Development of Minimum Bow Height Formula for Indonesian Waters

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Abstract: Freeboard was considered long ago as an important element of ship safety. It was recognized that in order to maintain seaworthiness ships must possess some amount of reserve buoyancy, i.e. some volume above the water-plane and below the watertight deck. Indonesian Bureau Classification, known as BKI (Biro Klasifikasi Indonesia) has authorized by the Government to carry out the survey and certification of load line. The study of minimum freeboard and bow height will be performed on ships register BKI for Indonesian waters are later become a reference in the calculation on load line. Bow height correction is performed based on probability of deck wetness analysis using strip theory. Both analysis of ship response (RAO) are performed at two positions are amidships position by beam sea condition that affect rolling motion and stem position by head sea condition that affect coupled motion of heaving and pitching. Probability of deck wetness was taken from the stern, amidships and particularly on stem position for 22 ship models. Development of the bow height calculation was modified using 4 scenarios that resulted linear regression formula of bow height minimum by ships length and wave height as parameters where the optimum results are in scenario 3 which assumes when the longer of the ships makes the wave higher and these results allow to reduce of bow height minimum up to 35 % from bow height minimum calculation according to Regulation 39 ILLC 1966 as amended Protocol 88.

Key words: freeboard, BKI, bow height, deck wetness, seakeeping, strip theory, beam sea, rolling, head sea, heaving, pitching

1. Introduction

Various kinds of marine transportation operating in indonesian waters to support the mobility both of people and goods, as well as a mode of transportation for connecting inter islands. Increased of national marine transportation activities will have an impact on the increasing incidents and accidents. It was shown by the high of ship accident in Indonesian waters. Based on the data from ministry of sea transportation during the period of 2007-2011there has been 27 ship accidents in Indonesian waters caused by sinking 37%, fire/explosion 41%, and 22% of collision [1]. One of the ship safety is affected by the freeboard and bow height parameters according to load line regulation, where one of the causes of sinking is shipping of green water is caused primarily by the relative deck motion [2]. Several countries have been involved in studies related to the revision of load line regulation ILLC 1966. The revision consists of several parts regarding the regulation of freeboard and bow height minimum related with deck wetness, and also issue of watertight integrity, the size and location of openings, crew safety, and the interpretation of the regulations relating to other IMO instruments. In Indonesia, some researchers have conducted a study related to the characteristics of the ship motion when operating in Indonesian waters, one of the largest studies that have been done is cooperation between several universities in Indonesia and Japan, as well as ministry of research and technology of Indonesia [3].

1.1 BKI Ship Register

BKI as the national classification bodies which classifying Indonesian flag ship have been authorized by the Indonesian government to carry out survey and issue load line certificates for national voyage, KM 3 Decree Year 2005 [4] and international voyage, ICLL 1966 [5]. That it is extremely necessary for BKI to contribute by giving a suggestion to the administration in the formulation of domestic rules especially on load line through by study of ship behavior or seakeeping when operating in Indonesian waters, especially for ships that have been registered in BKI.

According to the ship registered in Ministry of sea transportation, the number of Indonesian flag ship up to April 2010 is 52.890 units consisting of gross tonnage < 500 GRT amount to 46.076 units and gross tonnage ≥ 500 GRT amount to 6.814 units [6]. Another data from BKI informed that the ship registered up to July 2012 with total amount 8192 units, with the total gross tonnage of 12.911.545 GRT, by population of 34% pusher and tug boat, pontoon and barge is 32%, general cargo is 10.5%, tanker 5%, passenger and ro-ro ferries 4.5% and 14% for other types [7]. Furthermore BKI ship registered based on ship age expressed that mostly at the age of 0-5 years and the age of the vessel > 25 years, for 0-5 years mostly barge and tug boat and for the ship age > 25 years are the second hand ships imported from abroad.

1.2 Indonesian Vessels Overview

Currently the conditions of vessel in Indonesia in particular related with the freeboard and bow height minimum can be classified that ships with large ratio B/D and low freeboard are ro-ro ferries, landing craft, and self propulsion barge generally do not have forecastle, then bow height is calculated to the main deck as upper deck. And general cargo ship especially those imported from Japan mostly draught increased by ship owners to add the cargo, which initially the maximum draft position below the tween deck as freeboard deck, then after draft increased the position of freeboard deck changed to the upper deck. This affected in a reduction of the minimum bow height so it does not complies with the minimum bow height requirements according to regulation of ICCL 1966.

2. Bow Height and Probabilistic Deck Wetness Approach

Bow height (Fb) defined as the vertical distance at the forward perpendicular between the waterline corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at side, based on the international load line regulation 39 ICCL 1966 with the standard ICLL ships (C_b = 0.68 at d = 0.85D), shall be not less than:

$$56L\left(1-\frac{L}{500}\right)\cdot\frac{1.36}{C_b+0.68} \quad \text{mm for L < 250 m} \qquad (1)$$

$$7000\frac{1.36}{C_b+0.68} \quad \text{mm for L > 250 m} \qquad (2)$$

Development of the revision of bow height formula has been done by some studies based on probability deck wetness [8]. Some results and recommendations submitted to the IMO especially on Sub Committee Stability and Load Line on Fishing Vessel (SLF) by the regulation which contained on the regulation 39 ICLL as amended protocol 88, where the bow height shall not be less than:

$$F_b = \left(6075\cdot\left(\frac{L}{100}\right)-1875\cdot\left(\frac{L}{100}\right)^2+200\cdot\left(\frac{L}{100}\right)^3\right)\times\left(2.08+0.609C_b-1.603C_{wf}-0.0129\cdot\left(\frac{L}{d_1}\right)\right) \qquad (3)$$

Where F_b is bow height minimum, L is length at draught d_1, B is moulded breadth, d_1 is draught at 85% of the depth D, C_b is block coefficient at d_1, C_{wf} is waterplane area coefficient forward of LPP/2.

