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The Stability and Seakeeping Analysis of Hospital Ship Design in Karimunjawa Waters

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Abstract

An ambulance ship design is needed to facilitate an emergency in the Karimunjawa Islands. This research presents the simulations of its characteristics adapted to Karimunjawa waters. The design within 8 m length, 2.2 m width, 1.1 m height, and 0.37 m draft height were analyzed for stability and seakeeping. The equilibrium and strip theory analyses were applied by Maxsurf Stability and Maxsurf Motion, referring to IMO HSC Code 2000 Annex 8 and Seakeeping Criteria for Military Ships. Several parameters, such as load, speed, significant wave height, and direction, are determined. The results show that the stability of the loads is acceptable at 100%, 50%, and 25%. However, the seakeeping at 23 knots and the diagonal wave direction of significant wave height is unacceptable.

1. Introduction

Karimunjawa sub-district is one of 22 islands in Jepara that is 90 km away [1]. Karimunjawa has higher challenges and limitations, and the level of facilities and transportation access should be prioritized. Emergency patients who must be referred quickly to the main hospital (Jepara Regency) can only use passenger ships. An ambulance ship is needed to serve emergencies on the island.

To achieve optimal operations, ambulance ships must be able to operate in various conditions, including a sea state. It is defined by integrating significant wave height, wave period, wave spectra, and others. Its characteristics represent the input to design and ship criteria [2]. Varying sea states pose a challenge to ship operations. The wave height of the transition season I and the east season can reach 1.13 meters with a period of 5.56 seconds [3]. Certain conditions, such as heavy rain and high waves, make ships unable to operate.

The importance of designing ships that suit the conditions of Karimunjawa waters is the problem formulation that must be resolved. The ship's capability, namely in terms of stability, is essential to following the rules of IMO Resolution 267 (Adoption of the international code on intact stability) [4]. On the other hand, the influence of waves in Karimunjawa waters, identified with the ship's inclination ability, is also considered when designing [5]. Thus, the implementation of this research includes planning the design of an ambulance ship, which is supported by numerical studies. Then, stability and seakeeping software was used to conduct the equilibrium and strip theory analysis within several load conditions.

2. Methods

The research method used is a case study of ship design and analysis using numerical simulation such as Equilibrium for stability and Strip Theory for seakeeping. Equilibrium is one of the performance characteristics of a ship, and its items include Longitudinal Metacentric, Radius (BMt), Height (GMt), and Moment to change trim 1 cm [6]. Equilibrium will have an impact along with changes in width (B), water load (T), block coefficient (Cb), and displacement [7]. In addition, equilibrium conditions must be met by the ship after experiencing damage by damaged stability standards [8]. Then, the strip theory is a numerical estimation method in 2D form that can be extended to 3D with good results between model tests and full-scale trials. This method assumes several items, such as the ship's length being much greater than the beam or draft, the beam being much less than the wavelength, ship motions being small and linear concerning wave amplitude, etc [7].

Determining the primary dimension of ambulance ship design involves considering evacuation needs and the environment [9]. Using linear regression, it is obtained within 8 m length, 2.2 m width, 1.1 m height, and 0.37 m draft height.

Furthermore, a planing hull is applied to the water ambulance with a dead rise of 15^o, which aims to increase stability and minimize drag [10]. Additionally, adding chines to the hull was also carried out to reduce the roll-damping effect as speed increases so that transverse stability is good at high speeds [7].

Based on an approach to the primary size of comparison ships of similar size and to minimize suboptimal stability and ship movement when simulated, the design accommodates six passengers, including patients, health workers/nurses, and crew members, and 23-knot speed. The design of the water ambulance line plan for Karimunjawa Waters can be seen in Figure 1.

