

# Stockholm Agreement Analysis for Ro-Ro Passenger Ships Navigating in the North European Waters and the Baltic Sea

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**ABSTRACT:** This paper is an extension of work originally presented in 2019 EUROPEAN NAVIGATION CONFERENCE (ENC) [4]. The paper has described the important role of the Stockholm Agreement in safety of the Ro-Ro/Passenger ships in the north European waters. The present work describes the way in which we can improve the safety in strong chance of destruction of ship at sea. All results are generalized for a given group of ships. The specific construction of the RO-RO/ Passenger ships, being characterized by flat vehicle decks which are practically open, un-subdivided, and additional passenger accommodation space, with ramp fitted astern and in some cases in fore or side of the ship, giving access to cars, trucks and trailers, or specific trains which remain on board in their laden state, has resulted in international regulation requiring, amongst other things, strengthening the damage stability requirements for this type of ships. The more stringent damage stability criteria has been adopted on a regional basis by northern European countries as STOCKHOLM Agreement, in 1996. The paper concerns an analyze of damage stability calculations results in compliance with the STOCKHOLM Agreement, when the Ro-Ro/ Passenger ship is fully loaded, with maximum Deadweight (DWT) and maximum draught, or partly loaded, with reduced DWT, and occurs Minor or Major penetration of destroyed compartments.

## 1 INTRODUCTION

It should be noted that the sea transport has grown drastically during last times causing evolution in regulations enforced to provide safe sea passages. Many of the regulations are the result of losses of ships, which were previously regarded as safe.

By law, every ship in all loading conditions must satisfy damage stability requirements led in "The international convention for the Safety of Life at Sea, 1974" – ( SOLAS). The damage stability criteria has been modified in 1990, with additional, simplified stability information for the master. Depending on ship's size and ship's type, the SOLAS convention has

stringent requirements regarding the survival in case of damage.

Some regulations are described for a number of ship types in conventions and their relative Codes.

- International Bulk Chemical Code (IBC,1978) for chemical tankers;
- International Gas Code (IGC, 1978) for gas tankers;
- MARPOL (1978) for oil tankers;
- Additions to SOLAS (1990) convention for passenger ships.

The regulations enforced for the construction and maintenance of Ro-Ro / Passenger ships are much more stringent than those for cargo ships in an attempt to provide safe sea passage. The most dangerous problem for a Ro-Ro/Passenger ship with

an enclosed deck is the effect of a build-up of significant amount of water on that deck. The principle of additional water on deck has been adopted to account for the risk of accumulation of water on deck as a result of the dynamic behavior, in a sea way, or of the ship after sustaining side collision damage.

If the ship's position and stability are calculated, the question arises: if the damaged condition is sufficiently safe, and if the "critical openings" are still watertight which does not let water through.

The damage stability requirements applicable to Ro-Ro / Passenger ships in 1990 (SOLAS'90) include the effect of water ingress to the main Ro-Ro cargo deck in a sea state in order of 1.5 meters of significant wave height (hs).

There are a number of publications regarding the damage stability regulations [3, 5], which set to come into force in 2009 .

These new regulations are based on a wide range of related design parameters, such as the number, positioning and local optimization of transverse bulkheads, the presence and position of longitudinal bulkheads below the main vehicle deck, the presence of side casings, and the height of the main deck and double bottom. In addition, the effects of water on deck and of operational parameters as draught, center of gravity and trim, has to be taken into consideration. The open un-subdivided vehicle deck space of presented Ro-Ro/ Passenger ship, is shown in Figure 1.



Figure 1. The open cargo deck of Polish Ro – Ro/ Passenger ship: M/F "Gryf" [photo by author]

The damage stability criteria and provisions laid down in the SOLAS 2009 and STOCKHOLM Agreement are as follows:

1. Range of positive part of the GZ curve >10 DEG;
2. The area under the righting lever curve  $\geq 0.015$  mrad;
3. Maximum heeling angle < 12 DEG;
4. Metacentric height > 0.05 m;
5. Maximum  $GZ \geq 0,1$  m;
6. Maximum  $GZ \geq (\text{heeling moment}) / (\text{displacement}) + 0.04$  m , taking into account the greatest of the following moments:
  - The wind pressure of 120 N/m<sup>2</sup>,

- The crowding of all passengers towards one side of the vessel,
- The launching of a fully loaded davit-launched survival crafts on one side.

