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Probability of Deck Wetness and Bottom Slamming due to Height and Wave Directions on Klotok Boat

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***Abstract*— Sailing safety is an important aspect that must be considered to ensure the safety of the crew and passengers. One aspect that affects sailing safety is the probability of deck wetness and bottom slamming on each ship. A research object is a traditional wooden boat hull operating on the Penjam - Balikpapan route that transports passengers and vehicles. The aim is to provide information regarding wave conditions that support the safe operation of klotok ships. In this study, the variations in wave arrival directions used are 45°, 90°, 135° and 180° with a ship speed of 8 knots, and variations in wave height are based on the sea state approach, namely sea state 1 (0.488 m), sea state 2 (1.006 m), sea state 3 (1.433 m), and sea state 4 (2.012 m). Furthermore, the m0 value is obtained as an important component to measure the occurrence of deck wetness and bottom slamming through an approximation formula and validated with the NORDFORSK 1987 criteria. The results of the study indicate that the highest probability value of deck wetness occurs in the direction of wave arrival 180° with a wave height at sea state 4 (2.102 m). While the highest probability value of bottom slamming occurs in 2 variations of wave arrival direction, namely 135° and 180^0. The wave height that must be considered in the direction of wave arrival 135° is 1.433 m and 2.012 m. Meanwhile, if the direction of wave arrival is 180°, the wave height that must be considered is 1.006 m, 1.433 m, and 2.012 m. With initial information on the potential for deck wetness and bottom slamming, it can be recommended that ships will tend to sail safely if waves arrive at 45^0 and 90^0 degrees, while immediately avoiding ship movements in the direction of waves at 135^0 and 180^0 degrees, especially at extreme wave heights. This condition will occur if the gravity concentration position is in the forecastle position. Meanwhile, if the gravity concentration position is at the stern, the passenger room and vehicle deck show a probability value that tends to be safe.**

Keywords—*bottom slamming, deck wetness, hull, wafe, wooden boat*

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I. INTRODUCTION

Indonesia is an archipelagic and maritime nation, making ships the most common means of transportation used by Indonesians for inter-island trade [1]. Shipping companies often experience conflicts of interest when operating maritime transport [2]. On the one hand, passengers desire cheap, fast, and safe transportation, while on the other, ship operators seek to maximize profits. As a result, ship operators often neglect ship safety and passenger safety [3]. A klotok is a small wooden boat equipped with a diesel engine [4]. In addition to carrying passengers and goods, a klotok can also transport two-wheeled vehicles [5]. This capability makes the klotok an alternative mode of transportation for Balikpapan residents who want to reach Penajam more quickly by vehicle [6].

The klotok is a mode of public sea transportation that does not yet fully meet classification standards. Many uncertain events occur, and probability is used to measure the likelihood of these events. Similarly, ship movement due to ocean waves must be taken into account, because knowing the extent of their influence will better ensure the safety of both the crew and passengers, as well as the vehicles being carried. One of the effects of ship movement is deck wetness and bottom slamming. Deck Wetness is a condition at sea where water rises to the ship's deck due to large-amplitude waves, which can cause water to enter the deck [7]. This condition is related to passenger comfort and ship safety, where the greater the wave amplitude, the higher the waves will rise [8]. Bottom slamming is a situation where part of the ship rises at the bow and is above the water surface, then falls back to its original position. This may occur repeatedly, which can affect the impact force [9]. Furthermore, ship operations are also greatly influenced by varying sea conditions. Sea conditions are divided into levels known as sea states. Sea states describe each different sea condition such as wind speed, wavelength, wave height, and wave period [10]. The sea state scale ranges from 0 (zero) to 9 (nine), where each

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level of sea state describes increasingly severe conditions such as increasing wave height [11].

Essentially, ships are designed to transport people and goods for operations at sea [12]. To achieve these goals, a ship must possess several basic characteristics: the ability to float upright, move at the speed indicated by the initial design, be strong enough to withstand the loads caused by bad weather, and be able to navigate in a straight line and maneuver on the high seas as well as in confined waters [9].

