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Damage Stability Study of A 500 DW Ro-Ro Ferry Vessel

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Abstract

The development of the crossing transportation industry is currently increasing in the island areas. The use of Ro-Ro type ferry boats is extremely efficient in moving people, goods, and vehicles. The current research focuses on the damage stability of the 500 DWT Ro-Ro ferry, which aims to meet the needs of the Ro-Ro ferry in the archipelago area. The previously existing initial design of a barge hull with a main size Lpp = 40.15 m, B = 12 m, H = 3.2 m, and T = 2.15 m was used to analyze the damage stability condition further. First, the drawings were redrawn. Then, 3D modeling was performed and the tanks were inspected. The processing of the input data design was finally tested under several criteria based on damage stability in SOLAS 2009. This study concluded whether the 500 DWT Ro-Ro ferry design is acceptable considering damage stability. The GZ value is standardized in the scenario of calcge stability of the Ro-Ro ferry as a whole. Attention should be provided to the range of positive stability in intermediate stages considering the forward damage case, wherein the ship departs and the full load experiences failure.

Keywords: damage case, damage stability, ferry 500 DWT, GZ curve, SOLAS 2009

1. Introduction

The current development of ferry boats is rapidly increasing. Ferry boats are still needed in some areas. Most of the connections between islands in Indonesia still rely on ships to move places. The use of Ro-Ro-type ships is remarkably effective. The 500 DWT Ro-Ro type ship is effective for crossing areas 2-10 hour away. The advantage of this type of Ro-Ro ship lies in its capability to transfer people, goods, and four or more wheeled vehicles.

The operation of the 500 DWT Ro-Ro ferry may lead to a leakage risk due to various events. Therefore, in the design of the 500 DWT Ro-Ro Ferry, calculating the leakage stability is necessary to determine the ship's motion in leak conditions (herein referred to as damage stability calculation). This research will examine the damage or leak stability of the ship considering the initial ship design of the 500 DWT Ro-Ro Ferry by modeling the 500 DWT Ro-Ro Ferry ship and the tanks or compartments using the Maxsurf Modeler and Maxsurf stability software.

The International Maritime Organization is a specialised agency of the United Nations responsible for regulating shipping. Furthermore, the proposed calculation simulates leaks in the ship's compartments, starting from one leaking compartment until all compartments in the ship experience a leak. Afterward, the damage stability of the initial design of the 500 DWT Ro-Ro ferry is calculated and analyzed; whether the damage stability for this ship meets the International Maritime Organization (IMO) SOLAS damage stability criteria will also be examined [1, 2]. Excessive GM values will result in seakeeping problems [3].

2. Methods

Stability can be defined as the capability of the ship to return to its original state after being subjected to external forces. This capability is influenced by the dynamic arm GZ, which forms a coupling moment that balances the upward compressive force with gravity. The stability component comprises GZ, KG, and GM. Identifying the price of the dynamic arm GZ is crucial in stability calculation. After the GZ price is obtained, it is verified with the "Intact Stability Code, IMO." One of the functions of the damage stability calculation is to provide a risk analysis that can present an overall view of the causes and consequences of accidents [4]. Based on the IMO, one of the causes of ship sinking is accidents due to the returning arm loss of the primary stability of the ship [5].

Calculations of ship stability using the pressure integration technique are presented, compared with other numerical results, and discussed. The technique is then applied to estimate the flow rate through the damaged openings in the hull. The results conclude that this technique can be successfully applied to time-domain simulations of ship flooding for calculating the hydrostatic properties of a damaged ship and the flow rate through the damaged openings in the ship's hull [6]. The damage stability calculation method used to measure damage stability presents two commonly utilized methods.

Trim line added weight method. The principle of this calculation method is as follows: when the ship has a leak, the room where the water entered is still considered part of the ship. Meanwhile, the incoming water is considered an additional weight for the ship. Owing to the additional weight, ship displacement will change from its initial displacement before the leak. If the displacement increases, then the ship's draft will also increase.

Lost buoyancy method. The principle of this calculation method is as follows: when the ship has a leak, the room where water entered is no longer considered part of the ship. Thus, the part of the ship is reduced, thereby also decreasing buoyancy or the upward compressive force. Ship sinking will occur when the buoyancy decreases, thus increasing the ship's draft.

