Application of statistical methods and artificial neural networks for approximating ship's roll in beam waves

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ABSTRACT

In the paper, were presented approximations of numerical calculations of ship's roll on the basis of main service parameters of the ship. This way were obtained several relationships which make it possible to approximate ship roll in regular and irregular waves by using the parameters available in the phase of voyage routing. The relationships were elaborated by means of artificial neural networks as well as linear and non-linear regression methods. A comparative analysis of the methods regarding approximation accuracy against standard data was also performed.

Keywords : ship's roll, regular wave, irregular wave, approximation, neural networks, regression methods

INTRODUCTION

Within the contemporary shipping problems there is a problem of searching for ship voyage route satisfying several criteria among which the following usually are the most important :

- voyage duration time (at assumed parameters of ship propulsion system)
- operational cost which mainly depends on fuel consumption.

A limitation which seriously influence route choice is the condition of safe shipping, which consists of many factors among which ship's behaviour in rough seas should be distinguished.

So many parameters influence ship's behaviour in waves that accounting for all of them makes the voyage routing process very complicated. Hence, out of all the parameters, ship master is forced to take into account only most important ones, among which wave parameters, ship's motion parameters or also selected hydromechanical parameters of the ship, are numbered. The small amount of available information does not make it possible to use exact methods of determination of ship motion in waves.

In the subject-matter literature, methods making it possible to solve the problem in a satisfactory way, are still lacking. Design recommendations dealing with ship seakeeping qualities, given in classification rules, are of a very limited character. The calculation procedures there presented are rather inaccurate and they allow to determine only „designed" ship motion amplitudes and accelerations which are connected only to a certain degree with real ship behaviour in waves. The approximations of ship seakeeping qualities published in the scientific literature are too general, rather inaccurate, and usually applicable only to a given hull form [1,5].

In this paper an attempt to solve the problem has been undertaken, aimed at elaboration of a simplified but exact model of predicting ship's roll on the basis of main ship service parameters.

METHOD

The research in question was limited to approximation of ship's roll in regular and irregular waves coming from the direction perpendicular to ship's plane of symmetry. It was assumed that approximations of the oscillations have to be elaborated on the basis of the parameters taken into account in ship voyage routing and simultaneously having significant influence on the motions. Among such parameters the following are usually numbered :

- wave parameters in the form of its height and period (in the case of aproximation of ship roll in irregular waves)
- ship motion parameters
- ship service parameters associated with, a.o., ship mass distribution and its hull hydrostatic characteristics.

In the research in question it was adopted an approach of approximating the standard values of the roll angles ϕ (determined by means of exact numerical methods) by using the approximating function *f* on the basis of the n-element set of input parameters $W[X_1, X_2, ... X_n]$:

$$\phi = f(W) \quad (1)$$

where :

W - n-element set of input parameters : $X_1, X_2, ... X_n$
ϕ - standard values of roll angles calculated by means of the exact method
f - approximating function searched for.

STANDARD VALUES OF ROLL ANGLES

Standard values of roll angles were determined by using exact numerical methods based on the two-dimensional flow theory, i.e. the SEAWAY software (was elaborated by Shiphydromechanics Laboratory, Delft University of Technology, The Netherlands) which calculates ship motions in regular and irregular waves. In Fig.1 are presented the ship roll amplitude characteristics calculated by means of the software, and showed together with the characteristics obtained from model tests [10].

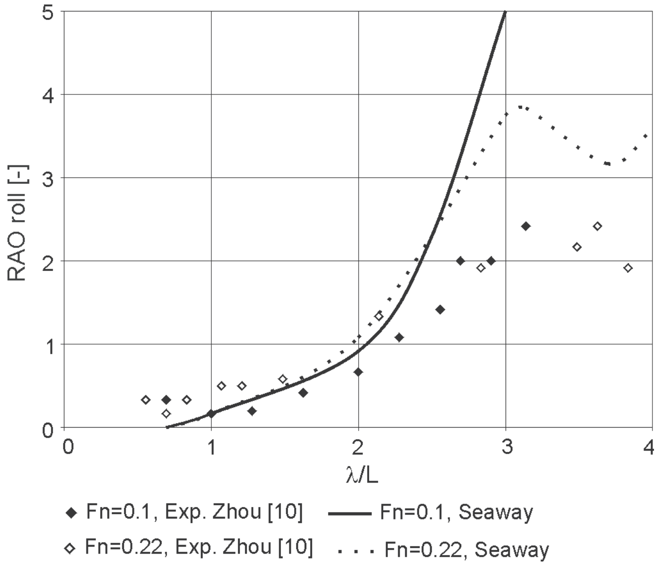


Fig. 1. *Roll angle amplitude characteristics of the containership „Nedlloyd Dejima" of : L = 270 m, B = 32.20 m, d = 10.85 m, C_B = 0.596, Z_G = 16.45 m, in beam waves, acc. [10]*

The approximations and numerical calculations were carried out for the S-175 model containership of the following main dimensions :

L (length between perpendiculars) = 175 m
B (breadth) = 25.4 m
d (design draught) = 9.5 m.

