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Safety of an Indonesian Ro-Ro Ferry with Different Weight Distribution on Vehicle Deck

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Abstract. The intact stability of an Indonesian ro-ro ferry is assessed by using the Second Generation Intact Stability Criteria for dead ship condition with two different weight distributions. The first distribution corresponds to weights concentrated near the centreline of the model. The second one corresponds to weights located farther from the centreline, in order to obtain a natural roll period corresponding to that provided by the standard formula in the IMO level 1 criterion. Roll decay tests and roll tests in regular beam waves are conducted for those two different weight distribution to obtain the natural roll period, the damping factors due to breadth-to-draught ratio (X_1) and bilge keels (k) as well as the effective wave slope coefficient, by using the three-step procedure test recommended by MSC.1/Circ.1200. The critical metacentric height in the level 1 criterion decreases as the roll radius of gyration increases. The weight distribution does not have a significant effect on the capsize index if the metacentric height is smaller than about 0.60 meters but it has a clear impact as the metacentric height increases. In the operation range of metacentric height, the capsize index is significantly affected by the weight distribution.

INTRODUCTION

Indonesian ro-ro passenger ferries are used in inter-island, inland and river transportation to carry passengers and vehicles. The vehicles are located in the main deck and the passenger accommodation is located in a superstructure above the main deck. The ships are designed with small draughts because the ports in the service areas are generally characterized by shallow water. To satisfy the capacity requirement, the ships are designed with large breadth. Indonesian ro-ro ferries are designed with a small freeboard in order to facilitate the process of loading and unloading vehicles in the port. These requirements result in designs with breadth-to-draught ratio approximately in the range of 2.3 to 8.3 and most of the ships have breadth-to-draught ratio larger than 3.50. The freeboard-to-breadth ratios of most Indonesian ro-ro passenger ferries is smaller than 0.10. As a result, the heel angle associated with the maximum of the righting arm is typically smaller than 25 degrees [1]. The vertical centre of gravity tends to be larger than the ship depth because all the payload is located above the main deck.

The Weather Criterion of IMO recently adopted as the vulnerability level 1 in the Second Generation Intact Stability Criteria (SGISC) [2,3] was developed based on ships with breadth-to-draught ratio smaller than 3.50, ratio between the vertical centre of gravity and the ship draught ranges from 0.70 to 1.50 and natural roll periods of up to 30 s and above. An overestimated value of variables to calculate the angle of roll to windward due to wave action could be obtained when it is applied to a ship with geometry characteristics different from those used to develop the criterion. For vessels with large breadth-to-draught ratios, the associated damping factor X_1 has been found to be smaller than that obtained by the recommended value of IMO [4,5]. Furthermore, for vessels with large breadth-to-draught ratios the effective wave slope coefficient obtained by using the formulae of Weather Criterion results in a larger value compared to that obtained by model experiment [5,6]. IMO suggested to use model experiments when

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the Weather Criterion is applied to ships with geometry characteristics different from those used to develop the criteria [7]. On the other hand, some extension of the range of application of the variables in the formula for calculating the roll angle toward windward due to wave action is necessary if model experiments cannot be conducted [6,8].

The natural roll period may have a significant effect on the angle of roll to windward due to wave action. The roll radius of gyration in the formula of Weather Criterion is an increasing function of breadth-to-draught ratio as well as length of waterline [9]. As a result, a ship with large breadth-to-draught ratio is predicted to have larger natural roll period compared to a ship with a smaller ratio, given all the other variables in the formula unchanged (ship breadth, length and transverse metacentric height). In reality, the roll radius of gyration depends on the weight distribution. A significant error may appear when the formula is applied to calculate the radius of gyration of ships with large breadth-to-draught ratios as well as large transverse metacentric height [10]. Another formula that can be used to estimate the radius of gyration is the Kato's formula, but it results in an overestimated value when it is applied to ro-ro passenger ships [11]. Papanikolaou et al. [11] also concluded that the formula used in the Weather Criterion (Morita's formula) may underestimate the roll radius of gyration of ro-pax ships and also found that the radius of gyration of ro-ro passenger ferries ranges between 0.43 and 0.45 of ship breadth.

