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The Investigation of Roll on-Roll off Truck Carrier Hull Design for Route Tanjung Priok (Jakarta) - Tanjung Perak (Surabaya)

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Abstract

This paper present the the investigation roll on-roll off (ro-ro) ship hull design that will be used as the truck carrier for route Tanjung Priok (Jakarta) to Tanjung Perak (Surabaya) where the main objective of this paper to get the best hull model from certain proposed hull model. The scope of investigation in this work cover on resistance, stability, and seakeeping analysis. The resistance analysis cover the prediction of resistance and main engine requirements. The stability analysis were performed to compare the stability of proposed model using IMO A.749(18) Chapter 3 criteria. And seakeeping analysis focused on criteria:Motion Sickness Incidence (MSI), slamming, and deck wetness. Five proposed hull model with the difference on displacement, block coefficient and forepeak form were investigated. Model 1-Model 4 have block cofficient in range 0.48 – 0.51 from ship comparison. In other side, Model 5 using block coefficient 0.65 according toAyre's block coefficient formula. The result of investigation indicates that Model 1- Model 4 has similar trend characteristic in resistance, stability, and seakeeping analysis. And Model 5 inferior than Model 1 – Model 4 in resistance performance but better in seakeeping performance especially in deck wetness criteria.

Keywords: Ro-ro ship, resistance, stability, seakeeping

1. Introduction

In the age of globalization, transportation becomes an important and essential for human liveto perform any daily mobility. As if transportation becomes inseparable from community life. Its very rare phenomena that people in a country on earth that do not use transportation for their activity these day and because of that, transportation continues to evolve over time. We already know that the society is already changing and evolving from a simple society into a complex society with high mobility and activity. This phenomena affects the paradigm and functio of transportation for the people in this world. This developments also have an impact on the behavior of the industry in line with the times. Industries in ancient times and presentproduce something and distribute it using transportation. And today, the modes of transportation by air, land and sea can be used to distribute products to markets.

In Indonesia itself, Java is the center of industry and government where the cycle industry constantly spinning rapidly. The growth of vehicle itself is high enough which reach point 21% per year.[1]As the result, the distribution the products of the industry which mostly based in Jakarta to markets primarily in Java region will continue to ongoing. Mostly, the industry choose land transportation mode to transport the product through the Pantura Road. As the result, the volume of vehicles passing through the Pantura Road so high. Inevitably, this situation causes many traffic accidents, damage to roads and congestion occurs. Traffic accidents can be caused by damage to roads and cause congestion. Similarly, damage to roads caused by strong volume of passing vehicles and can lead to accidents and traffic jams. And congestion itself is a result of damage to the road and traffic accidents.Large vehicles such as industrycontainertrucks contribute greatly to the damage to roads in the Pantura Road. And this will continue and result in material losses such as delay in distribution of product and soaring fuel costs. This situation would be its own obstacles for industry players to develop their business. The distribution of industrial products should be done more easily, quickly and cheaply. And to obtain them, necessary transportation modes other than land transportationis needed. As a maritime nation, sea transportation has the potential to be a solution to congestion on Pantura Road due to the high volumeof industial vehicle.

The sea transportation that can be used to distribute the product in Indonesia are general cargo ship, container ship and roll on - roll off (ro-ro) ship. From these three option, ro-ro ship is the best choice from the aspect mobility and money investment. In the aspect of mobility, the cargo in ro-ro ship can be moved in and out from ship itself because it is carried by truck and this methods really saving many time for loading and unloading activity. In the other side, general cargo and container ship need more time to loading and unloading from ship and also loading to truck that will distribute the product from harbour to other region. In the aspect of money investment, ro-ro ship is the cheapest one than other two option because ro-ro ship do not need the supporting facilities such as warehouse or container field and crane in the process of loading and unloading. So the ro-ro ship is more flexible, if in the future between the route Tanjung Priok to Tanjung Perak, ship must stop in certain harbour to do loading and unloading activity, there will be no problem even if the new harbour destination do not have warehouse, container field or crane.To get the best hull design, some analysis into some proposed hull design are required such as resistance, stability and seakeeping analysis.