SOLAS 2009 consolidated edition chapter II-1 part B-1. The requirement for subdivision and damage stability of cargo ships took effect on February 1, 1992; that is, all cargo ships built on or after the aforementioned date must follow the rules and requirements contained in SOLAS Chapter II-1 Part B-1 Regulation 5 up to 7-3. In the SOLAS requirements, terms related to calculations will be obtained, namely [7, 8]: 1) Subdivision Load line: the water line used to determine the bulkhead distance on the ship. 2) Deepest Subdivision Load Line: subdivision load line summer draft. 3) Partial Load Line: empty draft plus 60% distance between empty draft and deepest subdivision load line. 4) Light Services Draft: the required draft of the ship when the load is empty to maintain stability or submersion of the propeller. 5) Subdivision Length of the Ship (LS): the length measured between the vertical lines on the deepest subdivision load line. 6) Mad length: the midpoint of the subdivision length. 7) Aft terminal: the back end of the subdivision length. 8) Forward terminal: the front end of the subdivision length. 9) Breadth (B): the largest width of the ship on the deepest subdivision load line. 10) Draft (d) height from the molded baseline at the midpoint of the subdivision length to the subdivision load line. 11) Permeability (p): the volume of cargo space that can be occupied by leaking water.

Calculation of SOLAS requirements. The SOLAS regulations on subdivisions were established to obtain minimum bulkhead distances for ships that still affect safety standards. A subdivision degree index (R) for cargo ships with LS > 100 m indicates whether the subdivision of a ship is satisfied; this index is defined as the equation below [7]:

$$R = 1 - (128 / (LS + 152)), \qquad (1)$$

The attained subdivision index (A) of a ship cannot be less than the R index price. Index A is calculated on the basis of the equation below:

$$A = \Sigma pi\ si, \qquad (2)$$

where,

i = Indicates a compartment or group of compartments that are close together and are considered to have leaks, providing significant contributions to the value of A.

Pi = Calculation result (value) indicating the probability that the selected compartment (i) will be able to leak.

Si = Calculation result (value), which shows the probability that the ship will survive after the selected compartment (i) has a leak.

The triangles in figure 1 illustrate the possibility of single and multiple zones of damage on a ship with a watertight arrangement suitable for the division of seven zones [8].

The triangles on the bottom line indicate single-zone damage, and the parallelogram indicates adjacent-zone damage [9].

The initial stage must check the sizes of established models according to the ship data. The inspection includes the primary size of the ship, the displacement of

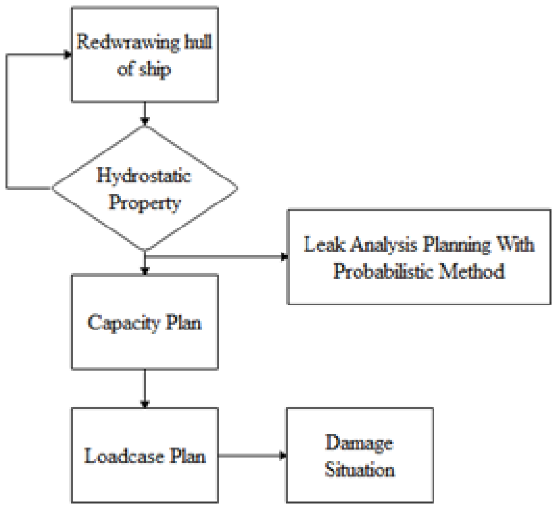


Figure 1. Steps for Damage Stability Calculation

the ship, the coefficient block, and the LS's LWL. The tolerance of the difference between the ship model and the actual data is less than 5%; the manufacture of tanks uses Maxsurf stability software. The location and coordinates of the tank points refer to the initial tank design, namely the 500 DWT Ro-Ro ferry. Next, the capacity planning of adjusted tanks to that of the ship's cargo is conducted. Load case planning is adjusted to the leak scenario before its usage. Afterward, damage stability is simulated using Maxsurf stability software on the probabilistic damage stability menu [10]. The steps for damage stability calculation are shown in Figure 1.

3. Results and Discussion

A case study in the calculation of damage stability using a 500 DWT Ro-Ro type ship. Ro-Ro ships are passenger ships with inter-island routes for 10 to 15 h of sailing. The stability damage value is conducted in the following stages. The first step is determining the variation in the ship's condition.

The vessel is divided into eight conditions, which are detailed as follows. The first condition is when the ship is empty. An empty vessel means that the entered parameter is only the weight of the vessel material. The second condition means that the ship is fully loaded and ready to sail. The third condition means the full cargo truck is on the car deck. The fourth condition means the ship is in a sailing position with full cargo details and 50% tank volume. The fifth condition means the ship is sailing with a whole truckload while the tank volume is 50%. The sixth condition means the ship is in a departing position with fully loaded cars, and the tank volume is 100%. The seventh condition is the same as the sixth, but the tank volume is only 50%. The eighth condition indicates that the ship sails without cargo on the deck.

