Crew Comfort Investigation for Vertical and Lateral Responses of a Container Ship

Ferdi Çakıcı, *Yildiz Technical University, fcakici@yildiz.edu.tr*
Burak Yıldız, *Yildiz Technical University, buraky@yildiz.edu.tr*
Ahmet Dursun Alkan, *Yildiz Technical University, alkanad@yildiz.edu.tr*

ABSTRACT

This study deals with the crew comfort on board analyses based on vertical and lateral responses of a container ship in sea states 4, 5 and 6. Crew on board might be affected by excessive motions of the ship where fatigue and lack of morale might began gradually and it leads to low concentration for deck operations. This is all called as seasickness phenomena and it should be investigated/evaluated influence on conceptual design decisions. Vertical and lateral responses calculations of the ship are carried out by using strip theory and short statistical method. The total roll damping coefficient is defined using Ikeda's estimation method. The obtained results are combined with the published seakeeping criteria in terms of human factor. In the end of study, operability indices of the container ship are shown with respect to sea states and selected criteria in polar diagrams and tables.

Key Words: *Operability, Ikeda's Method, Potential Theory, Human Factor*

1. INTRODUCTION

It always has been a significant issue to have seakeeping characteristics of ships in waves during design stage. It is very important to obtain the responses in waves due to the effects of the ship motions on human. Minimization for responses can definitely advance the operability and safety of the crew on deck. Reducing motions and accelerations in several sea states is necessary for the sake of crew on ship. Operability index (OI) for the bridge and bow operations should be increased. Intensive operability calculations on board for the commercial ships have to be evaluated during design stage.

It is very common to evaluate container ships as regard to their mobility in terms of seakeeping. However seakeeping performance of commercial ship in terms of crew morale has an important impact on overall performance and it is a measure of being under the specified seakeeping criterion. Absolute vertical and lateral accelerations are significant responses for the safety of crew. People who are not familiar with the excessive responses easily may get seasick.

Seakeeping analysis has been widely used after the development of the first practical strip theory. It is mainly based on the evaluation of the hydrodynamic characteristics of hull sections by using Lewis conformal mapping technique or Frank Close-

Fit approach (Frank, 1967). Although the strip theory is the quickest and relatively most accurate one it has main restrictions due to its theoretical assumptions. It has been most preferred tool during conceptual design stage for calculation of motions. Due to its theory is linear; solutions are more realistic for slender hulls and low Froude numbers. However, strip theory has been widely accepted and a large number of computer codes are developed.

A large number of researches could be found in the seakeeping literature. In the study of Sarıöz and Narlı (2005), they showed that the chosen criterion directly affects seakeeping performance of a ship and they calculated operability index values for selected criteria for sea state 5 and 6. In another study, they tabulated the operability performance indices for a passenger ship by using wave distribution scatter (Sarıöz and Sarıöz, 2005). In both studies, they deal with the vertical accelerations and obtain the limiting values by the help of ISO 2631 standards. In addition to what is mentioned above, seakeeping computations and comfort analyses for three different mono hull yachts are investigated by Nabergoj (2006). On the other hand, Scamardella and Piscopo obtained the overall motion sickness incidence for passenger ships (Scamardella and Piscopo, 2014). Cakici and Aydin discovered the overall seakeeping properties up to several sea states for the gulet type pleasure boats (2014). In another study, Cakici et al. presented the MSI and HI percentages of mega yacht and catamaran hulls for their general arrangements (2014).

In this study, a container ship model is taken as a sample for seakeeping calculations with 2-D strip method. It is shown the OI values of the ship model via polar diagrams according to specified sea conditions and suggested criteria. Selected responses are vertical-lateral accelerations and roll motion. For this responses, criteria are selected as regards to NORDFORSK project (1987) and Ferdinande V. (1969).

2. SEAKEEPING PERFORMANCE PREDICTION

The seakeeping performance of a ship in a particular sea environment depends on 4 main factors. These are:

- Response in regular waves (RAO)
- Sea state (SS)
- Vessel's speed and heading
- Standardized seakeeping criteria.

