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APPLICATION OF THE ROLLING PERIOD FORMULA IN DETERMINING METACENTRIC HEIGHT (GM) FOR SHIP STABILITY A CASE STUDY OF THE TRAINING SHIP SULTAN HASANUDDIN

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Keywords

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ABSTRACT

The Sultan Hasanuddin Training Ship of PIP Makassar was selected as the research object for this study. The study aims to analyze the stability of the ship by focusing on calculating the metacentric height (GM) value based on the moment of static stability, incorporating both manual methods and computer applications that generate GM values as indicators of seaworthiness according to the Intact Stability Code. The research method used in this study is a case study that involves descriptive, numerical, and comparative analysis of various ship parameters, including the length, width, and inside the ship, as well as other measurements required in the stability calculation. The GM calculation is carried out using the static stability moment approach and compared with the results of recording the ship's rolling period. The results show that the GM value generated from the calculation of the existing static stability moments, if deducted from the total value of the Virtual Loss of GM due to the inertia moment in the slack tanks, will produce an effective GM worth that is used as the basis for the ship stability benchmark. This research could contribute significantly to improving safety protocols and design standards in maritime operations. The benefits of this research include providing theoretical information for lecturers and cadets of PIP and commercial shipping officers, enriching teaching materials on ship construction and stability, and promoting a safety culture by offering practical information to estimate ship stability conditions before more detailed calculations are made.

INTRODUCTION

From the depths and mysteries of the ocean where humans have no strength at all, ships were made to pass through the ocean. Ships are one of the greatest human achievements ever achieved and with this achievement, the era of human exploration began in search of a new world through the sea. Since ancient times, humans have used the ocean to do trade, so it is not surprising if we say that the lifeblood of the economy in modern times like today is indeed maritime. It is implied from various statistical data that generally states that 90% of the world's goods trade is shipped by sea. According to the World Economic Forum, in 2022 60% of the total trade carried by ships was recorded in containerization with the valuation value carried by these containers reaching 14 trillion US dollars.

That is why until now, ships are still and will be the prima donna in terms of world trade, how and with what these goods are delivered, both export and import, between continents and between oceans.

As is known, the seafarer profession in the maritime world can be said to be "The most heavily regulated job in the world". Various types and types of regulations, both national and international, are summarized in one node to support shipping safety and security. IMO establishes 4 main pillars in ship operational activities that must be complied with both by ships, shipping companies and by the seafarers themselves (Ali, 2011; Baumler et al., 2021; Dalaklis, 2017; Fasoulis, 2021; Goulielmos & Anastasakos, 2005). It is known that the SOLAS (2008) Convention was agreed by IMO member countries as the first pillar that regulates safety standards related to ship construction, electrical systems, fire extinguishing, navigation equipment, other safety equipment and even to the regulation of safety and security management starting from the ship is designed and built until the ship is wrought. The second pillar is STCW (Standard Training and Certification for Watchkeeping) which regulates training and certification standards that must be possessed by everyone who will work on a ship, especially those who will carry out guard duties by referring to the size of the ship, the type of ship, the shipping area and their authority position on the ship (Manuel & Baumler, 2020; Moceiwai, 1996; Wanga, 2015). The third pillar is MARPOL which is a convention of all IMO members in the form of a commitment to maintain the marine environment so that it is maintained and all ship operational activities will not have a bad influence on the marine environment (Becker, 1997; Fitzmaurice, 2023; Karim, 2015; Lost-Sieminska, 2025; Tsimplis, 2025). The fourth pillar is a product of the ILO which is then recognized and implemented by the IMO and its member countries, namely the Maritime Labour Convention (MLC) which regulates the guarantee of the welfare of all workers in the maritime sector (Chang & Khan, 2023; Lessa, 2019; Lillie, 2008; McConnell et al., 2011; Piñeiro, 2023).

Merchant Marine Polytechnic of Makassar (PIP Makassar) as a Vocational University under Ministry of Transportation Human Resources Development Agency, takes strategic steps in an effort to meet the needs of the maritime industry and always strives to link and match the needs/demands of the industrial world and universities by bringing industries to campus which is expected to make students understand the world of work faster. From the industrial side, it is expected to reduce the costs incurred for job training and can also cut the adaptation time of new graduates in the world of work. In order to bring industries to campus, one form of support from the government is to entrust the management of a ship to PIP Makassar named the Sultan Hasanuddin Training Ship to be used as a means of education and training for cadets.

