

Hydrodynamical loads on a floating dock towed in sea conditions

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ABSTRACT



Response amplitude operators (RAOs), short-term and long-term predictions of hydrodynamical response of a floating dock towed in conditions of Baltic and North Sea, are presented and analyzed. The research was focused on: heave and pitch motions, dynamic pressure induced in different parts of the dock's bottom, vertical bending moment and resistance of the dock towed in head seas. The RAOs of the considered responses were determined by means of model tests and/or a computer calculation program based on strip theory. Discrepancies between so obtained values of the characteristics and predicted values of relevant responses, calculated on their basis, were indicated.

Key words: floating dock, sea-keeping qualities, response amplitude operators, short-term and long-term predictions, model testing, numerical calculations – strip theory

INTRODUCTION

Though floating dock is practically a „stationary” shipyard facility a need of its towing in open, more-or-less rough sea waters may appear. For this reason, practical need arises to predict values of its hydrodynamical properties, sea-keeping qualities in particular, apart from the necessity of determination and design control of its hydrostatical properties – floatability and stability. Besides, such predictions have a cognitive merit – they enrich knowledge in the field of shipbuilding.

The subject of the research are numerical characteristics of dock resistance, heave and pitch motions, vertical bending moment and dynamic pressure on its bottom, which are determined:

- ❖ for a box hull dock of the dimensions very close to those of the SINE 212 CD dock described in detail in [1]
- ❖ in the form of short-term and long-term predictions determined for sea states and their statistical distributions characteristic for navigation routes of the Baltic Sea and North Sea
- ❖ on the basis of relevant RAOs obtained:
 - ♦ either as a result of appropriate model tests carried out in the laboratory of the Department of Ship Theory and Design, Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology,
 - ♦ or by means of numerical calculations performed with the use of STATEK computer program [2] based on the *strip theory*.

This work has been realized within the frame of the *EUREKA-E! 2968 ECOLOGICAL DOCK* European research project and its results may find applications as:

- * data for assessment of seaworthiness of the designed SINE 212 CD dock
- * materials to assess adequacy and correctness of various methods for determining sea-keeping qualities of such objects as the considered dock

- * a contribution to more precise determination of strength requirements for floating docks, given in the rules of classification societies, e.g. in [3].

METHODS, PROCEDURES AND MODELS FOR PREDICTION OF HYDRODYNAMICAL PROPERTIES OF FLOATING DOCKS

General statements

Numerical values of short- and long-term predictions of the above mentioned sea-keeping qualities of the floating dock are based on the following assumptions:

- 1st – that the *dock-wave* system is a linear, narrow - band dynamic system in which the dock's wave-induced responses (R) are proportional and additive ones in relation to the excitation
- 2nd – that the stationary sea wave system (W) is a normal random process fully described by its spectrum density function $S_w(\omega)$
- 3rd – that probabilistic distributions of stationary sea states (stationary waving) for the considered navigation waters, are known.

The fundamental characteristics for so predicted sea-keeping qualities are the *Response Amplitude Operators* generally defined as:

- ♦ for the 1st order responses (in this case – heave and pitch motions, pressure and bending moment):

$$RAO \equiv \left| H_{R,\zeta}(\omega) \right| = \frac{a_R(\omega)}{\zeta_a(\omega)} \quad (1)$$

- ♦ for the 2nd order responses (in this case - resistance):

$$RAO \equiv r_{AW}(\omega) = \frac{R_{AW}(\omega)}{\zeta_a^2(\omega)} \quad (2)$$

The quantities which determine the RAOs are :

- ⇒ the amplitudes $\zeta_a(\omega)$ of harmonic (sinusoidal) waves of ω frequencies
- ⇒ the appropriate characteristics of dock responses : the amplitudes $a_R(\omega)$ of the 1st order responses and the average increase of its resistance $R_{AW}(\omega)$ determined in relation to its resistance in calm water.

