Intact Stability Criteria and Its Impact on Design of Indonesian Ro-Ro Ferries

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***Abstract*— The ro-ro ferries play an important role for inter-island transportation in Indonesia due to the geographic condition of Indonesia as an archipelago country with short diastance between the inslands. The ro-ro ferries are used to transport passengers, vehicles and goods. The water front condition of the ferries terminal mostly have shallow water. In order to accomodate the vehicles and goods, the ferries was designed with small draught and small freeboard with quite large breadth. Some of the Indonesian ro-ro ferries are difficult to fullfill the IMO intact stability criteria due to the above geometry characteristics. In order to have ro-ro ferries with high performance and safety in seaways, design methodology considering the IMO intact stability criteria is neccessary in the future. This paper discusses regarding effect of the IMO intact stability criteria on the characteristic geometry of Indonesian ro-ro ferries especially the ratio of breadth and draught as well as the freeboard and breadth ratio. These characteristic geometry are analized based on the righting arm of the ships on the critical vertical center of gravity. As results, it show that the breadth and draught ratio is recommended to be not large than 5.50 with the freeboard and breadth ratio at least 0.10. The block coefficient has no significant effect on characteristics of righting arm.**

Keywords—stability; ro-ro ferry; design; breadth; draught; freeboard

I. INTRODUCTION

The ro-ro ferries have an important role for inter-island transportation in Indonesia. This is due to the geographic characteristic of Indonesia with short distance between the island. Most of the teriminal ferries have shallow water front. Therefore the ro-ro ferries operating in Indonesia have small draught. In order to accomodate the passenger and vehicles as main payload, the ro-ro ferries were designed with large breatdh. As a result, the main characteristic of Indonesian ro-ro ferries are large ratio of breadth and draught and small rasio between freeboard and breadth. The small freeboard means to easily tranfer the vehicles into or out of the ship. The ratio between breadth and draught ranges from 3.273 to 7.00 for ships built in Indonesia wtih more than 95 persen have the ratio larger than 5.00. The ships were built in foreign countries have the ratio of breadth and draught from 3.173 to 6.809 with less than 19 persen have the ratio larger than 5.00. This difference geometry characteristic may have significant effect to their stability characteristics [1]. Lewis [2] identified that the ratio of breadth and draught for ro-ro ferries ranges from 1.80 up to 5.00.

The stability criteria recently used to evaluate stability of ships in Indonesia was adopted from the intact stability criteria of IMO which is used also for ocean going ships. This stability criteria was developed statistically in 1936 [3] based on safely operating and ships capsized with different ships type. The geometry characteristics of the sample ships may different with the ro-ro ferries of Indonesia especially for ships built in Indonesia. This can be seen from the difference of geometry characteristics of ro-ro ferries built in Indonesia and built in foreign country. This stability criteria has aslo been criticized by some researchers with different reasons such as the ships type and geometry characteristics of ships when the criteria was developed is different with the ships built after the development of the criteria especially ships built within the two last decades. The weather criteria for intact ships was developed based on ships data with ratio breadth and draught of 3.5 or less [4]. Its mean that the criteria may result in overestimate or underestimate stability when it is applied to Indonesian ro-ro ferries. The angle of maximum righting arm of most Indonesian ro-ro ferries is smaller than 25 degrees as recommended by the International Maritime Organization (IMO) [5]. This is because the small ratio of breadth and draught as well as the small freeboard. The deck edge immersed into the sea water with small heel angle and the radius metacentric significantly decreases due to decreasing of the waterline area. The same phenomena occurs when the ship bottom arise on the water level with small heeling angle due to small draught.

Demand for ro-ro ferries for inter-island transportation tends to increases because the ro-ro ferries are most cheaper and most effective sea transportation for short distance. The age of a half number of ro-ro ferries recently operating in Indonesia are more than 25 years especially the ships built in foreign country. In order to fulfill the demand of ro-ro ferries, existing design of ro-ro ferry need to be revised considering the intact stability criteria as the basis safety assessment of ships in seaways. The new generation of ro-ro ferries in Indonesia should comply with the IMO intact stability criteria so that some accident related to stability problem can be avoided in the future.

