

Comparative study of assessment the tanker ship behaviour in damage stability situations

C Andrei and R Hanzu-Pazara

Constanta Maritime University, Faculty of Navigation and Naval Transport, 104
Mircea cel Batran Street, Constanta, 900663, Romania

E-mail: cristian.andrei@cmu-edu.eu

Abstract. Although the design of the actual tanker ships is in a continuous process of improving, in order that these ships to be safer constructed and operated, the casualties continue to occur. Such casualties, like collision or grounding, are generating damage to ship's hull that apart from the fact that can considerably reduce the ship strengths it can lead to dangerous situations in respect of ships stability. Damage stability assessment, especially for tanker ships, is a topic of high importance and continuous improvement. This aspect is evidenced by the activity of International Maritime Organizations and Classification Societies, which improve continuously the regulations in this respect. The objective of the present paper is to illustrate a study that reveals the assessment of a particular tanker ship behaviour in damage stability situations. The study was carried out for particular situations of damage to ship's hull, resulting in flooding of a number of compartments, combined with particular loading conditions of the tanker vessel. It is presented an analysis, based of calculations, between vessel's stability prior and upon occurring the flooding. The stability criteria, intact and damaged, defined by international conventions was assessed for each particular situation of damage. Moreover, the study point out if the ship's damage stability condition, for particular situations presented, is in line with the international requirements in force and if any improvements for damage stability are necessary. This study recommends that tanker ships to have a safe range of intact stability to prevent the occurrence of unstable equilibrium in case if stability is affected by flooding. It can be a benefit for the officers working on board tanker ships being used as a possible guidance for the situations of damage stability as it demonstrate that intact stability margins in different loading conditions can be close to lower limits in case of damage stability.

1. Introduction

Large quantities of oil are transported every day on board tanker ships. Every time when a tanker ship commence the voyage, the first thought is that the ship and the cargo to arrive safely at destination. Marine pollution is one of the main concerns of our society [1]. Unfortunately, accidents where tanker ships are involved have occurred and continue to occur. Such accidents of tanker ships "Exxon Valdez" in 1989 and "Prestige" in 2002 revealed not only huge environmental pollution but also a lack in taking proper decisions upon damage the ship, in order to improve the ship stability by reducing the heeling angle [2].

Damage stability of tanker ships is a topic of high importance in maritime industry. As a result of this interest, the damage stability requirements for tanker ships are established by Classification



Societies as well as by international conventions such as SOLAS, MARPOL or International Load Line Convention.

Based on the incidents analysis of tanker ships [3, 4, 5], a number of studies in respect of damage stability of such type of ships were carried out [6, 7, 8, 9, 10], emphasizing the importance of correct assessment the damage stability as well as the potential risk generated by improper assessment. However, the case remains open as the damage stability still affects the tanker ships in particular situations.

The aim of the study presented in this paper is to have a clear picture of the stability parameters in different situations where damage to hull of a particular tanker ship occurred and generated flooding of different compartments in different locations of the ship. Based on the values of the stability parameters obtained after damage, measures are proposed to minimize the adverse effects of damage or to increase the stability of the ship.

The motivation of this study came from the fact that damage stability of tanker ships always brings new challenges, because of the impact on environmental pollution as well as on new designs of ships. Despite the fact that tanker ships are constructed more safety, the reality revealed that in case of particular situations of damage the hull, the safety range of stability is close or even below the lower limit.

The damage stability analysis, performed in the present paper, is important because it is necessary to establish a relationship between ship's parameters – length, width, draft, loading condition – and the location and extent of damage to hull.

2. Particular situations used for damage stability assessment

For the study of assessment, the damage stability, it was used a type 2 chemical/product oil tanker ship [11] with the following main building particulars:

Table 1. Ship's main particulars.

Length overall	183.175 m
Breadth moulded	27.40 m
Depth moulded	16.80 m
Draft scantling (moulded)	11.80 m
Displacement (at design draft)	49961.8 m

The ship has fifteen cargo tanks comply with the MARPOL 73/78 Annex II requirements for the carriage of pollution category X, Y, Z and OS substances. Water ballast tanks (green colored) are positioned adjacent, in portside and starboard side, to each cargo tank (see figure 1).

