Performance of Rescue Boat Operation when Operated in Waves

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Abstract. Search and rescue operations, especially in ship accidents, require speed and reliability from the rescue vessels in facing the challenges of extreme weather and sea waves. A rescue boat hydrodynamic performance study is very important to do to determine the ship's ability to withstand dangerous conditions while operating. Therefore, a rescue boat design is needed that is capable of high acceleration and can penetrate various extreme sea conditions. Three rescue boat hull models have been developed to obtain the hull model with the best seakeeping performance. A numerical arrangement based on computational fluid dynamics (CFD) techniques is used to predict seakeeping behaviour from three rescue boat hull model in wave. Three-dimensional diffraction panel method uses as a CFD solver method to predict the seakeeping performance of rescue boat high-speed operation in wave. From the study results, it was found that the first rescue boat hull model had a good seakeeping performance compared to other hull models.

1. Introduction

The National SAR Agency as an institution that is responsible for search and rescue problems needs to complete the need for adequate marine facilities in the form of search and rescue vessels capable of operating in accordance with the Indonesia Search Rescue Region (Indonesia SRR). Rescue boats are also needed a high-speed craft that are available in each port that have function as rescue ships. A design for a rescue boat that has high acceleration and can penetrate various extreme sea conditions. This is important because the rate of ship accidents in Indonesia is quite high. The Minister of Transportation of the Republic of Indonesia, through the Instruction of the Minister of Transportation of the Republic of Indonesia Number IM 10 of 2018, is to carry out security and order in the Work Environment and Port Interests for users of transportation modes and to coordinate with related agencies. This instruction is to respond to the high level of ship accidents in Indonesia.

Rescue Boat is necessary so as not to cause a lot of loss and casualties on sea transportation. Rescue boat itself is a rescue ship which is usually used during MOB or Man Overboard events (people who fall from the boat and float in the sea, or during natural disasters such as water overflows due to flooding in certain areas, etc.). Rescue and handling of shipping accidents must be carried out effectively and efficiently so as not to cause significant losses.

The speed and weight of the ship greatly affect the work of the ship when it is on the waves [1]. Likewise, the wave characteristics consisting of height and period and direction of wave propagation determine the response of motion on the ship. Motion responses such as rolling, pitching, and heaving will ultimately affect the comfort and safety of the crew and the goods being transported. Based on the explanation above, this study was conducted to evaluate and analyze the response of high-speed vessel
motion in various conditions in waves based on the conditions or the character of the voyage, especially in the response of the rolling, heaving, and pitching motion of the ship [2].

2. Rescue boat model

The simulation is done by modeling the hull of the rescue boat. Three prototype hull models are analyzed. The three hull models of the rescue boat have different hull characteristics from one another. Table 1 shows the principal dimension of the hull model. It can be seen form the picture that the first model ship has a length of 4.56 meters and a displacement of 936.4 kg, the second model has a length of 5.296 meters with a displacement of 1414 kg, and the third model has a length of 3.758 meters with a displacement of 904 kg. The second model has the largest physical size, and the third model has the smallest physical size. The three hull models will operate at an operating speed of 20 knots.

Table 1: Principal Dimension of Rescue Boat Hull Model.

| Parameter          | Unit | Model 1 | Model 2 | Model 3 |
|--------------------|------|---------|---------|---------|
| LOA                | m    | 4.56    | 5.296   | 3.758   |
| LWL                | m    | 4.3     | 4.756   | 3.559   |
| B                  | m    | 1.52    | 1.815   | 1.363   |
| T                  | m    | 0.35    | 0.396   | 0.3     |
| H                  | m    | 0.92    | 1.035   | 0.607   |
| Volume Displacement| m³   | 0.936   | 1.414   | 0.904   |
| Displacement       | kg   | 936.4   | 1414    | 904     |

Figure 1: Rescue Boat Hull Model 1.

Figure 1 shows the hull of the first rescue ship model. It has a V-shaped hull with a deadrise angle of up to 30°. This hull model does not have a chine in its hull, so it is a full V-shaped hull. Deadrise with a large angle can reduce the impact load that occurs when slamming and make it easier for the hull to break the incoming waves [3].
Figure 2 shows the hull of the second model rescue boat. This hull model has a V-shaped hull type with a deadrise angle of 20°. This hull model has a chine that serves to increase hydrodynamic lift when the ship is traveling at high speed [4]. The second hull model has a shape like a high-speed pleasure craft with a sharp bow that can increase difficulty in production. The shape of the hull is not simple because there are many curves in its hull when compared to the first hull model.

