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The influence of the ship static and dynamic characteristics on the amplitude of the oscillatory movements – RAO specter

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Abstract. Possibilities in anticipation of functional performance of the ships in real sea navigation conditions, since the early stages of design, is a challenge for naval architects, motivated by the need to reduce design time and cost of construction. The paper presents a computer-assisted study of the characteristics that define the behaviour of the ship under real navigation conditions (RAO spectrum of the ship response to the action of the sea waves) depending on the ship static and dynamic characteristics. For the study was used the features offered by OCTOPUS software. Program library was used for both the vessel itself and navigation modelling environment, for regular waves as well for the irregular waves which was modelled using Jonswap energy spectrum.

1. Generalities

Ship motions at sea have always been a problem for the naval architect. They have the responsibility to insure not only that the ship can safely ride out the roughest storms but that it can proceed on course under severe conditions with a minimum of delay or with minimum energy consumption.

As seakeeping problems have became more serious, rapid expansion began in the application of hydrodynamic theory, use of experimental model techniques and collection of full scale empirical data. Having criteria and indexes of performance whereby predictions can be tested, the naval architect requires guidance to choice of ship form, proportions, natural periods of rolling and pitching, freeboard forward and other characteristics favorable to good seagoing performance. Emphasis is on choosing the overall ship proportions and coefficients, since they must be established early in the design process and are shown to have more influence on performance than minor changes in full form. Consideration is also given to above-water form and freeboard, and to added power requirements in waves. Consideration is also given to design procedures that permit seakeeping considerations to be taken into account from the outset. It is shown that a choice among alternative designs can be made on the basis of economic considerations, for both commercial and naval vessels.

2. Theoretical aspects

The response of a ship behavior in a seaway is a complicated phenomenon involving the interactions between the vessel dynamics and several distinct hydrodynamic aspects of the sea. It would be impossible to cover comprehensively the entire subject of ship motions in this paper [1] [2] [3] [4] [5]. Therefore, will be mentioned only those aspects of ship motion theory that have proven useful to the subject. The general movements of the ship result from the coupling of the six simple movements (three of translation and three of rotation) that the ship, as a free rigid solid, can perform.

The general equations of the ship motions, considered as a rigid solid with six degrees of freedom, can be written using vector sizes:

$$\begin{cases} \boldsymbol{\eta} = [\boldsymbol{\eta}_1^T \quad \boldsymbol{\eta}_2^T]^T & \boldsymbol{\eta}_1 = [x \quad y \quad z]^T & \boldsymbol{\eta}_2 = [\varphi \quad \theta \quad \psi]^T \\ \boldsymbol{\nu} = [\boldsymbol{\nu}_1^T \quad \boldsymbol{\nu}_2^T]^T & \boldsymbol{\nu}_1 = [u \quad v \quad w]^T & \boldsymbol{\eta}_1 = [p \quad q \quad r]^T \\ \boldsymbol{\tau} = [\boldsymbol{\tau}_1^T \quad \boldsymbol{\tau}_2^T]^T & \boldsymbol{\eta}_1 = [X \quad Y \quad Z]^T & \boldsymbol{\eta}_1 = [K \quad M \quad N]^T \end{cases} \tag{1}$$

where:

$\boldsymbol{\eta}$ represent the general position vector of any point in the ship, having components: $\boldsymbol{\eta}_1$ vector of linear coordinates characteristic of translational movements; $\boldsymbol{\eta}_2$ the vector of the angular coordinates characteristic of the rotational movements;

$\boldsymbol{\nu}$ represents the general velocity vector of any point in the ship, having components: $\boldsymbol{\nu}_1$ vector of the linear velocities characteristic of the translational movements; $\boldsymbol{\nu}_2$ vector of angular velocities characteristic of rotational movements;

$\boldsymbol{\tau}$ represents the vector of forces and moments acting on the ship, having as components: $\boldsymbol{\tau}_1$ the vector of forces acting on the ship; $\boldsymbol{\tau}_2$ the vector of moments acting on the ship.

