ANALYSIS OF THE EFFECT OF BILGE KEEL ON THE ROLLING MOTION OF RO-RO FERRY SHIP USING THE STRIP-THEORY METHOD

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ABSTRACT

Ships are a mode of transportation that is often used by the community as a link between the islands. People generally use the ferry as a mode of crossing in addition to the economical price but also comfort is still preferred. But in recent years, researchers have often heard cases of shipwrecks. Especially ship crossing accidents caused by overturned ships. Based on this, prevention is needed to reduce the number of ship accidents in the future. One of the keys that can be taken is to improve the technical analysis before the ship is designed. One such analysis related to the ship is seakeeping ship. The method used in this study is to use strip – theory method through OSM program. This method is one of the commonly used methods because it calculates the 3D model into 2D. The results showed the effect of the use of Bilge keel on the ferry Ro-Ro tested with conditions x_0, x_1, x_2, and x_3 on the condition of the stationary ship with a wave height of 1,5 m and heading 90^o. The addition of Bilge keel is able to reduce the resonance of roll motion up to 58% in conditions of variation x_1, 61% in variation x_2, and 67% in conditions of variation x_2. Therefore, the installation of bilge keel has a significant effect on the rolling of ferry Ro-Ro.

Keywords: Roll Motion, Bilge Keel, OSM.

INTRODUCTION

The Ferry Ro-Ro is one of the modes of transportation that is currently popular in Indonesia, this is because this ship has a port in and out system that does not require a stretcher. But the Ro-Ro ferry has interesting facts. Based on the results of the study stated that one of the reasons the Ro-Ro ferry is more dangerous than other ships is related to the problem of ship stability [1]. There are six types of ship movements that are experienced when in waters including heave, surge, yaw, sway, pitch, and roll [2]. The ship has a control system with specifications that can make the ship stable in facing this movement. Ships can roll due to internal factors and external factors acting on the ship [3]. In addition, the movement of the ship's maneuvers and sea waves can interfere with the stability of the ship [4]. If the disturbance has not been minimized, then gradually the ship will not be able to return to the even keel position.

In 2018 there was a ferry accident which resulted in the extreme tilt of the ship [5]. There are not a few cases of ship accidents due to the loss of the ship's ability to return to its original position. Therefore, we need damping to damp the roll movement. Roll damping can control the magnitude of the roll movement amplitude [6], so that we need damping for reducing the ship movement. Damping motion on ships can be influenced by several components, namely hull friction, ship oscillatory motion, water waves, ship lifting force, and bilge keel. One of damping that can be regulated/ conditioned is by adding a structure to the hull, namely the bilge keel.

Based on the background above, the main problem in this study is related to the influence of the bilge keel on the rolling motion of the case study ship on the Ro-Ro 600 GRT ferry. The method used in this study is to use the strip theory method. This study aims to determine the effect of the addition of bilge keel on the rolling value of the Ro-Ro 600 GRT ferry.

METHODS

The research method used by the author is to use a quantitative approach. This study aims to test the independent variable on the dependent variable. The independent variable in this study is the bilge keel and the dependent variable in this study is the rolling of the ship. The main ship size data is shown in Table 1. Then related to simulation condition data can be seen in Table 2. Meanwhile, the shape of the Ro-Ro 600 GRT ship body plan can be seen in Figure 1.