Figure 3 shows the hull of the third model rescue boat. The third hull model also has a V-shaped hull, but with a much smaller deadrise angle of 15°. The small deadrise angle provides a large enough impact load when slamming occurs and has the potential to accelerate the aging of the construction at the bottom area [3]. The third model is also equipped with a chine on the hull to increase hydrodynamic lift when operating. The shape of the hull is simple and easy to manufacture and has a less curve shape in its hull.

3. Mathematical model and computing method
CFD solver three-dimensional diffraction panel method uses for seakeeping analysis. The three hull models are discretized so that they are arranged into small panels that compose the shape of the hull.
The three-dimensional Panel method can predict motion and wave load that occurs in the hull of a ship with forwards speed on regular waves [5].

3.1. Computational Grid

![Model 1](image1)

![Model 2](image2)

![Model 3](image3)

**Figure 4** Computational Grid Uses for Motion Analysis.

*Figure 4* shows the mesh used. A total of approximately five thousand panel elements are used to model the shape of the hull which is used as a model for ship seakeeping analysis. Estimates of the number of elements used are obtained from the results of the grid independence study which can be seen in Figure 5. There is a difference or error of 2.2% in the grid independence study process.

![Graph](image4)

**Figure 5** Grid Independence Study of Total Element Used.

3.2. Equations of motion on floating structures

The equation for the motion of a floating structure can be analyzed using Newton II's law:

$$\sum F = mi\ddot{x}$$  \hspace{1cm} (1)
Where translational and rotational modes of motion in structures, $\Sigma F$ represent resultant of force, $m$ is structural mass in kg and $\xi$ is structure acceleration.

The equation above shows a relationship between the resultant force and mass and the acceleration of the structure. The resultant force in the floating building is the result of the reduction of the action force with the reaction force. The action force referred to in this case is the excitation force received by the structure due to the uneven pressure distribution of the wave. The impact of this uneven pressure is called the Froude-Krilof force [6]. Besides, the presence of large structures will also cause changes in the pressure distribution. The impact of a change in the pressure distribution due to a large structure is called the diffraction force. The amount of excitation force will vary with changes in time. While the reaction force referred to here is the force that opposes the action force. The following is an equation that describes the relationship between the resultant force and the action and reaction force:

$$\Sigma F = F_{ekstasi} - F_{reaksi}$$

(2)

The reaction force is influenced by added mass, damping, and stiffness. The following is an explanation of each of these components:

1. Added mass
   Floating buildings that move due to waves will cause their displacement to change and push the fluid particles around them in a certain mass. This is considered to increase the mass of the object so it is called added mass. The added mass depends on the shape of the object and its mode of motion. The hydrodynamic force that occurs due to added mass is an inertia force $(F_a)$. Here is the formula for the inertia force:

$$F_a = (m + a)i\xi i$$

(3)

Where $a$ is added mass in kg.

2. Damping
   Damping is the impact of the energy dissipation of the structure. 'Even lost due to rubbing against the surface of the medium. In other words, if the structure is vibrated in calm water, the kinetic energy of the structure (movement) will decrease over time, this is called damping. The damping value is the same as the added mass, depending on the shape of the object and the mode of motion of the object. The following is the equation for the damping force

$$F_b = bi\xi i$$

(4)

Where $b$ is system damping in N m/s.

3. Stiffness
   Floating structures that move on the surface of calm water without waves will have the rigidity to return to the initial position which is influenced by the hydrostatic characteristics of the structure. Where this is called a restoring force. This phenomenon only occurs in three modes of structural motion, namely heave, roll, and pitch [7]. This is because the other modes of motion do not have natural frequencies which technically do not have their stiffness mechanism manifesting as return force. Here is the return style equation:

$$F_c = ci\xi i$$

(5)

Where $c$ is structure stiffness in N/m.

Based on the explanation above, equations 3, 4, and 5 can be substituted into equation 2 to become:

$$\Sigma F = F_{ekstasi} - (F_a + F_b + F_c)$$

(6)

By substituting equation 1 into equation 6, then equation 7 is obtained as follows:

$$m_i\xi i = F_{ekstasi} - (F_a + F_b + F_c)$$

(7)
\[ F_w = (mi + ai)\xi + bi\dot{\xi} + ci\ddot{\xi} \]  

Where \( \xi \) is position response of structure motion in m, \( \dot{\xi} \) is velocity of structure in m/s, and \( \ddot{\xi} \) is acceleration of structure motion in m/s\(^2\).