The second stage of the line plans from the initial design of Ro-Ro ferries is required performing 3D modeling on Maxsurf Modeler software. Therefore, the shape of the intended model does not differ from the original design form.

The third stage of tank arrangement is necessary to model the tanks and compartments on Maxsurf stability to facilitate damage stability analysis. More details on the main dimensions of the ship are shown in Table 1.

The 500 DWT Ro-Ro ferry ship comprises the following payload capacities: 7 units of sedan cars, 12 units of trucks, 202 passengers, and 18 crew. The fuel tank is on a double bottom located in front of the engine room bulkhead with a capacity of 58 tons. The freshwater tank on the double bottom is located in the midship with a capacity of 32 tons. General Arrangement of the 500 DWT Ro-Ro Ferry are shown in Figure 2.

Figure 2 shows the line plans of the ship after redrawing using Maxsurf Modeler software. The water line of the ship is divided in accordance with the height of the ship's draft, which is 3.2 m. The buttock line is divided in accordance with the vessel width, which is 12 m. Line Plans of the Sample 500 DWT Ro-Ro Ferry are shown in Figure 3.

The perspective shape of the redrawn results shows the shape of the stomach. The hull has a monohull shape, demonstrating an outstanding depth that produces significant buoyancy for passenger-type ships. Sample Model of the 500 DWT Ro-Ro Ferry are shown in Figure 4.

Table 1. Main Dimension of the 500 DWT Ferry Vessel

Main Dimensions		Units
LOA	45.50	M
LPP	40.15	M
B	12.00	M
D	3.20	M
T	2.15	M
Main Engine	2 × 800	HP
Speed	11.00	Knots
Crews	18	Person
Passenger	202	Person
Car	12	Truck
	7	Sedan

Figure 2. Sample General Arrangement of the 500 DWT Ro-Ro Ferry

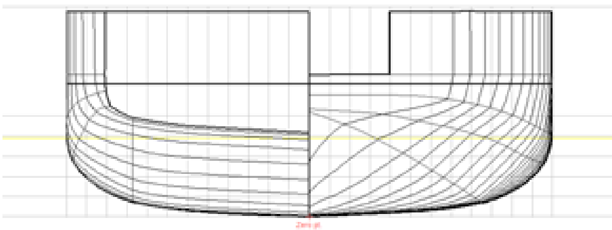


Figure 3. Line Plans of the Sample 500 DWT Ro-Ro Ferry

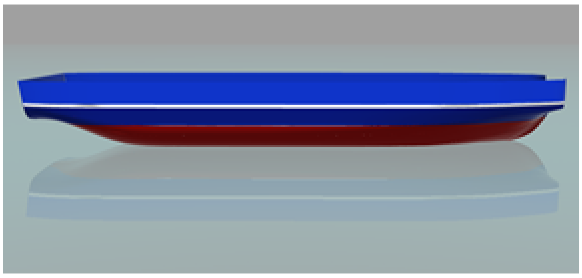


Figure 4. Sample Model of the 500 DWT Ro-Ro Ferry

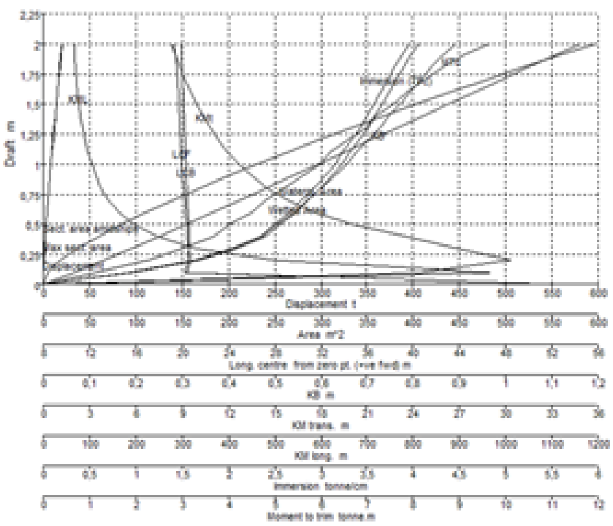


Figure 5. Hydrostatic Graph of the 500 DWT Ro-Ro Ferry

The following characteristics of the ship can be observed from the hydrostatic graph: the value of keel buoyancy, water surface area, longitudinal center buoyance, tons per centimeter, and displacement. The assessment results of ship characteristics are in accordance with the type of ferry ship. Hydrostatic Graph of the 500 DWT Ro-Ro Ferry are shown in Figure 5.