Its hull form is given in Fig.2.

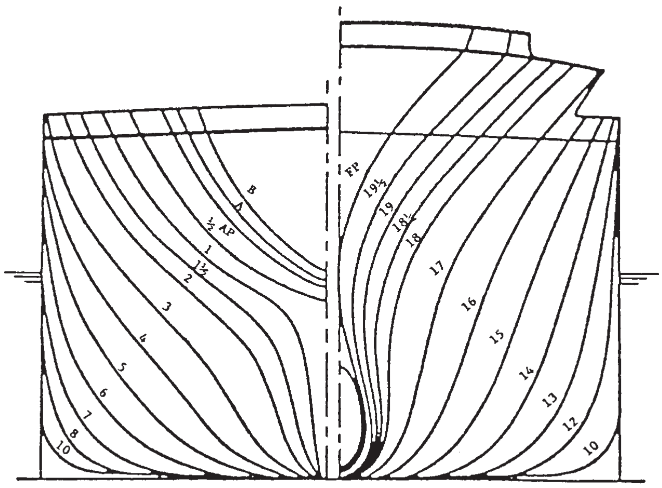


Fig. 2. *Theoretical hull frames of S-175 containership, acc. [4]*

The numerical calculations were performed by applying, a. o., the modified method of two-dimensional flow, accounting for diffraction of wave loads [4] , and assuming ITTC wave spectrum.

On the basis of literature data, were selected the parameters which have decisive influence on ship roll, and simultaneously considered as the service ones. To them it belongs, a.o. :

⇨ the ship volumetric displacement ∇
⇨ the initial transverse metacentric height GM
⇨ the height of the ship gravity centre Z_G.

Taking into account that the volumetric displacement ∇ can be expressed in the form of the mean draught *d* , and that the initial transverse metacentric height GM depends on the height of ship gravity centre Z_G, one decided to determine the ship roll approximations by using :

★ the mean draught d
★ the initial metacentric height GM

for which the following ranges of their values were assumed :

- for d : from 7 to 9 m
- for GM : from 0.3 to 1.5 m

and

- for the ship speed V : from 0 to 20 knots.

Additionally, for approximation of ship roll in irregular waves it was assumed :

- values of the significant wave height Hs : from 2 to 4.5 m, taken with 0.5 m step
- values of the characteristic wave period T : from 6.5 to 14.5 s, taken with 2 s step.

For all the above mentioned variants roll angle amplitudes of ship in regular and irregular waves were calculated, and this way the set of standard data for approximations was obtained.

APPROXIMATION OF ROLL AMPLITUDES OF S-175 CONTAINERSHIP IN REGULAR WAVES

The approximation of ship roll amplitudes in regular waves (in irregular waves as well) was carried out by means of statistical methods, i.e. linear and non-linear regression, as well as artifical neural networks. The latter method belongs to relatively novel mathematical-numerical methods placed in the field of „artificial intelligence", and it finds more and more applications in different domains of science and engineering. The research results published in [6, 8, 9] show broader and broader possiblities of application of artificial neural networks to the problems of ship design and operation.

On the basis of [1,8] and the performed investigations it has appeared that the best model of roll amplitude characteristics against the assumed standard data is the following :

$$Y_\phi(\omega) = \frac{a}{1-\left(\frac{\omega}{b}\right)^2} \qquad (2)$$

where :

a , b – coefficients dependent on ship service parameters
ω – wave frequency [s^{-1}].

The coefficients *a* and *b* were approximated by using the statistical methods and artificial neural networks, as shown below.

Approximation of the coefficients **a** *and* **b** *by using statistical methods*

To approximate the coefficients *a* and *b* in the equation (2) linear and non-linear regression was used. When using the linear regression the following relationships appeared the best out of all investigated models :

$$a = \alpha_0 \cdot d + \alpha_1 \cdot GM + \alpha_2 \cdot d^2 + \\ + \alpha_3 \cdot \frac{GM}{d} + \alpha_4 \cdot V + \alpha_5 \cdot GM \cdot d \tag{3}$$

$$b = \alpha_6 \cdot d + \alpha_7 \cdot \left(\frac{GM}{d} \right)^2 + \alpha_8 \cdot d^2 \tag{4}$$

where :

$\alpha_0, ..., \alpha_8$ – coefficients whose values are given in Tab. 1
The remaining symbols – as explained above.

