



Analysis of Metacenter Distance and Righting Moment under Various Drafts and Heel Angles for the Barokah 04 Fishing Vessel at Class I Panjang Port Authority

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Abstract

Today's, digital image processing is widely used in various fields to facilitate humans in doing work by analyzing videos or images for use in decision making in the industrial world. The use of industrial machine technology is one of the most important factors in efforts to facilitate human work, but an industrial machine is inseparable from work failure that can hinder the production process and cause harm to the industry. This study aims to detect a failure in industrial machinery by using video data of industrial machine movements recorded using a webcam camera. Image processing technology has advanced significantly over the last decade. Its application to low-power mobile devices has attracted many research groups in relation to new contexts such as augmented reality, visual search, object recognition, etc. As general purpose computing emerges for embedded GPUs and their programming models such as OpenGL ES 2.0 and OpenCL, mobile processors will gain more parallel computing capabilities. Therefore, adapting these advances to accelerate mobile image processing algorithms has become a hot topic. In this paper, our interest is based on a review of the current challenging tasks associated with mobile image processing using serial and parallel computing in several new application contexts.

Keyword: Draft, Fishing Vessel, Heel Angle, Metacenter, Righting Moment





INTRODUCTION

Traditional fishing vessels have been used by coastal communities for centuries to catch fish and other marine resources. These vessels are an integral part of the livelihoods of fishers, who depend on marine resources for sustenance and economic activity (Soedibjo, 2019; KSOP Kelas I Panjang, 2024). Typically, traditional fishing boats are constructed from natural materials such as wood or bamboo, which are readily available in the local environment (Linton, 2010; Wisby, 2007).

The stability of a vessel is a critical factor in ensuring safe operations. Ship stability refers to a vessel's ability to return to an upright position after being disturbed by external forces such as waves or wind (Froude, 1877; Hearn, 2014). A stable vessel minimizes the risk of capsizing, which could be fatal for fishers and negatively impact their catch (Ross & Wilson, 2002; Gade, 2005). In this context, the Metacenter (M) is a key point indicating the balance of the vessel relative to its tilt. The location of the Metacenter and its distance from the vessel's center of gravity play a crucial role in determining stability, particularly when the boat is inclined due to external factors (Kinnas & Patel, 2008; Riksman, 2016).

The draft of a vessel, defined as the vertical distance from the waterline to the bottom of the hull, affects the distribution of weight and the position of the Metacenter, thereby influencing stability (Imai & Kato, 2012; Verma & Ranjan, 2018; Molyneux, 2004). Vessels with deeper drafts generally exhibit higher stability due to the increased water volume, though this is contingent upon the vessel's design and usage.

The heel angle, or the angular tilt of the vessel relative to the horizontal plane when subjected to external forces, can alter the position of the Metacenter and affect the vessel's righting capability (Paik & Wang, 2007; IMO, 2017). For fishing boats, variations in heel angle may result from uneven deck loads or environmental influences such as waves and wind.

The Barokah 04 fishing vessel represents one of the vessels measured and analyzed in this study (KSOP Kelas I Panjang, 2024). As this type of vessel is commonly used for nearshore fishing, it is essential to ensure adequate stability under various sea conditions. Considering that fishing boats often operate in shallow waters and are susceptible to changing wave patterns, analyzing the stability characteristics of such vessels is particularly relevant for safety and operational efficiency (Linton, 2010; Soedibjo, 2019; Wisby, 2007).

The objective of this study is to analyze how the distance of the Metacenter and the righting moment of the vessel change under varying draft conditions and heel angles. This analysis aims to understand how operational conditions affect the stability and safety of the Barokah 04 fishing vessel, while providing recommendations for design improvements or



operational procedures to maintain stability during operations. By conducting this analysis, fishers and relevant stakeholders can gain insights into the influence of technical factors, such as draft and heel angle, on vessel stability.

