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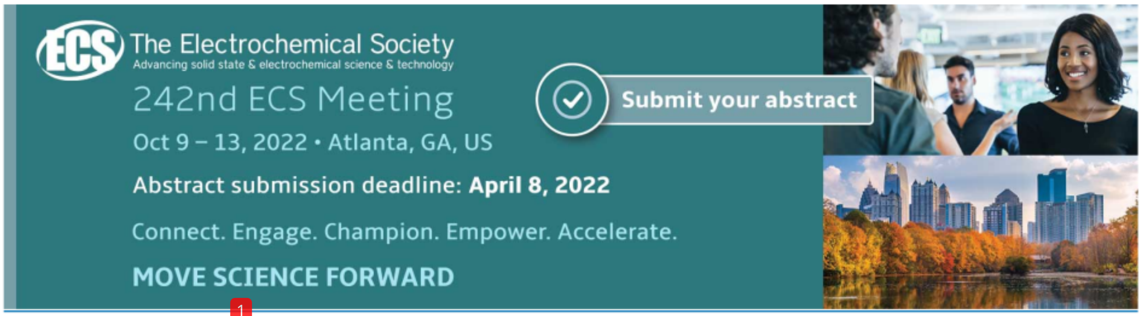

Experimental Study on Weather Criterion Applied to South Sulawesi Traditional Wooden Boats

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Abstract. The general stability criteria of International Maritime Organization (IMO) seem to be difficult to apply to the South Sulawesi traditional wooden boats because the down-flooding angle of most traditional wooden boats was smaller than 30 degrees. The weather criterion may be used to assess the stability of traditional wooden boats because limitation of heel angle depending only on the down-flooding angle. However the criterion was developed based on geometric characteristics of ships different from the South Sulawesi traditional wooden boats. In this paper, the hydrodynamics factors correspond to the parameters of weather criterion are determined by model experiments consist of roll decay test and test in regular beam waves. The critical metacentric height for different wave steepness is determined by using the weather criterion with parameters values based on model experiments.The damping factor due to breadth-to-draught ratio was larger than that provide in the weather criterion for corresponding breadth-to-draught ratio of 4.28.The effective wave slope coefficients for wave steepness of 0.004 and 0.006 are smaller than that obtained by the formula of weather criterion. However, a larger value was obtained for wave steepness of 0.008 and 0.01.The bilge keels position with slope of 15 degrees provided the largest damping moment. The South Sulawesi traditional wooden boats comply with the weather criterion when the wave steepness smaller than 0.08. The weather criterion can be applied to the traditional wooden boats if the parameters values of weather criterion formula have been developed.

1. Introduction

Traditional wooden boats safety could not be assessed in the initial design stage, because the ships were built without preliminary design based but solely based on the builder experience. The ship accidents in Indonesia were dominated by the traditional wooden boats compared to the other ships types. Based on the data of National Transportation Safety Committee of Indonesia (KNKT) in the year of 2013, the number of accident due to sunk was 67 casualty [1]. This number of accident is larger than the other types of accidents. The main cause is bad weather and technical factors.The operational limitation of the traditional wooden boats is important in order to know the maximum environmetal condition for the boats safely operated. Paroka, et al [2] applied the second generation intact stability criteria to determine the operational limitation of a traditional wooden boat built in South Sulawesi. The main drawback of those criteria is determination of the hydrodynamics characteristics to calculate the roll angle toward windward due to wave action. The weather criterion of International Maritime Organization (IMO) provided a formula to calculate the roll angle due to wave with parameters values of damping factors as well as effective wave slope coefficient [3]. The values of each parameters in the weather criterion were determined based on ships data with breadth-to-draught ratio smaller than 3.5, block coefficient smaller than 0.7 with ratio of vertical center of gravity and ship draught between 0.7 and 1.5 as well as the natural roll period up to 30 seconds.