A ship may have different roll radii of gyration as the weight distribution is changed. This could occur on Indonesian ro-ro ferries because the loading condition does not always follow the recommended loading plan developed at the design stage in which the largest weight of vehicles are located near the centreline. In certain conditions, depending on the availability of vehicles to be carried, a vehicle with large weight can be located near to starboard or portside of ship. This different weight distribution of payload may have significant effects on hydrodynamic characteristics such as natural roll period, damping of roll motion as well as effective wave slope coefficient. This means that the obtained safety level of Indonesian ro-ro ferries could be different for every trip, depending on the loading condition. Therefore it is important to investigate the effect of load distribution on the stability of Indonesian ro-ro ferries in order to obtain the safety level for different weight distribution.

This paper discusses about the effect of weight distribution on the stability of Indonesian ro-ro ferries. This is important because the weight distribution could differ depending on the vehicles which are actually carried during the operation of the vessel. The results can be used as operational guidance for distribution of vehicles in the main deck. Effect of the weight distribution on values of each variable to calculate the angle of roll to windward due to wave action can be investigated and it can be used as consideration regarding extension of their tabulated values in the level 1 criterion for dead ship condition.

METHODOLOGY

An Indonesian ro-ro ferry is used as a sample ship in this paper. The main dimensions of the ship and its body plan are shown in Table 1 and Fig. 1, respectively.

TABLE 1. Main information of the sample ship

Principles Dimension	Unit	Dimension
Length over all (Loa)	m	54.50
Length between perpendicular (Lbp)	m	47.25
Breadth (B)	m	13.00
Draught (T)	m	2.45
Depth (D)	m	3.45
Vertical position of metacentre (KM)	m	8.72
Block coefficient (Cb)	-	0.62
Service speed	knots	12.00
Windage area (A_L)	m^2	432.93
Vertical distance of the centroid of windage area from water surface (C_L)	m	4.43

This ship has breadth-to-draught ratio of 5.31 and the ratio between freeboard and breadth of 0.08. The ratio between vertical center of gravity and the ship draught is 1.63. The loading plan for the vehicle deck consists of 12 trucks and 3 small cars in the after part as well as 3 small cars in the forepart of the vehicle deck as shown in Fig. 2. In order to investigate the effect of weight distribution, two scenarios are considered. The first scenario considers a smaller radius of gyration of 0.36 B in which the heavier trucks are located in the centreline and the small cars located near to starboard and portside. The second scenario is the weight distribution with radius of gyration close to that obtained by the formula in Weather Criterion [9]. For the considered sample ship, the corresponding radius of gyration is 0.474B, which is larger than the upper limit proposed by Papanikolaou et al. [11]. The vertical centre of gravity is kept the same for the two different weight distributions.