The RAOs in question were determined :

- ☆ by means of the model testing of dock's resistance, heave and pitch motions as well as dynamical pressure on its bottom
- ☆ by calculations with the use of STATEK computer program [2], performed for heave and pitch motions and vertical bending moment.

Short-term prediction models

A crucial measure of short-term prediction of the 1st order response R, i.e. heave (z), pitch (θ), pressure (p) and vertical bending moment (M), is the variance m_0 (or D_R) of the responses, defined as :

$$m_{0,R} \equiv \hat{D}_R(H_{1/3}, T_1) = \int_{\omega} |H_{R,W}(\omega)|^2 S_W(\omega, H_{1/3}, T_1) d\omega \quad (3)$$

Knowing values of the variance $m_{0,R}$ one can determine any other numerical characteristics of short-term prediction of the 1st order response. Hence for instance the following may be determined :

- ⇒ probability of the event that the amplitude determined by the variance $m_{0,R}$ will exceed a given level of its value, u_R :

$$p_{K,R} = P\{a_R \geq u_R\} = \exp\left(-\frac{u_R^2}{2m_{0,R}}\right) \quad (4)$$

- ⇒ response amplitude whose exceedance probability in the conditions determined by the variance $m_{0,R}$, is p% :

$$a_{R,p\%} = \sqrt{2 \cdot \ln \frac{1}{p}} * \sqrt{m_{0,R}} \quad (5)$$

- ⇒ average amplitude value calculated from 1/n part of the largest amplitudes :

$$a_{R,1/n} = C * \sqrt{m_{0,R}} \quad (6)$$

where the factor C depends only on the value n, and its values amounts to e.g.: 1.25 for n = 1, 2.00 for n = 3, 2.55 for n = 10, etc.

The short-term prediction of dock's resistance was determined as follows :

$$R_{TW}(V, H_{1/3}, T_1) = R_T(V) + \hat{R}_{AW}(V, H_{1/3}, T_1) \quad (7)$$

where :

$R_T(V)$ – dock's calm-water resistance dependent on its forward speed V

$\hat{R}_{AW}(V, H_{1/3}, T_1)$ – average additional resistance of the dock, generated in the conditions of a given stationary sea waving, determined for a given speed of the dock as follows :

$$\hat{R}_{AW}(V, H_{1/3}, T_1) = 2 \int_{\omega} r_{AW}(V, \omega) S_W(\omega, H_{1/3}, T_1) d\omega \quad (8)$$

The spectrum density functions $S_W(\omega)$ of stationary sea waving, appearing in the expressions (3) and (8), were modeled by means of the ISSC standard of the following general form :

$$S_{SC}(\omega, T_1, H_{1/3}) = A\omega^{-5} \exp(-B\omega^{-4}) [m^2 s] \quad (9)$$

where the parameters A and B are expressed as follows :

$$A = \frac{173 H_{1/3}^2}{T_1^4} ; B = \frac{691}{T_1^4} \quad (10)$$

and they are the average statistical characteristics of wave states: i.e. the value of their significant wave height $H_{1/3}$ [m] and that of their significant wave period T_1 [s].

Taking into account the made assumptions as well as the form of the wave spectrum density function $S_W(\omega)$ described by (9) and (10), one can observe that the predictions (3) and (8) could be easily determined and presented in their relative form, i.e. that related to square of the wave height $H_{1/3}$. Hence the relative forms of the short-term predictions are as follows :

$$D_R(T_1) = \frac{\hat{D}_R(H_{1/3}, T_1)}{H_{1/3}^2} \quad (11)$$

$$R_{AW}(V, T_1) = \frac{\hat{R}_{AW}(V, H_{1/3}, T_1)}{H_{1/3}^2}$$

Long-term prediction methods

In this work the following ways of determination of long-term predictions of dock's responses, were applied :

- ➔ For the 1st order responses was applied the method based on full probability model, which determines the probability p_{LT} of the event that an assumed amplitude value u_{LT} of a given response R will be exceeded once a year during sea service of the dock :

$$p_{LT} = P\{p \geq u_{LT}\} = \sum_i \sum_j \exp\left(\frac{-u_{LT}^2}{2m_{0,R,i,j}}\right) p_j p_i \quad (12)$$

where :

p_j – probabilities determined by a given statistical distribution of sea states (states of stationary irregular waving) in i-th sea region

p_i – probabilities which determine possible appearance of a towed dock in the i-th sea region

$m_{0,R,i,j}$ – short-term prediction of variance of a given response R, determined by the expression (3), and relevant to the situation determined by occurrence of j-th sea state in i-th sea region.