Table 1. Principle Dimension of Ferry Ro-Ro 600 GRT

No	Main Dimensions	Values	Units
1	Length (L_{OA})	46,2	m
2	Length (L_{pp})	39,0	m
3	Breadth (B)	12,0	m
4	Depth (H)	3,0	m
5	Draft (T)	1,9	m

Table 2. Simulation Condition

No	Parameters	Values	Units
1	KG	4,2	m
2	Speeds	0; 6; and 12	knot
3	Rolling Relative Period ($T\phi_{relatif}$)	6,1	sec
	Rolling Periods $T\phi$ even breadth of bilge keel 0,2 m	6,1197; 6,1131; and 6,1066	sec
	Rolling Periods $T\phi$ even breadth of bilge keel 0,3 m	6,1295; 6,1197; and 6,1098	sec
	Rolling Periods $T\phi$ even breadth of bilge keel 0,5 m	6,1492; 6,1328; and 6,1164	sec
4	Wave height	0,5; 1; and 1,5	m
5	Length of wave λ/L_{pp}	0,2 – 2,5	
6	Wave direction	45; 90; and 135	o

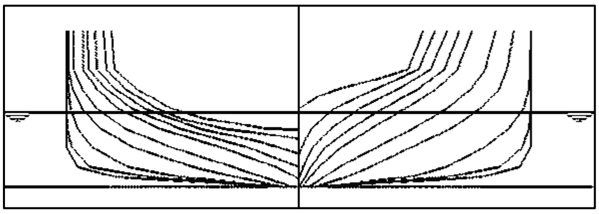


Figure 1. Body Plan of *Ferry* Ro-Ro 600 GRT

The results of this study are displayed in graphical form. The graph is the rolling motion of the Ro-Ro ferry without using a bilge keel and using a bilge keel with various variations x_0; x_1; x_2; and x_3. An explanation of the variations can be seen in Table 3. The results of the rolling motion are shown in the conditions L_{bk} = 15,6; Froude number 0, 0,158, and 0,316, and wave direction in 45°, 90°, and135° and wave height during conditions 0,5 m, 1 m, and 1,5 m.

Table 3. Variation of research

No	Name	Variations	Descriptions
1	Variation of the Effect of Adding a Bilge Keel (X)	X_0	Without bilge keel
		X_1	Bilge keel (B_{bk} = 0,2 m)
		X_2	Bilge keel (B_{bk} = 0,3 m)
		X_3	Bilge keel (B_{bk} = 0,5 m)

This research began with the stages of data collection, data input, OSM simulation. The output results from the OSM simulation are then analyzed by reviewing the graphical results of rolling motion on the ship. If the graphic results show the value of the rolling motion, then the simulation process is successful. The flow chart in this study can be seen in Figure 2.

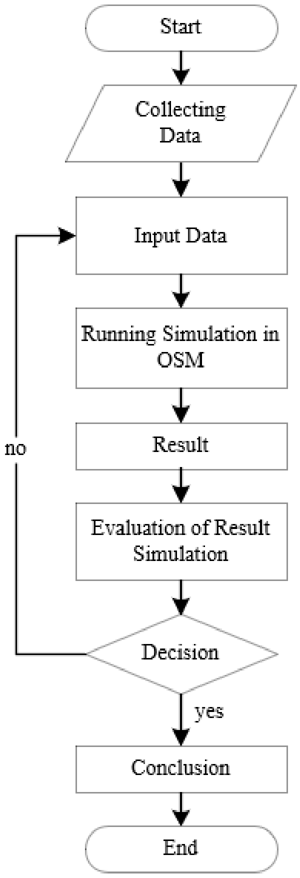


Figure 2. Flow chart of research

Seakeeping

In the context of ship stability, the ship has the ability to maneuver. Figure 3. shows the movement of the ship which is divided into 6 movements, or commonly known as 6 – degrees of freedom [7].