This paper discuss regarding design of Indonesian ro-ro ferries based on the intact stability criteria. Paroka and Umeda [6] show that freeboard has significant effect on righting arm characteristic and metacentric height. For each minimum freeboard, the minimum metacentric height (GM_{min}) can be determined. This relationship between the minimum freeboard and the minimum metacentric height was obtained for fishing vessels based on the weather criteria of IMO. They did not consider the area under the righting arm, the heel angle with maximum righting arm and the angle of vanishing stability. Paroka, Asri, Misliah, Sarna and Haswar [7] found that the vertical center of gravity has also effect on minimum ratio of breadth and draught. However, in a certain ratio of breadth and draught, effect of vertical center of gravity can be neglected. The vertical center of gravity of ro-ro ferries tends to be higher than the other ships type because all of passenger, cargo and vehicles located on or above the main deck or vehicle deck. The relationship between design parameter should be formulated in general way for easily used and applied for all owner requirement. Effect of parameters such as the vertical ceter of gravity should be avoid for means usefull of the formulae.

The main concern in this paper is to estimate the ratio of breadth and draught as well as the ratio of freeboard and breadth of the ro-ro ferries so that the problem relating to the intact stability criteria do not occur in the future Indonesian ro-ro ferries. This paper may become reference for preliminary design on ro-ro ferries not only for Indonesia but also for other country with geographic and envirenmental condition similiar with Indonesia of country using river transportation. Relation between design parameter mainly the ratio between breadth and draught as well as the ratio between the freeboard and breadth as the main factor relating to the stability problem may become basic for design ro-ro ferries in the future.

II. RESEARCH METHODOLOGY

Number of ships using as sample in this paper was 16 hull form models with the same length and breadth. These length and breadth was determined based on ratio of ship length and breadth of ro-ro ferries operating in Indonesia. The variation of draught was determined in order to obtain variation of the breadth and draught to be 4.0, 5.0, 6.0 and 7.0. These variation of breadth and draught ratio were also based on the ration of the recently operating ro-ro ferries. Therefore there are four different draught to be analized. All sample ships have different height under consideration of variation of freeboard and breadth ratio of 0.04, 0.06, 0.08 and 0.10. As explained in the previous section that the ratio of freeboard and breadth of the Indonesian ro-ro ferries was 0.04 to 0.10. Paroka, et. al [7] proposed the minimum freeboard of Indonesian ro-ro ferries cannot be smaller than 0.05 of ship breadth.

The principle dimension of each sample ships are shown in Table 1. In order to consider effect of hull form coefficient such as the block coefficient, the hull form for each sample ships was designed with six different block coefficients. The block coefficient was ranges from 0.55 up to 0.65 with increment of 0.02. Therefore, there were 96 different hull form with the same length and breadth.

TABEL I. PRINCIPLES DIMENSION OF SAMPLE SHIPS

Ships	LBP (m)	B (m)	H (m)	T (m)
A1	70.33	17.10	5.985	4.275
A2	70.33	17.10	5.643	4.275
A3	70.33	17.10	5.301	4.275
A4	70.33	17.10	4.959	4.275
B1	70.33	17.10	5.130	3.420
B2	70.33	17.10	4.788	3.420
B3	70.33	17.10	4.446	3.420
B4	70.33	17.10	4.104	3.420
C1	70.33	17.10	4.560	2.850
C2	70.33	17.10	4.218	2.850
C3	70.33	17.10	3.876	2.850
C4	70.33	17.10	3.534	2.850
D1	70.33	17.10	4.153	2.443
D2	70.33	17.10	3.811	2.443
D3	70.33	17.10	3.469	2.443
D4	70.33	17.10	3.127	2.443

The hull form for the different block coefficient of the sample ships are shown in Figure 1. In order to obtain different block coefficient for sample ships with the same principle dimension, sectional area was distributed differently along the ship length. This means that the water line area of each block coefficient will be different. As a result, the inertia of waterline area will also different due to variation of sectional area distribution.