Ships sailing at sea are affected by various external forces, such as wave action, water currents, and wind [13]. Predicting ship motion influenced by all of these factors is very complex, so simplifications are needed with several assumptions to make this problem simpler and more solvable. In this study, it is assumed that sea waves influence ship motion, while other factors are ignored [14]. By performing calculations using software on regular waves with various wave headings: 45° (stern quartering), 90° (beam sea), 135° (bow quartering), and 180° (head sea), the potential for deck wetness and bottom slamming can be identified, allowing for improvements in the klotok ship's performance.

Based on the discussion above, the simulation of the Klotok ship is an important part to support the development of the Klotok ship to avoid the phenomena of deck wetness and bottom slamming, where the problem of water entering the deck and vibrations due to bottom slamming disrupts the comfort and safety of passengers, especially when the sea water is high tide [15]. This condition shows the importance of conducting an in-depth technical review to calculate the probability of deck wetness and bottom slamming and determine the maximum height of the ship that can sail according to the NORDFORSK 1987 criteria.

II. METHOD

A. *Ship Data*

This article will examine a wooden passenger boat, commonly known as a klotok, found in the Balikpapan area. The ship's main dimensions are shown in Table 1. The klotok's shape can be seen in Figure 1.

TABEL 1.
MAIN DIMENSION

List	Number	Unit
Length Over All (LOA)	15,4	m
Length Perpendicular (LPP)	12,6	m
Breadth (B)	2,9	m
Depth (H)	1,5	m
Draught (T)	1	m
Freeboard (F)	1,4	m
Service Speed	8	knot

To solve the problem in this research object, a strip theory approach was used. Strip theory is a semi-analytical approach that divides the ship's hull into longitudinal slices (strips along the longitudinal axis) and assumes that the hydrodynamic response of each strip can be calculated as a two-dimensional (2D) problem. This approach assumes :

- Potential fluid flow (inviscid, irrotational, incompressible)
- Small (linear) motion
- Wavelength relative to the strip dimensions

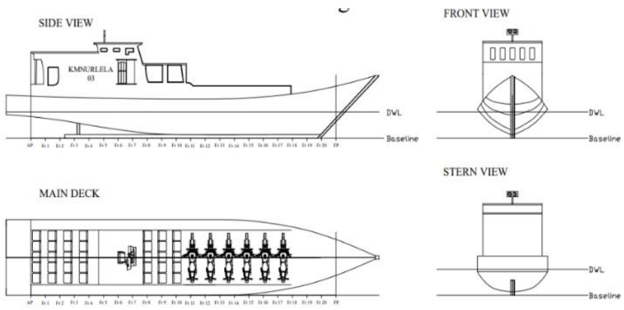

Figure 1. General Arrangement of Klotok

B. *Governing Equation*

For linear seakiping, the 6 DOF motion equation is used. For each frequency ω, the motion response of boat X can be determined using equation [16]

$$[-\omega^2 M_{total} + i\omega B(\omega) + C]\, X = F_{exc}(\omega)$$

Dimana,
M_{total} = M_{phys} + A (ω) : total mass (boat massa + added mass)
A (ω) = added mass matrix
B (ω) = radiation damping matrix
C = restoring force matrix
F_{exc} = wave excitation force
X = motion response [x, y, z, ϕ, θ, ψ] (surge, sway, heave, roll, pitch,yaw)

for the strip at X, the heave and pitch responses are calculated based on the wave pressure and potential functions [17]:

$$p\,(x, z, t) = -\rho \frac{\partial \Phi}{\partial t} - \rho g \eta$$

where,
Φ = speed protensial function
η = wave surfave elevation

for added mass (A) is calculated for each strip, then integrated along the ship with equation [18]

$$A_{ij} = \int_0^L a_{ij}(x)dx$$

For damping B_{ij} are also calculated per strip and integrated along the ship with the equation

$$B_{ij} = \int_0^L b_{ij}(x)dx$$

Meanwhile, the equation for the excitation force that works is;

$$F_j\,(\omega) \quad = \int_0^L f_j(x,\omega)dx$$

In this study, the angle of wave arrival will be varied, namely 45°, 90°, 135°, and 180°. Wave height is simplified with several assumptions using the reference sea state of Bhattacharyya, 1978 as in Table 2. In this study, it is assumed that only sea waves are a factor that influences ship movement, while other factors are considered not to have an influence.

