IOP Conf. Series: Materials Science and Engineering **400** (2018) 082001 doi:10.1088/1757-899X/400/8/082001

Damage stability analysis in particular flooding situations of a multipurpose cargo ship

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Abstract. Flooding of ship compartments is a very common event resulted from ships involvement in marine accidents, such us collision, grounding or structural breakdown. Once ship compartments are flooded to an extended level, the transverse stability starts to be affected and if the situation become dangerous, it can become critical or failing beyond the lower threshold values. In this damaged situation, a proper and accurate calculation and assessment of stability is very important. Calculation of damage stability for flooding situations is a very important subject for those who work in design and operation of ships. However, the subject was treated extensively in respect of tanker ships and less in respect of multipurpose cargo ships. The aim of work presented in this paper is to highlight some particular situations of flooding of compartments on board a multipurpose cargo ship when the stability parameters are decreasing enough so that fails to comply with recommended criteria. The particularity of the study for this type of ships came from the fact that are fitted with large box type cargo holds which in case of flooding are generating large free surface effects with a high negative impact on ship's stability. Thus, four situations of flooding are presented and the analysis of stability parameters are illustrated in line with the actual regulations, in respect of damage stability, established by international conventions. Based on the results of calculations, the study gives recommendations regarding the actions to be taken in order to limit the dangerous consequences of such situations. The results of the particular flooding situations presented can be used to continue the improvement of design and operation for this type of ships.

1. Introduction

Every marine casualty, when the ship's hull is penetrated and the compartments are flooded, represents a warning for maritime industry. This is because despite the improvements in design of newbuilding ships, such accidents continue to occur not only for existing ships but also for new ships. It seems that the improvements in this subject for new ships is not solving the gaps remained for old ships.

Accurate stability calculations in a case of a flooding event is of high importance, not only for assessment of ship condition but also for applying correct measures in respect of restoring the ship or in a worst case scenario for abandonment. Therefore, the understanding and knowledge of assessment the damage stability, for the particular case of flooding, still remain an open challenge for those who work in this field.

In the last years, ships continued to be involved in maritime casualties where flooding of various compartments on board vessel occurred [1, 2]. Researches and studies related to damage stability of ships in case of flooding where carried out [3, 4, 5] revealing mainly the process of flooding or the probabilistic subdivision of ships [6]. Except tanker ships, where the damage stability topic is extensively studied, for other types of ships, this subject represents a subject of research mainly for passenger and Ro-Ro ships [7, 8, 9] and less for multipurpose cargo ships.

The objective of the study presented in this paper is to illustrate the real case scenarios when due to flooding of compartments of a particular type of ship (a multipurpose cargo ship), the stability of ship fails beyond the recommended limits for damage stability situations.

The motivation came from the fact that, despite the researches carried out in respect of damage stability, it continues to exist a lack of information in respect of assessment the vulnerability to stability failure for multipurpose cargo ships, and especially in particular situations of flooding that can occur in reality.

The importance of the simulations carried out in this paper is emphasized by the fact that in particular situations of flooding, the stability requirements imposed by the regulations in force fails to comply.

2. Criteria for damage stability assessment in flooding situations considered

Damage stability regulations has suffered many improvements in the last decades, having as a target all the time the basic criteria to attain high standards for ship's safety. However, many of those improvements came after serious incidents that had unpleasant consequences with results in important pollutions of marine environment or loss of ships and lives.

Whilst, SOLAS Convention established statutory requirements for cargo ships in respect of subdivision, stating especially provisions regarding the position of the collision bulkhead in the fore part of the ship, additional criteria came from the classification societies regarding the position of the other transversal bulkheads.

The assessment of damage stability used in the present paper complies with the requirements as laid down in SOLAS II-1, Part B-1, Reg. 25-1 for cargo ships, as amended by IMO Resolution MSC. 194(80) [10].

