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The influence of the cruise speed on the amplitude of the oscillatory movements of the ship - OCTOPUS software-assisted study

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Abstract. In their current activity, the officers on board of the ships are interested in the practical ways by which, the complications generated by the sea waves can be overcome and the ship can be safely operated. The paper present a computer-assisted study of the characteristics that define the behaviour of the ship under real navigation conditions (amplitudes of the oscillatory movements, energy spectrum of the ship response to the action of the sea waves) depending on the cruise speed of the ship. OCTOPUS was used as a working tool.

1. Introduction

Solving the problems generated by the behavior of the ship during navigation, involves the elaboration of mathematical models that take into account the action of the disturbing factors of different categories. The general equations of motion of the ship are based on: appreciation of the disturbances that arise in the management of the ship with the help of propulsion and governance systems and appreciation of disturbances due to the navigation environment. The manifestation of the navigation environment, described as a random process of high complexity, required the use of numerical calculation methods for analyzing and predicting the movements of the ship. OCTOPUS includes a package of exclusively naval utility programs, being a software that allows to study the behavior of the ship on waves, under conditions of performance simulation of the navigation environment using the wave energy spectra.

2. Theoretical considerations

The general equation of motion of the ship, in real sea, in vector version, is recognized in the specialized literature with reference to this subject [1] [2] [3] [4] [5], reason for which it is preferred, for the rational dimensioning of the work, not to mention in more detail the meaning of the terms that intervene.

$$\boldsymbol{M}_\eta(\boldsymbol{\eta})\ddot{\boldsymbol{\eta}} + \boldsymbol{C}_\eta(\boldsymbol{\nu}_r,\boldsymbol{\eta})\dot{\boldsymbol{\eta}} + \boldsymbol{D}_\eta(\boldsymbol{\nu}_r,\boldsymbol{\eta})\dot{\boldsymbol{\eta}} + \boldsymbol{g}_\eta(\boldsymbol{\eta}) = \boldsymbol{\tau}_{M\eta} + \boldsymbol{\tau}_\eta \tag{1}$$

When writing the equation, was taken into account:

- analysis of phenomena, insisting on the ways of coupling the different movements of translation and rotation;
- use the principle of overlapping effects in assessing the irregularity of the sea;
- application of analytical mechanics to determine the inertia matrices of the ship's mass and complementary matrices for the movement of the ship;

- argued explanation of the concept of additional water masses on the ships body;
- adaptation and refinement of the strip theory in solving the problems raised by determining the hydrodynamic coefficients.

The equation was written according to the definitions and symbolizations imposed by SNAME regulations (Society of naval Architects and Marine Engineers).

3. Case studies for roll and pitch motion

The case study presented in this paper was performed for a ship used by the author also in other studies published over time [7] [8] [9]. The vessel, chosen to exemplify the study, is a multifunctional container type, with a hull with bulbus at the bow. The ship has a length of 175 m, a width of 25,4 m and a draft of 11 m.

The synthetic characterization of the ship, required by the simulation environment, refers to some geometrical and constructive features, static and dynamic mechanical parameters. Vessel geometry was established within the permissible limits for Lewis multi-parametric transformations, for 27 cross-sections arranged along the length of the vessel. The construction of the aft is suitable for equipping it with a semi-suspended, semi-compensated rudder, with hydrodynamic profile, wide in the center plane of the ship. The ship is equipped with a propeller with 4 fixed blades, also arranged in the center plane of the ship. The speed of the ship was varied between 12.5 and 18.5 kNts, the propeller shaft speed being between 80 and 150 rpm.

Was used the modified strip theory, supporting by the Ursell-Tasai theory of calculating the two-dimensional hydrodynamic coefficients [6]. For calculating the hydrodynamic coefficients of viscous damping, the Ikeda method was used. The regular wave system comprises 40 cosine waves with their own pulses ranging from 0.265 to 1.330 rad / sec.

For the study included in this paper, was used the Jonswap spectrum, resulted from the overlap of regular cosine waves having significant heights between 1.1 and 10.25 m and periods of zero between 5.35 and 9.65 sec.

In Fig. 1, Fig. 2, and Fig. 3, the wave spectra, input quantities for the rotational motion of the ship around the longitudinal axis (roll) around the transverse axis (pitch) and horizontally (yaw) are shown.

