APPLICATION OF THE SECOND GENERATION INTACT STABILITY CRITERIA TO AN INDONESIAN RO-RO FERRY SUPPORTED BY MODEL EXPERIMENT

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SUMMARY

The characteristics geometry of Indonesian ro-ro ferries are different with those used to develope the weather criterion in the intact stability criteria of International Maritime Organization. To evaluate the stability of Indonesian ro-ro ferries using the second generation intact stability criteria, an alternative assessment of weather criterion as the vulnerability criteria level 1 is necessary in order to find consistency of each level of vulnerability criteria. This paper discusses about stability evaluation of an Indonesian ro-ro ferry by using the second generation intact stability criteria with the damping factor correspond to the breadth and draught ratio determined by model experiment. The effective wave slope coefficients as function of vertical centre of gravity are calculated using the formula of weather criterion and the simplified strip theory at the wave frequency the same as the natural frequency of roll. The wind and waves characteristics are based on the scatter wave data of a ferry route in Indonesia. As results, the minimum metacentric height for vulnerability criteria level 1 obtained by model experiment is smaller than that obtained by using the values in the weather criterion. The inconsistency between the vulnnerability criteria level 1 and level 2 appears when the values of parameters in the weather criterion are used. However, it shows the consistency when the damping factor correspond to the breadth and draught ratio in the vulnerability criteria level 1 is determined by model experiment. The obtained safety level for the vulnerability criteria level 2 is 0.00008 correspond to the critical metacentric height 1.3 meters. This result show that the minimum safety level recommended by the International Maritime Organization can be applied to Indonesian ro-ro ferries.

NOMENCLATURE

CI	Capsizing index
C_i	Short-term capsizing probability
H_s	Significant wave height (m)
m_o	Variance deviation of roll motion (rad.^{2})
m_2	Variance of angular velocity of roll (rad.^{2}/s^2)
S_i	Occurence probability of sea state
T_{EXP}	Time exposure (s)
U_w	Mean wind velocity (m/s)
$\Delta\phi_{EA^+}$	Range of residual stability in leeward (rad.)
$\Delta\phi_{EA^-}$	Range of residual stability in windward (rad.)
λ_{EA}	Capsizing rate (1/s)

1. INTRODUCTION

The Indonesian ro-ro ferries are characterized by large large breadth compared to the ship draught to provide a large area of vehicles deck and the shallow water in the port area. In order to easily loading and unloading of vehicles, the freeboard is designed to be smaller around 0.10 of ship breadth [1]. Those ro-ro ferries are used for short inter-island and inland river-seas transportations. The vertical center of gravity could be higher than the ship height because the vehicles deck is located in the main deck and the passenger accommodation is above the vehicles deck. The safety of ship in seaways correspond to stability is evaluated by using the general intact stability criteria and the weather criterion of International Maritime Organization (IMO) [2]. Due to their geometry characteristics are different with those used to develope the criteria, some parameters of the criteria are difficult to comply such as the heel angle with maximum righting arm. This is because the angle of deck edge immersion smaller than 10.0 degrees due to small freeboard and small draught compared to the ship breadth [1]. On the other hand, the initial metacentric height, the area under the righting arm curve as well as the angle of vanishing stability are generally larger compared to other ships types due to large breadth and draught ratio.

The roll-back angle obtained in the weather criterion could be overestimate when it is applied to the Indonesian ro-ro ferries. The breadth and draught ratio of Indonesian ro-ro ferries is generally larger than the maximum ratio in the weather criterion. As result, the damping factor correspond to the breadth and draught ratio in the weather criterion could be overestimate [3], [4]. The effective wave slope coefficient obtained by formula of weather criterion is larger than that obtained by model experiment due to large vertical centre of gravity [4], [5], [6]. The formula to determined the coefficient "C" correspond to the formula of natural roll period could result significant error when it is applied to a ship with large breadth and draught ratio as well as large metacentric height [7]. Therefore, IMO provide an alternatif assessment of weather criterion based on model experiment especially for ships with geometry characteristics different with that used to develope the criteria [8]. The wind pressure used in the weather criterion was for wind velocity of 26 m/s. This wind velocity could be different depend on the location and geography characteristics.