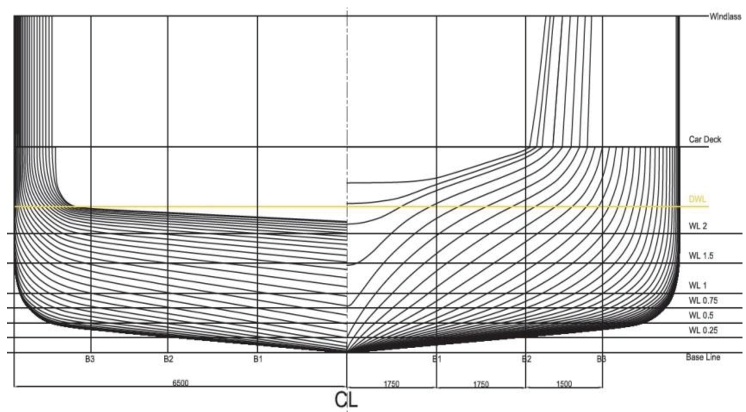

FIGURE 1. Bodyplan of the sample ship

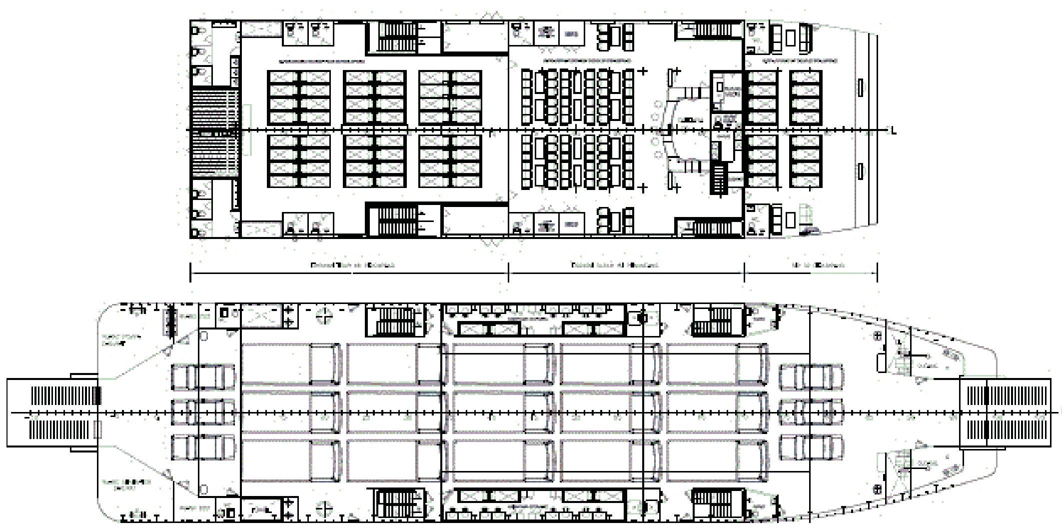

FIGURE 2. Vehicles and passenger decks layout

The damping factor due to breadth-to-draught ratio (X_1) and bilge keels (k) as well as the effective wave slope coefficient are estimated following the three-step procedure recommended by IMO (IMO, 2006). Firstly, the roll decay test is conducted to determine the natural roll period and the Bertin's coefficient as a function of roll amplitude as the following equation:

$$N(\phi_m) = a + \frac{b}{\phi_m} \quad (1)$$

where coefficients a and b are obtained by polynomial regression of the decrement of consecutive roll amplitude as a function of average amplitude of roll decay test. Those coefficients are also used to determine the linear and the quadratic damping coefficients following the procedure given by ITTC [12]. The capsize index in level 2 criterion is calculated by using those damping coefficients.

The second step is testing in regular beam seas which are conducted with five different wave frequencies, namely the roll natural frequency, two frequencies below the natural roll frequency and two others above the natural frequency of roll. Those wave frequencies are used to determine the roll amplitude based on four different waves steepness which are 0.01, 0.02, 0.03 and 0.04. The effective wave slope coefficient for each wave steepness is then determined by using the equation given in the guidelines of three-step procedure [7] as follows:

$$r = \frac{\phi_r^2 \cdot N(\phi_r) \cdot g \cdot T_r^2}{180 \cdot \pi^2 \cdot H_r} \tag{2}$$

Here, the Bertin's coefficients are determined by using Eq. 1 with the roll amplitude, $\O_r$, of roll test in regular beam waves for corresponding wave steepness. T_r and H_r are the wave period and the wave height for each wave steepness, respectively. The third step is to calculate the roll-back angle in regular waves by using the following equation:

$$\phi_{1r} = \sqrt{\frac{90 \cdot \pi \cdot s \cdot r}{N(\phi_{1r})}} \tag{3}$$

This equation is iteratively solved with the initial roll angle of 20.0 degrees until a convergence solution is obtained.

The damping factors corresponding to the breadth-to-draught ratio are determined by using the equation for calculating the roll angle to windward due to wind in the Weather Criterion [9] as shown in Eq. 4, where, in accordance with MSC.1/Circ.1200 [7], the roll angle toward windward due to wave action $\O_1$ is assumed to correspond to 70% of the roll amplitude obtained in the Eq. 3.

$$\begin{cases} X_1 = \dfrac{\phi_1}{109 \cdot X_2 \cdot k \cdot \sqrt{r \cdot s}} \\ \phi_1 = 0.7 \cdot \phi_{1r} \end{cases} \tag{4}$$

Here, X_2 is the damping factor corresponding to the block coefficient with value given in the Weather Criterion. The damping factor corresponding to the breadth-to-draught ratio is determined based on the data of model experiment for ship without bilge keels by using Eq. 4. Here, for ship without bilge keels, the damping factor corresponding to the bilge keels (k) is taken to be 1.0.