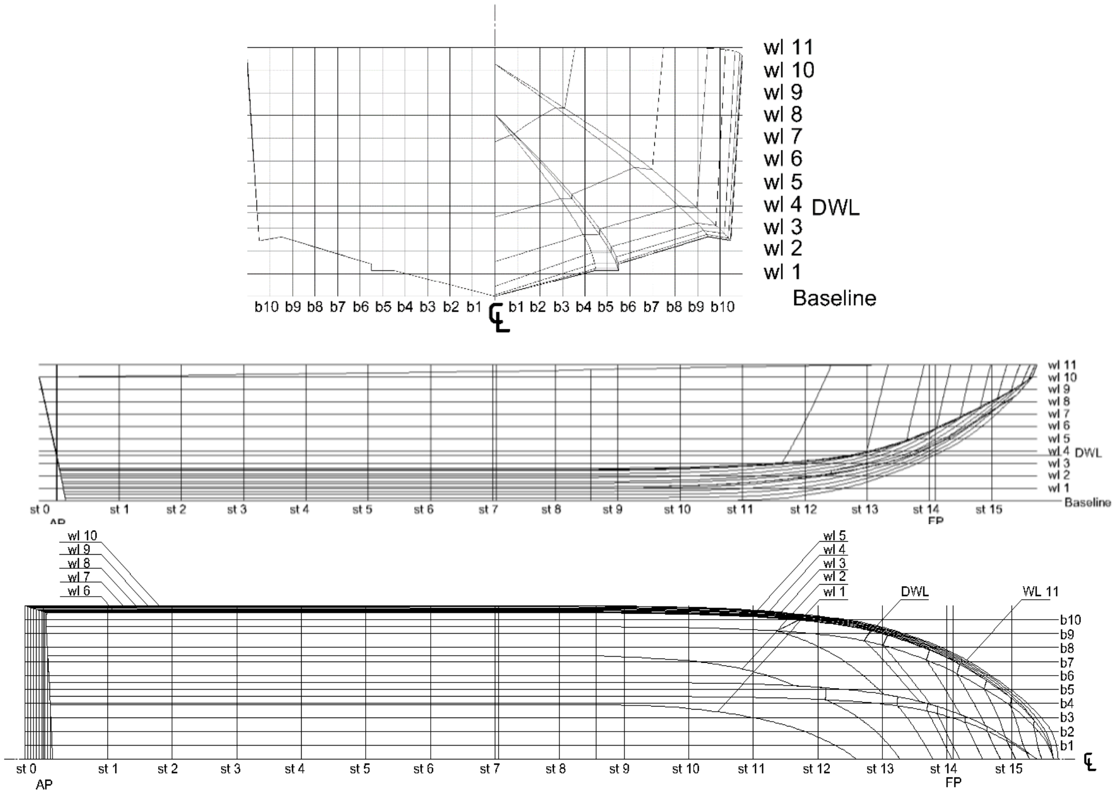


Figure 1. Ambulance water lines plan

Hydrostatic data for the water ambulance model can be seen in Table 1.

Table 1. Hydrostatic data of water ambulance

Criteria	**Value**	**Unit**
Displacement Model	2.410	ton
Volume Displacement	2.350	m^3
Wetted Surface Area	15.23	m^2
Length Water Line	6.985	m
Longitudinal Centre Buoyancy	3.290	m
Longitudinal Centre Floatation	3.350	m
Vertical Centre Bouyancy	0.250	m
Keel to Buoyancy	0.250	m

Table 2. Displacement estimation

Load	**Value**	**Unit**
6 Persons	0.600	ton
Baggage	0.120	ton
Medical Equipment	0.145	ton
Fuel Oil (Estimation)	0.100	ton
Fresh Water (Estimation)	0.120	ton
DWT	1.084	ton
Displacement	1.626	ton

$$Fn = (Vs \times 0.514)/\sqrt{((g \times LWL))} \quad (1)$$

Fn = Froude Number
g = Gravity (m/s^2)
LWL = Length Water Line (m)

Design validation is done by correcting the difference between the estimate and model displacement. The correction results show a margin error value of 0.482%. Then, the hull type with a Froude Number value, which results in 1.41, can also be concluded as a planning hull type due to Fn > 1.