Resistance analysis is used to predict the resistance of ship hull and capacity of main engine that needed to overcome the resistance. Holtrop and Mennen developed a method to determine the required propulsive power at the initial design state of ship. This method was developed through a regression analysis of random model experiments and full-scale data, available at the Netherlands Ship Model Basin.[2]And in their next work, the prediction for resistance was presented. Where the extension of the method was foccused on improving the power prediction of high-block ships with low L/B-ratios and of slender naval ships with a complex appendage arrangement and immersed transom stern.[3]

In stability aspect, since coming into being in 1959, IMO has adopted numerous international conventions and otherinstruments which are designed to improve maritime safety in general. Some of these are particularly relevant to ro-ros. The feature which distinguishes the ro-ro ship from other types is the open vehicle deck (or decks) which run the full length of the ship with a door at either end. It is crucial to the whole ro-ro concept and one of its most controversial features, since it has led to considerable concern about the safety of ro-ro ships is their stability in both the intact and damaged condition.As far as SOLAS is concerned, subdivision and damage stability requirements for passenger ships are contained in part B of chapter II of the 1960 version and chapter II-1 of the 1974 version. In both, the standard of subdivision varies according to the length of ships and the number of passengers on board. Passenger ships are defined as ships which carry more than 12 passengers.[4]

Seakeeping performance is becoming of increasing importance. With fast computers and sophisticated software readily available to designers, it is now possible for a vessel's seakeeping characteristics to beaddressed much earlier in the design spiral. Regulatory bodies and operators are becoming increasingly aware of the importance of specifying seakeeping requirements which the vessel must meet. The software tools described in this paper will helpdesigners address these issues.In general there is a demand for increased performance, this tended to be speed and endurance, but now many tenders also specifically address seakeeping requirements. This has been demonstrated by the large seakeeping budget spent on the development of the Stena HSS. However, for most smaller projects, this level of investment is not feasible, especially in the early stages of the design spiral or when bidding for tenders.[5]

A major goal of the present paper is to investigate and choose the best from allproposed hull design that will be projected to sail for Tanjung Priok-Tanjung Perak route. Therefore, all proposed model are modelled and simulated by numerical approach in the present paper.

2. Materials and Methods

This section describes the characteristic every proposed model which is focussed on the block coefficient and displacement characteristic. Here we shall first assume that the dimension of length over all is similar. For beam and draught of all proposed model are same. Also this section describe the method and criteria that were used in the simulation of proposed model.

2.1. Hull Design Model

In present paper, there are five proposed model that will be investigated. The proposed hull model noted as Model 1, Model 2, Model 3, Model 4, and Model 5.Principal dimension of proposed model is presented in Table 1. And three-dimension illustration model of proposed model is presented in Figure 1

Table 1.Principal dimension from proposed model.

Model No.	Design Length (m)	LOA (m)	Beam (m)	Draught (m)	Block Coeff.	Displacement (tonnes)	Service Speed (knot)
1	184.30	198.03	30.00	7.50	0.4820	20486	20
2	177.30	198.03	30.00	7.50	0.5042	20615	20
3	184.30	198.03	30.00	7.50	0.4921	20918	20
4	184.30	198.03	30.00	7.50	0.4862	20665	20
5	177.30	198.00	30.00	7.50	0.6499	27486	20

