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Some Notes on Risk and Safety Evaluation of RO-RO Passenger Ships Exploitation

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Abstract

Merchant ships vary considerably in size, type, general design and function. Some specific type of ships (Ro-Ro passenger/vehicle/train ferries) requires much more stringent regulations for construction, maintenance and safety than those for other. By law, a vessel 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.

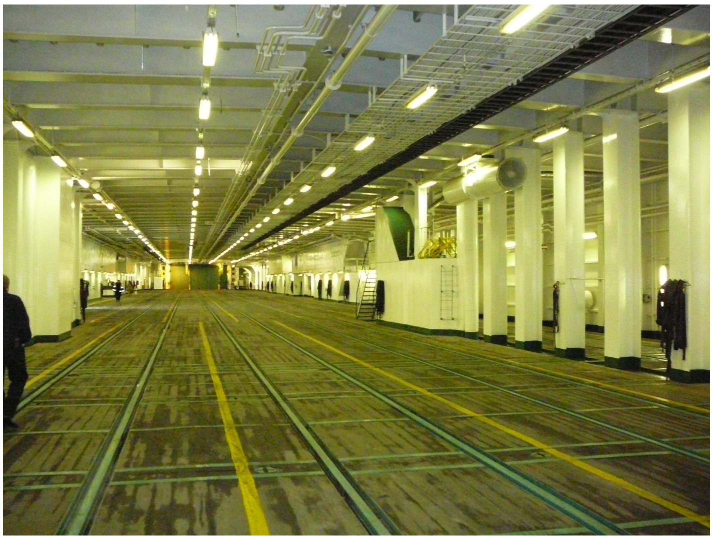
The paper concerns a selected aspects of damage stability requirements for Ro-Ro/ passenger ships. This type of ships is characterized by flat vehicle decks which are practically open, un-subdivided, and additional passenger accommodation space. The ramp is fitted astern and in some cases in fore or side of the ship, giving access to cars, trucks and trailers, or specific trains which remain on board in their laden state. The dramatic loss of the Ro-Ro passenger ships: M/F “Herald of Free Enterprise” in 1987, and M/F “Estonia” in 1994, respectively, 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 (STOCKHOLM Agreement, 1996).

Keywords: stability regulations, Ro-Ro/passenger ships, damage stability calculations.

Introduction

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. In addition, the RO-RO / Passenger ships have a supplementary damage stability regulations. There are a number of publications regarding the damage stability regulations (Vassalos Dracos, Papanikolau Apostolos, 2002; George Simopoulos Dimitris, Konovessis Email, Dracos Vassalos, 2008), 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 Ro-Ro/ passenger ship, is shown in Figure 1.



[M.Szymoński]

Figure 1. The open cargo deck of Polish Ro – Ro/ train/ passenger ship: M/F "Wolin"

The current damage stability standard is that a Ro-Ro vessel should be able to sustain damage to any two adjacent compartments, as it has been shown in Figure 2.

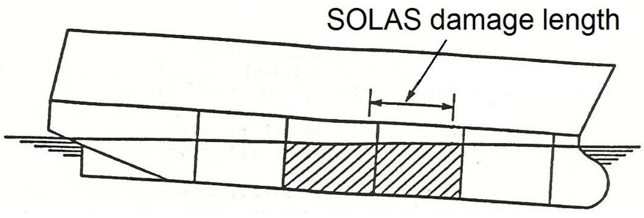


Figure 2 Description of SOLAS damage length.

In northern European countries, an increased standard of damage stability calculations is applied to existing Ro-Ro vessels, known as the STOCKHOLM Agreement 1996. The intention of the said Agreement is to obtain the same safety standards on every Ro-Ro/Passenger ship on regular scheduled international voyages between or to or from designated ports in North West Europe and the Baltic Sea. This Agreement requires either fulfilment of the deterministic standards of SOLAS 1974/1990 with an additional height of water on main deck (maximum of 50 cm), or the demonstration, by means of model experiments, that the RO-RO vessel can survive the sea state in a damaged condition.

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≥ 0.015 mrad;

3. Maximum heeling angle < 12 DEG;

4. Metacentric height > 0.05 m;

5. Maximum GZ ≥ 0,1 m;

6. Maximum GZ ≥ (heeling moment) / (dis-placement) + 0.04 m , taking into account the greatest of the following moments:

   6.a The wind pressure of 120 N/m²,

   6.b The crowding of all passengers towards one side of the vessel,

   6.c The launching of a fully loaded davit-launched survival crafts on one side.

Significant wave heights

The Agreement concerning 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,

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Figure 3 The side collision damaged of Ro-Ro/ Passenger ship.

the need to maintain all year round Ro-Ro/Passenger ferry services, the public dependence on such services, accidents at sea and the density of Ro-Ro/Passenger ships movements.

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. The Ro-Ro/Passenger ship with the hull damaged above the waterline is shown in Figure 3.

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.

Specific stability requirements pertaining to the Stockholm Agreement

Selected specific stability requirements for Ro-Ro/ Passenger ships operating in North West Europe ports and in the Baltic Sea have been described in this paper.

The most dangerous problem for the Ro-Ro/Passenger ships with an open un-subdivided vehicle deck spaces is water accumulating on deck when entering through damaged openings or side collision damage.

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 m 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 m to 4.0 m of the significant wave height. Taking into consideration the amount of water on the Ro-Ro deck, the figure of up to 0.5 m, 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 m.

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

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

Some model tests and analytical predictions made by the Naval Architects and Marine Engineers suggested that 0.5 m^3/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 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 m in damaged Ro-Ro/ Passenger ship would be required.