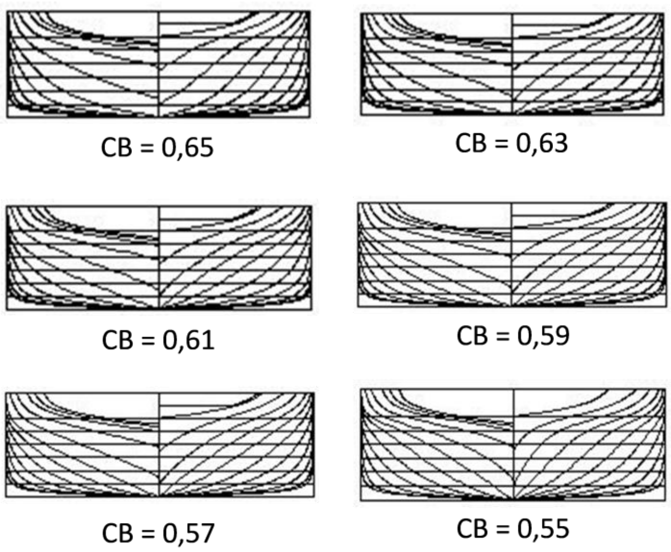

Fig. 1. Hull form of the sample ships with different block coefficient

The righting arm of the sample ship is then calculated for different heeling angle and vertical center of gravity. The center of gravity was increased until the righting arm curve of the ship cannot comply with the IMO intact stability criteria. This vertival center of gravity then called as the maximum or critical center of gravity. The characteristics of the righting arm such as the maximum righting arm and the angle of vanishing stability were investigated in this critical center of gravity.

III. RESULTS AND DISSCUSSION

Based on the explained methodology above, the righting arm of the each sample ship was calculated with results shown in Figure 2 for the ratio of breadth and draught of 6.00 and the block coefficient from 0.55 up to 0.65. Here, the vertical center of gravity was the maximum or the critical center of gravity.