Table 1

α_0	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
0.412	4.117	-0.028	-39.160	0.314	-0.035	0.058	3.040	-0.005

When applying non-linear regression
the following relationships appeared the best ones :

$$a = \alpha_0 + \exp\left(\begin{matrix} \alpha_1 + \alpha_2 \cdot d + \alpha_3 \cdot V + \\ + \alpha_4 \cdot GM + \alpha_5 \cdot \dfrac{GM}{d} \end{matrix} \right) \tag{5}$$

$$b = b_0 \cdot \beta_0 + b_1 \cdot \beta_1 \tag{6}$$

where :

$$b_0 = (\alpha_6 + \alpha_7 \cdot d + \alpha_8 \cdot V + \alpha_9 \cdot GM)$$
$$b_1 = (\alpha_{10} + \alpha_{11} \cdot d + \alpha_{12} \cdot V + \alpha_{13} \cdot GM)$$

$$\beta_0 = 1 \text{ if } b_0 \le \alpha_{14} \text{ otherwise } \beta_0 = 0$$
$$\beta_1 = 1 \text{ if } b_1 > \alpha_{14} \text{ otherwise } \beta_1 = 0$$

$\alpha_0, ..., \alpha_{14}$ – coefficients whose values
are given in Tab.2 and 3.

Table 2

α_0	α_1	α_2	α_3	α_4	α_5	α_6	α_7
0.9319	45.235	-5.2798	0.0676	105.41	-950.58	0.165	$2.25 \cdot 10^{-3}$

Table 3

α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}
$-5.46 \cdot 10^{-4}$	-0.013	0.064	-0.014	$8.339 \cdot 10^{-6}$	0.3284	0.212

Approximation of the coefficients a *and* b *by means of artificial neural networks*

Among all investigated networks used for approximating the coefficients *a* and *b* in the equation (2) the MLP neural networks of the below given form, showed the highest accuracy :

$$a, b = \frac{\left(\dfrac{1}{1 + e^{-([d, V, GM] \cdot S + P) \cdot A - B)}} \cdot C - \alpha_0 \right) - \alpha_1}{\alpha_2} \tag{7}$$

where :

the symbols : d, GM, V – as explained above.
S – the vector of normalizing values : [0.5 0.05 0.833]
P – the vector of displacement values : [- 3.5 0 - 0.250]

<u>The matrices, vectors and constants
necessary to determine the coefficient *a* :</u>

A – matrix of weight values :

$$\begin{bmatrix} -0.1304 & 0.8757 & -0.9335 & -0.0855 & 0.9179 & -0.0139 & 0.0338 & -0.6867 & 0.5367 & -0.3011 & 0.8537 & -0.1561 & -0.9966 \\ 0.4534 & 0.6205 & -0.7704 & -0.3399 & 0.4939 & 0.8646 & -0.7616 & 0.3134 & -0.5045 & -0.3016 & -0.3004 & 0.6048 & -0.0967 \\ 0.1259 & 0.0096 & 0.4784 & 0.9856 & 0.6298 & 0.7879 & -0.2093 & -0.5050 & -0.9623 & 0.2246 & -0.8858 & -0.2999 & -0.1227 \end{bmatrix}$$

B – vector of threshold values :

[-0.93 -0.764 0.847 -0.201 1.02 0.635 -0.568 -0.181 -0.522 0.926 1.109 -0.516 -0.863]

C – vector of weight values :

[1.03 -0.025 -0.528 -0.34 -0.469 -0.64 -0.259 -0.053 0.275 -0.588 -0.810 0.804 -0.082]

α_0, α_1, α_2 – the coefficients having the values :
α_0 = - 0.323, α_1 = - 0.305, α_2 = 0.496.

<u>The matrices, vectors and constants
necessary to determine the coefficient *b* :</u>

A – matrix of weight values :

$$\begin{bmatrix} 1.1072 & 2.6231 & 5.2094 & -4.4498 & 1.7052 \\ 0.5590 & 2.2139 & -1.6990 & 1.0816 & 0.8587 \\ -1.4717 & -2.6282 & -2.9165 & 0.8025 & -1.6338 \end{bmatrix}$$

B – vector of threshold values :

[-0.515 0.813 -1.374 1.575 -0.769]

C – vector of weight values :

[1.562 -1.461 -2.731 -3.637 2.197]

α_0, α_1, α_2 – the coefficients having the values :
α_0 = - 0.773, α_1 = - 0.547, α_2 = 3.475.

Assessment of the approximations

To assess accuracy of the approximations,
were used RMS values calculated from the expression :

$$RMS = \frac{1}{n} \sqrt{\frac{(Y_{\phi w} - Y_\phi)^2}{m}} \tag{8}$$

where :

RMS – error value
$Y_{\phi w}$ – standard values of ship roll amplitudes
Y_ϕ – approximated values of ship roll amplitudes
n – number of considered variants
m – number of the values approximated on the amplitude characteristics.