### 3.2.1. Response Amplitude Operator

Response Amplitude Operator (RAO) is called the transfer function. It is a response function that transfers the wave force into a dynamic response to the structure in the frequency range. The RAO graph contains the frequency parameter in its abscissa and the ratio between the amplitudes of the motion of a particular mode in its ordinate.

According to [7], RAO in translational motion is formulated as follows:

\[ RAO(\omega) = \frac{\zeta_{k0}(\omega)}{\zeta_0(\omega)} \frac{m}{m} \]  

Where \( \zeta_{k0}(\omega) \) is structure amplitude in meter and \( \zeta_0(\omega) \) is wave amplitude in meter.

Meanwhile, RAO on rotational motion which is the ratio between the amplitude of the rotational motion and the slope of the wave, namely the multiplication of the wave number and the wave amplitude \( (k_w = \omega^2 / g) \) is formulated as follows:

\[ RAO(\omega) = \frac{\zeta_{k0}(\omega)}{\left(\frac{\omega^2}{g}\right)\zeta_0} \]  

### 3.2.2. Wave Spectra

The wave spectrum used has 2 parameters, namely significant wave height \( (H_s) \) and zero-up crossing period \( (T_z) \). The spectrum can be represented in the JONSWAP spectrum. From data collected at the Joint North Sea Wave Observation Project or simply JONSWAP, Hasselmann found that there was an additional factor in the previously developed spectrum, namely Pierson-Moskowitz. Thus, the JONSWAP spectrum is the Pierson-Moskowitz spectrum multiplied by the peak enhancement factor \( \gamma_r \) [8]. The Pierson-Moskowitz spectrum can be seen in equation 12 below [9].

\[ S(\omega) = \frac{H_s^2}{4\pi} \left(\frac{2\pi}{T_z}\right) \omega^{-5} \exp \left[-\frac{1}{\pi} \left(\frac{2\pi}{T_z}\right)^4 \omega^{-4}\right] \]  

Where \( S(\omega) \) is the Pierson-Moskowitz wave spectrum in \( \text{m}^2/\text{rad/s} \), \( H_s \) is the significant wave height in meters, \( T_z \) is the zero-up crossing period in seconds, and \( \omega \) is the wave frequency in \( \text{rad/s} \). Then Pierson-Moskowitz is given a curve in the wave frequency function.

Recently, JONSWAP spectral formulations are widely used in the design and analysis of offshore structures operated in Indonesia. However, from some studies, it is recommended that Indonesian waters use smaller parameters, around 2.0 to 2.5. In essence, this is to reduce the dominance of energy contributed by certain wave frequencies only [7]. This processing can be seen in equation 13.

\[ S(JWP) = S(\omega)^{\gamma_r} \]  

Where \( S(JWP) \) is a JONSWAP wave spectrum, \( \gamma \) is a peak enhancement factor where the value for Indonesian waters is 2 to 2.5, \( r \) is formulated with \( r = \exp \left[\frac{(\omega - \omega_0)^2}{\tau \omega_0^2}\right] \), \( \omega_0 \) is the wave peak frequency and \( \tau \) is a shape parameter with 0.07 if \( \omega \leq \omega_0 \), and 0.09 if \( \omega > \omega_0 \).
From Figure 6 JONSWAP Wave spectrum with zero up crossing period of 3.5 seconds, with variations in wave height of 0.5 and 1.0 meters. It can be seen from the graph that the spectral density for waves with a height of 1.0 meter is greater than the wave height of 0.5 meters, this makes sense because the energy generated by the waves will increase as the wave height gets higher. In the graph, it is also shown that a wave with zero up crossing 3.5 seconds has the greatest energy at a wave frequency between 1.0 rad/s to 1.6 rad/s so it is possible that if there is a ship operating at that wave frequency it has the potential to have sufficient motion response. And it can also be seen that with small wave frequencies and high wave frequencies the spectral density has a fairly small value.

3.2.3. Response Spectra
Effect of hydrodynamic interaction on the added mass, damping potential, and the external force in analyzing the response of buildings floating on a regular wave. The response of marine buildings to random waves is to transform the wave spectrum into a response spectrum. The response spectrum is the energy density response to the structure due to wave loads. It can be formulated as follows [7]:

\[ S_{\xi r}(\omega) = [RAO(\omega)]^2 \times S_\xi(\omega) \]  

Where \( S_{\xi r}(\omega) \) is response spectra in m\(^2\)/s, \( S_\xi(\omega) \) is wave spectra in m\(^2\)/s and \( \omega \) is wave frequency in rad/s.

