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SEAKEEPING PERFORMANCE ASSESSMENT FOR A CONTAINERSHIP IN A SPECIFIC SEA AREA

Carmen GASPAROTTI, Liliana RUSU

"Dunarea de Jos" University of Galati, ROMANIA
carmen.gasparotti@ugal.ro

ABSTRACT

In the present work, the calculation of seakeeping performance given as an operability index is carried out for a containership with different characteristics. The operability index depends on the wave climate of the ocean area where the ships operate, the dynamic response of the ship to the waves, and the ship mission. The relation between the ship operability and the mission characteristics is established through the seakeeping criteria, which represent the acceptable limits of operation. The wave conditions considered were those usually encountered in the Black Sea, near to the Gloria drilling platform. The transfer functions of the absolute ship motions and of some derived responses such as accelerations and relative motions are obtained using a method based on the strip theory. The numerical results are pointing out the navigation restrictions for the container ship according to the sea state conditions.

Keywords: Black Sea, seakeeping performance, operability index, relative motions, significant wave height, transfer functions

1. INTRODUCTION

The global dynamic performance of ships depends on the seakeeping behaviour in the specified sea areas where the vessel is designed to operate. The seakeeping analysis is based on the short term statistical approach and ship motions seakeeping limit criteria, according to the sea state and navigation scenario[1].

The seakeeping behaviour of a ship in an sea area can be quantified by an operability index which can describe the ship ability to navigate in compare to the calm water condition. The operability index requires the following data: the navigation scenario and the seakeeping limit criteria, the hydrodynamic and inertia characteristics of the ship hull and the sea state where the ship operates, based on short term wave power density spectrum functions [2].

The ship seakeeping analysis includes the following steps [3], [4]:

1. The computation of the transfer functions of the absolute ship motions and of also derived values, such as accelerations and relative motions. The transfer functions can be

performed with computer codes based on the 2D strip theory [5], taking into account the ship geometric and inertial characteristics.

2. Short term ship dynamic response, based on the transfer functions and the specific wave spectra.

3. Based on the seakeeping criteria are calculate the polar diagrams, limit curves of maximum significant wave height according to safety operation criteria.

4. The computation of the seakeeping index in a given sea area for a navigation route, based on a long term specific wave scattering diagram [3].

This paper is focused on how the seakeeping performance assessment procedure is performed and how can be calculated the operability index of a containership with navigation route in the Black Sea.

2. SEAKEEPING PERFORMANCE ASSESSMENT PROCEDURE

The ship's seakeeping performance assessment is based on the oscillations ship dynamic response in irregular waves, coresponding to the sea states during its operating life. Fig. 1 presents an overview of the seakeeping performance assessment procedure. The procedure starts with the prediction of the ship's hydrodynamic response for a range of speed and heading angle values. The amplitude of the ship motions in irregular waves are short term predicted according to the sea state and the specific wave spectra. Finally, based on the seakeeping safety conditions and the long term wave scattering diagram the seakeeping operativiy index is obtained [1].

In the following sections, the seakeeping analysis steps are numericaly applied for a test ship.

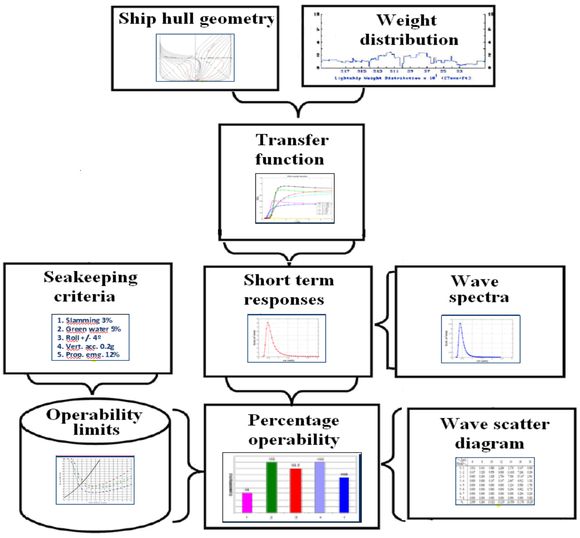


Fig. 1 Overview of the seakeeping performance assessment procedure (processed from [1])

3. CASE STUDY OF SEAKEEPING PERFORMANCE ASSESSMENT

3.1. Introduction

The seakeeping numerical analysis is applied to calculate the operability index of a containership, having the overall length 139, 965m, with navigation route in the Black Sea area. The short term significant response parameters are computed, depending on the sea state energy spectrum and the ship transfer functions. The container ship main dimensions and the offset ship lines are presented in Table 1 and Fig. 2.