Analysis of stability includes determining the position of stability, such as GM and GZ [8], sway period [9], and heel moments [10]. The stability analysis in this research refers to the IMO HSC Code 2000 Annex 8 regulations because it has provisions for calculating stability in high-speed craft conditions. The criteria for this regulation can be seen in Table 2.

$$GM = KB + BM - KG \quad (2)$$

GM = Metacentric height (m)
KB = Vertical distance between keel and center of buoyancy (m)
BM = Vertical distance between center of buoyancy and metacentre (m)

$$GZ = GM . Sin\ \varphi \quad (3)$$

GZ = Righting arm (m)
ϕ = Angle of heels

$$\Theta = \frac{2.C.B}{\sqrt{GM}} \quad (4)$$

ϴ = Heel period (s)
C = 0,373+0,023(B/T)-0,043(L/100)
B = Width (m)
GM = Metacentric height (m)

$$M = \Delta\ x\ GZ \quad (5)$$

which:
M = Heel moment
∆ = Displacement (ton)
GZ = Righting arm (m)

Table 3. IMO criteria HSC Code 2000 Annex 8 [11]

Code	Criteria	Value	Unit
HSC 2000 Annex 8 Monohull Intact	1.1. Weather criterion from IMO A.749(18)		
	The angle of the steady heel shall not be greater than (<=)	16.0	deg
	The angle of steady heel / Marginline immersion angle shall be less than (<)	80.0	%
	Area ½ shall not be less than (>=)	100.0	%
	1.2. Area 0 to 30 or GZ max	3.151	m.deg
	1.3. Area 30 to 40	1.719	m.deg
	1.4. Max GZ at 30 or greater	0.200	m
	1.5. Angle of maximum GZ	15.0	Deg
	1.6. Initial GMt	0.25	m

Data processing analysis of ship seakeeping using Maxsurf motions software. The analytical method, strip theory, is used to study aspects of heave, roll, and pitch. The choice of strip theory was based on limited validity tests, so the analysis setup stage was still early. The regulatory approach is based on external factors such as the height and wave period of Karimunjawa Waters. To produce seakeeping values, inputs and systems need to be determined, including the condition of the Karimunjawa Waters, as well as the characteristics of the water ambulance model. Analysis of seakeeping parameters, including wave spectrum, significant wave height, and wave period, are also determined.

Response Amplitude Operator (RAO) is the amplitude ratio between movement and wave in length and radian units [12]. Movement characteristics, which refer to wave frequency, ship length, and gravity, are among the research topics. The non-dimensional response pattern in this design can represent whether it is at a low frequency (sub-critical) or a high frequency (critical). The JONSWAP (Joint North Sea Wave Project) method results from wave research in the waters of the North Sea, which is used in calculating the wave spectrum in this research. Based on the form of waters in Indonesia, which are closed waters [13]. RMS is a standard deviation that aims to produce random wave characteristic values and the wave spectrum. Apart from that, one of the criteria for seakeeping is based on the Seakeeping Criteria for Military Ships, which is the analysis criteria in this research [14].

$$RAO = \frac{\zeta_{k0}}{\zeta_0} \quad (6)$$

$$S_\zeta(\omega) = \alpha g^2 \omega^{-5} exp\left\{-1.25.\left(\frac{\omega}{\omega_0}\right)^{-4}\right\} \gamma^{exp\left\{-\left(\frac{(\omega-\omega_0)^2}{2\tau{\omega_0}^2}\right)\right\}} \quad (7)$$

which:
α = $0.076\ (X_0)^{-0.22}$
X_0 = $gX/{U_w}^2$
X = Fetch distance
U_w = Wind velocity

γ = High (peakedness) parameter (1.0 until 7.0)
τ = Shape parameter

Table 4. seakeeping criteria for military ships

No	General Criteria
1.	12° Single amplitude average roll [13]
2.	3° Single amplitude average pitch [13]
3.	Significant heave acceleration ≤ 0.4g (no people working on deck) [15]
4.	Significant heave acceleration ≤ 0.2g (people working on deck) [15]

The simulation uses stability software to determine the range of heel angles, trim, load case, and tank definition. The load (load case) specified as a variable can be seen in Table 4 below. The simulations use motion software to determine speed, height, and heading, as in Table 5 below.