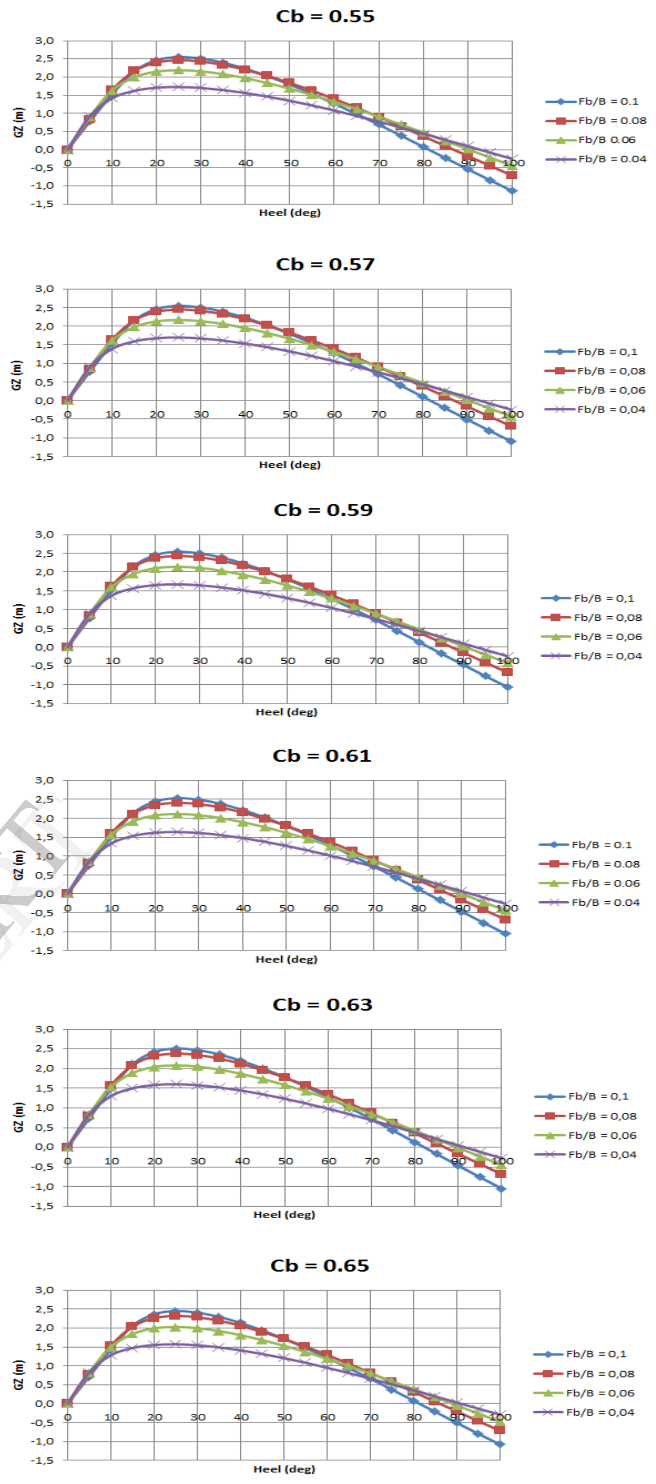

Fig. 2. The righting arm curve for the breadth and draught ratio of 6.0.

The righting arm of the ships does not significantly change due to increasing the freeboard when the heel angle less than 10 degrees. This means that the critical metacentric height of the ships does not affected by the freeboard and breadth ratio. However the maximum righting arm tends to be increase due to increasing the freeboard and breadth ratio especially when this ratio smaller than 0.08. In cases of large ratio of freeboard and breadth, The angle of deck immersion increases when the freeboard increases. In case of the heel angle smaller than the angle of deck immersion, the metacentric radius becomes larger when the heel angle increases. When the heel angle is larger than the angle of deck immersion, area of waterline tends to be decreases when the heel angle increases. Therefore the metacentric radius also decreases due to increasing the heel angle if the heel angle is larger. When the ratio is larger than 0.08, the maximum righting arm does not significantly icreases because of increasing this ratio. Even the angle of deck immersion increase, the bottom may arise on the sea water level in the heel angle smaller than the angle of deck immersion because of the small draught. The same phenomena as the small angle of deck immersion occurs when the ship bottom arrive on the sea water level. This results show that the maximum ratio of freeboard and breadth for design of ro-ro ferries should cosider the ratio of breadth and draught in order to get maximum effect of the freeboard on ship stability.

The righting arm of the ships does not significantly change due to alteration of the block coefficient. This means that the block coefficient does not have significant effect on ship stability. This result should be in advance investigated for ships with block coefficient larger than 0.65.

In order to investigate effect of the ratio of breadth and draught and the ratio of freeboard and breadth to the critical center of gravity, Figure 3 shows the relationship between the breadth and draught ratio to the ratio of critical vertical center of gravity and ship height for each block coefficient of the sampel ships.

Figure 3 shows that the critical vertical center of gravity significantly decreases due to increasing the breadth and draught ratio when this ratio is larger than 5.00. However, the critical vertical center of gravity does not significantly change because of increasing the breadth and draught ratio when the ratio is smaller than 5.00. In the same ratio breadth and draught, the critical vertical center of gravity increases due to increasing the freeboard. However in case of small freeboard and large ratio of breadth and draught, the critical vertical center of gravity does not significantly increases due to increasing the freeboard.

