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Sea waves models used in maritime simulators

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Abstract

The modern simulation software includes an impact of forces acting on the ship hull. One of the most significant forces is sea waves acting. The mathematical model allows simulation of ship motions in irregular sea wave area, both – at deep and shallow waters. The wave surface model enables simulation of the wave elevation in compliance with wave spectrum occurring in various conditions. The paper presents general description of the sea wave model used in maritime simulators. An example of such simulators is used at the laboratory of the Naval University of Gdynia, where it is operated basing on NT-Pro 5000 software by Transas Marine. The latest version of simulation software gives a possibility to select the wave spectrum. Selection of the waving type, depending on sea area location, makes the ship movement more reliable. This is an important element in testing the ships behavior process.

Introduction

The research carried out in the latter half of the last century on formation and proceeding sea waves, resulted in describing a variety of their mathematic models. They have been constantly developed and improved. While studying sea waves phenomenon, scientific centres suggested application of several wave spectrum models, dependent on a number of parameters considered (e.g. in the wind function, waving area or its frequency). Models of waves are very useful if the measurement data are lacking, however they may be subject to geographic and seasonal limitations. The models: Bretschneider, ITTC, Pierson–Moskowitz, Neumann, Philips or JONSWAP were worked out for different water areas (as for example the North Sea), therefore applying thereof is not a universal issue, in addition, it is limited by specific restrictions. Development of the models is strictly connected with various science domains and industry branches. One of the examples is development of navigation and manoeuvre simulators; in particular, their weather models [3]. Implementing the diversified wave models to their environment contributes to increasing possibility of applying simulation methods and of the level of the tests results credibility. In the first part of the paper a general characteristics of some wave models applied in the navigation and manoeuvre simulator, located at the Naval Academy in Gdynia is presented, whereas in the second part, the results of the simulation tests aimed at determining differences in a behaviour of the selected real vessel's model, affected by action of various sea wave models. This paper describes findings of the initial analysis and assessment of the vessel's simulation model under influence of various sea wave spectra.

Selected sea wave models

A majority of sea waves is induced by wind operation. Such waves are called wind-waves. On studying sea waves the research teams worked out a series of mathematic models of waves. Most ocean waves spectra may be described in a form of the standard formula, which has to be applied only in case waves heights are known [1]:

$$S(f) = \frac{A}{f^5} \exp\left(\frac{-B}{f^4}\right) \tag{1}$$

The above dependence is a general form of the ocean wave model. On conducting the studies carried out world-wide at various water areas, the scientists worked out more detailed models. While

selecting the wave model to apply in the research process, it is necessary to take into consideration also the following aspects and questions:

- Is the considered water area limited with any coastline which prevents full development sea?
- Are the sea waves under a process of formation or degradation?
- The water area depth; waves on deep water areas differ from those on shallow waters.
- Surface currents affecting waves' characteristics.

Below, three models of waves are presented, implemented to an environment of the simulator, based on Navi – Trainer 5000 software by Transas Marine.

Pierson–Moskowitz Spectrum

One of the most simple wave's spectra was worked out by Pierson and Moskowitz (1964). The scientists had assumed that waves begin their action in equilibrium with wind under condition of long lasting wind blowing over a large area. It is a concept of fully developed sea. To achieve a spectrum of the fully developed sea, they used measurements of waves, carried out with a use of accelerometers located onboard of British weather observing vessels, sailing on the North Atlantic. The spectrum is dependent on one of input parameters and a wind speed, wave height or peak period may stand for it. Due to the limitations they can be applied for investigations performed at an unlimited water area. Having the collected results analyzed, the spectrum was worked out and described, applying the below mentioned relation [1]:

$$S(f) = \frac{A}{f^5}\exp\left(\frac{-B}{f^4}\right) \tag{2}$$

where:

$$A = \alpha g^2 (2\pi)^{-4} \tag{3}$$

$$B = \beta\left(\frac{2\pi U}{g}\right)^{-4} \text{ or } B = \frac{5}{4} f_p^4 \text{ or } B = \frac{4\alpha g^2}{(2\pi)^2 H_S^2} \tag{4}$$

$$\alpha = 0.0081, \quad \beta = 0.74 \tag{5}$$

JONSWAP spectrum

To work out wave's spectrum for limited and shallow water areas, at the beginning of the seventies the Joint North Sea Wave Project was performed. To carry out the survey, along the German Coast there were located research stations. In effect of analysis of data from more than 2000 measurements, the scientists discovered that the wave's spectrum is not fully developed. However, in view of its characteristics, it is often used for purpose of studies and analyses referring to coastal navigation at limited water areas. The spectrum is two--parameter and dependent on two input parameters, which are a modal frequency and amplification coefficient. It is described in the following dependence (5) [1]:

$$S(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right] \gamma^{\exp\left[\frac{(f-f_p)^2}{2\tau^2 f_p^2}\right]} \tag{6}$$

where:

$$f_p = 2\pi/T_p \tag{7}$$

spectral peak or modal frequency of the JONSWAP spectrum (7);

$$\alpha = 0.0076\left(\frac{U_{10}^2}{F_g}\right)^{0.22} \tag{8}$$

is the wind speed at the height of 10.0 m above the sea;

$$\tau = \begin{cases} 0.07 & f \le f_p \\ 0.09 & f > f_p \end{cases} \tag{9}$$

Bretschneider spectrum

Bretschneider spectrum also called a modified, two-parameter Pierson–Moskowitz spectrum, worked out basing on research, carried out at the North Ocean. A difference between the original Pierson–Moskowitz's spectrum consists in a fact that Bretschneider's spectrum is function of the both – wave height and peak period [2]:

$$S(f) = \frac{A}{f^5}\exp\left(\frac{-B}{f^4}\right) \tag{10}$$

where:

$$A = \frac{5H_S^2 f_p^4}{16} \tag{11}$$

$$B = \frac{5f_p^4}{4} \tag{12}$$

Influence of waving on vessel behaviour

To verify the sea waves mathematical models, implemented to the simulator's environment, a series of manoeuvring trials were carried out. The following are general structure parameters of the vessel, a model of which was used for the research.

Table 1. Structural parameters of the vessel used in examinations

Mine hunter			
Displacement	503.0 t	Bow draft	2.1 m
Engine	2×2508 kW	Stern draft	2.1 m
Length	58.2 m	Height of eye	7.0 m
Breadth	8.0 m	Max speed	9.5 m/s

The vessel used for examinations was a mine hunter, owned by the Polish Navy. Due to its small draught and dimensions it is susceptible to waving and strong winds. The simulations were carried out at various water areas and with consideration of respective thereto waves' spectra. Each of trials was carried out at the identical hydrometeorological conditions (wave height = 1.7 m). While the trials discussed below were on, the wave was acting toward starboard side of the vessel heading north (KR = 000°). Conducting the trial was aimed at comparing the waves' mathematical models influence on the vessel's handling parameters, roll and sway, in particular. Considering a large number of wave models to choose and the extensive research material, the paper was focused on comparison of three models. Results of the carried out tests are presented below.

Ship's rolling

While manoeuvring trials performance there were recorded vessel's rolling; the diagrams are presented below. Basing on the collected materials' analysis it can be stated that the most intense rolling, reaching 13 degrees, occurred in a time of the course, when the vessel was a subject to Jonswap spectrum waves. Also the ship's rolling frequency is the highest for Jonswap spectrum. According to the results of the presented test specimen, within 1 minute the vessel rolled 14 times toward the same direction. In a time when the vessel was subject to acting of two other spectra, 13 rolls occurred. The more extensive rolling was caused by the wave of Jonswap spectrum characteristics, which is more steep and shorter than the ocean waves, which became a basis for the other examined wave spectra.

