Comparative Stability Analysis of a Frigate According to the Different Navy Rules in Waves

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ABSTRACT

As it is known, the naval ships are vulnerable to be damaged because of their mission. Therefore the most important parameter is survivability for them. This parameter is directly related to damaged stability analysis. In this study, the intact and damaged stability analysis of a frigate which is partially modernized have been carried out in waves according to three different navy rules. In addition to its conformity with these three different groups of rules, it has been examined that whether there are conflicting and varying points of different group of rules with each other and it has been tried to determine which one is more realistic.

Keywords: *damage stability, frigate, naval ship stability*

1. INTRODUCTION

Probability of damaging is very high for naval ships and it is related to their vocation. Therefore survivability is one of the most important parameter for them. Thereby intact and damaged stability analyses are so important for these ships in every circumstance.

Up to today there are many the studies which include the ships' intact and damaged stability analysis in waves. Some of them are mentioned.

A ship's intact and damaged stability analyses were made by Lee et al. (2012) via 2D linear method to determine the response of the ship in waves. On another study the waves were sent to model in different directions by Begovic et al. (2013). In that study the different scale of models' results were compared by the investigators. The global wave loads on ship which has zero speed was tried to determine by Chan et al. (2003). The analyses were made intact and damaged situations. An algorithm was developed by Hu et al (2013) to determine the optimum response when a naval ship has damage. A study about second generation intact stability criteria was done by Belenky et al (2011). It also included the effect of wave crest or through which were on the amidships on stability. A study about parametric roll motion of ships which come across a longitudinal wave was carried out by Taylan et al (2012).

In this study, the intact and damaged stability analyses of a frigate which is designed conceptually are implemented in waves according to three different navy rules. Also the results are compared with each other.

2. NAVY RULES

Basically, the stability analyses are made depend on two curves with regard to navy rules. One of them is the righting arm and the other is heeling arm. The heeling arm curve can be made by beam winds, icing, lifting of heavy weights over the side, crowding passengers on one side or high speed turning.

2.1 American Navy Rules (DDS079)

Basically, in reference to DDS079 stability criteria depend on the areas under the righting and the heeling arm curves, the ratio of these areas, the equilibrium angle of the two curves and the ratio of arm's value at the equilibrium angle and the maximum righting arm (GZmax) (DDS079,2002). On the Figure 1 classically, the areas and the curves are shown.

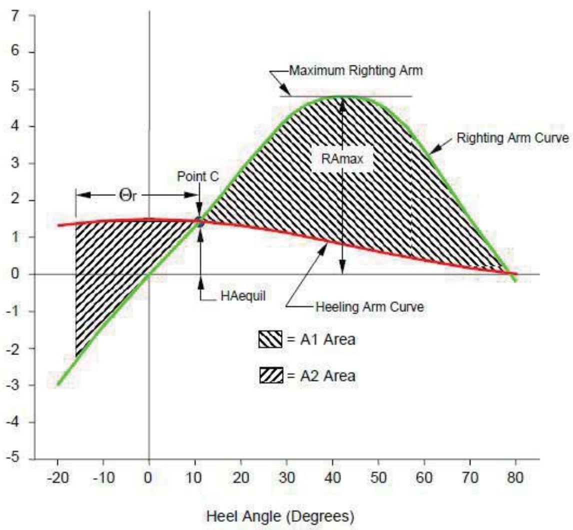


Figure 1. The areas and the curves with reference to DDS079 (2002)

With respect to the DDS079 the heeling arms are calculated by using these formulas:

Caused by beam winds:

9.

$$HA = \frac{0.0195 * V_w^2 * A * z * \cos^2 \varphi}{1000 * \Delta} \quad (1)$$

Caused by lifting of heavy weights or crowding passengers over the side:

$$HA = \frac{w * a * \cos \varphi}{\Delta} \quad (2)$$

Caused by high speed turning:

$$HA = \frac{V^2 * a_1 * \cos \varphi}{g * R} \quad (3)$$

In here,

A: projected sail area

V_W: wind speed

z: lever arm from half draft to centroid of sail area

a: transverse distance from centreline to end of boom

a_1: distance between ship's centre of gravity (KG) and centre of lateral resistance with ship upright

g: acceleration due to gravity

R: radius of turning circle

φ: angle of inclination

Δ: displacement

2.2 German Navy Rules (BV1030)

10. Basically, with reference BV1030 stability criteria depend on the equilibrium angle of the two curves. By using this angle a reference angle is determined. At the reference angle the residual arm must be greater than the minimum value (BV1030, 2001). In the Figure 2, the residual arm and the equilibrium angle are shown.