In the field of naval architecture the strip theory was imposed, in two variants:

- the original strip theory, in which the hydrodynamic actions of the free surface of the calm water and the disturbing actions of the waves are considered to develop independently, in a certain direction of movement (so the movements are decoupled).;
- modified strip theory, taking into account the influence of the encounter angle and which takes into account the complex interaction process between the hydrodynamic actions of the free surface of the calm water and the disturbing actions of the waves.

The general equation of the ship motion, in vector form, relative to the mobile coordinate system (whose origin coincides with the center of gravity of the ship) takes the form:

$$\boldsymbol{M}\dot{\boldsymbol{\nu}}_r + \boldsymbol{C}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \boldsymbol{D}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \boldsymbol{g}(\boldsymbol{\eta}) = \boldsymbol{\tau}_M + \boldsymbol{\tau} \tag{2}$$

The general equation of the ship motion, in vector form, written in relation to the fixed reference system (whose origin is in the plane of the free surface of the calm water) has the form:

$$\boldsymbol{M}_\eta(\boldsymbol{\eta})\ddot{\boldsymbol{\eta}} + \boldsymbol{C}_\eta(\boldsymbol{\nu}_r, \boldsymbol{\eta})\dot{\boldsymbol{\eta}} + \boldsymbol{D}_\eta(\boldsymbol{\nu}_r, \boldsymbol{\eta})\dot{\boldsymbol{\eta}} + \boldsymbol{g}_{\boldsymbol{\eta}}(\boldsymbol{\eta}) = \boldsymbol{\tau}_{M\eta}(\boldsymbol{\eta}) + \boldsymbol{\tau}_{\boldsymbol{\eta}}(\boldsymbol{\eta}) \tag{3}$$

The complex nature of the field of interest has led many researchers and naval engineers to explore the possibilities offered by mixed theories and methods which combine methods of rational, theoretical analysis with computer-assisted working.

3. Case study

To exemplify the facilities offered by OCTOPUS software in the study of the ship's behavior in real navigation conditions, was used the working modules related to:

- the ship geometry which, by its complexity, generates difficulties in the rigorous mathematical modelling;
- the navigation environment that generates hydrodynamic modelling difficulties for incident wave systems;
- the interactions between the body of the ship and the navigation environment, a complex phenomenon, whose mathematical expression by equations and boundary conditions (generated by the existence of the separation surfaces), implies the acceptance of simplifying hypothesis.

For example, a multifunctional semi-container ship with unlimited navigation area was used from the OCTOPUS software library. The ship has a bulbus provided in the bow and stern of a construction that allows the placement, in the center plane of the ship, of a semi-suspended rudder and a propeller with 4 fixed blades. The volume of the hull is close to the 28773 m^3 and the value of the block coefficient is 0.59. The height of the hull center is about 6 m and the value of the cross-center metacentric radius is 4.8 m. The crui se speed of the ship is 14 kNts, and for the study a four speed range was used (12.5; 14.5; 16,.5 respectively 18.5 kNts.

The geometry of the ship and the static and dynamic characteristics of the body are illustrated in Fig. 1.