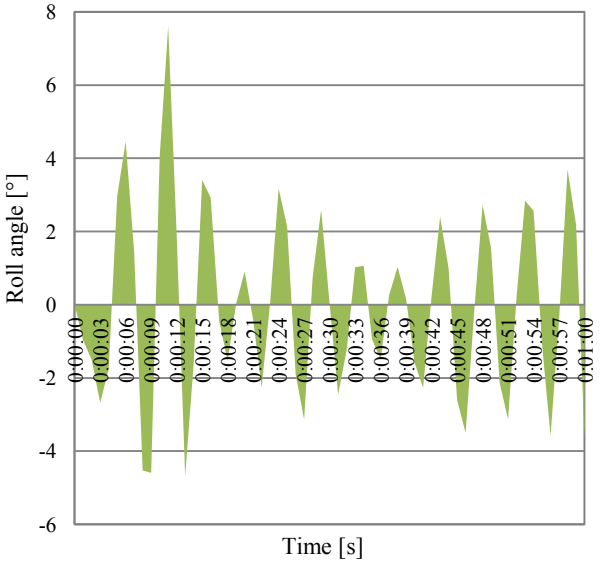

Fig. 1. Pierson–Moskowitz Spectrum roll angle

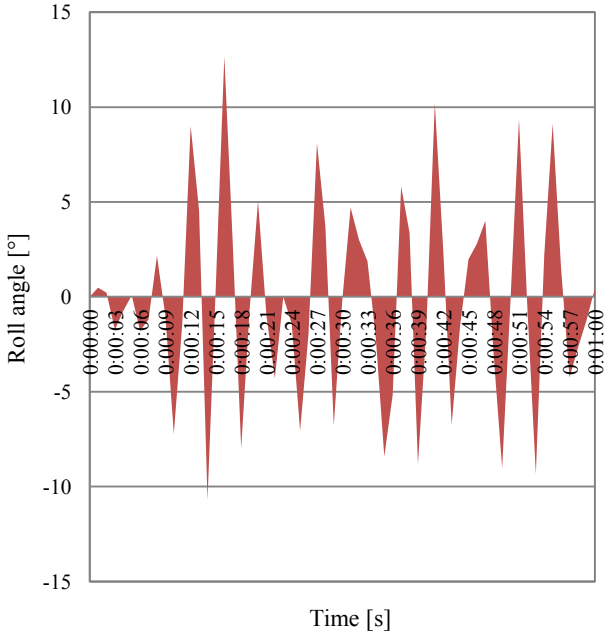

Fig. 2. JONSWAP Spectrum roll angle

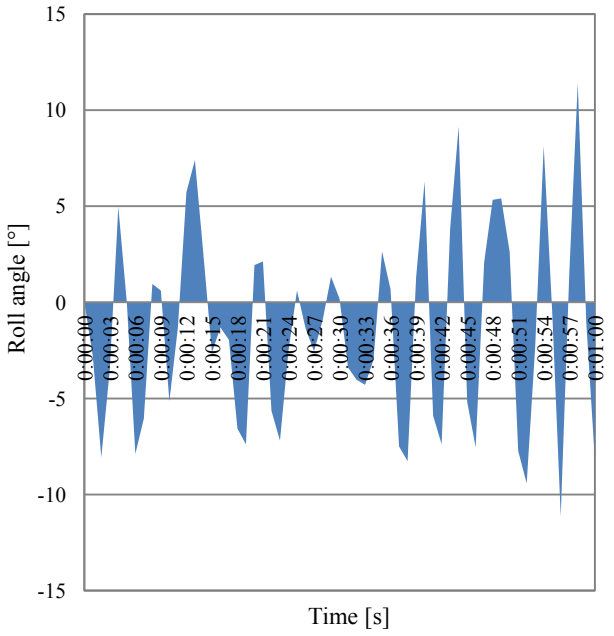

Fig. 3. Bretschneider Spectrum roll angle

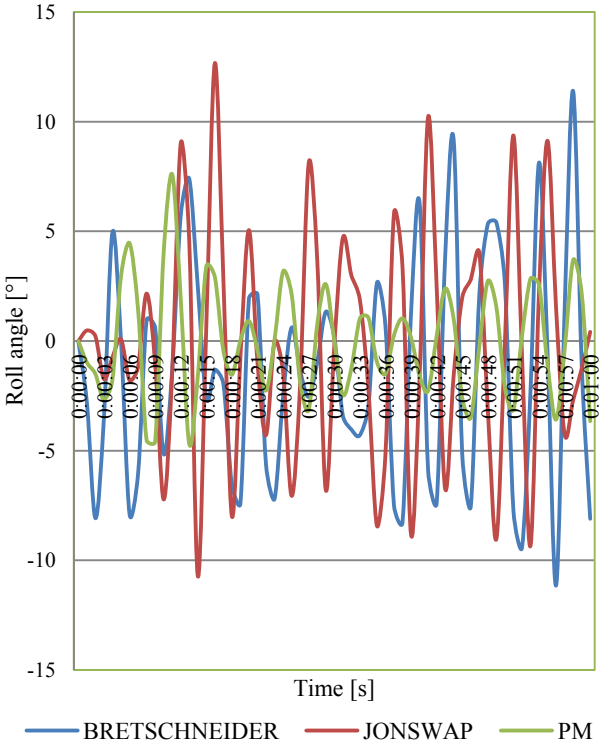

Fig. 4. Summary compilation of ship's rolling

Ship's sway

In a time of carrying out the second series of tests the vessel's sway / drift induced by waves was recorded. The tests results presented below prove that the most intense sway of the vessel, reaching 34 m, was caused by a wave of Bretschneider's spectrum. The wave of Jonswap spectrum induced a sway of 20.7 m instead. Thus it may be stated that the vessel is a subject to much more intense sway being affected by a long ocean wave

