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THEORETICAL INVESTIGATION ON THE SEAKEEPING PERFORMANCE OF A SUPPLY VESSEL WITH X-BOW

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ABSTRACT

The X-bow concept was developed by Ulstein company, in order to increase the ship hydrodynamic performance. Low resistance, reduced fuel consumption, smoother motion and low acceleration levels are some of the hydrodynamics improvements. A theoretical analysis on the seakeeping performance of a supply vessel with X-bow form was performed by using Aveva Marine Engineering Software and it is presented in this paper. The ship motions and accelerations on irregular waves were calculated and the influence of the roll gyradius and bilge keel was analysed. The conclusion reveals the important influence of the mentioned elements on the ship motions and accelerations.

Keywords: X-bow supply vessel, seakeeping performance, theoretical estimation

1. INTRODUCTION

The hydrodynamic safety of a ship running in waves field with a given speed represents a main component of the global security concept. Its evaluation is based on the seakeeping performance analysis in dangerous conditions.

The complexity of the theoretical approach on this topic is generated by the coupled motions of the ship with six degrees of freedom. The estimation of the ship motions and accelerations with a satisfactory accuracy level is necessary. For this purpose, different CAD-CAE systems can be used.

This paper presents a theoretical analysis on the seakeeping performance of a supply vessel with X-bow form which was performed by using Aveva Marine Engineering Software.

The X-bow concept was developed by Ulstein company, in order to increase the ship's hydrodynamic performance. Low resistance, reduced fuel consumption, smoother motion and low acceleration levels are some of the hydrodynamics improvements reported by Ulstein in the case of X-bow concept.

The main characteristics of the supply vessel are presented in Table 1.

Table 1. Main characteristics of the supply vessel

Main characteristics	Full scale
Length overall, L_{OA} [m]	83.3
Length of waterline, L_W [m]	79.5
Length between perpendiculars, L_{BP} [m]	82.3
Beam, B [m]	18.0
Depth, D [m]	20.3
Draft, T [m]	6.0
Longitudinal center of buoyancy, LCB [m]	37.203
Volumetric displacement, ∇ [m^3]	5755.1
Design speed, v [m/s]	15.0
Froude number, F_n	0.276
Block coefficient, C_B	0.646
Waterplane coefficient, C_W	0.827
Midship section coefficient, C_M	0.985

The transverse sections of the body lines plan are presented in Fig. 1.

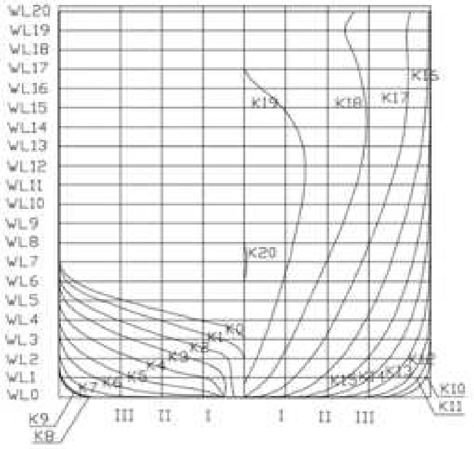

Fig. 1. Transverse sections of the supply vessel

A summary of the theoretical model, applied in this paper, in order to calculate the seakeeping performance of the supply vessel is presented in the next chapter.

2. THEORETICAL METHODOLOGY

The ship's motion equations on the incident waves can be written by using Newton's second law

$$\frac{d}{dt}(M \cdot \dot{\eta}) = H \qquad (1)$$

where M is the matrix of the masses and inertia moments of the ship, η is the ship motion and H represents the hydrodynamic forces and moments.

Under the linear hydrodynamic model assumption, the following relation can be written

$$H = F_E + G_R \qquad (2)$$

where F_E are the excitation forces and moments generated by the incident waves and G_R are the radiation forces and moments given by the relation [3]

$$G_R = -A \cdot \ddot{\eta} - B \cdot \dot{\eta} - C \cdot \eta \qquad (3)$$

The matrix A is the added masses matrix, B is the potential damping coefficients matrix and C is the restoring coefficients matrix.