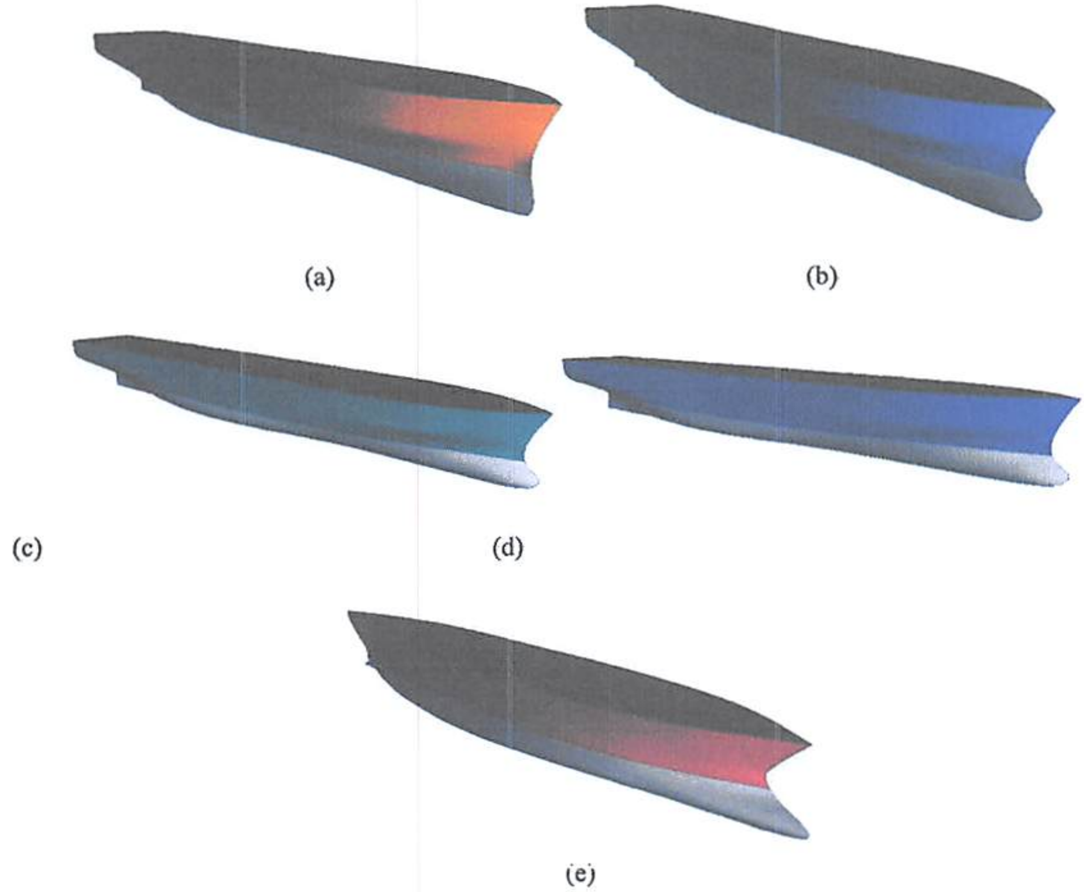


Figure 1. The proposed hull model: (a) Model 1; (b) Model 2; (c) Model 3; (d) Model 4 and (e) Model 5

2.2. Simulation Method and Criteria

Simulation and analysis of proposed model were done to investigate three main performance: resistance, stability, and seakeeping. Each of simulation have their method and criteria. In simulation of resistance, the present work used Holtrop method to predict resistance. According to the work of Holtrop and Mennen [3], total resistance of a ship has been subdivided and presented in Equation 1:

$$R_{Total} = R_F(1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \tag{1}$$

where:

R_{Total}	: total resistance
R_F	: frictional resistance according to the ITTC-1957 friction formula
$1 + k_1$	: form factor describing the viscous resistance of the hull form in relation to R_F
R_{APP}	: resistance of appendages
R_W	: wave-making and wave-breaking resistance
R_B	: additional pressure resistance of bulbous bow near the water surface
R_{TR}	: additional pressure resistance of immersed transom stern
R_A	: model-ship correlation resistance

In simulation of stability, the present work used the International Maritime Organization (IMO) criteria, resolution A.749(18) chapter 3 regard to code on intact stability for all types of ships.[6][7] And in the simulation of seakeeping, the present work used JONSWAP wave spectrum. JONSWAP spectrum was developed for the limited fetch North Sea by the offshore industry and is used extensively.[8] The equation of JONSWAP wave spectrum is presented in Equation 2 and 3.[8][9]

$$S^{+}(\omega) = S^{+}_{1}(\omega) + S^{+}_{2}(\omega) \quad (2)$$

$$S^{+}(\omega) = \frac{\alpha g^2}{\omega^5} \exp\left[-\beta \frac{{\omega_p}^4}{\omega^4}\right] \gamma^a \quad (3)$$

where:

$S^{+}(\omega)$: wave spectrum

$S^{+}_{1}(\omega)$: wave spectrum 1

$S^{+}_{2}(\omega)$: wave spectrum 2

α : the intensity of the spectra, default value = 0.0081

g : gravity force

ω : the wave frequency

ω_p : the peak wave frequency

β : a shape factor (rarely changed), default value = 1.25

γ : peak enhancement factor, default value = 3.3

σ : 0.07 if $\omega \leq \omega_p$ and 0.09 if $\omega > \omega_p$

a : $\exp\left[-\frac{(\omega - \omega_p)^2}{2\,{\omega_p}^2 \sigma^2}\right]$

The characteristic of wave that used in seakeeping simulation, the present work use the wave characteristic at Java Sea because the proposed hull design is projected to be used for route Tanjung Priok (Jakarta) to Tanjung Perak (Surabaya). The wind and wave characteristic of Java Sea is presented in Figure 2 and Table 2.