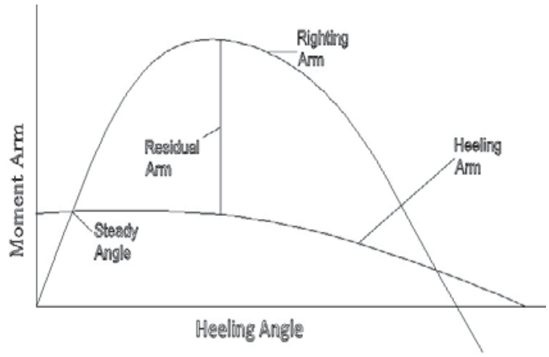


Figure 2. In regard to BV1030 (2001) the arm curves

With respect to the BV1030 (2001) some of the heeling arms can be calculated by using these formulas:

Caused by beam winds:

$$HA = \frac{A_w * (A_{WOH} - 0.5 * T)}{\Delta * g} * P_W * (0.25 + 0.75 * \cos^3 \varphi) \quad (4)$$

Caused by free surface effect:

$$HA = \frac{\sum(\rho * i)}{\Delta} * \sin \varphi \quad (5)$$

Caused by high speed turning

$$HA = \frac{C_D * V^2 * (KG - 0.5 * T)}{g * LWL} * \cos \varphi \quad (6)$$

Caused by crowding passenger over the side:

$$HA = \frac{P * Y}{\Delta * g} * \cos \varphi \quad (7)$$

In here,

A_W: projected sail area

A_{WOH}: centroid of sail area

P_W: wind pressure

ρ: density of liquids in the tanks

Y: transverse distance from centreline to centroid of passengers

i: moment of inertia of liquids in tanks

g: acceleration due to gravity

C_D: coefficient for turning

V: vessel speed

KG: centre of gravity

T: draft of vessel

φ: angle of inclination

Δ: displacement

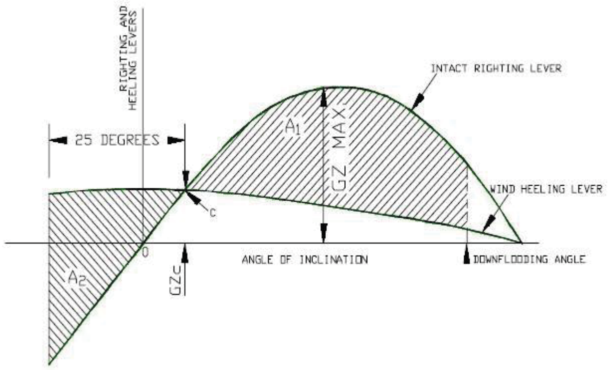
LWL: length of waterline

P: weight of passenger

2.3 English Navy Rules (NES109)

Basically, in accordance with NES109 stability criteria depend on the areas under righting and heeling arm curves, the ratio of these areas, the equilibrium angle of the two curves and the ratio of arm's value at the equilibrium angle and the maximum righting arm (GZmax). In addition of these criteria it has some other requirements. For example the value of GM, GZ_{MAX}, and the area of from 30° to 40° etc. (NES109, 2000)

Formulas in order to calculate heeling arms are same as the DDS079. But it has different notations and different limitations. In the Figure 3 classically; the areas and the curves are shown.



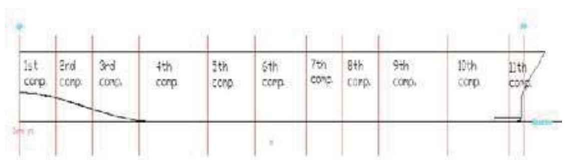
11. Figure 3. In regard to NES109 (2000) the areas and the arm curves

3. SPECIFICATIONS OF THE SHIP

12. Form used in analyses was designed by Sener (2012). This form has been designed conceptually in this study. During the design, from steel weight to weapon and electronic systems lots of parameters have been chosen, calculated and placed originally. In Table 1 the main values of the frigate are shown.

13. Table 1. Main values of the vessel

LOA	145	*m*
LPP	139	*m*
B_{MAX}	18,2	*m*
D	11,2	*m*
T	5,05	*m*
C_B	0,49	-
V	18	*knot*
V_{MAX}	30	*knot*



14. Figure 4 Subdivision of the frigate (Kahramanoglu, 2015)

15. In the Figure 3 the watertight bulkheads are shown on the vessel. The location of them has been settled by originally via taking into consideration experiments and other frigates (Kahramanoglu, 2015). But the damaged stability criteria are not considered when the locations are specified. Just the effect of this localization has been tried to observe on the different navy rules.