The phenomenon of shipping of water on deck or green water is caused primarily by the relative deck motion, that is the motion of the forward deck relative to the surface, but depends also on the height of the freeboard. It is often important to be able to predict the probability of deck wetness in a particular cycle of motion. The probability that the immersion exceeds the effective freeboard [9] is defined as:

$$P_S = P\{S_a > F_b\} = \exp\left[\frac{-H_b{}^2}{2m_{0s}}\right] \qquad (4)$$

Where Ps is the probability of deck wetness, S_a is the vertical relative motion amplitude at the bow, F_b is the freeboard effective, m0s is area relative motion spectrum, Hb is the bow height minimum. This yields for the bow height Hb:

$$Hb = \sqrt{-2m_{0s}.\ln(P_S)} \qquad (5)$$

There are some wave spectrum which has developed, one of which was applied to this study is the Pierson Moskowitz spectrum [10] with the spectrum formula:

$$S_{\zeta}(\omega) = 172.8 \bullet T_1 \bullet (\zeta_{w1/3})^2 (T_1 \bullet \omega)^{-5} \bullet \exp\left[-691 (T_1 \bullet \omega)^{-4}\right] \quad (6)$$

Where ω is the circular frequency, $\zeta_{w1/3}$ is the significant wave height, T_1 is the average wave period, T_p is the peak period, where T_p/T_1 = 1.296. The selection of this spectrum based on the parameter of spectrum measurements which was taken from closed sea in the gulf Mexico that having similarities with the geographical conditions in Indonesian waters.

Furthermore the ship response was obtained by the solution numerically of ship motion equations using SHIPMO software with 2D strip theory, particularly analyze on *heaving*, *pitching* and *rolling* motions. The formula for the solution of motion equation based on Newton's second law in six degree of freedom can be written as follows:

$$\sum_{n=1}^{6} (M_{jk} + A_{jk}) \ddot{\varsigma}_k + B_{jk} \dot{\varsigma}_k + C_{jk} \zeta = F_j e^{i\omega t} \quad j,k = 1,2,3,4,5,6 \quad (7)$$

Where M_{jk} is vessel mass matrice, A_{jk} is added mass matrice, B_{jk} is damping coefficient, C_{jk} is restoring force coefficient, $\zeta, \dot{\zeta}, \ddot{\zeta}$ are displacement, velocity, acceleration amplitude, $\zeta_1 = \zeta_x$ is displacement of x direction or *surge* motion, $\zeta_2 = \zeta_y$ is displacement of y direction or *sway*, $\zeta_3 = \zeta_z$ is displacement of z direction or *heave*, $\zeta_4 = \zeta_\phi$ is angular motion amplitude towards x direction or *roll*, $\zeta_5 = \zeta_\theta$ is angular motion amplitude towards y direction or *pitch*, $\zeta_6 = \zeta_\psi$ is angular motion amplitude towards z direction or *yaw*, F_1, F_2, F_3= F_x, F_y, F_z are exciting or encountering forces which resulting the translation motions *surge*, *sway* and *heave*, F_4, F_5, F_6= F_ϕ, F_θ, F_ψ are exciting or encountering momets which resulting the angular motions *roll*, *pitch* dan *yaw*.

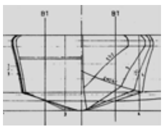
To determine the bow height minimum for Indonesian waters required a clarification through a ship model experiment to analyze the deck wetness that can be known the quantity of green water, with some constraints on the ship speed, wave heading, and point of deck wetness. Furthermore, the results of should be meet with the seakeeping criteria according to NordForsk, 1987 [11].

3. Experiment and Numerical Simulation

The selection of vessel models in this study were taken from BKI ship register which includes the type of vessels are general cargo, passenger and ferry, landing craft, self propelled barge and pontoon, fishing boats and speed boat. Then each type of vessel is taken one sample model with a length parameter based on the largest population for each type of vessel. The results are various ship models based on ship length 7 up to 250 meters. The ship data and body plans are expressed in Table 1 and Figure 1.

Table 1 Ships data taken from BKI Ship Register

No	Initial	Tipe	LOA (m)	LBP (m)	Bmld (m)	Hmld (m)	T (m)	Cb	Disp. at T (Tonne)	Vs (knot)
1	KI -1	Speed Boat	7.2	6.35	2.36	1.2	0.6	0.649	5.561	23
2	KI -2	Sea truck	10.75	10.75	3.36	1.3	0.75	0.736	18.31	23
3	KI -3	Crew Boat	16	14.32	4	2	0.67	0.45	14.28	28
4	KI -4	Tug Boat	28	26.34	7.8	3.5	2.75	0.65	390	10
5	KI -5	General Cargo	42	38	7.8	3.7	2.72	0.73	603	11.27
6	KI -6	SPOB	48.32	45.5	9	3	2.4	0.831	886.8	10
7	KI -7	Fishing Vessel	53.51	46.9	8.7	3.75	3.4	0.7	948	11.5
8	KI -8	Ferry Ro-Ro	55.5	47.25	13	3.45	2.45	0.65	1006	12
9	KI -9	General Cargo	57.6	53	9.3	5.55	3.5	0.69	1273	10
10	KI -10	LCT	60	51.73	11	3.2	2.56	0.83	1235	10
11	KI -11	Tanker	75.78	71.25	11.5	5.1	4.65	0.69	2694	12.5
12	KI -12	Cement Carrier	77.97	72	12.3	5.8	5.2	0.72	3524	11
13	KI -13	Passenger	89.58	83.4	16	5.5	4.5	0.503	3132	17
14	KI -14	Pontoon	91.44	87.78	24.38	5.48	4.295	0.88	8650	10
15	KI -15	General Cargo	113.63	103.43	19	8.91	6.55	0.71	9400	15
16	KI -16	Container	115.5	105.6	17	9	5.8	0.794	8485	12
17	KI -17	Cement Carrier	122.68	115	18	9.1	7.331	0.766	11911	13.5
18	KI -18	Passenger	123	115.5	18	12.3	6.25	0.603	8283	17
19	KI -19	General Cargo	127.73	119.8	18	8.2	6.2	0.821	11536	12
20	KI -20	Tanker	158	151.8	27	11.7	7	0.817	24025	14
21	KI -21	Bulk Carrier	223.13	213	32.2	17.9	13	0.803	73387	14.7
22	KI -22	Tanker	244.5	233	44	21.5	12.7	0.818	109417	15