Some research showed that the roll angle due to wave action calculated by using the weather criterion formula tended to be ovesestimate for ships with breadt-to-draught ratio larger than 3.5 and the ratio between the vertical centre of gravity and ship draught larger than 1.5 [4], [5], [6]. In order to applied the weather criterion to a ship with geometric characteristics different with those were used to develop the criterion, IMO suggested to used model experiment [7]. Eventhough, the damping factors correspond to the breadth-to-draught ratio, the block coefficient as well as the bilge keels still use the values given in the weather criterion. The damping factors correspond to the breadth-to-draught ratio of ships with the ratio larger than 3.5 was smaller than that provided in the weather criterion [6]. The damping factor due to bilge keels was also found to be smaller than that given in the weather criterion. Those previous researches showed that an alternative method to determine the values corresponding to the parameters in the weather criterion is necessary in order to apply the criteria to the traditional wooden boats mainly built in South Sulawesi.

Recently the stability of the traditional wooden boats is assessed by means the general intact stability criteria of International Maritime Organization (IMO). Several parameters in this criteria seems to be difficult to apply to the Indonesian traditional wooden boats such as the area under the righting arm curve up to 30 degrees of heel and the area under the righting arm curve between heel angle of 30 degrees and 40 degrees because the down flooding angle is mostly smaller than 30 degrees. If a reliable method to estimate the parameters values corresponding to the formula in the weather criterion is available, this criteria is potentially applied to the Indonesian traditional wooden boats. The weather criterion depend only on the down flooding angle without any limitation of heel angle. The weather criterion was also adopted as the first level of vulnerability criteria of the second generation intact stability criteria of IMO. Here, the ship operational aspects have been introduced. It is recognized that, in order to get a safer ship performance, addressing only design aspect cannot be enough. Operational measures should also be taken into account and operational guidance should be provided to the master. For this reason, both operational limitations and operational guidance have been developed in framework of Second Generation Intact Stability [8].

This paper discusses about application of weather criteria to assess stability of traditional wooden boat with parameters values correspond to the formula to calculate the roll angle due to wave action determined by model experiment. The obtained damping factors correspond to breadth-to-draught ratio as well as correspond to the bilge keels could be used to extend the values in the weather criterion. The obtained critical metacentric height could be used as operational limitation of the traditional wooden boats which is supposed to reduce the capsizing accident due to bad weather. The righting arm characteristics such as the area under the righting arm curve up to a certain angle of heel correponding to the critical metacentric height can be used to develop stability criteria for traditional wooden boats. The results could also be used to provide an operational guidance including the maximum wave steepness for the traditional wooden boats safely operate.

2. Methodology

The ship data used in this paper is a wooden boat built in Bulukumba South Sulawesi with principle dimension and the body plan are shown in Table 1 and Figure 1, respectively.

Table 1. Principle dimension

Parameter	Ship (m)	Model (mm)
Length (L)	22. 8	1140
Breadth (B)	4.8	240
Height (H)	1.6	80
Draught (d)	1.12	56
Vertical center of gravity (KG)	1.58	78.4
Block coefficient (Cb)	0.362	0.362
Displacement (Δ)	40.89	4.52

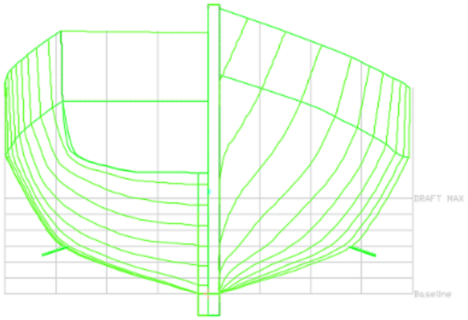

Figure 1. Body Plan

The hydrodynamics factors correspond to the weather criterion was determined by model experiment following the three-step procedure recommended by IMO [9]. The first step is the roll decay test which was performed for ship models without bilge keel and with three different positions of bilge keels consist of the angle of 15 degrees, 30 degrees and 45 degrees, respectively. The bilge keels dimension are determined based on the bilge keels used by the subject ship. The initial roll angle for those tests is 25.0 degrees. The roll motion in time domain is recorded using a dual axis inclinometer and it was stop when the roll amplitude smaller than 0.5 degrees. The extinction coefficients consist of a linear and a quadratic coefficients were statistically determined based on the data of roll decay test. These coefficients were used to determined the Bertin's coefficient by using the following equation [10]:

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

where a is the linear part and b is the quadratic part of extinction coefficients, respectively. ϕ_m is the average of two consecutive roll amplitude of roll decay test.