Table 5. Stability parameters

Type	Load Case 1	Load Case 2	Load Case 3
Fuel Oil (FO)	100%	50%	25%
Fresh Water (FW)	100%	50%	25%
Patient	2 persons	1 person	-
Nurse	2 persons	1 person	-
Crew	2 persons	2 persons	2 persons

Table 6. Seakeeping parameters

Load Case	Description
Speed	19; 21; 23 knots
Wave height	(Hs 0.5); (Hs 1); (Hs 1.5)
Wave heading	(0°, 45°, 90°, 135°, 180°)

3. Results and Discussion

3.1. Ship Stability

The analysis results of the three load cases are displayed in the form of a righting arm (GZ) curve in Figure 2. It can be seen that load case 1 produces a righting arm (GZ) value of 0.304 meters at 44.1°, load case 2 is 0.335 meters at 43.2°, and load case 3 is 0.337 meters at 43.2°. Apart from that, the GM value in load case 1 is 1.26 meters, load case 2 is 1.46 meters, and load case 3 is 1.68 meters. The phenomenon shows that the smaller the passenger load composition, the higher the value of both GZ and GM. This result happened due to the ship's total weight, which more weight lowers the GZ and GM; this also affected the back-to-keel condition's capability [2].

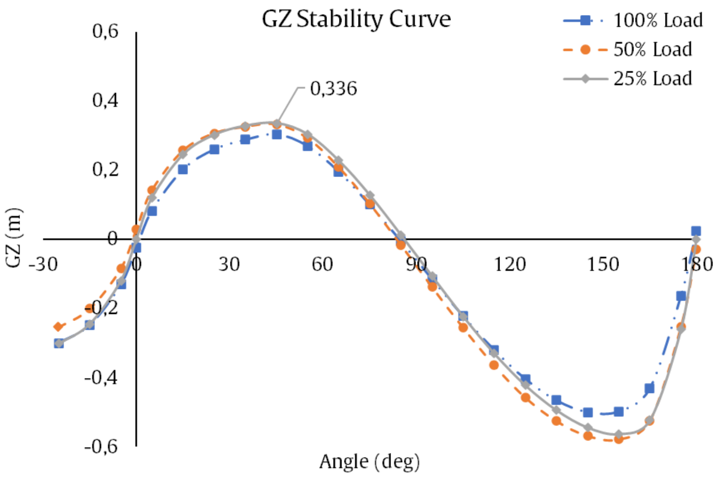


Figure 2. GZ Stability Curve

Table 7. HSC 2000 Annex 8 Monohull Intact

Code	Criteria	Value	Units	Load Case 1	Load Case 2	Load Case 3	Status
HSC 2000 Annex 8 Monohull. Intact	1.1 Weather criterion from IMO A.749(18)						
	The angle of steady heel shall not be greater than (<=)	16	deg	3.5	1.40	3.1	Pass
	Angle of steady heel / Marginline immersion angle shall be less than (<)	80	%	10.39	3.73	7.55	Pass

Area1 / Area2 shall not be less than (>=)	100	%	114.2	135.2	101.6	Pass
1.2 Area 0 to 30 or GZmax	3.151	m.deg	5.34	6.93	6.55	Pass
1.3 Area 30 to 40	1.719	m.deg	2.87	3.25	3.27	Pass
1.4 Max GZ at 30 or greater	0.2	m	0.30	0.33	0.33	Pass
1.5 Angle of maximum GZ	15	deg	44.1	43.2	43.2	Pass
1.6 Initial GMt	0.15	m	1.26	1.46	1.68	Pass

Changes in the composition of the load distribution on the ship will impact changes such as the point of gravity (G) [16]. The principle is that the location of the end of gravity will increase as the load or weight of the ship above increases, so the gravity distance to the metacentre (GM) will become smaller. A smaller GM will impact a smaller GZ value, which will also have a more negligible impact on the ship's ability or moment to return to its original position [2]. Additionally, placing the cargo in the lower or upper position also affects the stability of the ship, where the closer it is to the keel, the better the stability [5]. It can be concluded that the above phenomenon is in line with principles related to stability [17]. The stability analysis results regarding the HSC 2000 Annex 8 Monohull Code are in Table 7. Based on the three load cases, it can be concluded that it meets the criteria for good weather, area 0 to 30, 30 to 40, maximum GZ and angle GZ, and initial GMt.