Using the obtained damping factor due to breadth-to-draught ratio, the damping factor due to bilge keels is determined as follows:

$$k = \frac{\phi_1}{109 \cdot X_1 \cdot X_2 \cdot \sqrt{r \cdot s}} \tag{5}$$

Here, the considered roll angle to windward due to wave action is based on the results of the test in regular beam waves for the ship with bilge keels. The results are compared to the damping factors given in the Weather Criterion [9].

The obtained effective wave slope coefficient and damping factors are used to evaluate the stability of the sample ship by using the SGISC for dead ship condition. The wind velocity and the wave characteristics are based on seaways in the operation route of the ship with the wave scatter shown in Table 2 and the mean wind velocity as a function of the significant wave height is shown in Fig. 3, respectively. This scatter wave data are derived from an analysis of ERA data [13]. Details of the derivation of environmental data specific for operation in Indonesian waters have been reported by Paroka et al. [14]. The corresponding equation of mean wind velocity as a function of significant wave height is shown in Eq. 6. This equation is statistically derived based on mean wind velocity and significant wave height recorded for 10 years in the operational area of the examined ship. The maximum wind speed in the location is 15.0 m/s, corresponding to equivalent wind pressure for application in the Weather Criterion of 168 Pa. However, a wind pressure of 300 Pa has been used to evaluate the intact stability of ships operated in Indonesia.

TABLE 2. Wave scatter data of a ro-ro ferry route in Indonesia

Hs (m)	**T_Z (s)**															
	2.83	**3.40**	**3.97**	**4.53**	**5.10**	**5.67**	**6.23**	**6.80**	**7.37**	**7.93**	**8.50**	**9.07**	**9.63**	**10.20**	**10.77**	**11.33**
0.14	20	128	183	461	191	57	15	7	4	1	1	0	0	0	0	0
0.28	53	1020	1802	3657	3782	2381	1110	433	182	94	34	19	6	4	2	0
0.42	50	1580	4708	6061	5974	4341	1776	636	175	53	16	10	3	5	2	0
0.55	0	585	5973	9100	6296	3130	1090	249	54	17	5	2	0	1	0	1
0.69	0	39	3753	12004	7796	2999	735	114	11	3	0	0	0	0	0	0
0.83	0	0	745	9599	8371	2730	663	152	21	2	0	0	0	0	0	0
0.97	0	0	23	3325	7094	2610	715	88	31	8	0	0	0	0	0	0
1.11	0	0	0	562	4034	2299	482	97	41	0	0	0	0	0	0	0
1.25	0	0	0	3	1361	1575	482	76	15	0	0	0	0	0	0	0
1.38	0	0	0	0	276	990	418	69	4	1	0	0	0	0	0	0
1.52	0	0	0	0	8	441	392	69	9	0	0	0	0	0	0	0
1.66	0	0	0	0	0	170	310	113	12	2	1	0	0	0	0	0
1.80	0	0	0	0	0	26	140	72	16	2	0	0	0	0	0	0
1.94	0	0	0	0	0	6	75	64	16	1	0	0	0	0	0	0
2.08	0	0	0	0	0	0	17	42	12	3	1	0	0	0	0	0
2.22	0	0	0	0	0	0	7	18	17	6	1	0	0	0	0	0
2.35	0	0	0	0	0	0	0	6	17	4	0	0	0	0	0	0
2.49	0	0	0	0	0	0	0	3	11	3	1	0	0	0	0	0
2.63	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
2.77	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0

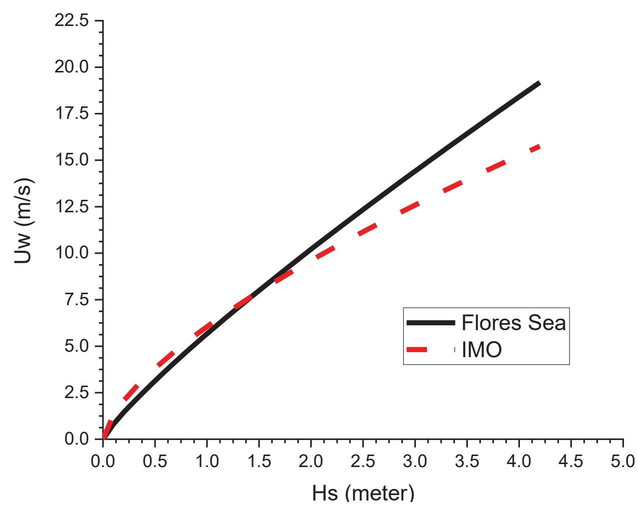

FIGURE 3. Mean wind velocity as a function of significant wave height

$$Uw=\left(\frac{H_s}{0.13}\right)^{0.85} \qquad (6)$$

The relation between mean wind velocity and significant wave height is different from that recommended by IMO [3]. The proposed equation results in a larger mean wind velocity compared to the equation in SDC 7/WP.6 [3] when the significant wave height is smaller than 1.50 m. However, for the larger significant wave height, the present equation results in a smaller mean wind velocity.