- ➔ For increase of resistance was applied the method which determines an average statistical (weighted) increase of resistance at accounting for all distinguished sea states which may appear in all distinguished sea regions :

$$\tilde{R}_{AW}(V) = \sum_i \sum_j p_i p_j \hat{R}_{AW,i,j}(V, H_{1/3}, T_1) \quad (13)$$

where : $\hat{R}_{AW,i,j}(V, H_{1/3}, T_1)$ are short-term predictions of average additional resistance, determined in accordance with the expression (8) for all the distinguished sea states and regions.

Hence, in compliance with the formula (7) the long-term prediction of full resistance of the towed dock can be expressed as follows :

$$\tilde{R}_{TW}(V) = R_T(V) + \tilde{R}_{AW}(V) \quad (14)$$

TESTS AND THEIR RESULTS

Scope and program of the tests

The tests of sea-keeping qualities of the dock, aimed at reaching the above determined targets, were performed within the following scope :

- the floating dock of the dimensions given in Tab.1, was the object of the tests

Tab. 1. Characteristics of the dock and its model.

Characteristics	Symbol	Dimension	Dock	Model
Length of waterline	L	m	184.16	1.8416
Breadth of waterline	B	m	42.00	0.4200
Draught	T	m	3.00	0.0300
Displacement	∇	m ³	22173.5	0.02217
Wetted area	S	m ²	8840.2	0.8840
Longitudinal radius of inertia	k_{yy}/L	-	0.25	0.25
Water density	ρ	kg/m ³	1.025	998.3
Water kinematic viscosity coefficient	ν	m ² /s	1.19*10 ⁶	1.01*10 ⁶

- first of all, dynamical pressures induced on the bottom of the dock, its vertical bending moment as well as resistance, and additionally heave and pitch motions, were tested
- all the above mentioned qualities were determined for head waves
- the RAOs :
 - for heave, pitch, pressure and resistance – were determined by means of model tests
 - for all responses except resistance and pressure – also by means of calculations
- short-term predictions were determined in the form given in the expressions (11)
- long-term predictions were determined in accordance with the expressions (12), (13) and (14) :
 - with the use of discrete distributions of p_i for stationary sea waves on the Baltic Sea and North Sea, identified on the basis of [5] and presented in [4] or/and [6]
 - on the assumption that the distribution of p_i is the following: $p(\text{Baltic Sea}) = 0.7$; $p(\text{North Sea}) = 0.3$
 - for dock's resistance within the range of its towing speed : $V_H = \epsilon \leq 2 \text{ kn}$; $5 \text{ kn} \geq$
 - for only one value of the speed : $V_H = 5 \text{ w}$ in the case of all the remaining responses of the dock.

Results of the tests

Here, main results of the above described tests (detail information on the tests and their complete results can be found in [6] and [7]) are collected and presented in two parts.

In the first part - the following items :

- the RAOs of heave and pitch motions of the dock (Fig.1), as calculated by using the computer program [2], and as measured during the model tests, and

- values of short-term (Fig.2) and long-term (Fig.3) predictions of the same responses of the dock, as calculated by using the RAOs and determined in the two above mentioned ways.

The presentation has first of all a cognitive merit as it is focused on showing a degree of quantitative coherence (or discrepancy) between the predictions of sea-keeping qualities of floating dock, based on the RAOs determined either experimentally or by calculations.