The accuracy analysis was carried out for :

1) values of the input parameters for which approximations were elaborated
2) the value of the initial metacentric height GM = 2 m, being out of the range of the elaborated approximations.

Values of the RMS errors regarding the elaborated relationships, for the above mentioned cases, are given in Tab.4. And, in Figs.3 to 5 the elaborated approximations are compared respective to selected variants.

Table 4

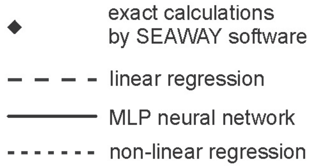
RMS error	MLP neural network	Linear regression	Non-linear regression
for the input parameters (case 1)	3.6	16.4	7.8
for GM = 2 m (case 2)	4.2	7.8	8.8

From Tab.4 and Fig.3 to 5 it results that the approximations obtained by using the MLP artificial neural network show the greatest accuracy regarding interpolation and extrapolation.

APPROXIMATION OF ROLL AMPLITUDES OF S-175 CONTAINERSHIP IN IRREGULAR WAVES

Approximations of numerically calculated significant values of roll angle amplitudes in irregular waves were performed on the basis of ship service parameters as well as wave parameters. To this end also statistical methods (linear and non-linear regression) and artificial neural networks were applied.

Explanation to Figs 3÷5 :



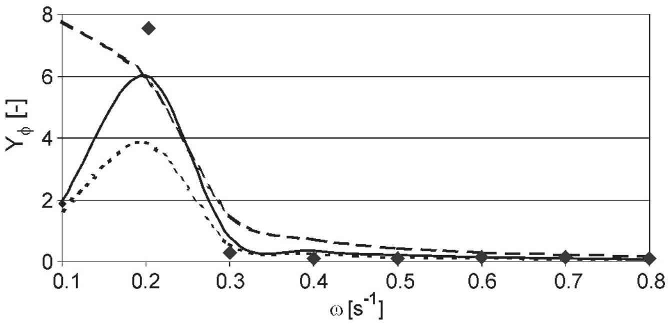


Fig. 3. *Values of the ship roll transfer function Y_ϕ , at V = 10 kts, d = 9 m, GM = 0.3 m*

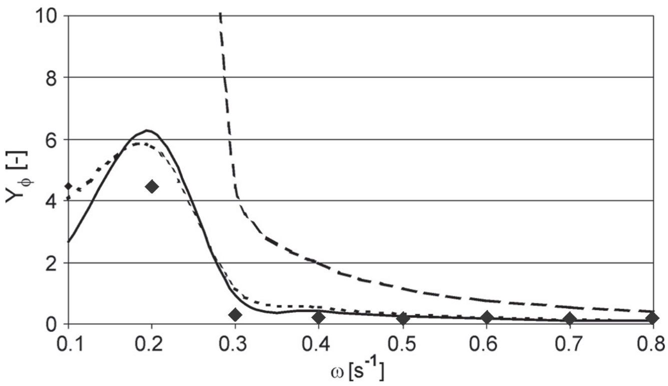


Fig. 4. *Values of ship roll transfer function Y_ϕ , at V = 20 kts, d = 7 m, GM = 0.3 m*

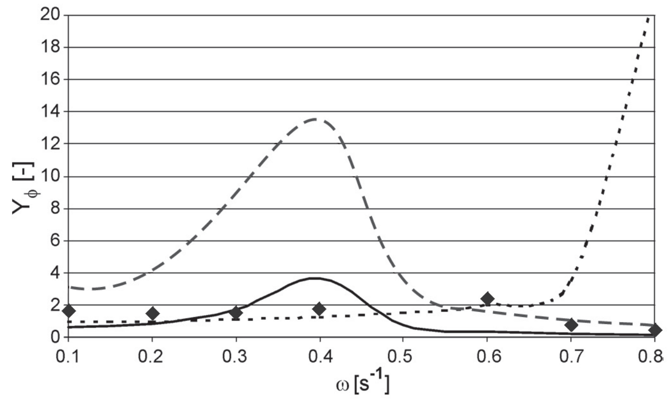


Fig. 5. *Values of ship roll transfer function Y_ϕ , at V = 10 kts, d = 8 m, GM = 2.2 m*

Approximation of ship roll amplitudes in irregular waves by means of statistical methods

When using linear regression, out of all considered relationships, the following one appeared the best :

$$\phi_{1/3} = \alpha_0 + \alpha_1 \cdot GM \cdot T \cdot Hs + \alpha_2 \cdot d \cdot GM \cdot \cdot V \cdot T \cdot Hs + \alpha_3 \cdot d^2 \cdot GM^2 + \alpha_4 \cdot GM^2 \qquad (9)$$

where :

$\phi_{1/3}$ – significant roll angle amplitude [°]

α_0 , α_1 , α_2 , α_3 , α_4 – the coefficients whose values are given in Tab.5

d, GM, V – as explained above

T – characteristic wave period [s]

Hs – significant wave height [m].