For ships with small draught, the angle of bottom arise on the sea water level is smaller especially for ships having large breadth. The righting arm will significantly decreases when the heel angle is larger then the angle of bottom arise.the maximum righting arm occurs in the heel angle smaller than 25 degrees as the minimum angle based on the intact stability criteria of IMO. Slightly increasing the vertical center of gravity, the ship will not comply with the stability criteria. Therefore, the critical vertical center of gravity decreases significantly when the breadth and draught ratio is larger than 5.00. Alteration of freeboard means than the ship height is change with the same draught. The angle of maximum righting arm is larger for larger freeboard because the angle of deck immersion is also increases when the freeboard increases. The righting arm of ship with large freeboard becomes larger than that with small freeboard. Therefore, the critical vetical center of gravity for ships with large freeboard is higher than these with smaller freeboard. In cases of more larger breadth or smaller draught, the freeboard has not significant effect on the critical vertical center of gravity because the angle of deck edge immersion and the angle of bottom arise becomes smaller.

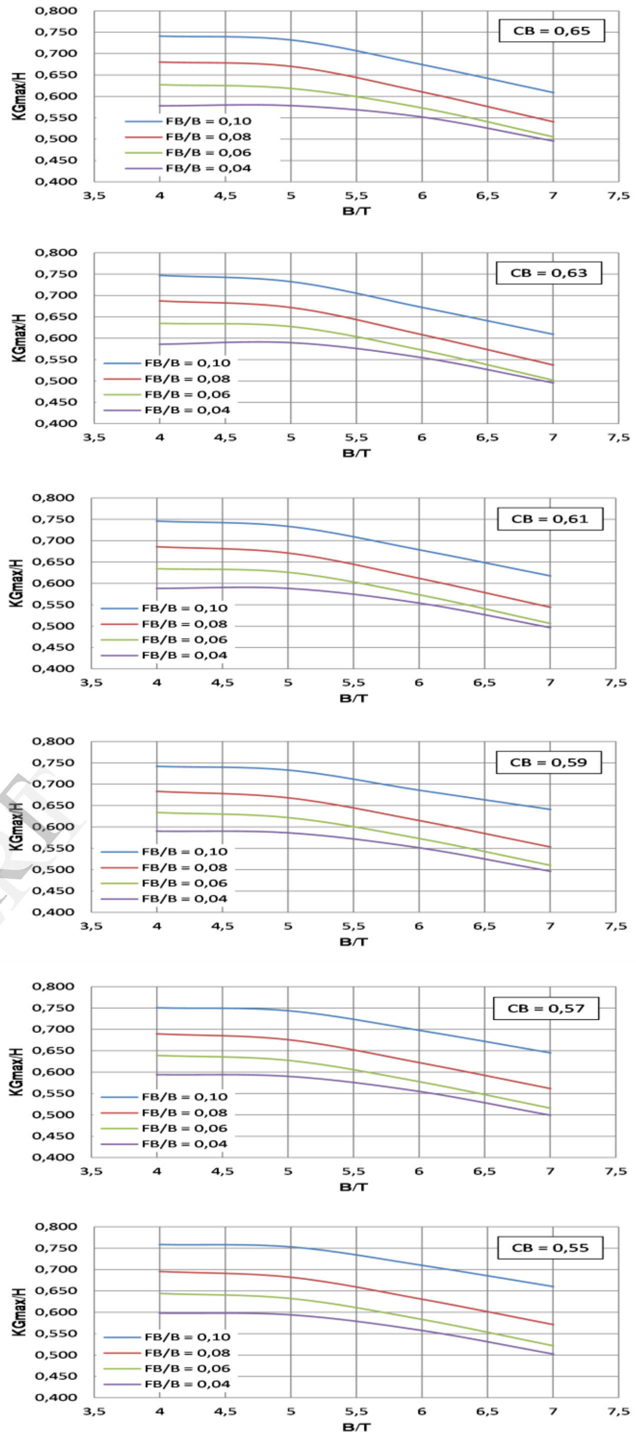

Fig. 3. Effect of breadth and draught ratio to the critical vertical center of gravity.