TABLE 2.
SEA STATE [11]

Sea State	0	1	2	3	4	5	6	7	8	9
Wind Vel. (m/s)	1.029	4.373	6.945	8.231	9.774	12.347	13.376	25.208	27.780	30.609
Wave Height (m)	0.03	0.488	1.006	1.433	2.012	3.200	4.359	8.870	16.185	22.708
Average Periode (Sec)	0.5	2.3	3.6	4.3	5.1	6.4	7	10.7	14.5	15.9
Average Wave Length (m)	0.254	0.508	1.321	1.803	2.515	4.064	4.775	11.176	20.574	25.019

Next, the probability value is calculated using the NORDFORSK approach, 1987. According to the Criteria Rules General Operability Limiting Criteria for Ship (NORDFORSK, 1987), the maximum value for the Probability of Deck Wetness is 0.05 or 5%, while for the Probability of Bottom Slamming is 0.03 or 3%. The formula used is:

Probability of Deck Wetness $= Exp - (F^2/2(m_0))$ (1)
Probability of Bottom Slamming $= Exp - (T^2/2(m_0))$ (2)

Dimana,
F = *freeboard*
T = Draft (m)
m_0 = nilai *relative vertical motion* (m^2)

NORDFORSK 1987

The General Operability Limiting Criteria for Ships established by NORDFORSK 1987 as seen in Table 2, is generally a standard criteria rule or guideline used to evaluate the analysis of a ship's ability to handle waves, especially for merchant ships. This criteria rule serves to adjust the results of calculations that have been carried out and helps find the limits set by the rules [14].

TABEL 3.
GENERAL OPERABILITY LIMITTING CRITERIA

Description	Merchant Ship
RMS of Vertical Acceleration at FP	0.275 g (L≤100m) 0.095 g (L≤330m)
RMS of vertical acceleration at Bridge	0.15 g
RMS of lateral acceleration at Bridge	0.12 g
RMS of Roll	6.0 deg
Probability of Slamming	0.03 g (L≤100m) 0.01 g (L≤330m)
Probability of Deck Wetness	0.05

C. *Remote Location*

In seakeeping analysis, remote location is a step to determine the location of the center of gravity, which is the result of combining the center of gravity of the ship and its cargo [19]. In this article, 4 remote location points are simulated as described in Table 4.

TABLE 4.
REMOTE LOCATION

No.	Lokasi	Long.(m)	Offset (m)	Heigth (m)
1	Forecastle	12.00	0.00	2.40
2	Passenger Room	4.50	0.00	2.21
3	Vehicle Deck	8.54	0.00	2.10
4	Stern	0.00	0.00	2.31

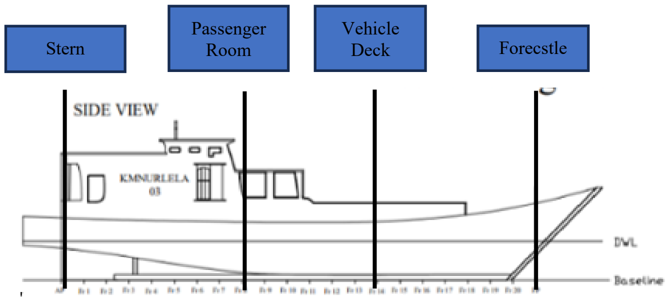

Figure 2. Tampilan *remote location*

D. *Wave Spectra*

The wave height variation data used in the study can be seen in Table 5. The wave spectrum applied uses Bretschneider parameters [20]. Where the equations that apply to these parameters are as follows:

$$S(f) = \frac{5}{16} H_s^2 \cdot \frac{1}{f^5} \cdot f_p^4 \cdot \exp\left(-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right)$$

Dimana,
$S(f)$: Energy Spectrum (m^2/Hz)
H_s : Significant wave heigth (m)
f : wave frequency (Hz)
f_p : maximum energy frequency (Hz)