4. COMPARATIVE STABILITY ANALYSES IN WAVES

Calculations are made considering each navy rules. On the intact stability analysis, initially, all calculations are made for the calm water. Then a sinus wave which has the same length and direction with the vessel is sent to the vessel. The wave crest is moved from fore to aft step by step. The same methodology is also used for the damaged stability analyses. On the damaged stability analyses, the wave crest is also considered.

4.1 Basic Differences Between Navy Rules

There are some differences between the navy rules. The calculation method of heeling arms and the assumptions are different. Therefore the results of the same analyses differentiate for each navy. The effects of the basic differences on the results are the main aim of this study.

Table 2. Basic differences among navy rules

Parameter	DDS079	NES109	BV1030
Wind speed (intact) (knot)	100	90	90
Wind speed (damaged) (knot)	35	34	40
Roll back (intact)(deg.)	25	25	-
Roll back (damaged) (deg.)	10,5	15	-
Damage length (m)	20,58	25	18
Wave height (m)	7,126	7,126	8,2
Limit of Initial heeling angle (damaged) (deg.)	15	20	25

In the Table 2, the values are demonstrated. Some of them are calculated and some of them are assumed such as wave height with regard to navy rules. Wave height has been assumed equal to DDS079 because of their methodology's similarity.

Damage cases are directly related to damage extents. The damage length values can be seen Table 2.So, as it is seen in Table 3, the damage compartments are different for each navy rules for some damage cases. Thereby the damage cases differentiate. It is assumed that the longitudinal extent of damage starts the near of the bulkhead shown in Figure 2 and moved towards to fore of the vessel. The transverse extent of damage is limited by centre line. The vertical extent of damage is limited by main decks. These limitations are chosen with regard to all navy rules.

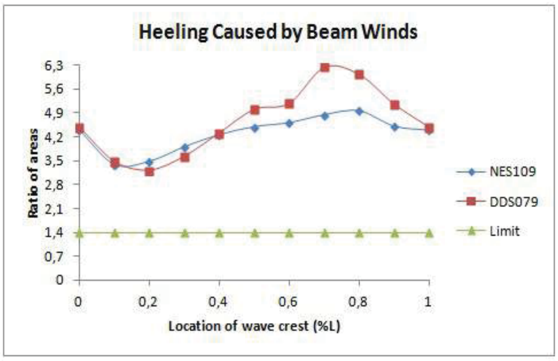
Table 3. Damage scenarios

Damage Scenario	Damaged Compartments		
	BV1030	NES109	DDS079
D1	1-2	1-2-3	1-2-3
D2	2-3	2-3-4	2-3
D3	3-4	3-4	3-4
D4	4-5	4-5	4-5
D5	5-6	5-6	5-6
D6	6-7	6-7-8	6-7
D7	7-8	7-8-9	7-8-9
D8	8-9	8-9	8-9
D9	9-10	9-10	9-10
D10	10-11	10-11	10-11

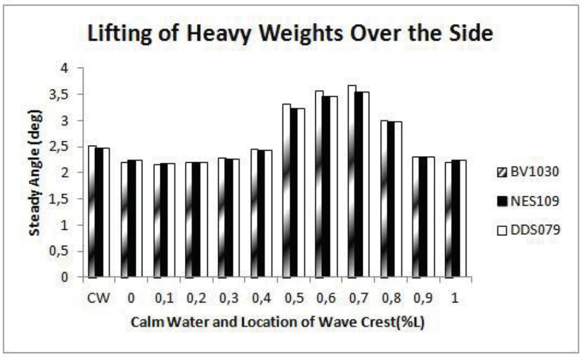
4.2 Intact Stability Analysis

All analyses are made for full load case. Firstly, analyses are carried out for calm water. Then they are repeated in waves. From fore to aft wave crest is moved 0.1*L step by step (Kahramanoglu, 2015).

16. In this section, effects of the beam winds, lifting of heavy weights and crowding passenger over the side, high speed turning and icing are investigated. In the figures some of the most critical results are shown. In Figure 5 effects of beam winds are shown. With respect to NES109 and DDS079 the ratios of areas are compared for different location of the wave crest.



