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Original Article

Seaworthiness of Pinisi Tourism Vessels Produced by Traditional Shipyards in Indonesia

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Abstract *- The high demand for Pinisi tour boats as an icon of Indonesia's maritime culture has led to an urgent need to ensure the safety and seaworthiness of these vessels. The transformation of Pinisi vessels from cargo ships to tourist vessels often neglects technical aspects such as stability and construction, thus increasing the risk of accidents, including sinking and fire incidents. The objective of this research is to assess the technical aspects of the seaworthiness and safety of Pinisi tour boats made in traditional shipyards in Bulukumba, South Sulawesi. The stability of the ship, its building system, and the impact of changes on its seaworthiness are all evaluated in the analysis. The findings demonstrated the superior seaworthiness of Pinisi ships built by conventional shipyards, according to the International Maritime Organization's (IMO) guidelines. However, because the ship was altered for tourism purposes, the angle of vanishing stability decreased by 22.73% and the Metacentric Indication (MG) value decreased by approximately 5.25%. To improve shipping safety, it is recommended that the construction be strengthened, materials used under the requirements of the timber shipping regulations be used, and navigation technology be carefully loaded and integrated without losing its Pinisi characteristics. This research contributes to improving maritime safety, sustainable tourism development, and preservation of cultural heritage in Indonesia's traditional shipping industry.*

Keywords *- Pinisi tour, Traditional shipyard, Stability, Safety.*

1. Introduction

The history and culture of South Sulawesi, especially the Bugis-Makassar tribe, are closely related to Pinisi ships and the sea. Pinisi ships, one of the cultural symbols of Indonesia's maritime glory, have an important role as a means of transportation and trade and have evolved into an icon of maritime tourism. Pinisi ships are used to transport various trade commodities to remote areas that are difficult to reach [1, 2]. They even serve cross-border voyages, becoming the backbone of the economy of Indonesia's islands [3]. Pinisi ships are built by Bugis-Makassar shipbuilders using traditional local craftsmanship passed down through generations.

However, along with the changing times, the function of Pinisi ships has evolved from general cargo merchant ships due to the decline in demand for freight transportation, so many Pinisi ships have transformed into passenger ships to meet the needs of maritime tourism. In recent years, Pinisi ships have not only become a cultural heritage but also a tourist attraction. Efforts to develop Pinisi-based tourism have resulted in tourist ships adapting to the change in function as passenger transportation and still maintaining traditional aesthetics despite being modified to meet the needs of tourists [4]. This development promotes the preservation of traditional shipbuilding culture in addition to helping the local economy. On December 7, 2017, UNESCO certified Pinisi shipbuilding as an intangible cultural property, recognizing it as a cultural treasure. To anticipate the high demand for tourist passenger transportation, many Pinisi ships are modified into luxury tourist ships to serve tourists. In this regard, it turns out that many cases of ship sinking and fire accidents involving Pinisi ships have become a public concern. According to Ministry of Transportation data, between 2021 and 2024, at least 27 accidents involving the Pinisi tourist ship occurred in Labuan Bajo, most of which sank due to stability issues, leaks, and fires. Especially those in maritime tourism areas such as Labuan Bajo, Raja Ampat, and Kepulauan Seribu. It is important to study and evaluate these incidents in an effort to increase the certainty that the modified ships have stability and seaworthiness and meet shipping safety standards for tourist passengers according to the IMO recommendations [5].

Modifications for Pinisi vessels are thought to pay less attention to technical aspects related to construction, ship stability, and vibration of the ship's machinery installation and electrical system. Modifications focus more on tourist comfort and less on dynamic load distribution, structural changes, and other technical requirements needed to maintain the seaworthiness of the ship. This is an important issue because tourist vessels sail with dynamic loads, i.e., vertical and horizontal movement of passengers, compared to traditional Pinisi ships designed for the transportation of goods. To increase the safety and security of ships in Indonesian waters, it is crucial to take into account this new problem [6]. Nevertheless, a significant research gap remains unaddressed. Most prior studies have emphasized the socio-cultural and economic value of Pinisi ships [3, 4], yet they rarely provide a rigorous technical assessment of structural and operational safety post-conversion. For instance, although Wahid et al. [5] identified general safety concerns in traditional shipping, they did not quantify how modifications impact key stability metrics. This study departs from such limitations by offering a technical evaluation grounded in ship design and engineering performance. Moreover, traditional shipyards that build these vessels still rely on hereditary techniques with minimal integration of safety regulations, as highlighted by Humang et al. [1] and Wahid et al. [2]. These practices, while culturally valuable, may unintentionally contribute to design vulnerabilities that endanger passenger safety, particularly when not aligned with safety criteria outlined in IMO recommendations [6].

This study aims to fill that gap by conducting a comprehensive technical assessment of the construction and modification processes of Pinisi ships produced in traditional shipyards, focusing on their compliance with design and stability standards. The analysis includes empirical evaluations of Metacentric height (MG), angle of vanishing stability, vibration impacts, and propulsion effectiveness. The novelty of this research lies in its use of quantifiable technical indicators to evaluate seaworthiness, specifically within the context of heritage ship transformation. Unlike existing studies that focus on cultural preservation or tourism promotion, this study applies a systems-level engineering approach to bridge tradition with safety. The results of this research provide practical recommendations that can be implemented by the traditional shipyard industry and policymakers. Additionally, this study supports initiatives aimed at enhancing the safety of Indonesian marine transportation, particularly pinisi ships, which can help foster the growth of safe and sustainable maritime tourism.