The mentioned requirements, for assessment of damage stability, are based on a probabilistic concept, which considers that a possible damage extent (in longitudinal, transverse and vertical direction) is taken into consideration with its probability according to standardized formulas. Despite the fact that this concept take into consideration a larger damage extent, it still allows other possible situations of damage that can have as result the sinking of ship, even that the possibility to occur such situation are low.

Thus, based on the IMO MSC.216(82) for damage stability calculation, a damage length of up to 24% of length between perpendiculars must be considered. In respect of dimensions of damage under the waterline, it is important to be mentioned that the regulations do not define such extent.

The importance of assessment the transversal stability in damage condition, for particular case of collision, is given by the increased risk of large flooding especially when the ship is developing large listing angles shortly upon the damage occurred.

Each flooding situation is considered in the present paper with a sufficient floating position and for each single situation the damage stability criteria regarding the final floating position are as follows [8]:

- Final angle of equilibrium $\leq$ 25 deg.
- Maximum righting lever GZ $\geq$ 0.12 m (within the range given below)
- Range of the GZ curve (positive) $\geq$ 16 deg. (beyond the angle of equilibrium)
- No immersion of weathertight or unprotected openings.

The damage stability calculations for flooding situations considered, according to these regulations, does not consider the influence of weather conditions nor is required a calculation of the longitudinal strength in flooding condition.

3. Model of multipurpose vessel used for simulations

For the calculation of ship's damage stability in particular flooding situations, it was used a well documented ship of multipurpose dry cargo type [11], having the particulars as follows:

Table 1. Ship's main particulars

Length overall	123.95 m
Breadth moulded	17.40 m
Depth moulded	11.40 m
Draft scantling (moulded)	8.00 m
Displacement (at design draft)	13.976 t

Vessel is fitted with seven pairs of double bottom ballast tanks and eight pairs of side ballast tanks (see figure 1).

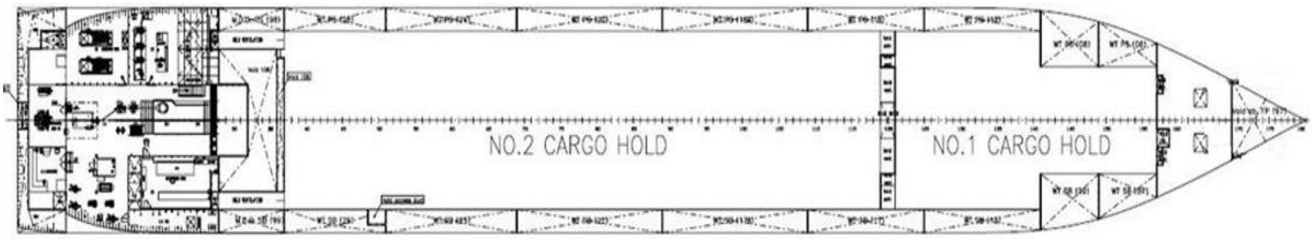

Figure 1. Illustration ship's cargo holds and ballast tanks arrangement.

The main reason for chosen this type of ship is the fact that is fitted with only two cargo holds of box type construction (see figure 2).

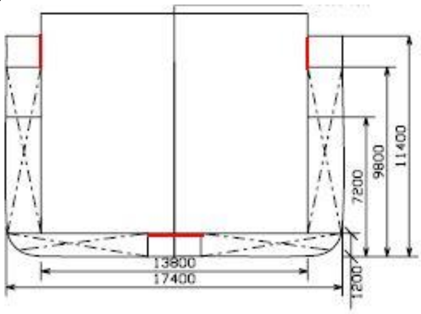

Figure 2. Illustration midshipsection of cargo hold.

Whilst cargo hold no.1 is of only 24.384 m in length, cargo hold no.2 is of 54.864 m in length. Having in view these particular dimensions of cargo holds, it was considered a very important aspect the study the flooding situations of cargo hold no.2 because, due to the dimension, is offering a large amount of flooding water as well as a large free surface effect with negative impact over transverse stability.

