Approximation of pitching motion of S-175 containership in irregular waves on the basis of ship's service parameters

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ABSTRACT

This paper presents approximations of pitching motion of S-175 containership in irregular waves within the full range of ship's service parameters. It continues the research described in [1] dealing with application of artificial neural networks to predict ship's motions. Reference pitch values were calculated by means of SEAWAY software based on accurate numerical methods. Approximating function was elaborated by using the artificial neural networks.

Keywords : seakeeping qualities, pitching, artificial neural networks, approximation, ship service parameters, irregular waves

INTRODUCTION

In the paper [1] were presented approximations of ship roll in regular and irregular waves, obtained on the basis of ship service parameters and wave parameters. Such approximations may find application a.o. in ship voyage routing problems as well as in controlling ship seakeeping ability during its service. From the there presented considerations it results that to approximate ship's roll statistical methods and artificial neural networks can be applied, and, the highest approximation accuracy, both within and outside the assumed range of input parameters, was obtained by applying the functions elaborated by means of artificial neural networks.

In this paper a continuation of the above mentioned research was presented. It was aimed at checking if artificial neural networks may be used to approximate another ship motion, namely pitching. Taking into account that in [1] the best results were obtained for ship's roll in irregular waves in this research the author decided to approximate ship pitching motion in irregular waves only. Additionally, the pitch approximations were expanded onto the full range of wave encounter angles.

SIGNIFICANT PITCH AMPLITUDES OF THE SHIP

To approximate the ship's pitching the method presented in [1,6] was applied. The reference data were determined by using SEAWAY software. In Fig.1 and 2 are presented the pitch transfer functions calculated by means of the SEAWAY, in comparison with experimental results; from the comparison it can be concluded that the SEAWAY provides sufficiently accurate results for the kind of ship motions in question.

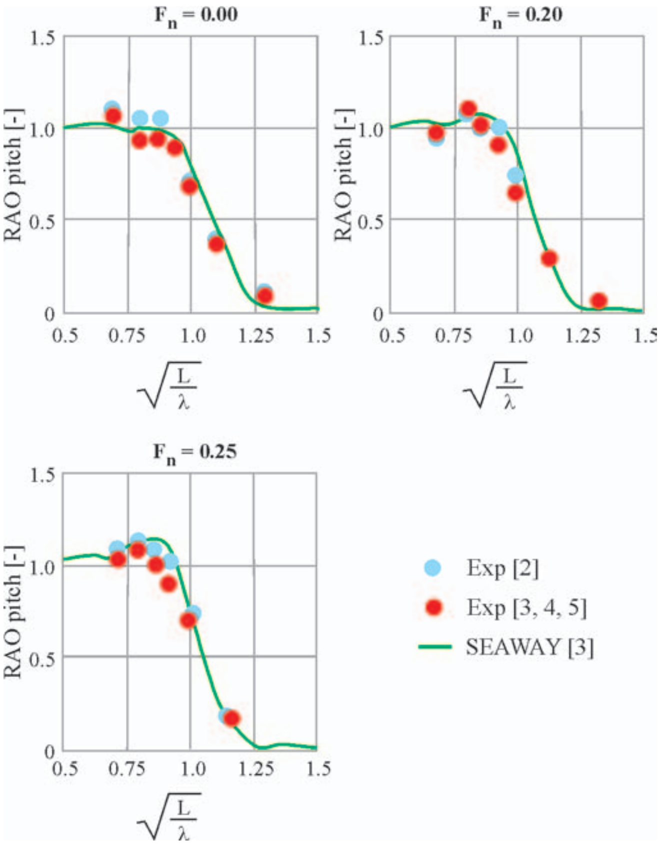

Fig. 1. Pitch amplitudes of the fast cargo ship „S.A. van der Stel" of L = 152.5 m , B = 22.80 m , d = 9.14 m , C_B = 0.563 , Z_G = 9.14 m , sailing in heading waves, acc. [2,3,4,5] .