2. Literature Review

2.1. Pinisi Vessels Construction Process

Traditional wooden boats, originating from the Bugis-Makassar culture in Indonesia, are a unique blend of hand skills, cultural heritage and community collaboration. The boat production process differs from modern shipbuilding, highlighting local knowledge and traditional techniques that have been passed down through generations [7]. Boat or shipbuilding involves the boat owner, the head boat builder, and his men. Collaboration and community involvement also play an important role in the Pinisi boatbuilding process.

The relationship between Punggawa (boat owner) and Lopi Panrita is built on mutual respect and cooperation to overcome various challenges in the construction process [8] after an agreement has been reached (cost of construction, wood materials, ritual fees, etc.). Then the Punggawa and his men search for wood and choose according to their needs, the curved shape of the “pamara” or linggi (Stern, stem) or the curved “kelu” or ivory (rib, Frame).

The pinisi shipbuilding process is a cultural practice that strengthens social ties and preserves local traditions as a symbol of the Bugis-Makassar community’s cultural identity. Rituals in the construction of pinisi ships are usually carried out before trees are cut down.

The type of tree felled is adjusted to the function of the ship’s construction elements, beams, or hull skin boards that will be used on the ship. For example, “bitti” wood is used for shell plating because it is waterproof, ulin wood for keel, and mango wood for superstructure. Cutting wood or boards always follows the direction of the wood veins so that their strength is guaranteed. The next ritual event is laying the keel, led by the panrita lopi. The keel blocks at the front are illustrated as male symbols, and the back as female symbols. After being lit by burning kemenyang, both ends are cut with a saw and must be done at once without stopping.

The cut ends of the keel must not touch the ground and are immediately thrown into the sea, with the intention of “tulak bala”, which means the husband goes to the sea to earn a living. The piece of the rear keel block (symbol of women) is kept at home, which is symbolized as a sailor’s wife who will faithfully wait at home until her husband comes or the sailor comes bringing good fortune [7].

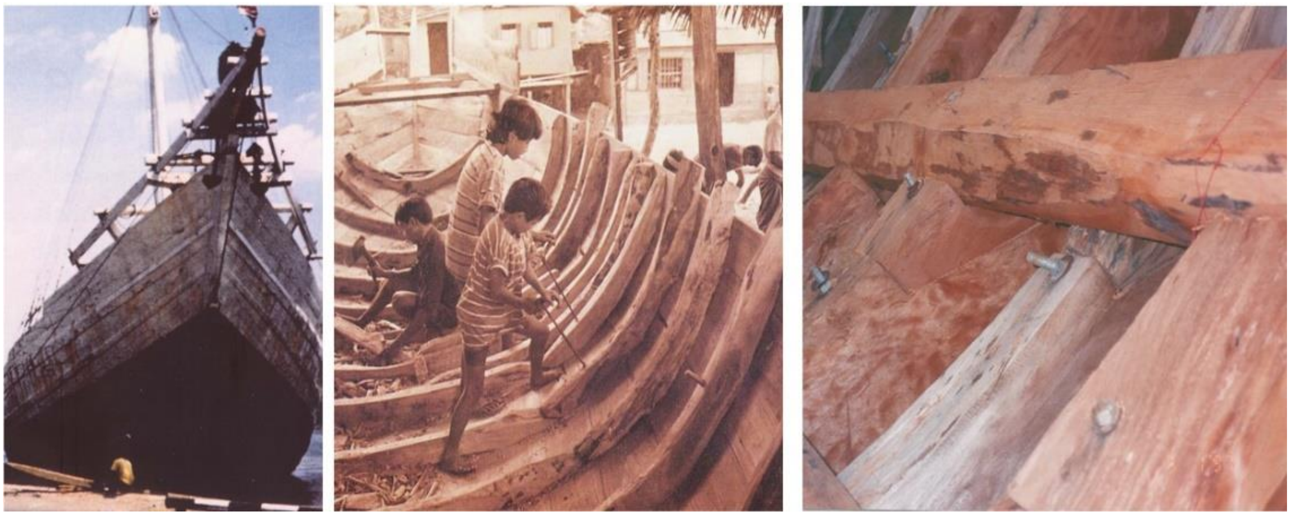

Fig. 1 Pinisi ship joint system

Generally, the keel connection is done with a blunt connection, known as the “lasso” or “telan” connection; the “honga” connection forms the letter “Z” to ensure the strength of the ship’s construction. The difference between traditional wooden shipbuilding and modern wooden shipbuilding is in the order in which the hull is constructed.

Traditionally, the skin plank is preceded by the “panyepe” (gar board strake), which is connected with a dowel on the staff keel and then follows the skin plank above it. In contrast, the modern way is done after the keel is installed, the ivory (frame) is arranged and following the installation of the shell plating is installed later. A picture of the Pinisi vessels’ connection is shown in Figure 1.

After the skin planks have been installed up to the fore, aft and left and right “pamara” (stern, stem) symmetrically, the “tulang” (ribs) are then installed transversely as skin reinforcement following the shape of the “kelu”, which is the basic ivory (frame) of the sitting arch installed on top of the keel transversely, connecting the left “tulang” with the “tulang” on the right. On top of the “tulang” and “kelu”, the “lepe-lepe” (floor, stringers) are installed to provide longitudinal strength. Finally, the deck beam is installed, followed by the installation of the mast and the “patti-patti” or deck house.

In terms of vessel strength (bending moment), it appears that in traditional boats, it is the shell plating that plays an important role, rather than the tusks or ribs. As is the case with modern wooden boats, the average thickness of the skin plating far exceeds the requirements of Classification and construction rules.

In contrast, the tusks of traditional boats are generally smaller than the class standard, but have a tighter frame spacing of one foot, which, according to the classification rules, is usually up to 50 cm for a wooden boat of the same size. In modern boatbuilding, the thickness is calculated using wooden ship construction rules, starting from scantlings for keel, floor, shell plating, stringer, stern, stem, deck beam, etc.