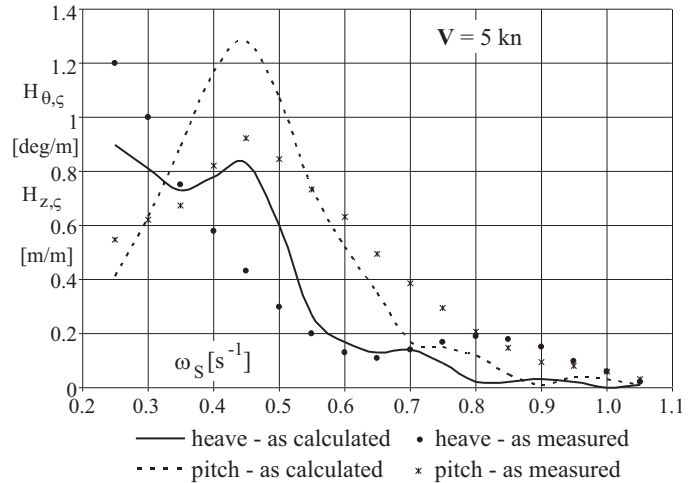


Fig. 1. Amplitude characteristics of heave and pitch motions of the dock.

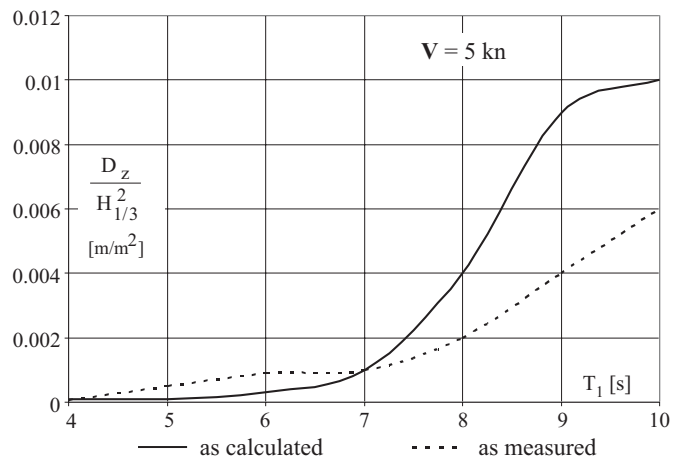


Fig. 2a. Relative variance of heave motions of the dock.

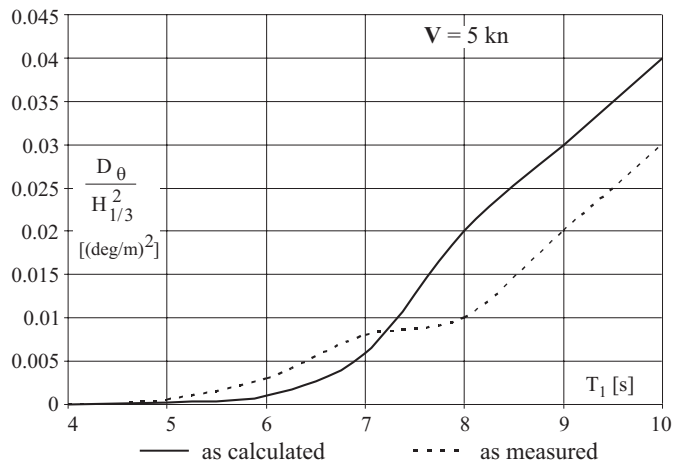


Fig. 2b. Relative variance of pitch motions of the dock.

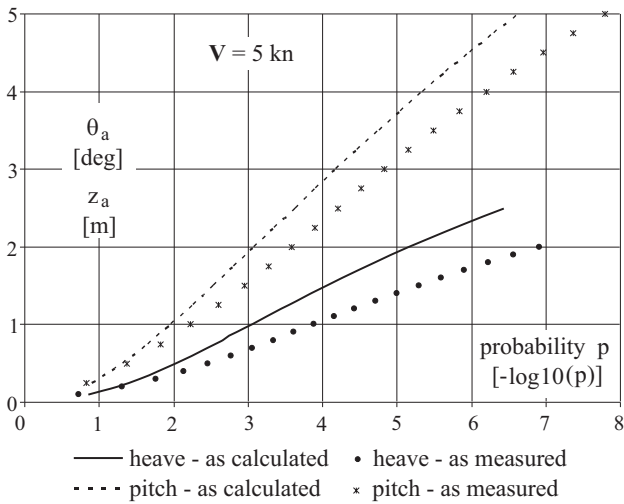


Fig. 3. Long-term prediction of heave and pitch motions of the dock.