The Sultan Hasanuddin Training Ship is a ship manned by a competent and experienced crew member as a captain and crew member of commercial ships and is used by cadets to get to know the ship directly and practice related to the skills they must have when working as a young officer on commercial ships both nationally and internationally. The operational activities of the training ship are the same as other commercial ships that carry out the functions of navigation, handling and regulating cargo, ship machinery, control systems, electrical systems and ship electronics systems, maintenance and repair as well as control of ship operational activities as well as control of the safety and security of the people on board. One form of controlling ship operational activities is the control of the seaworthiness of the ship where one of the indicators is the stability of the ship. As reported by the KNKT, during 2017-2021 there were 75 shipping accidents and the results of investigations and from these incidents there were 550 fatalities due to ship accidents and 99 other injuries. Based on the results of the investigation, it was found that one of the main factors causing accidents was technical factors which accounted for 52% of the total cause of accidents. Ship stability is the most crucial technical thing for ship safety, especially when the ship sails in bad weather with many waves and wind affecting the ship. Although stability calculations are always carried out before the ship leaves the port and is one of the requirements to get a Sailing Approval Letter (SPB) from the Port Administration, in reality in the field there are still many ships that have accidents due to the influence of bad weather while sailing.

Based on this, research was carried out on the Sultan Hasanuddin PIP Makassar Training Ship to determine the formula for estimating the value of GM ships using the rolling period approach. This study aims to analyze the stability of the ship by focusing on calculating the GM value based on the moment of static stability, incorporating both manual methods and computer applications that generate GM values as indicators of seaworthiness according to the Intact Stability Code. The research was limited to empty ship conditions, considering only rolling movements in calm water and regular wave conditions. The problem formulation includes calculating the GM value and comparing the results from the static stability moment with the buoyancy period formula. The benefits of this research include providing theoretical information for lecturers and cadets of PIP Makassar and commercial shipping officers, enriching teaching materials on ship construction and stability, and promoting a safety culture by offering practical information to estimate ship stability conditions before more detailed calculations are made. Additionally, the current study reveals research gaps compared to the work by Rusi et al. (2020) by focusing primarily on technical ship stability aspects while their study addresses a broader educational framework for maritime vocational training, emphasizing the need for an integrated model that connects technical assessments with pedagogical objectives. Moreover, while the Sultan Hasanuddin study provides practical stability assessments, it lacks a comprehensive theoretical framework linking these findings to educational needs, contrasting with Rusi et al. (2020)'s emphasis on training ships' roles in enhancing maritime education, thereby indicating a gap in applying stability assessments in educational contexts. The novelty of the current research lies in its quantitative analysis of GM values and static stability moments, offering empirical data essential for maritime safety, which can inform practical training scenarios for cadets and enhance their learning experiences.

METHODS

The research method used in this study is a case study that involves descriptive, numerical, and comparative analysis of various ship parameters. The research data was obtained through direct measurements of the main dimensions of the ship, including the length, width, and inside the ship, as well as other measurements required in the stability calculation. The quantitative data collection includes information related to tank conditions, weights, and formula for the rolling period and the metacentric height (GM) of the ship. The main concept definitions used include GM, which is a measure of static stability, and Rolling Period, which indicates the time it takes for the ship to return to upright after tilting.

Data collection techniques are carried out through observation and documentation studies. Observations include direct measurements of the volume and weight of liquids in ballast tanks, fresh water, fuel, and tank conditions, while the documentation study refers to data from the Sultan Hasanuddin Training Ship Stability Booklet. This study does not use a sampling system, but takes measurements on one occasion when the ship is empty. The analysis design includes steps ranging from literature study, data collection, checking calculation results, field testing, to analize of the swing period and conclusions. In the analysis stage, the GM calculation is carried out using the static stability moment approach and compared with the results of recording the ship's rolling period.