Standardized rules are not used in this process; the shipbuilders rely on traditional methods and their experience to produce a high level of precision. The resulting vessels remain sturdy and qualified for sea voyages. This process also includes the application of ethnomathematical concepts using the principles of geometry in the design and assembly of ship parts.

This use of ethnomathematics demonstrates a careful understanding of the shapes and structures required to create a seaworthy and stable vessel [9, 10]. The design of the Pinisi ship emphasizes the close relationship between the shipbuilder and the maritime environment. The shape and structure of the ship are designed with optimal stability and navigation in open waters. The production process of Phinisi ships in traditional shipyards, as shown in Figure 2.

Fig. 2 Production process of tourist pinisi at bulukumba traditional shipyard

2.2. Functional Transformation of the Tourism Pinisi Ship

The transformation of Pinisi ships from traditional cargo ships to tourist ships uses a comprehensive approach, encompassing structural and operational adjustments, as well as the implementation of sustainable practices. This process revitalized the Pinisi ship as a cultural icon and contributed to the economic and social well-being of the communities involved in its production. A fusion of tradition and innovation, it remains relevant to the modern maritime landscape. The first step in this transformation is structural modification to adapt the ship’s function to meet tourism needs. Traditional Pinisi boats were designed to carry cargo, with strong hulls and layouts that prioritized function. However, to suit the needs of tourism, modifications were required to improve comfort and aesthetics without compromising stability for vessel safety, including the addition of passenger cabins and wider decks for recreational activities. The modifications were inspired by modern maritime architecture while maintaining the traditional Pinisi aesthetics [4].

This transformation affects the stability of the ship, as the Pinisi design was not originally intended to carry live loads such as passengers in large numbers but rather cargo. When cargo is replaced by passengers, the ship’s center of Gravity (G) tends to shift, with more dynamic load distribution and more open space on the upper deck for passenger comfort. These changes have the effect of decreasing transverse stability values and potentially increasing the risk of tilting or capsizing, especially in rough sea conditions. Therefore, structural adjustments to lower the point of gravity, such as extra ballast in the hull space or adjustments to the deck position, are often required to compensate for the influence of passenger loads on ship stability (Figure 3).

Fig. 3 Construction of pinisi

The integration of tourist facilities such as toilets, dining and recreational areas needs to be taken into account so as not to destabilize the vessel, requiring careful modification planning to ensure that the historical value of the vessel and the safety of the voyage are maintained. The challenge lies in maintaining the balance between touristic functionality and traditional craftsmanship, which is the hallmark of Pinisi tour boat modifications. In addition to safety and operational aspects, it is also important to consider the environmental impact of operating the Pinisi as a tourist vessel. The application of eco-friendly materials and sustainable practices is important to reduce environmental impact and preserve the environment, which is an attraction for visitors and is linked to the Marine pollution program [4].

2.3. Evolution and Operation of the Pinisi Ship

The evolution of the Pinisi shape was formed from traditional engineering inspired by the shape of boats (Pajala, Padewakang, Pinisi), which are generally like coconut or cucumber fibers, where the boat is wide relative to the length, and draft or depth, so that stability is good, especially “form-stability”. Both from the results of calculations on paper and from the results of sailing tests, the Pinisi ship has a Metacentra (MG), which shows very good stability properties (Figure 4). Facts show that motorized sailboats rarely sink due to capsizing, but more incidents occur due to being overloaded or hull leakage, so that they enter seawater and lose buoyancy until the ship sinks.

Usually, water enters the ship or boat through the joints between the leather planks that have become loose due to vibrations. Experience has shown that the 100% traditionally built Padewakan boat “Hati Marege” with no auxiliary engine, during its sailing to Darwin, Australia, did not have the slightest ingress of water into the hold. The boat is 30 tons and has an “initial stability” of about 2.0 meters MG height.

Fig. 4 Padewakang type pinisi ship

History proves that Indonesia’s culture is closely related to boats and the sea. For centuries, the fleet of sailboats has still enlivened the trade and shipping routes throughout the archipelago, even across the vast ocean to Madagascar and the West coast of Africa. Its ability to sail the oceans has been proven by the “Pinisi Nusantara” expedition in 1986 to Vancouver, Canada, and the success of the “Amanna Gappa” boat in reaching Antsiranana port in Madagascar on October 5, 1991, after sailing the Indian Ocean for 50 days. It is unfortunate that the Amanna Gappa eventually sank on its voyage to the Cape of Good Hope, due to a leak that could not be overcome.

2.4. Stability Criteria

The stability of Pinisi ships is associated with recommendations or criteria set by the IMO, an important aspect to be guided in the design or modification of ships to improve operational safety. IMO has established stability criteria, aimed at ensuring the seaworthiness of ships and relevant for traditional vessels such as Pinisi that are adapting their function for tourism.

Pinisi ships, which are used for cargo transportation, must adhere to stability standards to ensure safer operation of the ship in voyages at sea. The principles of stability are important to understand for life safety at sea, especially for sailors who sail vessels with water conditions facing waves and wind speeds.

According to [11-13] all segments of the maritime industry need to pay attention to aspects of ship stability in shipping operations, because ships can capsize due to factors such as the free surface in the tank, the location, and shift of the cargo load, the shape of the hull and buoyancy, and the distance of the ship’s weight point (G) to the Metacentric point (M) of the Keel (K).

The wide hull shape and shallow draft affect the displacement of the pressure point (bouyancy) when the ship is tilted. The ship’s freeboard determines the angle of the water touch limit on the deck side. It affects the ship’s stability indicators reflected in the value of the distance between the metacentra point and the ship’s weight point, namely (MG), which is small, so it has the potential to face ship accidents due to loss of stability.