The minimum metacentric height for the vulnerability criteria level 1 is calculated by using the effective wave slope coefficient and the damping factors due to breadth-to-draught ratio (X_1) as well as due to bilge keels (k) estimated by using results of model experiment. The vulnerability criteria level 2 is also calculated following the procedures recommended by IMO with weighting factor of environmental condition shown in Table 2. The wave characteristics are modeled by using JONSWAP spectrum and the Davenport spectrum is used to model the wind gustiness. In this calculation, the effective wave slope coefficient is determined by using the Froude-Krylov assumption of roll exciting moment due to wave with simplified procedure based on substitution of ship sections with rectangles [15]. It has been found that the effective wave slope coefficient of an Indonesian ro-ro ferry obtained by this assumption is similar to that obtained by model experiment [5].

RESULTS AND DISCUSSION

The linear damping coefficients correspond to the weight distribution for ship with and without bilge keels are shown in Fig. 4. Here, C1 indicates the ship without bilge keels with wet radius of gyration of 0.36B, C2 for ship without bilge keels with wet radius of gyration of 0.48 B. C3 and C4 correspond to ship with bilge keels for wet radii of gyration of 0.38B and 0.49B, respectively. The quadratic damping coefficients for four different conditions of the ship refer to the condition for the linear damping coefficients are shown in Fig. 5. Here, the linear and quadratic damping coefficients are determined based on factors “a” and “b” of Bertin’s coefficient shown in Eq. 1 by using the procedure recommended by ITTC [12]. The metacentric height for four different conditions of model experiment is kept to be the same following the design metacentric height for full loading condition.

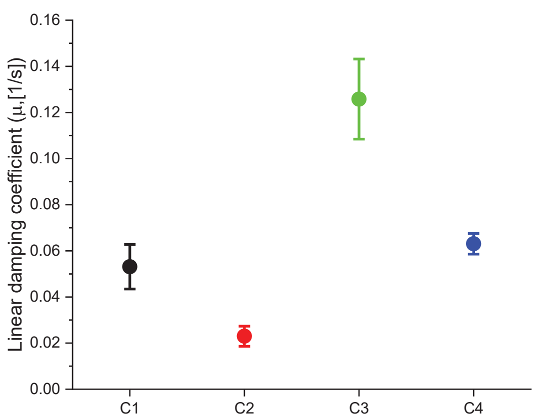

FIGURE 4. Obtained linear damping coefficient for the four conditions used in model experiments

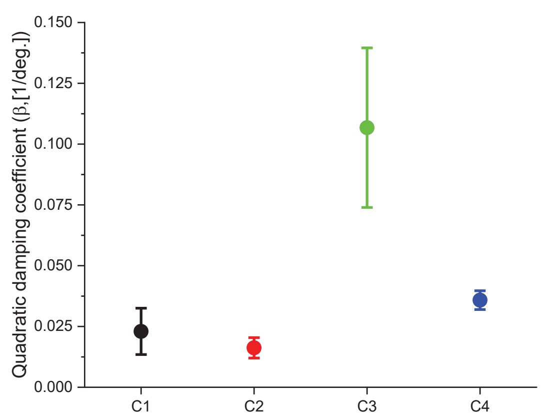

FIGURE 5. Obtained quadratic damping coefficient for the four conditions used in model experiments

