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Application of Artificial Neural Networks to investigations of ship seakeeping ability

SUMMARY

In order to optimize the ship design at its conceptual and preliminary stages with taking into account also seakeeping criteria, simple and simultaneously exact relationships between the basic ship design parameters and seakeeping ability are necessary. The wave-induced motions of the ship in irregular waves as well as phenomena accompanying the motions, are determined on the basis of the frequency transfer functions of the ship motions in regular waves.

In this paper an approximation method is presented for determination of such transfer functions with the use of the Artificial Neural Networks (ANNs). The attached results of numerical calculations show that the method provides exact data for ships of very different sizes, within wide ranges of ship velocity and direction of wave relative to the ship.

Continuation of the first part of the paper published in the Polish Maritime Research No.3(29), September 2001

Part II

EXAMPLE FREQUENCY TRANSFER FUNCTIONS OF WAVE-INDUCED SHIP MOTIONS CALCULATED BY USING THE ARTIFICIAL NEURAL NETWORKS

The calculation method of the frequency transfer functions of the wave-induced ship motions by means of Artificial Neural Networks (ANNs), presented in Part I of the paper, was applied to computation of rolling, heaving and pitching of the example ship of the following main particulars :

$L = 161.0$ m, $B = 23.0$ m, $d = 7{,}2$ m, $\nabla = 20\,000$ m^3, $C_B = 0.75$.

The calculations of the motions were performed for various values of the ship speed V and wave direction angle β_w relative to the ship. The frequency transfer functions generated by the ANNs were compared with the model characteristics calculated by using GRIM software. Results of the computations are presented in Fig.4, 5 and 6.

The ANN „learned" on the basis of the model frequency transfer functions of wave-induced ship motions was used for generating the wave-induced motion frequency transfer functions of several ships of different values of the design parameters (specified in Tab.2 and 3, Part I) as follows : $L/B = 6.0$; 6.5; 7.0; 7.5; $B/d = 2.8$; 3.0; 3.2; 3.4; $\nabla = 37\,000 \div 52\,000$ m^3 and the constant value of the block coefficient $C_B = 0.75$. Results of the calculations are presented in Fig.7, 8 and 9.

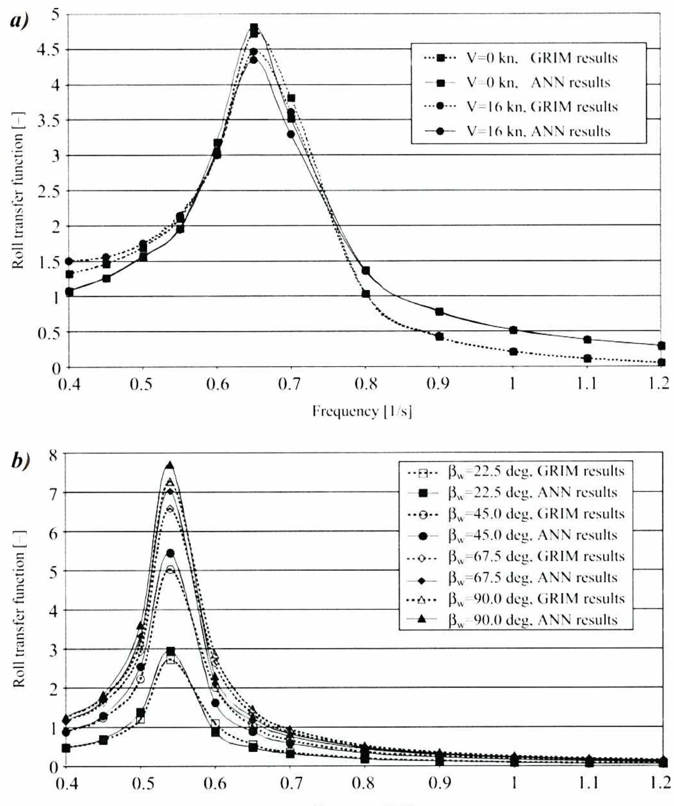

***Fig.4.** Roll frequency transfer functions*
***a)** at different ship speeds V, and $\beta_w = 90°$*
***b)** at different wave direction angles β_w, and $V = 12$ knots*

