Study of VLCC tanker ship damage stability during off-shore operation

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Abstract. Today, for the carriage of crude oil on sea are used larger tanker ships, especially from VLCC class. The operation of this type of ships requires in many cases special conditions, mainly related to water depth in the terminal area and enough maneuvering space for entrance and departure. Because, many ports from all over the world don’t have capacity to operate this type of ships inside, in designed oil terminal, have chosen for development of outside terminals, off-shore oil terminals. In case of this type of terminals, the problems of water depth and maneuvering space are fixed, but other kind of situations appears, regarding the safety in operation and environment factors impact on ship during mooring at oil transfer buoy. In the present paper we intend to show a study made using simulation techniques about VLCC class tanker ship in case of a damage condition resulted after a possible collision with another ship during loading operation at an off-shore terminal. From the beginning, we take in consideration that the ship intact stability, during all loading possible situations, has to be high enough, so that in case of some damage with flooding of different compartments due to hypothetical dimension water hole, the ship stability in the final stage of flooding to correspond to the requirements for damage stability and, also, to complementary requirements for damage ship stability.

1. Introduction
Stability of a non-damaged ship, in any loading situation, should be good enough, so that in case of damages by flooding of a number of compartments due to some water holes having hypothetic dimensions, the ship’s stability in the final stage of flooding should correspond to requirements concerning the damaged ship’s stability and supplementary requirements for the damaged ship’s stability. [1].

For ships having a length of more than 100 metres, requirements for the damaged ship’s stability should be fulfilled in case of a continuous flooding of the forepeak and the correspondent compartment.

In case of damage [2, 4, 6, 7] the following criteria for stability should be fulfilled for an oil tanker:

- Initial metacentric height in the final stage of flooding, before trying to increase it, is at least 0.05 metres;
- Damaged ship’s waterline before, during and after refloating should be at least 0.3 metres or $L_w - 10/150$ metres, according to which value is lower, to the inferior limit of hatchways, bulkheads and borders though which the ship could make water;
The heeling angle, in the final stage of asymmetrical flooding, before trying to refloat the ship, should not exceed 25° (or 30° if the tween deck is not in water); the listing angle after trying to refloat the ship should not exceed 17°.

The area below the static stability diagram (both before and after refloating), within the limits of 20° from the equilibrium position, should be of at least 0.0175 m rad.

In calculating the damage stability, water holes are considered to be situated both on the laterals of the ship and the bottom area, and their dimensions [3, 4, 6, 7] adopted as follows:

- **Length extension** - \( \frac{1}{3}L_{1}^{\frac{2}{3}} \) or 14.5 metres, whichever of these two results lower, for \( 0,3L_{1} \) from the fore perpendicular and \( \frac{1}{3}L_{1}^{\frac{2}{3}} \) or 5 metres, whichever of these two results lower, for any other part of the ship;
- **Transverse extension** - \( B_{1}/6 \) or 10 metres, whichever of these two results lower, for \( 0,3L_{1} \) from the fore perpendicular and \( B_{1}/6 \) or 5 metres, whichever of these two results lower, for any other part of the ship;
- **Vertical extension** – measured in the diametral plan according to the theoretical lines of the body: \( B_{1}/15 \) or 6 metres, whichever of these two results lower;

Requirements concerning the damaged ship’s stability should be fulfilled in case of the following locations of the lateral and bottom damages [7]:

- For tankers with a length \( L_{1} \) longer than 225 metres in any point along the length of the ship;
- For tankers with a length longer than 150 metres, but not exceeding 225 metres, in any point along the length of the ship except the bulkhead separating the engine department.

For the general study, flooding is considered in one compartment in proportion of 95%. Minimum values used for specific compartments onboard the ship are:

- Engine Room: \( 85\% \)
- Accommodation spaces: \( 95\% \)
- Empty tanks and ballast tanks: \( 98\% \)
- Spaces dedicated for consumption liquids: \( 0\% - 95\% \)

2. **Determining the ship’s stability in case of damage**

For determining the ship’s stability in case of damage, four damaging situations were considered, according to stages of ship’s operation, such as:

- **a)** Damages on the ship’s plating for a fully loaded ship with 100% reserves onboard;
- **b)** Damages on the ship’s plating for a fully loaded ship with 10% reserves onboard;
- **c)** Damages on the ship’s plating for a 75% loaded ship with 100% reserves onboard;
- **d)** Damages on the ship’s plating for a 50% loaded ship with 10% reserves onboard.

The ship considered as an example is an oil tanker, double hulled in the VLCC category having the following characteristics [5], [8]:

- **Length over all:** 318.62 metres
- **Width:** 52.00 metres
- **Draught:** 21.11 metres
- **Displacement:** 246.302 tons
- **Deadweight:** 209.997 tons
- **Netweight:** 36.300 tons

Ballast tanks are „L” shaped positioned, their total capacity, including the fore ballast tank being 54.844 tonnes. Dimensionally the ballast tanks are according to international standards.