4. Flooding situations considered and damage stability calculations

In all potential situations of flooding presented, the vessel was considered in loaded condition to the deepest draft, according to summer load line, and the damage to hull occurred as a real case due to collision with another vessel. The damage to hull extends over all four starboard side ballast tanks (taken as damaged one by one) including the cargo hold no.2.

Prior the damage situations, all intact stability criteria were fulfilled, according to Intact Stability Code 2008, for the loading situation considered.

4.1 Flooding situation no.1 – Hold no.2 and Water Ballast tank no.29 Starboard side

In flooding situation no.1, it was considered that hold no.2 and side ballast tank no.29 starboard side are in a 100 % stage of flooding (see figure 3).

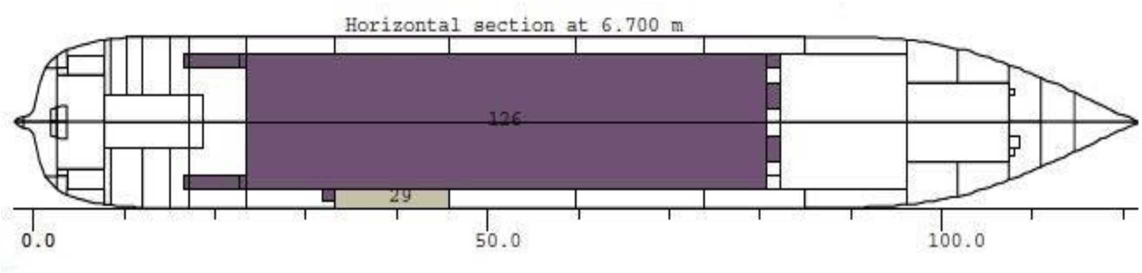

Figure 3. Illustration of flooding situation no.1.

The results of damage stability calculations are illustrated in table 2 and the conformity with criteria are illustrated in table 3 and figure 5.

Table 2. Calculation of range of GZ curve for flooding situation no.1.

Angle	NGsin(ϕ)	Area
0.00	-0.103	0.000
5.00	-0.031	0.000
10.00	-0.011	0.000
15.00	0.016	0.000
20.00	0.026	0.002
25.00	-0.004	0.003
30.00	-0.040	0.003
35.00	-0.094	0.003
40.00	-0.152	0.003

Table 3. Verify against stability requirements - flooding situation no.1.

	Criterion	Calculated Value
Maximum angle of inclination	4.7728 deg.	12.2523 deg.
Range of GZ curve	16.000 deg.	0.0000 deg.
Residual righting lever	0.1200 m	0.0000 m

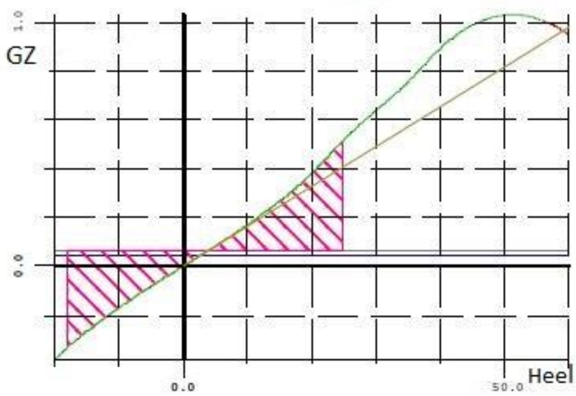

Figure 4. Stability curve prior flooding situation no.1.

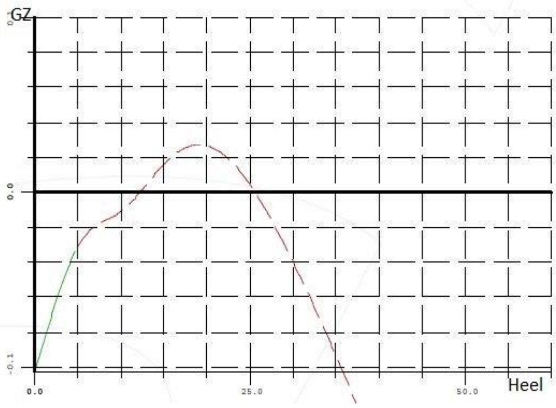

Figure 5. Stability curve for flooding situation no.1.