The second step of three-step procedure is test in regular beam waves. Results of this test were used to estimate the effective wave slope coefficient based on the Bertin's coefficient obtained from the equation (1) by using the equation as follow [9]:

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

where ϕ_r is the roll amplitude obtained in the roll test in regular beam waves with wave height H_r and wave period T_r. $N(\phi_r)$ is the Bertin's coefficient corresponds to the roll amplitude and g is the gravity acceleration. The wave height and wave period were determined based on the wave steepness or ratio between the wave height and the wave length. The roll test in regular beam waves was performed for four different wave steepness of 0.004, 0.006, 0.008 and 0.01 with five different wave frequencies consist of the roll natural frequency, two frequencies smaller and two frequencies larger than the roll natural frequency. The roll angle was measured by using a dual axis inclinometer and the wave elevation was measured by using wave probes located in starboard and portside of the model, respectively as shown in Figure 2. The model is free for sway, heave and roll motions but it was restricted for surge, pitch and yaw motions by a flexible wire rope installed on the steam and the stern with level the same as the vertical centre of gravity of the model.

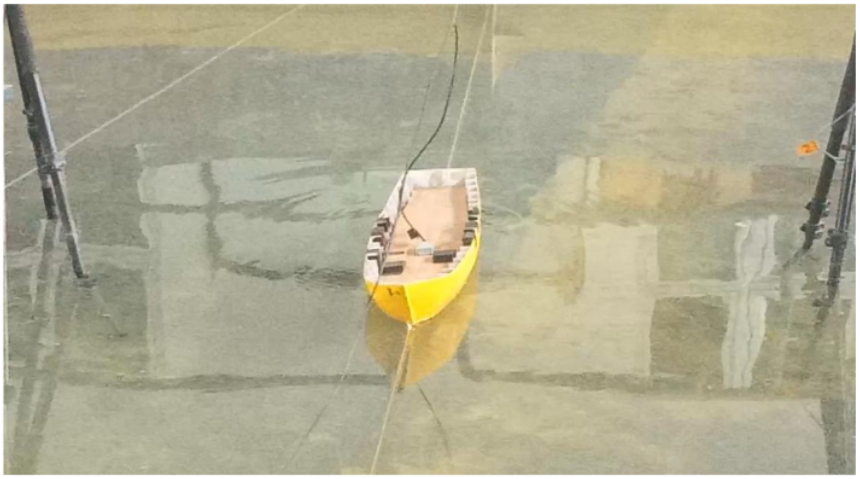

Figure 2. Setting model for roll test in regular beam wave.

The obtained effective wave slope coefficient is used to calculate the roll-back angle in regular wave for the actual wave steepness, following the adopted value of the weather criteria based on the natural roll period by iteratively solving equation (3) with an initial roll angle of 20.0 degrees.

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

The obtained roll-back angle then used to determine the roll angle toward windward due to wave action by taking into account the actual irregular nature of the sea with correction factor of 0.7. The damping factor corresponds to the breadth-to-draught ratio can be calculated by using the formulae to calculate the roll angle toward windward due to wave action in the weather criterion as follow:

$$X_1 = \frac{\phi_1}{109 \cdot k \cdot X_2 \cdot \sqrt{r \cdot s}} \tag{4}$$

where ϕ_1 is the roll angle to windward due to wave, k is the damping factor due to bilge keels which is taken to be 1.0 if the ship without bilge keels. X_2 indicates the damping factor corresponds to block coefficient.

The damping factor corresponds to the bilge keels is estimated by using the data of model experiment with bilge keels with the following equation:

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

Here, the damping factor due to breadth-to-draught ratio obtained from the equation (4) is used. The damping factors due to the breadth-to-draught ratio and due to the bilge keels are used to assess the stability of subject ship by using the weather criterion. To obtain the minimum metacentric height comply with the weather criterion, the b/a area ratio is calculated for variation of vertical centre of gravity ranges between 0.8 meters and 2 meters. The minimum righting arm characteristics of the subject ship are then calculated base on the vertical centre of gravity corresponding to the obtained minimum metacentric height.

4. Results and Discussion

The result of roll decay tests of model without bilge keel and those for model with bilge keels are shown in Figure3 and Figure 4, respectively.

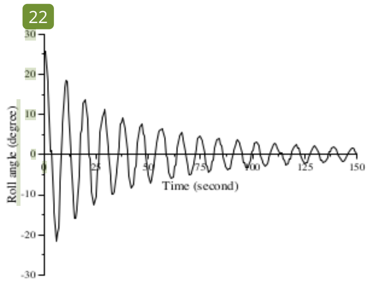

Figure 3. Roll decay test without bilge keels.