Recently, the second generation intact stability criteria (SGISC) is being in finalization step which is a performance based criteria. The revision of intact stability criteria is meant to consider the ships with geometry characteristics different with those used to develope the previous criteria. The weather criterion has been decided by IMO as the vulnerable criteria level 1 for dead ship condition and the vulnerable criteria level 2 was the probability of ship heel angle exceeding a certain angle such as the downflooding angle or the angle of vanishing stability. The level 1 of the vulnerability criteria means to separate between conventional and unconvetional ships. This criteria opens the challenge to overcome the problem of implementation of stability assessment for ship with geometry characteristics out of the range in the weather criterion. A ship comply with the vulnerability criteria level 1 should also comply with the level 2 of the vulnerability criteria. On the other hand, a ship is found to be vulnerable in the level 2 should also be vulnerable in the level 1. During this finalization, the criteria has been tested by applying to several ships types including large passenger ships as well as ro-pax ships. In some cases, the obtained safety level is inconsistence between the vulnerability criteria level 1 and the vulnerability criteria level 2. Therefore, the standard of minimum safety level especially for level 2 of vulnerability has not yet been decided. The IMO suggested the capsizing index to be 0.04 or 0.06 [9] but in the other document it is proposed to be 0.01. The inconsistency could be occur because the safety level in the weather criterion is calculated for one sea state while in the vulnerability criteria level 2, the casizing index is calculated for all possible sea state based on the scatter wave data of operational area. In the other hand, safety level of a ship could change depending on the sea state of operational area. The discrepancy of safety level between the vulnerability criteria level 1 and the vulnerability criteria level 2 may also occur due to different damping factors used in the weather criterion and the capsizing index especially for ships with breadth and draught ratio larger than 3.5.

This paper discusses about the minimum safety level of ships with geometry characteristics are not covered in the weather criterion based on the SGICS. This is important because most of ships used for inter-island and river-seas transportation especially for short distance have geometry characteristics with large breadth and shallow draught as well as small freeboard. The inconsistency of safety level for dead ship condition mainly occur for ships with lower weather deck and very large breadth means small ratio of freeboard and breadth [10]. Rudakovic and Backalov [11] used the capsizing index of 0.04 as the minimum safety level to analyze operational limitation of a river-sea ship using the SGISC. However they did not analyze the consistency between the vulnerability criteria level 1 and the vulnerability criteria level 2. If the consistency of the criteria can be found, the minimum safety level can be determined in advance and the SGISC can be considered to adopt as stability standard for ships with large breadth and draught ratio as well as very small freeboard. The obtained results can also be used to explain the reason of the consistency when the SGISC applied to such ships geometry characteristics.

2. METHODOLOGY

The second generation intact stability criteria is applied to an Indonesian ro-ro ferry with principal dimension shown in Table 1 and its body plan is shown in Figure 1. The righting arm curve of the ship for full loading condition is shown in Figure 2.

Table 1: Principal dimension of ship

Dimension	Ship (m)
Length perpendiculars (Lpp)	50.50
Breadth (B)	14.00
Height (H)	3.80
Draught (d)	2.70
Metacentric height (GM)	4.23
Vertical centre of gravity (KG)	4.717
Length of bilge keel	18.00
Breadth of bilge keel	0.25