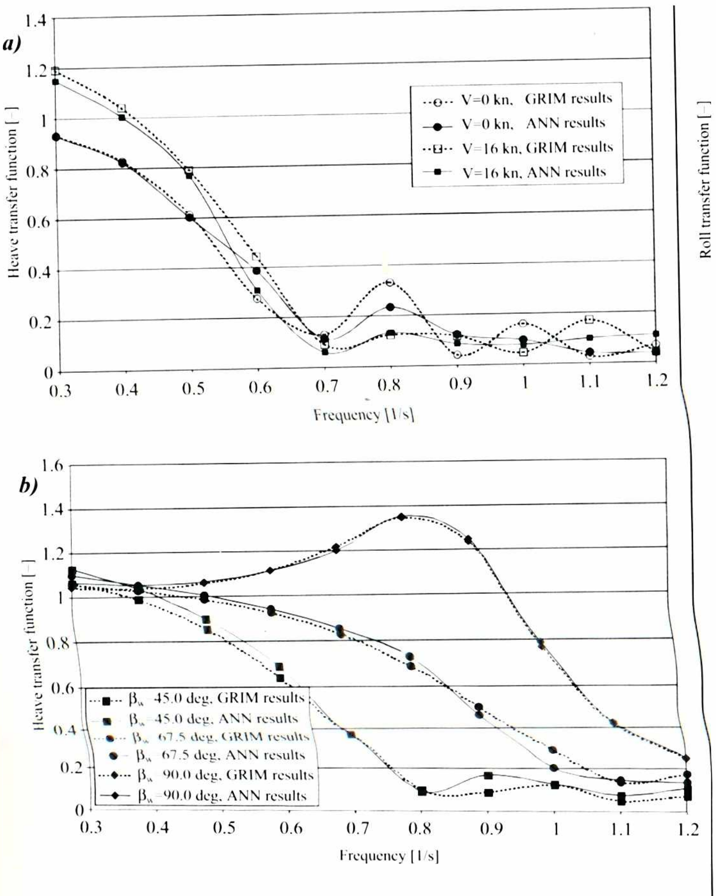

Fig.5. *Heave frequency transfer functions*
a) *at different ship speeds V, and $\beta_w = 0°$*
b) *at different wave direction angles β_w, and $V = 12$ knots*

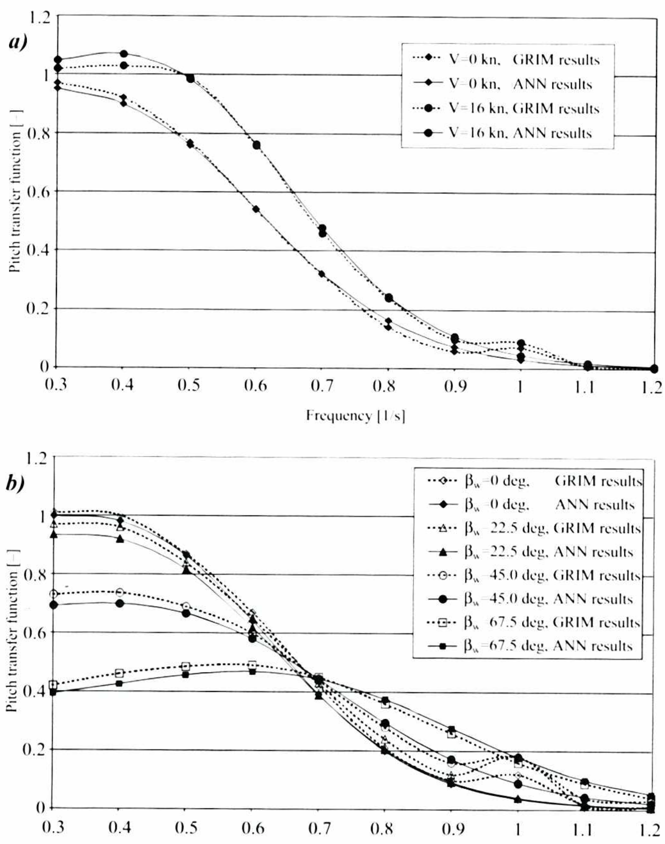

Fig.6. *Pitch frequency transfer functions*
a) *at different ship speeds V, and $\beta_w = 0°$*
b) *at different wave direction angles β_w, and $V = 8$ knots*

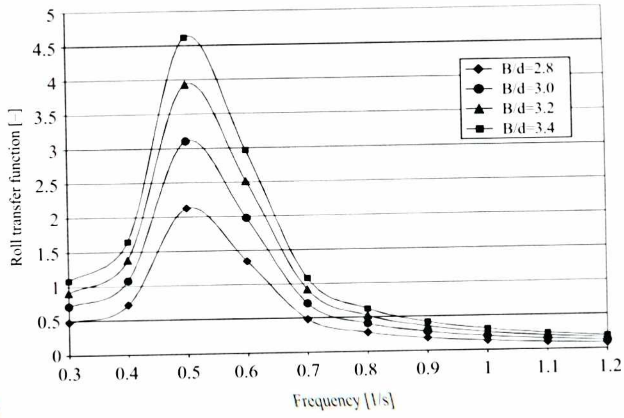

Fig.7. *Influence of B/d and ∇ on the roll frequency transfer functions of the investigated ship of $L = 192.4$ m, $B = 29.6$ m, $L/B = 6.5$, $C_B = 0.75$, $GM = 3.0$ m, and B/d = var, ∇ = var, at $\beta_w = 90°$ and $V = 4$ knots*