Table 5

α_0	α_1	α_2	α_3	α_4
- 0.34231	0.09918	- 0.00021	0.01735	- 1.00743

And, when applying non-linear regression, the exponential relationship of the below given form appeared the best out of all considered models :

$$\phi_{1/3} = \alpha_0 + \exp\begin{pmatrix} \alpha_1 + \alpha_2 \cdot d + \alpha_3 \cdot GM + \\ + \alpha_4 \cdot V + \alpha_5 \cdot T + \alpha_6 \cdot Hs \end{pmatrix} \qquad (10)$$

where :

α_0 , α_1 , α_2 , α_3 , α_4 , α_5 , α_6 – the coefficients whose values are given in Tab.6.

Table 6

α_0	α_1	α_2	α_3	α_4	α_5	α_6
-1.37532	-1.35646	0.07263	0.85908	- 0.01607	0.04597	0.27059

In both relationships the values of the determining coefficient prove that the proposed relationships well match up with the standard data. From variance analysis it results that both equations are essential. Simultaneously the regressions of dependent variables $\phi_{1/3}$ indicate that all components of both equations (including their free terms) are essential.

Approximation of ship roll amplitudes in irregular waves by means of artificial neural networks

Out of all considered networks, the following neural networks revealed the best approximation features :

- the MLP network of 5 inputs x 11 hidden neurons x 1 output
- the RBF (Radial Basic Functions) network of 5 inputs x 180 hidden neurons x 1 output.

Statistically significant roll angle amplitudes $\phi_{1/3}$ approximated by means of the MLP neural network can be calculated with the use of the following equation :

$$\phi_{1/3} = \frac{\left(\dfrac{1}{1 + e^{-([d, GM, V, T, Hs] \cdot S + P) \cdot A - B)}} \cdot C - \alpha_0 \right) - \alpha_1}{\alpha_2} \qquad (11)$$

where :

$\phi_{1/3}$, d, GM, V, T, Hs – as explained above

A – matrix of weight values :

$$\begin{pmatrix} 0.1387 & 0.3845 & -0.3169 & -0.1804 & -0.3674 & -0.6876 & 0.0606 & -0.3752 & 0.2717 & 0.0268 & 0.0807 \\ 0.1743 & -3.5447 & -2.1067 & -1.0170 & 0.1016 & -0.8214 & -1.3072 & 0.1762 & 3.2725 & -0.2252 & 2.8329 \\ 0.3839 & -0.9977 & 0.2728 & 0.0992 & 0.5148 & -0.2305 & -0.3881 & 1.5009 & -0.2839 & 0.6204 & 0.1285 \\ -0.4993 & 0.9608 & -1.3266 & -2.4275 & 1.0287 & -0.2497 & -3.1174 & -0.1543 & 3.1220 & -0.1918 & 3.7166 \\ 0.3733 & 0.9096 & 0.9033 & -0.2308 & 0.3956 & -0.0745 & 0.4807 & -1.1985 & 0.2697 & 0.6046 & -0.1800 \end{pmatrix}$$

B – vector of threshold values :

[0.2133 2.9327 -0.6466 -1.6343 -0.2292 0.7501 -2.5607 -1.9524 2.1205 0.9054 2.9620]

C – vector of weight values :

[0.2687 -1.7393 -1.0205 -1.7328 0.3104 0.7946 2.5177 -1.0679 -2.2512 0.7164 2.6939]

S – vector of values :

[0.500 0.833 0.050 0.125 0.400]

P – vector of displacement values :

[-3.500 -0.250 0.000 -0.813 -0.800]

α_0, α_1, α_2 – coefficients having the values :

α_0 = - 0.2061, α_1 = - 0.017, α_2 = 0.102.

To calculate values of the ship roll amplitudes $\phi_{1/3}$ approximated with the use of the RBF neural network one can apply the following generalized equations :

$$\phi_{1/3} = ([d, GM, V, T, Hs] \cdot A + B) \cdot C \qquad (12)$$

where :

A – [5 x 180] matrix of weight values
B – 180-element vector of constants
C – 180-element vector of weight values.

Input values for the equation (12) were normalized to be contained within the interval : 0...1, and the neurons of hidden layer were activated by means of an exponential function. Because of too large dimensions of the matrix *A* and remaining vectors it was decided not to present values of elements of the matrices and vectors as well as values of normalizing coefficients.

Values of correlation coefficients of both networks show that both proposed models well match up with standard values.