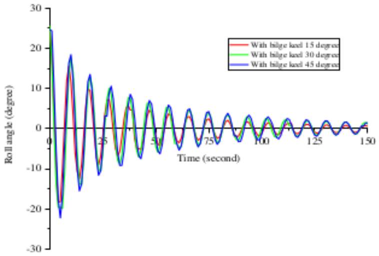

Figure 4. Roll decay test with different position of bilge keels.

The results show that bilge keel can reduce the roll amplitude, where the roll amplitude of model without bilge keels is larger than the roll amplitude of model with bilge keels. The bilge keels position with slope of 15 degrees result in the smallest roll amplitude compared to the position with slope of 30 degrees and 45 degrees, respectively. In order to calculate the Bertin's coefficient, the second order polynomial regression based on results of roll decay tests for ship without bilge keels and with three different positions of bilge keels are developed with the obtained linear and quadratic coefficients shown in Figure 5 and Figure 6, respectively. The presented values were average of five roll decay test for each bilge keels position.

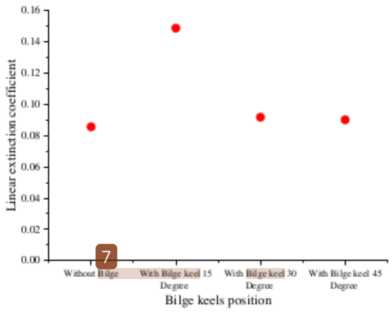

Figure 5. Linier extinction coefficient

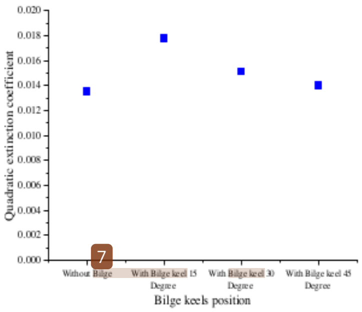

Figure 6. Quadratic extinction coefficient

The extinction coefficients (linear and quadratic coefficients) for ship with bilge keel are larger than that of model without bilge keels. These results indicate that the bilge keels have significant effects on the roll motion of the South Sulawesi traditional wooden boats. The bilge keels position with a slope of 15 degrees induced the largest extinction coefficients compared to the other positions. The extinction coefficients decrease due to increase the slope position of bilge keels. Increasing the linear coefficient due to bilge keels is larger than the increasing the quadratic coefficient for the bilge keels position with slope of 15 degrees. For bilge keels position with slope of 30 degrees and 40 degrees, effect of bilge keels on quadratic coefficient is more significant compated to the linear coefficient. Irkal, et al [11] found that the effect of bilge keels on quadratic damping coefficient was more significant compared to that on linear damping coefficients. The different results mainly for bilge keels position with slope of 15 degrees could be occured due to bilge keels dimension. The present bilge keels area was very small compared to the product of length of water line and breadth. The effect of bilge keels position has been investigated by Gu,et al [12] for FPSO by using CFD and model experiment. They found that the effective position of bilge keels was in the bilge radius of the ship. The damping moment induced by the bilge keels consists of the moment due to the drag force acting on the surface of the bilge keels and the moment due to pressure on the ship hull induced by the bilge keels.The effect of bilge keel on the damping of rolling motion is also influenced by the distance from the bilge keel to the centre of gravity of ship [13].

The damping factor due to the bilge keels depends only on ratio between total area of the bilge keels and product of the length of waterline and the ship breadth in the weather criterion. However, the breadth-to-draught ratio as well as the vertical centre of gravity could have significant effect because the difference distance between the bilge keels and centre of gravity of the ship as found by Katayama, et al [13]. The natural roll period of the ship without bilge keels was 4.14 seconds, and that for the ship with the bilge keels position of 15 degree of the slope was 4.18 seconds. The natural roll period was 4.15 seconds when the bilge keels was located with slope of 30 degrees and that of 4.17 seconds for the slope of 45 degrees. The increasing in the roll natural period due to the bilge keels is caused by reduction in the angular velocity of the roll motion due to the damping provided by the bilge keels as well as increasing the roll moment of inertia due to added inertia induced by the bilge keels. The formula to calculate the natural roll period in the weather criteria did not take into account the influence of bilge keels. The increasing of damping moment induced by the bilge keels can be verified from the roll amplitude obtained in roll test in regular beam wave, as shown in Figure 7 - 10.