17. Figure 5. Ratio of areas when beam winds cause heeling

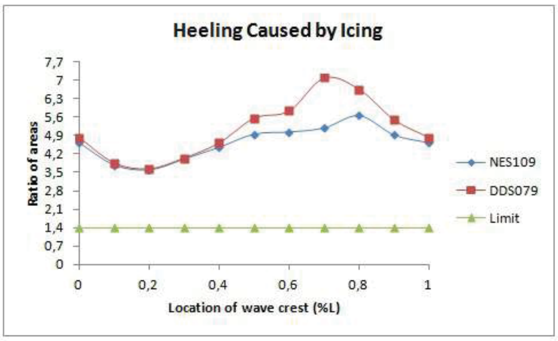


18. Figure 6. Effects of lifting of heavy weights over the side on the steady angle

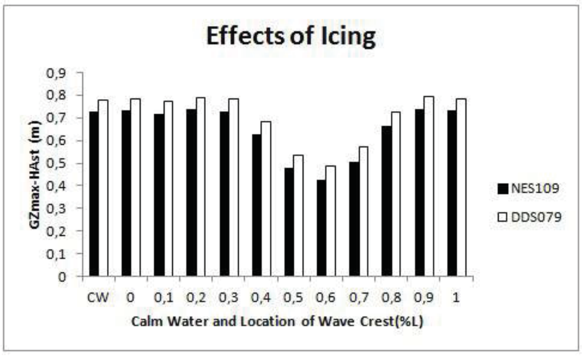
In figure 6 the effects of lifting of heavy weights on steady angle are shown. In this figure the results of DDS079 and NES109 are the same because their calculation methods of heeling arm caused by lifting of heavy weights are the same. However, there are some differences for BV1030. The reason is that, the calculation method is different for BV1030. (2) and (7)

19. Effect of icing has similarities. For this section the calculation method and assumptions are different between NES109 and DDS079.

Therefore, the results differentiate. There are no extra criteria for BV1030 for icing. In Figure 7 and Figure 8 the differences of effects of icing are shown.



20. Figure 7. Ratio of areas when icing causes heeling



21. Figure 8. The differences about the arms when icing causes heeling

4.3 Damaged Stability Analyses

For damaged stability analysis the scenarios in Table 3 are used. The analyses are carried out for each navy rules. At first, all calculations are performed for calm water alike intact stability analyses. Then they are repeated for different location of the wave crest (Kahramanoglu, 2015).

In both intact and damaged stability analyses, it is considered that ship is operating in head wave condition in addition to calm water. With respect to all of three navies the damaged stability analyses are performed for damaged conditions. Wind is coming to the ship from beam direction in all cases while the wind velocity differs in regard to the navy rules. However, wind velocities are different from intact ones (Table 2). The criteria are about the angles, areas and the ratio of GZ_{MAX} and GZ_{ST} (=HA_{ST}) for NES109 and DDS079. However, for BV1030 the criteria of damaged stability are about the angles and residual arm alike intact one.

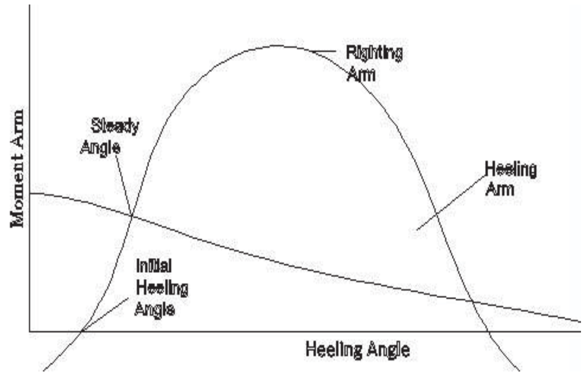


Figure 9. Initial heeling angle and steady angle in damaged stability analysis

In Figure 9 steady angle and the initial heeling angle are shown. These two parameters are crucial for each navy rules.

In Figure 10 and Figure 11, the steady angles and the initial heeling angles are shown for each navy rules and each damaged scenarios in calm water.