4.2 Flooding situation no.2 – Hold no.2 and Water Ballast tank no.25 Starboard side

In flooding situation no.2, it was considered that hold no.2 and side ballast tank no.25 starboard side are in a 100 % stage of flooding (see figure 6)

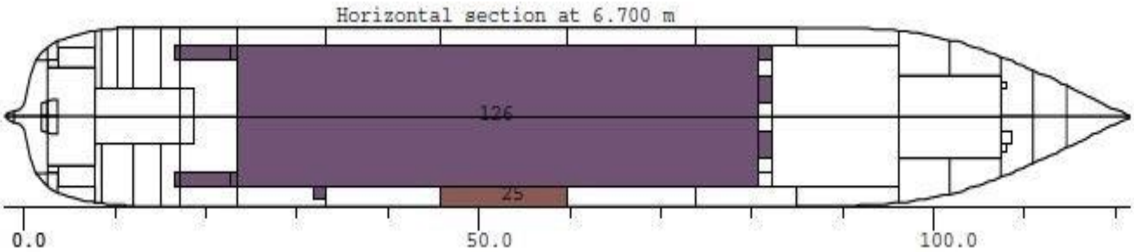

Figure 6. In this case simply justify the caption so that it is as the same width as the graphic.

The results of damage stability calculations are illustrated in table 4 and the conformity with criteria are illustrated in table 5 and figure 8.

Table 4. Calculation of range of GZ curve for flooding situation no.2

Angle	NGsin(ϕ)	Area
0.00	-0.115	0.000
5.00	-0.042	0.000
10.00	-0.020	0.000
15.00	0.009	0.000
20.00	0.021	0.002
25.00	-0.002	0.003
30.00	-0.045	0.003
35.00	-0.099	0.003
40.00	-0.157	0.003

Table 5. Verify against stability requirements - flooding situation no.2.

	Criterion	Calculated Value
Maximum angle of inclination	4.9657 deg.	13.5103 deg.
Range of GZ curve	16.000 deg.	0.0000 deg.
Residual righting lever	0.1200 m	0.0000 m

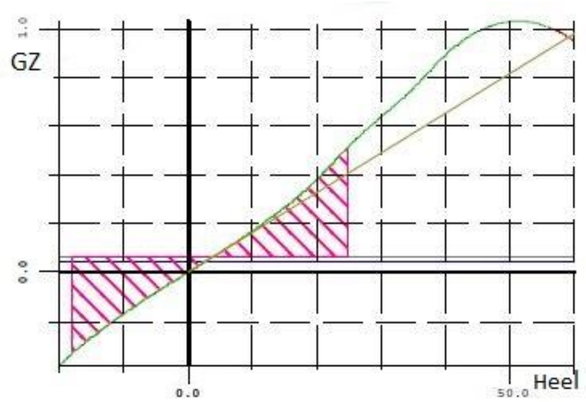

Figure 7. Stability curve prior flooding situation no.2.

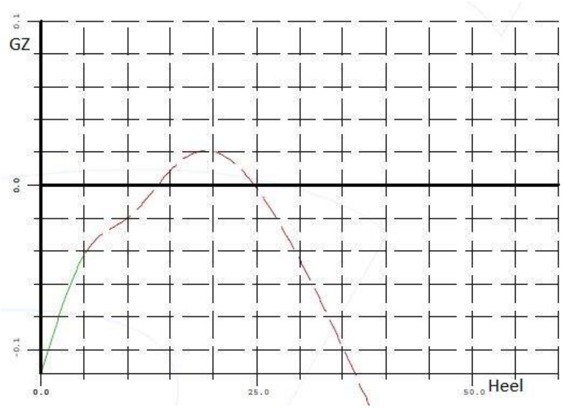

Figure 8. Stability curve for flooding situation no.2.

