ISSN 0554-6397
Prethodno priopćenje
(*Preliminary communication*)

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Seakeeping Analysis of a Double Ended Ferry

Abstract

Awareness of environmental protection is increasing, especially in recent years when warnings of imminent climate change have begun to appear in public space. In addition to one of the most significant environmental pollutants, global maritime transport is also mentioned, where environmental pollution is explicitly in the form of exhaust gases from marine propulsion engines. The trend of developing environmentally friendly, so-called "eco" ships is on the rise, primarily in the development of electric ferries designed to transport passengers and vehicles on short routes. This paper deals with a seakeeping analysis of a double ended ferry which is intended for sea route between Brestova and Porozina in the North Adriatic. The adopted dimensions and shape of the ship, the characteristics of sea waves for the adopted spectrum will be presented, and then the obtained results, considering the limits of the ship operability related to passenger comfort and cargo safety. The analysis was performed using computer software "Sesame HydroD". A seakeeping estimation for the ferry is finally adopted and possible directions for future developments are proposed.

Keywords: Seakeeping, electric ferry, Sesame HydroD

1.Introduction

The development of double ended ferries with electric propulsion has certainly taken an important roll in shipbuilding in recent years. Efforts were made in the comparison of basic parameters for double-ended ferries [5] for new hybrid design in the future. In this paper, insight in seakeeping behaviour of such vessel is shown. Seakeeping analysis was done for double-ended ferry which is intended for route beetween Brestova and Porozina in North Adriatic sea. Analysis was done using DNV's software *Sesame HydroD,* using *Wasim* module. *Wasim* is a time-domain 3D-BEM code using rankine approach. ITTC wave spectrum is chosen with main parameters derived from [2]. Performed analysis was done for one loading condition and one service speed.

Inputs that are necessary for this type of analysis, with this software, are hull form, center of mass and desired speed. Hull form has the biggest impact on seakeeping performance where length of a ship plays the most significant role. Optimization of hull forms in terms of seakeeping are usually not „fine tunings" but rather changes of main dimensions, form coefficients or mass redistribution. Results of the presented analysis are shown in common way of *RAO's* of a vessel with some time domain diagrams. If one is to say „*this vessel has good seakeeping characteristics!"* what is the physical and mathematical evidence for this statement? It is when *operability* of the vessel enters the game. Operability of the vessel simply shows *how practical would this ship be on certain sea state.* To evaluate operability, appropriate criteria and their limiting values needs to be adopted. In this analysis limiting criteria is adopted with regards to comfort of passengers and crew, and safety of transported cargo. Comfort during the trip is assesed considering roll motions while cargo safety considering vertical accelerations. Operability assesment for this type of ship would be more precise if real seakeeping performance criteria were developed. Roll motion resctriction is adopted from [4], while simple methodology for pitch and heave restriction calculation are presented with very basic formulations. Lashing sytems on ferries and Ro-Ro ships require careful attention during design proccess. While further investigations of seakeeping and maritime characteristics are needed for this type of ship, this work represent small but valuable contribution for having an insight in ship behaviour in real conditions.

2. Input data and environment modeling

To perform numerical seakeeping analysis, two groups of data are necessary. Firstly, it is important to define ship hull form, which most often meets the requirements for displacement or/and draught. Among hull form, it is also necessary to perform weight study to get information about center of gravity of the ship and mass moments of inertia. Basic CAD model of the double ended ferry was prepared by the company Flow Ship Design d.o.o, Figure 1, along with weight study.