3.2. Seakeeping

An analysis of ship maneuvers, one of the aspects of suitability assessment, must be carried out to anticipate things detrimental to material and crew life [5]. Speed, wave height, and wave direction parameters have been analyzed, producing significant amplitudes. These results are presented as Root Mean Square (RMS) roll angle, RMS pitch angle, and RMS heave angle curves with several wave heights of significance (Hs). This analysis uses irregular waves from the JONSWAP wave spectrum. Figures 3, 4, and 5 show the ship's movement analysis results.

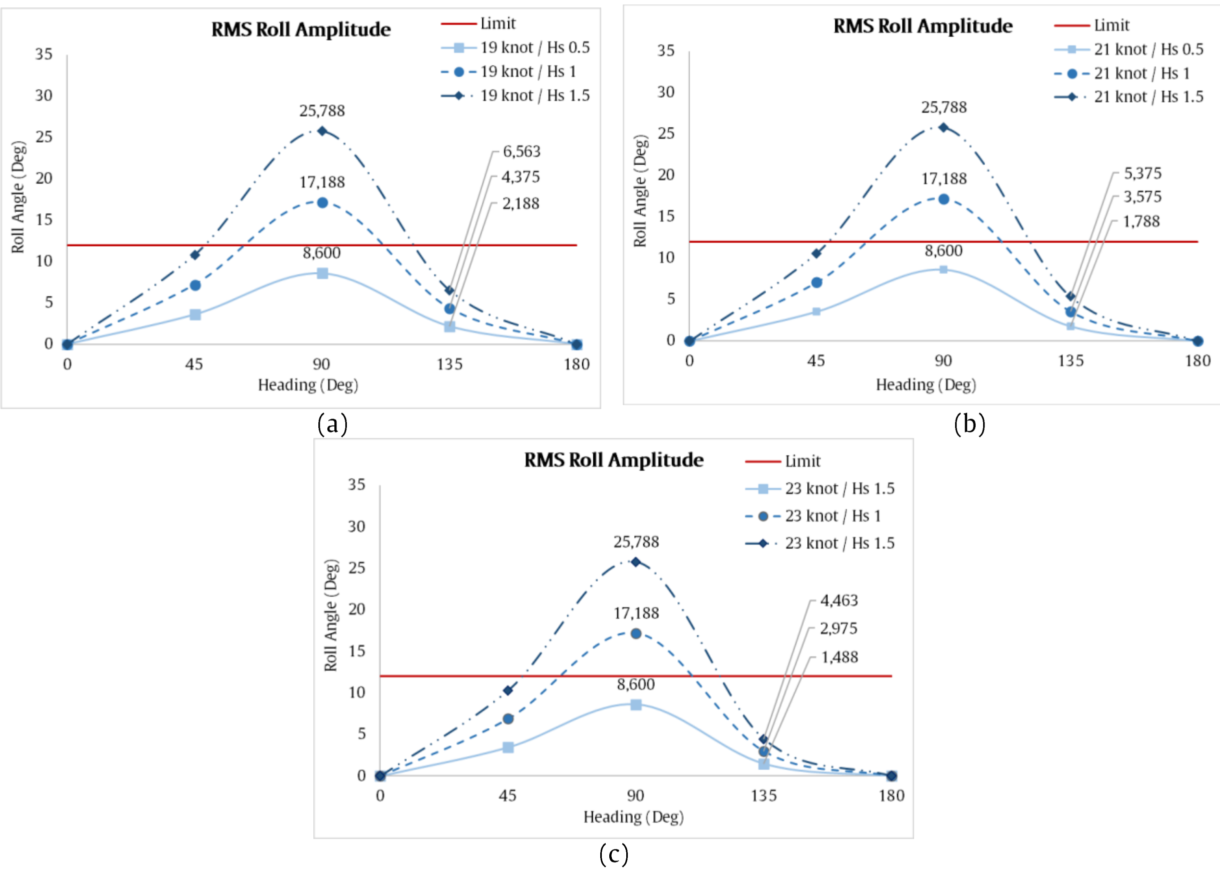
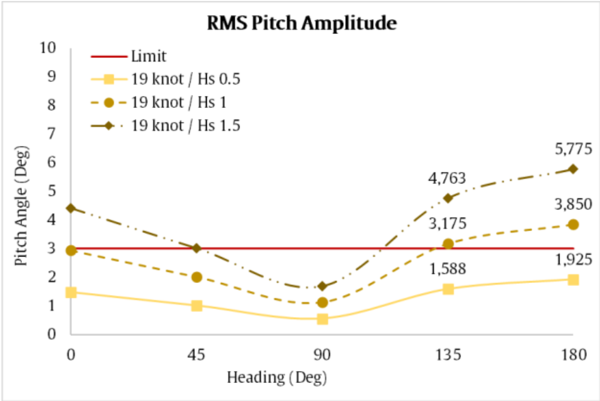
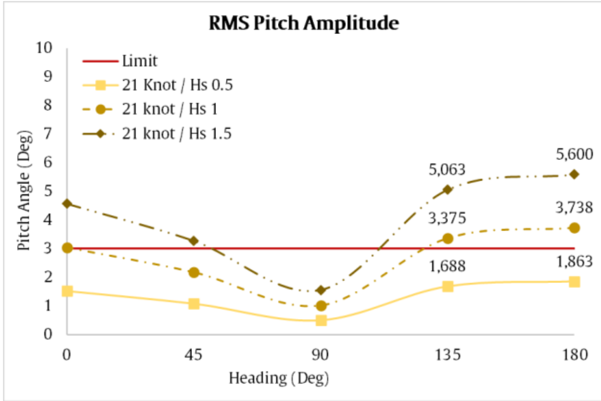
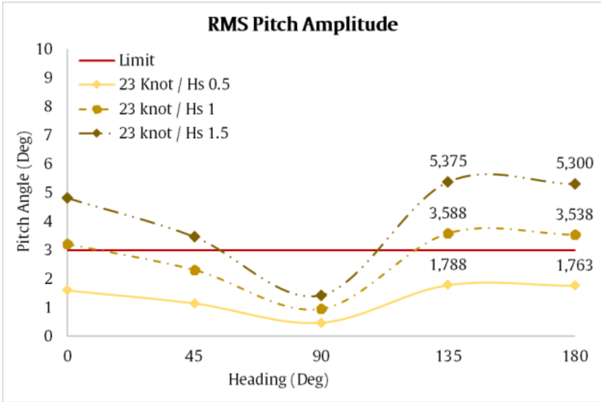