The Indonesian ro-ro ferries uses the main deck for vehicle and the passenger deck located on the second deck or higher so that the vertical center of gravity seems to be higher than the other ships type. Based on this fact, the vertical center of gravity will be higher than 0.70 of the ship height. Using the critical vertical center of gravity shown in Figure 3, the maximum ratio of breadth and draught for Indonesian ro-ro ferries is 5.50 with freeboard and breadth ratio is not less than

0.10. This limitation is similiar with the ratio obtained by the other researcher [7]. Even though, characteristic of ferry terminal should be considered for determining the freeboard.

Even the critical vertical center of gravity decreases due to increasing the ratio of breadth and draught when this ratio is larger then 5.50 but the maximum righting arm tends to increases when this ratio increases. The maximum righting arm also increases due to increasing the freeboard of the ships. Comparing with the IMO intact stability criteria for the maximum righting arm which cannot smaller than 0.20 meters, the obtained results shows that the maximum righting arm of the sample ships is more larger than that criteria. However the heeling angle of the maximum righting arm tends to decreases because of the increasing of breadth and draught ratio. The angle of maximum righting arm becomes smaller than 25.0 degress as the minimum heeling angle for maximum righting arm in the intact stability criteria. This occurs when the breadth and draught ratio is larger than 5.50 as shown in Figure 2 where the critical vertical center of gravity significantly decreases due to increasing the breadth and draught ratio. The maximum righting arm for each breadth and draught ratio with different freeboard are shown in Figure 4.

When the breadth and draught ratio increases, the matacentric radius also increases, therefore the righting arm increases. The increasing of the metacentric radius occurs due to the large of waterline area in larger heeling angle until the angle of deck edge immersion or angle of the bottom arise on the sea level. The maximum righting arm does not significantly change for different block coefficient. Based on this results, it can be concluded that the maximum righting arm comply with the intact stability criteria for all geometry characteristics of the sample ships.

One of the other IMO intact stability criteria is the angle of vanishing stability. The angle of vanishing stability is the heel angle in which the righting arm of the ships is the same as zero or the angle of water level reach the deck opening or the angle of 40.0 degrees which one is the largest. In order to assurance safety of the ships in operation, the angle of zero righting arm becomes main attention to avoid loss stability when the ships experience large heeling angle. The angle of zero righting arm with different breadth and draight ratio as well as different freeboard and breadth ratio for different block coefficient are shown in Figure 5.

The angle of vanishing stability tends to increases if the breadth and draught ratio increases. For the same breadth and draught ratio, increasing the freeboard result in larger angle of vanishing stability. Alteration of the angle of vanishing stability in smaller breadth and draught ratio is larger than that for larger breadth and draught ratio. The center of bouyancy significantly move to the heel direction when the heel angle is smaller than the angle of deck immersion. If the heel angle is larger than the angle of deck edge immersion, transverse distance of the center of bouyancy tends to decreases when the heeling angle increases and having the same tranverse distance with the center of gravity in a certain heeling angle. The righting arm becomes zero in this heeling angle and called as the angle of vanishing stability.For ships with large breadth and draught ratio, alteration of center of bouyancy due to the heel angle is not significant comparing with that for smaller breadth and draught ratio.