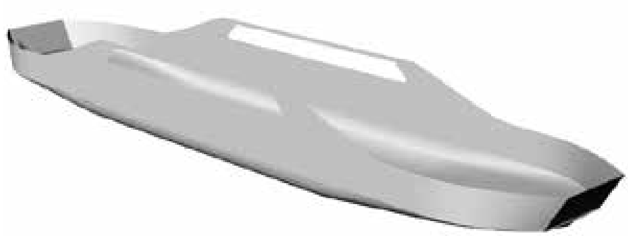

Figure 1. Double ended ferry CAD model [2]

Loading condition that is considered for seakeeping analysis is the "worst" probable condition while the ship is intact. This loading condition includes maximum number of passengers and trucks. Parameters for this loading condition and main dimensions are as follows, [7]:

Δ = 2780 t	$L_{OA}=101.9\ m$
T = 2.5 m	$L_{PP}=92.7\ m$
L_{CG} = 46.0 m	$B=20\ m$
V_{CG} = 5.3 m.	$D_{MainDeck}=3.8\ m$

Also, analysis was performed with service speed of 12.0 knots. The meshed Double-ended ferry hull that is done in *Wasim* is seen on Figure 2. Regarding viscous roll damping, quadratic damping coefficient is employed to account for the vicsous effects on roll motion. [9]

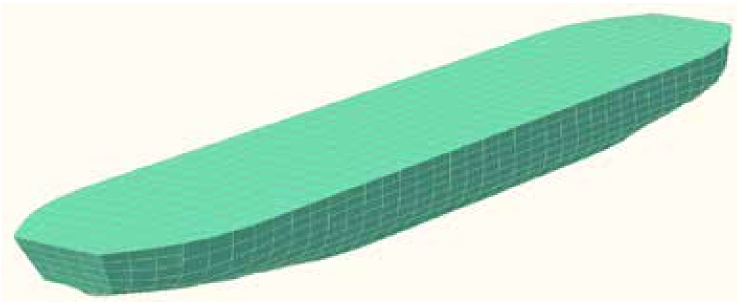

Figure 2. Hull mesh

The sea characteristics were modeled through ITTC (Bretschneider) spectrum that is most used in these types of analysis [1], [8]. Although JONSWAP spectrum could be more appropriate for this area, due to inconsistencies in data ITTC spectrum is chosen [10]. The significant wave height *Hs* was taken as 0.8 meters with average period *T* of 4.6 seconds, which correlates to sea state 4 (four). The spectrum is shown in figure 3.

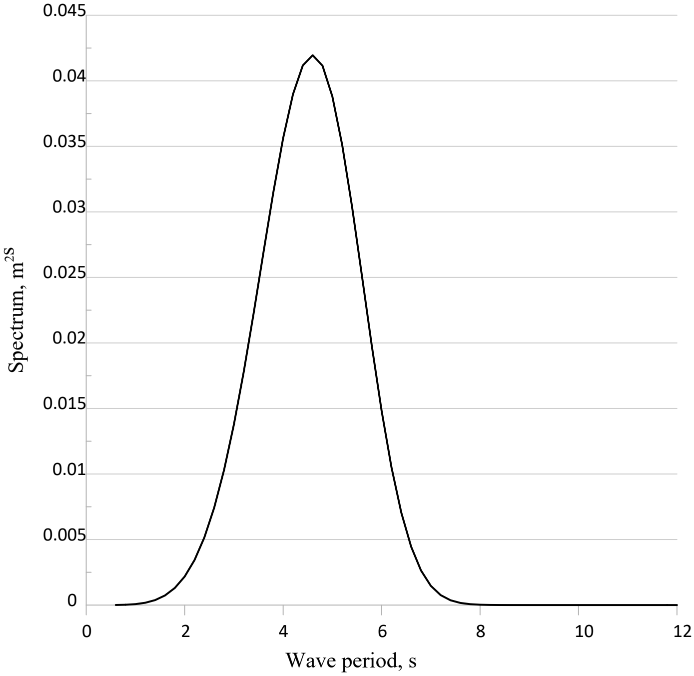

Figure 3. ITTC 57 wave spectrum

Figure 4. shows sea route for which this ferry is intended. Route between Porozina, southernmost village of Island Cres and Brestova that is located on Istrian peninsula. Total length of the route is around 2.5 nm with high traffic in the canal.