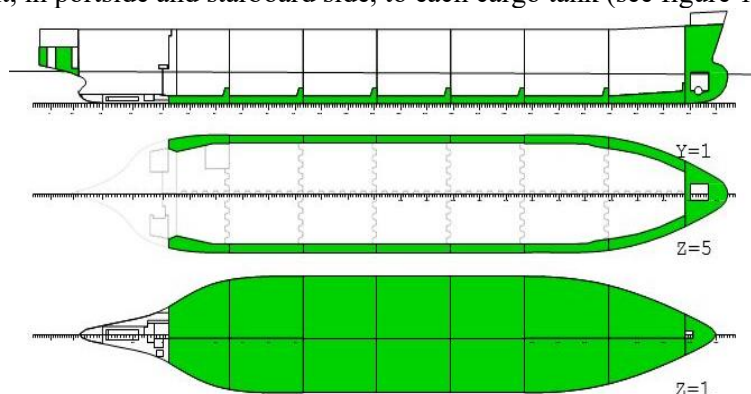


Figure 1. Ballast and cargo tanks arrangement.

The damage stability calculated in the present study is according to MARPOL 73/78 and its amendments and was considered for the most dangerous three situations, as follows [12]:

2.1 Damage situation no.1 - Bottom racking damage

- Longitudinal extent: $0.4L$ measured from forward perpendicular, $0.4L=0.4 \times 177.028=70.811$ m
- Transverse extent: $B/3$ anywhere in the bottom, $B/3=27.4/3=9.133$ m
- Vertical extent: breach of the outer hull.

In the above damage situation, the vessel was considered in full loading condition (see figure 2) and the ship's hull was affected in the region of ballast tanks no.1, 2 and 3 portside (see figure 3).

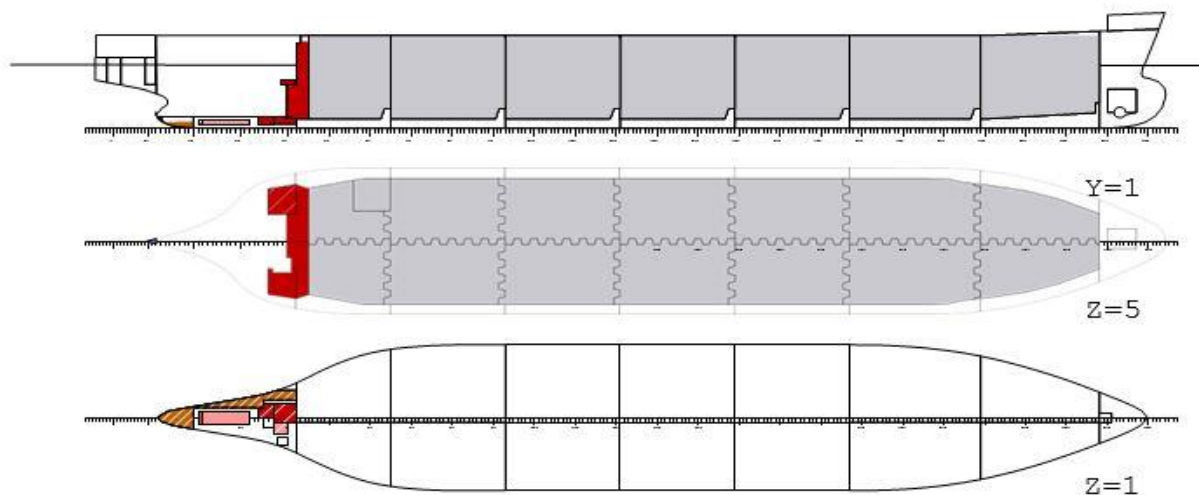


Figure 2. Loading condition of ship in damage situation no.1.



Figure 3. Compartments affected in damage situation no.1.

2.2 Damage situation no.2 - Bottom damage

- Longitudinal extent: for 0.3L from F.P., min ($1/3L^{2/3}$, 14.5), take:10.50 m
- Longitudinal extent: any other part of ship, min ($1/3L^{2/3}$, 5.0), take:5.0 m

- Transverse extent: for 0.3L from F.P., min (B/6, 10), take: 4.50 m
- Transverse extent: any other part of ship, min (B/6, 5), take: 4.50 m
- Vertical extent: for 0.3L from F.P., min (B/15, 6), take: 1.80 m
- Vertical extent: any other part of ship, min (B/15, 6), take: 1.80 m

In this damage situation, the vessel was considered loaded in cargo tanks no.1 and no.4 (see figure 4) and the ship's hull was affected in the region of ballast tanks no.2 and 3 portside and cargo tanks no.2 and 3 portside (see figure 5).