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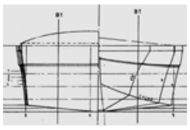

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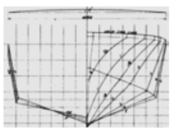

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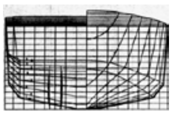

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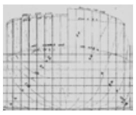

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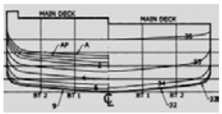

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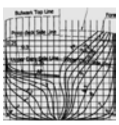

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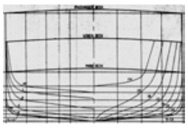

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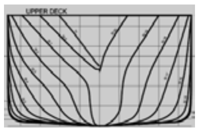

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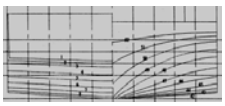

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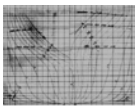

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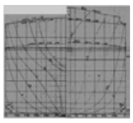

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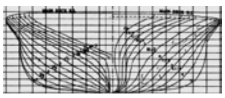

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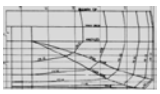

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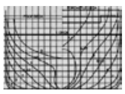

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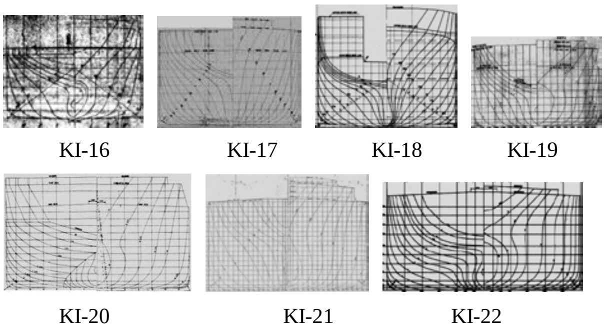
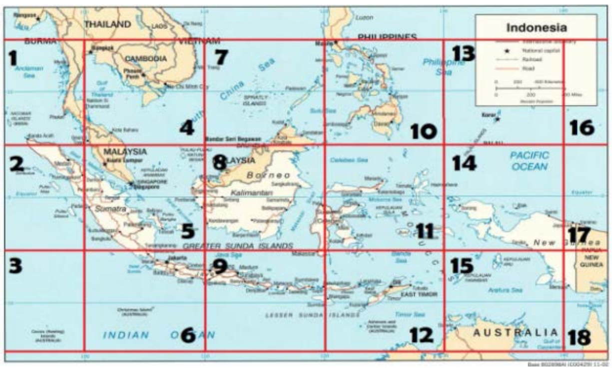


Fig. 1– Body Plan of 22 ship models

The wave data were retrieved by wave recording obtained from the Indonesian Meteorology, Climatology and Geophysics (BMKG) during 7.5 years from 2000 to 2007. Then divided the Indonesian territorial waters to 18 zones with boundaries of grid areas 10 latitude and 10 longitudinal, which is presented according to Figure 2, the area of each zone is taken 5 waves data points that are positioned at the corners of the zone and one point is positioned of the center of the zone, so if the position of these points to be connected to form a diagonal line and the five points will represent all the data within the zone. The number of waves data recording for 7.5 years at each point a number of (24 hours x 365 days x 7.5 years = 65,000 wave recording data for each point).



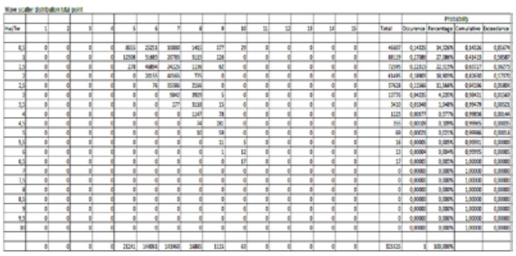


Fig. 2–Indonesian waters zone and scatter diagram zone 1

Furthermore, the overall wave data grouped in the form of a scatter diagram with parameters of wave height and period. From the scatter diagram calculated significant wave height (H1/3) and the largest number of periods in each area are displayed according to Table 2.

Table 2 Significant wave height and the largest period for each zone

Area	Hs (1/3) m	Period (T) sec	Area	Hs (1/3) m	Period (T) sec
1	2.382	6	10	2.445	6
2	2.154	6	11	1.750	6
3	2.679	7	12	1.786	6
4	2.137	6	13	2.465	6
5	1.907	6	14	1.998	6
6	2.318	6	15	2.266	6
7	2.495	6	16	2.241	6
8	1.709	6	17	1.834	6
9	1.925	6	18	2.456	6

To validate the numerical calculations performed physical model experiment using general cargo type which increased of ship draft when operating in waters of Indonesia, where the initial full load draft 3.3 meters to 3.5 meters, the ship particular according to Table 3. Probability deck wetness analysis done using model experiment for free running condition. The experiment was done at maneuvering and Ocean Basin (MOB) Hydrodynamics Laboratory with a size of 60 m x 35 m x 2.5 m for each length, width and depth. MOB is equipped with a wave generator for generating regular and irregular waves and wave absorber to dampen the reflected wave. The experiment conducted using irregular waves with a duration equivalent to about 2 hours in full scale.