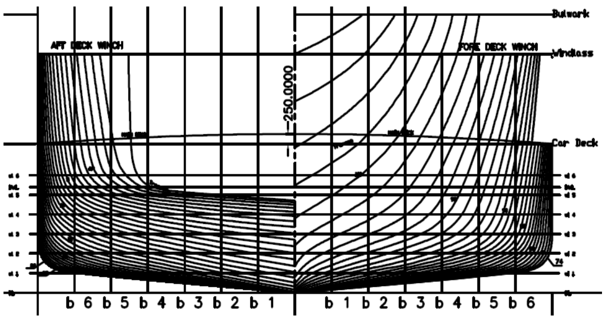

Figure 1: The body plan of subject ship

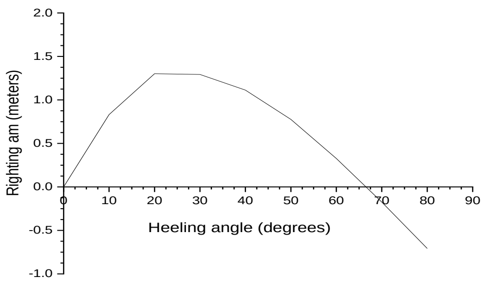

Figure 2: Righting arm curve of the subject ship for full loading condition

The vulnerability criteria level 1 for variation of metacentric height range from 0.50 meters to 8.8 meters are calculated with the damping factor correspond to breadth and draught ratio is determined following the value in the weather criterion and by model experiment. The critical metacentric height is calculated for two different effective wave slope coefficient. The first effective wave slope coefficient is obtained by using the formula of weather criterion [2]. The second one is obtained from the simplified strip theory as recommended by IMO to use in the vulnerability criteria level 2 [12]. Here, the effective wave slope coefficient is determined based on the natural frequency of roll for each vertical centre of gravity. The effective wave slope coefficients obtained by formula of IMO is shown in Figure 3 and those obtained by simplified strip theory for wave frequency the same as the natural frequency of roll as well as model experiment are shown in Figure 4.

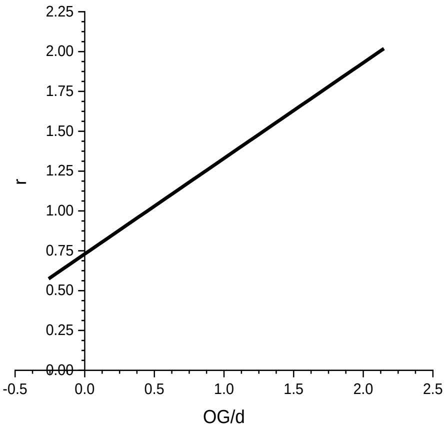

Figure 3: Effective wave slope coefficient obtained by formula of IMO

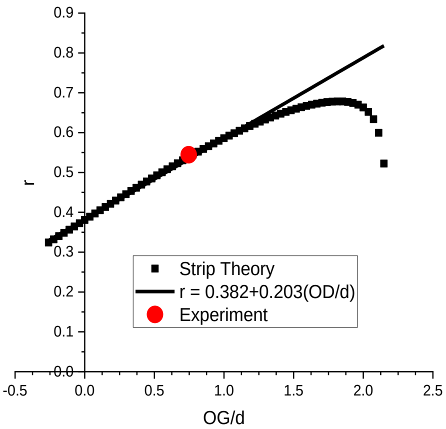

Figure 4: Effective wave slope coefficient obtained by simplified strip theory and model experiment

The effective wave slope coefficient of the ship obtained by formula of IMO is alrger than that obtained by simpified strip theory and by model experiment. For large vertical center of gravity, the effective wave slope coefficient obtained by formula of IMO is larger than 1.0. The result of model experiment is coincide with that obtained by simplified strip theory.

The natural roll period of the subject ship is 4.453 seconds which is smaller than the minimum natural roll period in the weather criterion. Therefore, the wave steepness is determined to be the same as that corresponds to the minimum natural roll period in the criteria. The wind pressure is determined based on the wind speed data of one route of Indonesia ro-ro ferry. Tha maximum wind velocity is 20 m/s correspond to wind pressure of 300 Pa. The wind pressure could be smaller depend on the location. The others variable in the weather criterion formula such as the damping factor correspond to the block coefficient and the bilge keel are determined following the weather criterion.

The capsizing index as the parameter of the vulnerability criteria level 2 for the same range of vertical centre of gravity the same as that in the level 1 is calculated with linear and quadratic damping coefficients determined by model experiment. The effective wave slope coefficients are determined using the same methos as used in the calculation of vulnerability criteria level 1. The statistics wave data of route of ro-ro ferry between Bulukumba and Selayar Island with scatter wave data shown in Figure 5 is used.