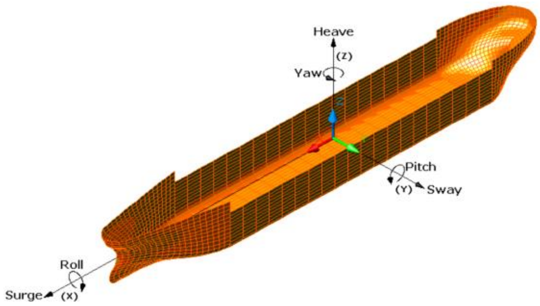


Figure 3. Isometric of movements of ship [2]

The oscillatory motion of the floating structure due to wave excitation consists of 6-degrees of freedom, as shown in Figure 3. The three translational motions in the x, y, and z directions, are respectively *surge* ($\zeta 1$), *sway* ($\zeta 2$) and *heave* ($\zeta 3$), while for rotational motion about the three axes is *roll* ($\zeta 4$), *pitch* ($\zeta 5$) and *yaw* ($\zeta 6$) [8]. Of all the ship's movements, what the author focuses on in his research is rolling motion. Rolling motion is a ship movement that moves in a rotational manner. Equation (1) is used to calculate the rolling motion as follows: [9], [10]

$$a\frac{d^2\phi}{dt^2} + b\frac{d\phi}{dt} + h\phi = M_0 \cos \omega_e t \qquad (1)$$

Where:

Inertia Force : $a\frac{d^2\phi}{dt^2}$
Damping Force : $b\frac{d\phi}{dt}$
Restoring Force : $h\phi$
Exciting Force : $M_0 \cos \omega_e t$

The response from the ship's movement is divided into four parts are additional inertial forces, damping forces, restoring forces, and exciting forces [4].

a. Additional inertia force, is the increase in the mass of the ship so that the ship can return to its original position;
b. Damping force, is a damping force directed against the direction of the ship's motion by producing a gradual reduction in the ship's amplitude;
c. Restoring force, is the return force (equilibrium position). This force can also be said as an additional buoyancy force; and
d. Exciting force, is the external force acting on the ship. This response originates from the integration of additional buoyancy forces and waves along the length of the ship.

The amount of rolling motion has an impact on ship performance, so roll damping is required to reduce rolling motion [11]. The magnitude of the roll damping value can be calculated through Equation (2) below : [12]

$$B_{44} = B_f + B_e + B_w + B_l + B_{bk} \qquad (2)$$

Where:

B_{44} = roll damping
B_f = hull friction damping
B_e = eddy damping
B_w = wave radiation damping
B_l = lift damping
B_{bk} = bilge keel damping

Based on Equation (2) the damping component that can be adjusted is the use of a bilge keel. Bilge keel is a damping component that is used by adding construction to the hull. The bilge keel is also the part used as a damper for the ship's rolling motion. The use of Bilge keel on ships can be useful as a stability enhancer [3]. The bilge keel has a function in increasing damping when the ship is rocking.

RESULT AND DISCUSSION

The ship's ability to return to the even keel position needs special attention. The movement of the ship adjusts to the waves that hit the ship [13]. One of the movements which is the main focus in this research is the rolling motion of the ship. Cases of ship accidents due to excessive tilt of the ship often occur [14], so it needs special attention to minimize the impact of rolling motion. Roll damping is a component that functions to reduce rolling motion, one of which can use a bilge keel [15]. So, the authors examine further related to the influence of the bilge keel on rolling motion on the Ro-Ro 600 GRT ferry.

The Effect of Bilge Keel

Based on the results of this study, there is an influence from the direction of arrival of the waves on the efficiency of ship rolling motion between using a bilge keel and without using a bilge keel. Figure 4~ Figure 6 is a graph showing the ship's rolling motion based on heading 45°; 90°; and 135° in the condition of a stationary ship and a wave height of 0.5 m with variations without using a bilge keel (x_0), added bilge keel 0,2 m (x_1), 0,3 m (x_2), and added bilge keel 0,5 m (x_3)