Table 3 Ship Particular

Item	Ship	Model
LOA (m)	57.600	2.504
LPP (m)	53.000	2.304
Breadth, B (m)	9.300	0.404
Depth, H (m)	5.550	0.241
Draft, T Full Load (m)	3.500	0.152
Block Coefficient, Cb	0.690	0.690
Displacement (Tonne)	1273	0.102
LCG fromTransome (m)	26.077	1.134
VCG fromBaseline (m)	3.331	0.145
Roll Gyration, kxx (m)	2.530	0.110
Pitch Gyration, kyy (m)	13.800	0.600
Vessel Speed (knot)	10 (Fn=0.22)	2.085

The scale model of the ship is 1: 23 according to Figure 3, the deck is assumed straight from front to back without sheer, no chamber, no bulwark and without forecastle (no effective length). Ship model was ballasted to meet the draft, trim, radius of gyration in longitudinal and transversal using balance swinging.

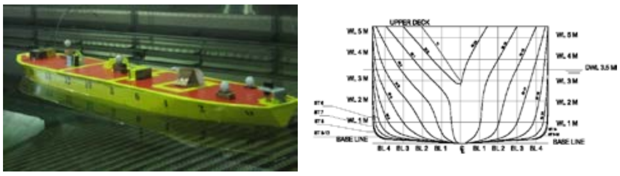


Fig. 3–Model and Body Plan

The experiment were conducted at irregular wave both of head seas (180 degrees) and beam sea (90 degrees) and using the Pierson Moskowitz wave spectrum [10], with the number of wave cycles of about 200, the peak period and significant wave height used in the experiment are peak period Tp = 8 sec and Hs = 1.3 meters, ship speed assumed of 10 knots (Fn = 0:22).

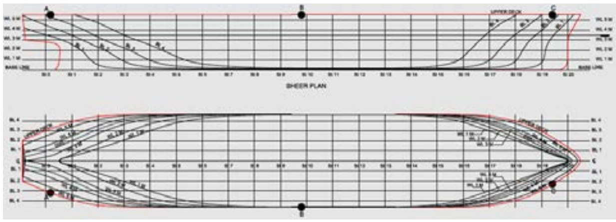


Fig. 4 – Point of Deck Wetness

The calculation both of the relative vertical motion and the probability of deck wetness measured at the position of the stem, middle and stern of the position of the point A, B and C according to Figure 4. The equipment used to capture the motion of the ship response in 2D and 3D that uses Qualisys Track Manager (QTM) software, then during the running experiment together with making a video recordings and photographs to see the visualization of the ship model motion.

The comparison of bow height (H_b) based on experimental and numerical for these model in accordance with the probability of deck wetness Ps ≤ 0.05 which assume of significant wave height 1.3 meters, are shown on Table 4. Where the probability of deck wetness calculated on the direction of head sea and beam sea with ship speed 10 knots (Fn = 0:22).

Table 4 Bow height comparison between experiment and numeric for each point based on Ps ≤ 0.05

Description	Heading	Ps 0.05 Hb Poin A (m)	Hb Poin B (m)	Hb Poin C (m)
Eksperiment	Head Sea	0.230	0.900	1.750
	Beam Sea	0.630	1.000	1.300
Numerical	Head Sea	1.286	0.694	1.457
	Beam Sea	0.939	0.775	0.674

While the probability of deck wetness value (Ps) for each point A, B and C on the existing bow height (H_b) is 2.05 meter, for head seas and beam sea condition as shown in Table 5.

Table 5 The comparison of Ps for existing bow height (H_b) 2.05 meter

Description	Heading	Bow Height (H_b) 2.05 meter Ps Poin A (%)	Ps Poin B (%)	Ps Poin C (%)
Eksperiment	Head Sea	0.000	0.000	2.000
	Beam Sea	0.000	0.000	0.000
Numerical	Head Sea	0.050	0.000	0.266
	Beam Sea	0.000	0.000	0.000

From the comparative results of experimental and numerical values with the similar parameters of the wave and ship, it can be known that for head sea condition noted especially at point C in stem position caused having the highest frequency of occurrence of deck wetness due to couple motions heaving and pitching, then for beam sea condition at point B in amidships position which has a high probability of deck wetness due to the rolling motion. From the comparison of the two (experimental and numerical) points C and B, the difference both of them was not significant and the further analysis of ship models can be performed using numerical calculation by SHIPMO software. The minimum bow height analysis to be concentrated on the probability of deck wetness to point C.

4. Result and Discussion

4.1 Bow Height Minimum Evaluation

The bow height calculation according to regulations 39 ILLC 1966 (ILLC, 2005) on some ship models shown at Figure 5 expressed that the longer ship required increasing bow height gradually, as linear curve. This is affected the parameters used in calculating of the bow height only consists variables of length and shape of the ship hull/block coefficient by assuming the same wave height for the difference ship length.

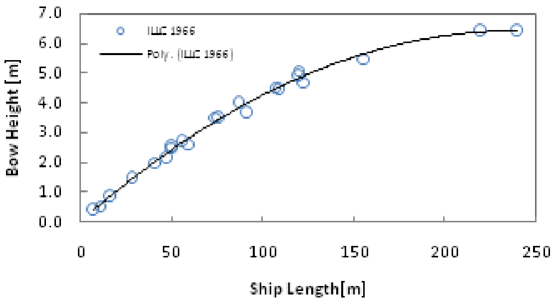


Fig. 5–Bow height minimum according to ILLC 1966

Furthermore, the bow height calculation according to Regulation 39 ILLC 1966 as amended by the Protocol 88, which expressed that the updated formula is analyzed using probability of deck wetness approach, where the value of bow height consist of some variables such as ship length, width, draft, block coefficient (C_b), coefficient of waterplane area forward (C_{wf}) and waterplane area forward (A_{wf}), if compared with previous bow height (according ILLC 1966) which only uses a ship length and block coefficient Cb 0.68 parameters. The results of bow height calculation for 22 vessels according to Figure 6 shows that the curvature shape of bow height decrease for some vessels with large hull size and length (with parameter function of block coefficient and coefficient of waterpalane forward), this is caused of ship motion or ships response due to couple motions heaving and pitching will be decreased for some vessels with large displacement and length.