In the second part are presented values of the predictions of the hydrodynamical loads on the dock towed in sea conditions, whose values may find application in dock designing. Hence, the following items are shown here :

- long-term prediction of additional resistance of the towed dock (Fig.4) and short-term and long-term prediction of dynamic pressures acting on its bottom (Fig.5 and 6), determined on the basis of relevant RAOs obtained experimentally

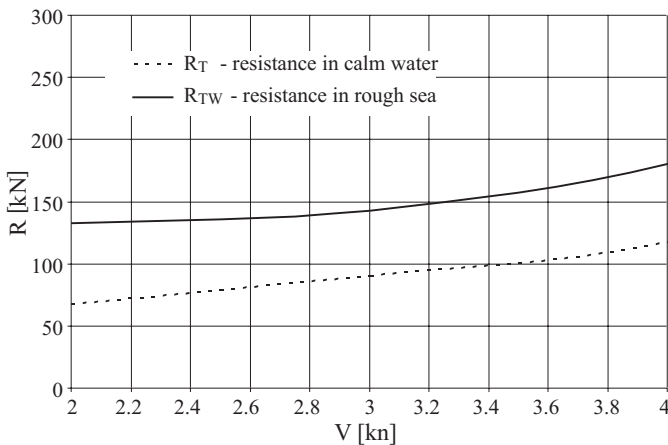


Fig. 4. Long-term prediction of resistance of the dock.

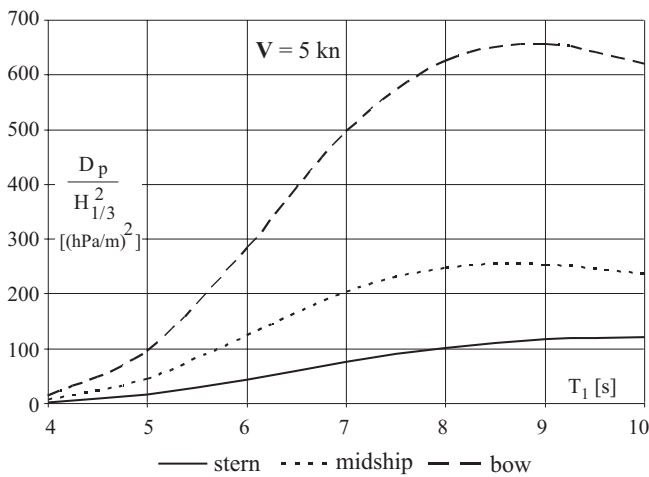


Fig. 5. Relative pressure variance for the dock.

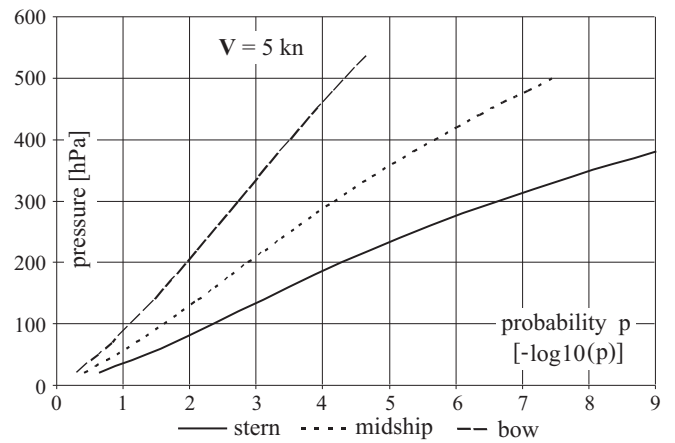


Fig. 6. Long-term prediction of pressure for the dock.