Assessment of the approximations

To assess accuracy of the approximations, RMS' values calculated from the following expression, were applied :

$$RMS' = \sqrt{\frac{(\phi_w - \phi_{1/3})^2}{n}} \qquad (13)$$

where :

RMS' – error value
ϕ_w – standard values of ship roll amplitudes
$\phi_{1/3}$ – approximated values of ship roll amplitudes
n – number of considered variants.

The accuracy analysis was carried out for :

1) values of the input parameters for which approximations were elaborated
2) the value of the initial metacentric height GM = 2 m, and that of the significant wave height Hs = 3 ÷ 6 m, being behind the range of the elaborated approximations.

Values of the RMS' errors associated with the elaborated relationships for the above mentioned cases are given in Tab.7.

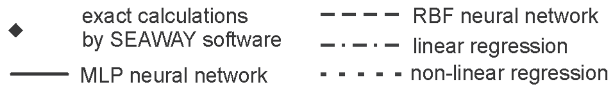
Table 7

RMS' error	MLP neural network	RBF neural network	Linear regression	Non-linear regression
for the input parameters (case 1)	0.15°	0.21°	0.76°	0.83°
for the values behind the range of input parameters (case 2)	0.69°	5.32°	1.99°	2.53°

From the table it results that in both cases the most accurate appear the approximations obtained with the use of the MLP artificial neural network. The approximations elaborated by means of linear regression are loaded with a small error in the case of interpolation, and with rather large one as far as extrapolation operations are concerned.

Addtionally, to more precisely verify the proposed relationships the falsification method was applied [7]. To this end, such ranges of input parameters were searched for which the elaborated approximations appeared the least accurate. Results of the investigations are graphically presented in Fig.6÷÷8 (for interpolation), and in Fig.9 (for extrapolation). The diagrams confirm that in both cases the approximation with the use of the MLP artificial neural network appears the most accurate.

Explanation to Figs 6÷9 :



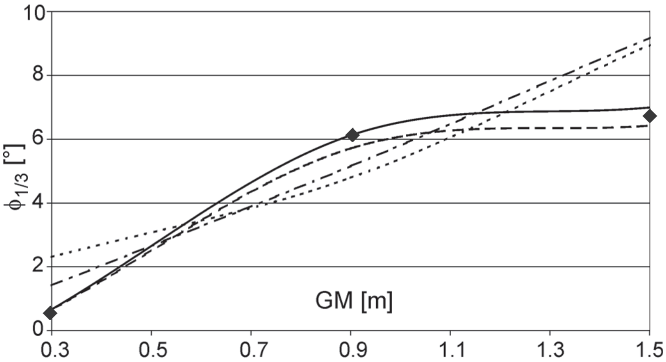


Fig. 6. *Significant ship roll amplitudes $\phi_{1/3}$, at GM = var , d = 7 m , V = 0 , T = 14.5 s , Hs = 4 m.*

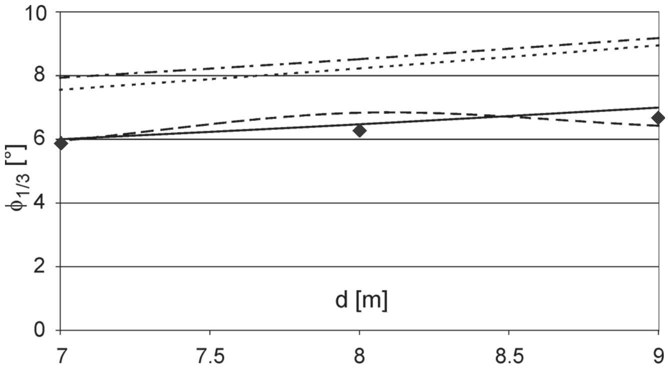


Fig. 7. *Significant ship roll amplitudes $\phi_{1/3}$, at d = var , GM = 1.5 m , V = 0 , T = 14.5 s , Hs = 4 m*

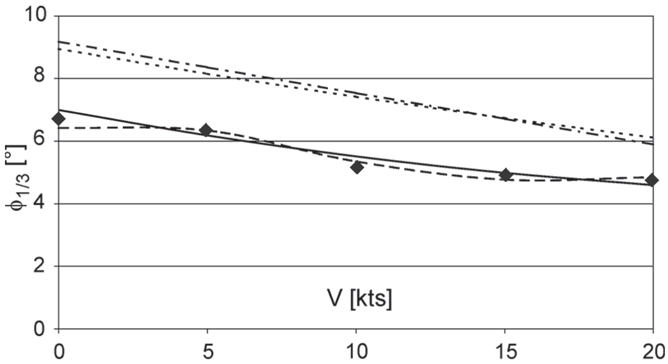


Fig. 8. *Significant ship roll amplitudes $\phi_{1/3}$, at V = var , d = 9 m , GM = 1.5 m , T = 14.5 s , Hs = 4 m*