Figure 4. Route Brestova – Porozina [3]

Geographical characteristics of this sea passage dictates the wind directions, which usually cause beam seas which can be the most challenging, unpleasant, and dangerous of all conditions to navigate. Seven wave directions were considered in the analysis, ranging from stern to bow with step of 30 °, figure 5.

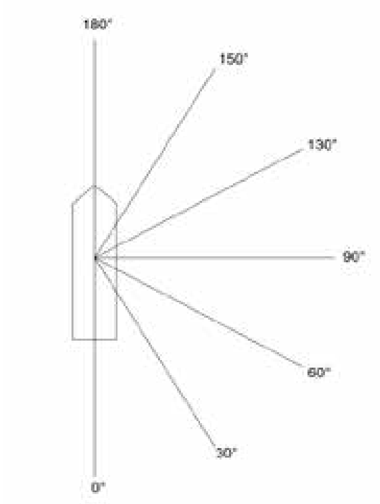

Figure 5. Wave directions applied in calculations

3. Operability criteria

For the sake of seakeeping evaluation of a ship, operability and usability of the ship should be considered. For double ended ferry there are two goals that must be met:

◊ Passenger and crew comfort
◊ Cargo safety

According to these two goals, the corresponding criteria will be defined. In [4], limiting value for roll motion for transit passengers is **2.5 ° RMS**[1] . This value will be adopted for overall crew and passenger comfort. Regarding cargo safety which in this case are road vehicles, limiting value is defined in the following way:

According to [6], section 3.4.3, maximum securing load for road vehicles of more than 3.5 tonnes should be not less than **100 kN**. Having that value in mind it is possible to calculate critical acceleration from equation:

$$F_{msl} = ma_{kr} \quad (1)$$

[1] RMS – root mean square is defined as the square of the mean square values

m = 18750 kg, average mass of road truck

F_{msl} = 100 000 N, maximum securing load

Which gives us our limiting value for acceleration:

a_{kr} = ***6.4 m/s²***

Short summary of operability criterias with their associated limit values are listed in table 1.

Table 1. Limiting values for operability assessment

Operability criteria	***Limiting value***
Passenger and crew comfort	*<RMS roll* 2.5 ^{o}
Cargo safety	*<6.4* m/s^2

There are however other possible operability criteria that would be of interest. Ramp accessibility during vehicle boarding when the ferry is operating in unprotected ports could also be a potential operability limit, especially in the port of Brestova that is relatively unprotected of waves and wind. The influence of wind should also not be neglected, especially when the vessel is approaching the pier. Due to relatively small windage area, wind drift and heeling of the vessel should be canceled out, or at least minimised by steering manouvers from the captain

4. Results

Seakeeping analysis was carried out with DNV's software for hydrodynamic analysis SESAME HydroD. Simulation is carried out in time domain but it can be transformed into frequency domain via fourier transformations. The code is based on Rankine panel method which solves fully 3-dimensional radiation and diffraction problem. Potential flow codes are still the most prevalent numerical choice for evaluations of seakeeping properties of ships for it's low computational costs. It is however unable to accurately resolve the nonlinearity of waves and rigid body motions, wave breaking, etc. Snce it is common practice to display the seakeeping properties of a ship with response amplitude operators (RAO) that are defined in equation (2), RAO's for roll, pitch and heave are presented.

$$RAO = \left|\frac{R_a}{\zeta}\right|^2 \quad (2)$$

Response amplitudes for heave and pitch will be shown for head waves including encounter angles from 120° up to 180°. Roll amplitudes will include encounter angles from 30° up to 120°. In figure 6. no significant peaks for heave motion is visible. Regarding pitching, on figure 7. there are peaks in the range of 1-1.5 rad/s of encounter frequency but with no significant amplitudes. Regarding roll motions, as expected, amplitudes are highest for beam seas as it is clear on figure 8.