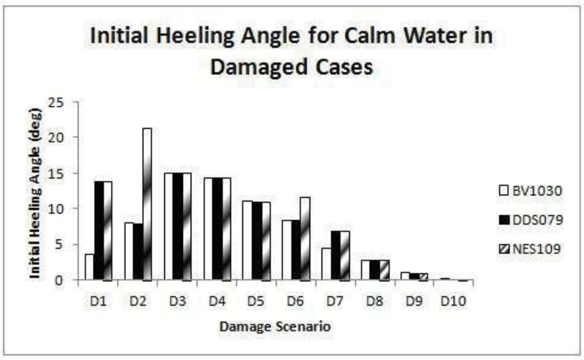


Figure 10. Initial heeling angle for calm water in damaged cases

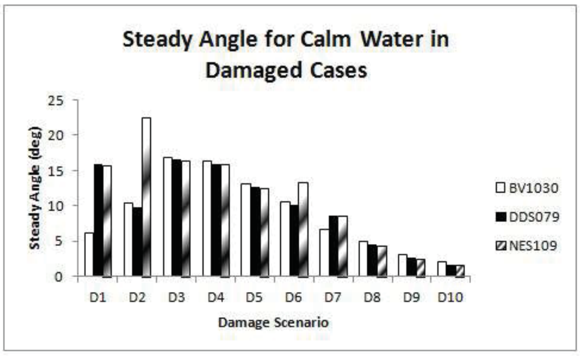


Figure 11. Steady angle for calm water in damaged cases

22. As can be seen from Figure 10 when number of damaged compartments is also same, the initial heeling angles are the same because this is related to vessel's hull form and distribution of weights. Figure 11 shows some differences for steady angles. This is related to the calculation of heeling arm in addition to vessel's hull form and distribution of weights.

Results of D1, D2, D6 and D7 scenarios are shown with more detail. Because these scenarios have differences in terms of initial heeling angle and steady angle and also they are more critic than the others (Kahramanoglu, 2015).

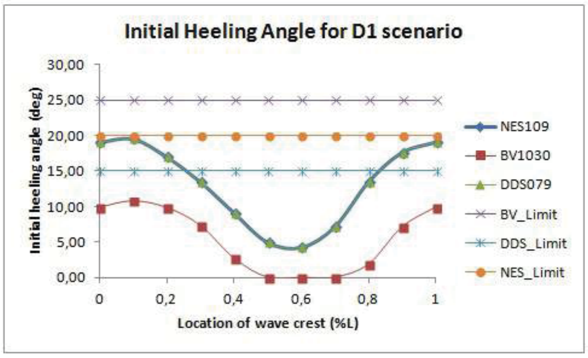


Figure 12. Initial heeling angle for D1 scenario

In Figure 12, initial heeling angles are shown for D1 scenario. It is observed that, the results of NES109 and DDS079 are the same. However, results of BV1030 are different and it can be also realised that the results of BV1030 are less than the others. All these results are just related to number of damaged compartments. For D1 scenario, NES109 and DDS079 have same number of damaged compartments which is more than BV1030 (Table 3).

In Figure 13, initial heeling angles are shown for D2 scenario. For this scenario, because NES109 has more damaged compartments than BV1030 and DDS079, its results are higher. Moreover when the location of the wave crest is between 0,6*L and 0,8*L, the criteria of damaged stability for NES109 is not adequate. The reason of differences between DDS079 and BV1030 is the wave height for this scenario (Table 2).

There are similarities between Figure 13 and Figure 14. As before the number of damaged compartments is higher for NES109. Because of this reason, the initial heeling angle values are higher. In addition to NES109, the criteria of damaged stability for DDS079 for D6 scenario are not adequate for some location of wave crest, too.

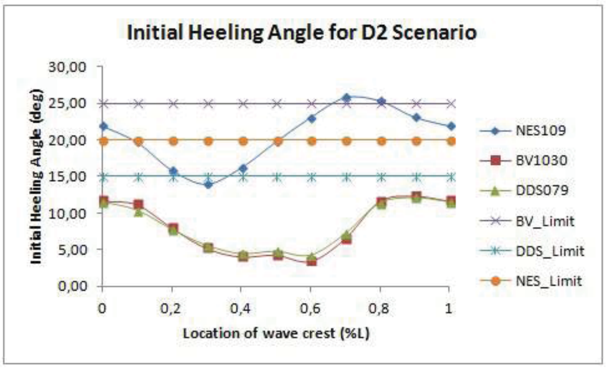


Figure 13. Initial heeling angle for D2 scenario

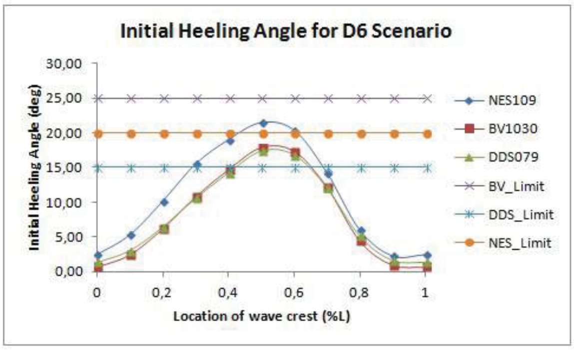


Figure 14. Initial heeling angle for D6 scenario

The results of other scenarios for initial heeling angle do not have significant differences between each other. The little differences' reason is the wave height (Kahramanoglu, 2015).