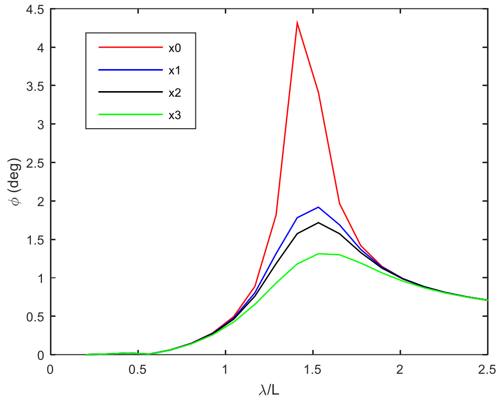


Figure 4. Wavelength relationship with the ship's rolling moment head. 45°

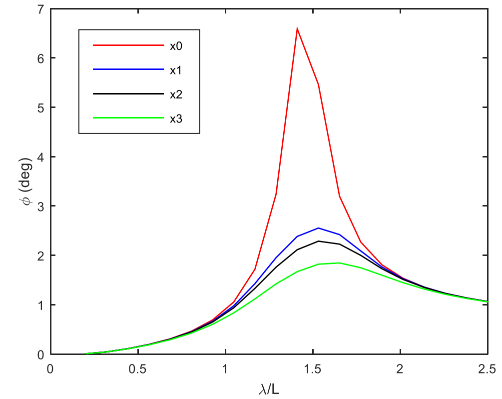


Figure 5. Wavelength relationship with the ship's rolling moment head. 90°

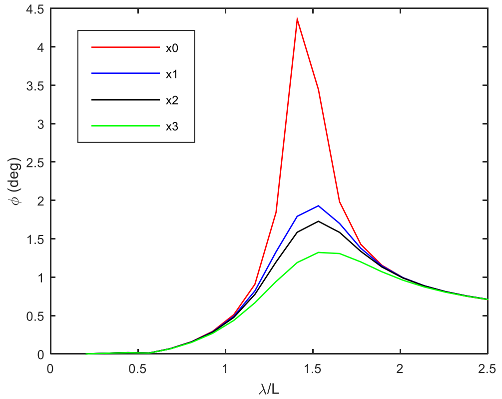


Figure 6. Wavelength relationship with the ship's rolling moment head 90°

Figure 4~ 6 shows the results of the rolling resonance of the Ro-Ro ferry at a stationary condition and a wave height of 0.5 m. From these results it displays the rolling value of the ship for each

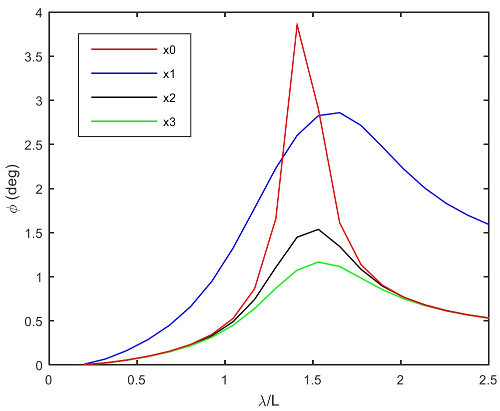
Wavelength/Lpp. In addition, these results also show the results of rolling resonance in ship conditions without the use of a bilge keel (variable x_0) and using a bilge keel using a bilge keel by using bilge keel (variable x_1, x_2, and x_3), where each variation represents each condition of the bilge keel width representing each condition of a different bilge keel width.

Based on the results above, the direction of the incoming wave is on heading 90° has a considerable influence compared to heading 45° and 135°. Resonance rolling on heading 45° and 135° have a size that is not too significant difference. These results are reinforced by previous research which states that the greatest roll response occurs when the wave direction is from the side [16].