Ship’s damage situations are considered to be the result of a collision between the oil tanker operating offshore and another ship. Damage resulted is considered to affect only the ballast tanks, without affecting the cargo tanks, therefore excluding any risk of pollution with oil. Being intact, before damage, the ship fulfills the stability criteria for all loading situation. Having a simmetrical ship
with compartment symmetrically distributed onboard, damage was considered only on one board, because damage on the other board leads to the same result only with the opposite sign for listing.

For a proper study of the ship’s stability in case of damage and determining the necessary actions imposed to be taken in such cases, stability calculus software was used onboard oil tankers.

2.1. Damage on the plating in case of the fully loaded ship with 100% reserves onboard.

Characteristic data of the ship before damage (figure 1):
- displacement: 248.934 tone
- deadweight: 212.637 tone
- metacentric height (GM): 3.0 metres
- corrected metacentric height (GM cor): 3.03 metres
- draught forward: 20.83 metres
- draught aft: 21.35 metres
- trim difference: 0.55 metres
- transverse list: 0.06 degrees
- total ballast: 11.871 tons
- total reserves: 1750 tons

Figure 1. Transverse section through the ship’s tanks before damage.

The analysed damage was produced below the water line of ship, in the no.2 and no. 3 lateral ballast tanks area on the port side. Damage led to flooding of two tanks in proportion of 80%, representing an approximate quantity of 4500 tons of water in each tank (figure 2).

Figure 2. Transverse section through the ship’s tanks after damage.

After damage, the ship’s trim (figure 3) shows some changes, also the transverse listing angle, the position of the centre of buoyancy and the position of the centre of gravity, the new values being:
- corrected metacentric height (GMcor): 3.09 metres
- draught forward: 22.44 metres
- draught aft: 22.15 metres
- trim difference: - 0.3 metres
- transverse list: - 2.58 degrees
| Heel (deg) | GZ (m) |
|-----------|--------|
| 0         | 0.00   |
| 5         | 0.27   |
| 10        | 0.55   |
| 15        | 0.82   |
| 20        | 1.01   |
| 25        | 1.09   |
| 30        | 1.13   |
| 35        | 1.13   |
| 40        | 1.09   |
| 45        | 1.04   |
| 50        | 0.93   |
| 55        | 0.82   |
| 60        | 0.75   |
| Free surface (reduction) | 1.08 m |
| Dynamic stability (area 0–40 deg) | 8.24 mrad |
| GM        | 3.1 m  |

**Figure 3.** Ship’s stability after damage.

From the data analysis, it results that the ship fulfills stability criteria in case of damage, such as: metacentric height in the final stage of flooding is higher than 0.05 metres, the listing angle in the final stage of flooding does not exceed $25^\circ$, area below static stability diagram within the limits of $20^\circ$ from the equilibrium position is higher than 0.0175 m rad (figure 3).

2.2. **Damage of plating in case the ship is fully loaded and with 10% reserves onboard**

Ship’s characteristics before damage are (figure 4):
- displacement: 248.934 tons
- deadweight: 212.637 tons
- metacentric height (GM): 3.2 metres
- corrected metacentric height (GM cor): 3.23 metres
- draught forward: 20.83 metres
draught aft: 21.35 metres
trim difference: 0.55 metres
transverse list: 0.06 degrees
total ballast: 11.871 tons
total reserves: 175 tons

**Figure 4.** Transverse section through the ship’s tanks before damage.

Damage considered (figure 5) was produced below the ship’s water line, around the fore ballast tank and the no.1 ballast tank on the starboard. Damage led to flooding in two tanks in proportion of 75%, representing a quantity of approximately 7000 tons in the forward ballast tank and 4200 tons in the no.1 lateral tank.

**Figure 5.** Transverse section through the ship’s tanks after damage.

Following damage, there are some changes registered in the ship’s trim, transverse listing angle, position of the centre of buoyancy and position of the centre of gravity, the new values being:
- corrected metacentric height (GMcor): 2.91 metres
- draught fore: 24.99 metres
- draught aft: 18.98 metres
- difference in trim: - 6.0 metres
- transverse list: 1.47 degrees
Heel (deg) | GZ (m)
---|---
0 | 0.00
5 | 0.25
10 | 0.51
15 | 0.77
20 | 0.96
25 | 1.04
30 | 1.08
35 | 1.08
40 | 1.05
45 | 1.00
50 | 0.90
55 | 0.79
60 | 0.72
Free surface (reduction) | 1.33 m
Dynamic stability (area 0-40 deg) | 7.79 mrad
GM | 2.9 m

**Figure 6.** Ship’s stability after damage.

After damage, stability criteria in case of damage for an oil tanker are fulfilled as resulted from stability diagram represented in figure 6.