4. Results and Discussion
Ship motion obtained from the CFD simulation results is represented in the transfer function or RAO. Ship motion which is analyzed is the heave translation motion and the rotational motion of pitch and roll. The simulation is carried out at a speed of 0 knots up to a speed of 20 knots which is the speed of operation of a rescue boat. When the ship is moving in wave sea conditions, the ship will get an external force from the waves which cause translational or rotational movements due to the response of external forces due to waves [10]. The response from the ship will vary depending on the magnitude of the wave frequency and wave height. RAO describes the response from the ship due to differences in wave frequency received by the ship.
4.1. Rescue Boat Ship Motion RAO

Figure 7 shows the response of the rescue boat first hull model heave motion in a function of wave frequency. It can be seen from the graph that the highest response to heave motion occurs at a vessel speed of 20 knots with a wave frequency of between 1.5 rad/s to 2.5 rad/s.

As the ship speed increases, the motion peak frequency of the ship's response will shift to a low wave frequency and the heave response value is also higher, this is because at high speed the hydrodynamic lift is the dominant force so that the higher the speed of the ship, the greater the ship's lifting force which causes heave response will be higher [11]. It can be seen at a higher frequency, increasing the speed of the vessel results in smaller motions.
Figure 8 show the roll response on the ship. It can be seen from the graph, that the response of the ship's roll will increase as the speed of the ship's operation increases, and the response will be very high at a wave frequency of 2 rad/s to 3.5 rad/s for hull model 3. In contrast to the case of heave motion which experiences a shift in peak frequency with increasing speed, heave motion does not experience a shift in peak frequency. Hull's third model has a very different response compared to other prototype models, with a very large roll response. Meanwhile, hull model 1 and hull model 2 have almost the same tendency for roll motion behaviour, but hull model 2 has a higher roll response, especially on high-frequency waves.
Figure 9 shows the ship pitch response due to variations in wave frequency. It can be seen from the graph, that the pitch response has a trend similar to that of heave motion whereas the speed increases, the response will increase and there will be a shift in the peak frequency towards low frequency waves [11]. However, there is another thing that is different, namely in a stationary condition the ship experiences a high pitch response where the pitch response at rest exceeds the response of the ship when traveling at a speed of 20 knots and occurs at a fairly high wave frequency. Also, there is a difference in the pitch attitude tendency at a speed of 5 knots where at this speed the ship has a large response at low frequencies, namely between 0.5 rad/s to 1.5 rad/s. Overall the ship will experience a high pitch response if it operates at a wave frequency of 1.5 rad/s to 2.5 rad/s.

4.2. Rescue Boat Motion Response

Motion response is obtained by using equation 12, namely by multiplying the RAO square with the wave spectrum to get the motion spectrum response from the ship. Then statistical analysis was
performed to obtain the Root Mean Square (RMS) motion of each ship's motion mode, the ship's heave, roll, and pitch. Ship motion RMS is obtained using equation 15 below [12]:

\[ RMS = \sqrt{m_0} \] (15)

Where \( m_0 \) is the area under the spectrum response curve obtained using numerical calculations. The area under the curve can be formulated in the following equation 16 below [12]:

\[ m_0 = \int_0^\infty \omega \psi_0 S_\eta d\omega \] (16)

Therefore, from the formula above, the ship's response is obtained for the three modes of motion for each operating speed, which is shown in Figure 10, Figure 11 and Figure 12. Motion simulation is performed using regular waves with the characteristics of zero up crossing period of 3.5 seconds and a wave amplitude of 0.5 meters and 1.0 meters.

It can be seen in Figure 10 that the heave motion response in head sea condition will increase as the ship's speed increases, this is because when the ship is traveling at high speed, the hydrodynamic lift will increase in proportion to the square of the ship's speed [3]. Besides, it can also be seen that at a speed of 5 knots there is a difference in trend where there is a heave response which is almost the same as the heave response at a speed of 14 knots so that it can be concluded that if the ship operates at low speed, especially the operating speed of 5 knots and the operation area is very wavy it is dangerous to the ship and needs to be avoided. It can also be seen that the first hull model has a fairly good heave performance where the heave response value at speeds of 8 to 17 knots is quite small and increases significantly at speeds of 20 knots. However, overall heave performance, the heave performance of the first hull model is better than the heave performance of other hull models.