The CSA chart shows the area under the waterline. This area extends from the vertical line of the FP bow to the vertical line of intersection with the backwater line (also known as the length water line). Observations from the CSA graph reveal the wet area exposed to water. This area can be used as a consideration for determining the damage zone where the object is directly exposed to water. The widest area is in the midship based on the CSA chart. Meanwhile, the area of the bow and stern decreased due to the shape of the ship. Curve Surface Area of the 500 DWT Ro-Ro Ferry are shown in Figure 6.

The damage leakage zone is determined between each transverse bulkhead, and the distance between each bulkhead is measured on the basis of the tank arrangement. A leak zone table is obtained considering the bowed position of Zone 1. The establishment of damage cases is realized by filling in the damage cases tab in the Maxsurf software by creating a new case with a name according to the leaked compartment. Damages Zone are shown in Table 2.

Leakage planning for oil tankers is regulated by MARPOL Annex 1 (Regulation for the prevention of pollution by oil), Chapter 4 Part A, regulations 24 and 28 regarding damage assumption. Leak zone simulation are shown in Figure 7.

Damage lightship condition. The condition of the empty ship comprises the components of a 320-ton lightship carrying a weight of the hull construction ship material. Main engine 2 contains units weighing 3 tons each and is located in the engine room. The calculation results are divided into the following three positions: after, midship, and forward damage. The calculation results Damage Case After Lightship are presented in the following.

Overall the calculation of Damage case After Lightship fulfills the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 3.

The calculation of the Damage Case of Midship Lightship Meets the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 4.

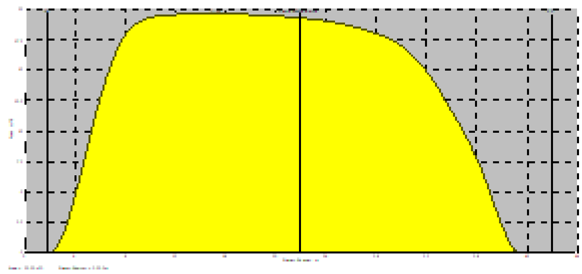
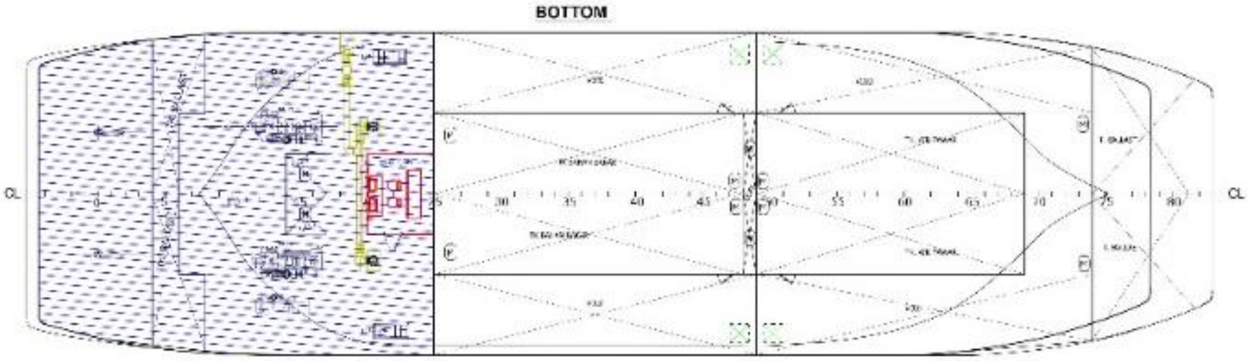