The added masses and damping coefficients can be calculated on the basis of the sources distribution method, suggested by Frank [2].

The general form of the ship motion equations is obtained by replacing the expressions (2) and (3) in relation (1)

$$(M + A)\ddot{\eta} + B\dot{\eta} + C\eta = F_E \qquad (4)$$

The response amplitudes operators of the ship's motion RAO_η and accelerations RAO_a can be determined on the basis of the solution of the system (4)

$$RAO_\eta = \left(\frac{\eta}{\zeta_w}\right)^2 \qquad (5)$$

$$RAO_a = \left(\frac{a}{\zeta_w}\right)^2 \qquad (6)$$

where ζ_w is the regular wave amplitude and a is the ship acceleration.

For a given sea state with power spectral density S_w, the response spectra of the motions S_η and accelerations S_a can be calculated with the expressions [1]

$$S_\eta(\omega_e) = RAO_\eta \cdot S_w(\omega_e) \qquad (7)$$

$$S_a(\omega_e) = RAO_a \cdot S_w(\omega_e) \qquad (8)$$

where ω_e represents the encountering circular frequency.

Based on the mentioned response spectra, the spectra moments of zero order for motions m_0^η and accelerations m_0^a can be calculated by using the relations

$$m_0^\eta = \int_0^\infty S_\eta(\omega_e) \cdot d\omega_e \qquad (9)$$

$$m_0^a = \int_0^\infty S_a(\omega_e) \cdot d\omega_e \qquad (10)$$

Also, the root mean square values of the amplitudes of the ship's motions RMS_η and accelerations RMS_a on irregular waves can be evaluated by using the expressions

$$RMS_\eta = \sqrt{m_0^\eta} \qquad (11)$$

$$RMS_a = \sqrt{m_0^a} \qquad (12)$$

Specific criteria based on RMS values were adopted for the ship motions and accelerations:

- Roll motion, $RMS_\Phi = 8$ deg.;
- Pitch motion, $RMS_\theta = 3$ deg.;
- Lateral acceleration, $RMS_{ay} = 2$ m/s^2;
- Vertical acceleration $RMS_{az} = 4$ m/s^2.

Based on the specific criteria, the polar diagrams can be obtained, in order to determine the influence of the speed and ship-wave incident angle on the seakeeping performance, for a given sea state.

3. PRACTICAL EVALUATION

The ITTC spectrum was selected in order to analyse the seakeeping performance of the supply vessel, on irregular waves with significant height H_w of 1 m, 1.5 m and 2 m.

The lateral and vertical accelerations were calculated in a point situated on the transvers section of the forward perpendicular, on the main deck edge.

The specific criteria for roll and pitch motions were fulfilled for the considered sea states (Fig. 2).

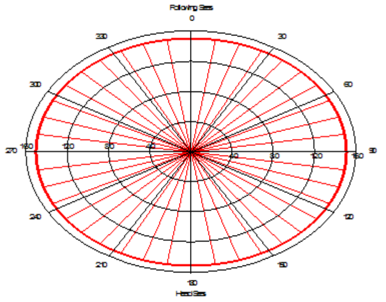

Fig. 2. Polar diagram. Roll and pitch motions

In the case of lateral acceleration, the mentioned criterion was not fulfilled for quartering and beam waves, with significant height greater then 1 m (Figs. 3 and 4).