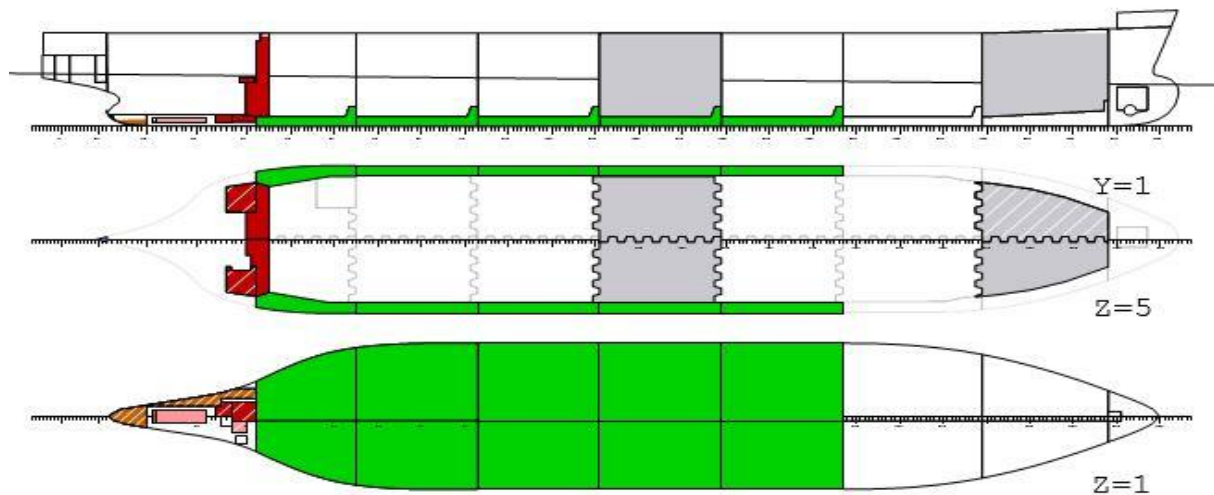


Figure 4. Loading condition of ship in damage situation no.2.

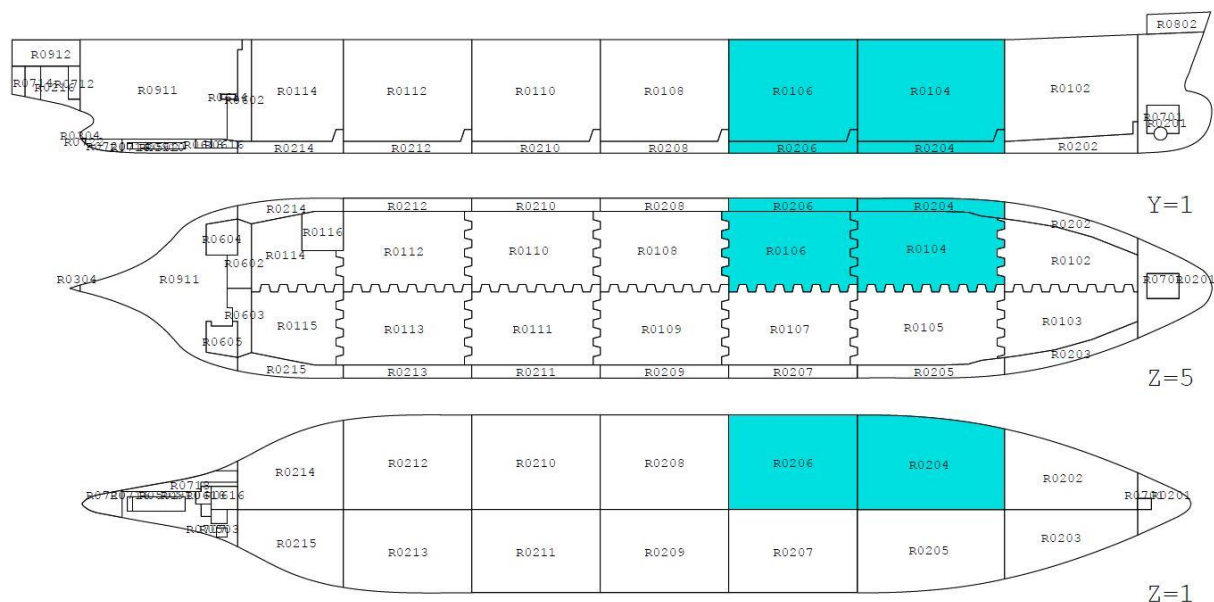


Figure 5. Compartments affected in damage situation no.2.