This parameter is important in assessing the vessel's ability to return to an upright position after being struck by waves or wind. Research shows that a minimum B/T ratio of 2.50 is required to meet stability criteria, with an optimal KG/D ratio of 0.65 to improve stability [14, 15]. This ratio helps to ensure that the Pinisi has stability in various sea conditions when it is used for tourism in rough waters. The subsequent transformation of a cargo Pinisi vessel into a tourism vessel must also consider the implications for stability. IMO criteria related to ship stability can be seen in Figure 5.

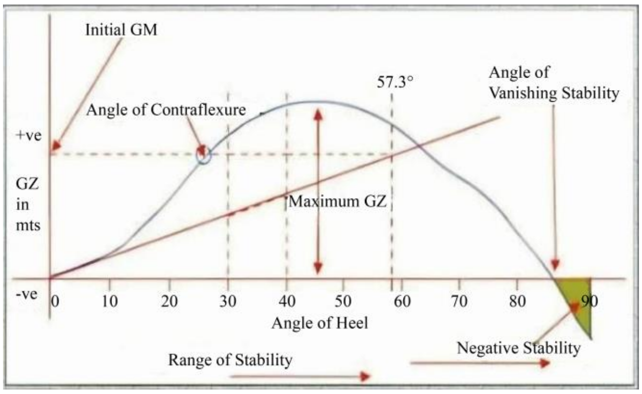

Fig. 5 IMO A.749 criteria stabilities

The addition of passenger cabins and recreational areas can shift the center of Gravity (G), potentially compromising stability if not properly managed [16]. Therefore, conducting a stability pre-assessment during the pre-design phase is important to ensure that the modifications do not adversely affect the ship's performance. IMO emphasizes the importance of conducting stability assessments for all types of vessels, including traditional ones such as Pinisi, to ensure compliance with safety regulations [17, 18]. In addition to structural considerations, operational aspects of Pinisi ships must also comply with IMO guidelines. This includes crew training on stability management and emergency procedures, which are crucial for maintaining safety during voyages [19]. The integration of modern technologies for navigation and stability assessment can further improve the operational safety of ships and allow real-time monitoring of stability conditions [18, 20].

3. Materials and Methods

The method used in this research is a *Metasynthesis* approach, which is to develop qualitative data sourced from previous research related to the manufacture and operation of Pinisi-type ships, such as Pinisi Nusantara, Padewakan Amana Gappa and the pilot project of Pinisi shipbuilding in cooperation with Hasanuddin University, Director General Perla and the Indonesian Ship Classification Bureau. The sample ship studied is the KLM Lakessing Pinisi Ship, which has been modified from the Pinisi Cargo ship to the Pinisi Tourism Ship. The dimensions of the Pinisi ship are as follows:

Deck Length	= 27.00 m
Waterline Length (LWL)	= 21.93 m
Keel Length	= 17.56 m
Width (B)	= 6.58 m
Height (H)	= 2.93 m
Landing (T)	= 1.60 m
Speed (V)	= 10-12 Knots
Main Engine/Auxiliary	= 350 Hp/190 Hp
Generator 1/Generator	= 30 Kva/20 Kva
Fuel Oil/Fresh Water	= 4 Ton/9 Ton
Passenger Capacity	= 40 Person
Crew	= 6 Person

The ship was chosen considering that the ships built are sister ships with a range of main size ratios as follows: L/B = 3.42 to 4.15; B/H = 1.75 to 2.45; L/H = 5.85 to 10.00; and B/T = 2.84 to 3.23. General Arrangement of Pinisi Ship KLM Lakessing can be seen in Figure 6.