RESULTS

Overview of the Research Location

The Sultan Hasanuddin Training Ship is one of 6 Training Ships which are sister ships owned by the Ministry of Transportation which was built in 2017 by PT. SteadFast Marine, Pontianak. This ship is designed with dimensions of Length (LOA) of 63 meters, Width (Breadth Molded) of 12 meters, Deep Molded (Deepth Molded) of 4 meters, Draft (Draft Molted) of 2 meters and a volume of 1,200 GT. As a training ship, this ship is able to carry 20 crew members (crew and captain), 4 VVIP (Super Numeric), 10 instructors and 100 cadets consisting of 80 male cadets and 20 female cadets. From the existing Ship Particular Ship and Stability Booklet, in an empty condition, Displacement KL. Sultan Hasanuddin is 898.63 with the KG value of the empty ship obtained from the stability experiment activity of 4.83 m.

Serving speed from KL. Sultan Hasanuddin is recorded at 12 knots from 2 Mitsubitshi Diesel Engine Model S6R2-T2MPTK3L main engine. The Power Output produced is 759 bKW at RPM 1406 with a fuel consumption per main engine of 217.7 liters/day. There are 3 auxiliary engines of Mitsubitshi Diesel Generator Model S6B3-T2MPTK. The Power Output produced by each generator is 355 bKW at 1500 RPM with a fuel consumption per generator of 67.5 liters/day. When operating in the port, the training ship uses the Harbour Generator Model AD 136T with a power output of 130 KVA/380V/50 Hz with a daily fuel consumption of 39 liters/day. Based on this data, the Daily Fuel Consumption when the ship is sailing with the use of 1 generator is 502.9 liters/day, while when the ship is in the Port with the use of one of the Auxiliary Engines and Harbour Generators is 106.5 liters/day.

Based on the existing Tank Capacity Plan, Sultan Hasanuddin Training Ship consists of 8 fuel tanks, 2 of which are daily tanks with a capacity of 3.49 tons each. The total capacity of fuel tanks is 183,824 m^3 or 172.03 tons for an average specific gravity of 0.85 tons/m^3.

For freshwater tanks, there are 6 tanks with a total capacity of 224.67 m^3 (tons). 1 left and right tanks of 40.69 m^3 (tons) each, 2 left and right tanks of 35.47 m^3 (tons) each, while tank 3 each of the left and right tanks has a capacity of 36.18 m^3 (tons). For ballast, there are 4 tanks with a total capacity of 83,464 m^3 or 100.88 tons with a maximum capacity of 31.79 tons Fore Peak Tank (F.P.T), 1 left and right tanks of 13.84 tons each and 2 left-right tanks of 20.71 tons each. In addition to these tanks, there are also sludge tanks and bilge storage tanks with a maximum capacity of 5.09 tons and sewage storage tanks with a maximum capacity of 3.08 tons. The total capacity of Sultan Hasanuddin Training Ship tanks~~.~~ is 510.85 tons.

Based on the results of the inclining experiment in Sultan Hasanuddin Training Ship, the light displacement is known to be 898.63 tons at the draft of 1.95 m. The height of the ship's point of gravity against the keel (KG) when the ship is empty is 4.83 m. The maximum draft of the ship (draft when loaded in Summer Draft) is 2.86 m with a displacement of 1427 tons.

Static Stability Calculation

Stability calculation of Sultan Hasanuddin Training Ship was carried out during the research was a calculation of the moment of static stability with the final value obtained being the GM value. The condition during the calculation is that the ship is empty in the sense that there is no cargo, no passengers and no ballast. Meanwhile, fuel tanks, freshwater tanks and seawage tanks, sludge tanks and bilge tanks are filled with the following data:

1) The 1st left freshwater tank was filled with 12.88 tons from a maximum capacity of 40.69 tons, the 1st right freshwater tank was filled with 12.35 tons from a maximum capacity of 40.69 tons.

2) The 2nd left freshwater tank is filled with 18.11 tons from a maximum capacity of 35.47 tons, the 2 right freshwater tank is filled with 32.04 tons from a maximum capacity of 35.47 tons.
3) The 3rd left freshwater tank is filled with 26.64 tons from a maximum capacity of 36.187 tons, the 3 right freshwater tank is filled with 26.64 tons from a maximum capacity of 36.187 tons.