Figure 3. RMS roll amplitude a) 19 knot, b) 21 knot, c) 23 knot.



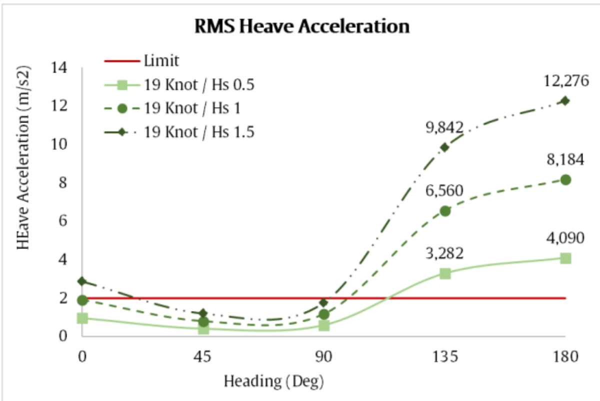


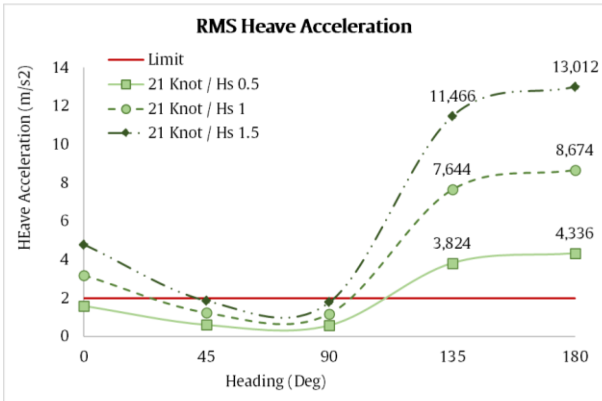
(a) (b)