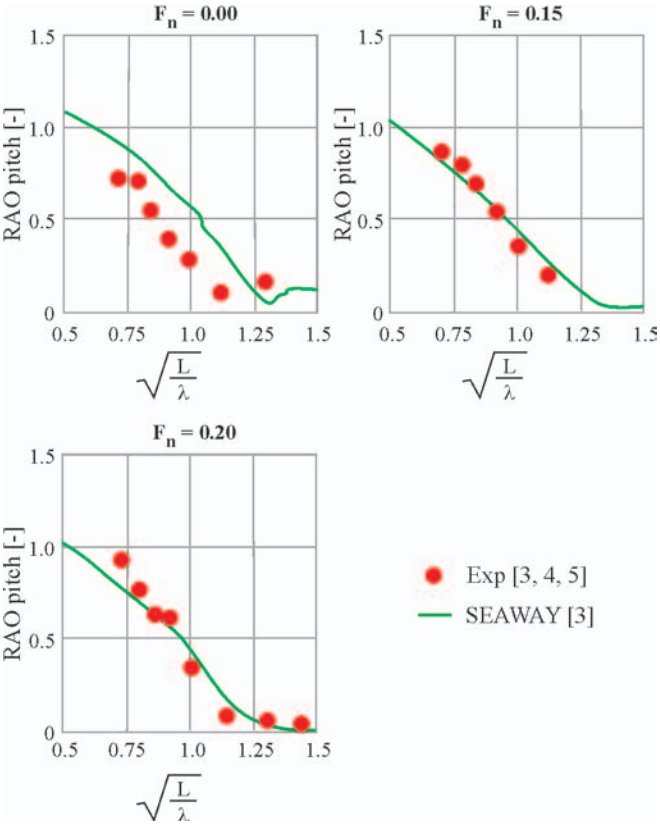

***Fig. 2.** Pitch amplitudes of the fast cargo ship „S.A. van der Stel" of L = 152.5 m , B = 22.80 m , d = 9.14 m , C_B = 0.563 , Z_G = 9.14 m , sailing in following waves, acc. [3,4,5] .*

Calculations of the significant pitch $\psi_{1/3}$ were performed, similarly as in [1], for the example S-175 containership of the following main dimensions :

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

The following ranges of ship service parameters and wave parameters were taken into account :

- ship's speed V : from 0 to 20 kn, at every 5 kn
- ship's draught d : from 5 m to 11 m, at every 2 m
- wave encounter angle β = 0° (head wave), 10, 20, 30, 60, 90, 120, 150, 160, 170, 180° (following wave)
- significant wave height Hs : from 2 m to 5 m, at every 1 m
- characteristic wave period T : from 6.5 s to 14.5 s, at every 2 s.

As a result of the calculations was obtained the data set containing 4400 records which was further used to elaborate pitch approximations. In Fig.3 through 6 are presented selected

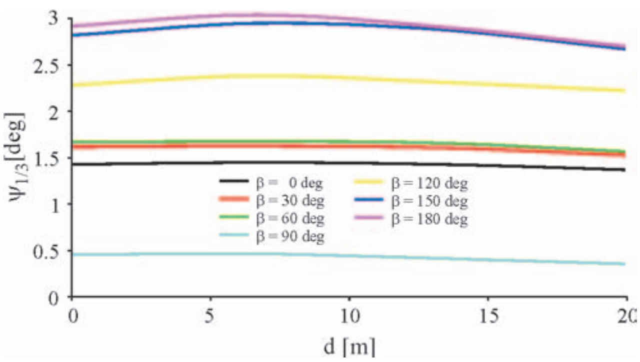

***Fig. 3.** Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership, d = var , β = var , V = 20 kn , Hs= 5 m , T = 10.5 s .*

relationships between the pitch amplitudes calculated this way, ship service parameters and wave parameters, in different combinations.