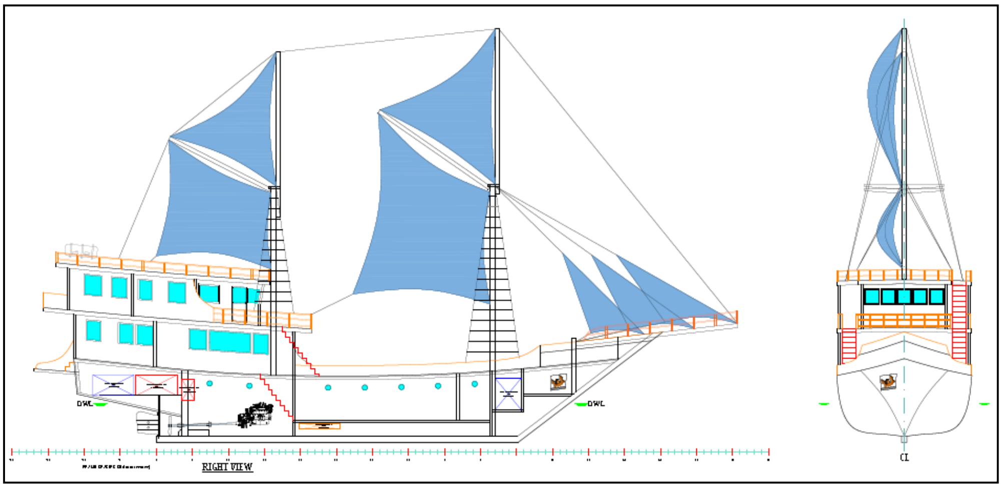

Fig. 6 General arrangement of the sample ship

Evaluation of the technical aspects (stability) of Pinisi ships due to changes in function from freight transportation to tourist passenger ships is carried out by comparing the conditions of Pinisi ships that function to transport cargo and Pinisi ships modified to become Pinisi Tour ships. The analysis was carried out on stability conditions with a change in the weight point of gravity (G) and the dynamics of symmetrical and asymmetrical passenger movements to see changes in stability due to the movement of people on the deck and the influence of the Metacentra point (M). The criteria used are IMO criteria A.749 (18) Ch. 3, where: (A) is the area of the curve up to 30°, ≥ 0.055 m-rad., or (≥ 3.151 m-deg). (B) is the area of the curve up to 40°, ≥ 0.090 m-rad., or (≥ 5.157 m-deg). (C) is the area of the curve between 30° and 40°, ≥ 0.030 m-rad., or (≥ 1.718 m-deg). (X) is 40° or greater than 25° as the angle of maximum. (E) is the minimum GZ stability arm of 0.20 m at an angle of inclination ≥ 30°. (F) is the maximum GZ at an angle of inclination (≥ 30°) and shall not be less than 25. Details of the IMO A.749 (18) Ch. 3 criteria are shown in Figure 5.

4. Results and Discussion

4.1. Characteristics of the Pinisi Tour Ship

A tourist Pinisi ship is a type of ship designed or the result of the transformation of a cargo Pinisi ship for tourist activities on the water. It is smaller than a regular passenger ship and is equipped with comfort and safety facilities for tourists. The size of tourist Pinisi ships varies, ranging from those with a capacity of tens to hundreds of passengers. Smaller vessels are usually used for tours in calmer waters, while larger vessels are used for long-distance voyages.The building materials of tourist Pinisi ships are generally made of wood. The choice of material depends on the intended use, water conditions, and budget. The engines used on tourist Pinisi ships also vary, ranging from diesel to electric. The size of the ship, the intended speed, and the acceptable noise and vibration levels all influence the engine selection. Facilities found on Pinisi tour ships vary according to the class of the boat and the destination. Common facilities include: Passenger cabins that can be single, double, or even suites; Comfortable dining areas to enjoy meals during the cruise; Spacious open decks to relax and enjoy the view; and Entertainment equipment such as a sound system, TV, or karaoke. Pinisi tour ships are required to have all the necessary safety gear, including fire extinguishers, life jackets, and life rafts. The ship must also meet applicable shipping safety standards. Pinisi tour ships are equipped with modern navigation equipment, such as GPS, radar, and compass. This equipment is essential to ensure the safety of the voyage, especially in unfamiliar waters.

The design of the ship is adjusted to the tourism objectives to be achieved, such as snorkelling, diving, or simply enjoying the scenery. The conditions of the waters, waves, and depth will influence the ship's design, especially concerning navigation safety. The ship's design must comply with regulations regarding safety and environmental standards. Stability and the vessel's capability are defined as the ship's response to wind speed, currents, and sea waves. A rigid ship will return to an upright position very quickly. Such a condition of the ship has a high Motion Sickness of Incident (MSI) value. Essentially, stability refers to a ship with a sufficient righting moment to return to an upright position when subjected to external forces that cause it to tilt.

4.2. Strengthening Construction and Ship Vibration

Research on several similar Pinisi ships indicates that, in terms of both longitudinal and transverse strength, traditional boat construction is sufficiently robust under any wave conditions (hogging and sagging conditions), with average stress levels remaining below the allowable stress for wood. However, the connection system needs to be reinforced and improved, such as between the skin boards and the ribs or with the keel, which are generally only connected with wooden pegs. Such connections can easily become loose and may result in leaks, leading to sinking.

This is particularly likely if the hull experiences vibrations from the auxiliary engine's rotation, especially if the engine's foundation is not adequately reinforced locally. Therefore, all connection systems need to be strengthened using galvanized bolts or screws, as required by the Indonesian Wooden Ship Construction Regulations and Classification Bureau. Although the construction of Pinisi is entirely traditional, it employs reinforced connections with galvanized bolts, proving effective in preventing leaks during its voyage to Vancouver, Canada, across the Pacific Ocean.

Another important consideration is the need for partition walls between spaces, at least between the engine room and the cargo hold, to ensure that the ship maintains sufficient buoyancy in the event that one of the compartments experiences a leak and is flooded with seawater. To reduce the influx of seawater, at least two electric pumps should be prepared that can operate independently and in parallel.

The design load for deck cargo and the planning requirements related to the hydrostatic forces of the construction are greater than the actual load during operations of the Pinisi ship with a Gross Register Tonnage (GRT) of 360. The stress on the transverse construction system (deck beams, ribs, and bottom reinforcements) is lower than the stress permitted by the materials used in constructing the Pinisi ship. The stress on the overall robust construction system against longitudinal reinforcements is very strong, and the stress experienced due to wave forces under Beaufort scale 5 at the bottom and deck remains below the allowable stress.

The results of the vibration measurements on the prototype Pinisi ship with a Gross Register Tonnage (GRT) of 360, using a Handvibrograph, indicate that the vibrations experienced by the ship do not pose a risk to human health and do not interfere with the operation of the ship's instruments (see Figure 7). The maximum vibration speed recorded is 3.8 mm/s at the transverse partition of the engine room and 2.89 mm/s at the superstructure, while according to ISO 6.954 criteria, at a frequency of around 30 Hz, the maximum tolerable vibration speed is 4 mm/s. The amplitude is also classified as good, below the ISO criterion of 0.05 mm, while the actual measurement is 0.023 mm at the superstructure. Overall, the impact of vibrations on the structural strength of the ship is not hazardous, as indicated by the relatively small vibration amplitude or deflection recorded (0.012 mm on the ribs and skin), resulting in very low strain (see Figure 8).