Table 1. The main dimensions of the containerships

Containership	**C**
Length overall	139.965
Length between perp., *Lpp* (m)	130
Beam, *B* (m)	21.8
Draft, *T* (m)	7.3
Depth, *D* (m)	9.5
Deadweight (ton)	9500
Long. position of CG	-2.526
Service speed, U_s (kts)	18

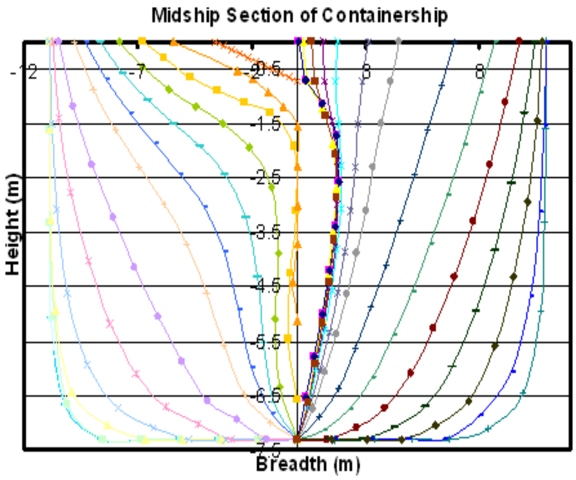


Fig. 2. The offset ship lines of the containership

It is assumed that green water on deck occurs when the relative motion is larger than the freeboard on the bow. Assuming maximum green water on deck probability of 5%, the operability index of the ship was calculated.

3.2. Ships Motions in Regular Waves

3.2.1. Transfer Functions of Absolute Motions

The first step includes the computation of the ship response transfer functions on ship main degrees of freedom, for all the heading angles in regular waves, for the ship service speed. In preliminary analysis a heading angle of 30 degrees is enough. The transfer functions plots are expressed by the motions amplitude at unit wave amplitude and by abscise wave length / Lpp.

The transfer functions include absolute ships motions (heave, roll and pitch), and derived responses at selected positions on the ship, such as relative motions and accelerations. Figures.3.a-c present heave, pitch and roll transfer functions.

The heave motion transfer function reaches a unit value limit for all the heading angles when the wave length is about five times the ship's length. It can also be noticed that for wave length around the ship length, the heave motion's amplitude is maximum, corresponding to the eigen heave oscillation period. For oblique incident waves ß=120°, 90º the heave motion amplitude is increased.

The roll motion transfer function has significant peaks in the case of heading angles ß=90^0, ß=120^0, ß=150^0, considering only the radiation hydrodynamic damping without the viscous one. For heading angle ß=180^0 the roll motion doesn't occur.

In the case of incident waves ß=60^0, where the roll amplitude is unitary, the wave length is equal with ship's length and this is called *parametric roll motion*. This happens when we have a decrease of transversal metacentric height because of instantaneous decrease of area of flotation when the wave crests passes through the amid ship.

For heading angle ß=90^0 the pitch motion doesn't occur. The maximum pitch amplitudes are obtained for the following heading angles: ß=180^0, ß=150^0, ß=30^0, ß=0^0.