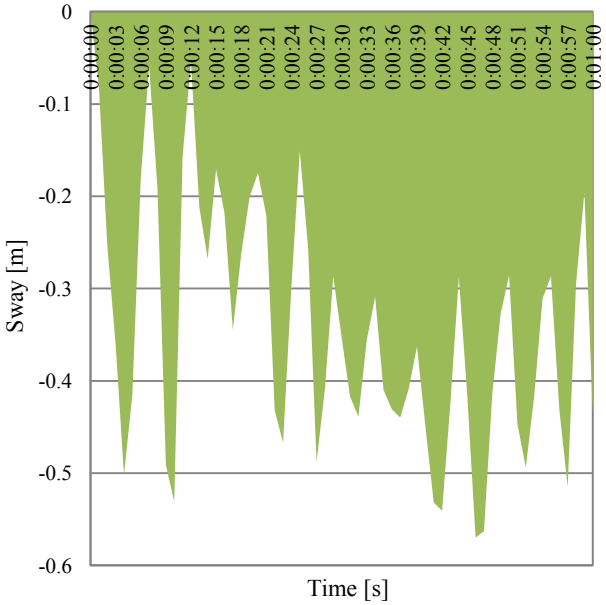

Fig. 5. Pierson–Moskowitz Spectrum sway

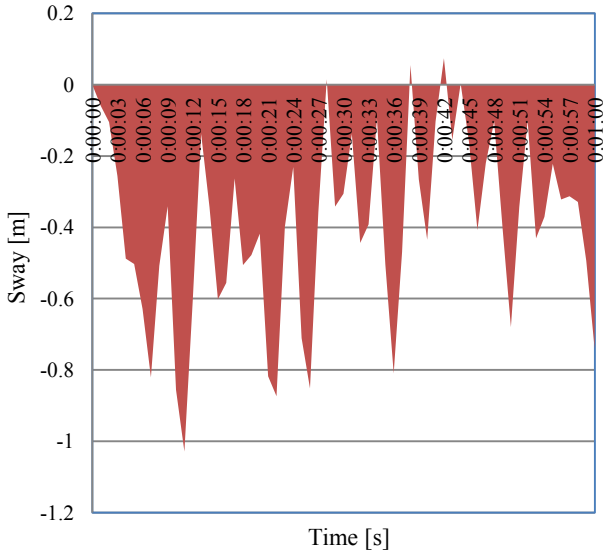

Fig. 6. JONSWAP Spectrum sway

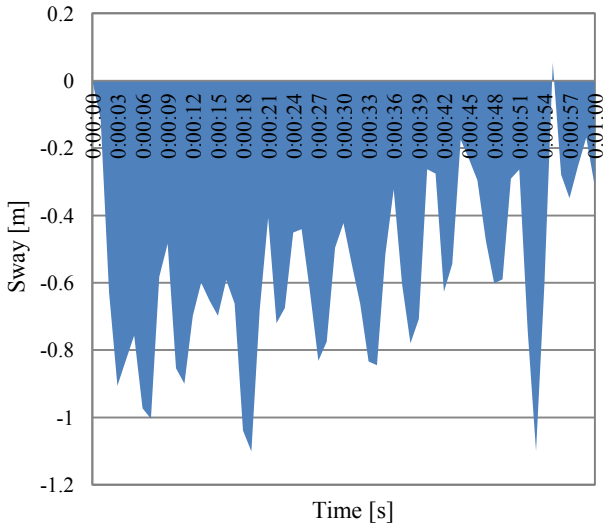

Fig. 7. Bretschneider Spectrum sway

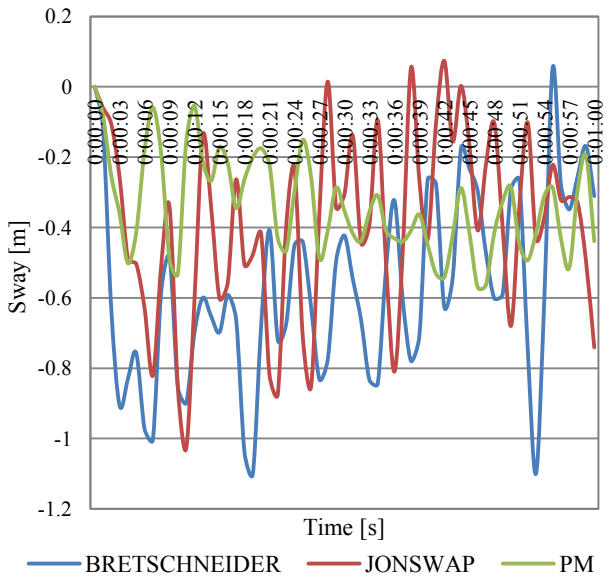

Fig. 8. Summary compilation of the vessel's sway data

Conclusions

In effect of the simulation tests' results analysis and comprising specific vessel movement parameters on one diagram (Figs 4 and 8), it is possible to present a difference in behaviour of a vessel affected by activity of sea waves of various spectra.

The opportunity of applying various sea waves' spectra is an essential aspect for the research process. In spite of the fact that works over waves' models have been carried out for some dozens years, the software for navigational simulators was completed with the above models not before last years. The collected results and performed analysis allow to state, that further tests and simulation trials on the subject would provide us with more detailed information about implementation of sea waves' spectra into navigation and manoeuvre simulators' environment.

The results obtained on the research prove, that the simulation software is broadly applicable in studies and tests conducted in diversified hydrometeorological conditions. Anyhow, the present stage of research gives no answer for the question – are the implemented models of sea waves activity adequate to the waves truly occurring at specific water areas in any type of hydrometeorological conditions. A problem of determination of the waves simulation models' adequacy level and analysis of behaviour of vessels' simulating models in comparison to the real ones' behaviour at sea area are to be a subject of the successive research of the authors.

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