Furthermore, this study is expected to contribute to the reduction of accidents caused by stability issues, enhancing both operational efficiency and safety at sea. It holds significant importance in optimizing the safety of fishing vessels operating in coastal areas. Proper vessel stability helps minimize the risk of capsizing or loss of balance while sailing, thereby increasing the safety level for fishers who operate these boats. In addition, the research supports the development of environmentally friendly and sustainable local shipbuilding technologies and contributes to the advancement of Indonesia's fisheries industry.

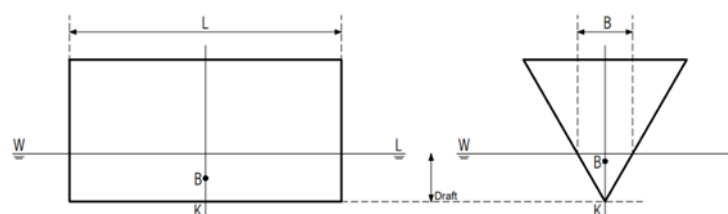
Overall, this study is not only crucial for the operation of the Barokah 04 fishing vessel but also serves to improve safety standards for fishing vessels in general, potentially creating a positive impact on the sustainability of the fishing sector in Indonesia.

METHOD

The study employs a descriptive quantitative method with a case study approach on the Barokah 04 fishing vessel. The research aims to calculate, analyze, and describe the relationship between changes in draft, heel angle, the Metacenter distance (GM), and the righting moment. Data collection methods include observation, interviews, and documentation.

The collected data were analyzed using the following steps:

The calculation of the Center of Buoyancy (KB) represents the center of gravity of the portion of the vessel submerged in water (draft of the vessel).



Gambar 1. Bangunan Prisma (V)

Sumber: Raditya Danu



$$KB = \frac{2}{3} \text{ draft}$$

Description of Variables:

KB = vertical distance from the keel (base line of the vessel) to the center of buoyancy (B).

T (draft) = vertical distance from the waterline to the keel.

Function of the Formula:

1. This formula is used to determine the position of the center of buoyancy (B) for vessels with simple hull shapes, such as triangular or V-shaped prisms.
2. In floating structures with symmetrical hulls like a triangular prism, the submerged volume distribution is uneven.
3. Consequently, the center of buoyancy does not lie at the midpoint of the draft ($\frac{1}{2} T$), but slightly lower, approximately **$\frac{2}{3}$ of the draft (T)**.

The analysis of KB, in combination with heel angle and Metacenter distance, allows for a precise assessment of the vessel's stability and the righting moment under various sea conditions. These calculations provide critical insights for operational safety, design evaluation, and recommendations to maintain stability during fishing operations.

RESULTS AND DISCUSSION

The Class I Port Authority (KSOP Kelas I) functions as a technical implementing unit under the Directorate General of Sea Transportation, Ministry of Transportation. It is responsible for overseeing and managing commercial port operations, with a particular focus on Panjang Port. This institution plays a critical role in ensuring maritime safety, regulating port activities, and supporting local fisheries and shipping industries. By providing administrative oversight and technical guidance, KSOP Kelas I helps maintain orderly and efficient operations, which are essential for sustaining economic activity in the coastal region.

The AN Barokah 04 fishing vessel is a small-scale catch vessel designed to support coastal fisheries, particularly for small- to medium-scale operations. Construction began with the keel laying on January 8, 2020, and the vessel was officially launched on August 18, 2020. With an overall length (LOA) of 12.20 meters and a beam of 3.84 meters, the vessel falls within the small vessel category, making it highly suitable for nearshore operations. These dimensions provide sufficient stability and effective maneuverability, ensuring that the vessel can conduct fishing



activities safely and efficiently. Its design reflects both operational practicality and the safety requirements necessary for local coastal fisheries.