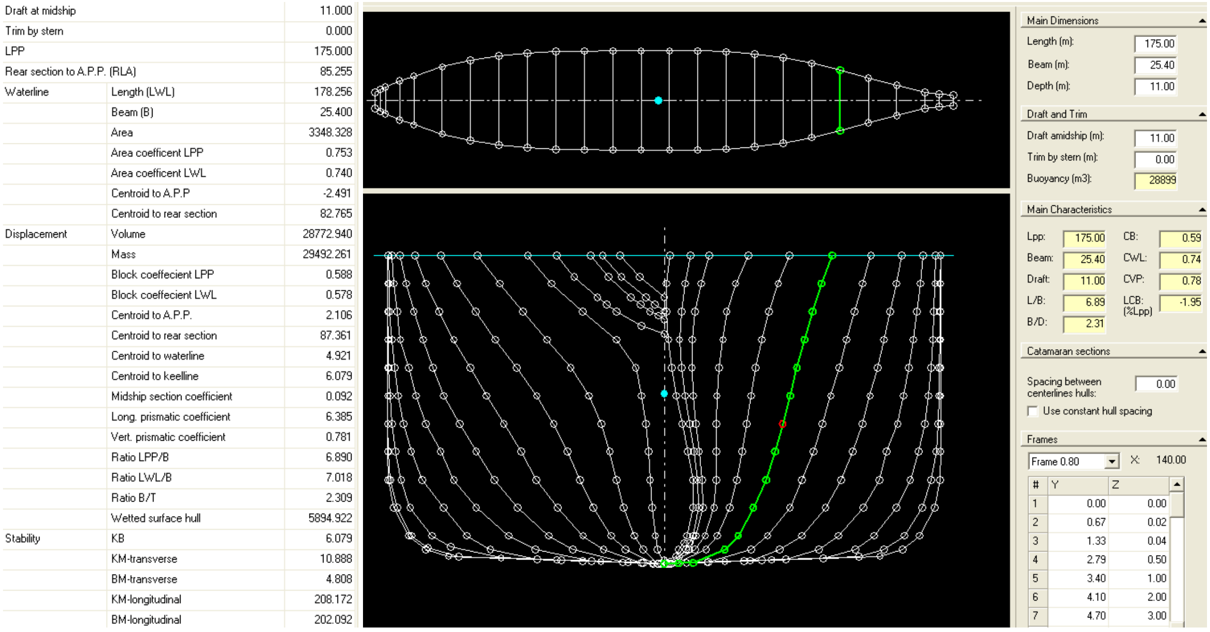
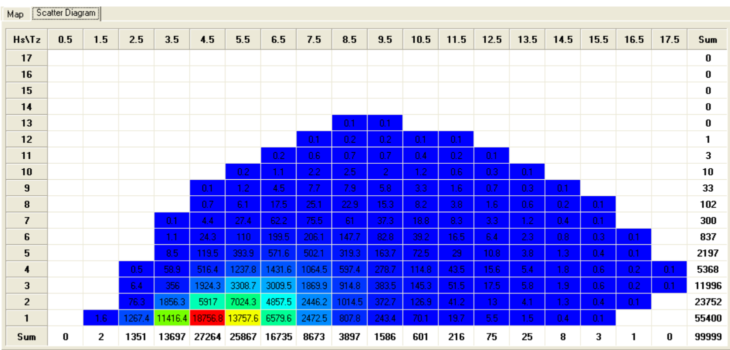


Fig.1. Ship geometry

In Fig.2, a voyage was created in the Mediterranean Sea, by generating a waypoint from Piraeus (Greece) to Marseille (France).

Fig.2. Navigation route

The Fig.3 shows the wave scatter diagram. A wave scatters diagram shows the probability for a wave combination of significant weights (Hs) and the zero cross period (Tz). The scatter diagram is used for statistical analysis. The following spectra definitions are available: Neumann, Bretschneider (equals Pierson – Moskowitz) and Jonswap (the ultimate was used in this study).