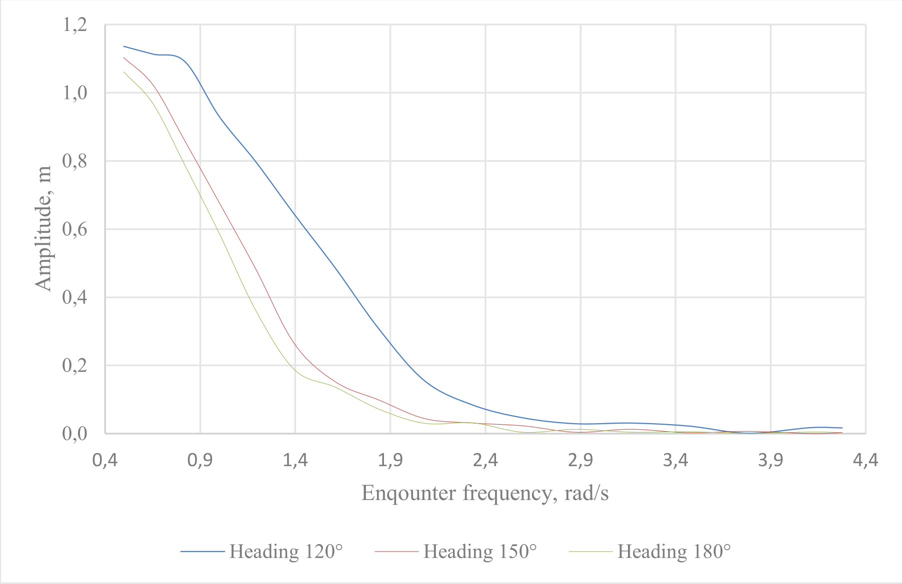

Figure 6. RAO's for heave motions

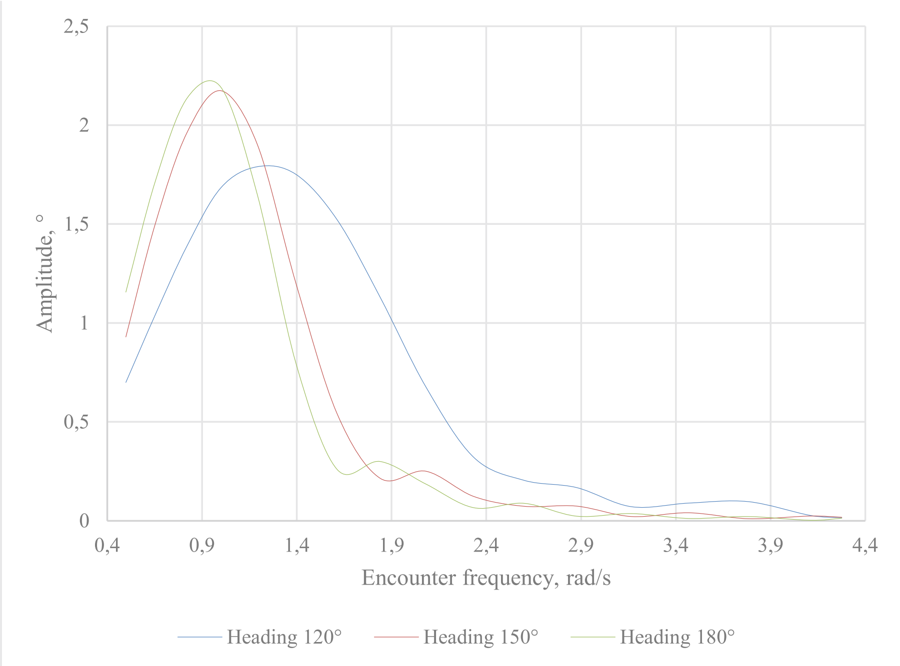

Figure 7. RAO's for pitch motions

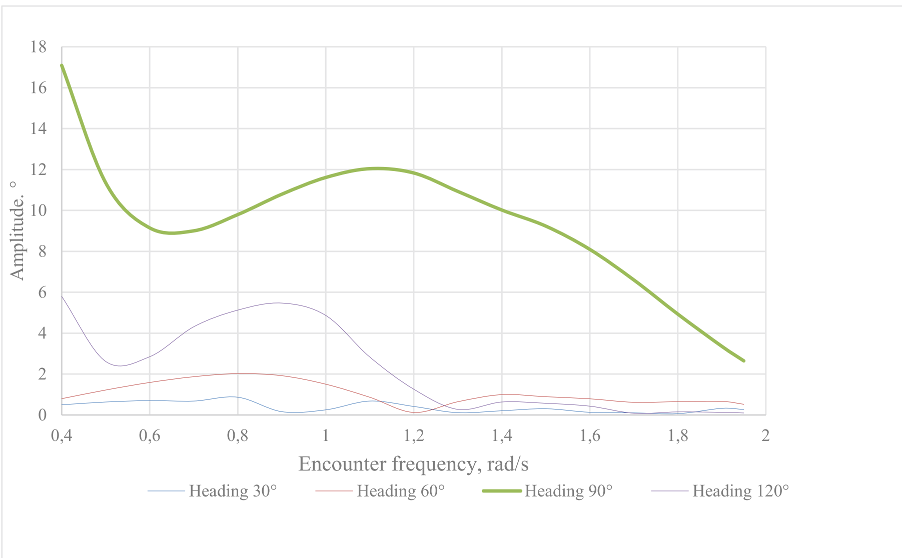

Figure 8. RAO's for roll motions

In Sesame HydroD software, graphical postprocessing options are available. Figures 9. and 10. show ship response for head and beam seas.