The magnitude of the roll resonance on the condition 45° with ship conditions ferry Ro-Ro 600 GRT without bilge keel is 1,62°. Heading 90° and ferry Ro-Ro without bilge keel achieve 2,44°, while on condition 135° resonance of rolling without bilge keel is 1,63° the addition of the bilge keel has a significant impact, meaning that there is a reduction in rolling resonance in ship conditions with the addition of the bilge keel. In the condition of heading 45° the effectiveness of roll damping on x_1 was able to dampen rolling motion by 41,14%, while on x_2 was able to dampen rolling motion by 47,52%, and x_3 was able to dampen rolling motion by 59,11%. Then in condition of heading 90° the effectiveness of roll damping on x_1 was able to dampen rolling motion by 48,69%, while on x_2 was able to dampen rolling motion by 54,39%, and x_3 was able to dampen rolling motion by 64,51%. At the same time in condition of heading 135° the effectiveness of roll damping on x_1 was able to dampen rolling motion by 41,39%, while on x_2 was able to dampen rolling motion by 47,78%, and x_3 was able to dampen rolling motion by 59,36%.

The Effect of the Bilge Keel on Wave Height

Wave height has a role in the size of the rolling resonance. Based on Figure 7~Figure 9 shows the roll resonance graph at heading 90° with the ship at rest.



Figurer 7. Wavelength relationship with the ship's rolling moment Hw 0.5 m

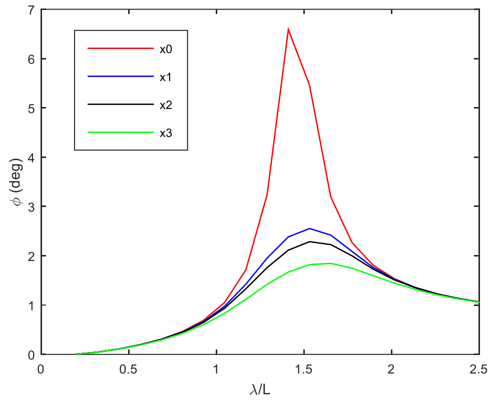


Figure 8. Wavelength relationship with the ship's rolling moment Hw 1 m

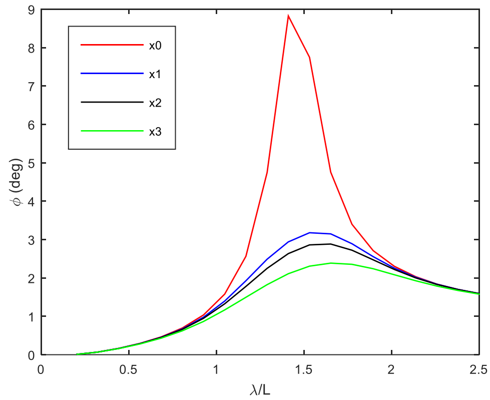


Figure 9. Wavelength relationship with the ship's rolling moment Hw 1.5 m

The waves affect the rolling motion of the ship. Based on Figure 7~9, the greater the wave height, the greater the value of the rolling motion. By 23~44%, there is a reduction in roll resonance for every 0.5 m increase in wave height.

In the condition of a ship without a bilge keel (x_0) the magnitude of the roll resonance at a wave height of 0,5 m; 1 m; and 1,5 m are 0,99°; 1,77°; and 2,44°. So with the addition of the bilge keel in the x_1 variation there is a reduction in the roll resonance to 0,51° at a wave height of 0,5 m; 0,78° at a wave height of 1 m; and 0,79° at a wave height of 1,5 m. Whereas with the addition of the bilge keel in the x_2 variation produce the roll resonance decreases to 0,45° at a wave height of 0,5 m; 0,72° at a wave height of 1 m; and 0,73° at a wave height of 1,5 m. Whereas with the addition of the bilge keel in the x_3 the roll resonance decreases to 0,35° at a wave height of 0,5 m; 0,59° at a wave height of 1 m; and 0,61° at a wave height of 1,5 m.

The Effect of Bilge Keel on Ship Speed

When the ship moves, the ship must exert a force on its environment. So that the ship has a role in the size of the ship's rolling motion. Based on Figure 10~Figure 12 concerning the effect of ship speed on the rolling motion of the Ro-Ro 600 GRT ferry when the wave height is 0.5 m.