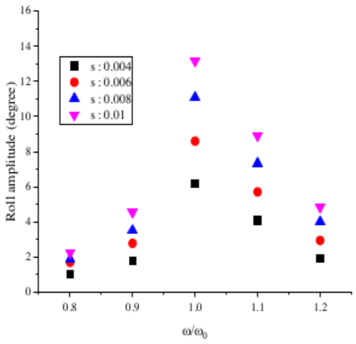

Figure 7. Roll amplitude without bilge keel

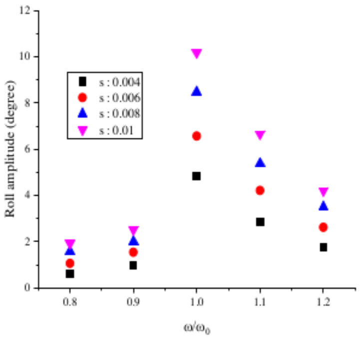

Figure 8. Roll amplitude for bilge keel position with slope of 15 degrees

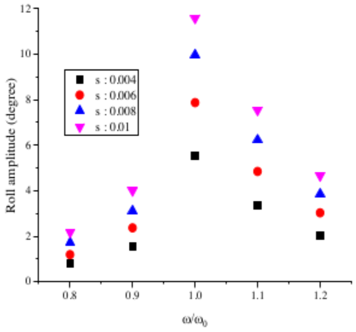

Figure 9. Roll amplitude for bilge keel position with slope of 30 degrees

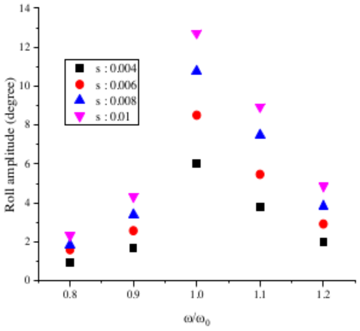

Figure 10. Roll amplitude for bilge keel position with slope of 45 degrees

The roll amplitude for the position of bilge keels with slope of 15 degrees was smaller than that for ship without bilge keel and for ship with the two others positions of bilge keels. The roll amplitude decreases approximately 2.98% for bilge keel sposition with slope of 15 degrees, 1.6% for bilge keels position with slope of 30 degrees and 0.43% for bilge keels position with slope of 45 degrees.

Figure 11 shows the effective wave slope coefficient correspond to the roll natural frequency of the models without and with bilge keels, respectively.

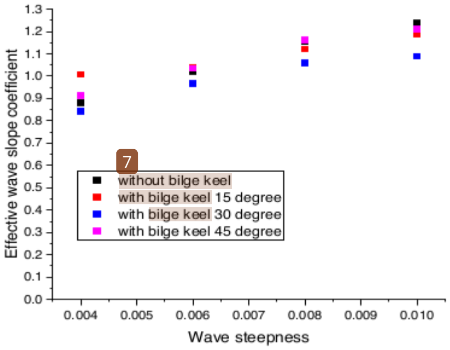

Figure 11. Effective wave slope coefficient

The effective wave slope coefficients for wave steepness of 0.004 and 0.006 are smaller than that obtained by the formula of weather criterion. However, the effective wave slope coefficients for wave steepness of 0.008 and 0.01 are larger than that obtained by the weather criterion formula for both models without and with bilge keels. Some researches showed that the effective wave slope coefficient obtained by the formula of weather criteria is too large if it is applied to ships with geometric characteristics different with those used to develop the criteria [6], [14]. The effective wave slope coefficient in Figure 11 showed that the bilge keels have no significant effect.

The damping factor due to the breadth-to-draught ratio was larger than that provide in the weather criterion for corresponding breadth-to-draught ratio of 4.28 as shown in Figure 12. These results were different with those obtained for differents ships types such as ro-ro ferry [15]. Here, the damping factor due to block coefficient was determined to be same as the value provided in the weather criterion.