Table 2. Monthly analysis wind characteristic for Indonesia water region [10]

No	Location	Wind 10 m Average (Knot)	Significant height Average (meter)	Maximum height Average (meter)	Wave Frequency Wave > 3 Meter
1	Aceh north sea	8 - 18	1.0 - 3.0	1.25 - 3.75	30 - 60 %
2	Aceh west sea to North Sumatera	2 - 10	1.0 - 2.25	1.25 - 3.25	0 - 30 %
3	West Sumatera Sea	2 - 5	0.6 - 1.5	1.0 - 2.0	0 - 5 %
4	Bengkulu sea to Lampung west sea	2 - 7	0.4 - 1.5	0.7 - 2.0	0 - 5 %
5	Sunda Strait	2 - 6	0.4 - 1.5	0.5 - 2.0	0 - 5 %
6	Banten south sea to West Java sea	5 - 11	1.0 - 1.75	1.2 - 2.25	0 - 5 %
7	Central Java south sea	5 - 10	0.6 - 1.3	0.75 - 2.0	0 - 5 %
8	East Java South Sea	5 - 12	0.6 - 1.5	0.75 - 2.0	0 - 5 %
9	Bali south sea to NTB	6 - 15	0.4 - 1.6	0.6 - 2.2	0 - 5 %
10	Sawu Sea	4 - 16	0.75 - 1.75	1.0 - 2.25	0 - 5 %
11	Timor Sea	5 - 15	1.0 - 1.75	1.5 - 2.5	0 - 5 %
12	Malaca Strait	3 - 10	0.4 - 2.2	0.6 - 2.5	0 - 5 %
13	Natuna sea	7 - 15	0.75 - 1.3	1.25 - 2.0	0 - 5 %
14	Java Sea	5 - 15	0.75 - 1.25	1.0 - 2.0	0 - 5 %
15	Bali Sea	4 - 10	0.75 - 1.25	1.0 - 1.6	0 - 5 %
16	Flores Sea	5 - 15	0.75 - 1.5	1.2 - 2.0	0 - 5 %
17	Maluku Sea	5 - 10	0.75 - 1.25	1.0 - 2.0	0 - 5 %
18	Buru Sea - Seram Sea	3 - 11	0.5 - 1.6	0.75 - 2.0	0 - 5 %
19	Sulawesi Sea	2 - 8	0.4 - 0.75	0.6 - 1.25	0 - 5 %
20	Halmahera Sea	4 - 10	0.7 - 1.25	1.0 - 1.5	0 - 5 %
21	Banda Sea	10 - 19	1.5 - 2.0	2.0 - 3.25	0 - 15 %
22	Arafuru Sea	10 - 17	1.2 - 2.0	1.5 - 2.5	0 - 5 %

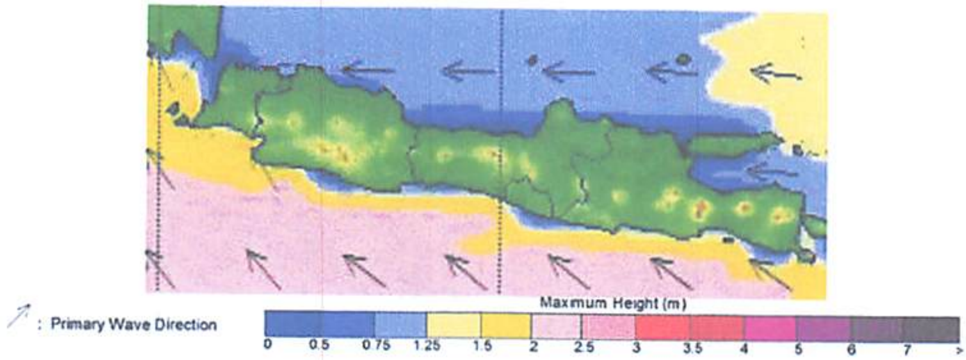


Figure 2. Wave height and primary wave direction at Java Sea [11]

3. Results and Discussion

This section contain the result from several simulation and analysis from five proposed model. Resistance, stability and seakeeping are three main focussed of hull design characteristic that will be also discussed.

3.1. Resistance Analysis

Resistance analysis was performed to predict resistance that will be experienced by all proposed hull design if they sail until their service speed. Also from this analysis, we could predict the propulsive power to overcome the resistance and reach the desireable service speed. The result of resistance analysis is presented in Figure 3 and prediction of propulsive power in Figure 4.