Figure 1. AN Barokah 04 Fishing Vessel
Source: Class I Panjang Port Authority (KSOP)

Table 1. Specifications of the AN Barokah 04 Fishing Vessel

Ship Name	AN Barokah 04
Ship Flag	Indonesia
Vessel Type	Fishing Vessel
Year of Construction	2020
Hull Material	Wood
Engine	Mitsubishi 120 HP
Overall Length (LOA)	12.20 meters
Beam (Width)	3.84 meters
Draft	1.30 meters
Underdeck Volume	30.05 m ³
Gross Tonnage	11
Net Tonnage	4

Sources: Data Processed (2025)

Based on the initial stability calculations (GM) at various vessel drafts, the metacentric height (GM) values ranged from a draft of 1.05 m to 1.20 m. At a draft of 1.05 m, the GM was 1.577 m; at 1.10 m, it was 1.683 m; at 1.15 m, it reached 1.721 m; and at 1.20 m, it increased to

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1.894 m. All GM values are positive, indicating that the vessel is in a stable transverse condition under the assessed draft scenarios. The results of the calculations are as follows:

For draft $T = 1,05$ m

$$\begin{aligned} \frac{B_{1,05}}{3,84} &= \frac{1,05}{1,30} \Rightarrow B_{1,05} = \frac{3,84 \times 1,05}{1,30} = 3,102 \text{ m} \\ KB &= \frac{2}{3} T = \frac{2}{3} \times 1,05 = 0,70 \text{ m} \\ BM_T &= \frac{(B_{1,05})^2}{6T} = \frac{(3,102)^2}{6 \times 1,05} = 1,527 \text{ m} \\ KM &= KB + BM_T = 0,70 + 1,527 = 2,227 \text{ m} \\ GM &= KM - KG = 2,227 - 0,65 = 1,577 \text{ m} \end{aligned}$$

Therefore, GM at draft 1,05 m is 1,577 m.

For draft $T = 1,10$ m

$$\begin{aligned} \frac{B_{1,10}}{3,84} &= \frac{1,10}{1,30} \Rightarrow B_{1,10} = \frac{3,84 \times 1,10}{1,30} = 3,249 \text{ m} \\ KB &= \frac{2}{3} T = \frac{2}{3} \times 1,10 = 0,733 \text{ m} \\ BM_T &= \frac{(B_{1,10})^2}{6T} = \frac{(3,249)^2}{6 \times 1,10} = 1,600 \text{ m} \\ KM &= KB + BM_T = 0,733 + 1,600 = 2,333 \text{ m} \\ GM &= KM - KG = 2,333 - 0,65 = 1,683 \text{ m} \end{aligned}$$

Therefore, GM at draft 1,10 m is 1,683 m.

GM Pada draft 1,10 adalah 1,683 m

Table 2. Draft and GM Calculation Results

Draft	KB(m)	BM_T (m)	KM(m)	GM(m)
1,05	0,70	1,527	2,227	1,577
1,04	0,733	1,600	2,333	1,683
1,15	0,76	1,671	2,371	1,721
1,20	0,8	1,744	2,544	1,894

Source; Data Processed (2025)

Figure 1 illustrates the relationship between the vessel draft and the corresponding metacentric height (GM) of the Barokah 04 fishing vessel. This figure is intended to provide a

visual representation of how variations in draft influence the transverse stability of the vessel under operational conditions. By plotting GM values against draft measurements, the figure allows for a clear assessment of the vessel's stability performance across different loading scenarios.