2.3 Damage situation no.3 - Side damage

- Longitudinal extent: min ($1/3L^{(2/3)}$, 14.5), take: 10.50 m
- Transverse extent: (B/5, 11.5), take: 5.50 m
- Vertical extent: from the base line upwards without limit.

In this damage situation, the vessel was considered in full loading condition (see figure 6) the ship's hull was affected in the region of engine room bottom, engine room above bottom and steer gear room (see figure 7).

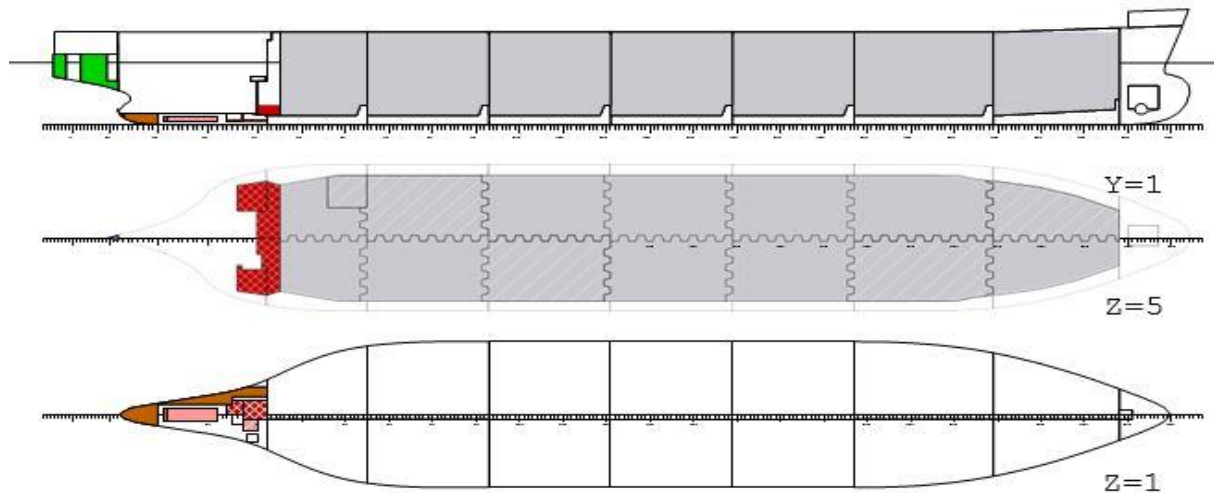


Figure 6. Loading condition of ship in damage situation no.3.