3.2.2. Derived Ship Transfer Functions

The derived responses of the ship have been calculated for seven heading waves at the forward speed (18 kts) and the amplitudes of transfer functions were presented as functions of l/L_{pp}. The following derived responses were performed vertical acceleration at the bridge, lateral acceleration at the bridge, vertical relative motion at the bow and vertical relative motion at the propeller. The points for which these

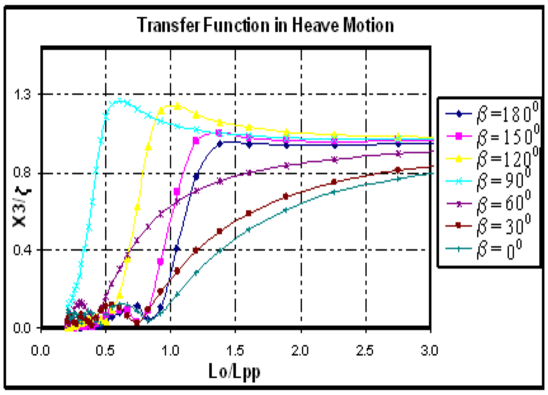


Fig. 3a.Transfer function in heave

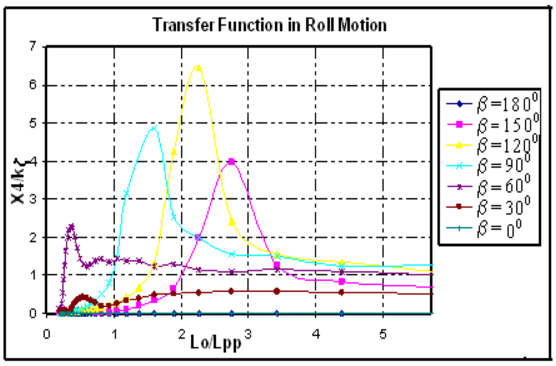


Fig. 3b.Transfer function in roll

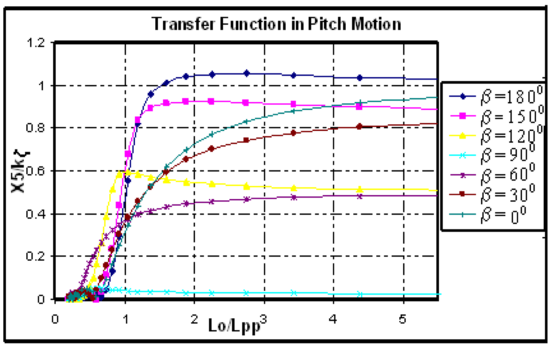


Fig. 3.c.Transfer function in pitch

Table 2. Points of calculating derived responses

Containership	**Location (m)** ***x ,y ,z***
Point bridge	-55.168, 0, 14.449
Point bow	62.276, 0, 5.1
Point propeller	-57.520, 0, 4.7

motions were calculated were chosen in such way that the amplitudes of motions to be of interest for ship and crew activity.

The positions on the ships where the derived transfer functions are calculated are presented in table 2. These positions are related to the green water on the deck criterion. Figures 4a-d present vertical and lateral acceleration on the bridge, the relative motion at the bow and the relative motion at the propeller.

The vertical acceleration was calculated on bridge, at stern because of reason of comfort on board ship.

It's noticed that a great amplification of vertical acceleration it obtained when the ship navigates in heading angles with wave length similar with ship's length but not all heading angles create an amplification of vertical acceleration, such as the cases ß=0^0, ß=30^0, ß=60^0. Consequently, it is also preferable that the point considered for reason of comfort on board of ship in that point being assumed to be favorable the crew activities.

The navigation in heading angles ß =120^0, ß =150^0, ß =180^0 is not recommended because of great amplifications of vertical acceleration on bridge. This it happens for great values of wave length and this is expected because the transition crest-wave to wave though is made slowly.

The relative motion at the bow was calculated on deck, at bow because of reason of slamming and wet deck.

Like in the case of vertical acceleration there were observed amplifications of relative motion on deck when wave length is equal with ship's length for heading angles ß=120^0, ß=150^0, ß=180^0. In these