- short-term and long-term predictions of vertical bending moment (Fig.7 and 8), whose RAO was calculated.

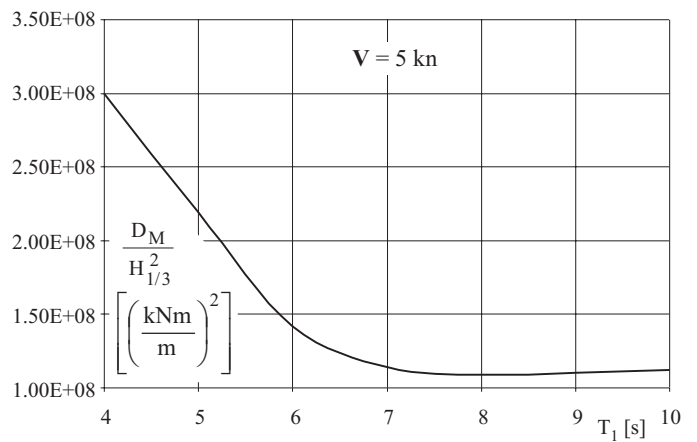


Fig. 7. Relative variance of vertical bending moment in the dock.

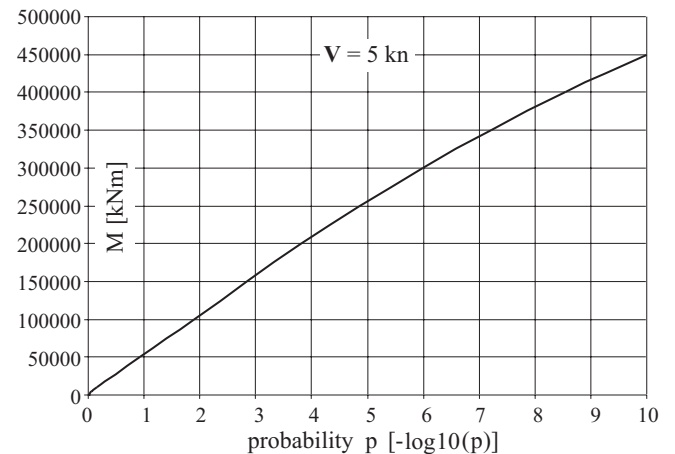


Fig. 8. Long-term prediction of vertical bending moment in the dock.

Moreover, in Tab.2 are presented u_R values of predicted pressures induced on the fore part of dock's bottom, and dock's vertical bending moment, determined :

- ◆ on the basis of the relationship (4)
- ◆ for the variances $m_{0,R}$ of those responses relevant to average (expected) and modal sea state of the Baltic Sea and North Sea
- ◆ for the probability value $p_{K,R} = 10^{-4}$.

The so determined values u_R were practically calculated as :

$$u_R = \sqrt{18.42 m_{0R}(T_1, H_{1/3})} \quad (15)$$

In Tab.2 the values u_R are given together with the values u_{LT} of long-term predictions of the dock's responses in question determined according to the formula (10) only for Baltic Sea, only for North Sea as well as for both the seas together.

Tab. 2. Comparison of the predicted values of u_{LT} and u_R determined for $p = 10^{-4}$

Responses of the dock	u_{LT} values for			u_R values			
	Baltic Sea	North Sea	Both seas together	Baltic Sea		North Sea	
				Average waving $T_1 = 5.36$ s $H_{1/3} = 1.43$ m	Modal waving $T_1 = 5.50$ s $H_{1/3} = 0.95$ m	Average waving $T_1 = 6.35$ s $H_{1/3} = 1.95$ m	Modal waving $T_1 = 6.40$ s $H_{1/3} = 1.20$ m
Bending moment [10 ⁴ kNm]	23	17	21	8.2	5.5	9.5	5.8
Pressure (at bow) [hPa]	335	520	460	81.2	59.2	171.5	106.8

SUMMARY

○ Very great discrepancies between all quantitative characteristics of heave and pitch motions of the floating dock in question, have been observed, namely :

- * especially large (reaching 100%) are differences of values of the RAOs in the frequency interval : $\omega \in \langle 0.3s^{-1}; 0.5 s^{-1} \rangle$ and, in consequence, values of variances of the motions corresponding to high sea states (for wave periods $T_1 > 8s$)
- * less different are values of the relevant long-term predictions
- * the differences in values of variances and long-term predictions, especially for pitch motion, are much smaller (by abt. 50%) than those for heave motion.