The spectra are presented according to a variation of the encounter pulse in the range 0.2 - 1.4 rad / sec and for the considered speed range (12.5; 14.5; 16.5 and 18.5 kNts).

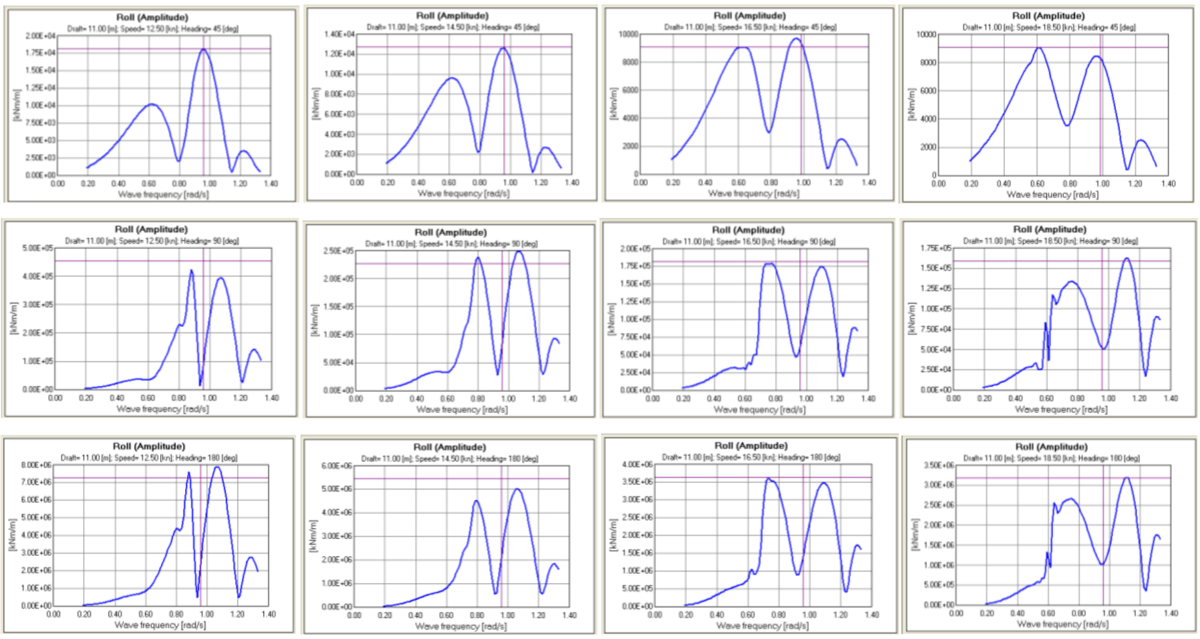

Fig.1 Wave spectra – roll motion

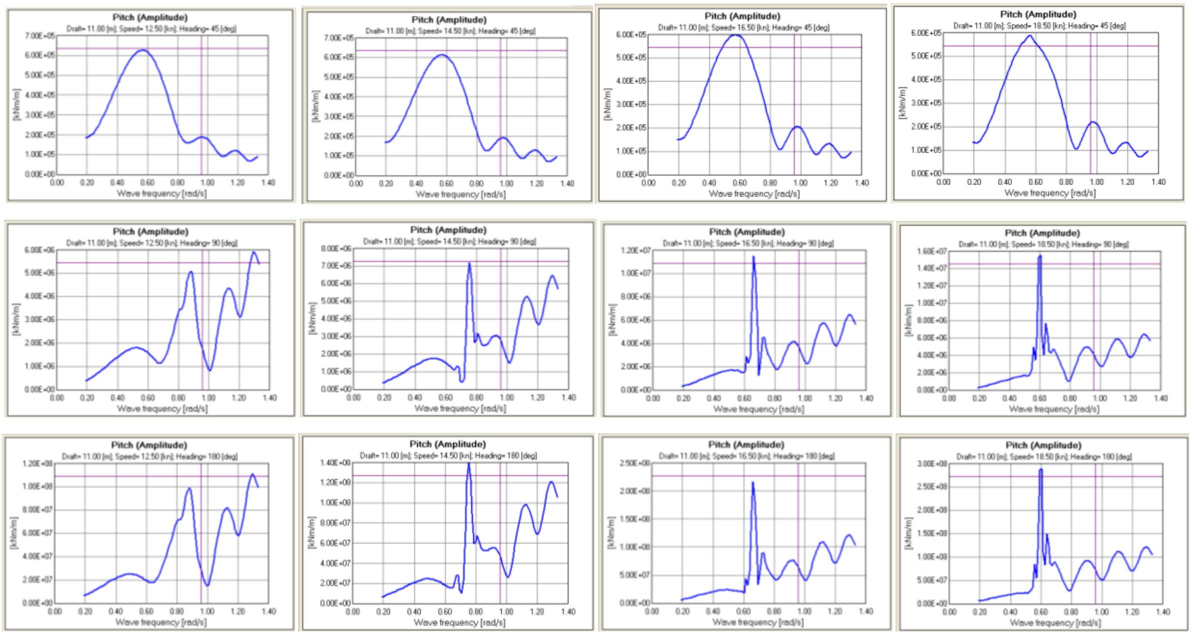

Fig.2 Wave spectra – pitch motion

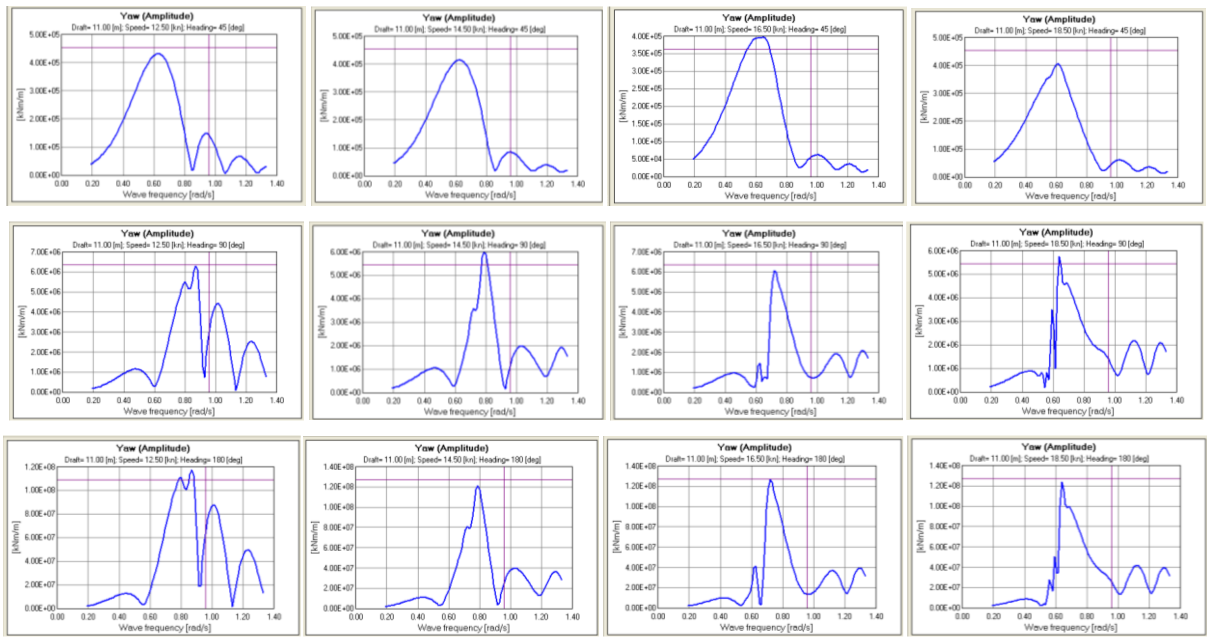

Fig.3 Wave spectra – yaw motion

The ship is a system that, when is subject to the action of "input" sizes responds with other "output" sizes, through a transfer function. The ship system, excited by waves, produces different responses for the six degrees of freedom it can have, as a free rigid solid.

For the study of the movements that the ship executes on waves, this transfer function is called RAO (Response Amplitude Operator).

Fig. 4. illustrates the response spectrum of the ship for the rotational motion of the ship around the longitudinal axis (roll). In Fig.5. the response spectrum of the ship is shown for the rotational motion of the ship around the transverse axis (pitch). Fig.6. illustrates the response spectrum of the ship for rotational motion of the ship in horizontal plane (yaw).