Figure 6. Curve Surface Area of the 500 DWT Ro-Ro Ferry

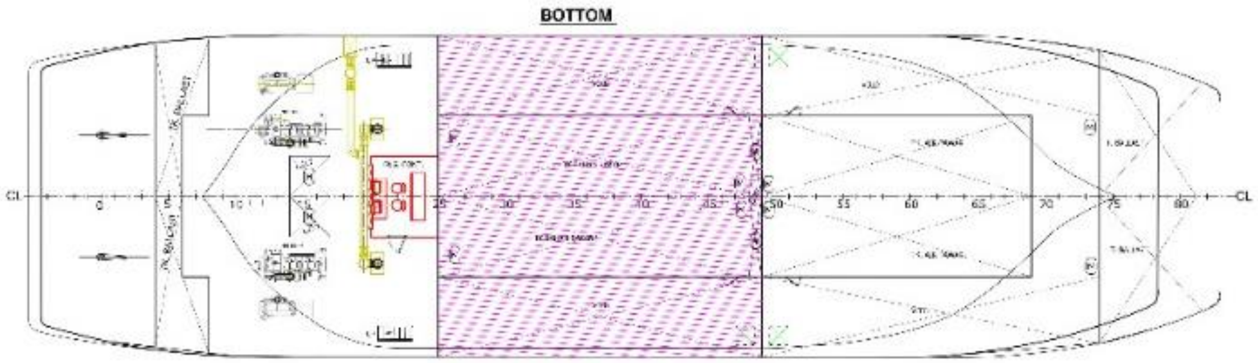
Table 2. Damages Zone

No	Room	After	Midship	Forward
1	Ballast tank 1 (after)	Damage		
2	Ballast tank 2 (after)	Damage		
3	Oil tank 1		Damage	
4	Oil tank 2		Damage	
5	Fresh water tank 1			Damage
6	Fresh water tank 2			Damage
7	Void 1 (S)		Damage	
8	Void 1 (P)		Damage	
9	Void 2 (S)			Damage
10	Void 2 (P)			Damage
11	Ballast tank 1 (Fore)			Damage
12	Ballast tank 2 (Fore)			Damage
13	Engine room	Damage		

After Zone



Midship Zone



Forward Zone

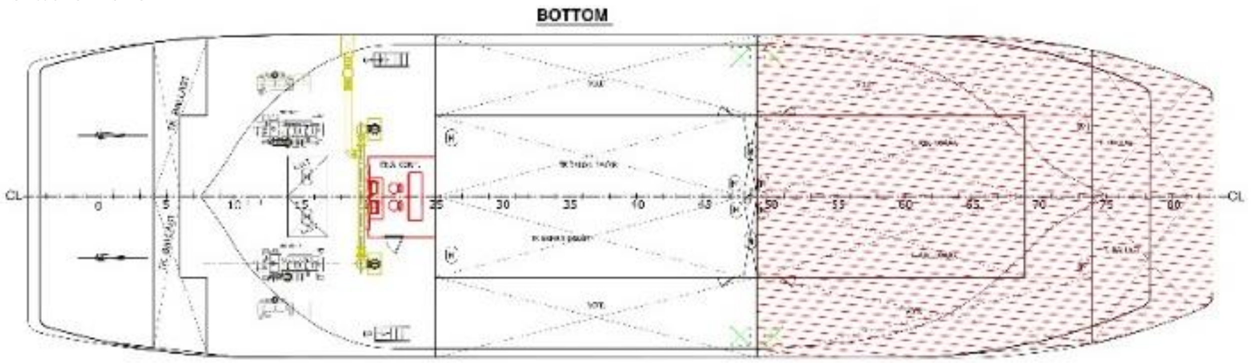


Figure 7. Leak Zone Simulation

Table 3. Damage Case After Lightship

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	4,166	Pass
Range of positive stability in int stages	7,0	deg	126,5	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	37,25	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	37,25	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	4,166	Pass
Lifting heeling arm	0,000	m	4,166	Pass
Wind heeling arm	0,000	m	4,166	Pass

The calculation of the Damage Case of Forward Lightship meets the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 5.

Table 4. Damage Case of Midship Lightship

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	3,996	Pass
Range of positive stability in int stages	7,0	deg	127,600	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	31,497	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	31,497	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	3,996	Pass
Lifting heeling arm	0,000	m	3,996	Pass
Wind heeling arm	0,000	m	3,996	Pass

Table 5. Damage Case of Forward Lightship

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	3,972	Pass
Range of positive stability in int stages	7,0	deg	126,000	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	35,412	Pass
	0,4297	m.deg	35,412	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	3,972	Pass
Lifting heeling arm	0,000	m	3,972	Pass
Wind heeling arm	0,000	m	3,972	Pass

Table 6. Damage Case After Departing Without Payload Condition

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	2,247	Pass
Range of positive stability in int stages	7,0	deg	142,400	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	193,716	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	193,716	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	2,247	Pass
Lifting heeling arm	0,000	m	2,247	Pass
Wind heeling arm	0,000	m	2,247	Pass

Damage case of departing without payload condition. The scenario condition of the second position of the ship lies in a state of departure without cargo. The additional compartments in the first condition are as follows: fuel tanks 1 and 2 with a capacity of 23,949 tons each and freshwater tanks 1 and 2 with a capacity of 32,732 tons each. The calculation results of damage stability in three positions can be observed in the following table.