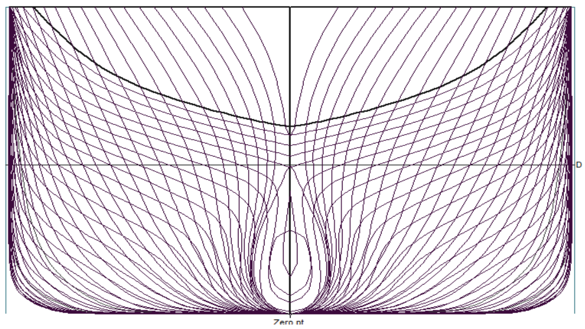

Figure 1 Body plan of the vessel

Body plan and geometric features of the chosen container ship is shown in Fig.1 and Table 1 respectively.

Table 1 Geometric properties of the vessel

Ship	Figures
Displacement, Δ (kN)	48562.16
Draft, T (m)	5.250
Waterline length, L_{OA} (m)	104.321
Waterline length, L_{WL} (m)	100.453
Waterline beam, B_{WL} (m)	16.495
Prismatic coefficient, C_P	0.582
Block coefficient, C_B	0.570
Waterplane area coefficient, C_{WP}	0.698
LCB from FP, LCB, %LWL	-53.871 (+fwd)
Vertical center of buoyancy, KB (m)	2.852
Vertical center of gravity, KG (m)	6.562
Cruise Speed (kts)	18.26
GM_T (m)	0 824

While the behaviour of a ship in regular waves depends on its weight, main dimensions, hull form parameters and weight distribution, the sea state information is based on annual measurements and it may differ for each sea states. Vertical and lateral plane accelerations in regular waves can be calculated by using 2D strip methods in conceptual design phase. Typical RAO, wave spectrum and response spectrum curve is shown in Fig.2, 3 and 4, respectively, for seakeeping calculations.

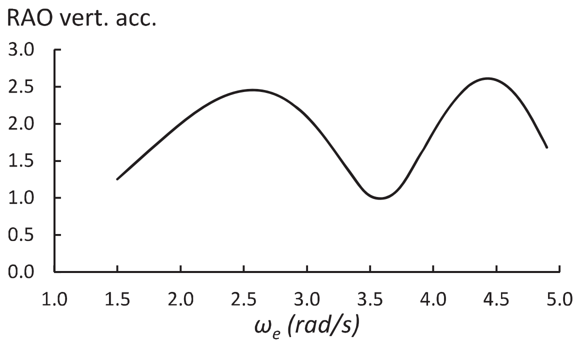

Figure 2 Typical RAO curve

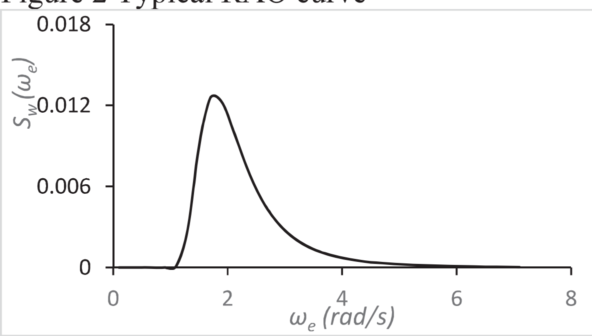

Figure 3 Typical wave spectrum curve

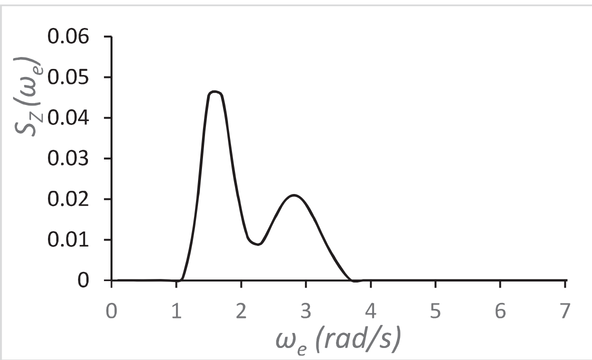

Figure 4 Response spectrum curve

Roll motion is the most critical response of a ship in waves among ship motions and it is important to calculate the roll motion during design stage. Roll motion affects the crew performance, ship habitability, limits the operability, causes the cargo shift, loss of deck cargo and even leads to ship capsize. Accurate prediction of roll motion is necessary for operational and safety considerations, especially for container ships. Roll damping coefficient has to be determined correctly for an exact prediction of the roll motion. One of the most used methods to determine roll damping is Ikeda's estimation method. According to Ikeda (1978), see also Himeno (1981), the total equivalent linear roll damping coefficient can be divided into five components. These components are composed of skin friction damping, eddy damping, wave damping, lift damping and bilge keel damping. These are indicated in equation 1.

$$B_e = B_F + B_E + B_W + B_L + B_{BK} \tag{1}$$

In this study, Ikeda's method is used for the prediction of roll damping coefficient.