○ It may be assumed that similar differences occur between values of the RAOs and predictions of pressure and bending moment, i.e. the responses having *par excellence* practical, design merit. (For practical reasons it was not possible to investigate the relations within the scope of this work).

○ The observed and anticipated discrepancies are difficult to be explained. A much greater quantitative coherence of the calculated and experimentally determined RAOs, has been expected. All the more, the problem seems to be surprising because :

- * the model tests were performed in a sufficiently reliable way, and
- * the calculation model based on strip theory should provide sufficiently correct results for the dock in question first of all because of the uniform form of its frame sections and its very low speed ($F_n = 0.06$).

Perhaps, the very low ratio $L/B = 4.38$ of the dock could be a cause of the discrepancies as the strip theory is assumed to be applicable only for *slender body* objects. However there are very firm statements, e.g. those given by 18th ITTC, that the calculation models based on strip theory are able to provide sufficiently accurate results in determining motions of the floating objects having L/B ratio as low as 2.5 ([8]).

○ One way or another, the observed discrepancies show that practically predicted (in design process) values of wave loads for the dock may be unreliable.

○ The uncertainty is additionally heightened by the fact that relevant requirements of classification institutions are given in a very enigmatic, quite ambiguous form.

For instance, the relevant rules of Polish Register of Shipping (PRS) ([3]) state only that :

- * *calculated (design) pressure applied to dock's plating is to be composed of hydrostatic pressure and hydrodynamic pressure whose values are to be determined at the probability level of 10^{-4}*
- * *total value of design bending moment is to be determined with accounting for values of wave-induced bending moment at the probability level of 10^{-4} .*

The rules do not specify a determination method of the loads or even a way of their prediction. Yet, as shown in Tab.2, very different can be values of various but possible predictions determined at the same probability level (e.g. 10^{-4}) and based on the same method of determination of the variance $m_{0,R}$ for a given load.

BIBLIOGRAPHY

1. SINUS (Design Office) : „SINE 212-CD 0051-1, Technical Specifications”. Gdańsk, 2004
2. „User's manual of STATEK computer program” (in Polish). Research report no. 146/CPBR 9.5-1109/90, Ship Research Institute, Gdańsk University of Technology. Gdańsk, 1990
3. Polish Register of Shipping : „Rules for the construction and classification of floating docks” (in Polish). Gdańsk, 1987
4. Stasiak J.: „Service margin – solution to the problem or a problem waiting for solution?”. Polish Maritime Research, Special issue – *Baltecologicalship*. Gdańsk, 2004
5. Hogben N., Dacunha N.M.C., Olliver G.F.: „Global Wave statistics”. British Maritime Technology, 1986
6. Grygorowicz M., Stasiak J.: „Hydromechanical properties of a floating dock towed in sea conditions – short-term and long-term predictions” (in Polish). Research report no. 177/E/05. Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology. Gdańsk, 2005
7. Grygorowicz M., Stasiak J.: „Hydromechanical properties of a floating dock towed in sea conditions – short-term and long-term predictions, Part II” (in Polish). Research report No. 224/E/2005. Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology. Gdańsk, 2005
8. Faltinsen O., Svensen T.: „Incorporation of Sea-keeping Theories in CAD”; *CFD and CAD in Ship Design*, Proceedings of the Inter. Symposium on CFD and CAD in Ship Design. Wageningen, The Netherlands. September 1990, Elsevier 1990