Map | Scatter Diagram

Hs\Tz	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	Sum
17																			0
16																			0
15																			0
14																			0
13									0.1	0.1									0
12								0.1	0.2	0.2	0.1	0.1							1
11							0.2	0.6	0.7	0.7	0.4	0.2	0.1						3
10						0.2	1.1	2.2	2.5	2	1.2	0.6	0.3	0.1					10
9					0.1	1.2	4.5	7.7	7.9	5.8	3.3	1.6	0.7	0.3	0.1				33
8					0.7	6.1	17.5	25.1	22.9	15.3	8.2	3.8	1.6	0.6	0.2	0.1			102
7				0.1	4.4	27.4	62.2	75.5	61	37.3	18.8	8.3	3.3	1.2	0.4	0.1			300
6				1.1	24.3	110	199.5	206.1	147.7	82.8	39.2	16.5	6.4	2.3	0.8	0.3	0.1		837
5				8.5	119.5	393.9	571.6	502.1	319.3	163.7	72.5	29	10.8	3.8	1.3	0.4	0.1		2197
4			0.5	58.9	516.4	1237.8	1431.6	1064.5	597.4	278.7	114.8	43.5	15.6	5.4	1.8	0.6	0.2	0.1	5368
3			6.4	356	1924.3	3308.7	3009.5	1869.9	914.8	383.5	145.3	51.5	17.5	5.8	1.9	0.6	0.2	0.1	11996
2			76.3	1856.3	5917	7024.3	4857.5	2446.2	1014.5	372.7	126.9	41.2	13	4.1	1.3	0.4	0.1		23752
1		1.6	1267.4	11416.4	18756.8	13757.6	6579.6	2472.5	807.8	243.4	70.1	19.7	5.5	1.5	0.4	0.1			55400
Sum	0	2	1351	13697	27264	25867	16735	8673	3897	1586	601	216	75	25	8	3	1	0	99999

Fig.3. Wave scatter diagram

Fig. 4 shows the wave spectrum, considered the input size for the rotational movements of the ship (roll, pitch and yaw) corresponding to a encounter pulsation in the field of 0,2 - 1,4 rad/sec and, for reasons of proper sizing of the work, only for the speed of 12.5 kNts.

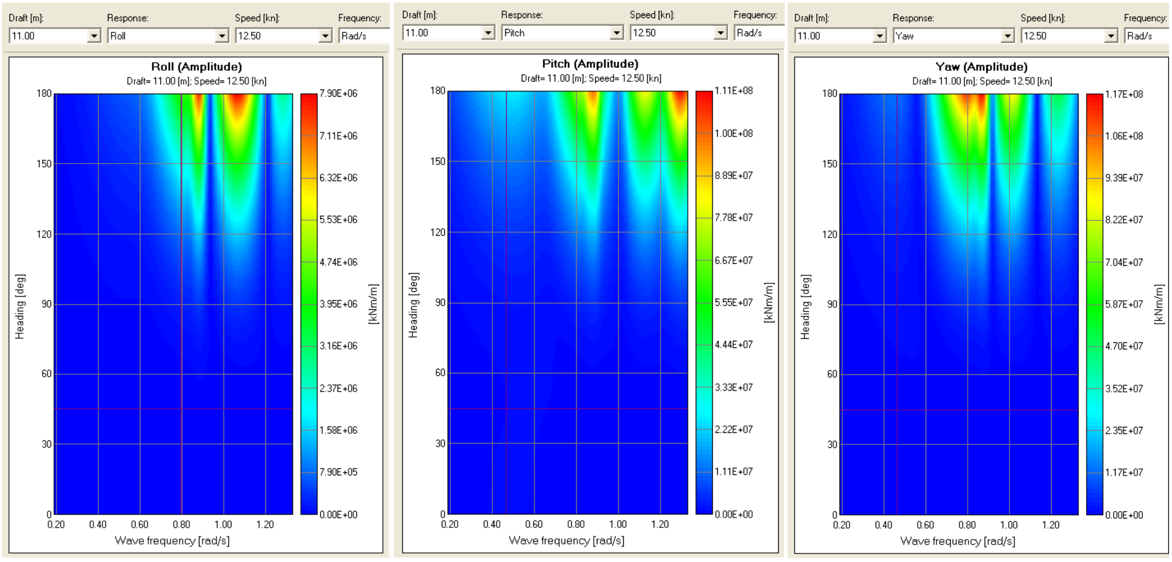


Fig.4. Wave spectra

4. Conclusions

Like any free rigid body, the ship can perform six simple movements (three translations and three rotations) relative to the axes of a coordinate system. In real sea navigation, the ship performs much more complex movements, generated by various disturbing factors and which express the combination, in different planes, of the simple movements.