2.1 Definition of environmental conditions

Motion responses in irregular waves are significant since there are almost no regular waves in nature. Irregular sea surfaces can be defined by the help of wave spectra that is composed through a probabilistic distribution model. This function must be adoptable with the characteristics of the seaway. In this study, the seaway is taken on one parameter Pierson –Moskowitz formulation. The analyses are performed at sea states 4, 5 and 6 and the corresponding characteristic wave heights and modal periods of North Atlantic are shown in Table 2.

Table 2 Wave heights of North Atlantic

Sea State	Significant wave height (m)
4	1.88
5	3.25
6	5.00

2.2 Operability Index Based on Ship Motions

A typical seakeeping polar diagram involves wave heading and sea state for a given seakeeping limit by using the results of ship motion analyses in irregular seas. Thus polar diagram shows an area where human tolerance is valid and the rest of area refers at least one seakeeping limit criterion is violated. The percentage rate between human tolerant or safer area to violating area of any seakeeping limiting criterion of a seakeeping polar diagram is so-called as Operability Index (OI). This one is defined by both mechanical vibrations from various sources and vibrations resulting from ship motions in waves. In this study OI values are computed by integrating the limiting speeds from stationary speed to cruise speed for all headings, specified sea conditions and seakeeping criterion by employing

$$OI = \frac{1}{2\pi V_0}\int_0^{2\pi} V_{lim}(H_{\frac{1}{3}}, \mu)d\mu \quad (2)$$

Where:
OI: Operability Index based on ship motions (-)
V_o: Ship Speed (m/s)
V_{lim}: Limiting Criterion Speed (m/s)
μ: Heading (rad)
$H_{1/3}$: Characteristic Wave Height (m)

Operability indices of the container ship are computed for sea state four to six at speeds from zero to cruise speed. OI gives a robust idea according to limit vertical and lateral accelerations defined by existing studies. Safety of crew is closely related to vertical and lateral accelerations. In Figure 5-8, one can easily have an idea for safer places at bridge and bow of the container ship and as well as roll motion in terms of speed and route. The coloured zones show safer regions. Selected criteria are shown with Table 3.

Table 3 Selected Criteria

RMS Lat. Acc. (m/s^2)	RMS Vert. Acc. (m/s^2)	RMS roll motion (deg)
0.12g (bridge)	0.15g (bridge)	6°
	0.20g (bow)	

2.3 Limiting Wave Height for all heading and speed range

The limiting significant wave heights are computed based on each criterion. The results are displayed in Fig. 10. This figure clearly illustrates the influence of the selected response on the maximum allowed significant wave heights.
Necessary computation method is presented in Eq.3.

$$LSWH = Max\ H_{1/3}\{R_i(V_j \mu_k) \leq R_i^{cr}\}$$
(3)

Where:
LSWH: Limiting Significant Wave Heights (m)
μ_k: Heading 0:π° (rad)
$H_{1/3}$: Characteristic Wave Height (m)
R_i: Computed Response
R_i^{cr}: Criterion Defined Response
V_j: Ship speed 0: V_{cruise} (m/s)

3. SEAKEEPING CALCULATIONS AND RESULTS

In this part of the study calculated polar diagrams for lateral and vertical responses are presented with figures.

For sea state four and five, polar diagrams are all safe due to there is no exceed values of specified responses in accordance with selected criteria. Therefore, this sea conditions are not dangerous for crew on deck. However, in sea state six, polar diagrams give two different regions. While coloured zone is safe for the operetion; the non-coloured zone is critical. Figure 5-8 show the polar diagrams for selected responses.