The fuel tank 1 left is filled with 0.1 tons from a maximum capacity of 30.76 tons, the fuel tank 1 right is empty. The fuel tank 2 left is filled with 3.69 tons from a maximum capacity of 30.71, the fuel tank 2 right is filled with 3.49 tons from a maximum capacity of 30.71 tons. The fuel tank 3 left is filled with 0.1 tons from a maximum capacity of 21.06 tons, the fuel tank 3 right is empty. The daily fuel tank of the left is filled with 2.48 tons from the maximum capacity of 3.49 tons, the daily tank of the right fuel is filled with 2.48 tons from the maximum capacity of 3.49 tons.

All ballast tanks consisting of Fore Peak Tank, Ballast 1 Tank left-right, Ballast Tank 2 left-right are in empty condition. However, the seawage tank is filled with 1.75 tons from a maximum capacity of 3.08 tons. The sludge tank was filled with 2.55 tons from a maximum capacity of 5.09 tons and the bilge tank was filled with 1.55 tons from a maximum capacity of 5.09 tons.

From the condition of the tanks that have been described above, there is an inertia moment (Free Surface Effect) in tanks that are in a slack condition or are not fully filled or not empty at all. If the magnitude of the moment of inertia is divided by the displacement of the ship at that time, it will result in a pseudo-increase value of center of gravity height and may caused Virtual loss of GM. The GM value generated from the calculation of the existing static stability moment, if deducted from the total value of the Virtual Loss of GM due to the inertia moment in the slack tanks, will produce an effective GM value that is used as the basis for the ship's stability benchmark.

The total moment of inertia in the freshwater tank was 579.86 Ton-M with the resulting Virtual loss of GM value of 0.54 m. The total inertia moment in the fuel tank is 254.68 Ton-M with the resulting Virtual loss of GM value is 0.2 m. For Ballast Tank, Fore Peak Tank, Seawage Tank, Sludge Tank and Bildge Tank, because most of them are empty, the total inertia moment in freshwater tanks is only 2.64 Ton-M with the resulting Virtual loss of GM value considered 0. Total Virtual Loss of GM of all. Sultan Hasanuddin Training Ship tanks in the slack condition is 0.74 m, where this value will later be deducted from the GM value resulting from the calculation of the static stability moment.

The total Static Stability Moment that occurred/was generated at the time of calculation was 4,437.99 Ton-M and the ship's displacement was 1,055.71 Tons, so that the KG value resulting from dividing the total static stability moment by the ship's displacement value at that time was 4.20 m. From the draft of the average ship at the displacement, it is known that the ship's KM value is 6.66 m. So that the GM value of the ship at that time was 2.46 m which was obtained from the reduction of the KM value and the KG value of the ship produced. If the GM value is subtracted by the Virtual Loss of GM value that has been described earlier, the effective GM value of the training ship in the calculation carried out during the study is 1.72 m.

Estimated GM Value with the Ship Rolling Period Method

The calculation of the ship's rolling period is carried out when the ship is swaying (undergoing rolling) due to external forces, both waves and when the ship is swaying due to the movement of the loading rod that is lifting the load. The research data collection activity was carried out when the ship was anchored outside the pond/basin of Soekarno Hatta Port, Makassar. The ~~boat~~ swing that occurred at that time was the boat swing obtained when the ship swayed due to the waves.

From the 3 literature studies used in this writing, it was found that 2 formulas were used for the calculation of GM referring to the value of the rolling period that occurred, namely:

1) The formula, where this formula refers to IMO Assembly Resolution A 167 International Code on Intact Stability, 2008- Part A and Weather Criterion According to IMO Res. A 749 (18) and is also used in the KL Stability Booklet. Sultan Hasanuddin.

$$T_{\emptyset} = \frac{2.C.B}{\sqrt{GM}} \tag{1}$$

2) The formula, where this formula adds the component of the value g which is the acceleration caused by the gravitational force, namely 3.131 which in the calculation is equated with other values to only two decimal places of 3.13 and the value of π is known to be 3.14. In addition, another difference is that the value of C is considered a constant which is 0.35.

$$T = \frac{2.\pi.C.B}{\sqrt{g.GM}}(s) \tag{2}$$

The determination of the value of the obling period during the implementation of research data collection was carried out using a digital stopwatch on a smart phone so that the value obtained reached the decimal value rather than the second of time that occurred when the ship was rolling. From the observations made by the research team, the value of the olengan period from KL. Sultan Hasanuddin is 7.01 seconds.