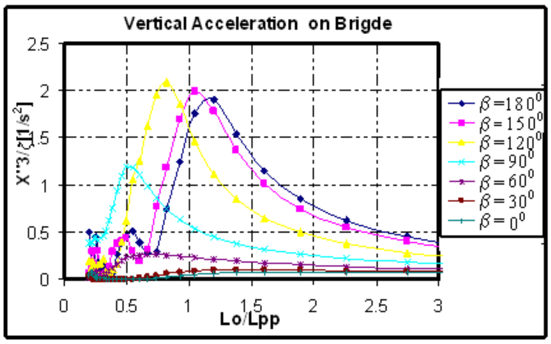


Fig.4.a. Vertical acceleration on bridge

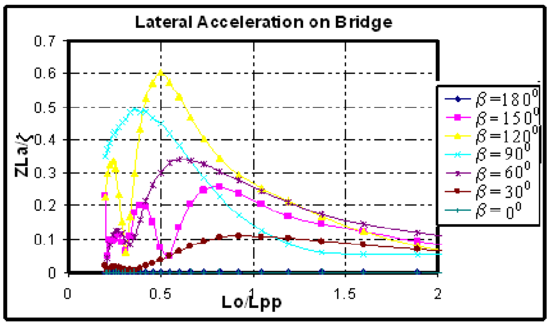


Fig.4.b. Lateral acceleration on bridge

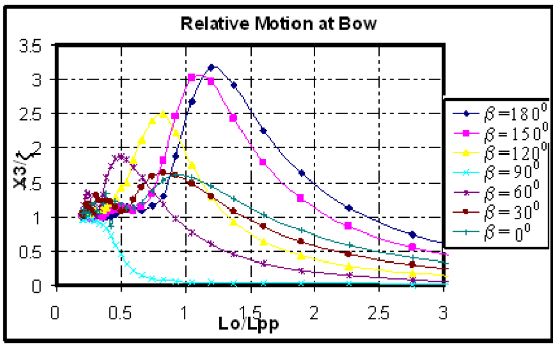


Fig.4.c. Relative motion at the bow

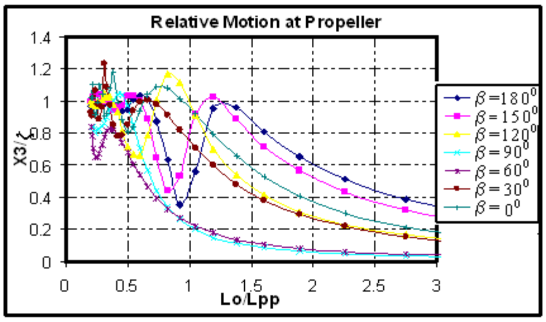


Fig. 4.d. Relative motion at the propeller

conditions, relative motion on deck reaches to get considerable values up to a value of perpendicular length three times greater than the wave amplitude that provoked the motion. As in the previous case of vertical acceleration it is also noticed an extinction of relative motion for big values of wave length divide by ship's length.

3.2.3. Speed Influence on Derived Responses

In this section the influence of the forward speed on the relative motion at the bow was investigated for all the seven headings.

Five speeds between zero and the service speed were considered. The analysis of the results shows that, for heading angles ß=150^0 and ß=180^0, the relative motion at the bow is reaching maximum values for l/L$_{pp}$=1, where influence of speed on considered motion is maximum. From this point the speed influence is beginning to decrease until some point where the speed doesn't influence anymore the amplitude of motion. Figures 5a and b present the influence of the forward speed on the relative motion at the bow in heading angles, for ß=180^0, ß=150^0. In the cases of the following directions ß=120°, 90º the remarks presented are still maintaining with few exceptions; one is that the peak of motions is registered earlier for ß=120° at l/L$_{pp}$=0.8 and for ß=90° at l/L$_{pp}$=0.5. For these heading angles the influence of speed disappears faster than the previous case especially for ß=90°. Figures 5 c, d present the influence of the forward speed on the relative motion at the bow in heading angles, for ß=120^0, ß=90^0.

In the following cases (ß=60^0, ß=30^0, ß=0^0) the relative motion at bow is very little influenced by speed. Figures 5 e, f, g present the influence of the forward speed on the relative motion at the bow in heading angles, for ß=60^0, ß=30^0, ß=0^0.