Knowing the physical phenomena and the laws governing the manifestation of water - as an environment in which the ship floats and moves - both at rest and on the move, raises very complex problems in terms of analytical modeling.

The simplest way to approach the problems raised by the mathematical modeling of the waves, is to understand their irregularity as a result of overlapping a very large number of regular cossinusoidal waves having individual and distinct characteristics and moving in different directions [6]. That is why, the only analytical way to represent the agitation and irregularity of the sea is the energy spectrum [6] [7] [8].

The ship can be understood as a system which, being disturbed by a series of physical quantities called "input", responds with a series of physical quantities called "output", via a transfer function. For the study of the behavior of the ship on waves, this transfer function is an operator named RAO (Response Amplitude Operator).

The energy spectrum of the wave have, obviously, an correspondents to an energy spectrum of the "response of the ship" which describes the behavior of the ship on waves and which can be determined with the relation [6].

$$S_r(\boldsymbol{\omega}) = \left(\frac{r_A}{\tilde{h}_A}\right)^2 S(\boldsymbol{\omega})$$

The ship system, excited by waves, produces different responses for each of the six degrees of freedom it has, so the RAO spectra has different values for each type of movement which describes.

In Fig. 5, Fig. 6 and Fig7 it is shown the RAO spectra for the roll, pitch and yaw movements of the ship considered for example, on the chosen navigation route, for the chosen speed spectrum and for the angles of incidence with the sea waves considered in this analysis.

