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Patrol Boat Strengthening Against a Collision with COLL Notation Based on Class Rules and Regulation in Indonesia - An Overview

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Abstract
Indonesian maritime security and law enforcement rely frequently on Patrol boats. However, collisions can occur during the operation, leading to potential loss of life, damage to the ship, and environmental harm. In preventing such incidents, the government needs to strengthen the patrol boats against collisions in accordance with class rules and regulations in Indonesia. The COLL notation is an additional notation for vessel collision protection, which specifies the required strength of the vessel's hull and structural components to minimize the risk of damage and reduce the consequences of a collision. This study highlights the key areas that require strengthening, including the vessel's bow, stern, and hull, as well as the propulsion system that needs to be considered in the design stage. The addition of collision bulkheads, increasing the hull plating thickness, and reinforcing the engine mounts and shafting are also necessary to ensure the vessel's safety against collision. In conclusion, strengthening patrol boats against a collision with COLL notation based on class rules and regulations in Indonesia is one of the methods available that can be applied for the design stage to increase the level of operational safety of patrol boats.

1 Introduction

Patrol boats play a crucial role in ensuring maritime security and law enforcement in Indonesia. With its vast maritime domain, Indonesia relies heavily on patrol boats to protect its territorial waters, prevent smuggling and illegal fishing, and combat piracy. Moreover, the surrounding waters of Indonesia, known for its archipelago, are prone to incidents of collision due to the complex maritime traffic flows [1]. Therefore, it is crucial to strengthen patrol boats against collision in compliance with class rules and regulations in Indonesia. The COLL notation, an international standard for vessel collision protection, specifies the required strength of the vessel's hull and structural components to minimize the risk of damage and reduce the consequences of a collision. The Indonesian class rules and regulations for patrol boats cover all aspects of vessel design, construction, and operation, including strengthening the vessel against collision. These rules and regulations are based on international standards and best practices and are regularly updated to

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ensure that they reflect the latest developments in the field. Compliance with these rules and regulations is mandatory for all new or existing vessels operating in Indonesian waters. Indonesian Classification Bureau, which is BKI, formulated the COLL notation as an additional notation in Rules for Classification and Construction Part 1, Volume II Section 35 [2].

This article focuses on crucial elements that need to be strengthened and covers several important areas of the ship. These key locations include the stern, bow, and hull, each of which is essential to the overall structural integrity. Additionally, the propulsion system, a vital component that determines the vessel's mobility and maneuverability, is being strengthened with focused attention. Additionally, the inclusion of collision bulkheads becomes a necessity to strengthen the vessel's resistance to impacts. The vessel's resistance in collision situations is greatly increased by this strategic addition, acting as a protection. Furthermore, the careful process of increasing hull plate thickness gains significance because it directly affects the ship's capacity to endure external stresses and forces. Along with these precautions, strengthening the engine mounts and shafting stands out as a crucial step in assuring the safety of the vessel. These parts, which are crucial to the ship's mechanical and propulsion systems, must be reinforced to guard against potential weaknesses that can jeopardize its security and functionality. These extensive improvements and reinforcements work together to create a strong and secure vessel that can navigate through potential collision risks while assuring the safety of its passengers and cargo.

Several studies have been conducted on ship strengthening against a collision, including the use of numerical simulations and experimental tests [3-16]. Researchers have conducted a numerical analysis to examine the collision protection of a patrol boat, with a particular emphasis on the collision response [17]. Furthermore, other researchers conducted a series of numerical parametric studies to analyze collisions involving cylindrical structures and various types of impactors [9]. Despite the deformed object having a different shape than a typical fast patrol boat hull, the research provides a comprehensive understanding of the numerical procedures applied in collision cases. Additionally, several studies have focused on experimental tests to evaluate the performance of a reinforced patrol boat in collision scenarios [18][19]. This study aimed to investigate the impact of collision energy absorption on hull deformation and damage. The findings may propose energy-absorbing structures that can reduce collision forces and ensure the safety of the crew and passengers on board.