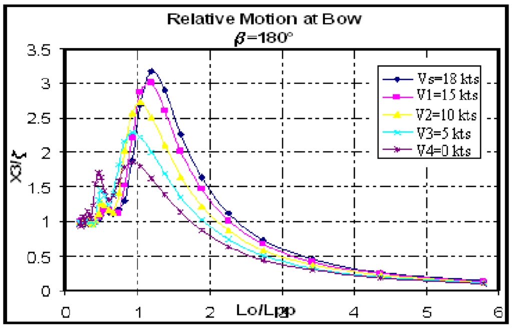


Fig. 5.a. Speed influence on relative motion at bow, for ß=180°

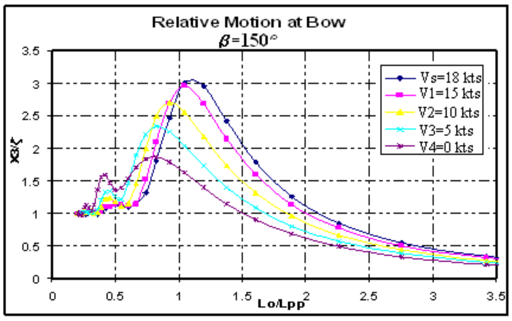


Fig. 5.b. Speed influence on relative motion at bow for ß=150°

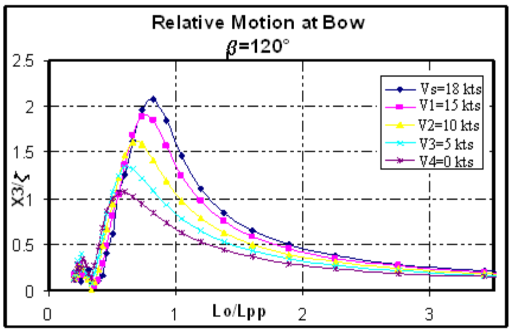


Fig. 5.c. Speed influence on relative motion at bow, for ß=120°

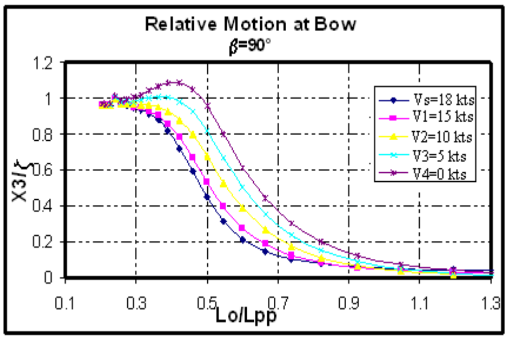


Fig. 5.d. Speed influence on relative motion at bow, for ß=90°

3.2.4 Ship Responses to Irregular Waves

The establishment of the seakeeping performance of a ship and the determination of explicit design parameters has to be done in a realistic seaway.

The seakeeping quality will be quantified by an operability index that measures the degradation of the ship ability to carry out its mission comparatively to the calm water condition. It is usual to define a seakeeping index as the percentage of time that the ship is operational.

The seakeeping index depends mainly on three factors, they are: the wave climate of the ocean area where the ship operates, the dynamic response of the ship to the waves, and the ship mission. The relation between the ship operability and the mission characteristics is established through the seakeeping criteria [6].