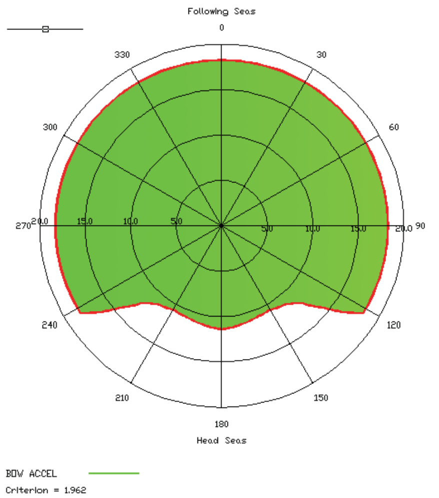

Fig.5 Bow Vert. Acc. Operability Diagram for SS6

Table 4 Exceeding routes and limiting speeds (knots) for Bow Vert. Acc.

μ	V_{lim} @150°	V_{lim} @180°
122°-180°	**11.1 knot**	**11.3 knot**

While figure 5 shows the bow vertical acceleration polar diagram, figure 6 shows the bridge vertical acceleration polar diagram for SS6. Exceeding routes and limiting cruise speed for specified responses are shown in Table 4-6.

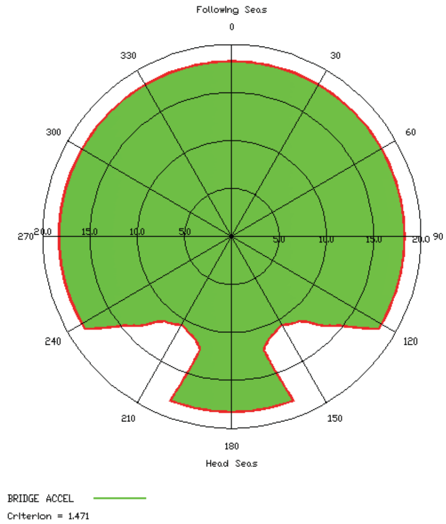

Fig.6 Bridge Vert. Acc. Operability Diagram for SS6

Table 5 Exceeding routes and limiting cruise speed for Bridge Vert. Acc.

μ	V_{lim}@150°	V_{lim} @160°
123°-160°	**11.2 knot**	**11.9 knot**

Table 6 Exceeding routes and limiting cruise speed for Roll Motion

μ	V_{lim} @60°	V_{lim} @70°
55°-70°	**6.9 knot**	**6.9 knot**

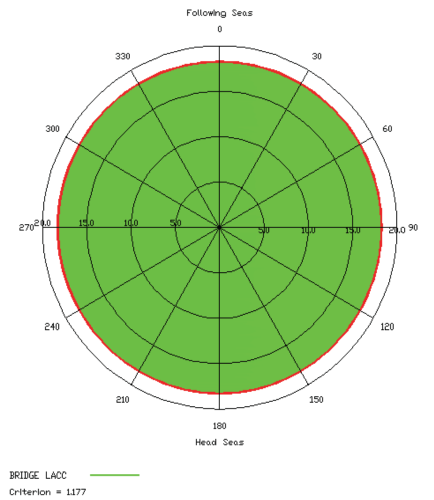

Fig.7 Bridge Lat. Acc. Operability Diagram for SS6

Bridge lateral acceleration polar diagram in Fig. 7 gives an idea that calculated lateral acceleration values are under the selected criterion. There is no exceeding route and limiting cruise speed value for this response.

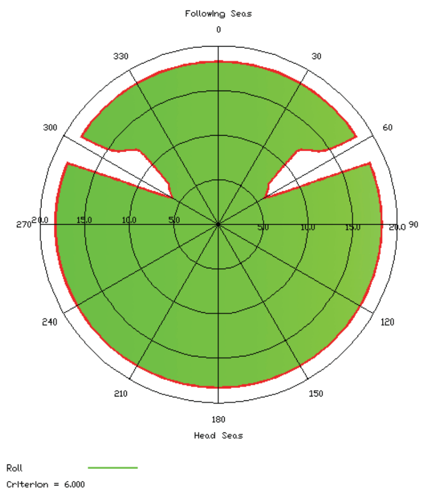

Fig.8 Roll Motion Operability Diagram for SS6

Roll motions of chosen container ship are calculated in irregular waves for sea states 4, 5 and 6. Safe regions are shown in polar diagram as seen in Fig. 8.

Fig. 9 can be obtained by the help of figures 5 -8. OI values are shown between 0-1 for the three sea states.