During the sea passage not all ballast tanks can be filled up. The ship can be in Full load or Part load condition, and still have a number of empty ballast tanks. If such empty ballast tank is damaged, after that a sea water flows in, which can lead to a dangerous list or even capsizing. However, a completely full ballast tank that incurs a damage, can also be dangerous.

The selected cases of the Ro-Ro/Passenger ship in damage condition are discussed in this paper, when the Ro-Ro/ Passenger ship is fully loaded, with maximum Deadweight (DWT) and maximum draught, or partly loaded, with reduced DWT, and occurs Minor or Major penetration of destroyed compartments.

Damages with Minor penetration correspond to the small penetration from the ship's side limited by the wing tanks or by the longitudinal bulkheads. The Major penetration corresponds to the damage with penetration through wing tanks or longitudinal bulkheads to the opposite side of the ship.

For the above ship's designs: fully loaded and partly loaded, the stability calculations has been made in compliance with the STOCKHOLM Agreement to determine what the position, stability and list would be in damaged condition.

## 2 SIGNIFICANT WAVE HEIGHTS

The water is assumed to enter the Ro-Ro vehicle deck via a damaged "critical opening" and accumulated on deck. It is required that Ro-Ro/Passenger ship, in addition to complying with the full requirements of SOLAS'90, further complies with part of regulations of SOLAS with the defined water on deck. The height of water on deck (hw) is dependent on the residual freeboard after the damage (fr), and is measured in way of the damage. The residual freeboard (fr) is defined as the minimum distance between the damaged Ro-Ro vehicle deck and the final waterline, as it was shown in Figure 2.

The damage stability requirements applicable to the Ro-Ro/ Passenger ships in 1990 (SOLAS'90) include the effect of water entering the vehicle deck in sea state in the order of 1.5 meters significant wave height. If the significant wave height, in the area concerned, is 1.5 meters or less, than no additional water is assumed to accumulate on the damaged Ro-Ro deck.

In order to enable the ship to survive in more severe sea states, those requirements have been upgraded to take into account the effect of water on deck for sea state between 1.5 meters to 4.0 meters of the significant wave height. The significant wave height (hs) is the qualifying parameter, in association with a 90% probability that hs is not exceeded for Ro-Ro/Passenger ships operating regular scheduled voyages between designated ports in geographically

defined restricted areas: North West Europe and the Baltic Sea.

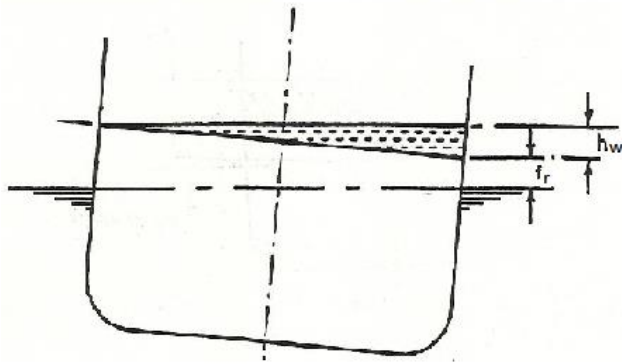


Figure 2. The residual freeboard definition. [2, 4]

It has to be assumed, that a variable quantity of water on ro-ro deck depends not only on the residual freeboard and significant wave height, but also on the variable angle of heel.

### 3 THE STOCKHOLM AGREEMENT (1996)

The STOCKHOLM Agreement, concerning a specific stability requirements for Ro-Ro/Passenger ships undertaking regular scheduled international voyages between or to, or from designated ports in North-West Europe and the Baltic Sea has noted in particular, the prevailing, often adverse, sea and weather conditions with low visibility, the low water temperatures, the need to maintain intensive all year round passenger ferry services, recent accidents and the density of Ro-Ro/Passenger ship movements.