Fig. 7 Vibration measurement using a handvibrograph

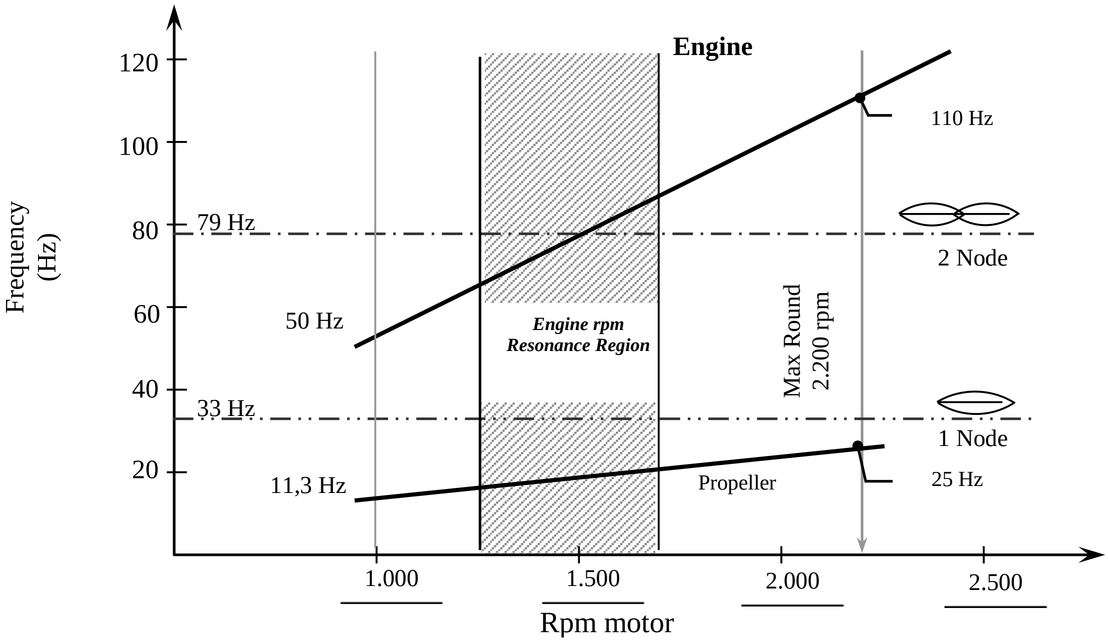

Fig. 8 Natural frequency curves of vibration and vibrations from the motor and propeller

From the vibration frequency curve of the Pinisi ship, it can be concluded that, in terms of vibration, the selection of the number and rotation of the propeller on the 360 GRT Pinisi is very good (see Figure 8). Resonance between the vibrations triggered by the propeller and the hull does not occur because the frequency of the propeller is always below the natural frequency of the hull, and the vibrations that occur are dominated by the main motor.

The critical stress on the hull construction in the engine room is recommended to be reinforced with longitudinal supports (side girders) between the keel and the galar kim. Any leaks occurring in the engine room, cargo hold, and deckhouse due to an imperfect loading system should be repaired. For the safety of the ship's hull from impacts when docking, especially in open ports and during heavy waves, it is advised to equip the sides of the ship with fenders. The construction of the transverse bulkheads does not align with their intended function or purpose, making it difficult for operators to arrange items or cargo in the lower main deck. The construction of these transverse bulkheads should comply with construction system regulations. There should be a manhole on the main deck, which should be installed with a minimum threshold height of 60 cm.

4.3. Ship Propulsion Equipment

The electrical wiring installation system does not use protective measures. The cable installation does not meet the requirements (not suitable for marine use), and the wire or cable insulation is not heat-resistant or is extensively worn, which can lead to short circuits (see Figure 9). It is recommended to use a cable installation system that does not directly attach to the deck beams, requiring several branch panels for various power users, ground connection panels, and emergency lighting installations (DC system).

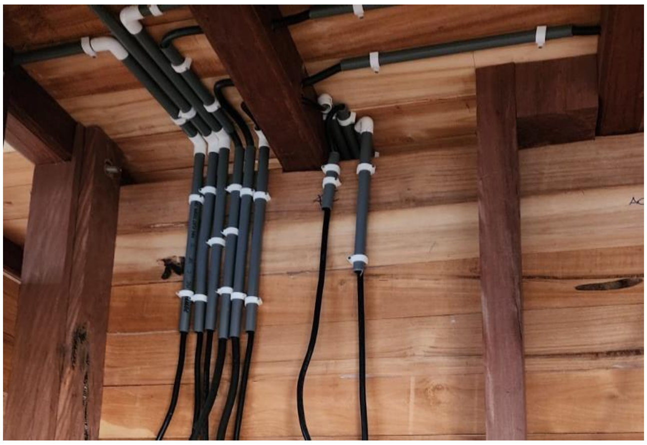

Fig. 9 Electrical installation on the pinisi tourist ship (not marine standard)

The temperature in the engine room necessitates an air circulation system with natural ventilation that is sufficient to maintain the engine room temperature around 41 - 45 °C; however, insufficient air circulation has caused the temperature to reach 45 °C – 57 °C. A skylight construction for the engine room is required, with a height of +90 cm and a protected cover in case of rain. Ventilation in various compartments (must be installed), especially in bulkhead spaces or the bow of the cargo hold and engine room, is essential for achieving good engine combustion efficiency.

The use of sails as the primary propulsion on the Pinisi ship is highly dependent on the direction and speed of the wind, as well as the area of the sail that catches the wind. The thrust force is determined by the main sail and is greatly influenced by the performance of the sail system. The average effective wind power usage is only about 6 days per month, with an average wind speed of 11 knots. Therefore, the existence of sails as the primary propulsion is somewhat difficult to maintain for ships larger than 100 GRT.