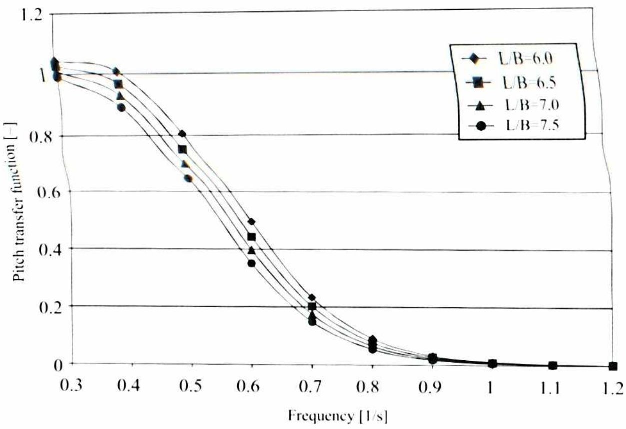

Fig.8. *Influence of L/B and ∇ on the pitch frequency transfer functions of the investigated ship of $B = 29.6$ m, $d = 10.6$ m, $B/d = 2.8$, $C_B = 0.75$, and L/B = var, ∇ = var, at $\beta_w = 0°$ and $V = 4$ knots*

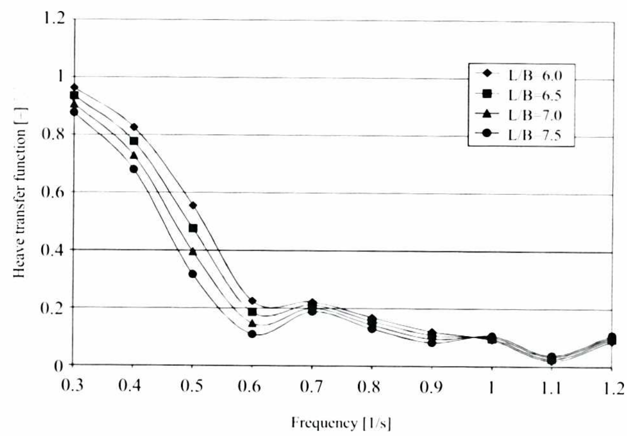

Fig.9. *Influence of L/B and ∇ on the heave frequency transfer functions of the investigated ship of $B = 29.6$ m, $d = 10.6$ m, $B/d = 2.8$, $C_B = 0.75$, and L/B = var, ∇ = var, at $\beta_w = 0°$ and $V = 4$ knots*

PHENOMENA ACCOMPANYING THE WAVE-INDUCED SHIP MOTIONS

For optimization of the ship hull form and main dimensions, with taking into account seakeeping ability criteria it is necessary to know the ship motions in irregular waves.

By applying the linear ship motion theory [4] the random ship motions induced in irregular waves are determined on the basis of known ship motions in regular waves and spectral density function of irregular wave energy. The variance of wave-induced ship motions is then expressed as follows :

$$D_{UU}(\beta_W, F_N) = \int_0^\infty \left|Y_{U\varsigma}(\omega_E, \beta_W)\right|^2 S_{\varsigma\varsigma}(\omega_E)\, d\omega_E \qquad (15)$$

where :

D_{UU} - variance of the motion U,U =1, 2, ..,6

β_w - wave direction angle respective to ship

F_N - Froude number of the ship sailing at the speed V

$Y_{U\zeta}$ - amplitude characteristics of the motion U of the ship on regular wave, sailing with the speed V at the course angle β_w respective to the wave direction

ω_E - encounter frequency of wave-induced ship motions

$S_{\zeta\zeta}(\omega_E)$ - spectral density function of irregular waves energy, whose value mainly depends on the significant wave height H_S and wave period T

$$\omega_E = \omega - kV\cos\beta_W \qquad (16)$$

ω - regular wave frequency

$k = \frac{\omega^2}{g}$ - wave number

g - gravity acceleration

V - ship speed.