The stability requirements have been upgraded to take into account the effect of water which could accumulate on the damaged Ro-Ro deck, and to establish the stability standard to enable the ship to survive in more severe sea states. The knowledge of the wave heights in sea areas covered by the discussed Agreement, is necessary when taking into account the effect of a hypothetical amount of sea water accumulating on the first deck above the waterline of the Ro-Ro/ Passenger ship, when entering through bow, stern, and side doors assumed to be damaged.

Taking into consideration the amount of water on the Ro-Ro deck, the figure of up to 0.5 meters, depending on the significant wave height and residual freeboard, have been undertaken in STOCKHOLM Agreement.

It is clear, that the residual freeboard of damaged ship has a significant effect on amount of water to be cumulated on Ro-Ro deck. The maximum residual freeboard to be taken into account was agreed as 2.0 meters.

If the residual freeboard  $\geq 2.0$  meters, then the height of water on deck  $hw = 0.0$  meters.

If the residual freeboard  $\leq 2.0$  meters, then the height of water on deck  $hw = 0.5$  meters.

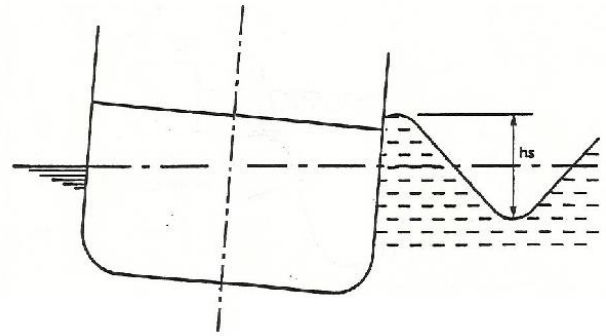


Figure 3. The height of water on deck ( $hw$ ) calculations, with the relation to a significant wave height ( $hs$ ). [2, 4]

For example, if residual freeboard is equal  $fr = 1.25$  meters and the height of significant wave:  $hs = 3.5$  meters, the height of water expected on deck:  $hw = 0.5$  meters.

Some model tests and analytical predictions made by the Naval Architects and Marine Engineers [2] suggested that  $0.5 \text{ m}^3/\text{m}^2$  was a reasonable water level for 4.0 m significant wave height. The same tests and analytical predictions indicated that the height of water on the Ro-Ro/Passenger cargo deck goes to zero as the "residual freeboard/significant wave height" ratio rises above 0.5. Therefore in order to assume zero water accumulation, in a significant wave height of 4.0 m, a residual freeboard of 2.0 meters in damaged Ro-Ro/ Passenger ship would be required.

### 4 DESCRIPTION OF ANALYSED RO-RO / PASSENGER SHIP

The general arrangement of the analyzed ship is shown in Figures 4 & 5.

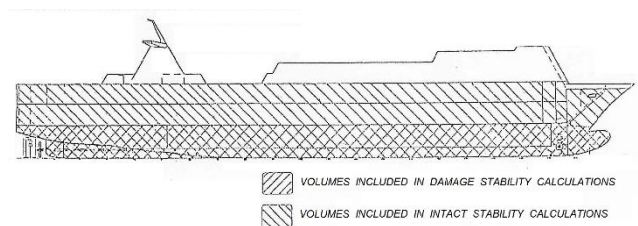


Figure 4. Reference for volumes included in Ro - Ro / Passenger ship as buoyancy for stability. [1, 4]

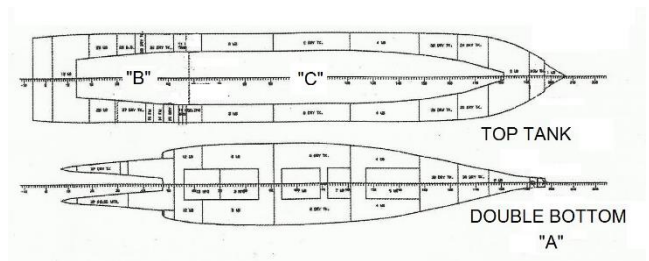


Figure 5. The general arrangement of volumes included in damage stability calculations. [1, 4]

In Figure 5: A – The double bottom with Ballast Tanks, Fuel Tanks, and Dry Tanks; B – Engine room; C - Cargo space in lower deck and the wing tanks.

The volumes "A", "B", "C" are included in damage calculations.