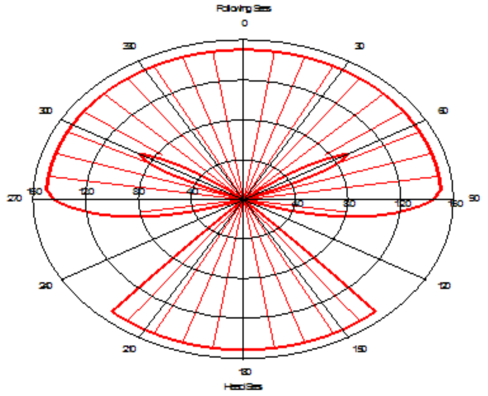

Fig. 3. Polar diagram. Lateral acceleration for H_w=1.5 m

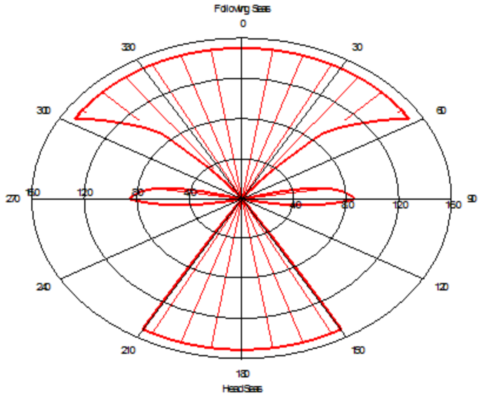

Fig. 4. Polar diagram. Lateral acceleration for H_w=2 m

Also, the specific criterion was not fulfilled in the case of vertical acceleration (Figs. 5 and 6), in principal for head waves and fore quartering waves, with significant height exceeding 1 m.

The changing of the speed or ship-wave incident angle represents solutions to avoid the critical domains.

The influence of the roll gyradius on the roll motion was analysed. The values of the nondimensional roll gyradius were adopted in the domain 0.2 … 0.4 with step of 0.05 and their influence on the RMS_Φ function was established. The nondimensional roll gyradius was calculated by means of the roll gyradius over beam ratio.

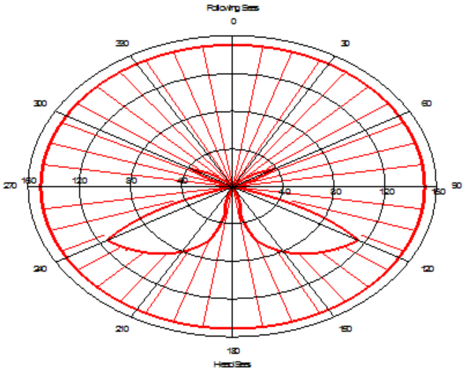

Fig. 5. Polar diagram. Vertical acceleration for H_w=1.5 m

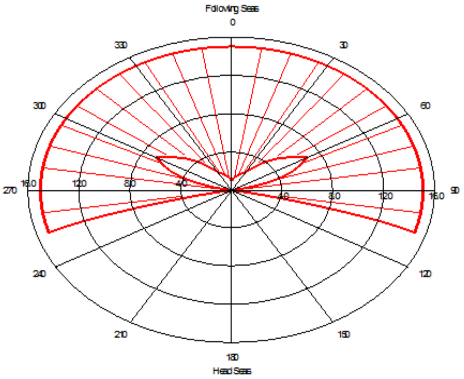

Fig. 6. Polar diagram. Vertical acceleration for H_w=2 m

Figs. 7 and 8 depict the diagrams of the RMS_Φ function depending by the ship-wave incident angle μ and the nondimensional roll gyradius *rxx*, at zero and design speeds respectively, on irregular waves with significant height H_w=2 m.

If the roll gyradius increases, the RMS_Φ function decreases at zero speed. In the case of the design speed, the maximum values of the RMS_Φ function depend on the ship-wave incident angle. If *rxx*=0.3 and μ=60°, the maximum value is obtained. On beam, fore quartering waves or head waves, the RMS_Φ function decreases if the roll gyradius increases.

A similar analysis was performe on the influence of the roll gyradius related to the lateral acceleration RMS_{ay} and vertical acceleration RMS_{az}. Figs. 9, 10, 11 and 12 illustrate the variation of the RMS_{ay} and RMS_{az} functions, on irregular waves with significant height H_w=2 m, depending by the ship-wave incident angle μ and the nondimensional roll gyradius *rxx*, both at zero and design speeds.