Jung et al. [20] formulated a numerical model to replicate the collision between a patrol boat and another vessel. Their investigation delved into the impacts of the vessel's velocity and collision angle on hull deformation and structural impairment. The outcomes underscored the notable influence of the collision angle on the vessel's reaction, demonstrating that fortifying the vessel's bow and keel could enhance its collision resilience. In a separate study, Harris et al. [21] examined a procedural framework for analyzing ship collisions through the utilization of a simplified analytical approach applied to colliding vessels. In this context, the evaluation of collision frequency was executed for a designated route, encompassing pertinent traffic data, as discussed by Otto et al. [22].

Yu et al. [23] proposed an innovative technique for optimizing the design of collision protection systems for patrol boats. They harnessed genetic algorithms to determine the optimal design parameters while considering factors such as the vessel's structural integrity, weight, and cost. Their findings underscored the efficacy of the proposed methodology in enhancing the vessel's collision resistance, all the while minimizing the weight and cost of the protection system. Furthermore, an investigation regarding work hardening and strain rate is expounded upon [24]. Notably, amid a research landscape predominantly focused on the structural strength of metamaterials, Mouritz et al. [25] emphasize the pivotal role of advanced composite structures in naval vessels. By possessing safety factors ranging from 4 to 10 and substantial strength-to-weight ratios, these materials are progressively gaining importance as potential substitutes for metal materials, thereby fulfilling future safety prerequisites. In certain scenarios, corroded steel structures may diminish the structural response during collisions [26].

Compliance with class rules and regulations is critical for ensuring the safety of patrol boats against collision. The Indonesian class rules and regulations cover all aspects of vessel design, construction, and operation, including strengthening the vessel against collision. None of the papers mentioned above specifically review the class notation procedure for the fast patrol boat. As a result, this paper aims to provide an overview of the crucial areas that necessitate strengthening and emphasizes the significance of adhering to regulations and notations in order to ensure compliance. Compliance with the Indonesian class rules and regulations and the COLL notation is an additional notation that applies to all vessels operating in Indonesian waters. The criteria for assigning the "COLL" notation, which assesses a ship's ability to withstand potential damage while preserving its structural integrity, are presented.

2 Fast patrol boat design constraint

Several parameters restrict the design specifications for fast patrol boats in order to ensure the best performance, safety, and operating capabilities. In the design stage, the parameters need to be determined, such as size and weight, speed, seakeeping, range and endurance, payload and mission equipment, crew safety and comfort, structural strength, and maneuverability. These requirements can be addressed by the physical design of the craft, which can lead to the operational limit for fast patrol boats. These limitations are governed by operational restrictions relating to structure capacity, crew capacity, and installed power, as shown in Figure 1a below. Then, an example of the use of a 32-meter patrol boat, frequently employed in patrols for monitoring illegal fishing, is illustrated in Figure 1b.

a b

Figure 1. (a) Illustration of operational restriction of fast patrol boat, (b) Illustration of operational of fast patrol boat in Indonesia [27]

Designing a fast patrol boat involves carefully considering and balancing these design constraints to meet operational requirements while ensuring safety, performance, and reliability. Designers need to conduct extensive analysis, simulation, and testing to validate the design parameters and ensure that the final vessel meets the desired operational criteria. One of the design constraints that designers must meet is ensuring that the structure's bottom panel of a fast patrol boat can withstand the slamming load, particularly in rough seas. Strengthening the bottom panel area of the boat is also necessary to handle the repetitive slamming loads resulting from the momentum of the boat's speed. In a numerical analysis conducted by Muryadin et al. [27], the slamming load was applied to the bottom panel. The analysis utilized a specific pressure range and duration to test the strength of the bottom panel.

3 Review on collision class notation (COLL) for Indonesian water territory

Ships that have reinforced side structures to withstand collisions may receive additional notations of "COLL" with index numbers ranging from 1 to 6, added to their Classification Character. The index numbers are determined by comparing the critical deformation energies of the strengthened side structure to those of a single-hulled ship without any strengthening or ice strengthening. The critical deformation energy is the energy level that, when surpassed during a collision, is expected to cause a critical situation. The index numbers are assigned based on the characteristic ratio C* of the critical deformation energies, as shown in Table 1 below. In special circumstances, "COLL" notations higher than "COLL 6" may be assigned if the design and construction of the ship justify it. In order to assign a "COLL" notation to a ship, the vessel must have adequate residual longitudinal strength while in a damaged condition. Critical situations may occur during the operation, such as the tearing up of cargo tanks, resulting in the leakage of oil, chemicals, and other hazardous materials. Additionally, water ingress into dry cargo holds while transporting valuable or dangerous goods, as well as the tearing up of fuel oil tanks causing fuel oil leakage, are also examined.