Various possible ship's damage scenarios, concerning a several number of different compartments to be flooded, are considered to include the worst sake of ship's survivability.

The following particulars has been taken into account for damage stability analysis:

- Gross Tonnage 18 653
- Length overall 158,0 m
- Breadth 24.0 m
- Height 45.0 m
- Draught maximum 5.9 m
- Displacement for maximum draught 13 692 t

The calculations has been performed for the ship with maximum value of DWT and with the minimum allowable Metacentric height GM, according to the requirements described in the Loading Manual [9].

In addition, the calculations were performed for reduced DWT, for the ship with no full cargo on decs, in order to show the way in which the improvement of the seaworthiness of the Ro-Ro/Passenger ship, expecting a bad weather conditions during the sea passage, can be done.

In the state of maximum DWT, the mean draught is equal 5.75 meters, and the Metacentric height GM = 1.53 meters.

In the state of reduced DWT, the mean draught is equal 5.40 meters, and the Metacentric height GM = 1.83 meters.

The calculation were made for Minor penetration – it means the small penetration from the ship's side, limited by the wing tanks or by the longitudinal bulkheads.

In case of calculations made for the Major penetration, which corresponds to penetration through wing tanks or longitudinal bulkheads to the centerline, a very important is fact, that in all the cases, which has been presented below, there is no residual stability , and ship will capsize or sink.

Such penetration can fill up the engine room "B" or cargo space "C" , which is shown in Figure 6.

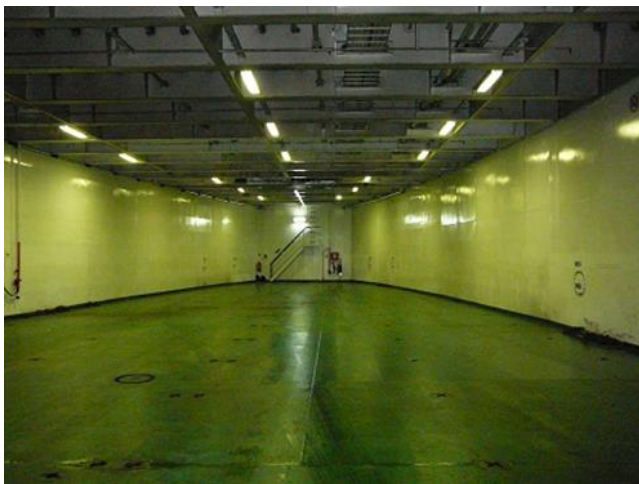


Figure 6. The open cargo space "C" below the main deck, located on " Top Tank", and surrounded by the wing tanks. [photo by author]

## 5 ANALYSIS OF SHIP'S SURVIVABILITY IN DAMAGE SITUATIONS

Details regarding the stability of the Ro-Ro/ Passenger ship for selected damage scenarios and compliance for the STOCKHOLM Agreement are shown below. A several cases has been taken into account.

### 5.1 The case of minor penetration below the main deck

This Case is presented in Figure 7.

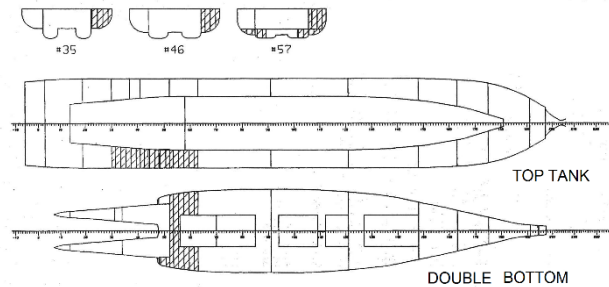


Figure 7. The Minor penetration of starboard side compartments. [ 7 , 9 ]

5.1.1 The intact conditions for the ship in maximum DWT state, are as follows: mean draught: 5.75 meters, no trim, the intact Metacentric height:  $GM_0 = 1.53$  meters.

The damaged compartments	Permeability [%]
27 Dry tank	0.95
Tanks 22, 23, 24, 35	0.95
15 FW tank	0.95
14 + 30 FW tanks	0.95
Dry tank	0.95
WB tank	0.95
11 SB Heeling tank	0.95

Extent of damage is as follows: Damage between frames: 30 – 63, Penetration: inboard 4.80 meters, Flooded volume: 6 767.1 m<sup>3</sup> .