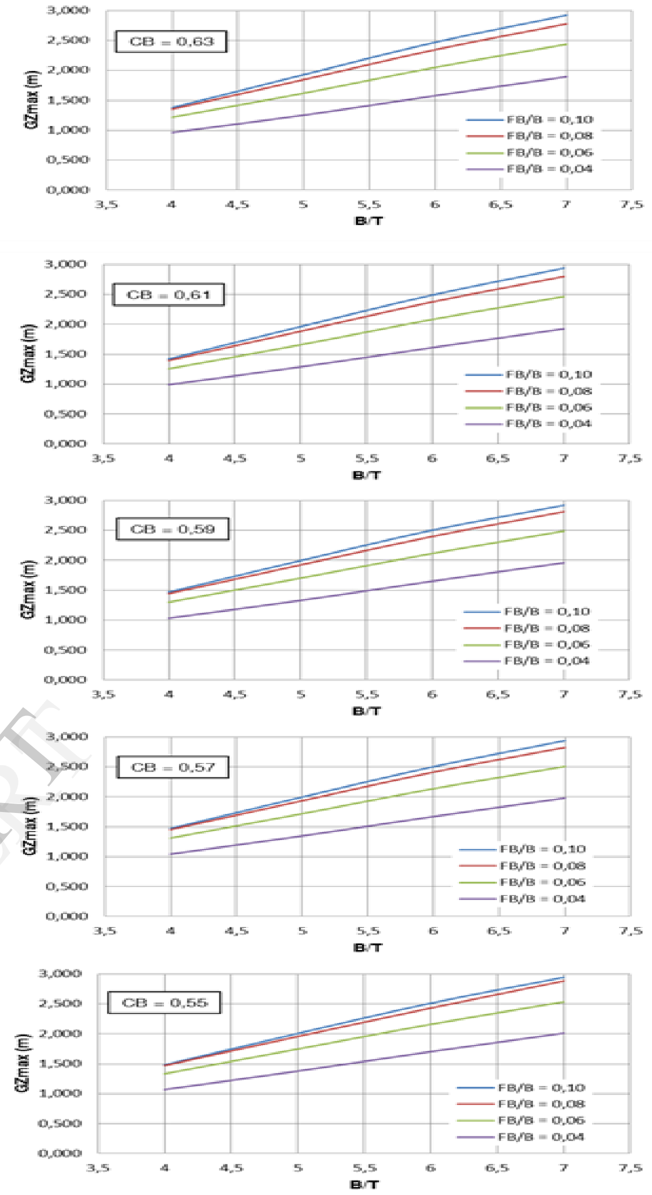

Fig. 4. The maximum righting arm for different breadth and draught ratio and different freeboard and breadth ratio.

Figure 5 shows that the angle of vanishing stability does not change significantly due to increasing of the breadth and draught ratio when this ratio smaller than 5.00 for the freeboard and breadth ratio of 0.04. This phenomena starts to arise in the freeboard and breadth ratio of 0.06. In cases of small freeboard and small draught, the angle of deck edge immersion and the angle of bottom arise on the sea water level are small so that it does not affect the angle of vanishing stability.