TABLE 5.
WAVE SPECTRA

Sea State	Type	H_s (m)
1	Bretschneider Parameter	0.488
2	Bretschneider Parameter	1.006
3	Bretschneider Parameter	1.433
4	Bretschneider Parameter	2.102

III. RESULT AND DISCUSSION

3.1 Probabilitas Deck Wetness

The probability of deck wetness was measured at four remote control positions on the ship's main deck, namely at the stern, passenger compartment, vehicle compartment, and forecastle, with the same ship speed of 8 knots. Furthermore, all probabilities of deck wetness at each remote location were evaluated using the 1987 NORDFORSK standard of 5%. The computational simulation obtained the following probability calculation results:

A. Stern Position

The computational simulation results for the combined center of gravity concentration of the cargo and the ship's structure at the stern indicate a safe condition. This safe condition is demonstrated for four variations in wave direction and four variations in wave height. The safe value refers to the probability value for each variation not exceeding the 1987 NORDFORSK criterion of 5%. The probability distribution for each variation in wave height and direction at this position is shown in Figure 3.

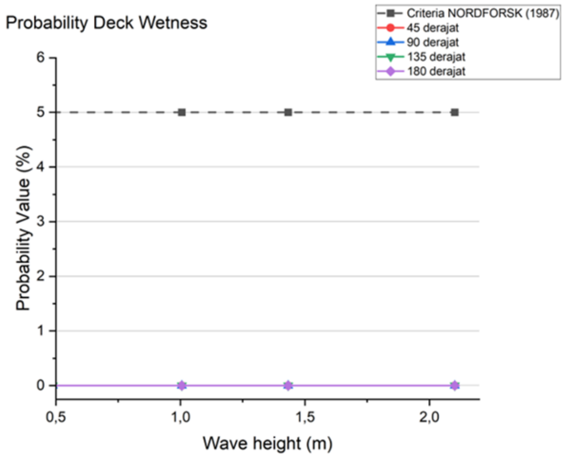

Figure 3. Deck Wetness Probability on Stern Position

B. Vehicle Deck

The deckwetness probability performance, with the center of gravity of the load and structure concentrated in the vehicle compartment, showed results that tended to be similar to those at the stern. The deckwetness probability value remained below the 5% tolerance limit of the 1987 NORDFORSK standard, as shown in Figure 4. With this value, the klotok vessel's voyage in this position is still safe, given the simulated wave direction and wave height.

3.

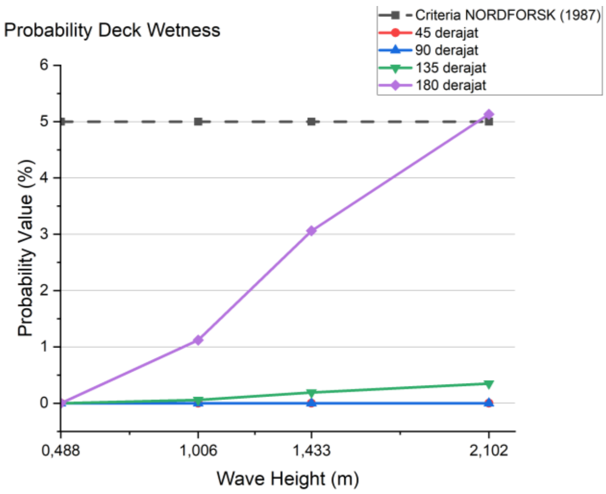

Figure 4. Deck Wetness Probability on Vehicle Deck

C. Passenger Room

The simulation of the remote location position in the passenger compartment shows the results of the calculation of the probability of safe deck wetness. The probability value is still below the 1987 NORDFORSK Standard. Low probability values are shown for each wave height variation, as seen in Figure 5.