Knowing D_{UU} one can calculate the U-th motion amplitude at an assumed value of exceedance probability, e.g. assuming that :

$$D_{1/3} = 2\sqrt{D_{UU}} \qquad (17)$$

In the similar way one can determine variances of the phenomena accompanying the wave-induced ship motions (i.e. slamming, deck wetness, propeller emergence, accelerations). The amplitude characteristics of the phenomena can be expressed with the use of the amplitude characteristics of the ship motions, for example :

for accelerations :

$$Y_{HL\varsigma}(i\omega_E, \beta_W) = \omega_E^2\left[Y_{x\varsigma} - y_A k Y_{\psi\alpha} + \left(z_A k - \frac{\omega^2}{\omega_E^2}\right) Y_{\Theta\alpha}\right]$$

$$Y_{HT\varsigma}(i\omega_E, \beta_W) = \omega_E^2\left[Y_{y\varsigma} + x_A k Y_{\psi\alpha} - \left(z_A k - \frac{\omega^2}{\omega_E^2}\right) Y_{\phi\alpha}\right]$$

$$Y_{V\varsigma}(i\omega_E, \beta_W) = \omega_E^2\left[Y_{z\varsigma} - x_A k Y_{\theta\alpha} + y_A k Y_{\phi\alpha}\right] \qquad (18)$$

for deck wetness :

$$Y_{DW\varsigma}(i\omega_E, \beta_W) = Y_{z\varsigma} - x_{DW} k Y_{\Theta\alpha} + y_{DW} k Y_{\phi\alpha} + - \varsigma_A \cdot \exp\left[-i\left(x_{DW} k \cos\beta_W + y_{DW} k \sin\beta_W\right)\right] \qquad (19)$$

where :

$Y_{HL\varsigma}, Y_{HT\varsigma}, Y_{V\varsigma}$ - frequency transfer functions of acceleration components (horizontal-longitudinal, horizontal-transverse, vertical, respectively)

$Y_{x\varsigma}, Y_{y\varsigma}, Y_{z\varsigma}, Y_{\phi\alpha}, Y_{\theta\alpha}, Y_{\psi\alpha}$ - frequency transfer functions of wave-induced motions (surge, sway, roll, heave, pitch, yaw, respectively)

x_A, y_A, z_A - coordinates of the point at which acceleration due to wave-induced motions is calculated

x_{DW}, y_{DW}, z_{DW} - coordinates of the point at which deck wetness due to wave-induced motions is calculated

ς_A - regular wave amplitude

$i = \sqrt{-1}$

The frequency transfer functions of accelerations, deck wetness and other phenomena accompanying the wave-induced ship motions can be calculated by means of the frequency transfer functions obtained from ANNs.

In Fig.10 and 11 the frequency transfer functions of vertical accelerations and deck wetness are presented, calculated by means of GRIM software and the ANNs for the ship of the following parameters:

L = 206.67 m, B = 32.6 m, d = 9.32 m, C_B = 0.71, ∇ = 45 000 m³.

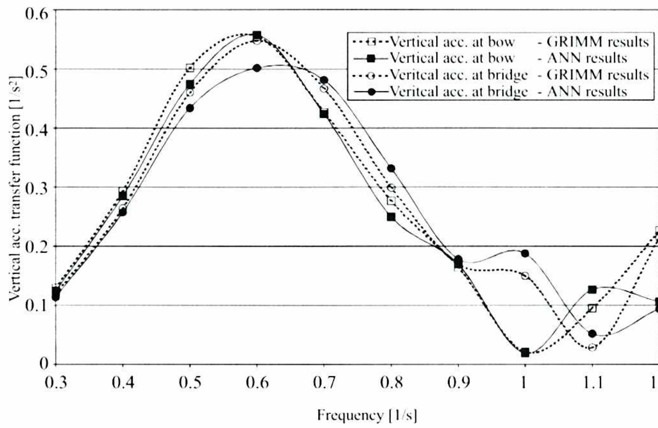

Fig.10. *Vertical acceleration transfer functions for the ship of : L = 206.67 m, B = 32.6 m, d = 9.32 m, C_B = 0.71, ∇ = 45 000 m³, sailing at : V = 4 knots, β_w = 180°*

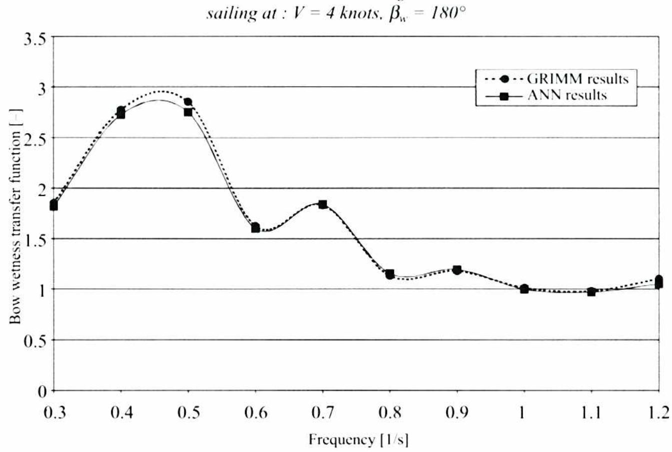

Fig.11. *Bow wetness transfer functions for the ship of : L = 206.67 m, B = 32.6 m, d = 9.32 m, C_B = 0.71, ∇ = 45 000 m³, sailing at : V = 4 knots, β_w = 180°*