It is estimated that around 70% of boats now rely on auxiliary engines as the main propulsion for sailing ships, especially for Pinisi ships over 200 GRT. The desired speed for operators is around 8 knots; some operators have even used engines to achieve speeds of up to 9 knots. There is a trend among ship operators to use auxiliary engines as the main propulsion system for Pinisi ships.

4.4. Pinisi Ship Stabilities

Figure 10 shows a comparison of stability between the Pinisi ship used for cargo transport and the modified Pinisi ship converted into a passenger tourist vessel. The stability curve of the ship is illustrated under departure and arrival conditions at the destination dock, where both conditions have different Righting Arms (GZ).

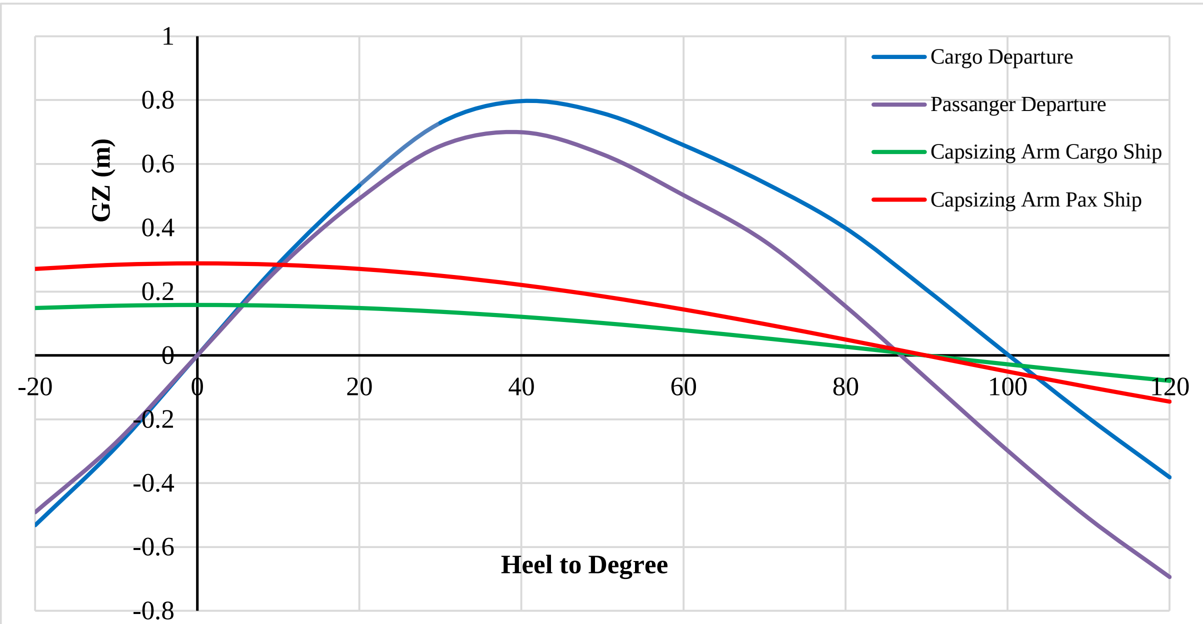

Fig. 10 Stability curves of cargo and tourist pinisi

Figure 10 shows that the cargo and tourist Pinisi ships, in their departure conditions, have different ranges of stability, where the angle of vanishing stability for the cargo ship reaches 110 degrees, while for the tourist ship, it only reaches 85 degrees. Several factors contributing to the differences in stability characteristics between the tourist Pinisi and cargo Pinisi ships include load factors, hull shape, main deck configuration, and metacenter (distance MG), as explained in Table 1. The stability criteria according to IMO A.749 relate to the Righting Arm (GZ) and the influence of moments that disrupt the ship's stability due to external factors (wind, waves, and shifting cargo, among other disruptive moments) that cause the ship to tilt and lose stability from its upright position or capsizing arm. The criteria that must be met by the ship to ensure safety while sailing are based on the recommendations of IMO A.749 (18) Chapter 3, which addresses the moments of submergence when the ship turns, wind and wave moments, and passenger shifting moments as follows (Table 2)

Table 1. Differences in factors affecting the stability of pinisi ships

Factors	Tour Pinisi Ships	Cargo Pinisi Ships
Load	The passenger load is relatively light but dynamic in both vertical and horizontal directions. This affects the center of Gravity (KG) and the Metacenter (MG)	The cargo load is heavier, with the concentration of the load located below the deck in the cargo hold, resulting in a relatively low center of Gravity (KG).
Hull shape	The hull shape is wider, and the ship has a shallow draft for passenger comfort.	The hull shape is adjusted according to the cargo capacity, with a relatively larger and deeper draft.
Metacentera Main Deck	There is relatively ample space for passengers, with no hatch sill, allowing for more freedom in passenger accommodation.	There is a hatch sill for the cargo hold, along with loading and unloading equipment, as well as space for the freedom of loading and unloading operations.
(MG Distance)	Relatively low, the center of Gravity (G) shifts to the main deck and the open passenger area.	The MG point is higher, while the G point is lower due to the cargo load in the hold below the main deck.