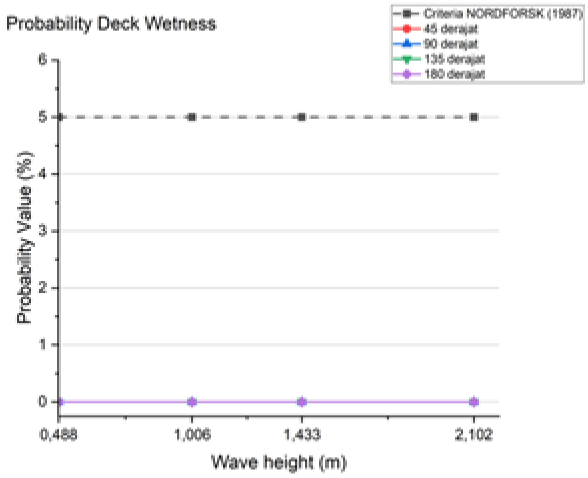

Figure. 5. Deck Wetness Probability on Passenger Room

D. Forecastle Deck

Simulation of deckwetness probability calculation at the remote control position in Forecastledeck shows different results compared to other remote control positions. One variation of the wave arrival direction, namely 1800, shows a higher probability value when compared to the tolerance limit of NORDFORSK 1987. In this wave arrival direction, the increase in probability value is directly proportional to the simulated wave height as seen in Figure 6. Meanwhile, other variations of wave arrival direction show values that are still safe at each variation of wave height.

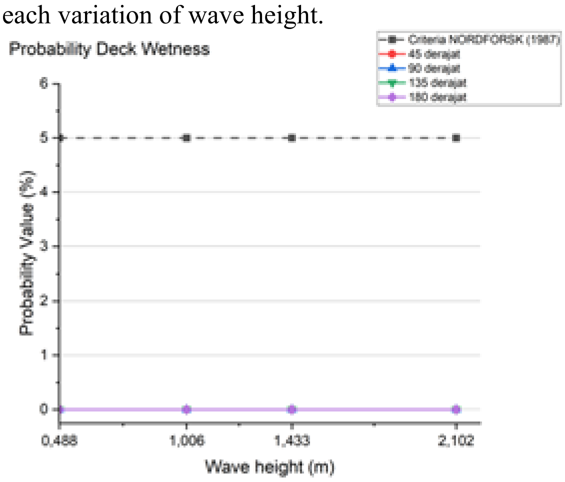

Figure 6. Deck Wetness Probability on Forecastle

3.2 Probability of Bottom Slamming

The probability of bottom slamming was measured at 4 remote control positions on the ship's main deck, namely at the stern, passenger compartment, vehicle compartment, and forecastle with the same ship speed of 8 knots. Furthermore, all probabilities of bottom slamming at each remote location were evaluated using the 1987 NORDFORSK standard of 3%. From the computational simulation, the following probability calculations were obtained:

A. Passenger Room

The simulation of bottom slamming performance on a klotok ship if the remote control point is set at the middle passenger deck position shows a bottom slamming probability value that is still below the

NORDFORSK 1987 criteria. Each variation in wave height and wave direction has a probability value below 3% as depicted in Figure 7.

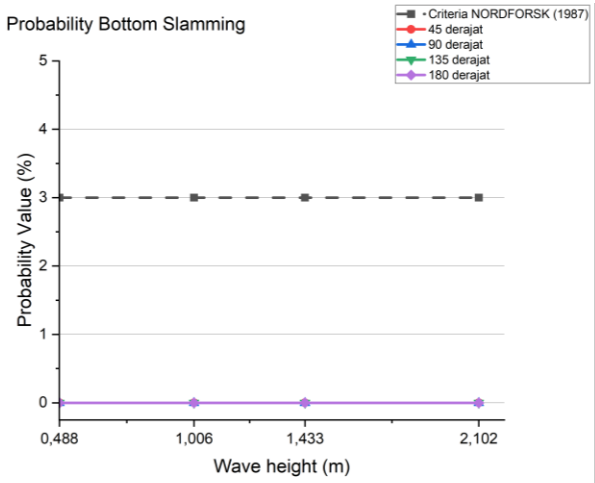

Figure. 7. Bottom Slamming Probability on Passenger Room

B. Stern Position

Meanwhile, for the bottom slamming performance on a klotok ship, if the remote control point is set at the rear deck position, it shows a bottom slamming probability value that tends to be the same as the previous variation, namely the probability value is still below the NORDFORSK 1987 criteria. Each variation in wave height and wave direction has a probability value below 3% as depicted in Figure 8.