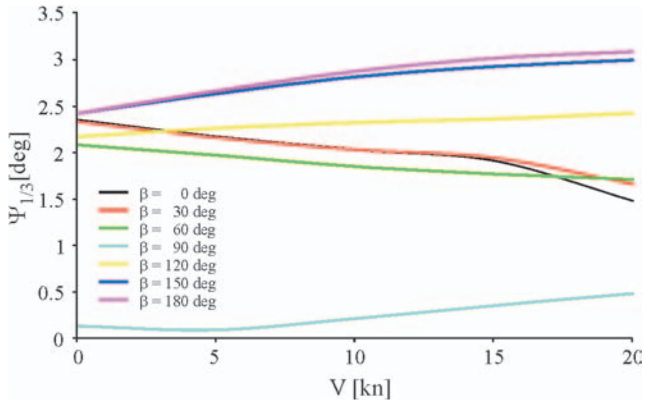

***Fig. 4.** Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership, V = var , β = var , d = 7 m , Hs = 5 m , T = 10.5 s .*

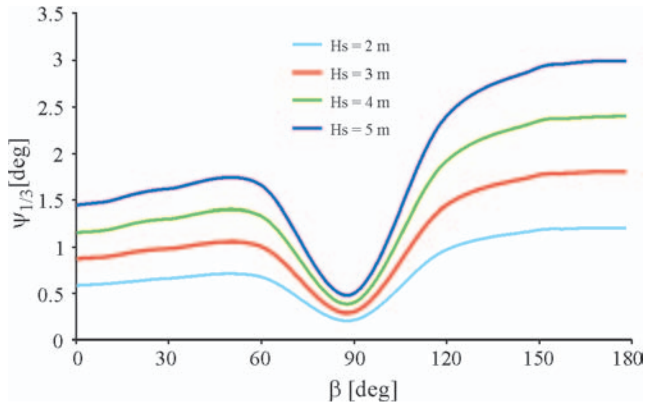

***Fig. 5.** Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership, β = var , Hs = var , d = 7 m , V= 20 kn , T = 10.5 s .*

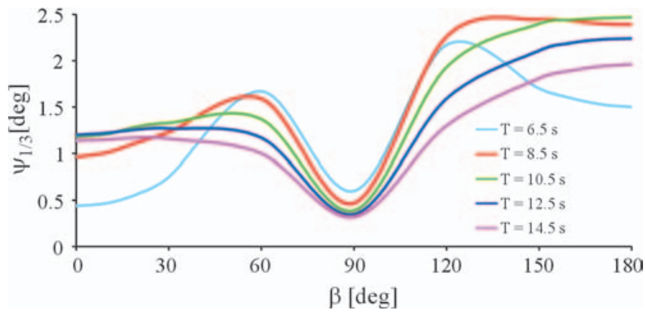

***Fig. 6.** Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership, β = var , T = var , d = 7 m , V= 20 kn , Hs = 5 m .*

PITCH APPROXIMATION BY MEANS OF ARTIFICIAL NEURAL NETWORKS

In accordance with [1] the function approximating the significant pitch amplitudes $\psi_{1/3}$ can be determined by using the following formula:

$$X \xrightarrow{\Psi_{1/3}} Y \tag{1}$$

where :

X – set of assumed ship service parameters (input)
Y – set of values of significant pitch amplitudes (output) calculated by using exact methods
$\psi_{1/3}$ – searched function approximating the significant pitch amplitudes.

It was assumed that the pitch approximations had to be elaborated for the following parameters :

- ✩ ship draught d
- ✩ ship speed V
- ✩ wave encounter angle β
- ✩ significant wave height Hs
- ✩ characteristic wave period T.

For determining a function approximating the pitch amplitudes $\psi_{1/3}$ the artificial neural networks were applied. In this research the following types of them were tested :

- ❖ Multilayer Perceptron (MLP) of a sigmoidal activation function
- ❖ Generalized Regression Neural Network (GRNN) – a regression network
- ❖ Radial Basic Function Network (RBF).

The phase of searching for the most appropriate network contained the following steps :

- ➢ description of the best network structure by means of genetic algorithms
- ➢ learning a network (usually by using the back-propagation method)
- ➢ testing a network
- ➢ assessment of approximation accuracy obtainable within a network on the basis of the testing data.

To validate and test the networks the set containing 50 % amount of the variants deleted by sampling from the learning data set.