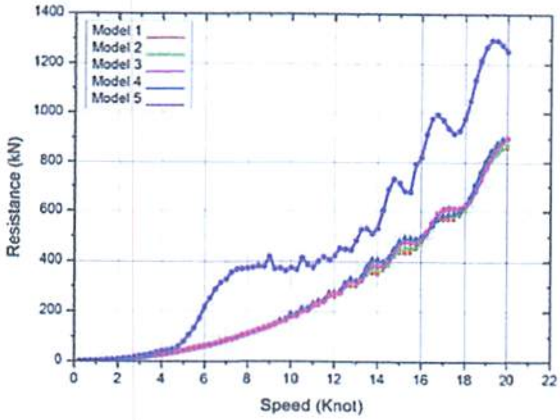


Figure 3. Interaction graph between resistance and speed

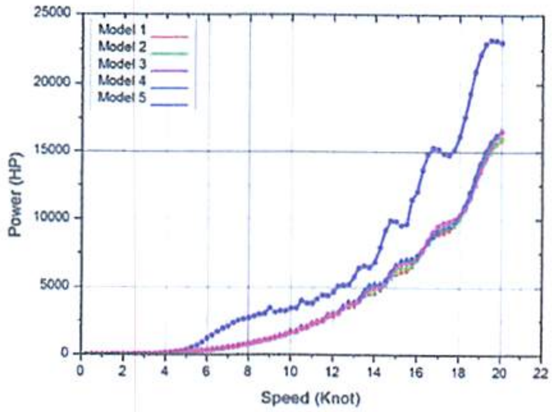


Figure 4. Interaction graph between propulsive power and speed

From the result, we obtain the information that Model 1, Model 2, Model 3, and Model 4 has similar trend in resistance-speed graph as well as in propulsive power-speed raph. The range of block coefficient 0.48 – 0.51 did not give the significant difference. But for Model 5 with block coefficient 0.65 or has significant difference block coefficient than the other one experienced higher resistance and of course the will need higher propulsive power to overcome the resistance. Model 5 which use Ayre's method to determine the block coefficient experience the higher resistance because higher block coefficient will affect the form of hull design which is fat or slim. With Ayre's method, ship will gain more capacity but do not suitable for high service speed that have been decided before. The prediction of propulsive power requirment is not acceptable or in this case much higher than the other model.

3.2. Stability Analysis

Stability analysis is performed to predict and obtain the information about stability of hull design and verify the result with stability standard. In stability analysis, IMO A.749 (18) *Code on intact stability, Chapter 3* was used. In this standard, several requirement that must meet are:

1. Area 0 to 30
2. Area 0 to 40
3. Area 30 to 40
4. Max GZ at 30 or greater
5. Angle of maximum GZ
6. Initial GMt
7. Passanger crowding: angle of equilibrium
8. Area 0 to angle of GZ maximum

All the result must meet with the standard. Even if one of the criteria of standard is fail, the design is recommended to fix so meet with the standard. Stability characteristic is highly connected with safety for passenger, crew, asset, and also ship itself, so all requirement of IMO according to stability safrty must meet.

From stability analysis we obtain the result of length of arm for heel from 0° to 90° and verification of stability characteristic for all proposed model. The verification the result and IMO standard is presented in Table 3 while the graph of length of arm is presented in Figure 5.

Table 3. The verification result of stability analysis with IMO Standard

Code	Criteria	Value	Units	Model 1	Model 2	Model 3	Model 4	Model 5	Status
A.749(18) Ch3 - Design criteria applicable to all ships	Area 0 to 30 shall not be less than (>=)	3.151	m.deg	113.278	112.753	110.734	113.278	147.539	Pass
	Area 0 to 40 shall not be less than (>=)	5.157	m.deg	182.486	181.833	178.287	182.486	213.024	Pass
	Area 30 to 40 shall not be less than (>=)	1.719	m.deg	69.208	69.080	67.553	69.208	65.485	Pass
	Max GZ at 30 or greater shall not be less than (>=)	0.200	m	8.746	8.728	8.429	8.746	6.650	Pass
	Angle of maximum GZ shall not be less than (>=)	25.000	deg	86.400	86.400	86.400	86.400	30.000	Pass
	Initial GMt shall not be less than (>=)	0.150	m	18.890	18.755	18.514	18.890	31.828	Pass
	Passenger crowding: angle of equilibrium shall not be greater than (<=)	10.000	deg	0.000	0.000	0.000	0.000	0.000	Pass
	Area 0 to angle of Gzmax shall be greater than (>)	3.151	m.deg	113.278	112.753	110.734	113.278	147.539	Pass