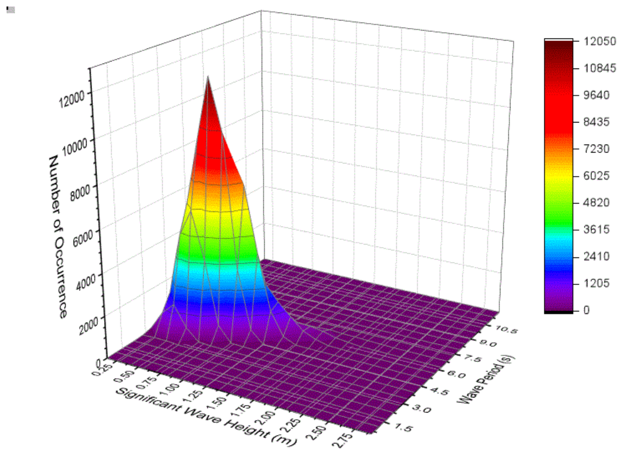

Figure 5: Scatter wave data

The mean wind velocity is calculated as function of significant wave height. This equation is statistically developed based on recorded data of wind and waves with the equation shows as follow [13]:

$$U_w = \left(\frac{H_s}{0.13}\right)^{0.85} \quad (1)$$

This equation is different with formula IMO [12] as the location data colllected is different. The spectrum of wave exciting moment is calculated by using the Jonswap spectrum and the Davenport spectrum is used to calculate the spectrum of wind moment due to wind gustness. The casizing index is calculated using the following equation [9]:

$$CI = \sum_{i=1}^{N} C_i \, S_i \qquad (2)$$

The probability of roll angle exceeding an acceptable angle, here the downflooding angle or the angle of vanishing stability which is the smallest for a certain exposure time is calculated by using the equation as follows [9]:

$$C_i = 1 - exp(-\lambda_{EA} T_{EXP}) \qquad (3)$$

Here, the exposure time determined to be one hour. The occurence probability of a sea state is determined as the number of occurence devided by the total number of wave recorded. The wave data recorded shown in Figure 5 is used to determine the probability of each pair of significant wave height and the mean wave period. The capsizing rate in the equation (3) is calculated by using the equation as follows [9]:

$$\lambda_{EA} = \frac{1}{2\pi}\sqrt{\frac{m_2}{m_0}}\left(exp\left(-\frac{\Delta\phi_{EA^+}{}^2}{m_0}\right) + exp\left(-\frac{\Delta\phi_{EA^-}{}^2}{m_0}\right)\right) \qquad (4)$$

Here, the residual stability range in leeward and windward directions are determined by maintaining the area under the righting arm curve from the static heel angle due to steady wind to the downflooding angle or the angle of vanishing stability, which one is the smallest. This means that the residual stability range could be larger than the downflooding angle or the angle of vanishing stability depends on characteristics of the righting arm curve. The variance of roll angle and the variance of angular velocity of roll are calculated based on the spectrum of total exciting moment induced by combined action of gustness wind and waves for each sea state.

3. RESULTS AND DISCUSSION

The index “b/a” as the parameter of the vulnerability criteria level 1 for several different vertical centre of gravity are shown in Figure 6. Here, the solid line indicates the results obtained based on the recommended values of each parameter of weather criterion and the dash line show the index “b/a” with the damping factor correspond to the breadth and draught ratio obtained by model experiment and the effective wave slope coefficient calculated by the simplified strip theory. As the damping factor correspond to the breadth and draught ratio obtained by model experiment is smaller than that in the weather criterion, the results obtained by experiment is larger than that obtained based on the recommended values of IMO. The critical metecentric height is 3.9 meters if the values of parameters in the weather criterion is used and that is 1.6 meters when the damping factor correspond to the breadth and draught ratio obtained by model experiment and the effective wave slope coefficient calculated by simplified strip theory are used. The smaller damping factor due to breadth and draught ratio determined by model experiment result in smaller roll-back angle compared to that obtained by using the values in the weather criterion. This smaller roll-back angle is also induced by smaller effective wave slope coefficient obtained by simplied strip theory than that calculated by using the formula in the weather criterion. Therefore, the index “b/a” become large than that by using the values in the weather criterion.