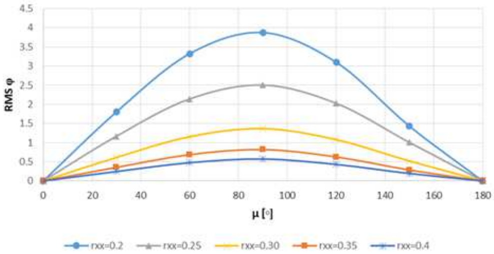

Fig. 7. RMS_Φ function at zero speed, for H_w=2 m

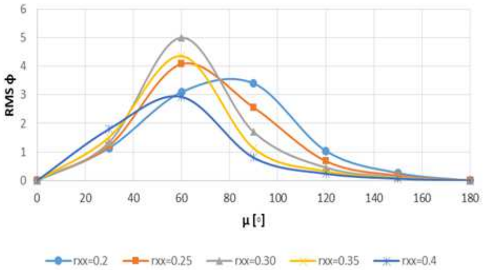

Fig. 8. RMS_Φ function at design speed, for H_w=2 m

In the case of zero speed, two maximum values were observed for RMS_{ay} and RMS_{az} functions, for ship-wave incident angle μ having the values 60° and 120° respectively. In the case of design speed, only one maximum value was obtained, when μ=120° for RMS_{ay} and when μ=150° for RMS_{az}.

The maximum values at zero and design speeds were obtained for the RMS_{ay} function when the nondimensional roll gyradius *rxx*=0.4. For the RMS_{az} function, when *rxx*=0.2 the maximum values were obtained.

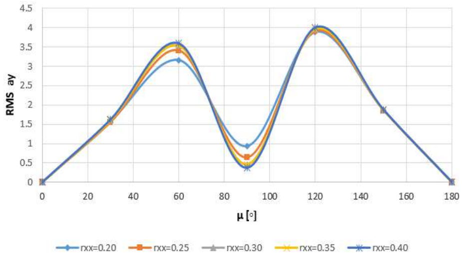

Fig. 9. RMS_{ay} function at zero speed, for H_w=2 m

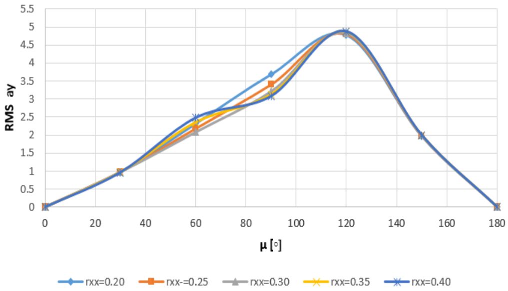

Fig. 10. RMS_{ay} function at design speed, for H_w=2 m

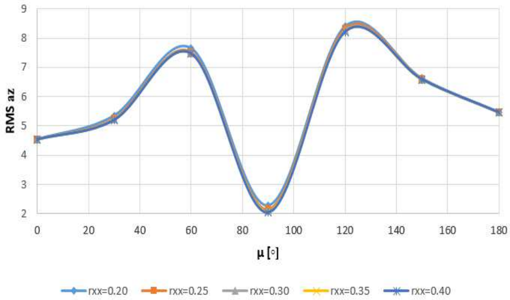

Fig. 11. RMS_{az} function at zero speed, for H_w=2 m

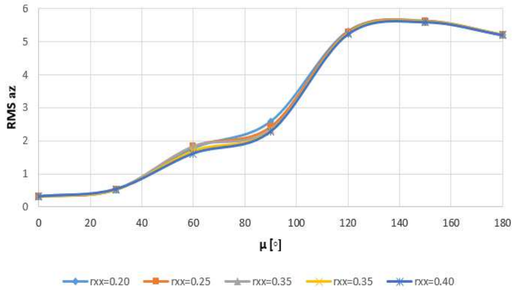

Fig. 12. RMS_{az} function at design speed, for H_w=2 m

The influence of the bilge keel on the roll motion was analysed in the final part of this study. The beam of the bilge keel was modified in the range 0.2 m … 0.6 m, with step of 0.1 m and the length of the bilge keel was equal with 0.7 L_W=55.67 m.