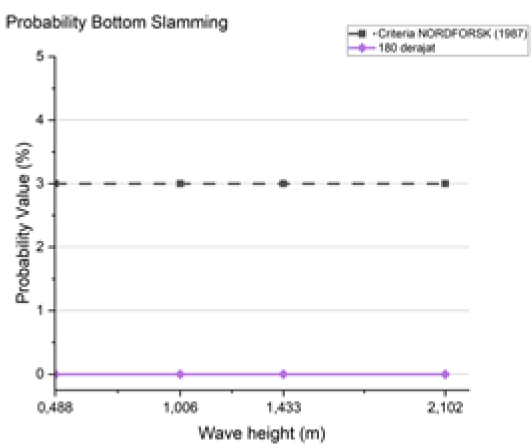

Figure. 8. Bottom Slamming Probability on Stern

C. Forecastle Deck

Another phenomenon occurs in the bottom slamming probability simulation if the remote control is placed on the forecastle deck. There are two directions of incoming waves that have the potential for bottom slamming, namely at the 1350 and 1800 wave directions as seen in Figure 9. It should be noted that bottom slamming will occur if the wave height is 1,433 m and 2,102 m. Meanwhile, at a wave height of 1,006 m, it still needs to be considered because the probability value is close to 3%.

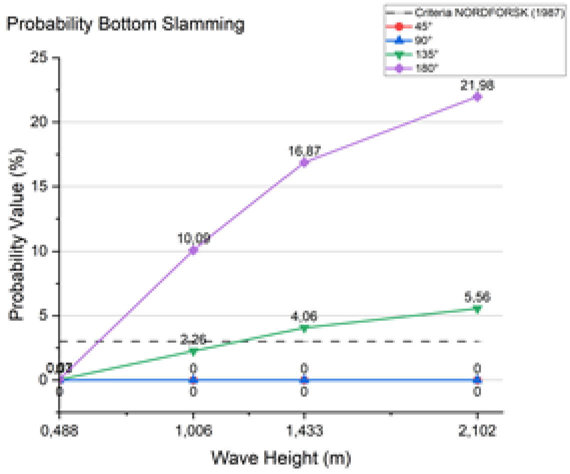

Figure. 9. Bottom Slamming Probability on Forecastle Deck

D. Vehicle Deck

The probability of bottom slamming with the remote control positioned on the vehicle deck remains safe. The probability values for each variation in wave direction and wave height remain below 3%. The probability of occurrence is even below 1%, as shown in Figure 10.

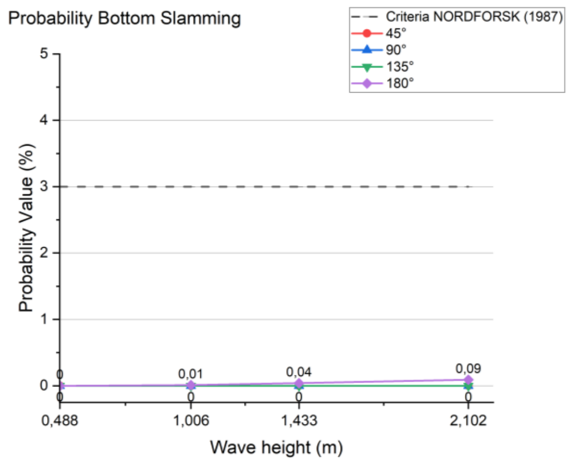

Figure. 10. Bottom Slamming Probability on Vehicle Deck

IV. CONCLUSIONS

Computational simulations of the traditional Klotok ship have been performed well, with the results demonstrating various phenomena. Of the four varying center of gravity positions for the ship and its cargo, the position on the forescattle exhibited unsafe deck wetness and bottom slamming performance, exceeding the standard probability values of 5% for deck wetness and 3% for bottom slamming (NORDFORSK 1987). Other positions, however, still showed safe conditions. Based on these simulation results, it is highly recommended to place the cargo on the main deck in the center.
However, variations in wave heights should be considered in this simulation, as they can cause deck wetness and bottom slamming in all locations. For your information, the load heights simulated in this study only used wave heights found in Balikpapan Bay.

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