Table 1. COLL-Notation [1]

C*	"COLL"-Notation
2	COLL 1
3	COLL 2
4	COLL 3
6	COLL 4
10	COLL 5
20	COLL 6

3.1 Collision scenario

To determine the assumption in a collision scenario, ships with similar displacement and design draughts as the struck vessel will be considered striking ships. The bow shapes are one of the parameters that need to be considered for the computation. Two bow shapes will be examined: Bow Shape 1, which features a raked bow contour without a bow bulb, and Bow Shape 2, which has a raked bow contour with a bow bulb. The computational analysis did not include extremely fully shaped bow configurations. Multiple collision scenarios for both Bow Shape 1 and Bow Shape 2 were examined, with a focus on analyzing the performance of strengthened and non-strengthened side structures. The collision cases cover the design and ballast draughts of the ships involved in the accidents. The key factor in determining the deformation energy is the draught differentials (ΔT) between the colliding ships, illustrated in Figure 2 below.

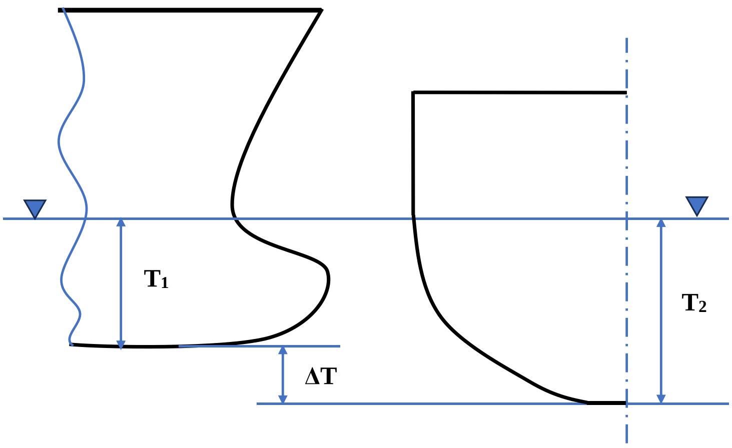

Figure 2. Draught differential ΔT between collision of two ships

The collision scenarios that are determined by the draught differentials [1] are formulated below:

Collision case 1

$$\Delta T_1 = T_{2max} - \frac{3.T_{1min} + T_{1max}}{4} \quad (1)$$

Collision case 2

$$\Delta T_2 = T_{2max} - \frac{T_{1min} + 3.T_{1max}}{4} \quad (2)$$

Collision case 3

$$\Delta T_3 = \frac{T_{2min} + 3.T_{2max}}{4} - T_{1max} \quad (3)$$

Collision case 4

$$\Delta T_4 = \frac{3.T_{2min} + T_{2max}}{4} - T_{1max} \quad (4)$$

where,

T_{1max} is the design draught of the striking ship, T_{1min} is the ballast draught of the striking ship, T_{2max} is the design draught of the struck ship, and T_{2min} is the ballast draught of the struck ship.

3.2 Calculation of the Deformation Energy

The deformation energy was calculated using a BKI-approved Method. If the bow and side structures are found suitable, the Minorsky approach might be accepted for high-energy collisions. However, the Minorsky approach might need to provide accurate findings for collisions with low energies. The ultimate loads of the bow and side structures in the impacted area, as well as their interactions, are taken into account in the analysis of these collisions. The ideal elastic-plastic material behaviour assumption serves as the foundation for the computations of ultimate loads. The mean value of the lowest nominal upper yield point and the tensile strength used to calculate the limit stress (R_{UC}) [1] are as follows:

$$R_{UC} = \frac{1}{2}(R_{eH} + R_m) \quad (5)$$

where,

R_{eH} is a hull structural steel with a minimum nominal upper yield point of steel R_{eH} of 235 N/mm^2, and R_m is the tensile strength of the hull structure with steel materials. The estimation of the shell's elongation at fracture was at 5%.