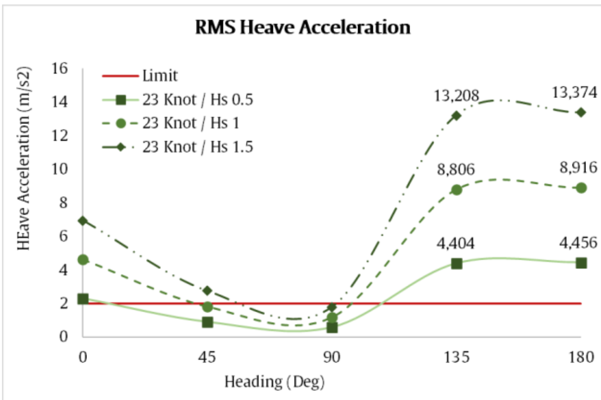
(c)

Figure 4. RMS pitch amplitude a) 19 knot, b) 21 knot, c) 23 knot.





(a) (b)



(c)

Figure 5. RMS heave acceleration a) 19 knot, b) 21 knot, c) 23 knot.

Figures 3, 4, and 5 are the results of ship seakeeping analysis at speed (19, 21, and 23 knots), significant wave height (Hs) (0.5, 1, 1.5 meters), and analysed from various angles of entry of waves coming towards the hull. Figure 3 shows the ship's roll amplitude result, with a maximum roll limit (deg) of 12 degrees according to the reference in Table 3. The higher the significant wave, the more the ship's roll degree will increase, especially the position of the substantial wave direction

(Hs) coming from the side or 90°. The results show that the ship design only meets the seakeeping criteria if the significant wave height (Hs) is 1 and 1.5 meters and the wave direction is from the side of the ship's hull or 90°. Meanwhile, the ship still meets the seakeeping criteria for wave directions from 0°, 45°, 135° and 180°, and in all conditions of significant wave height (Hs).

Figure 4 shows the result of the pitch amplitude of the ship, with a maximum pitch limit of 3 degrees, according to the reference in Table 3. The phenomenon is that the degree of inclination shows the smallest value in conditions of significant wave direction (Hs) on the side or 90°, compared to the direction of another wave. Apart from that, the higher the speed, the higher the ship's pitch will increase. So it can be concluded that the pitch amplitude is acceptable in conditions of significant wave height (Hs) of 0.5 meters (in all conditions of wave speed and direction), as well as in conditions of significant wave height (Hs) of 0.5 and 1 meter with the wave direction being diagonal or 45°.

Figure 5 shows the ship's heave acceleration result, with a maximum acceleration limit (deg) of 3 m/s^2 according to the reference in Table 3. The phenomenon occurs in very high values in wave conditions that come from the direction of 135° and 180°, while wave conditions that come from the direction of 45° and 90° show values that tend to be small. From the data above, it can be concluded that the ship's heave acceleration is accepted in conditions of significant wave height (Hs) of 0.5, 1, and 1.5 meters in all speed conditions, namely waves coming from the direction of 90°, for surges from the direction of 45° it is only accepted at significant wave height (Hs) 0.5 and 1 meter in all speed conditions.

The varying wave heading (Hs) shows significant differences in roll amplitude, pitch amplitude, and heave acceleration conditions. The increase or high frequency at a heading angle of 180 degrees means that the pitch amplitude and heave acceleration also increase. Apart from that, the increase in roll amplitude, the effect of increasing wave heading (Hs), also affects heading angles of 135 or 225 degrees. This phenomenon aligns with research conducted by previous researchers [18] [19]. The polar chart, one of the tools to prevent parametric rolling, explains that the maximum degree of rolling included in the dangerous category is the condition of waves passing over the ship at angles of 135 degrees and 225 degrees. This condition can impact instability and even accidents [20].

4. Conclusion

The ambulance ship design has been analyzed in terms of stability and seakeeping. Stability for 100% load, 50% load, and 25% load with parameters such as speed, significant wave height, and wave direction follows the HSC 2000 Annex 8 criteria Monohull Intact. However, several seakeeping conditions didn′t meet the criteria due to exceeding the maximum limit. According to this result, it can be concluded that this design can operate in such situations and consider the environment. Also, the design still needs development, for instance, trial and error in determining the primary dimension to comply with all the criteria, both stability, and seakeeping, so that this design can facilitate the emergency optimally.

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