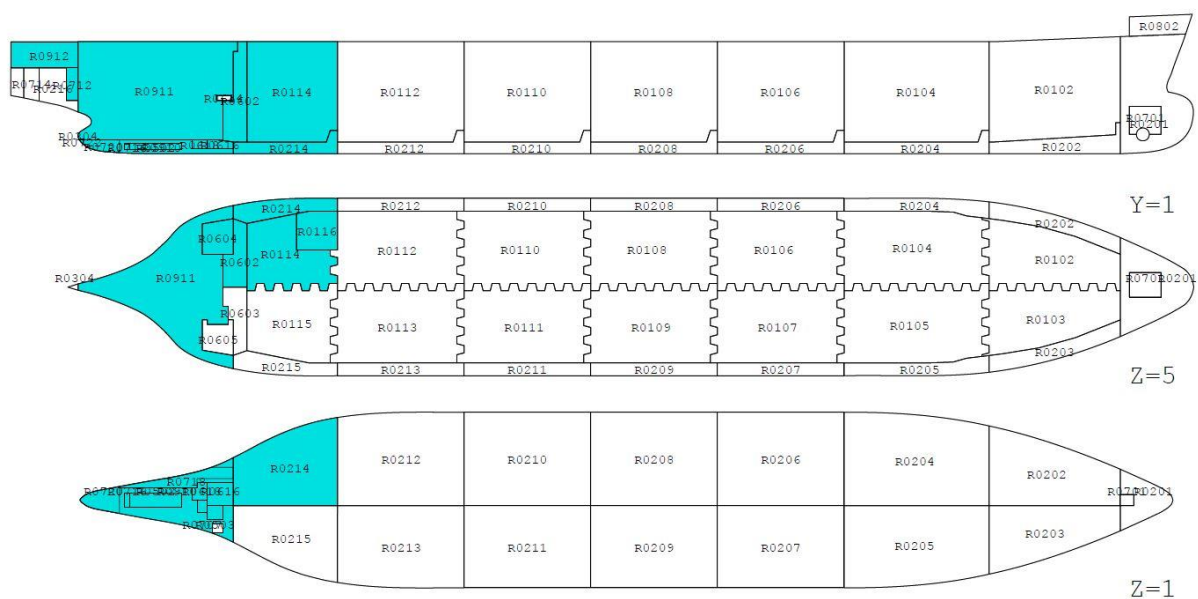


Figure 7. Compartments affected in damage situation no.3.

3. Comparative study of damage stability situations and analysis of results

For the comparative study, the assessment of ship's stability was made prior and upon occurring the damage situations. The calculations, for intact and damage stability, were carried out by using an approved and certified stability software [13] used on board ships.

3.1 Damage situation no.1 – Bottom racking damage

Table 2. Intact stability criteria prior damage situation no.1.

	Requested	Calculated	Status
Area under GZ curve up to 30 deg.	0.055 mrad	0.232 mrad	OK
Area under GZ curve up to 40 deg.	0.090 mrad	0.395 mrad	OK
Area under GZ curve from 30 to 40 deg.	0.030 mrad	0.163 mrad	OK
Max GZ > 0.2	0.200 m	0.942 m	OK
Max GZ at an angle > 25 deg.	25.00 deg	36.604 deg	OK
GM > 0.15 m	0.150 m	1.170 m	OK
IMO weather criterion (areas)	1.000	7.395	OK
IMO weather criterion (max heel)	16.000 deg	1.592 deg	OK

Table 3. Damage stability criteria - situation no.1.

	Requested	Calculated	Status	Min GM
Maximum heel	< 25 deg	15.374 deg	OK	0.347 m
Range of positive GZ	> 20 deg	34.441 deg	OK	0.441 m
Maximum GZ to be at least 0.1 m within the 20 deegreed range	> 0.1 m	0.487 m	OK	0.487 m
Area under GZ curve within 20 degrees	> 0.0175 mrad	0.111 mrad	OK	0.440 m

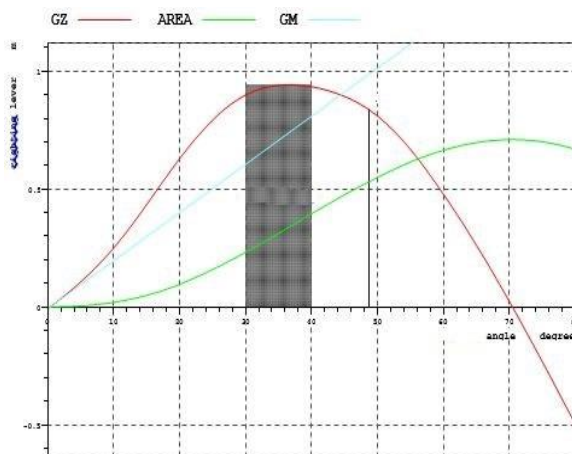


Figure 8. Righting lever curve prior damage situation no.1.

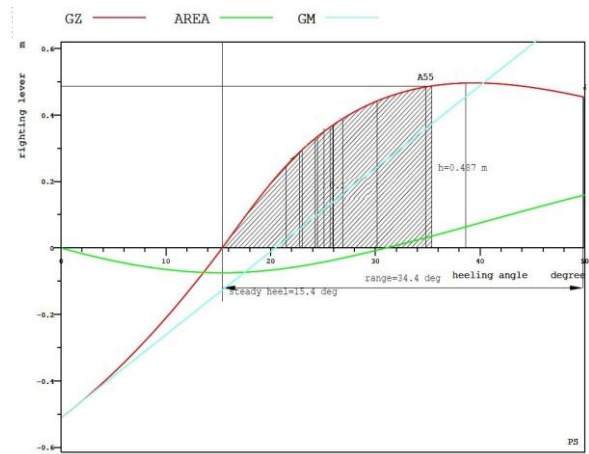


Figure 9. Righting lever curve for damage situation no.1.