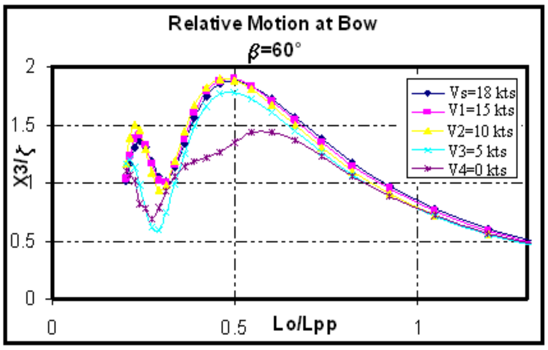


Fig.5.e. Speed influence on relative motion at bow for ß=60°

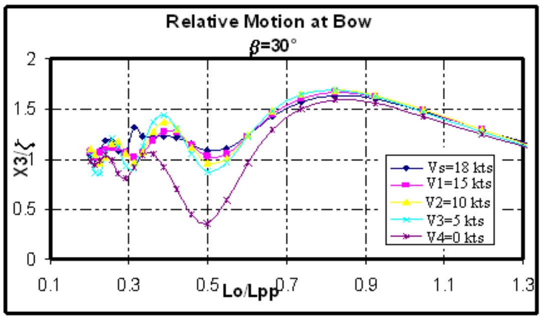


Fig.5.f. Speed influence on relative motion at bow, for ß=30°

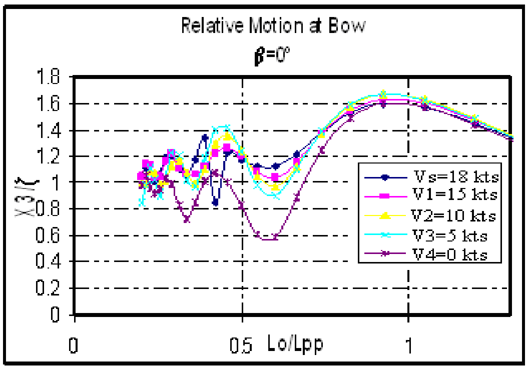


Fig.5.g. Speed influence on relative motion at bow for ß=0°

Usually the seakeeping criteria related to absolute motions and accelerations are presented in terms of a limit value for the root mean square (σ_R) of the response. The criteria can be also defined in terms of the probability of exceeding a critical value, as it is used for slamming, deck wetness, or propeller emergence [6].

The response spectrum $\Phi_{yy}(\omega_e)$ is obtained from the input wave spectrum $\Phi_{\zeta v\zeta v}$ (ω_e) by means of the response transfer function $H_y(\omega)$:

$$\phi_{yy}(\omega_e) = \left|H_y(\omega_e)\right|^2 \cdot \phi_{\zeta v\zeta v}(\omega_e) \quad (1)$$

The variance of the process can be obtained from the spectrum integrating:

$$\sigma_R^2 = \int_0^\infty \varphi_{yy}(\omega_e) d\omega_e = \qquad (2)$$

$$= \int_0^\infty \omega_e^n \left|H_y(\omega_e)\right|^2 \varphi_{\zeta v\zeta v}(\omega_e) d\omega_e$$

The *significant value* of the response R_S (double amplitude), may be calculated from the standard deviation as

$$R_S = 2\sigma_R \qquad (3)$$

The next step is to calculate the maximum significant wave height allowed, for a given mean wave period, ship speed and heading, satisfying the defined seakeeping criteria. The wave spectra that are used in this type of calculations are usually parameterized in terms of the significant wave height H_S , so the wave spectrum can be written in terms of the normalized wave spectrum $\Phi_{1\zeta v\zeta v}$ (ω_e).

$$\phi_{yy}(\omega, H_S, T_z) = H_S^2\phi_{\zeta v\zeta v}(\omega, 1, T_z) = H_S^2\phi_{\zeta v\zeta v}(\omega,, T_z) \tag{4}$$

The corresponding response spectrum is given by

$$\phi_{yy}(\omega) = H_S^2\phi_{1\zeta v\zeta v}(\omega) = H_S^2\phi_{1\zeta v\zeta v}(\omega)H^2(\omega) \tag{5}$$

and the variance of the response is

$$\sigma_R^2 = \int_0^\infty \phi_{yy}(\omega)d\omega = H_S^2\int \phi_{1\zeta v\zeta v}(\omega)H_S^2(\omega)d\omega \tag{6}$$

which can be represented as:

$$\sigma_R^2 = H_S^2\sigma_{R1}^2 \tag{7}$$

where σ_{R1} is the standard deviation of the response to a sea state of unit significant wave height. If the seakeeping criterion is defined as a limiting root mean square of the response σ_{CR} , then the maximum significant wave height for a given mean wave period T_z and ship heading is calculate by:

$$H_{s\max}(T_Z, \beta) = \frac{\sigma_{CR}}{\sigma_{R1}} \tag{8}$$

If the criterion is defined as a probability of exceeding a critical value p_{CR} , then the corresponding root mean square of the response is obtained from the following relation:

$$\sigma_{CR} = \sqrt{\frac{R_{\max}^2}{2\ln(1/p_{CR})}} \tag{9}$$

where R_{max} is the limiting magnitude of the response which has the probability p_{CR} of being exceeded. As an example, for green water on deck phenomena R_{max} is usually the free board at the bow. Knowing now the probability distribution of short-term sea states for a given ocean area, it is possible to select all sea states were the containership is operational.