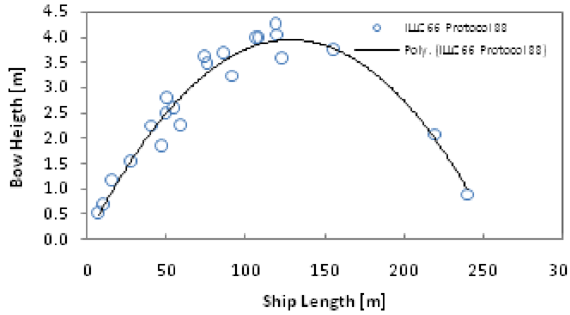


Fig. 6–Bow height minimum according to ILLC1966 as amended by protocol 88

Next in Figure 7 shows the bow height existing of 22 ship models. From the regression results can be known that the same trend with previous curve on Figure 11 where the bow height proportionally to the length the ship, the curve shape tends to linear.

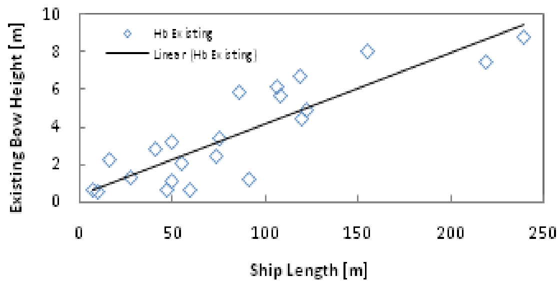


Fig. 7–Existing bow height of 22 ship models

4.2 Probability of Deck Wetness According to Several of Significant Wave Height

Probability of deck wetness is calculated by varying the wave height 0.5 meters to 9 meters, and it can be seen the value of the probability of each ship model by wave height variations. Probability of deck wetness at stem position (point C) toward the wave height variation with head seas condition, are presented as per Figure 8.

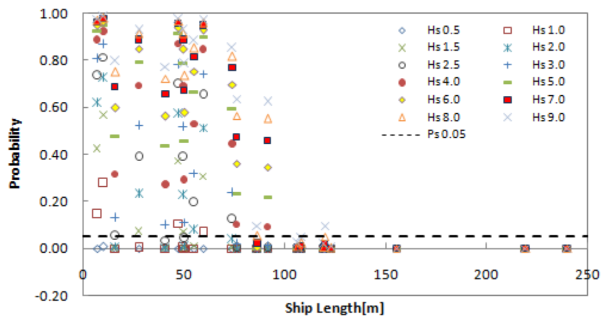


Fig. 8–Probability of deck wetness for various wave heights, Hs

For wave height Hs 0.5 meters the probability values for all ships below the safety margin by using deck wetness probability criteria Ps ≤ 0.05. Furthermore, for wave height Hs 0.5 meters to 2 meters for small ships (speed boat), Ro-Ro ferry, LCT, SPOB and vessels length below 60 meters, the probability values have exceeded the probability criteria. For wave height Hs 2 meters to 7 meters have exceeded the criteria on vessels up to 100 meters length, and for ships above 100 meters the probability exceeded Ps 0.05 occurs in wave height over 7 meters.

In general it can be concluded that the ship length and displacement (ship shape) affects the occurrence of deck wetness phenomenon, where the longer of ships then the smaller the probability of deck wetness, this is because the ratio of vessel length to the wavelength to be greater and the frequency encounter between wave crest and trough against the ship hull is relatively high so that the ship response to be smaller and the possibility of resonance is also getting smaller. Then the effect of low freeboard or the large ratio B/D, causing the value of probability of deck wetness to be high.

4.3 Bow Height Minimum Formula Modification

Determination of minimum bow height formula for Indonesian waters has been conducted through several simulations and scenarios based on parameters wave height and length of the vessel (22 models with variations in ship shape) with criteria of deck wetness probability Ps ≤ 0.05 of the total cycle of motions. The deck wetness position to be reviewed at point C (stem position) with head sea condition for irregular waves.

In scenario 1 the bow height minimum calculated up to a maximum probability of deck wetness criteria Ps ≤ 0.05 that will get the value of the maximum wave height is allowed, according to Table 6. From Figure 9 shown the comparison between the values of existing bow height, bow height according ILLC 1966 as amended Protocol 88 and bow height as scenario 1.

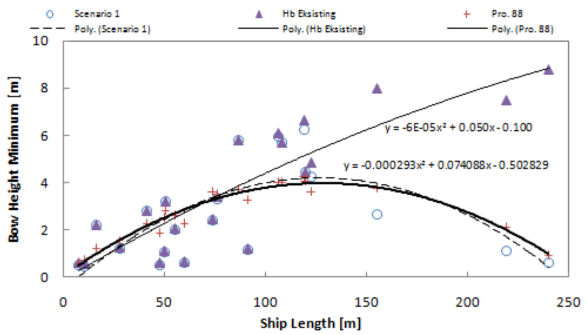


Fig. 9–The comparison of bow height existing, protocol 88 and scenario 1on Ps ≤ 0.05 by wave height maximum

For existing bow height values tend to be linear where bow height value is proportional to the ship length of the while the calculation results of bow height minimum scenario 1 by using criteria of Ps ≤ Ps 0.05 these value almost equal with the bow height in accordance ILLC Protocol 1988. And the regression results can be formulated as follows:

$$F\left(L_{pp}\right) = 7.409\left(\frac{L_{pp}}{100}\right) - 0.503 - 0.0293\left(\frac{L_{pp}^{\ 2}}{100}\right) \qquad (8)$$

In Table 6 shows that the maximum wave height for varying values of Ps ≤ 0.05, which for small ships and vessel with large ratio B/D (i.e. LCT, SPB and Fery R-Ro) maximum allowable wave height less than 1.5 meters (sea state on calm waters and moderate). As for ships with large displacement and length, the value of the maximum permissible wave height is high.