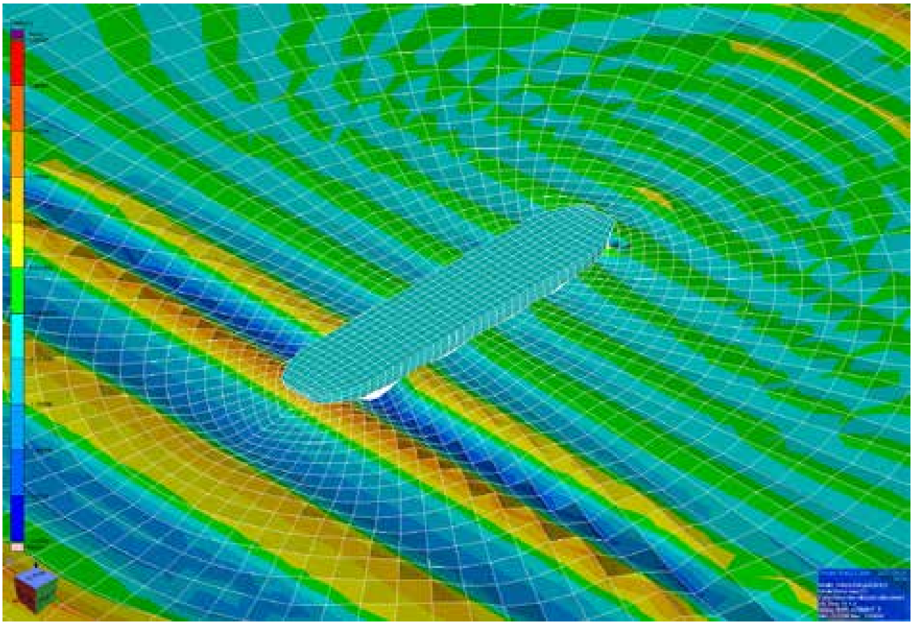

Figure 9. Graphical excerpt from Wasim – head seas

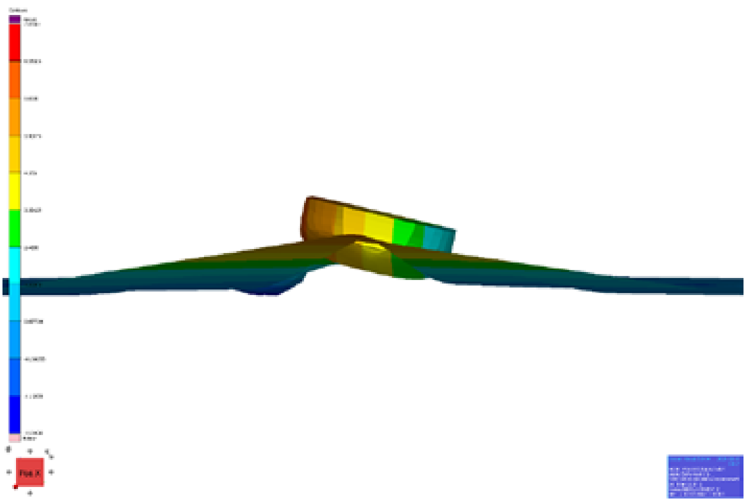

Figure 10. Graphical excerpt from Wasim – beam seas

4.1. Operability assesment

Given that sea and wind statistics for the area of navigation (Vela Vrata) are missing for this analysis, probability of occurrence of wave heights and directions will be ommited.

4.1.1. Passenger and crew comfort assesment

Observing RAO's for roll motion from figure 8. it is clear that the heaviest response is to be expected in beam seas. Therefore, roll response spectrum for beam seas is shown in figure 11. with it's corresponding value of zero moment.

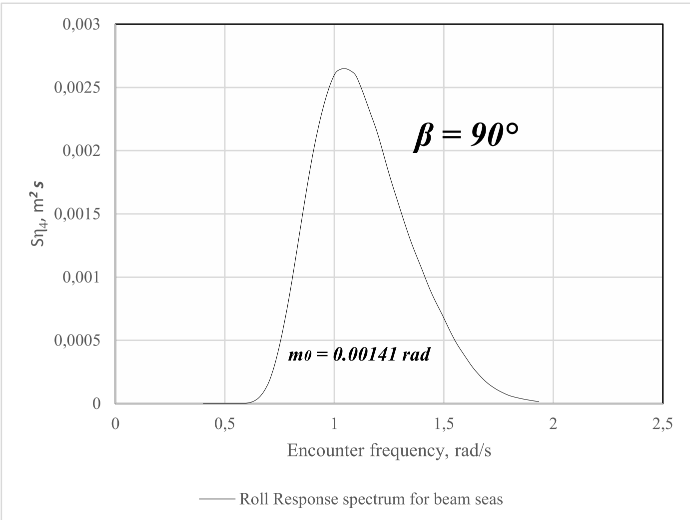

Figure 11. Roll response spectrum for beam seas

Since the relation beetween *rms* and zero moment is:

$$\sqrt{m_0} = rms \tag{3}$$

First operability criteria for passenger and crew comfort, for the given weather conditions, is satisfied:

$$\mathbf{2.119° < 2.5°}$$

4.1.2. Cargo safety assesment

Regarding **cargo safety** as an operability criteria, vertical accelerations were examined at the front point on the ship at the garage deck, where position of trucks is highly probable. Point coordinates are 70 meters from aft perpendicular, 5 meters above baseline and in the centerline . Response spectrum of vertical acceleration is shown on figure 12. with it's corresponding moment. Among calculation in frequency domain, time simulation of voyage in duration of 20 minutes is carried out with paying attention to variability of vertical accelerations, figure 13. Maximum expected accelerations are found to be around 0.55 m/s^2. It can be concluded that due to the small wave height and short wave periods, acceleration amplitudes are not large.