The calculation of deformation energy [1] uses the equation below:

For bow shape 1:

$$\overline{E_{01}} = \frac{1}{8}\left[E_{01,1} + 3.E_{01,2} + 3.E_{01,3} + E_{01,4}\right] \quad (6)$$

$$\overline{E_{11}} = \frac{1}{8}\left[E_{11,1} + 3.E_{11,2} + 3.E_{11,3} + E_{11,4}\right] \quad (7)$$

For bow shape 2:

$$\overline{E_{02}} = \frac{1}{8}\left[E_{02,1} + 3.E_{02,2} + 3.E_{02,3} + E_{02,4}\right] \quad (8)$$

$$\overline{E_{22}} = \frac{1}{8}\left[E_{22,1} + 3.E_{22,2} + 3.E_{22,3} + E_{22,4}\right] \quad (9)$$

Where,

$E_{01,i}$ = deformation energy for un-strengthened ship, bow shape 1, collision case i, i = 1~4
$E_{11,i}$ = deformation energy for strengthened ship, bow shape 1, collision case i, i = 1~4
$E_{02,i}$ = deformation energy for un-strengthened ship, bow shape 2, collision case I, i = 1~4
$E_{22,i}$ = deformation energy for strengthened ship, bow shape 2, collision case i, i = 1~4

Depending on the deformation energies determined for various collision scenarios, the average values of the critical deformation energies for both strengthened and unstrengthened side structures. For the calculation of the mean values of critical deformation energies for the evaluation, weighting factors are taken into account. With regard to both Bow Shape 1 and Bow Shape 2, as well as for collision scenarios 1 through 4, specific formulas below are used to calculate mean critical deformation energies.

Assessing the structural integrity and crashworthiness of ships is accomplished by the calculation of ratios of the mean critical deformation energies for ship collision. These ratios indicate the ability of a ship's structural elements to disperse and absorb energy during a collision occurrence. Significant forces are applied to the hull structures of two ships during collisions, which could result in deformation or damage. The amount of energy that the ship's structure can absorb before suffering significant deformation or failure is referred to as critical deformation energy. A comparison of various ship designs or structural configurations can be made by determining the ratios of mean critical deformation energies. The following formulas should be used to get the mean critical deformation energy ratios [1]:

For bow shape 1:

$$\overline{C_1} = \frac{\overline{E_{11}}}{E_{01}} \quad (10)$$

For bow shape 2:

$$\overline{C_2} = \frac{\overline{E_{22}}}{E_{02}} \quad (11)$$

The characteristic ratio C* of deformation energy for the ship is the mean value resulting from the two weighted ratios $\overline{C_1}$ and $\overline{C_2}$ of the mean critical deformation energies. The characteristic ratio of deformation energy refers to a dimensionless parameter used to assess the severity of the collision. It is calculated by dividing the total deformation energy absorbed during the collision by the initial kinetic energy of the striking vessel. This ratio provides insights into the energy dissipation and structural damage caused by the collision. A higher characteristic ratio indicates a greater amount of energy absorbed during the collision, suggesting a more severe impact and potential for significant structural damage. The following formula is used to calculate the characteristic ratio C*:

$$C^* = \frac{1}{2}(\overline{C_1} + \overline{C_2}) \quad (12)$$

3.2 Critical collision speed

The maximum speed at which a ship might collide with anything or another ship without causing serious structural damage or endangering its integrity is known as the critical collision speed. By taking into account things like the ship's structural strength, energy absorption capability, and collision resistance, it aids engineers and naval architects to in calculating the maximum safe operating speeds for boats in various scenarios. Additionally, it assists in constructing ships that are able to withstand impact forces and reduce the possibility of catastrophic damage, safeguarding the environment, crew, and cargo.