According to this methodology the relevant parameters which characterise the ship behaviour are predicted as functions of the variance of the response spectrum, which in turn depend on the sea state energy spectrum and the ship transfer function. As a case study in relationship with the application of the above methodology, computations were being performed for a 139, 965-m containership. It is assumed that the containership operate in Black Sea and the wave climate statistics are based on wave measurements provided by a wave staff located on the Gloria drilling platform.

In the previous section was calculated the relevant ship response transfer functions for all directions between head waves and following waves and then the influence of the forward speed on the relative motion at the bow was also investigated for all the seven headings.

Next, it is necessary to calculate the ship responses related to the criterion to stationary sea states of unit significant wave height. The calculations are done for the all range of mean wave periods. Comparing the resulting root mean square of the responses with the seakeeping criterion (eq. 8), operability limiting boundaries are obtained. The vessel meets the seakeeping criteria for the wave height–wave period combinations below the boundary curves. Figure 6 presents these results for the ship for all headings. For each wave heading considered the ship is operational for the sea states that are below the corresponding curve. Finally, having the probability distribution of the short-term sea states for a given ocean area, it is possible to select all the sea states were the containership is operational (table 3).

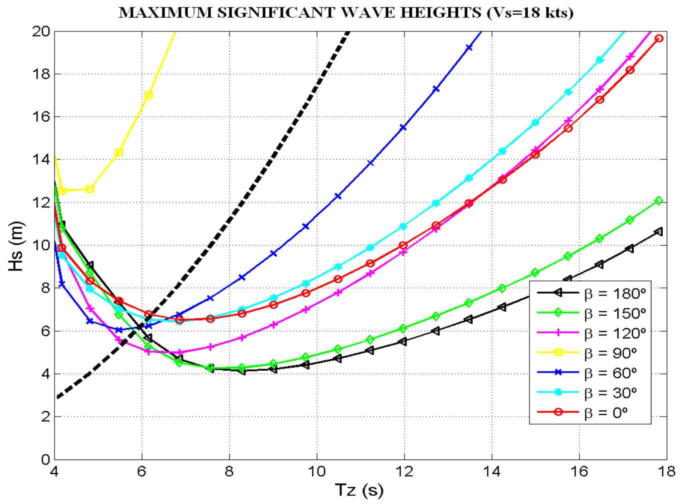
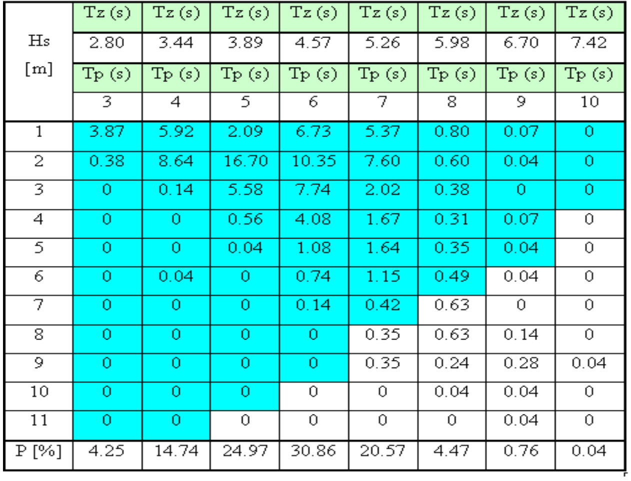


Fig. 6. Maximum allowed Hs for all headings and water on deck criterion at the forward speed

Table 3. Joint relative frequency of occurrence of Hs – Tp.