Table 1. Stability factors

Maximum righting arm (max. GZ)	- 0.08 m
Heel angle at GZ max.	10.3 deg
Range of GZ curve	0.0 deg

Table 2. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	- 4.62 m	0.16 m
Door 3 rd. Deck	50	- 9.72 m	0.25 m
Bow door	197	-3.63 m	0.15 m

In the state of maximum DWT, the ship will capsize in the above conditions of damage, due to the stability loss.

5.1.2 *The intact conditions for the reduced DWT: the mean draught is equal 5.40 meters, and the intact Metacentric height  $GMO = 1.83$  meters.*

The extent of damage: Penetration: inboard 4.80 meters, flooded volume: 757.3 m<sup>3</sup>.

The Floating Conditions of ship in this case of damage are as follows:

Table 3. Floating conditions

Draught	Trim			Heel	GM
	Aft	Midships	Forward		
5.82 m	5.46 m	5.09 m	- 0.73 m	10.7 deg	1.0 m

Table 4. Stability parameters

Maximum righting arm (max. GZ)	0.02 m
Heel angle at GZ max.	12.5 deg
Range of GZ curve	3.6 deg

Table 5. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	1.09 m	0.10 m
Door 3 rd. Deck	50	0.64 m	0.23 m
Bow door	197	1.90 m	0.10 m

In this case of damage, the ship in state of reduced DWT has a small stability margin, but she will float in equilibrium position. The stability is however not sufficient to comply with the criteria of SOLAS'90.

## 5.2 The case of major penetration below the main deck

This case is presented in Figure 8.

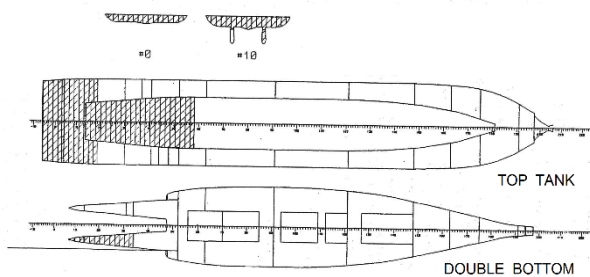


Figure 8. The damage case of Major penetration. [1, 4]

5.2.1 *The intact ship's conditions in state of maximum DWT are: the mean draught of 5.75 meters, and the intact Metacentric height  $GMO = 1.53$  meters.*

Damaged compartments	Permeability [%]
13 WB tank	0.95
38 SB Dry tank	0.95
Engine room	0.85
37 SB bilge water	0.95
Steering gear room	0.85

Extent of damage is as follows: damage between frames: 6 – 58. Penetration: inboard 4.80 meters, flooded volume: 6 767.1 m<sup>3</sup>.

Table 6. Stability parameters

Maximum righting arm (max. GZ)	- 0.02 m
Heel angle at GZ max.	0.0 deg
Range of GZ curve	0.0 deg

Table 7. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	-7.53 m	0.16 m
Door 3 rd. Deck	50	-11.5 m	0.25 m
Bow door	197	-2.29 m	0.15 m

In the above case, the fully loaded ship capsizes due to the stability loss.

5.2.2 *In the state of reduced DWT, the extent of damage is as follows*

Penetration: inboard 4.80 meters, flooded volume: 2 757.9 m<sup>3</sup>.

Table 8. Floating conditions

Draught	Trim			Heel	GM
	Aft	Midships	Forward		
8.09m	6.08 m	4.06 m	- 4.06 m	0.9 deg	1.39 m

Table 9. Stability parameters

Maximum righting arm (max. GZ)	0.05 m
Heel angle at maximum righting arm	5.0 deg
Range of the GZ curve	7.4 deg

Table 10. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	-6.37 m	0.08 m
Door 3 rd. Deck	50	1.33 m	0.21 m
Bow door	197	3.61 m	0.07 m

In this case of damage, the ship in state of reduced DWT has a small stability margin, but she will float in equilibrium position. The stability is however not sufficient to comply with the criteria of SOLAS'90.