4.3 Flooding situation no.3 – Hold no.2 and Water Ballast tank no.21 Starboard side

In flooding situation no.3, it was considered that hold no.2 and side ballast tank no.21 starboard side are in a 100 % stage of flooding (see figure 9)

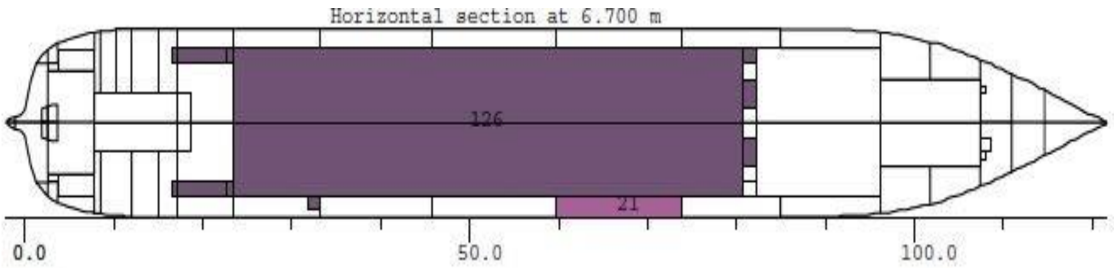

Figure 9. Illustration of flooding situation no.3.

The results of damage stability calculations are illustrated in 6 and the conformity with criteria are illustrated in table 7 and figure 11.

Table 6. Calculation of range of GZ curve for flooding situation no.3.

Angle	NGsin(ϕ)	Area
0.00	-0.115	0.000
5.00	-0.042	0.000
10.00	-0.016	0.000
15.00	0.014	0.000
20.00	0.027	0.002
25.00	-0.004	0.004

30.00	-0.039	0.004
35.00	-0.092	0.004
40.00	-0.151	0.004

Table 7. Verify against stability requirements - flooding situation no.3.

	Criterion	Calculated Value
Maximum angle of inclination	5.3298 deg.	12.8840 deg.
Range of GZ curve	16.000 deg.	0.0000 deg.
Residual righting lever	0.1200 m	0.0000 m

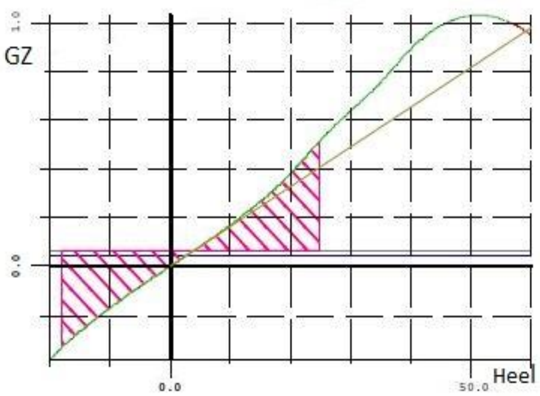

Figure 10. Stability curve prior flooding situation no.3.

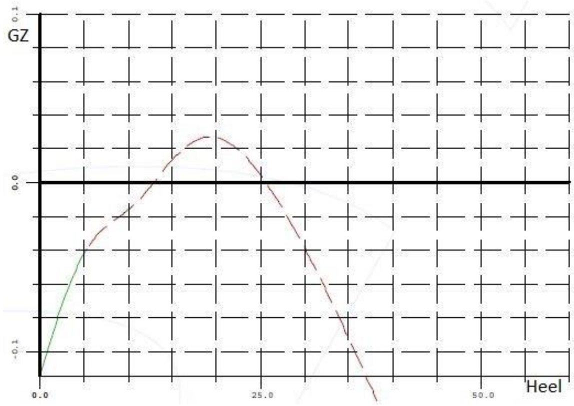

Figure 11. Stability curve for flooding situation no.3.