Hs [m]	Tz (s)	Tz (s)	Tz (s)	Tz (s)	Tz (s)	Tz (s)	Tz (s)	Tz (s)
	2.80	3.44	3.89	4.57	5.26	5.98	6.70	7.42
	Tp (s)	Tp (s)	Tp (s)	Tp (s)	Tp (s)	Tp (s)	Tp (s)	Tp (s)
	3	4	5	6	7	8	9	10
1	3.87	5.92	2.09	6.73	5.37	0.80	0.07	0
2	0.38	8.64	16.70	10.35	7.60	0.60	0.04	0
3	0	0.14	5.58	7.74	2.02	0.38	0	0
4	0	0	0.56	4.08	1.67	0.31	0.07	0
5	0	0	0.04	1.08	1.64	0.35	0.04	0
6	0	0.04	0	0.74	1.15	0.49	0.04	0
7	0	0	0	0.14	0.42	0.63	0	0
8	0	0	0	0	0.35	0.63	0.14	0
9	0	0	0	0	0.35	0.24	0.28	0.04
10	0	0	0	0	0	0.04	0.04	0
11	0	0	0	0	0	0	0.04	0
P [%]	4.25	14.74	24.97	30.86	20.57	4.47	0.76	0.04

The percentage operability is obtained by combining the operability limiting boundaries with the probability of occurrence of the sea states given in a wave scatter diagram, for a certain ship speed and wave heading, or weighted over all headings, respectively. Summing up the probabilities of occurrence of these sea states, the expected probability for a ship operating satisfying the defined criterion is obtained. This probability represents the *seakeeping index*. A simplification was introduced in the procedure by neglecting the wave directionality on the wave climate statistics.

Table 4. Seakeeping indexes.

Head (°)	**Containership**
180	0.94
150	0.95
120	0.95
90	1
60	0.99
30	0.99
0	0.99
Average	**0.97**

If the seakeeping criterion is defined as a limiting root mean square of the response σ_{CR} , then the maximum significant wave height for a given mean wave period T_Z and ship heading is calculate using expression (8). Based on these criteria, the limiting significant wave heights have been determined as a function of the mean period.

Table 4 presents the seakeeping index for the ship heading and when green water deck criterion is satisfied at the forward speed. With this set of results it is possible to analyze the influence of each of the ship heading. The ship is operational 97% of the time during the year. The operability is lower at head seas.

In practice, this containership could satisfy the green water deck criterion for longer periods than the estimated values because the shipmaster may change the route to avoid stormy seas or change the heading, and he may also reduce the speed to reduce the ship responses. The influence of the ship speed on the maximum significant wave heights in head waves is illustrate in Fig. 7.

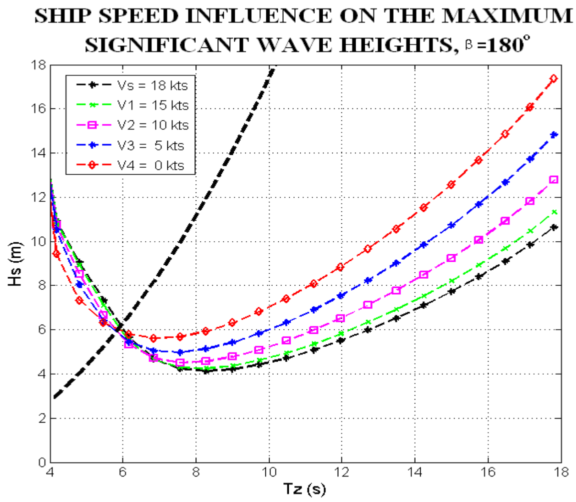


Fig. 7. Ship speed influence on the maximum significant wave heights in heading angles

4. CONCLUDING REMARKS

An analysis of the seakeeping characteristics of a containership advancing in regular and in irregular waves, respectively was carried out. The hydrodynamic calculations were performed with computer codes based on the strip theory, while the ship responses to irregular sea states were done using methods based on standard spectral techniques and probabilistic methods.

The wave conditions considered were those usually encountered in the Black Sea, near to the Gloria drilling platform.

The influence of the wave heading angles on relative motions at the bow was analysed. It was also observed that, for certain wave headings, an increase or a decrease of the ship forward speed induces important modifications of the relative motions at the bow.

The seakeeping performances were calculated as a function on the hydrodynamic characteristics of the ship and the ocean conditions where the ship operates. The result is given as an operability index that represents the percentage of time during which the ship is operational.

Generally, the relation between the ship operability and the mission characteristics is established through the seakeeping criteria. In this way the seakeeping index represents the percentage of time during which the ship responses are below to those defined by green water deck criterion. For the cases presented in this work, the operability index resulted is 97%.

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