The calculation of Damage Case After Departing Without Payload condition meets the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 6.

The calculation of the Damage Case of Midship Departing Without Payload condition meets the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 7.

The calculation of the Damage Case of Forward Departing Without Payload Condition meet the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. Range of positive stability in int stages. The calculation results are shown in Table 8.

Damage to full truck and full car. The cargo of the ship is included in full space; that is, the car deck contains 12 trucks, 7 small cars, 202 passengers, and 18 crew. The weight of 1 unit truck is 8 tons, while 1 small car weighs 2.5 tons. The ship also has four void tanks located on the right and left of the double bottom. The weight of the void tanks is 52.8 tons each. Ballast tanks 1 and 2 each have a mass of 2.01 tons. The total load case based on the condition of the ship is full of 1021,430 tons.

The calculation of Damage Case After Full Load Condition meet the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. . The calculation results are shown in Table 9.

The calculation of Damage Case Midship Full Load Condition meet the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. The calculation results are shown in Table 10.

The calculation of the Damage Case Forward Full Load Condition does not meet the value of the criteria set by IMO SOLAS Chapter II-1 Part B Regulation. Range of positive stability in int stages. The calculation results are shown in Table 11.

Table 7. Damage Case of Midship Departing Without Payload Condition

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	2,071	Pass
Range of positive stability in int stages	7,0	deg	179,0	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	16,7270	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	16,7270	Pass

Table 8. Damage Case of Forward Departing Without Payload Condition

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	1,888	Pass
Range of positive stability in int stages	7,0	deg	−87,340	Fail

Table 9. Damage Case After Full Load

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	1,859	Pass
Range of positive stability in int stages	7,0	deg	141,8	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	18,541	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	18,541	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	1,859	Pass
Lifting heeling arm	0,000	m	1,859	Pass
Wind heeling arm	0,000	m	1,859	Pass

Table 10. Damage Case Midship Full Load

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	1,799	Pass
Range of positive stability in int stages	7,0	deg	143,2	Pass
GZ curve-Class I-ONE COMP DMG	0,8594	m.deg	17,504	Pass
GZ curve-Class II, III-ONE COMP DMG	0,4297	m.deg	17,504	Pass
Value of max. GZ above heeling arm- multiple heel arms				Pass
Pass crowding heel arm	0,000	m	1,799	Pass
Lifting heeling arm	0,000	m	1,799	Pass
Wind heeling arm	0,000	m	1,799	Pass

Table 11. Damage Case Forward Full Load

Criteria	Value	Units	Actual	Status
Value of max. GZ in int stages	0,050	m	1,664	Pass
Range of positive stability in int stages	7,0	deg	−82,37	Fail

4. Conclusions

A 500 DWT Ro-Ro ferry ship is divided into three scenarios based on the calculation of damage stability (SOLAS 2009 Consoled Edition Chapter II-1 part B-1). The first scenario is a lightship compartment, the second is a departing position without cargo, and the third is a fully loaded ship. Each scenario is further divided into three damage cases: after, midship, and forward cases. The damage stability assessment is based on the GZ value (0.05 m standard) and the range of positive stability (7.0° standard) in the intermediate stages. Considering the ship's scenario in a lightship condition value of max GZ in intermediate stages, each damage case is 4166, 3996, and 3972 m, which are declared in PASS status. Meanwhile, the range of positive stability in the intermediate stages of the damage case is 126.5, 127.6, and 126.

In the second scenario, the ship is in the departing position without cargo, and the max GZ value in the intermediate stages of the damage case is 2247, 2071, and 1888 m, which is declared PASS. The range of positive stability in the intermediate stages of the damage case is 142.4, 179, and −87.34. One of the forward damage cases is declared FAIL because the value does not match the standard.

The last scenario is the ship's condition with a full cargo value of max GZ in the intermediate stages of damage case, which is consecutively 1859, 1799, and 1664 m and is declared PASS. The range of positive stability in the intermediate stages of a damage case is 141.8, 143.2, and −82.37. In the forward damage case, FAIL does not match the standard value in the forward damage case.

The overall GZ value is included in the standard based on the calculation results of the damage stability of the Ro-Ro ferry. Special attention must be provided to the range of positive stability in intermediate stages in the forward position damage case when the ship departs and the full load experiences failure.

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