4.4 Flooding situation no.4 – Hold no.2 and Water Ballast tank no.17 Starboard side

In flooding situation no.4, it was considered that hold no.2 and side ballast tank no.17 starboard side are in a 100 % stage of flooding (see figure 12).

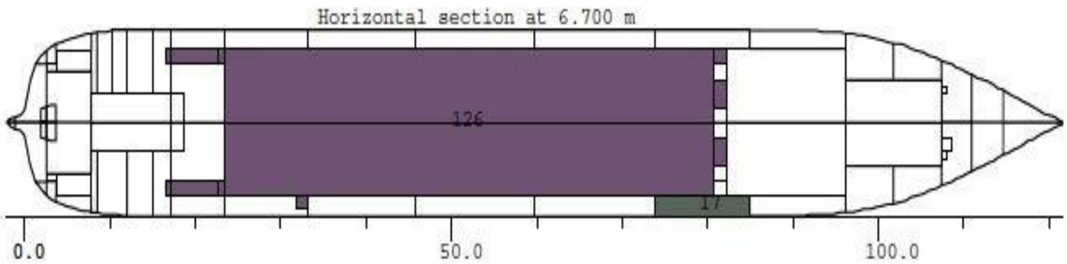

Figure 12. Illustration of flooding situation no.4.

The results of damage stability calculations are illustrated in table 8 and the conformity with criteria are illustrated in table 9 and figure 14.

Table 8. Calculation of range of GZ curve for flooding situation no.4.

Angle	NGsin(ϕ)	Area
0.00	-0.091	0.000
5.00	-0.017	0.000

10.00	0.010	0.000
15.00	0.038	0.000
20.00	0.052	0.006
25.00	0.030	0.010
30.00	-0.013	0.011
35.00	-0.067	0.011
40.00	-0.127	0.011

Table 9. Verify against stability requirements - flooding situation no.4.

	Criterion	Calculated Value
Maximum angle of inclination	5.7644 deg.	7.5191 deg.
Range of GZ curve	16.000 deg.	0.0000 deg.
Residual righting lever	0.1200 m	0.0000 m

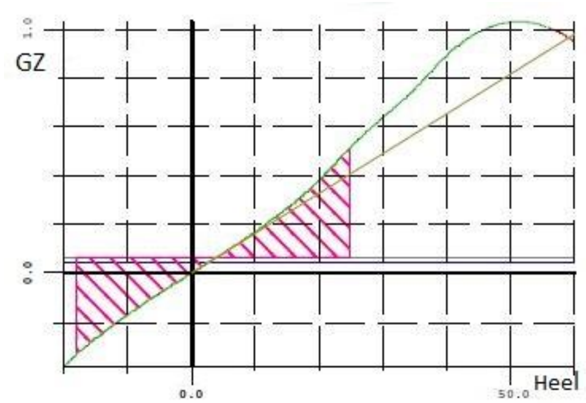

Figure 13. Stability curve prior flooding situation no.4.

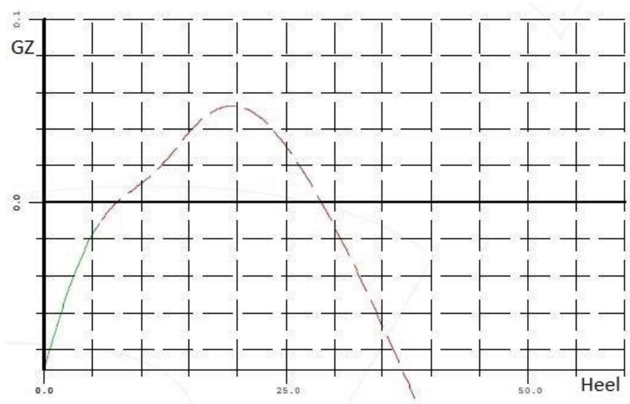

Figure 14. Stability curve for flooding situation no.4.