The linear and quadratic damping coefficients decrease due to increase of radius of gyration. For the ship without bilge keels, the linear damping coefficient decreases about 72% due to the increase of the radius of gyration while the quadratic damping coefficient decreases about 42%. For the ship with bilge keels, the increase of radius of gyration reduces the linear and quadratic damping coefficients by about 60% and 78%, respectively. These results show that the linear damping coefficient is more significantly affected by weight distribution compared to the quadratic damping coefficient for ship without bilge keels. In case of a ship with bilge keels, a similar effect of weight distribution on the linear and quadratic damping coefficients is obtained. The effect of bilge keels on damping coefficients for the condition with a smaller radius of gyration is more significant compared to the ship with larger radius of gyration. The different effect of weight distribution on damping coefficients for the ship with and without bilge keels could be induced by the difference of natural roll period due to different radii of gyration. The angular velocity of roll for a condition with longer roll period is smaller compared to a condition with shorter roll period. Therefore the damping coefficients become smaller. The roll period increases 6.6% due to bilge keels for the condition with radius of gyration of 0.36 of ship breadth. For the radius of gyration of 0.48 of ship breadth, the natural period of roll increases 2.2% due to bilge keels. The effect of bilge keels on natural roll period has also been investigated in a previous work by Paroka et al. [5].

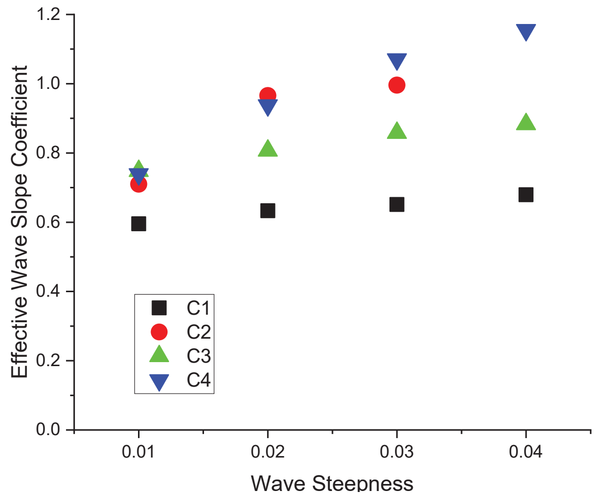

FIGURE 6. The effective wave slope coefficient

The effective wave slope coefficient obtained by tests in regular beam waves is shown in Fig. 6. These coefficients correspond to the resonance frequency of the ship. For ship with radius of gyration 0.48B or larger, bilge keels has no significant effect on the effective wave slope coefficient. However, for the smaller radius of gyration, the effective wave slope coefficient of the ship with bilge keels is larger than that for ship without bilge keels. A similar result has been found by Paroka et al. [5], but with smaller differences. The obtained effective wave slope coefficients are smaller than that obtained by formulae of Weather Criterion which is 1.099. These results also show that the effective wave slope coefficient obtained by the formulae of Weather Criterion is similar to that obtained for the case with the same roll natural period as that obtained by the formula of Weather Criterion. For smaller roll natural period, the obtained effective wave slope coefficient is smaller than that obtained by formulae of Weather Criterion. This is crucial for Indonesian ro-ro ferries because the weight distribution on vehicle deck could be different depending on available vehicles to be carried. Therefore, a methodology for estimating the radius of gyration for a ship with geometry characteristics different from those used to develop the Weather Criterion is necessary in order to apply the SGISC to ships with different geometry characteristics.

The damping factor corresponding to breadth-to-draught ratio (X_1) of the subject ship is 0.674, which is smaller than the recommended value of Weather Criterion for ship with breadth-to-draught ratio larger than 3.5 (X_1=0.8) for ship with the radius of gyration coefficient the same as that obtained by Weather Criterion formulae. For smaller radius of gyration coefficient, the damping factor due to breadth-to-draught ratio for the sample ship is X_1=0.47. Also this damping factor is smaller than that obtained for ship with a larger radius of gyration coefficient. These results show that the damping factor corresponding to the breadth–to-draught ratio in the Weather Criterion should be extended to cover ships with breadth-to-draught ratio larger than 3.50. The damping factor proposed in SLF 46/6/10 [8] can be an alternative applied to a ship with breadth-to-draught ratio larger than 3.50 especially Indonesian ro-ro ferries. A smaller damping factor compared to the recommended value of IMO has also been found by Deakin[4].