Table 6 Maximum wave height for probability of deck wetness Ps ≤ 0.05

Initial	Ship Type	Lpp (m)	Allowable Maximum Hs (m)	Existing Bow Height (m)	Bow Height Scenario 1 (m)
KI-1	Speed Boat	7.100	0.672	0.600	0.502
KI-2	Sea truck	10.250	0.581	0.540	0.480
KI-3	Crew Boat	16.000	2.479	2.230	2.224
KI-4	Tug Boat	27.600	1.335	1.260	1.201
KI-5	General Cargo	41.000	2.614	2.810	2.785
KI-6	SPOB	47.300	0.733	0.600	0.509
KI-7	Ferry Ro-Ro	49.900	1.343	1.106	1.056
KI-8	Fishing Vessel	50.300	2.551	3.200	3.185
KI-9	General Cargo	55.100	1.794	2.050	1.991
KI-10	LCT	59.500	0.861	0.650	0.593
KI-11	Tanker	73.950	2.063	2.450	2.429
KI-12	Cement Carrier	76.000	3.393	3.400	3.297
KI-13	Passenger	86.400	7.930	5.800	5.791
KI-14	Pontoon	91.440	3.458	1.191	1.153
KI-15	General Cargo	106.390	9.900	6.081	5.933
KI-16	Container	108.200	8.977	5.684	5.682
KI-17	Passenger	119.334	9.900	6.650	6.247
KI-18	Cement Carrier	119.700	7.957	4.449	4.444
KI-19	General Cargo	122.770	9.900	4.850	4.263
KI-20	Tanker	155.200	9.900	8.000	2.643
KI-21	Bulk Carrier	219.300	9.900	7.500	1.129
KI-22	Tanker	239.900	9.900	8.800	0.609

In scenario 2 the bow height minimum is determined by the variation of wave height based on vessel length, the longer of the vessel then the larger wave height is assumed, the probability of deck wetness criterion may not exceed Ps ≤ 0.05.

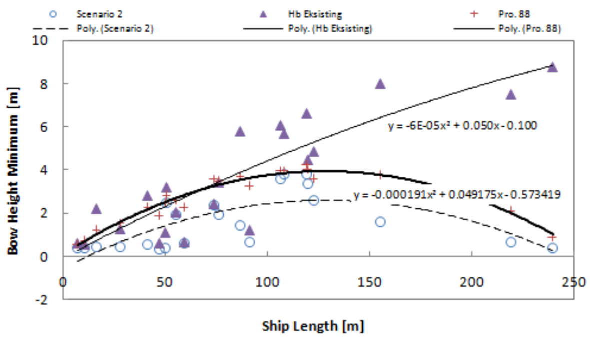


Fig. 10–The comparison of bow height existing, protocol 88 and scenario 2 by wave height variations

Figure 10 shows the same comparison between the value of the existing bow height, bow height according to ILLC 1966 Protocol 88 and bow height minimum scenario 2. Existing bow height values is the same, while the results of bow height calculation of scenario 2 for Ps ≤ 0.05 there is an average reduction of 47.037% compared with the bow height values according ILLC Protocol 1988. The regression results of bow height can be formulated as follows:

$$F(L_{pp}) = 4.917\left(\frac{L_{pp}}{100}\right) - 0.573 - 0.0191\left(\frac{L_{pp}^{\ 2}}{100}\right) \qquad (9)$$

In Table 7 shows the variation of wave height in accordance with the vessel length by criteria Ps ≤ 0.05. The wave height variations are intended as a vessel operating limitation with wave height parameters. The lowest wave height 0.5 meters (calm waters/smooth water condition) was applied to vessels with a length up to 50 meters. And wave height up to 2 meters (moderate) was applied to vessels over 50 meters up to 100 meters high and wave height above 2 meters (high and very high condition) for ships over 100 meters up to 250 meters. For ships with the large ratio B/D and low freeboard assumed wave height up to a maximum wave height with deck wetness criterion Ps ≤ 0.05.

Table 7 Wave height variations with ship length parameter, scenario 2

Initial	Ship Type	Lpp (m)	Wave Height Hs (m)	Bow Height Existing (m)	Ps	Bow Height Min (m)	Ps 0.05	Status Ps ≤ Ps 0.05
KI-1	Speed Boat	7.100	0.500	0.600	0.044%	0.373	5%	OK
KI-2	Sea truck	10.250	0.500	0.540	0.589%	0.412	5%	OK
KI-3	Crew Boat	16.000	0.500	2.230	0.000%	0.449	5%	OK
KI-4	Tug Boat	27.600	0.500	1.260	0.000%	0.450	5%	OK
KI-5	General Cargo	41.000	0.500	2.810	0.000%	0.533	5%	OK
KI-6	SPOB	47.300	0.500	0.600	0.013%	0.348	5%	OK
KI-7	Ferry Ro-Ro	49.900	0.500	1.106	0.000%	0.393	5%	OK
KI-8	Fishing Vessel	50.300	2.000	3.200	0.729%	2.497	5%	OK
KI-9	General Cargo	55.100	1.750	2.050	4.408%	1.942	5%	OK
KI-10	LCT	59.500	0.850	0.650	4.845%	0.585	5%	OK
KI-11	Tanker	73.950	2.000	2.450	3.911%	2.355	5%	OK
KI-12	Cement Carrier	76.000	2.000	3.400	0.010%	1.944	5%	OK
KI-13	Passenger	86.400	2.000	5.800	0.000%	1.460	5%	OK
KI-14	Pontoon	91.440	2.000	1.191	0.007%	0.667	5%	OK
KI-15	General Cargo	106.390	6.000	6.081	0.019%	3.596	5%	OK
KI-16	Container	108.200	6.000	5.684	0.122%	3.797	5%	OK
KI-17	Passenger	119.334	6.000	6.650	0.010%	3.786	5%	OK
KI-18	Cement Carrier	119.700	6.000	4.449	0.509%	3.351	5%	OK
KI-19	General Cargo	122.770	6.000	4.850	0.003%	2.583	5%	OK
KI-20	Tanker	155.200	6.000	8.000	0.000%	1.602	5%	OK
KI-21	Bulk Carrier	219.300	6.000	7.500	0.000%	0.685	5%	OK
KI-22	Tanker	239.900	6.000	8.800	0.000%	0.369	5%	OK

In scenario 3 same as scenario 2, but there are differences in assumptions of wave height variation with the value of the ship length range to be smaller, where the bow height minimum was determined by the variation of wave height based on vessel length, the longer the vessel then the larger wave height is assumed, with probability of deck wetness criterion may not exceed Ps ≤ 0.05.