2.3. *Damage of the plating in case of the ship being 75% loaded and with 100% reserves onboard*

The characteristics of the ship before damage, according to figure 7, are:
- displacement: 225.952 tons
- deadweight: 189.657 tons
- metacentric height (GM): 5.7 metres
- corrected metacentric height (GM cor): 5.71 metres
- draught fore: 19.07 metres
- draught aft: 19.30 metres
- difference in trim: 0.23 metres
- transverse list: - 0.02 degrees
- total ballast: 26.120 tons
- total reserves: 1750 tons

Figure 7. Transverse section through the ship’s tanks before damage.

The damaged which is analysed was produced below the ship’s water line, in the no. 3 ballast tank area on the starboard side, like the figure 8 shows. The damage led to flooding of the tank in 85%, representing a quantity of approximately 4800 tons.

Figure 8. Transverse section through the ship’s tanks after damage.

Following damage, after analysing the stability diagram (figure 9), the following trim values were registered for the ship:
- corrected metacentric height (GMcor): 5.27 metres
- draught fore: 18.61 metres
- draught aft: 19.93 metres
- difference in trim: 1.32 metres
- transverse list: 1.40 degrees
| Heel (deg) | GZ (m) |
|-----------|--------|
| 0         | 0.00   |
| 5         | 0.49   |
| 10        | 1.00   |
| 15        | 1.52   |
| 20        | 1.89   |
| 25        | 2.12   |
| 30        | 2.26   |
| 35        | 2.30   |
| 40        | 2.28   |
| 45        | 2.19   |
| 50        | 2.00   |
| 55        | 1.77   |
| 60        | 1.55   |
| Free surface (reduction) | 2.19 m |
| Dynamic stability (area 0-40 deg) | 15.44 mrad |
| GM        | 5.3 m  |

**Figure 9.** Ship’s stability after damage.

The analysis of data following damage leads to the conclusion that the ship fulfills the stability criteria in case of damage.

2.4. **Damage of the plating in case of the ship being 50% loaded and with 10% reserves onboard**

The characteristics of the ship before damage are (figure 10):
- displacement: 167.551 tons
- deadweight: 131.251 tons
- metacentric height (GM): 8.1 metres
- corrected metacentric height (GM cor): 8.12 metres
- draught fore: 13.50 metres
- draught aft: 15.51 metres
- difference in trim: 2.00 metres
- transverse list: 0.01 degrees
- total ballast: 11.400 tons
- total reserves: 175 tons

**Figure 10.** Transverse section through the ship’s tanks before damage.

The analysed damage was produced below the water line of the ship, in the no.2 and 3 ballast tanks area on the starboard side. The damage led to a flooding in the two tanks of 70%, representing a quantity of approximately 4000 tons in each tank (figure 11).

**Figure 11.** Transverse section through the ship’s tanks after damage.

Ship’s characteristics after damage (figure 12) are:
- corrected metacentric height (GMcor): 8.48 metres
- draught fore: 13.93 metres
- draught aft: 15.56 metres
- difference in trim: 1.63 metres
- transverse list: 1.29 degrees
In this case, analysing all the ship parameters after collision, the stability criteria for the ship in case of damage are fulfilled.

3. Actions for refloating the ship in case of damage

In studying oil tankers’ stability, an important part is represented by the study of situations which involve damage of the ship’s hull, increased risk situations in operating these ships. Risks which arise after damage on the ship’s hull are related both to the ship’s seaworthiness and the pollution potential of these situations.

In the damage cases studied in this paper, the ship is considered during off-shore terminal operation and damages arise due to collision with another ship. Even if in the areas where off-shore oil terminals are placed, maritime security actions are intensified, risk situations may appear, leading to the ship’s damage during operation, and also damage of the terminal’s building elements and inevitably to the stopping of operation for the necessary period of time for evaluating and fixing damages.
In the studied cases, damage was produced only on the ship’s hull during operation, with the ballast lateral tanks area being affected, without damage on the cargo tanks and implicitly eliminating the risk of pollution with oil.

Actions proposed and analysed for refloating the damaged ship include:

- controlled ballasting operations;
- cargo transfer operations between the ship’s tanks.

In damage situations the ship’s Master may interfere with the purpose of providing damage stability and ship’s refloating through controlled ballasting of tanks on the opposite side from the damage or by transferring cargo between the ship’s tanks, mainly from the tanks on the damage side to the tanks from the opposite side.