CONCLUSIONS AND FINAL REMARKS

- The expressions which approximate the particular wave-induced ship motions, known from the literature sources, are based on statistical investigations or regression analyses applied to the model frequency transfer functions. Their accuracy is insufficient hence they are of limited applicability.
- Another solution is to apply Artificial Neural Networks (ANN) which are characterized by several unique features [13].
- The method presented in this paper, for approximation of frequency transfer functions of wave-induced ship motions by means of ANN is simpler and more exact. Such network when „learned" with the use of the model frequency transfer functions of the wave-induced ship motions is able to generate these characteristics for the assumed main ship design parameters (L, B, d, C_B,∇) - without any need of generating the exact hull form, for large ranges of ship size and speed and full range of wave direction respective to ship, and obtaining very high exactness of the results.

❖ The ANN-generated frequency transfer functions of the wave--induced ship motions, were also applied to predict other phenomena accompanying the motions (such as slamming, propeller emergence, deck wetness, accelerations), and also high exactness of the results was obtained.

❖ Moreover, such ANN can be „learned-up" on the basis of results from other sources (e.g. during ship service).

❖ The presented method can also be extended by a module of automatic generation of input parameters to ANN on the basis of fuzzy sets, and next by a module of automatic modelling of the ANN structure with the use of genetic algorithms and an ANN automatic learning module [9].

Appraised by Jan Kulczyk, Assoc.Prof.,D.Sc.

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NOMENCLATURE

B	– ship breadth
C_B	– block coefficient
d	– ship draught
D	– ship motion variance
GM	– transverse metacentric height
k	– wave number
L	– ship length
X	– input parameters to ANN, or ship design parameters
Y	– output parameters (results) from ANN, or amplitude characteristics of wave-induced motions
∇	– ship volume displacement
ζ	– wave elevation
ω	– regular wave frequency
$\omega_{\phi 0}$	– natural frequency of rolling
ω_e	– encounter frequency

*C*onferences

EA & GO 2001

From 30 May to 1 June 5th National Conference on

Evolutionary Algorithms and Global Optimization

had place in Jastrzębia Góra. It was organized by the Institute of Electronic Systems and Institute of Automation and Applied Informatics, Warsaw University of Technology, as well as Ship Automation Department of Gdynia Maritime Academy.

The conference scientific program comprised 37 papers which were presented during 8 topical sessions :

- Evolution models and mechanisms
- Multi-modal and multi-criterial optimization
- Genetic operators
- Computer Aided Design
- Controlling
- R&D and evolution
- Global optimization
- Learning and identification.

Some papers tightly related to maritime problems were presented by representatives of Gdynia Maritime Academy :

❖ *Application of the back propagation method to parameter tuning in a fuzzy ship course controller* – by Leszek Morawski and Mirosław Tomera

❖ *Experiments in on-line mode trajectory planning at sea by using evolutionary algorithm* – by Roman Śmierzchalski

as well as by authors from Technical University of Szczecin :

❋ *Fuzzy-logic-based control of vessel motion executed along a given trajectory* – by Bogdan Broel - Plater

❋ *Application of multi-dimensional membership functions in modelling of navigational safety problem* – by Marcin Korzeń and Andrzej Piegat

ZTM

Gdańsk - Gdynia - Szczecin

On 15 November 2001 the plenary scientific-organizational meeting of the Marine Technology Unit (ZTM), Section of Transport Technical Means, Polish Academy of Sciences, was held at Technical University of Szczecin.

During the scientific part of the meeting two representatives of the University presented the following papers :

➢ *Application of elastic-plastic hinges to calculation of static and dynamic behaviour of beams having gaps* – by Jan Drewko, D.Sc.

➢ *Accumulation of cold in ship air coolers as a source of thermal improvement of anti-clock wise thermodynamic cycle* – by Bogdan Zakrzewski, D.Sc., M.E.

Both papers were vividly commented.

During the organizational part of the meeting the annual report of the Unit's activity in 2001 and intentions for the next year was presented and discussed.