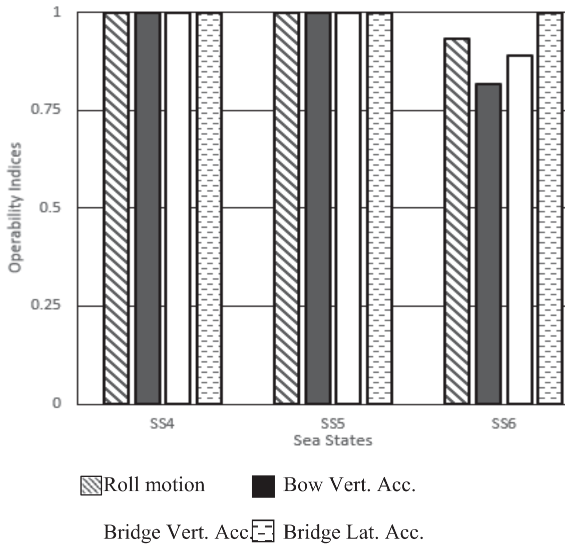

Fig.9 Comparison of Operability Indices

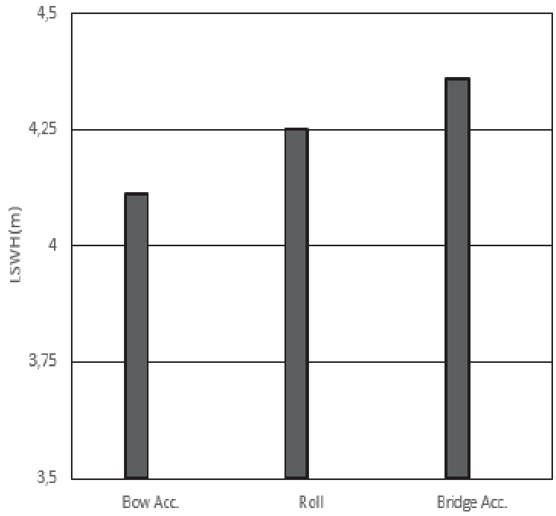

Fig.10 Limiting Significant Wave Heights for Selected Responses

4. CONCLUSIONS

Operability indices regarding crew comfort on board for a container ship are investigated with respect to different sea states, seakeeping phenomena and criteria. The study underlines the crew comfort operability percentages under the lateral and vertical responses for a given seaway and sea state. The limiting wave heights are calculated for each response.

The authors suggest that seakeeping analyses on crew comfort on board as well as on vessel behavior are remarkably important that must be considered during concept design level. Such analyses will gain useful information on optimal positioning of bridge and accommodation locations as well as defining seakeeping ship.

5. REFERENCES

K. Sarioz, E. Narli, "Effect of Criterion on Seakeeping Performance Assessment", Ocean Engineering 32, (2005) 1161–1173.

K. Sarioz, E. Narli, "Effect of Criterion on Seakeeping Performance Assessment", Ocean Engineering 32, (2005) 1161–1173.

Nabergoj, R. (2006). "Passenger comfort and seakeeping: A new challenge for high-tech ship design", Proceedings of SMALL CRAFT: An International Conference on Small Craft Related Sciences and Technology, Bodrum, Muğla.

Scamardella, A. and Piscopo, V. (2014), "Passenger ship seakeeping optimization by the Overall Motion Sickness Incidence", Ocean Engineering, Vol:76, pp: 86-97.

Cakici F. and Aydın M., (2014) "Investigation of Habitability Indices of YTU Gulet Series in Various Sea States", Brodogradnja/ Shipbuilding.

Çakici, F., Sukas, O. F. and Alkan, A. D., (2014) "An Investigation of Comfort on Board Calculations for a Passenger Catamaran and Mega Yacht Hulls", 2nd International Symposium on Naval Architecture and Maritime. INT-NAM 2014, (pp. 589-594).

NORDFORSK 1987, "The Nordic Cooperative Project, Seakeeping Performance of Ships Assessment of a Ship's Performance in a Seaway", Marintek, Trondheim.

Ferdinande V. 1969, "Analysis of Slamming Phenomena on a Model of a Cargo Ship in Irregular Waves", International Shipbuilding Progress, November

Ikeda, Y., Y. Himeno, and N. Tanaka,"A Prediction Method for Ship Roll Damping", Report of the Department of Naval Architecture, University of Osaka Prefecture, 1978e, No. 00405.

Himeno, Y., "Prediction of Ship Roll Damping-State of the Art", U. Michigan Dept. of Naval Arch. and Marine Engineering, 1981, Report 239