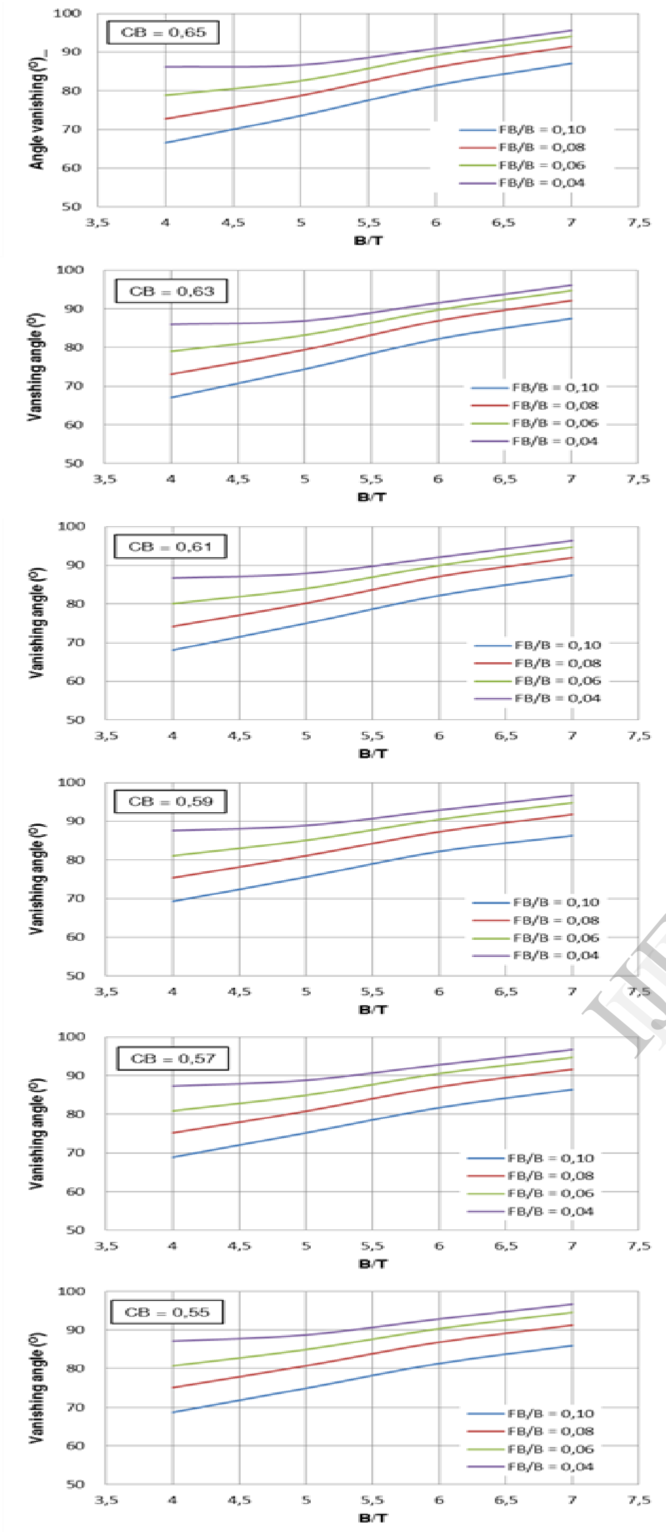

Fig. 5. The angle of vanishing stability for variation of breadth and draught ratio with different freeboard and block coefficient.

Here, the large ratio of freeboard and breadth has smaller the angle of vanishing stability and oppositely the smallest freeboard has the largest angle of vanishing stability. In case of large freeboard, alteration of the center of bouyancy due to heel angle is larger than that with small freeboard. Therefore, the angle of vanishing stability becomes smaller. When the draught of the ships is large then the angle of bottom arise on the sea water level becomes larger so that the alteration of the center of bouyancy to be smaller. As a result, the angle of vanishing stability is larger. However the angle vanishing stability for all sample ships is larger than 40.0 degrees. It means that the sample ships have enough safety level regarding the angle of vanishing stability.

IV. CONCLUSIONS

Bases on the calculation results and analysis for all sample ships with different freeboard and draught, some conclusions can be remarked as follows:

1. The righting arm significantly increases due to increasing the freeboard. However when the ratio of freeboard and breadth is larger than 0.10, the righting arm tends to be constant even the freeboard increases. This freeboard and draught ratio depends on the breadth and draught ratio.
2. The maximum righting arm tend to be constant for variation of breadth and draught ratio but that tends to increases due to increasing the freeboard.
3. The maximum vertical center of gravity or the vertical critical center of gravity significantly decreases if the bradth and draught ratio increases when the ratio is larger than 5.50. It means that the effective ratio in stability point of view is 5.50.
4. The angle of vanishing stability tends to increases due to increasing the breadth and draught ratio when this ratio is larger than 5.00 but the vanishing angle tends to be constant when the ratio is smaller than 5.00.
5. The block coefficient has no signifikan effect on the characteristics of righting arm in all breadth and draught ratio as well as in all freeboard and breadth ratio.

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