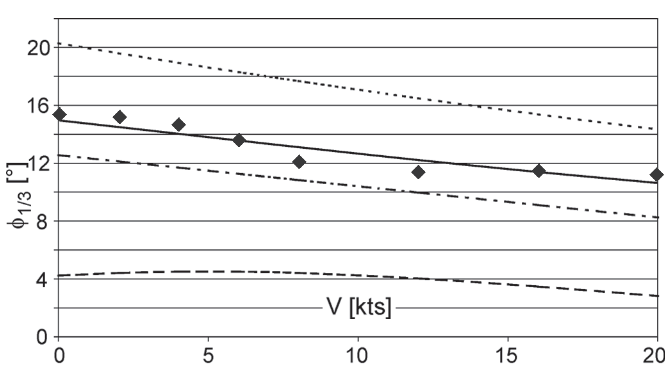


Fig. 9. *Significant ship roll amplitudes $\phi_{1/3}$, at V = var , d = 9 m , GM = 2 m , T = 9.5 s , Hs = 6 m*

ACCURACY ASSESSMENT OF THE ELABORATED APPROXIMATIONS WITH A VIEW OF PREDICTING SHIP ROLL IN IRREGULAR WAVES

The above presented relationships make it possible to approximate ship roll in regular and irregular waves. The first method allows to approximate roll amplitude characteristics on the basis of the ship service parameters (d, GM, V) and next to calculate any statistical values of roll amplitudes for any wave spectrum. And, the second method makes it possible to directly approximate ship roll amplitudes in irregular waves.

In this part of the investigations the two approaches were compared regarding their accuracy in predicting ship roll motion in irregular waves against the standard values. The analysis was performed on assuming the values of input parameters to be contained within :

- the ranges of the parameters for which the approximations were elaborated
- behind the ranges of the parameters, in order to test this way extrapolation capabilities of the elaborated relationships.

In the first case the calculations were carried out for :

d = 8 m   GM = 0.9 m   Hs = 4 m.

And in the second case for :

d = 9.5 m   GM = 2 m   Hs = 6 m.

In both cases the characteristic wave period T was assumed equal to10 s, and the ship speed V within the range from 0 to 20 knots.

The analysis was performed for the approximations whose accuracy was the greatest and which were described by :

- for ship roll in regular waves – the relationship (2) having the coefficients approximated with the use of (3), (4), and (7)
- for ship roll in irregular waves – the relationships (9) and (11).

In order to determine ship roll in irregular waves the expression (2) and the wave energy spectrum recommended by ITTC was used. Results of the calculations are graphically presented in Fig.10 and 11.

Explanation to Figs 10,11 :

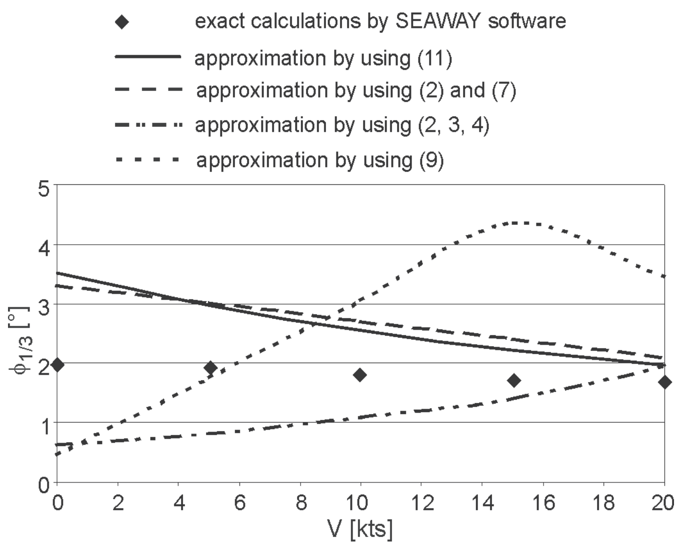


Fig. 10. *The significant ship roll amplitudes $\phi_{1/3}$, at V = var , d = 8 m , GM = 0.9 m , H = 4 m , T = 10 s*

From the diagrams given in Fig.10 and 11 it results that both presented approaches show similar interpolation capabilities. The extrapolation of roll amplitudes in irrerular waves by using (9) and (11) yields rather accurate results against the standard values. Whereas the application of the approximation (2) to determine significant roll amplitudes in irregular waves brought in erronous solutions, especially in the case of extrapolation.