5. Analysis of damage stability results

The results of stability calculations, carried out for all above four flooding situations considered, revealed the fact that actual damage stability conditions do not comply with the stated criteria, established by SOLAS 2009 Convention for cargo ships.

In all four flooding situations considered, the calculated value for the damage stability parameters are beyond the recommended one, as illustrated in tables 3, 5, 7 and 9. The large values of maximum angles of inclination are generated by the fact that the mass of water from hold no.2 is acting as a weight shifted to listed part of the vessel.

Lack of residual righting arm, especially for the range of small angle of inclination, could put the vessel in the unstable and dangerous situation. However, the fact the maximum inclination angle is beyond the recommended one, established by criteria, does not represent a condition that the vessel will capsize.

Taking into consideration that flooding of hold no.2, in all situations considered, is generating a large free surface effect, it could be a situation hard to be controlled, especially if the rolling motions, in case of occurrence of high seas, amplify the inclination of the ship. Moreover, the possibilities to bring the vessel to an improved condition, in respect of floating and stability aspects, are very limited, as the biggest compartment is flooded without the possibility to be emptied.

For safety reasons, the ship's stability threshold values have to be determined for all loading conditions and compared with stability regulations in force. The limit curves of metacentric height presented in the approved stability booklet have to be carefully studied and loading of vessel should be accordingly made.

As an immediate action taken on board vessel it is to be assessed by the master weather the flooding situation will lead to immediate capsizing or sinking of the ship, considering the actual weather and sea conditions. If the quantity of water that enter to cargo hold is exceeding the capacity of the pumps, the first measure is to try to isolate the flooded compartments. If such a measure cannot be applied, and the situation is judged as a very critical and the ship is in immediate danger of capsizing or sinking, the ultimate measure is to abandon the ship.

The particular situations of flooding described and analyzed, revealed the fact that is recommended as much as possible to avoid such situations, as the situation of ship, in respect of stability, become critical. The absence of subdivision of the cargo hold, for the particular type of ship used in calculations, can lead to serious consequences even up to sinking. In particular situations of ship damage which involves flooding, the concept of a large box type cargo hold cannot be entirely feasible. It was demonstrated that damage stability requirements cannot be met without subdivision of cargo hold by watertight transversal bulkheads. Thus, for such particular type of ship, the necessary survivability has to be designed for a certain level of safety.

The measures to control the flooding have to be very well defined and included in a damage control plan. A high training level of the crew, to ensure quick and appropriate action in case of flooding, is absolute necessary.

6. Conclusions

Flooding on board vessels are one of the most dangerous situation that can occur during the voyage. Those dangerous situations occurred because of accidents, such us collision, grounding or structural breakdown, can lead to loss of ship stability or even capsize.

The flooding situations presented in this paper, was considered particular situations due to the fact that the biggest cargo hold, of a multipurpose cargo ship, was flooded together with one side ballast tank, because of collision with another ship. The calculation and analysis of damage stability criteria was carried out for each particular case of flooding presented.

The study is based on the idea to reveal the vulnerability of the multipurpose cargo ships, with large box type cargo holds, in front of stability failure in particular flooding situations. The purpose was to highlight those particular situations of flooding, when the parameters of stability are below the limits imposed by the recommended criteria, as well as the amplitude of the problems occurred.

Based on the stability calculations carried out it was emphasized the fact that in all the flooding situations proposed, the stability of the ship does not comply with the recommended criteria. Such researches on damage stability for multipurpose cargo ships can reveal the fact that actual damage stability criteria are insufficient for particular situations. Therefore, the necessity of establishing new damage stability regulations with impact on ship design may have to be taken into consideration.

The aspects and the results presented in this paper can be part of the future works in this field, for improvement of ship design and operation solutions to avoid exposure to such dangerous situations. Moreover, it is necessary to consider that damage stability assessment is a main component of maritime safety and thus it is very important that the ships to have onboard performant computers for such calculations and analysis.

7. References

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