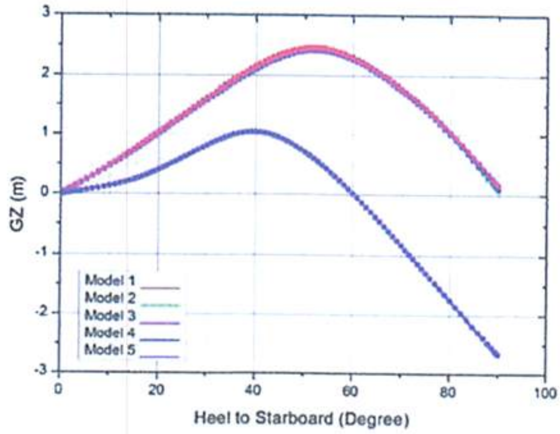


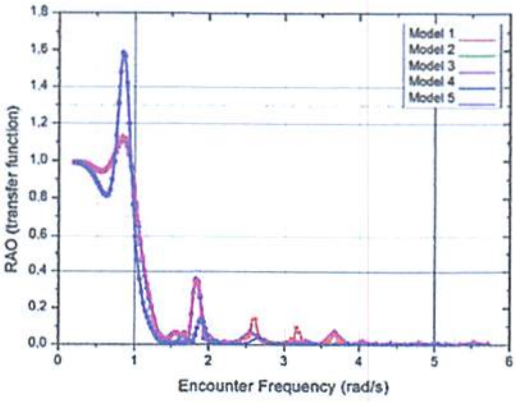
Figure 5. Interaction graph between righting armand heel degree

From the result of stability simulation and verification that is presented in Table 3, we can conclude all proposed model meet with IMO criteria which is acceptable from stability aspect. In other side, from aspect righting lever curve (GZ curve)Figure 5, the lever curve from Model 5 reach maximum at 40° and for this model, the stability vanish in 60°. Whereas the stability of other model vanished at 90°. Bigger angle where the position of vanishing stability point exist, indicates the hull model better in stability performance. Even the the proposed hull meet with IMO criteria but we can choose the best from the best in aspect of stability with compare the point of vanishing stability.For proposed model with block coefficient 0.48-0.51, we get the similar point of vanishing stability and also indicates model block coefficient modification in range 0.48-0.51 there are no significant difference in aspect of postion of vanishing stability point. In other hand, the dynamic stability may be determined by measuring the area under the righting lever curve (GZ curve) up to a certain angle of heel. The larger the area, the better is the dynamic stability.[12]

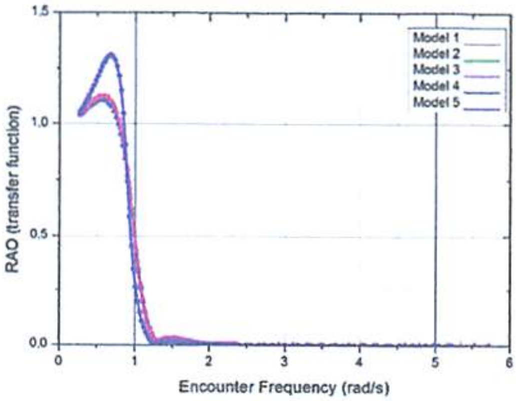
3.3. Seakeeping Analysis

Seakeeping simulation are performed using the wave and wind characteristic at Java Sea. According to data from Badan Meteorologi Klimatologi dan Geofisika (BMKG) in Table 2 and Figure 2, Java Sea have wave height average in range 0.75 m – 1.25 m with maximum height average in range 1 m – 2 m. Wind speed average at Java Sea is between 5 knot – 15 knot. The result of seakeeping simulation is presented in Figure 6 for encounter wave frequency heaving, pitching, and rolling. For the response wave encounter 90° and 180°, Model 5 has significant difference in aspect heaving and pitching, but for rolling motion, all proposed model have the same Response Amplitude Operator (RAO) transfer function but different in encounter frequency for Model 5.Nevertheless all proposed model still have similar trend for all motion. The result that is presented in Figure 6 represent the highest (RAO) transfer function for each motion. This RAO transfer function for each motion will be compared with wave encounter frequency for wave encounter angle: 90°and 180°. The highest wave encounter frequency in wave spectral must not superposition with RAO transfer function of heaving, pitching and rolling because the hull design will experiance extreme respon (heaving, rolling, or pitching). As the result, the passanger will experience sea sickeness and the passanger comfort disturbed. For the example if wave encounter frequency from wave spectral reach 5 rad/s for wave encounter angle 90°, then RAO transfer function of heaving, rolling and pitching must not maximum in this frequency for wave encounter angle 90°. Simulation for all proposed hull design indicate there are no superposition between RAO transfer function and wave encounter frecuency of wave spectral. This method is presented by Courser in his work.[5]

Besides carrying truck, the proposed model also will carry human, in this case truck driver. Therefore, comfort level of passanger must be calculated. In seakeeping analysis, the level comfort of passanger can be calculated using Motion Sickness Incidence (MSI) graph. Where this graph explain how many passanger will experience sea sickeness during travel period. The lower diagram indicates the lower possibility of passanger experience sea sickness. This method also was presented in Course work where he compare MSI graph between hull with round bilge and chine.[5] The result of MSI analysis for all proposed hull model is presented in Figure 8. The graphs in Figure 8 indicate that all proposed hull model have good MSI analysis result.