Table 2. Stability evaluation of tour traditional ships, and traditional ship goods based on IMO criteria

No.	Criteria A.749(18) Ch.3	Criteria	Units	Pinisi Cargo	Pinisi Tours	Status
1	Max Area of GZ 0 to 30	≥3,151	m.deg	119,69	110,55	Pass
2	Max Area of GZ 0 to 40	≥5,157	m.deg	197,13	179,36	Pass
3	Max Area of GZ 30 to 40	≥ 1,718	m.deg	77,44	68,81	Pass
4	Max GZ at 30 or greater	≥ 0,20	M	0,80	0,70	Pass
5	Angle of maximum GZ	≥ 25,00	deg	40,90	38,20	Pass
6	Initial Metacentric Height	≥ 0,15	m	1,72	1,63	Pass

Based on the results of the analysis, there is a noticeable difference in the stability arm curve (GZ) between the two conditions. The cargo-carrying Pinisi ship exhibits more stable characteristics than the tourist Pinisi ship designed for passenger transport. The value of Initial Metacentric Height from the center of Gravity (G) to the metacenter (M) (initial GM) shows that the cargo Pinisi (MG = 1.72 m) is greater than that of the tourist Pinisi (MG = 1.63), and the freeboard is approximately 1.33 m, with a heeling angle at which water reaches the deck (Q deck) being 22.25 degrees. The criteria recommended by IMO A.749 (18) Chapter 3 regarding ship stability, known as the "Code on Intact Stability," provides detailed guidelines for assessing a ship's stability under various operational conditions. The Range of Stability refers to the maximum heel angle that a ship can achieve before reaching neutral stability. In other words, it is the range of angles at which a ship still possesses sufficient restoring force to return to an upright position after being tilted by external forces such as wind or waves. A larger range of stability indicates that the ship is safer to operate in adverse weather conditions. Changes in the ship's load can affect its range of stability; therefore, stability calculations are crucial before a ship sets sail. Based on the analysis results of the stability curves in Table 3 under various conditions for the 360 GRT Pinisi ship, it is evident that the stability criteria set by the International Maritime Organization (IMO) are met. Thus, the stability feasibility of the 360 GRT Pinisi type is assessed as good, indicating a high level of seaworthiness for sailing.

Table 3. Stability evaluation of the 360 GRT Pinisi Ship

Description.		Condition Alternative			
		I	II	III	IV
1. Departure Condition	Payload	100%	-	50%	-
	Supplies and fuel	100%	-	100%	-
2. Departure Condition	Payload	-	100%	-	50%
	Supplies and fuel	-	10%	-	10%
3. Displacement (ton)		575	564	397	387
4. Sarat (m)		3,50	3,40	3,17	2,85
5. Location of the centre of gravity (KG) (m)		2,724	2,719	2,940	2,958
6. Q_{range} (degrees) $Q \geq 40^o$		60,05	60,00	59,07	60,00
7. Max arm, h_{max} $Q \geq 30^o$		33,20	32,80	36,76	36,50
8. Location of metacentral point ($MG \geq 0{,}15$ m)		1,984	1,781	1,360	1,192
9. Curved Area Stability		0,191	0,192	0,212	0,197
- 30^o-$40^o \geq$ (0,030 m/rad)		0,106	0,109	0,130	0,130
- $Q = 40^o \geq 0{,}09$ (m/rad)		0,297	0,303	0,342	0,307
10. $Q_{geladak}$ (degrees)		16,31	18,85	24,41	31,37

The stability characteristics of the Pinisi-type boat are fundamentally unquestionable, primarily in terms of Weight Stability, which serves as a benchmark for the seaworthiness of both cargo Pinisi and tourist Pinisi ships. The height of the Metacenter (MG) and the Form Stability (form stability) with a sufficiently large Range of Stability are notable. Instances of Pinisi ships capsizing or sinking due to stability weaknesses are rare; however, they often occur due to excessive loading on deck or leaks. Additionally, it is essential to establish adequate freeboard, watertight covers for deck openings, and sufficient hatch sill heights to protect against large waves encountered at sea.

5. Conclusion and Recommendation

The results of the stability curve analysis for the Pinisi ship under various conditions indicate that the stability criteria set by the International Maritime Organization (IMO) are met. Therefore, the stability feasibility of the Pinisi-type vessel is assessed as good, indicating a high level of seaworthiness for sailing.

The stability characteristics of the Pinisi-type boat are fundamentally unquestionable, especially regarding weight stability, which serves as a benchmark for the seaworthiness of both cargo and tourist Pinisi ships. The height of the Metacenter (MG) and the form stability with a sufficiently large stability range are notable.

The causes of the technological gap in traditional shipping are attributed to the continued use of conventional elements, very low application of technology, and a lack of written information about the advantages and disadvantages of such technologies in scientific literature. The technical conditions (stability, construction/vibration, and propulsion system) are generally assessed as good and have a high level of seaworthiness for sailing, meeting the standards set by the International Maritime Organization (IMO) and ISO 6954 regarding construction vibration criteria.

Future research may explore how modernization efforts in traditional Pinisi vessels can be aligned with cultural preservation, especially in documenting indigenous shipbuilding knowledge. In addition, studies involving passenger perception and operational risk under various sea conditions could complement the technical findings.

Based on the research findings, several recommendations are made, including:

- As a non-conventional vessel, the Pinisi ship needs to meet the safety standards set by the Minister of Transportation Regulation No. KM 65 of 2009 through hull construction reinforcement, use of materials that comply with regulations, and management of dynamic loads.
- Modifications to the Pinisi ship for tourism purposes require enhancements in hull construction aspects, improvements in joint systems to reduce leaks caused by vibrations, optimization of the propulsion system, installation of bulkheads to maintain buoyancy in case of leaks, and upgrades to the electrical system to meet maritime safety standards.
- The increase in production costs due to the difficulty in obtaining wood raw materials can be addressed by diversifying materials using a technological approach, such as a combination of wood and steel.
- The transformation of the Pinisi ship from cargo to tourist vessel requires an enhancement in human resource capacity (crew members) through training in safety management, passenger service, and mastery of modern navigation technology to meet tourist needs, as mandated by Law No. 66 of 2024 concerning Shipping.

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