3.2 Damage situation no.2 – Bottom damage

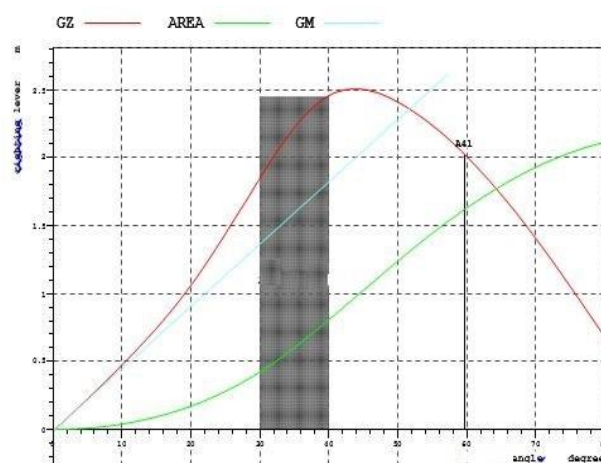
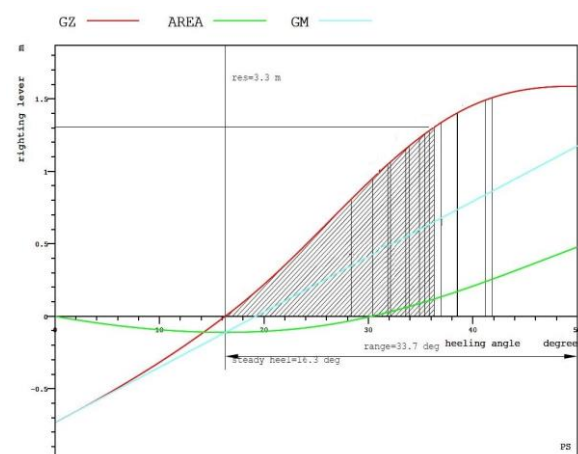
Table 4. Intact stability criteria prior damage situation no.2.

	Requested	Calculated	Status
Area under GZ curve up to 30 deg.	0.055 mrad	0.423 mrad	OK

Area under GZ curve up to 40 deg.	0.090 mrad	0.806 mrad	OK
Area under GZ curve from 30 to 40 deg.	0.030 mrad	0.384 mrad	OK
Max GZ > 0.2	0.200 m	2.506 m	OK
Max GZ at an angle > 25 deg.	25.00 deg	43.807 deg	OK
GM > 0.15 m	0.150 m	2.625 m	OK
IMO weather criterion (areas)	1.000	6.380	OK
IMO weather criterion (max heel)	16.000 deg	1.130 deg	OK

Table 5. Damage stability criteria - situation no.2.

	Requested	Calculated	Status	Min GM
Maximum heel	< 25 deg	16.297 deg	OK	1.288 m
Range of positive GZ	> 20 deg	33.703 deg	OK	0.779 m
Maximum GZ to be at least 0.1 m within the 20 degree range	> 0.1 m	1.304 m	OK	0.512 m
Area under GZ curve within 20 degrees	> 0.0175 mrad	0.229 mrad	OK	0.518 m

**Figure 10.** Righting lever curve prior damage situation no.2**Figure 11.** Righting lever curve for damage situation no.2