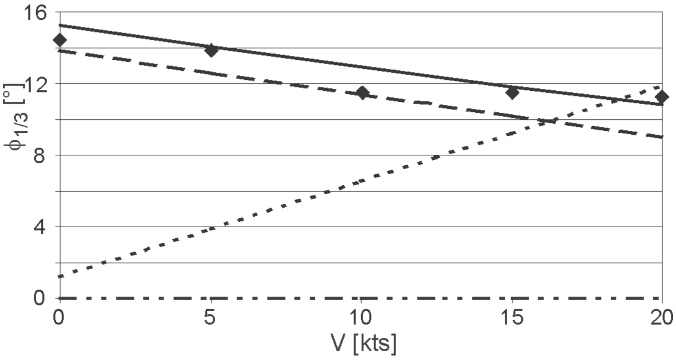


Fig. 11. *The significant ship roll amplitudes $\phi_{1/3}$, at V = var , d = 9.5 m , GM = 2 m , H = 6 m , T = 10 s*

RECAPITULATION

- In the paper were presented approximations of ship roll in regular and irregular waves by means of artificial neural networks and linear and non-linear regression methods, on the basis of main ship service parameters (speed, draught, initial transverse metacentric height), and – in the case of approximation ship roll in irregular waves – wave parameters (significant height and characteristic period of waves). The example approximations were elaborated for S-175 model containership.
- From the performed investigations it results that the relationships obtained by means of MLP artificial neural networks show the largest accuracy regarding interpolation and extrapolation of ship roll amplitudes both in regular and irregular waves.
- Next, basing on the above mentioned approximations, two approaches to predicting ship roll amplitudes in irregular waves were analyzed :
  - approximation of roll amplitudes in regular waves, and next calculation of their significant values in irregular waves
  - direct approximation of roll amplitudes in irregular waves.
- From the performed investigations it results that the approximation of ship roll angles by means of amplitude characteristics yields satisfactory results only in the case of interpolation. Whereas the second approach provides relatively accurate solutions both in the case of interpolation and extrapolation.
- The presented method makes it possible to approximate ship roll angle amplitudes calculated by using exact numerical methods, and they can be also applied to determine optimum ship voyage routes. The proposed approach may be also used to approximate real values of roll angle amplitudes on the basis of data recorded onboard the ship during its service.

NOMENCLATURE

B - ship breadth
C_B - block coefficient
d - ship draught
F_n - Froude number
GM - initial transverse metacentric height

H_s - wave height
L - ship length between perpediculars
T - characteristic wave period
V - ship speed
Z_G - height of the ship gravity centre
∇ - ship volumetric displacement
λ - wave length
ϕ - roll amplitude
ω - wave frequency

Akcronyms

ICLL - International Convention on Load Lines
MLP - Multilayer Perceptron
RAO - Response Amplitude Operator
RBF - Radial Basic Functions
UBS - Universal Bulk Cargo Ship

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FOREIGN conference

Task force 2 workshop of European Federation of Corrosion (EFC)

Under auspices of EFC technical scientific projects are carried out as the task force 2 dealing with :

Corrosion and protection of steel structures against corrosion

The activity is supervised by Prof. K. Darowicki, Head of the Department of Electrochemistry, Corrosion and Materials Engineering, Chemical Faculty, Gdańsk University of Technology.

On 20-21 June 2004 in Prague, the Department in cooperation with the Department of Metals and Corrosion Engineering, Czech's Institute of Chemical Technology, organized the workshop on :

Industrial heat exchanger problems – – Non-destructive Testing (NDT) inspection

Results of altogether 17 projects were presented, 12 out of which were prepared by scientific workers from Gdańsk University of Technology. It was the following presentations :

- Darowicki K., Felisiak W.: *Applications of ellipsometry in corrosion measurements*
- Darowicki K., Kawula J.: *Applications of conducting polymers to corrosion protection – a review*
- Darowicki K., Mirakowski A.: *Use of acoustic emission to detect the pitting corrosion of aluminum*
- Darowicki K., Orlikowski J., Arutunow A.: *Detailed analysis of the passive-active transition during the passive layer cracking using dynamic electrochemical impedance spectroscopy*
- Darowicki K, Ślepski P.: *Electrode impedance measurement of non-stationary systems*
- Darowicki K., Szociński M.: *Impedance investigation of organic coatings subjected to alternating mechanical stress impact*
- Darowicki K., Zieliński A.: *Application of electrochemical noise technique in corrosion monitoring*
- Klenowicz Z., Darowicki K., Krakowiak S., Krakowiak A.: *Flow monitoring shows the way to diminish erosion of tube outer surfaces*
- Krakowiak S., Darowicki K., Ślepski P.: *Pitting corrosion – practical experience and laboratory investigations*
- Miszczyk A., Darowicki K.: *Intercoat adhesion monitoring using impedance spectroscopy*
- Orlikowski J., Krakowiak S., Ślepski P., Darowicki K., Arutunow A.: *Digital monitoring system of corrosion in electrochemical environments*
- Żakowski K.: *A time-frequency method for detection of electromagnetic field interference on metal constructions*.

Apart from the above, 4 reports were presented by scientists from Chech Republic and one from Portugal.