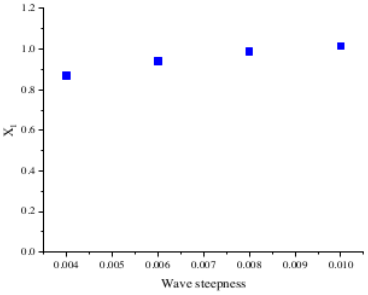

Figure 12. Damping factor due to breadth-to-draught ratio

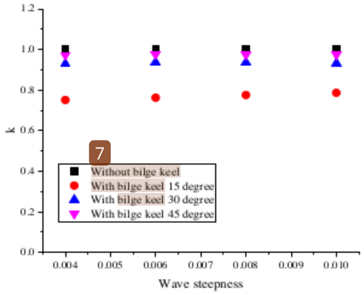

Figure 13. Damping factor due to bilge keels

Figure 13 showed the damping factor due to bilge keels. The damping factor corresponds to the bilge keels was different due to different bilge keels position. The bilge keels position with slope of 15 degrees results in the smallest damping factor. The damping factor for the bilge keels position with slope of 30 degrees and 45 degrees was not significantly different. This results agreed with the extinction coefficients obtained in roll decay test as shown in Figure 5 and Figure 6, respectively. The damping factors correspond to the bilge keels were smaller than that obtained in the weather criterion. The obtained damping factors and the effective wave slope coefficient are used to assess the stability of subject ship using the weather criterion. Here, the angle of down-flooding was determined to be 30 degrees. This angle could be smaller depending on the watertightness of cover construction for opening on weather deck. The wind pressure of 300 Pa corresponding to a wind velocity of 20 m/s was used to calculated the wind moment lever as well as the rol angle toward windward due to wave action. In order to obtained the critical metacentric height, the calculation of area ratio b/a was conducted for vertivcal centre of gravity ranges from 0.8 meters to 2 meters. The corresponding righting arm curve of the variation of vertical centre of gravity is shown in Figure 14.

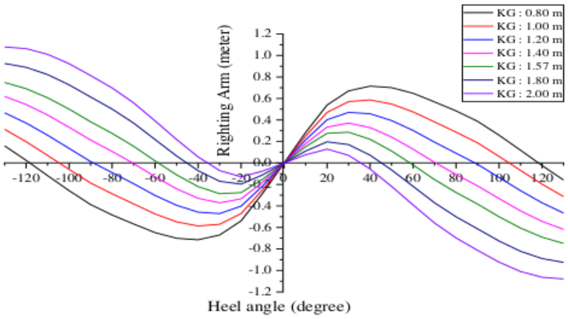

Figure 14. Righting arm for variation of vertical centre of gravity.

The area ratio b/a for wave steepness of 0.06, 0.08 and 0.10 are shown in Figure 15 – 18 for ship without and with bilge keels, respectively.

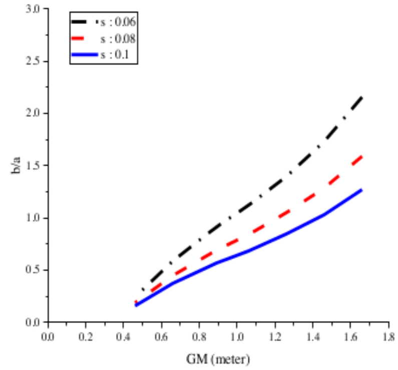

Figure 15. The area ratio b/a for ship without bilge keel.

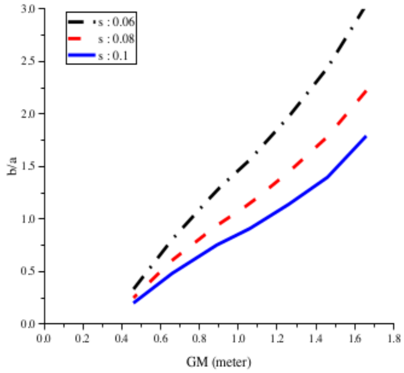

Figure 16. The area ratio b/a for ship with bilge keels position with slope of 15 degrees.

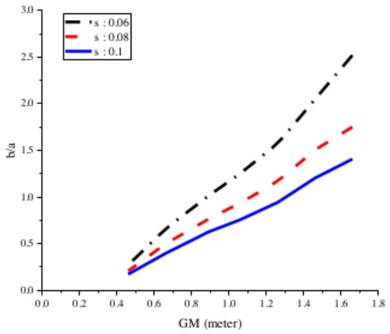

Figure 17. The area ratio b/a for ship with bilge keels position with slope of 30 degrees.