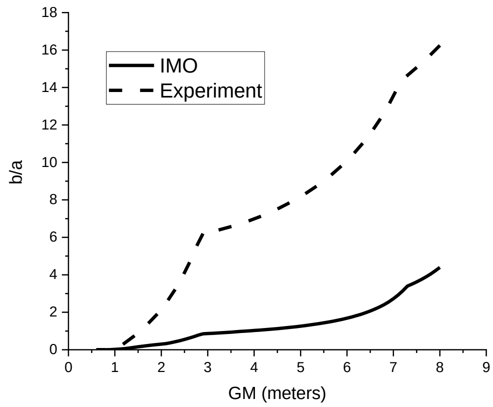

Figure 6: The index “b/a” for variation of matacentric heigh with wind pressure of 300 Pa

Figure 7 show the capsizing index of the subject ship based on the statistics wave data of a route of inter-island transportation in Indonesia serviced by ro-ro ferry. The solid line is the capsizing index with the effective wave slope coefficient obtained by simplified strip theory as function of wave frequency and the dash line for the effective wave slope coefficient calculated by weather criterion formula. Similiar to the vulnerability criteria level 1, the capsizing index by using the effective wave slope coefficient of the weather criterio formula is larger than that obtained by using the simplified strip theory.

This is due to larger effective wave slope coefficient obtained by the formula of weather crirerion.

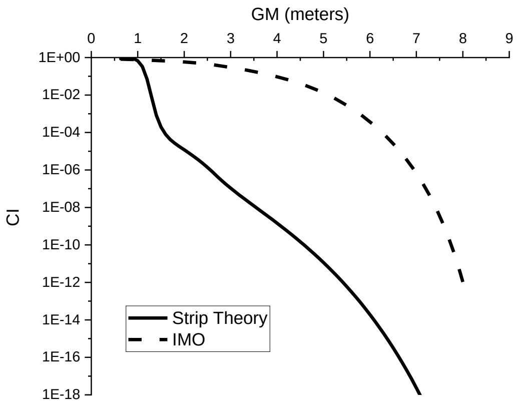

Figure 7: Capsizing index for variation of metacentric height with effective wave slope coefficient obtained by strip theory and formula of IMO.

The vulnerability criteria level 1 and the vulnerability criteria level 2 is not consistence when the effective wave slope coefficient is calculated by using the formula of IMO. The ship is found to be vulnerable in the level 1 when the metacentric height is smaller than 3.9 meters. This metacentric height correspond to a capsizing index of 0.142. This capsizing index is larger than the maximum capsizing index recommended by IMO. If the maximum acceptabel capsizing index follows the IMO recommendation, the minimum metacentric height of the ship is 4.7 meters. This results indicate that the damping factor correspond to the breadth and draught ratio in the weather criterion is overestimate and therefore it should be extended to breadth and draught ratio smaller than 3.50. When the effective wave slope coefficient is calculated by simplified strip theory and the damping factor correspond to the breadth and draught ratio is determined by model experiment, the capsizing index correspond to the vulnerability boundary in the level 1 is 0.00008. This capsizing index is smaller than the maximum capsizing index recommended by IMO. This means that both the vulnerability criteria level 1 and the vulnerability criteria level 2 shows consistency.

Figure 8 and Figure 9 show the relationship between the index “b/a” and the capsizing index for the effective wave slope coefficient calculated by formula of weather criterion and by simplified strip theory, respectively. If the safety standard of IMO with the capsizing index of 0.04 is assumed as the acceptable safety level for the Indonesian ro-ro ferries, the minimum value of index “b/a” should be 1.18. This capsizing index correspond to the metacentric height of the subject ship of 4.7 meters which is the actual metacentric height for full loading condition. This means that applying the values of parameters in the weather criterion to a ship with breadth and draught ratio larger than 3.50 and the ratio between vertical centre of gravity and draught larger than 1.50 result in an overestimate roll-back angle in beam wind and waves so that the vulnerability criteria level 1 and level 2 for dead ship condition becomes inconsistence due to the index “b/a” in the level 1 becomes smaller. The damping moment of the subject ship is larger than that predicted in the weather criterion and the effective wave slope coefficient of the formula of weather criterion is overestimate when it is applied to a ship with large breadth and draugth ratio. This phenomena has been found by others researchers such as Deakin [3] and Sato, et al [14].