Figure 10 shows the roll motion response for each model of the rescue boat hull in a function of operating speed with beam sea conditions. It can be seen from the graph the first hull model and the second hull model have a good roll response. Where the response to the 0.5-meter wave amplitude ranges an average of 1.6 degrees to 2.4 degrees. While the third hull model has a roll response that is very extreme and dangerous, it can be seen at rest condition, the ship experiences an extreme roll
response and along with the increasing speed of the ship the roll response decreases, but the decrease in roll response is still classified as extreme conditions because the wave amplitude is 0.5 meters. with a 20 knots speed of the third hull, the model has a roll response of 7.4 degrees, and the ship's roll response will increase the higher the wave amplitude increases. Therefore, from the results of the analysis, it is concluded that the smallest roll response was experienced by the first hull model with an average roll value of 1.6 degrees at a wave amplitude of 0.5 meters and an average of 3.2 degrees at a wave amplitude of 1.0 meter.

![Roll Response on Hs = 0.5 m](image1)

**Figure 11** Rescue Boat Roll Response RMS on Beam Sea (90°) with 0.5 meter and 1.0 meter Wave Amplitude.

![Roll Response on Hs = 1.0 m](image2)

(a) Roll Response on Hs = 0.5 m  
(b) Roll Response on Hs = 1.0 m

![Pitch Response on Hs = 0.5 m](image3)

(a) Pitch Response on Hs = 0.5 m  
(b) Pitch Response on Hs = 1.0 m

**Figure 12** Rescue Boat Pitch Response RMS on Head Sea (180°) with 0.5 meter and 1.0 meter Wave Amplitude.
Figure 12 shows the pitch motion response of a rescue boat model in the operating area with a wave amplitude of 0.5 and 1 meter in the function of the ship's operating speed. It can be seen from the graph, that the pitch motion has the same trend as the heave motion response whereas the ship's speed increases, the pitch motion will be higher. This is also due to the additional hydrodynamic lift force of the ship which causes an increase in the length of the ship. Extreme conditions also occur at speeds of 5 knots and speeds of 0 knots or rest condition. It can be seen the pitch motion at low speed is quite high and exceeds the pitch response at high speed so that it is very dangerous for the ship to operate at a low speed in rough sea conditions. And second hull model has the smallest pitch response where at a speed of 8 knots to 17 knots the pitch response is smaller than other ship models. So, it can be concluded that the best pitch response is experienced by ships with the second hull model.

5. Conclusion
Three high-speed craft hull models have been developed which will be used as hull models for rescue boats. The three-boat model has different hull shape characteristics so that they have different hydrodynamic performance, especially the seakeeping performance. So that the seakeeping performance analysis of the three hull models of the rescue boat was carried out using Computational Fluid Dynamics (CFD). The three-dimensional diffraction panel method is used to predict the motion behaviour of rescue boats operating at high speeds with operating speeds of up to 20 knots. The three hull models are simulated with two variations of the wave amplitude, the wave amplitude of 0.5 and 1.0 meter. From the simulation results, several things can be concluded regarding the motion behaviour of the three hull models.

1. As the speed of the ship increases, there will be a shift in the peak frequency of the heave to low-frequency waves as shown in Figure 7.
2. The three ship models have a very large pitch response at rest which can be seen in Figure 9. This is because when the ship is at rest the ship does not provide resistance to the load given by waves, it becomes different if the ship is in a moving condition the ship has kinetic energy when the ship is moving which is still able to absorb the load due to waves.
3. The heave motion response will increase with increasing ship speed. This occurs due to the increase in hydrodynamic lift, whereas the ship's speed increases, the hydrodynamic lift will increase which is directly proportional to the square of the ship's speed.
4. Roll motion will be very dominant in beam sea conditions. In beam sea conditions, the roll motion does not experience significant changes in the first and second hull models even though the ship's operating speed increases. In contrast to the third hull model where the roll motion will decrease as the speed of the ship increases, it is estimated that this is due to differences in the shape of the hull and the characteristics of the different hulls between the three-ship models.
5. The first ship model performed better for heave and roll motion than the other two models. Meanwhile, the second hull model has the best pitch response compared to other hull models. The best performance is chosen based on the response value of the three modes of motion with the smallest value. In this study, the first hull model was selected as the model with the best seakeeping performance.

The author realizes that there are still many deficiencies in research and in writing this paper, therefore to be able to provide development for future research, the author wants to provide some suggestions regarding research development. It would be better if the simulation is carried out using irregular short crest waves rather than using irregular long crest waves as the author has done, this is done to obtain simulations that are almost the same as the actual conditions. Also, the motion caused by the ship's maneuvering at high speed needs to be done because the ship's maneuvering at high speed is a high-speed craft operation that is very dangerous and has the potential to cause accidents.

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