If the value of the rolling period is included in both of the above formulas by entering the known T value and the GM value to be taken into account, then the formula will be as follows:

By entering the value of the 7.01 second rolling period obtained when taking the research data, the GM value obtained based on the conversion results of the two formulas above produces the following values:

1) Formula 1:

$$T_{\emptyset} = \frac{2.C.B}{\sqrt{GM}}$$

Modified into:

$$\sqrt{GM} = \frac{2.C.B}{T}$$

Thus, the GM value derived with formula:

$$GM = \frac{2^2.C^2.B^2}{T^2}$$

Where:
T = 7.01 seconds
B = 12 m
d = 2.41 m
L (LoWL) = 57.99 (based on 2.41 m draft)
C = 0.373 + 0.023 . B
d – 0.043 . L100
= 0.46

Now we put into the equation:

$$GM = \frac{2^2.(0.46)^2.(12)^2}{(7.15)^2}$$

$$= \frac{4 . 0.212 . 144}{49.1401}$$

$$= 2.48\ m$$

2) Formula 2:

$$T = \frac{2.\pi.C.B}{\sqrt{g.GM}}(s)$$

Modified to:

$$\sqrt{g.GM} = \frac{2.\pi.C.B}{T}$$

or:

$$g.GM = \frac{2^2.\pi^2.C^2.B^2}{T^2}$$

With this modified formula, now we put into the equation:

$$GM = \frac{2^2.\pi^2.C^2.B^2}{T^2.g^2}$$

where:
T = 7.01 seconds
B = 12 m
π = 3.14 m
g = 3.13 m
C = 0.35

The result:

$$GM = \frac{2^2.(3.14)^2.(0.35)^2.(12)^2}{(7.01)^2.(3.131)^2}$$

$$= \frac{4 . 9.86 . 0.12 . 144}{49.1401 .\ 9.80}$$

$$= 1.44\ m$$

Discussion

The research data collection activity began by identifying the weights on the ship to calculate the ship's GM value using a static stability moment. The data on the weight of the liquid in the tank was obtained from the results of the sound of the tanks on board while the value of the weight of each weight in the tank was obtained from the stability booklet from Sultan Hasanuddin Training Ship.

The GM Value of Sultan Hasanuddin Training Ship obtained from the results of the calculation of the ship's static stability moment when the research data was taken and the value obtained was 2.46 m. Because when taking research data, there are many tanks in slack condition or not in full condition, there is an inertia moment due to the movement of liquid in the tanks when the ship is rolling so that the total value of the inertia moment that occurs divided by the displacement value of the ship will produce a virtual loss of GM value which will reduce the GM value obtained from the calculation of the static stability moment so that effective GM Sultan Hasanuddin Training Ship which is the result of the reduction is 1.72 m.

From the results of the calculation of the GM value using Formula 1, namely with the value of T = 7.01 seconds, the GM value is 2.48 m and the value is close to the GM value of the calculation of the ship's static stability moment without taking into account the virtual loss of GM resulting from the inertia moment in the slacked tanks, which is 2.46 m.

Furthermore, the result of calculating the value of GM using Formula 2 is with the same T value, which is 7.01 seconds but the value of C which is calculated as a constant is 0.35 and adding the component of the value of g which is the value of acceleration caused by gravity which is 1.31, then the resulting GM value is 1.44 m. This value is close to the effective GM value calculated from the ship's Static Stability Moment minus the Virtual Loss of GM so that the final result obtained is 1.46 m.

CONCLUSION

The GM value for KL Sultan Hasanuddin, obtained from static stability calculations, is 2.46 m, with an effective GM of 1.46 m after accounting for the Virtual Loss of GM due to the moment of inertia in slack tanks. The GM value calculated from a 7.01-second mobilization period using Formula 1 is 2.48 m, closely aligning with the static stability moment value of 2.46 m. Using Formula 2, the GM value is 1.44 m, which is near the effective GM of 1.46 m. Given that the study was conducted while the ship was anchored at Soekarno-Hatta Port, limiting rolling potential, it is recommended that future research assess stability on at least five sister ships and other commercial vessels to validate these findings. Additionally, exploring various operational conditions, such as different loading scenarios and environmental factors, through dynamic stability tests outside the controlled anchorage will enhance understanding of vessel stability and contribute to improving safety protocols and design standards in maritime operations.

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