The following formula [1] determines the critical collision speed:

$$V_{cr} = 2{,}75 \sqrt{\frac{E_{cr}}{m_2}\left[1 + \frac{m_2}{m_1}\right]} \quad (13)$$

where,

V_{cr} is the critical collision speed in knot, E_{cr} is deformation energy, once the critical speed has been reached in Kj, m_1 is the mass of the striking ship, including 10% hydrodynamic added mass in ton, and m_2 is the mass of the struck ship, including 40% of hydrodynamic added mass. When calculating the critical speeds for collision cases, the assumption is made regarding the draughts of the ships involved. These following equations [1] assumed draughts serve as reference points for evaluating the collision dynamics and structural response:

Collision case 1

$$T_1 = \frac{3.T_{1min} + T_{1max}}{4} \quad (14)$$

$$T_2 = T_{2max} \quad (15)$$

Collision case 2

$$T_1 = \frac{T_{1min} + 3.T_{1max}}{4} \quad (16)$$

$$T_2 = T_{2max} \quad (17)$$

Collision case 3

$$T_1 = T_{1max} \quad (18)$$

$$T_2 = \frac{3.T_{2max} + T_{2min}}{4} \quad (19)$$

Collision case 4

$$T_1 = T_{1max} \quad (20)$$

$$T_2 = \frac{T_{2max} + 3.T_{2min}}{4} \quad (21)$$

where,

T_{1max} is the design draught of the striking ship, T_{1min} is the ballast draught of the striking ship, T_{2max} is the design draught of the struck ship, and T_{2min} is the ballast draught of the struck ship.

For the collision cases 1 to 4, the average value of the critical speeds determined for different collision scenarios or a range of operating conditions determined by the mean critical speed $\overline{V_{cr}}$ for both bow shapes with the following formula [1]:

For bow shape 1

$$\overline{V_{cr1}} = \frac{1}{8}[V_{1cr1} + 3.V_{1cr2} + 3.V_{1cr3} + V_{1cr4}] \quad (20)$$

For bow shape 2

$$\overline{V_{cr2}} = \frac{1}{8}[V_{2cr1} + 3.V_{2cr2} + 3.V_{2cr3} + V_{2cr4}] \quad (21)$$

Where,

V_{1cri} is the critical speed for bow shape 1 with collision case i, i = 1 to 4. The V_{2cri} is the critical speed for bow shape 2 with collision case i, i = 1 to 4. The critical speed characteristic for ship collision refers to the specific speed at which a vessel is deemed to be critically vulnerable to collision impacts. According to the formula below [1], the mean value of the two weighted speeds, $\overline{V_{cr1}}$ and $\overline{V_{cr2}}$, provide the crucial speed characteristic for the ship:

$$V^*{}_{cr} = \frac{1}{2}(\overline{V_{cr1}} + \overline{V_{cr2}}) \tag{22}$$

Table 2. Minimum values for the mean critical speed V^*_{cr} [1]

"COLL" - Notation	V^*_{cr} (kn)
COLL 1	1.0
COLL 2	1.5
COLL 3	2.5
COLL 4	4.0
COLL 5	5.5
COLL 6	7.0

To qualify for the "COLL" Notation assignment, the ship must meet or exceed the minimum values for critical speed V^*_{cr}, as specified in Table 2. These minimum values of critical speed serve as criteria for evaluating the ship's ability to withstand collision impacts. The "COLL" Notation will be assigned based on the characteristic ratio of deformation energy, and minimum values of the mean critical speed should be met to provide assurance that the vessel has been designed and constructed to meet the required standards for collision safety.

4 Validation study: Experimental works as benchmarking of collision energy

The collision phenomenon has two main characteristics, namely the external dynamics and the internal mechanics [28]. In the fast patrol boat collision test model, the external dynamic is related to the energy released by the crushed, ship which is mostly the illegal fishing vessels modeled with the V-impactor with various weights. Meanwhile, the internal mechanics' reaction of the fast patrol boat body hull will be represented by the stiffened panels with the real scale used. By employing the collision procedures defined by the class, testing activities can be conducted to obtain the actual performance of the side shell structure of a patrol boat. The tests can be carried out using a commonly used drop mass impact testing facility, which is employed to assess the crashworthiness of a structure. Figure 3 shows the experimental work on the side shell structure of a 50 m fast patrol boat [29].

Figure 3. Experimental study on side shell structure of fast patrol boat

The test was initiated by following the procedure above. The test model was created using the same geometry as the side shell structure. In a simplified curved side hull, it was idealized as a flat panel. The segmented shell was defined between the double bottom and main deck, from web frame to web frame. During the test, there are limitations in replicating the exact collision energy. Therefore, the height and weight of the striker were maximized to establish a baseline for predicting the potential response under higher collision energies.