3.3 Damage situation no.3 – Side damage

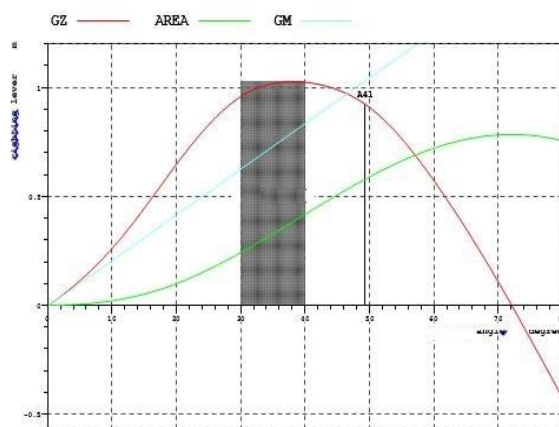
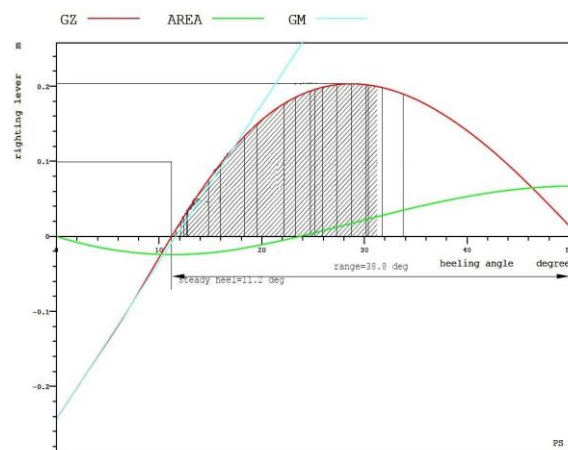
Table 6. Intact stability criteria prior damage situation no.3.

	Requested	Calculated	Status
Area under GZ curve up to 30 deg.	0.055 mrad	0.242 mrad	OK
Area under GZ curve up to 40 deg.	0.090 mrad	0.418 mrad	OK
Area under GZ curve from 30 to 40 deg.	0.030 mrad	0.176 mrad	OK
Max GZ > 0.2	0.200 m	1.027 m	OK
Max GZ at an angle > 25 deg.	25.00 deg	38.104 deg	OK
GM > 0.15 m	0.150 m	1.203 m	OK

IMO weather criterion (areas)	1.000	7.673	OK
IMO weather criterion (max heel)	16.000 deg	1.424 deg	OK

Table 7. Damage stability criteria - situation no.3.

	Requested	Calculated	Status	Min GM
Maximum heel	< 25 deg	11.226 deg	OK	0.734 m
Range of positive GZ	> 20 deg	38.774 deg	OK	0.889 m
Maximum GZ to be at least 0.1 m within the 20 deegred range	> 0.1 m	0.203 m	OK	0.979 m
Area under GZ curve within 20 degrees	> 0.0175 mrad	0.051 mrad	OK	0.910 m

**Figure 12.** Righting lever curve prior damage situation no.3.**Figure 13.** Righting lever curve for damage situation no.3.

The calculations presented reveals the fact that in all three situations of damage considered, the recommended damage stability criteria are fulfilled. However, the following comments can be made:

- The metacentric height after flooding, for the maximum heeling angle decreasing considerably, especially for damage situations where the vessel was in full loaded condition (up to 70% in damage situation no.1 as illustrated in table 3 and up to 49% in damage situation no.3, as illustrated in table 7). This is the result of the effect of free surfaces, which generates a vertical virtual raise of ship's centre of gravity.
- Area under GZ curve within 20 degrees was decreasing up the values close to lower limits, especially for the damage situation no.3. This is the result of decreasing the restoring moment for small angles of inclination generated by the small values of metacentric height and implicitly of righting arms.

However, compliance with damage stability criteria does not insure immunity against any dangerous situations, even capsizing, regardless of the circumstances.

Having in view that the damaged situations presented, were considered as occurred in calm sea when only static loads are acting and the vessel has no oscillation motions, the values described above are still sufficient. Hence, in case of adverse sea conditions, when rolling and pitching motions of vessel have to be taken into consideration, the minimum values for metacentric height and area under GZ curve can be insufficient for the ship to remain in a stable equilibrium condition. This is because of stability loss related to large variations in restoring moments when vessel is on the wave crest.

Thus, the probability that the vessel to develop a loll angle, passing to a neutral or unstable equilibrium position, have to be taken into consideration for those to work on board vessel.

In this situation, as an emergency action that have to be taken is to lower the vessel's centre of gravity by transferring the cargo from one or more cargo tanks into empty double bottom tanks, increasing the metacentric height. The cargo tanks, from where the cargo is transferred, has to be completely emptied in order to avoid the large negative effect of free surfaces, having in view that those tanks has a large width that can develop large free surfaces.

From the design point of view, the solution may be in the optimization of ballast tanks construction, with smaller tanks with less volume, whilst from operational point of view it is imperious necessary to load the ship in strict conformity with the loading manual approved by Classification Society. Limited KG curves as well as loading conditions stated in the manual have to be followed accordingly.