The MLP network of the structure : 5 (inputs) x 7 (hidden neurons) x 1 (output), appeared the most accurate (Fig.7), being characterized by:

- ✦ the smallest learning RMS error = 0.12°
- ✦ the smallest testing RMS error = 0.13°

Values of RMS error were calculated from the formula (2) :

$$\mathrm{RMS} = \sqrt{\frac{(\Psi_w - \Psi_{1/3})^2}{n}} \qquad (2)$$

where :

ψ_w – reference values of significant pitch amplitudes used for learning or testing a neural network
$\psi_{1/3}$ – approximated significant pitch amplitudes
n – number of records.

The calculations were carried out by using the package STATISTICA Neural Networks.

The searched function approximating the significant pitch amplitudes $\psi_{1/3}$ elaborated by means of the above mentioned neural network was represented analytically with the use of the equation (3):

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

where :

d – ship draught [m]
Hs – significant wave height [m]
T – characteristic wave period [s]
V – ship speed [kn]
β – wave encounter angle [deg]
$\psi_{1/3}$ – significant pitch amplitude [deg].

A – matrix of weighting factors :

$$\begin{bmatrix} 0.320 & -0.082 & 0.111 & 0.059 & 0.253 & -0.348 & 3.170 \\ 0.265 & -0.193 & 1.283 & 0.182 & 0.332 & 0.033 & 0.291 \\ 3.872 & 16.732 & -2.413 & -20.422 & -0.447 & -3.375 & -1.039 \\ 0.390 & 1.056 & 0.831 & -0.944 & -1.138 & -0.124 & 0.133 \\ -3.097 & -0.575 & -4.895 & 0.620 & 0.655 & 2.671 & 0.647 \end{bmatrix}$$

B – vector of threshold values :

$$[2.58 \quad 9.69 \quad 2.75 \quad -12.15 \quad -0.46 \quad -2.61 \quad -2.10]$$

C – vector of weighting factor values :

$$\begin{matrix} 2.9538 \\ -4.5864 \\ -1.8491 \\ -4.5384 \\ -1.3287 \\ 3.7736 \\ 0.7011 \end{matrix}$$

S – matrix of coefficients :

$$\begin{bmatrix} 0.01667 & 0 & 0 & 0 & 0 \\ 0 & 0.0500 & 0 & 0 & 0 \\ 0 & 0 & 0.0056 & 0 & 0 \\ 0 & 0 & 0 & 0.3333 & 0 \\ 0 & 0 & 0 & 0 & 0.1250 \end{bmatrix}$$

P – vector of shift values :

$$[-0.83333 \quad 0 \quad 0 \quad -0.667 \quad -0.8125]$$

α_0, α_1, α_2 – coefficients having the values :

$\alpha_0 = -1.37$ $\quad$ $\alpha_1 = -0.0065$ $\quad$ $\alpha_2 = 0.3268$

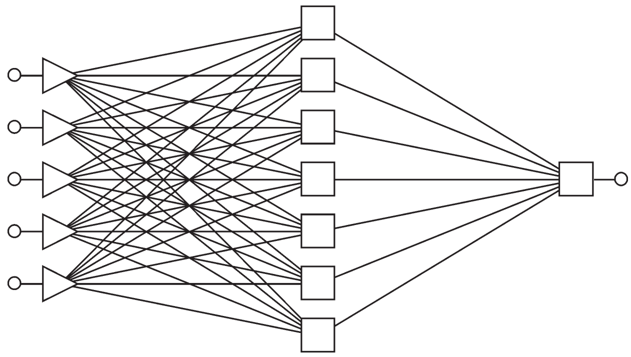

Fig. 7. *Structure of the artificial neural network approximating pitch amplitudes .*

Sensitivity analysis of the elaborated neural network showed that all input parameters have been important, at the following decreasing significance :

- ★ the wave encounter angle β
- ★ the significant wave height Hs
- ★ the characteristic wave period T
- ★ the ship draught d
- ★ the ship speed V.

In Fig.8 through 10 is presented the comparison of the pitch approximations calculated by applying Eq. (3) with the values calculated by using the exact methods included in the SEAWAY software. The there presented data were not used for modelling the neural network. From the diagrams it results that the function approximating the pitch amplitudes described by Eq. (3) is very exact and shows the same trends as the data.