Actions taken onboard the ship for refloating the ship after damage should be accompanied by actions regarding the stopage of operation, making sure that the connection between the operating ship and the operation buoy shall not be affected, as well as asking for assistance in order to secure the ship and bringing her to port.

For the studied damage cases, actions for refloating the ship are based on controlled ballasting operations in the ballast tanks from the opposite side from that where damage in produced. Refloating the damaged ship by transferring cargo may be realised in cases in which the ship has a loading degree which allows such operations.

For the first studied case, damage on the no. 2 and 3 ballast tanks on the port side, actions for refloating the ship were represented by controlled ballasting of the no. 2 and 3 ballast tanks from starboard side, no. 2 ballast tank from starboard side for 50% and no.3 ballast tank on the starboard side for 90%. Through controlled ballasting of the two tanks, an opposite listing moment from that of the damage is created, which leads to decreasing the listing angle towards equilibrium, the final value being – 0.98 degrees, producing a change in the trimming difference from 0.3 metres astern to 0.41 metres astern. In the final stage of refloating, the metacentric height has a value of 2.9 metres, superior to the minimum necessary value according to the register rules for the damage ship. Following the refloating operation, tensions on the ship’s body are within normal limits, the ship’s hull not being longitudinally and transversally stressed.

In case of flooding after damage in the forward ballast tank and no.1 starboard ballast tank, ship’s refloating actions are represented by controlled ballasting of no. 3 ballast tanks on both sides, with a higher degree of filling in the opposite tank from that of the damage. Transverse listing of the ship after refloating shall be 0.4 degrees, the difference in trimming being 5.6 metres to the bow. Due to damage produce in the two tanks situated forward, the difference in the ship’s trim shall have higher values both before and after refloating. Metacentric height after refloating is 2.7 metres, higher than the minimum necessary value.

During the necessary operations for refloating the ship, special attention should be given to values of the cutting forces and torsion moments developed in the ship’s hull, especially in the ship’s central area, where these values are close to critical limits for the ship situated in high seas. An increase in these values may lead to failure and deformation of the resistance structure in the ship’s hull, which finally lead to cracking and rupture.

In both cases, redressing the ship by unloading oil products from the ship’s tanks was proposed, providing the necessary trim for bringing the ship to the nearest port. Also, in case of the ship fully loaded, the possibility of transferring cargo between the ship’s cargo tanks is excluded.

Due to the loading degree of the ship, according to the final angle of longitudinal and transverse listing of ship, pollution by oil by spilling cargo from tanks on the ship’s deck through the overflow holes of the cargo tanks. Limiting pollution is possible by taking action as soon as possible in such a way as to lead to a decrease of the level in the cargo tanks lower than the evacuation valves.

In cases number three and four, ships refloating actions were represented by controlled ballasting of the ballast tanks on the opposite side from that of damage, final trimming values providing buoyancy for the ship in optimal condition for bringing her to the nearest port. Also, considering the
level of liquid in the cargo tanks, cargo transfer operations are possible and recommended in order to fulfill the damaged ship’s stability criteria.

Ship’s stability requirements are also provided for the situation when an external moment affects the ship, such as wind or wave, leading to a change in the ship’s transverse stability.

4. Conclusions
World economy development will request more and more energy supplies. In order to produce more energy, it will be necessary to reach more primary resources. Nowadays, energy production uses mainly oil and natural gases worldwide. Taking into account that the biggest energy consumers are not the holders of the resources in the same time, it will be necessary to develop transportation systems able to supply these quantities.

An important actor in this system is represented by the maritime transport. The maritime industry posses enough transport units necessary to satisfy oil and gas requirements, the limitations appearing in many cases only because of poor development of harbor logistics. To avoid these limitations, many harbor authorities decided to develop new terminals, and so the most preferred solutions became the off-shore terminals.

Designing solutions for refloating of the damaged ship were aimed to bringing the ship in the area of prevention of loss of stability by enhancing the effects of damage by other factors acting on ship.

In the emergency cases studied in the paper, the ship is considered while operating at offshore terminal and damages occur due to her collision with another ship. Even if the safety measures are high in the areas where the offshore terminals are placed, dangerous situations can occur, possible resulting in damage of the ship under operation, damage of the terminal elements and inevitably lead to the cancelling of operations for a period of time needed to assess and fix the damages.

Validation of the proposed solutions regarding refloating of the ship after damage should include these effects, considering how these can reduce or amplify the ship list value or the values of forces and moments generated into the hull.

Where external moments amplified efforts in the hull structure, operations involving the transfer of ballast and cargo between ship tanks should only be made to achieve a minimum necessary conditions of ship stability in order to allow a safe towing to inner harbour or other protected area. For the studied cases, when an external moment act and produce changes of the ship transverse stability of the vessel, damage stability criteria are fulfill.

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