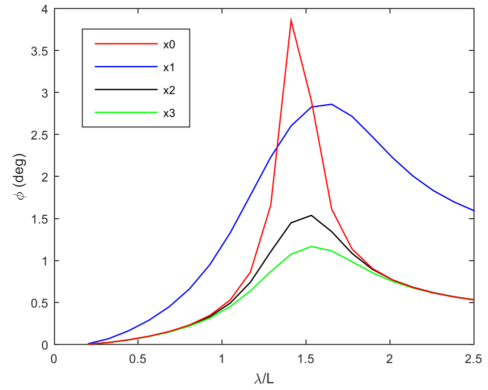


Figure 10. Wavelength relationship with the ship's rolling moment Vs 0 knot

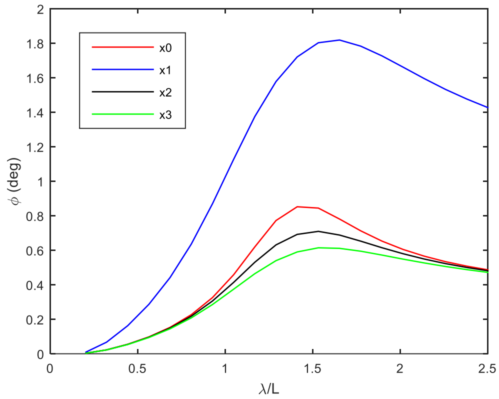


Figure 11. Wavelength relationship with the ship's rolling moment Vs 6 knot

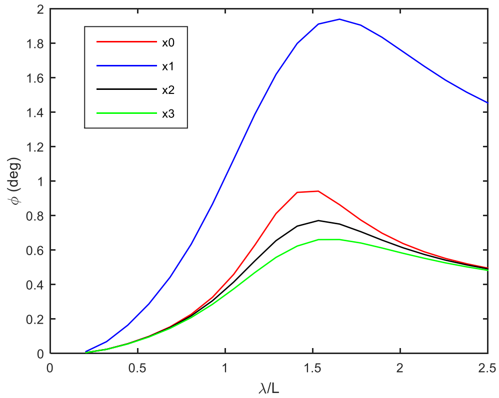


Figure 12. Wavelength relationship with the ship's rolling moment Vs 12 knot

Figure 10~12 shows the rolling resonance graph on the condition of the ship with a heading of 90° at a wave height of 0.5 m. Based on the research results it is known that the rolling resonance is greater when the ship is stationary. But there is a damping on the ship's roll motion when the ship is running.

It can be seen in Figure 10~ Figure 12 that the greatest rolling value is in the x_0. in the condition of the ferry without a bilge keel. When the ship is stationary, the rolling resonance can be 1° in condition on without bilge keel and wave height 0,5 m and heading 90°. In the condition of the ship with a speed of 6 knot (Fn = 0,158) resonance of rolling is 0,28. In the condition of the ship with a speed of 12 knot (Fn = 0,316) Resonance of rolling is 0,32. In a stationary condition, the use of a bilge keel can help reduce the rolling of the ferry by 0,51 at x_1; 0,45 at x_2; and 0,35 at x_3. Then when the ship is moving at a speed of 6 knot the use of the bilge keel can help reduce the rolling of the ferry by 0,25 at x_1; 0,24 at x_2; and 0,21 at x_3. Meanwhile, in the condition of the ship moving at a speed of 12 knots, the use of the bilge keel can help reduce the rolling of the ferry by 0,27 at x_1; 0,26 at x_2; and 0,22 at x_3

CONCLUSION

Based on the results above, there is a significant effect with the addition of the bilge keel related to the rolling motion of the Ro-Ro ferry. There was a reduction in rolling resonance of 50% - 67% by adding the bilge keel in a stationary condition with a heading of 90° and a wave height of 1,5 m. There is an influence of wave height and ship speed on the size, so the addition of the bilge keel has a positive effect to reduce rolling motion. This is reinforced by the condition when the ship does not use a bilge keel with rolling which has a greater rolling resonance, so that the addition of the bilge keel is able to dampen the roll motion.