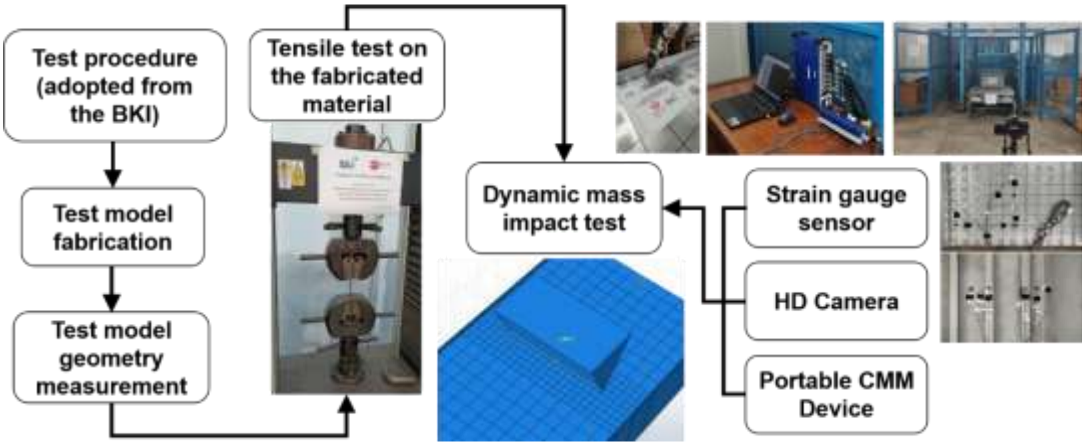

Figure 4. Further experimental study on side shell structure of fast patrol boat

The detailed procedure is provided in Figure 4. It includes a series of procedures for an extensive examination of the behavior and response of the side shell structure in dynamic situations using a test model. After the test model is fabricated, precise measurements using a Coordinate Measuring Machine (CMM machine) will be used to measure the 3D point location of each grid line that has been drawn on the surface of the test model. The experimental inquiry will be using various impact tests conducted using a 5-panel model with various weights of the striker ranging from 250 kg to 500 kg. This planned range of tests facilitates an in-depth study of the structural reaction under a range of impact scenarios, hence deepening the findings obtained. Data acquisition is utilized to record strain gauge readings attached to the surface of the structural member to obtain the structural response during the test. These sensors make it possible to record complex strain distributions in real time, revealing the dynamic interaction between external forces and structural reactions. Following impact testing, a crucial evaluation of the structural deformation profile takes place. The use of a portable CMM, a device that painstakingly measures the level and type of deformations displayed by the test model, facilitates this process. This crucial phase increases the study's accuracy by giving precise quantitative data on the deformations that were sustained. Moreover, An HD camera with slow-motion capability is purposefully employed to enhance the comprehensive recording of the dynamics of the impact test. This method of visual documentation clearly illustrates the motion and behavior of the impact test, enhancing the research with a real visual illustration of the dynamic forces in motion.

5 Conclusions

This study reviews the adoption of the regulations outlined in the BKI Rules for Classification and Construction, specifically concerning the Strengthening Against Collision. These regulations aim to enhance the safety of patrol boats against accidental limit loads. The results provide a comprehensive understanding of fulfilling the COLL-notation class requirements. In particular, an experimental test is proposed to validate the class procedure for assessing the ship's construction. The test indicates that the procedure is feasible and can be implemented effectively to evaluate the structural response of the fast patrol boat structure.

Several important recommendations for future research and practical applications emerge from the findings of this study. Testing protocol improvement in the future work could enhance test variables like impact velocities, angles, and positions for a comprehensive structural assessment, while advanced equipment and measurement techniques may further elevate data precision in experimental trials. The combination of computer modeling and simulation with experimental techniques has immense potential. Almost all collision possibilities could be realistically investigated by precise numerical models, optimizing the depth of the investigation and saving time and money. Dynamic response under multi-impact scenarios investigating the fast patrol boat's dynamic response under multiple impacts offers an interesting angle for additional research. Investigating the cumulative effects of many hits or impacts coming from various angles may reveal potential weaknesses that could manifest in complicated collision scenarios.

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