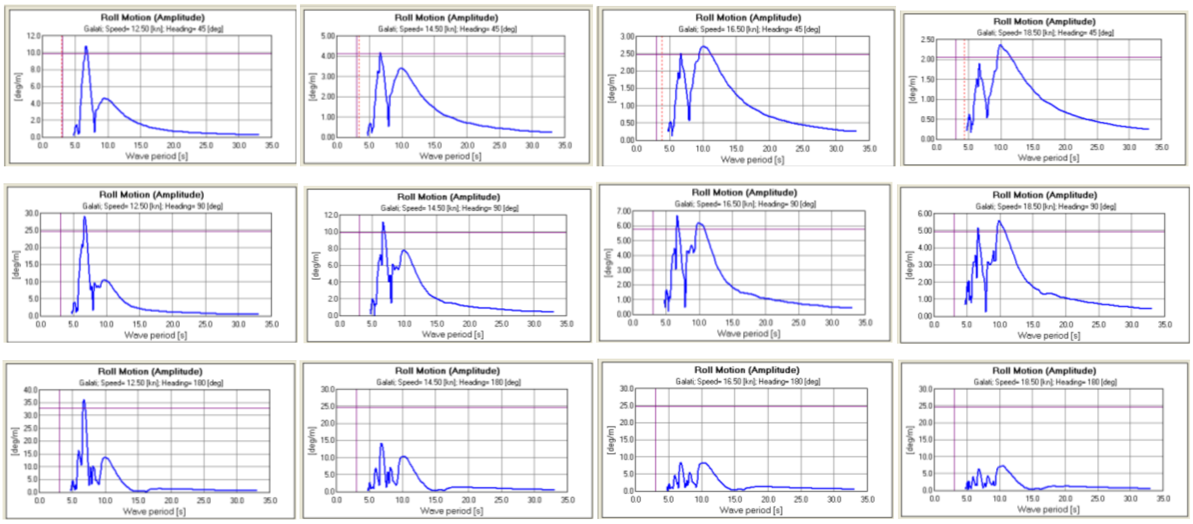

Fig.4. RAO spectra for roll motion

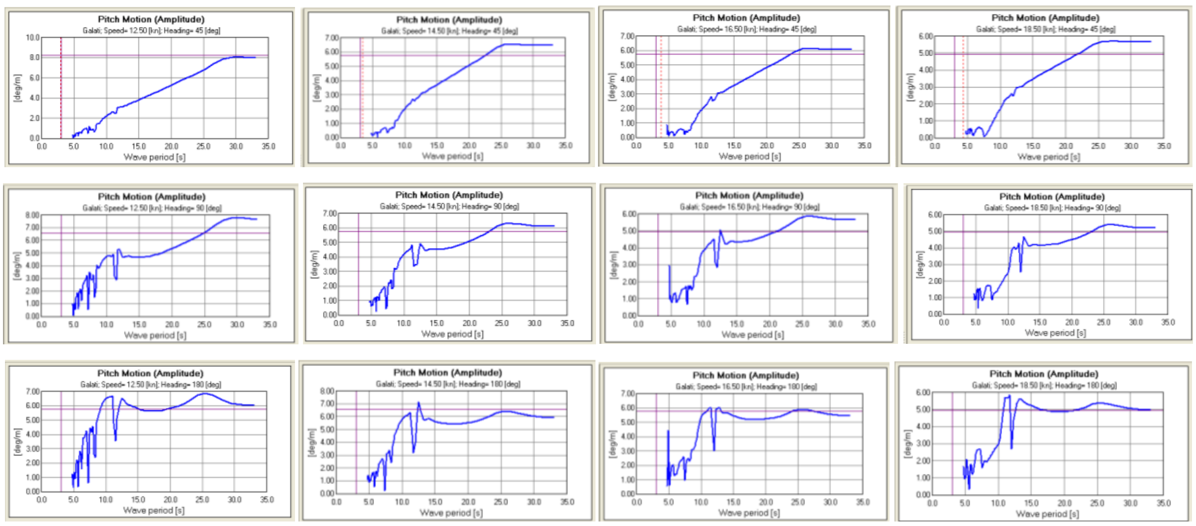

Fig.5. RAO spectra for pitch motion

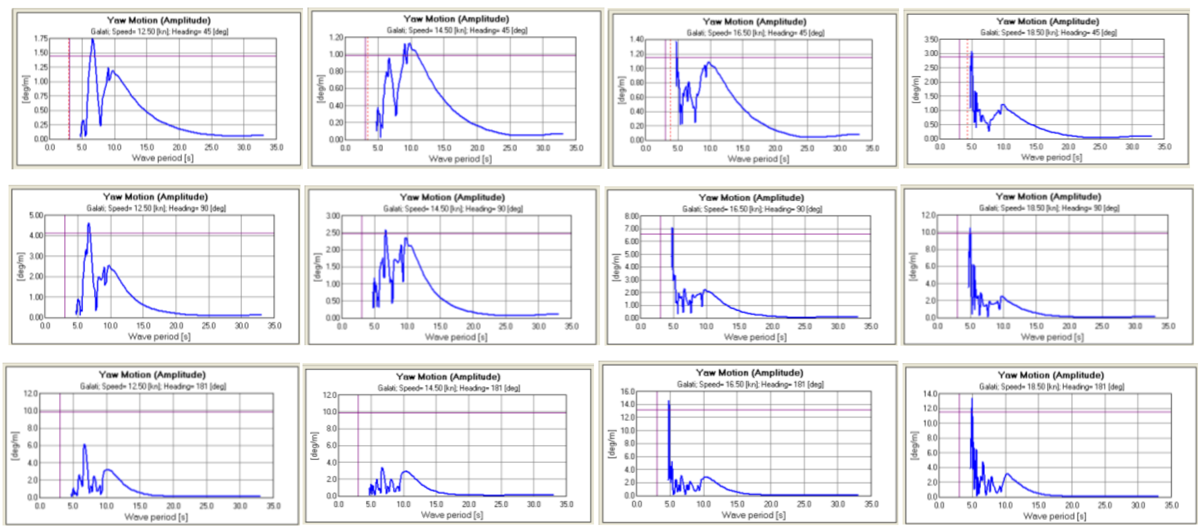

Fig.6. RAO spectra for yaw motion

4. Conclusions

In this paper, attention has been paid to the influence that the speed of the ship has on the roll, pitch and yaw motions of the ship, in response to the disturbing action of the waves.

In the study, the speed of the ship was varied from 12.5 to 18.5 kNts, which corresponde to a variation of the propeller shaft speed between 80 rot / min and 150 rot / min. Also, the ruder angle was varied to port side, from 10^0 to 35^0 with a step of 5^0.

Among the problems that concern the researchers in the field, are those related to the loss of transverse stability, which can lead to the overturning of the ship, caused by:

- dangerous inclinations in a board, determined by the ship turning, under the conditions of a high degree of agitation of the sea;
- heavy roll oscillations, determined by the action of the resonant waves.

The researchers noted the dimness of the ship's marching qualities, as a result of the worsening of the propulsion system's functioning (the propellers come out of the water and are overloaded by the turbulent water flow regime).

It is not to be neglected the harsh regime of oscillations to the strong impact between the body of the ship and the waves, in conditions of high speed of march and of unfavorable positioning in relation to the wave front.

It can be concluded that:

- when the speed of movement of the ship increases, the resistance to advancement of the ship decrease during complex movements (transversely-vertical, longitudinal-vertical or combined in a horizontal plane) as a result of the occurrence of the drift phenomenon. As a result, the speed of the ship, under the condition of performing complex movements on the wave, is lower than that of the constant road, at the same power of the propulsion machinery;
- for high speeds of the ship and large steering angles, the transverse stability of the ship is affected, being able to reach its reversal;
- for low speeds of the ship and small angles of rudder, the giration diameter of the ship increases greatly, which should be avoided;
- the roll of the ship is influenced less than the speed of the ship; the ship stabilizes at a certain angle of transverse tilt after approximately 300 - 500 seconds from the beginning of the movement; for a low speed of the propeller shaft the angle of transverse tilt is small but increases dangerously with increasing the speed.

Acknowledgements

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