REFERENCES

[1] Muzdalifah, L., Chrismianto, D., and Hadi, E. S., 2016. Analisa Keselamatan Kapal Ferry Ro-Ro Ditinjau dari Damage Stability Probabilistik. J. Tek. Perkapalan. Vol. 4 (2) pp. 409–417.

[2] Yasim, A., Wibowo, R. K. K., Laksana, D. D., Puspita, H. I. D., Sakinah, W., Widitiyo, P. G. and Rudianto, 2022. Hydrodynamics Comparison of V-shaped and U-shaped Hulls of 5 GT Fishing Vessels Based on the Characteristics of Southern Java Waters. *International Journal of Engineering Research and Development*. Vol. 18 (3) pp. 16–24.

[3] Widyatmoko, A., Samuel, S., Manik, P., and Trimulyono, A., 2021. Analisis Pengaruh Jumlah Bilge Keel terhadap Gerakan Rolling pada Kapal Patroli 14 m. War. Penelit. Perhub. Vol. 33 (1) pp. 1–10.

[4] Romadhoni, 2019. Analisa Seakeeping Ferformance Kapal Cepat Model Planing Hull Chine. J. INOVTEK POLBENG. Vol. 9 (1) pp. 30–37.

[5] KNKT, 2018. Laporan Investigasi Kecelakaan Pelayaran : Miringnya Kapal Lestari Maju.

[6] Hendratmoko, H., Hasanudin, H., and Utama, I. P., 2012. Studi Eksperimen Pengaruh Lunas Bilga Terhadap Gerakan Rolling. J. Tek. ITS, Vol. 1 (1), pp. 94–97.

[7] Puspita, H. I. D., Kusnadi, R. F., and Syaikhu, D., 2022. Optimalisasi Lambung Kapal Penangkap Ikan dengan Bahan Dasar Fiberglass Di Pelabuhan Perikanan Puger. Zona Laut : Jurnal Inovasi Sains Dan Teknologi Kelautan. Vol. 3 (1) pp. 38–46.

[8] Djatmiko, E. B., 2012. Perilaku dan operabilitas bangunan laut di atas gelombang acak. ITS-Press. Surabaya. Indonesia.

[9] Agus, A. P., 2017. Prediksi Gerak Heaving dan Pitching pada Model Kapal Perikanan

Menggunakan Aplikasi Maxsurf dengan Variabel Peralatan Uji Tarik. Universitas Hasanuddin.
[10] Bhattacharya, R. 1978. Dynamics of Marine Vehicles.
[11] Ikeda, Y., Fujiwara, T., and Katayama, T., 1993. Roll Damping of a Sharp-Cornered Barge and Roll Control by New Type Stabilizer. Proc. Third Int. Offshore Polar Eng. Conf. Vol. 3 (June 1993) pp. 634–639.
[12] Haver, T., 2016. Roll Damping Predicition for Vessels; Sheerlegs and Barges. Delft University of Technology.
[13] Puspita, H. I. D., and Utama, I. K. A. P., 2017. Studi Karakteristik Hidrodinamika Kapal Ikan Tradisional Di Perairan Puger Jember. Jurnal Kelautan Nasional. Vol. 12 (1) pp. 1–7.
[14] KNKT, 2018. Penta Prima.
[15] Virliani, P., and Mintarso, C. S., 2011. Pengembangan Kapal Ikan Kelas 30 GT Daerah Pantai Selatan Jawa Timur. Wave: Jurnal Ilmiah Teknologi Maritim. Vol. 5(1) pp. 27-31.
[16] Ali, B., Katayama, T., and Ikeda, Y., 2004. Roll damping characteristics of fishing boats with and without drift motion. International shipbuilding progress. Vol. 51 (2-3) pp. 237-250.