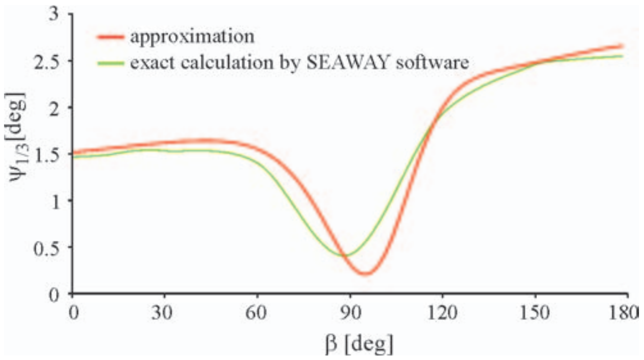

Fig. 8. *The approximations of significant pitch amplitudes, compared with the testing values, for :* β *= var , V = 20 kn , T = 12.5 s , Hs = 5 m , d = 11 m .*

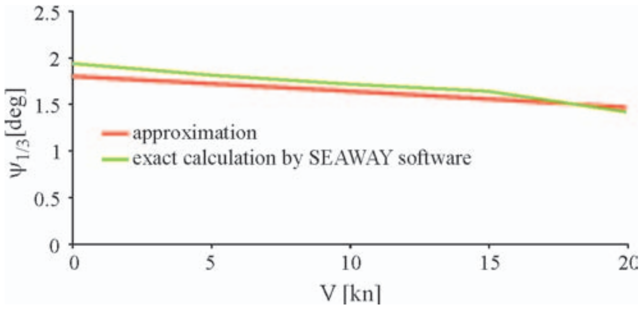

Fig. 9. *The approximations of significant pitch amplitude, compared with the testing values, for : V = var ,* β *= 0 deg , T = 12.5 s , Hs = 5 m , d = 11 m .*

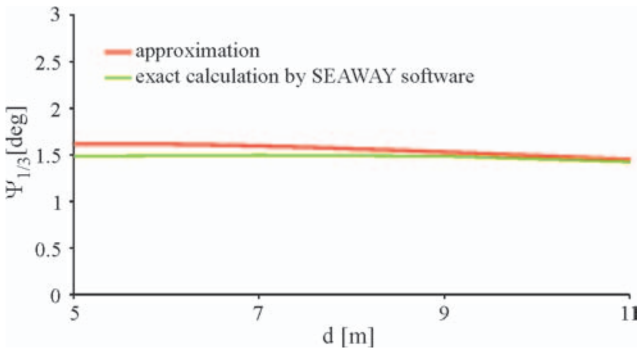

Fig.10. *The approximations of significant pitch amplitudes, compared with the testing values, for : d = var ,* β *= 0 deg , T = 12.5 s , Hs = 5 m , V = 20 kn .*

RECAPITULATION

- In this paper are presented the approximations of pitch amplitudes, based on the following ship service parameters :

  ⇒ ship speed
  ⇒ ship draught
  ⇒ wave encounter angle,

  and the wave parameters :

  ➢ significant wave height
  ➢ characteristic wave period,

  considered within a broad range of the above specified parameters.
- The pitch amplitude approximating function was elaborated with the use of artificial neural networks and presented in the analytical form. The function is highly accurate as compared with the testing data calculated by means of the exact methods.
- The reference pitch amplitude values were calculated by using exact numerical methods. On the assumption that the values do not significantly differ from real ship's pitching data, the presented approach can be applied to predict ship's pitch on the basis of the data recorded on board the ship.
- The obtained research results confirm that the artificial neural networks can be applied to approximate such ship response as pitch and roll (presented in [1]) both in the phase of ship's design and operation. [1].

NOMENCLATURE

B – ship breadth
C_B – ship block coefficient
d – ship draught
F_n – Freude Number
GM – initial transverse metacentric height
Hs – significant wave height
L – ship length between perpendiculars
RAO – Response Amplitude Operator
T – characteristic wave period
V – ship speed
Z_G – height of ship centre of gravity
β – wave encounter angle
λ – wave length
$\psi_{1/3}$ – approximated significant pitch amplitude
ψ_w – reference significant pitch amplitude

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