## 5.3 The case of major penetration in fore part of the ship

This case is presented in Figure 9

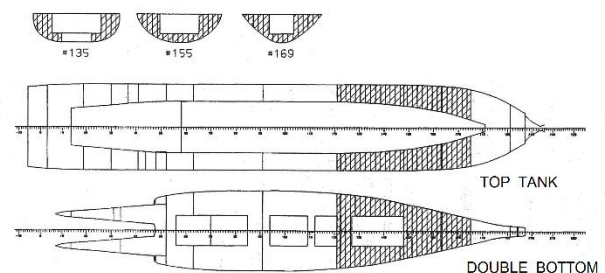


Figure 9. The case of Major penetration in fore part of the ship. [1, 4]

5.3.1 *Intact condition for the fully loaded ship are as follows: Mean draught = 5.75 meters, intact Metacentric height  $GMO = 1.53$  meters*

Damaged compartments	Permeability [%]
4 WB tank	0.95
3B Dry tank	0.95
3A Dry tank	0.95

The extent of damage is as follows: Frames: 121 – 175, Penetration: inboard 4.80 meters, Flooded volume: 2 727.4 m<sup>3</sup>.

Table 11. Floating conditions

Draught	Trim		Heel	GM
Aft	Midships	Forward		
4.91m	6.82 m	8.73 m	3.81 m	0.0 deg -0.68 m

Table 12. Stability parameters

Maximum righting arm (max. GZ)	0.00 m
Heel angle at maximum righting arm	0.0 deg
Range of the GZ curve	0.0 deg

Table 13. Critical openings

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	3.08 m	0.08 m
Door 3 rd. Deck	50	2.84 m	0.21 m
Bow door	197	-0.68 m	0.07 m

In this case the fully loaded ship will capsize due to the stability loss.

5.3.2 *Intact condition for the Partly loaded ship: Mean draught = 5.40 meters, intact Metacentric height  $GMO = 1.83$  meters*

Extent of damage is as follows: Penetration: inboard 4.80 meters, Flooded volume 2 508.5 m<sup>3</sup>.

Table 14. Floating conditions

Draught	Trim		Heel	GM
Aft	Midships	Forward		
4.66m	6.35 m	8.03 m	3.37 m	0.0 deg 0.04 m

Table 15. Stability parameters

Maximum righting arm (max. GZ)	0.00 m
Heel angle at maximum righting arm	1.0 deg
Range of the GZ curve	1.7 deg

Table 16. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	3.32 m	0.08 m
Door 3 rd. Deck	50	3.20 m	0.21 m
Bow door	197	0.00 m	0.07 m

In this case of damage, the ship in state of reduced DWT will capsize due to the stability loss.

5.4 *The case of penetration in midship, below the main cargo deck This case is presented in figure 10*

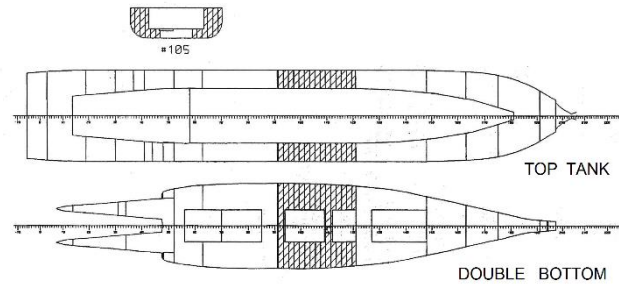


Figure 10. The case of penetration into the midship's compartments. [1, 4]

5.4.1 *Intact condition for the ship state of maximum DWT are as follows: Mean draught = 5.75 meters, intact Metacentric height  $GMO = 1.53$  meters*

Damaged compartments	Permeability [%]
6 Dry tank	0.95

The extent of damage is as follows: Damage between the frames: 91 – 121, Penetration: inboard 4.80 meters, Flooded volume: 1 385.4 m<sup>3</sup>.

Table 17. Floating conditions

Draught	Trim		Heel	GM
Aft	Midships	Forward		
6.03m	6.23 m	6.43 m	0.40 m	0.1 deg 0.89 m

Table 18. Stability parameters

Maximum righting arm (max. GZ)	0.12 m
Heel angle at maximum righting arm	9.0 deg
Range of the GZ curve	13.1 deg

Table 19. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	1.87 m	0.08 m
Door 3 rd. Deck	50	2.51 m	0.21 m
Bow door	197	1.48 m	0.07 m

In this case of damage, and in state of maximum DWT, the ship has a good stability. She will float in equilibrium position. The stability complies with the criteria of SOLAS'90' .