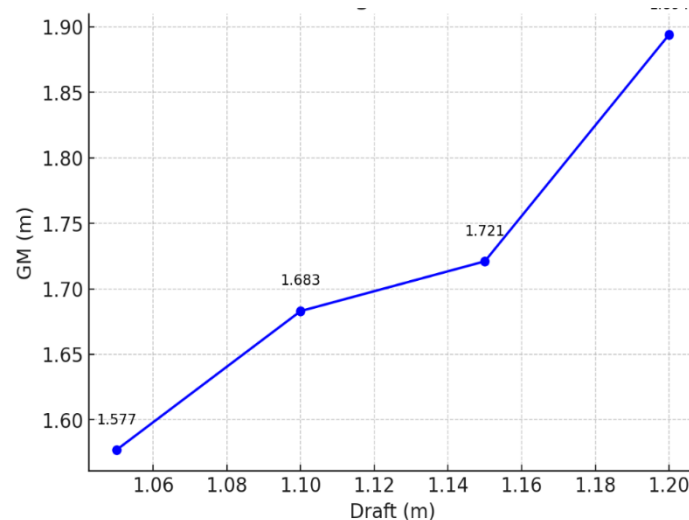


Figure 2. Draft vs GM Comparison

Based on the analysis, it can be concluded that for draft conditions ranging from 1.05 m to 1.20 m, the vessel exhibits positive GM values. This indicates that the vessel is capable of returning to its original upright position after experiencing disturbances or tilting. The progressive increase in GM values with deeper drafts suggests that the vessel's stability improves under higher loading conditions. Consequently, the vessel can be considered safe to operate within this draft range, as its initial stability is assured and it can withstand heeling forces caused by external factors such as waves, wind, or uneven deck loading. A GM value of zero, which indicates neutral stability, may occur at specific critical draft values, marking the threshold where the vessel's upright equilibrium is no longer self-restoring.

The calculation of the metacenter height (KM) using the following equation provides further insight into the vessel's stability characteristics. By evaluating KM in conjunction with GM and draft variations, it is possible to determine the conditions under which the vessel transitions from stable to neutral or potentially unstable equilibrium. This analysis is crucial for establishing safe operational limits, guiding vessel handling, and informing recommendations for load management to ensure that GM remains positive under all expected draft and



environmental conditions. Such calculations are essential for the safe operation of the vessel and for minimizing the risk of capsizing in coastal water

$$KM=KB+BM$$

$$0,65 = \frac{2}{3} T + \left(\frac{3,84^2 \times T}{1,3 \times 6} \right)$$

$$0,65 = \frac{2}{3} T + 1,89 T$$

$$0,65 = 0,6 T + 1,89 T$$

$$0,65 = 2,49 T$$

$$T = \frac{0,65}{2,49} = 0,261$$

By substituting the values $B=3.84$ m and $D=1.30$ m, the calculations indicate that the critical draft is reached at $T=0.261$ m. Under this condition, the metacentric height (GM) equals zero, meaning the center of gravity (G) aligns with the metacenter (M). In terms of stability theory, this state is referred to as neutral equilibrium. In neutral equilibrium, the vessel does not generate a righting moment when subjected to tilting. In other words, if the vessel experiences external disturbances—such as waves, wind, or shifting cargo—it will not return to an upright position and may remain at a new heel angle.

This situation is particularly hazardous in practical navigation because even minor changes in load conditions or weight distribution could result in a negative GM, placing the vessel in a state of unstable equilibrium. Such instability increases the risk of capsizing. Therefore, a draft of 0.261 m is considered critical and unsafe for operation. The vessel must not operate at this draft, and it should always sail with a draft beyond this critical value to maintain a positive GM. A positive GM indicates a sufficient righting moment to preserve vessel balance and ensure operational safety.