(a)



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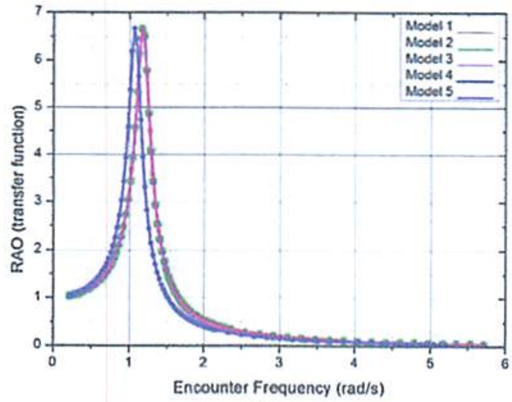
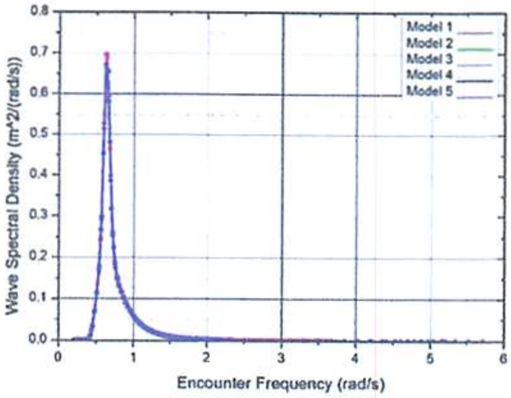
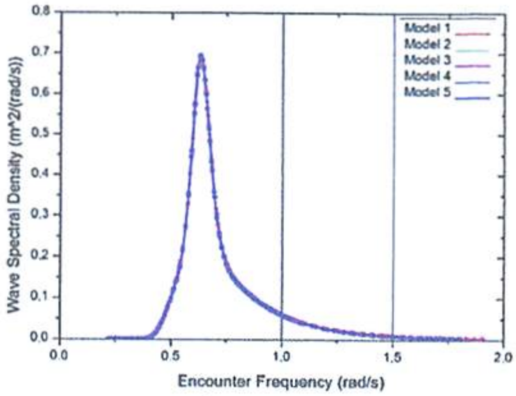


(c)

Figure 6.RAO transfer function: (a) Heaving motion with wave encounterangle 90°, (b) Pitching motion with wave encounterangle 180° and (c) Rolling motion with wave encounterangle 90°



(a)



(b)

Figure 7. Wave frequency: (a) Wave encounter angle 90° and (b) Wave encounter angle 180°