5.5 *Intact condition for the ship with the reduced DWT are as follows: Mean draught = 5.40 meters, intact Metacentric height  $GMO = 1.83$  meters*

Extent of damage is as follows: Penetration: inboard 4.80 meters, Flooded volume 1 316.7 m<sup>3</sup>.

Table 20. Floating conditions

Draught	Trim		Heel	GM
Aft	Midships	Forward		
5.68m	5.86 m	6.04 m	0.36 m	0.1 deg 1.05 m

Table 21. Stability parameters

Maximum righting arm (max. GZ)	0.19 m
Heel angle at maximum righting arm	11.3 deg
Range of the GZ curve	16.6 deg

Table 22. Critical openings distance to the waterline

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	2.21 m	0.08 m
Door 3 rd. Deck	50	2.87 m	0.21 m
Bow door	197	1.87 m	0.07 m

The ship in state of reduced DWT has a good stability, and will float in equilibrium position. The stability complies with the criteria of SOLAS '90.

## 6 CONCLUSIONS

Results of the damage stability calculations, presented in this paper are getting knowledge of risk in practice of Ro-Ro/ Passenger ship's exploitation. This type of ships, with open un-subdivided cargo decks, is losing the stability in case of damage very easy.

The damage stability calculations, presented above, are giving a clear image of risk when some of the ship's compartments have been damaged.

It should be noted very clear, that in case of damage the Ro-Ro/Passenger ship in state of reduced DWT, and Minor penetration, has much better chance for float in equilibrium position with a small stability margin, than in case when the ship is fully loaded, with maximum DWT, having the same damaged compartments.

The Major penetration in case of damage of the Ro-Ro/Passenger ship resulting always as the stability loss.

If the ship's floating condition and stability are calculated, a question arises if the damaged condition is sufficiently safe. In some cases the answer is simple: if a ship sinks, it is no longer safe. When staying afloat, the amount of submersion or list, and the residual freeboard has to be stated.

The results of the calculations which has been presented above, are giving the proof of the significance of simplified stability information for the Master and tools for fast verification: if the Ro-Ro / Passenger ship sinks, or staying afloat.

Stating that in state of reduced DWT the Ro-Ro/Passenger ship has much better chance to survive in case of damage than the ship in state of maximum DWT, the important advice should be noted.

When the extremely bad weather, and sea state conditions are predicted for the sea passage of the Ro-Ro/Passenger ship, it is better to have this ship in state of reduced DWT than in state of maximum DWT. The above is in connection with the accelerations, which

are extremely high in fore and after part of the Ro-Ro/Passenger ship, and may cause the damage of cargo lashing, and shifting of vehicles during the bad weather. As the effect of the above, the ship is missing the stability. Due to the above, there is a practical advice to reduce the number of vehicles loaded in fore and after part of main deck and on higher deck, in order to reduce destructive effect of the high value acceleration, and to get the partly loaded conditions of the ship.

The process of the development of safety regulations pertains the construction of bulkheads, watertight doors in lower deck, watertight of ventilation channels, construction of longitudinal bulkheads, installation of monitoring systems for critical openings, systems of monitoring for leakage in cargo decks, systems of fast drainage of lower vehicle decks.

Damage stability calculations are made during the ship's design phase, but they are limited to a number of cargo conditions. In the design phase it is impossible to predict all load variations that occur throughout the exploitation of the ship. By law, a ship in all conditions must satisfy the damage stability requirements. This means, that the loading conditions may not be exactly as it was in the design calculations.

In practice there are two solutions:

1. Every ship has a table or diagram of maximum allowable KG in damage conditions.
2. A specialized computer software provides instructions for captain in every imaginable or real situation.

The results presented in this paper were performed by using the certified vessel's software for loading and stability calculations according to SOLAS 2009 and STOCKHOLM Agreement (1996), taking into account the imaginable reduced value of DWT or fully loaded Ro-Ro / Passenger ship, with maximum DWT.

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