater than mean ones, i.e.: MSI < 78%, R < 730 kN, $\phi < 7°$, $a_t < 1.7$ m/s² (Tab. 5)
- ϕ and a_t values smaller than mean ones and MSI and R values greater than mean ones, i.e.: MSI < 90%, R < 1165 kN, $\phi < 2°$, $a_t < 1.39$ m/s² (Tab. 6).

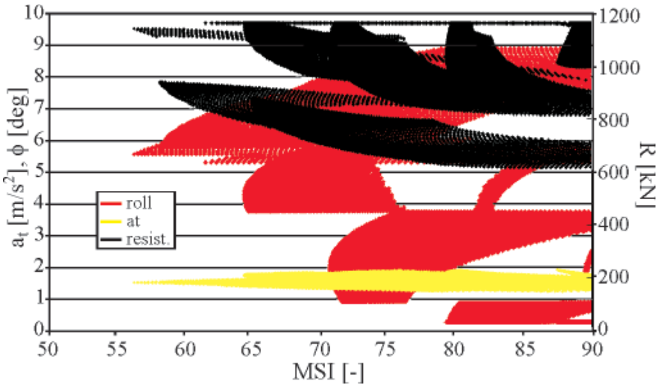

Fig. 13. *The set of all optimum design solutions in the sense of Pareto, MSI = 55 ÷ 90 %, R = 614 ÷1164 kN, f = 0.26 ÷ 8.91°,* a_t *= 1.22 ÷ 1.91 m/s²*

Tab. 4. *Optimum design solutions in the sense of Pareto, MSI < 85.5%, R < 889 kN,* $\phi < 4.59°$, $a_t < 1.57$ *m/s²*

CB [-]	CWL [-]	L/B [-]	B/D [-]	MSI [%]	R [kN]	ϕ [°]	a_t [m/s²]
0.63	0.87	5.32	3.57	85.46	883.65	2.97	1.59
0.63	0.87	5.34	3.57	85.14	883.48	2.97	1.59
0.63	0.87	5.36	3.57	84.83	883.34	2.97	1.59
0.63	0.87	5.34	3.59	84.67	887.48	2.92	1.59
0.63	0.87	5.36	3.59	84.36	887.36	2.92	1.59
0.63	0.87	5.38	3.59	84.06	887.28	2.92	1.59

Tab. 5. *Optimum design solutions in the sense of Pareto, MSI < 78%, R < 730kN,* $\phi < 7°$ a_t *1.7 m/s²*

CB [-]	CWL [-]	L/B [-]	B/D [-]	MSI [%]	R [kN]	ϕ [°]	a_t [m/s²]
0.62	0.81	5.5	4.07	77.81	728.99	6.98	1.35
0.62	0.81	5.52	4.07	77.51	728.99	6.98	1.36
0.62	0.81	5.54	4.07	77.22	729.05	6.98	1.36
0.62	0.81	5.56	4.07	76.93	729.16	6.98	1.36
0.62	0.81	5.58	4.07	76.64	729.32	6.98	1.37
0.62	0.81	5.6	4.07	76.36	729.54	6.98	1.37
0.62	0.81	5.62	4.07	76.08	729.8	6.98	1.38

Tab. 6. *Optimum design solutions in the sense of Pareto, MSI < 90%, R < 1165 kN,* $\phi < 2°$, $a_t < 1.39$ *m/s²*

CB [-]	CWL [-]	L/B [-]	B/D [-]	MSI [%]	R [kN]	ϕ [°]	a_t [m/s²]
0.61	0.85	5.18	4.45	89.7	1164.2	1.92	1.39
0.61	0.85	5.18	4.47	89.68	1164.2	1.87	1.39
0.61	0.85	5.2	4.47	89.67	1164.2	1.87	1.39

CONCLUSIONS

- Both economic criteria and technical limitations constitute important factors in the process of single- and multi-criterial design optimization. To perform such optimization ship designers should be equipped with suitable tools in the form of calculation methods. Determination of additional hull resistance in waves or ship sea-keeping qualities by means of the presently used design algorithms is excessively complicated as to make it possible to perform optimization successfully. This results from various causes but the most important is that simple and simultaneously exact relations between hull form parameters and ship behaviour in waves are lacking. To predict ship responses in waves is only possible by using exact numerical methods for a given ship hull form.

- A method which makes it possible to solve the problem is presented in this work. To approximate additional resistance in waves and selected sea-keeping qualities, artificial neural networks were used. Despite relatively low number of model variants and wide range of ship hull parameters the obtained approximations are characterized by high accuracy and simple structure.

- The presented approximations may be applied to design analyses (e.g. such as in [2]) or as objective functions in various optimization methods of ship design parameters. In this paper an example of single- and multi- criterial optimization of car passenger ferry ship design parameters is presented. In the first phase ranges of optimum design parameters with respect to the assumed criteria taken into account separately, were determined. In the second phase sets of design solutions optimum in the sense of Pareto, were determined. In each of the phases the solutions were presented in such form as to give a decision maker (ship operator, designer) possibility to select variants most favourable to him.

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