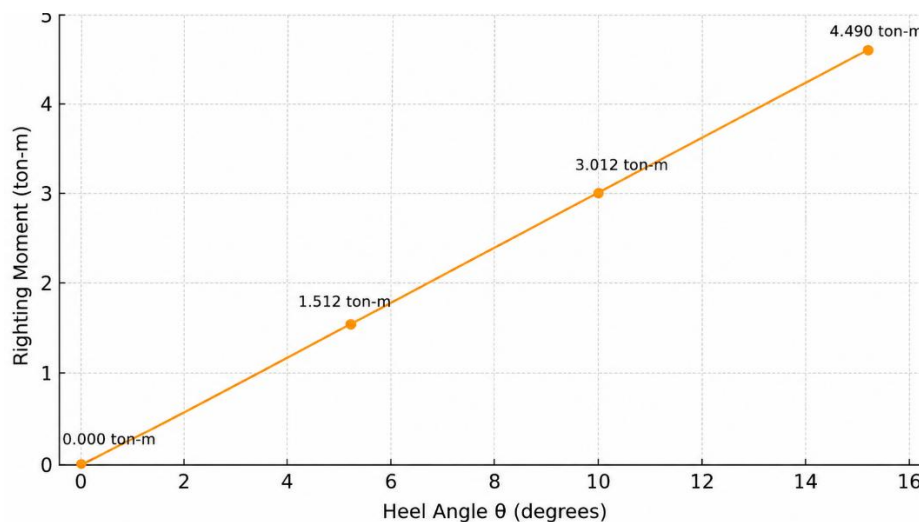


Figure 3. Righting Moment Graph (GM = 1.577 m)

Based on the calculated relationship between draft (T) and the metacentric height (GM), it was observed that GM increases as the vessel's draft increases. This trend is illustrated in Table 4.2 and Figure 4.4, where at a draft of 1.05 m, GM equals 1.577 m, and gradually rises to 1.894 m at a draft of 1.20 m. The increase in GM is attributed primarily to two factors: the rise in KB (the vertical position of the center of buoyancy) and BM (the metacentric radius) as the draft increases. Theoretically, this relationship can be expressed by the following equation:

$$GM = KM - KG \text{ dengan } KM = KB + BM$$

The value of KB is proportional to the vessel's draft (T), while BM is inversely related to the draft according to the formula $BM = \dots$. In this study, since the vessel's beam (B) in the prism model increases with the draft, the overall metacenter height (KM) rises significantly as the draft increases. With the center of gravity (KG) fixed at 0.65 m, the increase in KM results in a progressively higher GM, enhancing the vessel's stability.

Stability calculations show that GM equals zero at a draft of 0.261 m. This condition indicates that the vessel's center of gravity (G) is exactly aligned with the metacenter (M), placing the vessel in a state of neutral equilibrium. Theoretically, neutral stability means that the vessel does not generate any righting moment when it experiences tilting. If the vessel heels due to external forces, such as waves or cargo shifting, it will remain at the inclined position without any restoring force to return it to the upright orientation.



This condition is particularly hazardous because even minor disturbances can shift the vessel's balance toward a negative GM. If this occurs, the vessel enters a state of unstable equilibrium, in which it tends to increase its heel angle and may eventually capsize. Therefore, a draft of 0.261 m is considered a critical draft that must be avoided during vessel operation. This draft represents an unsafe equilibrium threshold, where even small changes in load or environmental influence can immediately compromise stability.

To ensure safe operation and maintain stability, the vessel should operate at a draft either higher or lower than this critical value, provided that GM remains positive. This analysis demonstrates the importance of critical draft assessment in vessel design and operation, as it provides essential information regarding safe stability limits for maritime activities.

CONCLUSION

The analysis indicates that the metacentric height (GM) of the vessel increases with an increasing draft, primarily due to the rise in the center of buoyancy (KB), which in turn elevates the metacenter height (KM). At small heel angles ($\leq 10^\circ$), the metacenter remains relatively constant, making GM a reliable indicator of the vessel's initial stability. However, at moderate to large heel angles ($> 10^\circ$), both BM and KM decrease due to changes in the submerged hull geometry, leading to a reduction in GM and overall stability. The GZ curve indicates that the vessel can return to an upright position up to a heel angle of 30° ; however, further analysis is required to confirm compliance with IMO IS Code standards. These findings emphasize the importance of monitoring GM and draft for safe vessel operation, ensuring stability under varying loading and environmental conditions.

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