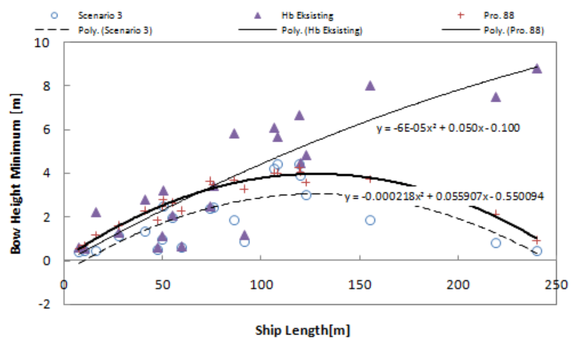


Fig. 11–The comparison of bow height existing, protocol 88 and scenario 3 by wave height variations

Figure 11 shows the same comparison between the value of the existing bow height, bow height according to ILLC 1966 Protocol 88 and bow height minimum scenario 3. Existing bow height values is the same, while the results of bow height calculation of scenario 3 for Ps ≤ 0.05 there is an average reduction of 36.619% (35%) compared with the bow height values according ILLC Protocol 1988. The regression results of bow height can be formulated as follows:

$$F\left(L_{pp}\right)=5.591\left(\frac{L_{pp}}{100}\right)-0.550-0.0218\left(\frac{L_{pp}}{100}^{2}\right) \qquad (10)$$

In Table 8 shows the variation of wave height in accordance with the vessel length ≤ Ps 0.05 with a range of ship length to be smaller, by assuming the lowest wave height 0.5 meter (waters calm/smooth water condition) was applied to vessels with a length of up to 20 meters. For wave height up to 1.25 meters (slight) was applied for ship length 20 meter up to 50 meter, wave height up to 2 meters (moderate) was applied to vessels above 50 meter up to 75 meters, wave height up to 2.5 meters (moderate) was applied to vessels over 75 meter up to 100 meter and wave height above 2.5 meter up to 7 meter (high and very high) was applied for vessels above 100 meter up to 250 meters. For ships with the large ratio B/D and low freeboard values assumed up to wave height maximum with deck wetness criterion Ps ≤ 0.05.

Table 8 Wave height variations with ship length parameter, scenario 3

Initial	Ship Type	Lpp (m)	Wave Height Hs (m)	Bow Height Existing (m)	Ps	Bow Height Min (m)	Ps 0.05	Status Ps ≤ Ps 0.05
KI-1	Speed Boat	7.100	0.500	0.600	0.044%	0.373	5%	OK
KI-2	Sea truck	10.250	0.500	0.540	0.589%	0.412	5%	OK
KI-3	Crew Boat	16.000	0.500	2.230	0.000%	0.449	5%	OK
KI-4	Tug Boat	27.600	1.250	1.260	3.799%	1.124	5%	OK
KI-5	General Cargo	41.000	1.250	2.810	0.005%	1.332	5%	OK
KI-6	SPOB	47.300	0.700	0.600	4.302%	0.487	5%	OK
KI-7	Ferry Ro-Ro	49.900	1.250	1.106	3.718%	0.983	5%	OK
KI-8	Fishing Vessel	50.300	2.000	3.200	0.729%	2.497	5%	OK
KI-9	General Cargo	55.100	1.750	2.050	4.408%	1.942	5%	OK
KI-10	LCT	59.500	0.850	0.650	4.845%	0.585	5%	OK
KI-11	Tanker	73.950	2.000	2.450	3.911%	2.355	5%	OK
KI-12	Cement Carrier	76.000	2.500	3.400	0.283%	2.429	5%	OK
KI-13	Passenger	86.400	2.500	5.800	0.000%	1.825	5%	OK
KI-14	Pontoon	91.440	2.500	1.191	0.220%	0.833	5%	OK
KI-15	General Cargo	106.390	7.000	6.081	0.184%	4.195	5%	OK
KI-16	Container	108.200	7.000	5.684	0.722%	4.430	5%	OK
KI-17	Passenger	119.334	7.000	6.650	0.112%	4.417	5%	OK
KI-18	Cement Carrier	119.700	7.000	4.449	2.067%	3.910	5%	OK
KI-19	General Cargo	122.770	7.000	4.850	0.043%	3.014	5%	OK
KI-20	Tanker	155.200	7.000	8.000	0.000%	1.869	5%	OK
KI-21	Bulk Carrier	219.300	7.000	7.500	0.000%	0.799	5%	OK
KI-22	Tanker	239.900	7.000	8.800	0.000%	0.431	5%	OK

In scenario 4 wave height was taken from highest H1/3 of18 zones Indonesian waters, so that all ships length applied with the same wave height.