4. Conclusions

In the paper presented, it was proposed a comparative study and analysis of damage stability of a tanker ship after occurring of three particular damage situations. The purpose was to identify damage situations that can have influence on stability of tanker ships. For this study, calculations were carried out for assessment the intact as well as the damage stability of a real tanker ship, whilst the calculations and simulations were made with a approved and certified simulator software.

The results of the study concluded that all the stability requirements for tanker ships, recommended by international regulation in force, are fulfilled. However, the values of stability parameters after damage indicating that those are close to the lower limit recommended values, which can be considered as a warning for those who operates the ship. The study revealed that damage stability criteria recommended by MARPOL was established for the lowest level of risk that can be take in consideration.

Damage stability understanding and assessment, especially for a tanker ship, is of paramount importance for ship's officers. By taking proper actions, in case of ship damage, in order to improve the ship's stability, it can be protected not only the ship and the cargo but also the marine environment to avoid oil spill pollution that can generates huge claims.

In order to have a clear picture of stability performance of a tanker ship after damage, it is imperious necessary to determine and take into consideration all the factors that ensure the ship's possibility to remain within safety levels of stability.

The study presented can be of real benefit not only for those who work on board vessel but also for those who work in maritime industry, being a step forward to continue researches and studies for development solutions to eliminate the possibility of occurring such damage as well as the consequences in case of damage.

5. References

- [1] Acomi N, Acomi OC 2016 The effect of early berthing prospects on the energy efficiency operational index in oil tanker vessels, *IOP Conf. Series: Materials Science and Engineering* **145** (2016) 082001, 1-6.
- [2] Santos TA, Guedes Soares C 2008 Global Loads due to Progressive Flooding in Passenger Ro-Ro Ships and Tankers, *Ship and Offshore Structures* **3**(4): 289-302.
- [3] Apostolatos P, Eleftheria E 2007 Casualty Analysis of Tankers, *Journal of Marine Science and Technology January 2007* **12**(4): 240-250
- [4] Papanikolaou A, Eliopoulou E, Alissafaki A, Aksu S, Delautre S and Mikelis N 2005 Critical Review of AFRAMAX tanker incidents, Newcastle upon Tyne, *3rd International Conference ENSUS, Journal of Engineering for the Maritime Environment, May2005* 13-15 April 2005, 1-3

- [5] Papanikolaou A, Eliopoulou E, Alissafaki A, Aksu S, Delautre S and Mikelis N 2005 Systematic Analysis and Review of AFRAMAX tanker incidents, Portugal, *11th International Association of the Mediteranean Congress IMAM* **26-30** September 2005, 2-5
- [6] Ajay G 2011 Verification of Damage Stability Requirements for Tankers, Washington, *Proceedings of the 12th International Stability Workshop USA* (electronic version only), http://www.shipstab.org/files/Proceedings/ISSW/ISSW_2011_Washington_USA/Session_02_Regulatory_and_Compliance_Issues/02_5_Gour.pdf, 1-3.
- [7] Hanzu-Pazara R, Arsenie P, Duse A and Varsami C 2016 Study of VLCC tanker ship damage stability during off-shore operation, *IOP Conference Series: Materials Science and Engineering* **145** (2016) 082020
- [8] Michael J G, James C C, John S S, Heinvee M, Tabri K 1998 Study of Double Hull Tanker Lolling and Its Prevention, *Marine Technology*, Vol. **33**, 183-202.
- [9] Robert DT, Luca L 2008 Operational Evaluation of Damage Stability for Tank Vessels, *Proceedings of the 10th International Stability Workshop* Daejeon, Korea, 203-210.
- [10] Rodrigo PF 2015 Stability Investigation Damaged Ships, *Journal of Marine Science and Technology* Vol.**23**, No.**4**, 399-406
- [11] *Chemical/Product Oil Tanker Technical Manual*, Yard ref. no. K0000305, Guangzhou Shipyard International Co., Ltd., Guangzhou, China, 221-237.
- [12] IMO, *MARPOL International Convention for the Prevention of Pollution from Ship 1973, including Protocol of 1978 and all amendments*, William Clowes Ltd, Beccles, Suffolk, UK, 121-122
- [13] IACS 2005, *URL5, Onboard Computers for Stability Calculations, revision 1 February 2005*, International Association of Classification Societies, London, 2-5