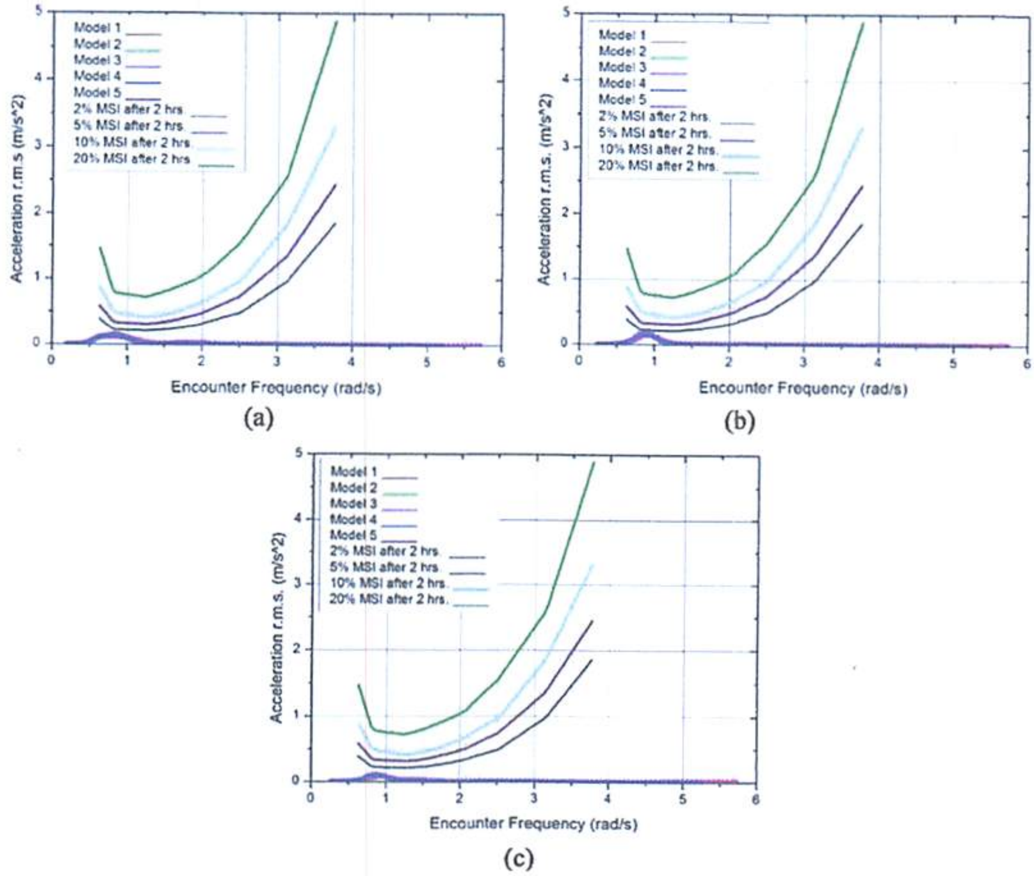


Figure 8.MSI: (a) Wave encounter angle 90°, (b) Wave encounter angle 135° and (c) Wave encounter angle 180°

The last criteria for seakeeping analysis are slamming and deckwetness. The probability of hull experience slamming and deckwetness must be pressed as low as possible. Slamming and deckwetness can affect the ship structure and stability if the propability of its occurence is high. From the analysis of all proposed hull model, we obtain the information that Model 5 have great result where for all wave encounter angle, the probability of deck wetness and slamming are lowest if compared by other model. Other four model result for deckwetness is not bad, where the possibility deck wetness occur is lower than one incidence per hours for wave encounter 90°. The result for other proposed hull model for wave encounter 135° and 180° meet good agreement with thecriteria where the possibility of occurence per hour almost zero. The resume of slamming and deckwetness analysis are presented in Table 4, Table 5 and Table 6.

Table 4. Slamming and deckwetness for wave encounter angle 90°

No.	Criteria	Model 1	Model 2	Model 3	Model 4	Model 5	Unit
1	Deck wetness	0.986	0.961	0.951	0.970	0.039	MII/h
2	Slamming	0.000	0.000	0.000	0.000	0.000	MII/h

Table 5. Slamming and deckwetness for wave encounter angle 135°

No.	Criteria	Model 1	Model 2	Model 3	Model 4	Model 5	Unit
1	Deck wetness	0.001	0.001	0.001	0.001	0.000	MII/h
2	Slamming	0.000	0.000	0.000	0.000	0.000	MII/h

Table 6. Slamming and deckwetness for wave encounter angle 180°

No.	Criteria	Model 1	Model 2	Model 3	Model 4	Model 5	Unit
1	Deck wetness	0.000	0.000	0.000	0.000	0.000	MII/h
2	Slamming	0.000	0.000	0.000	0.000	0.000	MII/h

4. Conclusion

This paper has describe the investigation of proposed hull model that will be used as truck carrier for route Tanjung Priok (Jakarta) – Tanjung Perak (Surabaya), where resistance, stability and seakeeping analysis is presented. The simulation of proposed hull model is using numerical analysis to obtain the initial prediction of hull characteristic for several hull performance.

From all analysis can be concluded that every proposed hull model have their advantage and weakness, where Model 1 until Model 4 are superior in resistance, stability, RAO, MSI and slamming analysis but weak in aspect of slamming. In the other hand, Model 5 is mainly weak in resistance and stability but good in slamming criteria. But from overall analysis and simulation, Model 3 is better than other model. And the next step after computer numerical simulation, the choosen model could be tested in towing tank analysis to obtain actual data from hull performance as well as to compare the result with computer numerical analysis result. This comparison is needed because numerical prediction tools for seakeeping have not yet reached the stage where they can reliably predict absolute motions data with the accuracy of large scale model tests. However, they are very useful forcomparative analysis, particularly in initial design where seakeeping performance would perhaps otherwise be virtually ignored due to constraints of time and budget.

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