The damping factor corresponding to the bilge keels is determined by using Eq. 5 with damping factor correspond to breadth-to-draught ratio based on results previously mentioned. Here, the roll angle toward windward due to wave action is determined based on the results obtained by using Eq. 3 and the relation $\phi_1 = 0.7\phi_{1r}$ (see Eq. 4). The effective wave slope coefficient is based on the results shown in Fig. 6 for ship with bilge keels. The obtained damping factor due to bilge keels (k) is smaller than that recommended in the Weather Criterion. The damping factor due to bilge keels for radius of gyration coefficient the same as that obtained by Weather Criterion formulae is 0.55 and that for the smaller radius of gyration coefficient is 0.73. The damping factor corresponding to the bilge keels based on the Weather Criterion is 0.978. The damping induced by bilge keels does not only depend on the area of bilge keels but also depends on the distance from the vertical center of gravity of ship especially for ships with large breadth-to-draught ratio [16]. Fesman et al. [17] found that the bilge keels can increase the damping coefficient by about 40%. A numerical result shows that the bilge keels can significantly increase the damping moment of a ship [18]. Here, the damping factor k corresponding to the bilge keels decreases by about 15% due to increase in the radius of gyration coefficient from 0.38 B to 0.49 B. When the radius of gyration increases, the roll natural period also increases, and the damping coefficient decreases. Therefore, the total damping factor due to breadth-to-draught ratio and bilge keels for ship with larger radius of gyration coefficient is larger than that with smaller radius of gyration coefficient. The increasing of total damping factor due to increase the radius of gyration is about 8.0%. The summary of obtained results is shown in Table 3.

TABLE 3. Summary of obtained results

Scenario	k_{44}	X_1	k	r
C1	0.36 B	0.470	1.00	0.679
C2	0.48 B	0.674	1.00	0.996
C3	0.38 B	0.470	0.73	1.071
C4	0.49 B	0.674	0.55	0.883

Using the damping factors due to breadth-to-draught ratio (X_1), the damping factor corresponds to bilge keels (k) and the effective wave slope coefficient, the vulnerability level 1 of SGISC is calculated with the wind pressure of 300 Pa, to evaluate the intact stability of subject ship. The area ratio b/a for vertical center of gravity between 1.225 m and 8.50 m, corresponding to metacentric height ranges from 0.22 m to 7.495 m is shown in Fig. 7. For the same range of vertical centre of gravity, the vulnerability level 2 is also calculated by using the wave data shown in Table 2 and the mean wind velocity following from the relation in Eq. 5. The results are shown in Fig. 8.

The area ratio b/a is significantly affected by weight distribution mainly for the ship without bilge keels. The effect of weight distribution becomes small for ship with bilge keels. Here, the wave steepness for the smaller radius of gyration is not different from that for the larger radius of gyration as the roll natural period remains below 6.0 seconds even if the radius of gyration is taken in accordance with the formula of Weather Criterion. Results of model experiment show that the damping coefficients tends to decrease if the radius of gyration coefficient increases for both the ship without and with bilge keels as shown in Fig. 4 and Fig. 5, respectively. This means that the damping factor due to breadth-to-draught ratio as well as due to bilge keels could be different due to different radius of gyration coefficient. As result, the minimum metacentric height for vulnerability criteria level 1 could be different due to different weight distribution. The critical metacentric height for the C1 condition is 1.193 m and 1.793 m for C2 condition. In case of C3 condition, the obtained minimum metacentric height is 0.693 m and that for C4 condition is 0.793 m.

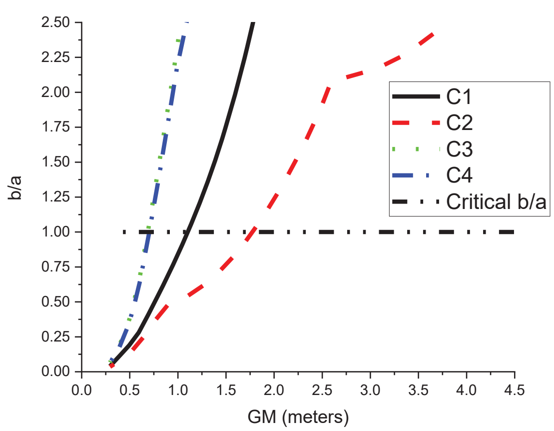

FIGURE 7. Area ratio b/a for different weight distributions for ship without and with bilge keels