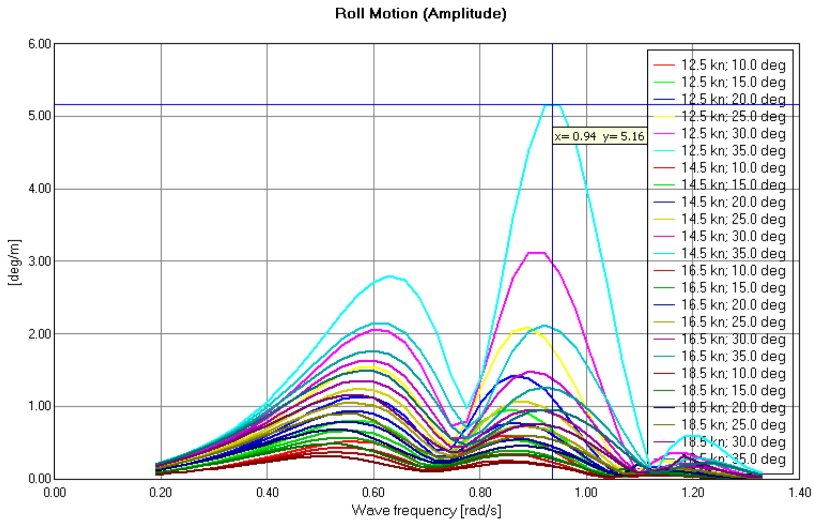


Fig.5. RAO spectre for roll motion

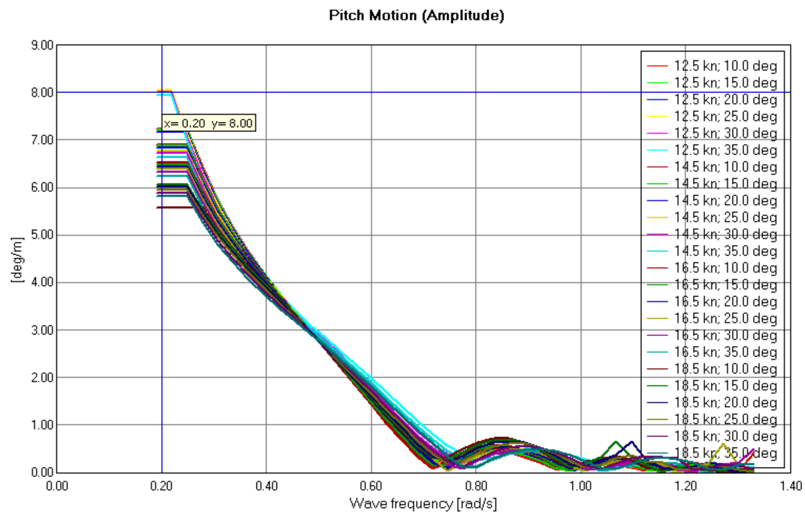


Fig.6. RAO spectre for pitch motion

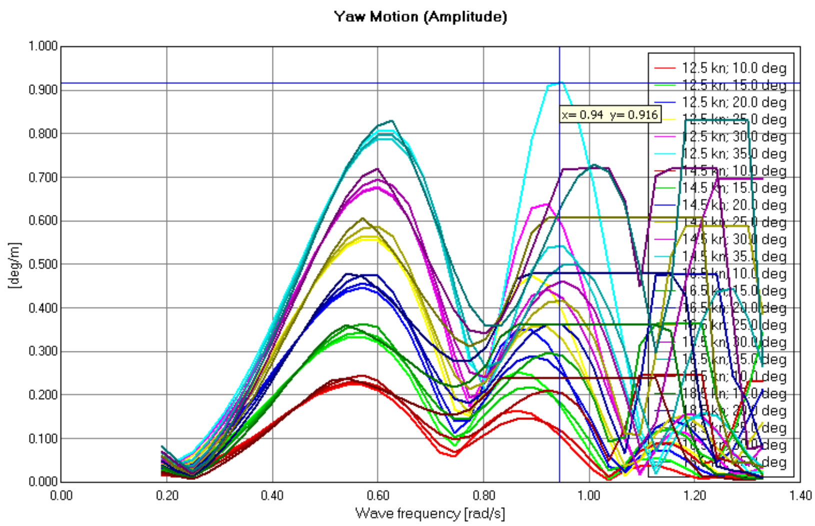


Fig.7. RAO spectre for yaw motion

Therefore, the researcher interested in studying the behavior of the ship under real navigation conditions, is facing problems related to the modeling of the ship (geometry and static and dynamic nautical qualities) and the modeling of the navigation environment (unfortunately still widely used theoretical wave spectra instead of real spectra). But perhaps the most complex problem, which remains only partially resolved and it is open to future research, is that of the complex combination of ship movements and the complex interaction between the body of the ship and the navigation environment.

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References
[1] Domnişoru, L., *Dinamica navei în mare reală*, Galaţi, Universitatea „Dunărea de Jos”, 1997.
[2] Bhattacharyya, R., *Dynamics of marine vehicles*, New-York, John Wiley & Sons, 1978.
[3] Edward, V.L., *Principles of naval architecture*, Vol. I, II, III, New Jersey, The Society of Naval Architects and Marine Engineers, 1989.
[4] Fossen, T., *Guidance and control of ocean vehicles,* University of Trondheim, Norway, John Wiley & Sons, 1994.
[5] Stoker, J.J., Water waves the mathematical theory with applications, New york, John Wiley&Sons, 1992.
[6] Journee, J.M.J., *Theoretical manual of Seaway*, Delft University of Technology, Shiphydromecanics Laboratory, Netherlandes, 2001.
[7] Blanke, M., Fossen, T., *Nonlinear output feedback control underwater vehicle propellers using feedback form estimated axia flow velocity*, IEEE, Journal of Oceanuc Engineering, 2000
[8] Maier, V., *Solicitări generale în arhitectura navală modernă*, Bucureşti, Editura Tehnică, 1997.