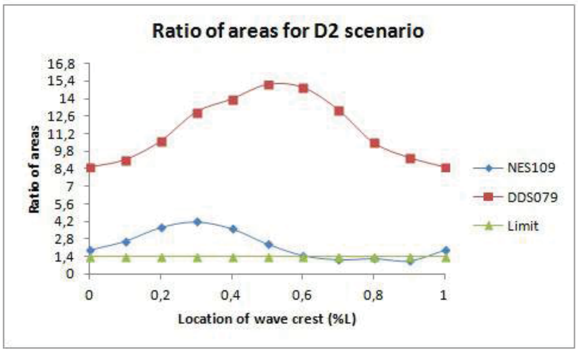


Figure 15. Ratio of areas for D2 scenario

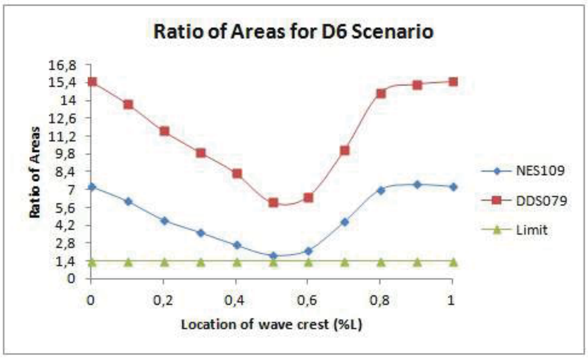


Figure 16. Ratio of areas for D6 scenario

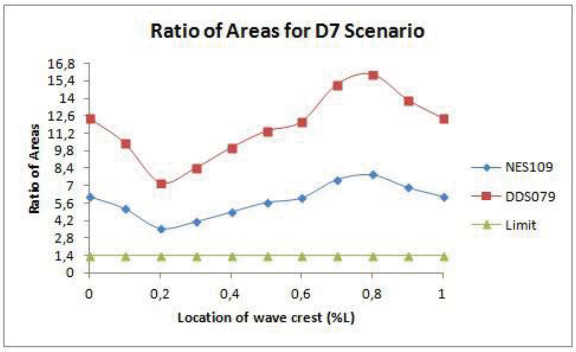


Figure 17. Ratio of areas for D7 scenario

When Figure 15 is examined, it can be realised that when the location of crest is between 0,6*L and 0,7*L the ratios of areas are lower than minimum value for NES109. It means that the stability requirements are not satisfied for NES109 when the location of crest is between 0,6*L and 0,7*L. However, according to DDS079 all the points satisfy the criteria. The reason of these differences is same as before ones. The calculation method of areas and the number of damaged compartment are different so the results differ.

In Figure 16, the reasons of differences are same with Figure 15. Moreover, the ratios are lower for NES109 for both figures.

In Figure 17, one of the reasons mentioned just before is disappeared. The number of compartments is the same for NES109 and DDS079 for D7 scenario. However, the values of NES109 are again lower. At this point, while it is known that the only difference is the calculation method of areas. The effects of the method can be picked out easily. The other scenarios' results for ratios are just same with D7 scenario.

5. CONCLUSIONS

For each navy rules, effects of beam winds are more important than the others for intact stability analysis. NES109 and DDS079 have more strict rules than BV1030 for intact stability.

For damaged stability analysis the most important parameter was length of damage. In this respect, NES109 had the maximum value and BV1030 is the minimum. Therefore, sometimes NES109 had more damaged compartments than BV1030 and sometimes it had more damaged compartments than BV1030 and DDS079. This has made it difficult to meet adequate stability criteria.

When present form and load case are taken into consideration;

- Satisfying criteria of initial heeling angle was more difficult than criteria of ratio of areas.
- Among three navy rules, BV1030 was the simplest to meet criteria.
- Because considering areas and being limit values higher, NES109 was the most suitable one (just for this form and loadcase)
- Location of wave crest was very important for stability analyses and the most critical points of it were a little bit forward from amidships and it is thought that it could be related to vessel's form.
- When damage was near amidships, it could be more critical for each navy rules.

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