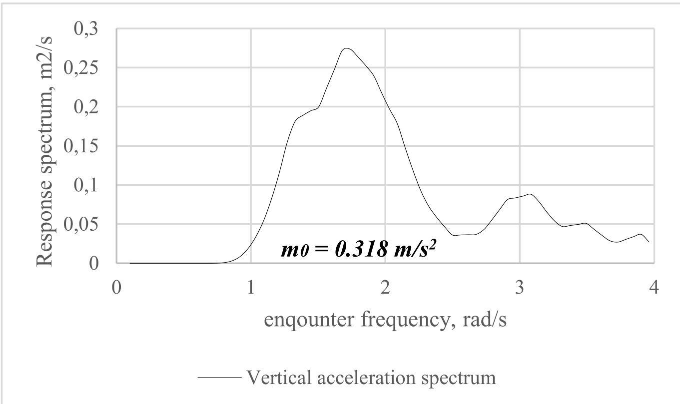

Figure 12. Pitch accelerations – excerpt from HydroD

According to (2), operability criteria for cargo safety is also satisfied:

$$\mathbf{0.563\ m/s^2 < 6.4\ m/s^2}$$

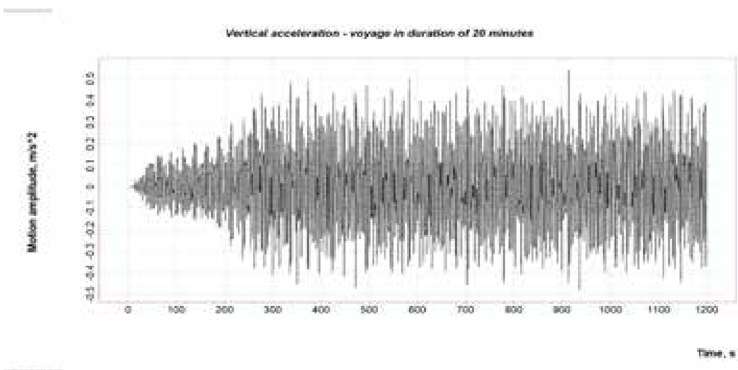

Figure 13. Vertical accelerations – excerpt from HydroD

5. Conclusions

The development of a database for seakeeping and overal maritime characteristics of double-ended ferries is surely needed, given the latest efforts in the field of „eco-ships". This work shows a methodology for estimation of seakeeping characteristics of such ships where further developments and improvements are possible. Key improvements would include development of operability criteria for „eco-ships" such as heave vertical motion limit for ramp accesibility during vehicle boarding and an investigation of scatter diagram of weather conditions for navigational routes of these kind of ships. These data, with the seakeeping calculation for the whole range of ship speeds and wave headings, will allow us to estimate operability index and compare several desing options. The analysis in this work showed favourable seakeeping characteristics for navigation in sea passage Vela Vrata, with no need for implementing motion stabilizers other than standard bilge keels. Roll amplitudes are in acceptable range, satisfying more sensitive passengers on board. Vertical acceleration is also observed and no significantly high values are found. Since the sea state adopted in this analysis has relatively small significant wave height, these results were to be expected. Lastly, since electrial propulsion is implemented in this ship, it would be of great importance to have an insight into attainable ship speed during rough weather for estimating needs for batteries on bord.

Nomenclature and units

Δ - ship displacement, t
T - draught, m
L_{CG} - longitudinal center of gravity, m
V_{CG} - vertical center of gravity, m
Hs – significant wave height, m
T – mean period, m
m – average vehicle weight, kg
Fmsl – maximum securing load, N
a_{kr} - *critical accceleration, m/s²*
RAO – response amplitude operator
Ra – response amplitude, m, °
ζ – wave amplitude, m
m_0 – zero moment
rms – root mean square as roll criteria, °

Acknowledgements

This work was done as a part of *Maritime Environment-Friendly TRanspOrt systems (METRO)* project*,* with main objective to improve the quality, safety and environmental sustainability of marine and coastal transport services and nodes by promoting multimodality in the programme area. Lead partner is University of Trieste – Department of Naval Architecture with Faculty of Engineering being one of the partners.

This work has also been supported by the Croatian Science Foundation under the project project IP-2018-01-3739. This work was also supported by the University of Rijeka (project no. uniri-tehnic-18-18 1146 and uniri-tehnic-18-266 6469).

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