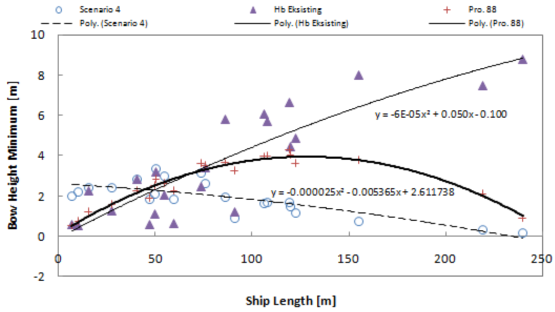


Fig. 12–The comparison of bow height existing, protocol 88 dan scenario 4 with Hs 2.679 meter

Figure 12 show a comparison between the value of the existing bow height, bow height according to ILLC 1966 Protocol 88 and bow height minimum scenario 4. In the calculation of scenario 4 where the probability value for the ship length up to 75 meters exceeded the existing bow height and bow height on ILLC 1966 Protocol 88. Based on the figure above that the curve of bow height scenario 4, the minimum value is inversely proportional to the existing bow height. Thus the regression results can be formulated as follows:

$$F\left(L_{pp}\right)=0.536\left(\frac{L_{pp}}{100}\right)-2.611-0.0025\left(\frac{L_{pp}}{100}^{2}\right) \qquad (11)$$

In Table 9 shows the results of calculation bow height minimum by assuming wave height from the highest significant wave height H1/3 of 18 zones in Indonesian waters, with a value of 2,637 meters. From the calculation can be evaluated that by assuming the same wave height then the probability of deck wetness of ships length up to 75 meters did not meet the criteria, due to the probability value exceeded the criteria requirement Ps ≤ 0.05. However ships with a length of 75 meters above the probability value have a large margin than required. It is caused by the ratio of vessel length to the wavelength where for small ships with a small ratio having large response of the vessel due to wave motion (relative motion direction), if compared with the large ships.

Table 9 Probability of deck wetness by assuming the highest wave height H1/3 of 18 zones Indonesian waters

Initial	Ship Type	Lpp (m)	Wave Height Hs (m)	Bow Height Existing (m)	Ps	Bow Height Min (m)	Ps 0.05	Status Ps ≤ Ps 0.05
KI-1	Speed Boat	7.100	2.679	0.600	75.968%	1.999	5%	FAIL
KI-2	Sea truck	10.250	2.679	0.540	83.339%	2.211	5%	FAIL
KI-3	Crew Boat	16.000	2.679	2.230	7.898%	2.403	5%	FAIL
KI-4	Tug Boat	27.600	2.679	1.260	43.676%	2.409	5%	FAIL
KI-5	General Cargo	41.000	2.679	2.810	5.826%	2.855	5%	FAIL
KI-6	SPOB	47.300	2.679	0.600	72.845%	1.862	5%	FAIL
KI-7	Ferry Ro-Ro	49.900	2.679	1.106	43.397%	2.106	5%	FAIL
KI-8	Fishing Vessel	50.300	2.679	3.200	6.770%	3.344	5%	FAIL
KI-9	General Cargo	55.100	2.679	2.050	23.991%	2.972	5%	FAIL
KI-10	LCT	59.500	2.679	0.650	68.490%	1.844	5%	FAIL
KI-11	Tanker	73.950	2.679	2.450	16.538%	3.155	5%	FAIL
KI-12	Cement Carrier	76.000	2.679	3.400	0.790%	2.603	5%	OK
KI-13	Passenger	86.400	2.679	5.800	0.000%	1.956	5%	OK
KI-14	Pontoon	91.440	2.679	1.191	0.652%	0.893	5%	OK
KI-15	General Cargo	106.390	2.679	6.081	0.000%	1.605	5%	OK
KI-16	Container	108.200	2.679	5.684	0.000%	1.696	5%	OK
KI-17	Passenger	119.334	2.679	6.650	0.000%	1.690	5%	OK
KI-18	Cement Carrier	119.700	2.679	4.449	0.000%	1.496	5%	OK
KI-19	General Cargo	122.770	2.679	4.850	0.000%	1.154	5%	OK
KI-20	Tanker	155.200	2.679	8.000	0.000%	0.715	5%	OK
KI-21	Bulk Carrier	219.300	2.679	7.500	0.000%	0.306	5%	OK
KI-22	Tanker	239.900	2.679	8.800	0.000%	0.165	5%	OK

4. Conclusions

Modification of the minimum bow height Indonesian waters conducted through 4 scenarios by assuming the wave height with the criterion of deck wetness probability Ps ≤ 0.05. Scenario 1 bow height values calculated up to Ps ≤ 0.05 in order to obtain the maximum wave height for each vessel, and the result is the bow height minimum curve close to the bow height value according to ILLC 1966 Protocol 88. Scenario 2 and 3 assumes the wave height according to the ship length where the longer and larger ships and the greater freeboard then the wave height assume to be higher. Scenario 4 assumes the highest wave height H1/3 of 18 zones Indonesian waters is 2.679 meters, the result is that the longer of ship length then the smaller of bow height minimum. According to 4 scenarios of development of bow height for Indonesian waters, the scenario 3 is recommended to be applied because suitable with the operating conditions of the vessel and the assumption of wave height will be used as the operational constraints of ships at sea. The minimum bow height formula and the proposed restrictions as follows:

$$F\left(L_{pp}\right) = 5.591\left(\frac{L_{pp}}{100}\right) - 0.550 - 0.0218\left(\frac{L_{pp}{}^{2}}{100}\right)$$
or

35% reduction of bow height values according to Regulation 39 ILLC 1966 Protocol 88.

$$F_b = 0.35x\left[6075\left(\frac{L}{100}\right) - 1875\left(\frac{L}{100}\right)^2 + 200\left(\frac{L}{100}\right)^3\right]x\left[2.08 + 0.609C_b - 1.603C_{wf} - 0.0129\left(\frac{L}{d_1}\right)\right]$$

or $$F\left(L_{pp}\right) = 0.057 + 3.924\left(\frac{L_{pp}}{100}\right) - 0.015\left(\frac{L_{pp}{}^{2}}{100}\right)$$

Meanwhile vessel operating restrictions are as follows:

Ship Length (m)	Wave Height, Hs (m)	Sea State
≤ 20	0.5 - 1.25	Slight
21 – 75	1.25 – 2.5	Moderate
76 – 100	2.5 - 4	Rough
≥ 100	6 - 9	High

Exemption for vessels with large B / D (B/ > 3 meter) eg: LCT, Barge, and Ro-Ro ferry. Where the bow height correction value is greater than the values calculated by the freeboard, then the provisions of the bow height correction calculation can be ignored by the terms of ship operations are at a maximum wave height of 1 meter (slight).

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