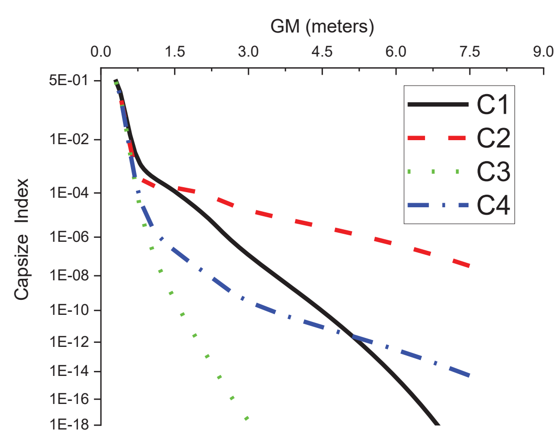

FIGURE 8. Capsize index for different weight distributions for ship without and with bilge keels

The capsize index from level 2 vulnerability criteria shows a different trend. Here, a significant difference of capsize index due to different weight distribution and due to bilge keels occur when the metacentric height is larger than 0.60 m. The ship with larger radius of gyration coefficient has a larger capsize index compared to a ship with smaller radius of gyration coefficient. The bilge keels has also a significant effect on capsize index when the metacentric height is larger than 0.60 m. Following the recommended maximum capsize index by IMO of 0.06, the minimum metacentric height for all examined conditions of weight distribution for ship without and with bilge keels is not significantly different of 0.493 m. Those minimum metacentric heights are smaller than the minimum metacentric height obtained in the vulnerability criteria level 1 of 0.693 m for C3 condition. The critical angle of heel for calculating the area ratio b/a and the capsize index is taken to be the same as the down flooding angle, i.e. 38.5 deg. Nevertheless dangerous conditions could occur even when the roll angle is smaller than the down flooding angle due to deck edge immersed as the freeboard of the subject ship is 1.0 m. The deck edge immersion will occur when the roll angle is 8.75 degrees or larger.

In case of operational condition with metacentric height of 4.0 m, the area ratio b/a for C1 condition of weight distribution is 7.15 and that is 2.62 for C2 condition, decreases about 63% due to increase in the radius of gyration. The decreasing of area ratio b/a is 15% when the ship uses bilge keels. The effect of bilge keels on level 1 criterion is more significant for a larger radius of gyration. The area ratio b/a increases about 78% due to bilge keels for subject ship with radius of gyration of C2 condition to be C4 condition. The increasing is about 49% for radius of gyration of C1 condition to be C3 conditon. The capsize index of examined ship without and with bilge keels significantly increases due to the increase in the radius of gyration as shown in Fig. 8. In the operation range of metacentric height, i.e the metacentric for full loading condition of 4.0 m, a different weight distribution may result in a different capsize index. This means that the safety level of Indonesian ro-ro ferries does not depend only on the righting arm characteristics but also depend on weight distribution especially on vehicles deck. Therefore distribution of vehicles on the vehicles deck should be determined at the initial design stage and should be followed during ship operation.

CONCLUSION

The damping coefficient and the effective wave slope coefficient of an Indonesian ro-ro passenger ferry with different weight distributions as well as with and without bilge keels have been determined by using model experiment. The damping factors related to breadth-to-draught ratio (X_1) as well as due to the bilge keels (k) are smaller than the values given in the Weather Criterion for both ship without and with bilge keels. Therefore it is especially suggested to extend the damping factor associated to breadth-to-draught ratio (X_1) to cover breadth-to-draught ratios larger than 3.50. The damping factor corresponding to bilge keels (k) also need to be reduced for ships with breadth-to-draught ratio larger than 3.50 and a large vertical center of gravity. The effective wave slope coefficient for ship with the radius of gyration the same as or larger than that calculated by using the formula of Weather Criterion is similar to that obtained by model experiment. The effective wave slope coefficient of ship with larger radius of gyration is larger than that of ship with smaller radius of gyration. The results are used to calculate the minimum metacentric height based on level 1 and level 2 vulnerability criteria for dead ship condition from Second Generation Intact Stability Criteria. The minimum metacentric height of subject ship based on the level 1 vulnerability criterion is 0.693 m for ship with C3 condition, and 0.493 m for the level 2 vulnerability criterion. The weight distribution has no significant effect on the capsize index when the metacentric height of the subject ship is smaller than 0.60 m. However, the capsize index considerably altered depending on weight distribution when the metacentric height exists in the range of operational metacentric height of the subject ship.

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