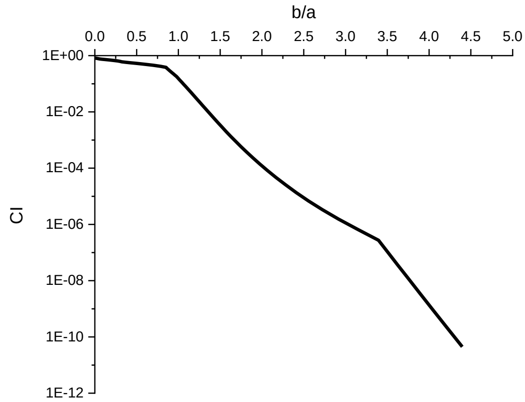

Figure 8: The capsizing index correspond to the index “b/a’’ of weather cirterion with damping factor based on weather criterion

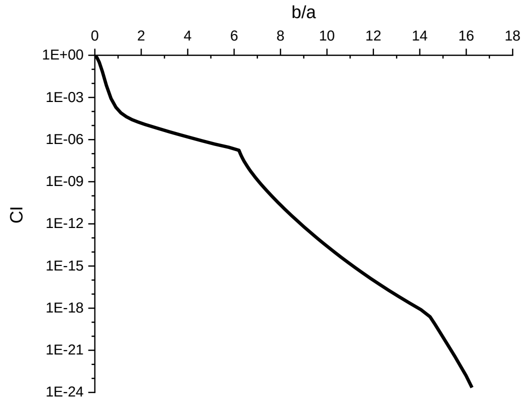

Figure 9: The capsizing index correspond to the index “b/a” of weather criterion with damping factor obtained by model experiment

When the damping factor correspond to the breadth and draught ratio obtained by model experiment and the effective wave slope coefficient obtained by simplified strip theory are used, the capsizing index correspond to the minimum metacentric height obtained in the vulnerability criteria level 1 is smaller than the minimum safety level recommended by IMO. The metacentric height correspond to this minimum safety level is 1.3 meters. The value of index “b/a” in this metacentric height is 0.50 smaller than 1.0 as the safety boundary.

This results show that the same damping factor should be used in both vulnerability criteria level 1 and the vulnerability criteria level 2 in order to find its consistency.

4. CONCLUSIONS

The second generation intact stability criteria has been used to calculate the minimum metacentric height correspond to the vulnerability criteria level 1 and the corresponding capsizing index in the vulnerability criteria level 2. Based on the obtained results and discussions, it can be conluded that the difference method to determine the damping factors in the vulnerability criteria level 1 and level 2 induce inconsistency of the criteria for dead-ship condition. Therefore, it is recommended to used the same estimation method especially for ships with geometry characteristics different with those used to develope the weather criterion. For ship with breadth and draught ratio larger than 3.50, the inconsistency appears due to the damping factor correspond to this ratio is overestimate compared to that obtained by model experiment. It is important to consider extention of breadth and draught ratio in the weather criterion to accomodate ships with ratio larger than 3.50. The effective wave slope coefficient obtained by formula of weather criterion seems to be overestimate when applied to a ship with large breadth and draught ratio. It is necessary an advance investigation of alternative method to determined the effective wave slope coefficient for ships with breadth and draught ratio larger than 3.50. The safety level recommended by IMO in draft of second generation intact stability criteria is more conservative compared to the present result. This means that the minimum safety level can be used for the present subject ship as the minimum safety level.

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Daeng Paroka is a lecturer and a researcher at Department of Ocean Engineering Hasanuddin University Indonesia. His subject is stability of ships and others floating structures. He has conducted research regarding probability assessment of ship stability in beam seas, developed an alternative assessment of weather criterion applied to an Indonesian Ro-Ro Ferry. He also investigated effect of righting arm characteristics on roll motion on beam seas to determine minimum requirement in stability point of view for ships with large breadth and draught ratios.

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