Figs. 13 and 14 present the diagrams of the RMS_{Φ} function depending by the ship-wave incident angle μ and the beam of the bilge keel, in the critical case with the non-dimensional roll gyradius *rxx*=0.2, on irregular waves with significant height H_w=2 m, at zero and design speeds respectively.

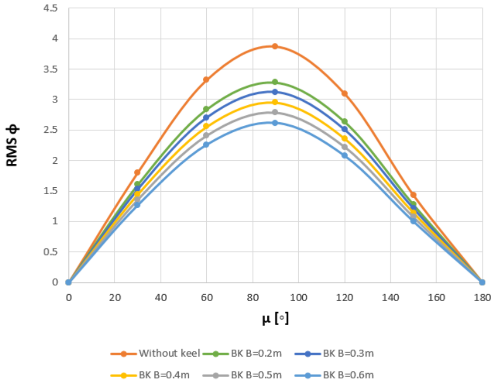

Fig. 13. RMS_{Φ} function at zero speed, with bilge keel influence, for H_w=2 m and *rxx*=0.2

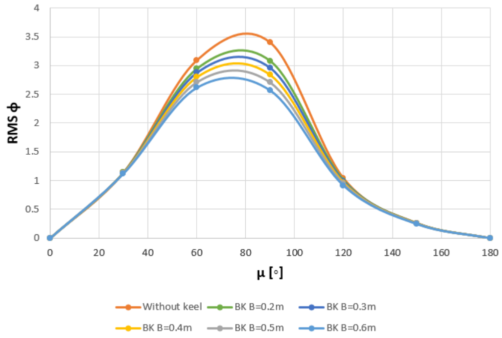

Fig. 14. RMS_{Φ} function at design speed, with bilge keel influence, for H_w=2 m and *rxx*=0.2

An important contribution on the roll damping can be observed at zero and design speeds, due to the bilge keel.

If the beam of the bilge keel increases, the RMS_{Φ} function of the roll motion decreases.

4. CONCLUDING REMARKS

The evaluation of the hydrodynamic safety of a ship running in waves field with a given speed is based on the seakeeping performance analysis in dangerous conditions.

A theoretical investigation on the seakeeping performance of a supply vessel with X-bow form was performed in this paper, on irregular waves with significant height equal with 1 m, 1.5 m and 2 m, by using Aveva Marine Engineering Software.

The ship's accelerations were calculated on the main deck edge, in the transvers section of the forward perpendicular.

The X-bow concept was proposed by Ulstein company, in order to increase the hydrodynamic performance, the ship motions and accelerations included.

The adopted criteria for roll and pitch motions were fulfilled for all sea states. According with the Ulstein concept, the moderate amplitudes of the motions for supply vessel were determined.

In the case of vertical and lateral accelerations, restricted navigation area in the polar plots were identified, for waves significant height exceeding 1 m.

The influences of the roll gyradius and bilge keels on the roll motion were analysed.

If the roll gyradius increases, the RMS_{Φ} function decreases both at zero speed and design speed, on beam or fore quartering waves. If μ=60° and *rxx*=0.3, a maximum value of the RMS_{Φ} function was obtained at the design speed.

Also, an important influence of the bilge keel was demonstrated, in the critical case when the nondimensional roll gyradius has the value *rxx*=0.2, on irregular waves with the significant height H_w=2 m, at zero and design speeds respectively.

All these theoretical results must be validated on the basis of experimental model tests.

Acknowledgements

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