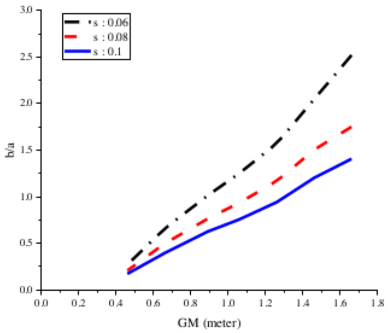

Figure 18. The area ratio b/a for ship with bilge keels position with slope of 45 degrees.

The area ratio b/a decreases when the wave steepness increase. This means that a larger area under the righting arm curve is necessary when the ship operated in the severe weather. The minimum stability requirement was based on the weather criterion with area ratio b/a equal to 1.0. The maximum vertical centre of gravity of ship without bilge keels was 1.51 meters corresponding to the wave steepness of 0.06. A vertical centre of gravity of 1.25 meters was obtained for ship without bilge keels in the wave steepness of 0.08. For wave steepness of 0.10, the maximum vertical centre of gravity for ship without bilge keels was 1.04 meters. The critical metacentric heights (GM) of ship with dan without bilge keels for three different wave steepnes are shown in Figure 19. The bilge keels position with slope of 15 degrees provide the smallest critical metacentric height. The area under the righting arm curve up to heel angle of 30 degrees or the down-flooding angle which one is the smallest corresponding to the critical metacentric height is shown in Table 2.

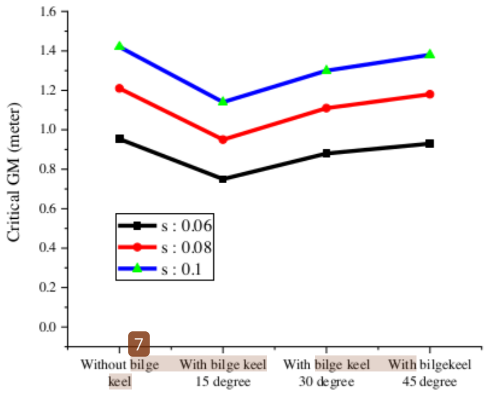

Figure 19. Critical metacentric height.

The required minimum area under the righting arm curve up to the angle of vanishing stability or the down-flooding angle or the angle of 30 degrees which is the smallest can be obtained for the corresponding wave steepness as shown in Table 2. Those area correspond to the critical metacentric height shown in Figure 19. The area under the righting arm curve is larger than that given in the general criteria of IMO [3] for all wave steepness. The critical metacentric height for all wave steepness are also larger than the minimum metacentric height given in the IMO general criteria. This means that the weather criterion should be considered to assess the stability of traditional wooden boats.

Table 2. The area under the righting arm cuver up to heel angle of 30 degrees.

Slope of bilge keels position	Area under the righting arm curve up to 30 degrees (m.deg.)		
	s = 0.06	s = 0.08	s = 0.1
Without bilge keels	6.33	8.30	9.92
15 degrees	4.77	6.31	7.77
30 degrees	5.77	7.54	8.99
45 degrees	6.15	8.07	9.61

4. Conclusion

The stability of a traditional wooden boats built in Tanaberu of South Sulawesi has been assessed by using the weather criterion of IMO with hydrodynamics factors correspond to the formula to calculate the roll angle to windward due to wave determined by model experiment. The bilge keels position with slope of 15 degrees provide the most largest damping coefficient. The maximum wave steepness for the ship safely operated was 0.06 with the critical metacentric height of 0.75 meters corresponding to area under the righting arm curve up to the heel angle of 30 degrees of 4.77 m.deg. The results show that an additional criteria such as weather criterion is necessary in assessing stability of the traditional wooden boats in order to identify the operational limitation. A larger area under the righting arm curve up to heel angle of 30 degrees is need when the ship operated in a higher wave steepness. In order to apply the weather criterion to the traditional wooden boats, the values of parameters to calculate the roll angle to windward due to wave need to be determined for large range of breadth-to-draught ratio, bilge keels geometry as well as block coefficient by using model experiment or computational fluid dynamics.

5. Acknowledgments

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