As the conclusion it should be noted that the Ro-Ro/Passenger ship, in addition to complying with the full requirements of SOLAS'90, further complies with that part of the SOLAS'90 criteria contained in paragraphs 2.3 to 2.3.4 of regulation of Chapter II-1 Part B of SOLAS, and with the defined water on deck. The height of water on deck is dependent on the residual freeboard after damage, and is measured in way of the damage.

The residual freeboard in this case is defined as "the minimum distance between the damaged Ro-Ro deck and the waterline at the location of the damage", as it was shown in Figure 4.

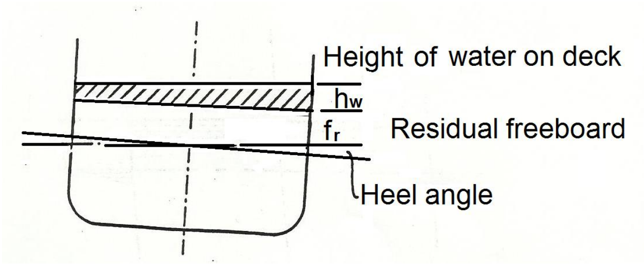

Figure 4 Description of SOLAS residual freeboard f r.

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.

The STOCKHOLM Agreement has been complied by the existing Ro-Ro/Passenger ships according to the timetable, which was based on the calculation of ratio A/Amax (where A is attained subdivision index):

Value of A/Amax:	*Date of Compliance:*
Less than 85%	1 April 1997
Less than 90%	31 December 1998
Less than 95%	31 December 1999
Less than 97.5 %	31 December 2000
97.5% or more	31 December 2001

But in any case, not later than 1st of October 2002.

The above timetable shows the year by year safety evaluation in respect to the Ro-Ro/Passenger ships serving in North West Europe ports and in the Baltic Sea.

The general description of analyzed Ro-Ro / passenger ship

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

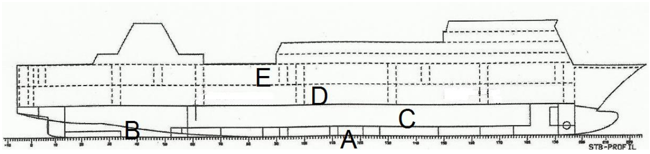

Figure 5a. The general arrangement of Ro – Ro / Passenger ship.

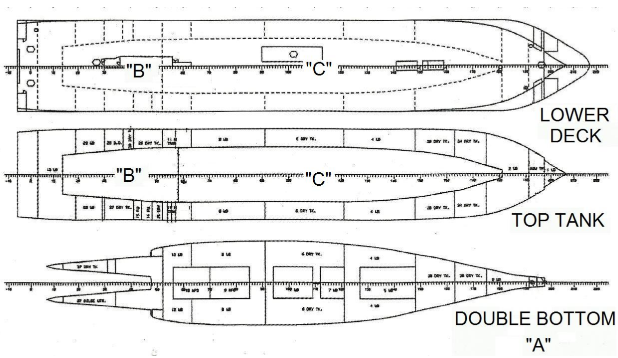

Figure 5b. The general arrangement of Ro – Ro / Passenger ship.

Where:

A – double bottom with Ballast Tanks, Fuel Tanks, and Dry Tanks; B – Engine room; C - Cargo space in lower deck; D – cargo space in main deck; E – cargo space in higher deck .

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

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

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

Gross capacity	18 653 RT
Displacement	13 692 T
Length overall	158 m
Breadth	24.0 m
Height	45.0 m
Draught maximum	5.90 m

To describe a selected situations, in which the ship‘s hull has been damaged, a ship’s Full Load Condition with the minimum allowable GM, as per requirements from the “Loading Manual”, was taken into account.

In the Full Load Condition, to be taken into account, GM equals 1.53 m, mean draught equals 5.75 m, and the ship is with the even keel.

A damage is assumed to occur between two watertight bulkheads in case of one compartment damage, with one watertight bulkhead damaged in case of two compartments damage, or with two watertight bulkheads damaged, etc.

Analysis of ship’s survivability in damage situations

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

The Case of one compartment damage located below the main cargo deck is presented in Figure 6.

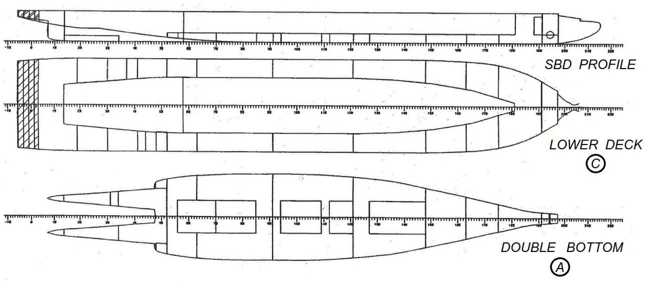

Figure 6 . One compartment damage.

The damaged compartment is located in stern part of the ship, between frames #-6 and #-3, and corresponds with the Steering Gear Room. The permeability of this compartment equals 0.85. Inboard penetration equals 4.80 m. Flooded volume is 4.8 m³.

The ship CONDITIONS of FLOATATION with damaged Steering Room are as follows:

Table 1

Draught			Trim	Heel	GM
Aft	Midships	Forward			
5.76 m.	5.75 m.	5.74 m.	0.01 m.	0.0 deg.	1.50 m.

Maximum righting arm (max. GZ)	0.28 m.
Heel angle at GZ max.	12.0 deg.
Range of GZ curve	18.5 deg.

CRITICAL OPENINGS:

Table 2

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	2.14 m.	0.08 m.
Door 3 rd. Deck	50	2.91 m.	0.21 m.
Bow door	197	2.16 m.	0.07 m.

The ship has good stability, and will float in equilibrium position. The stability complies with SOLAS'90 criteria.

The Case of two compartments of the Ro-Ro ship's damage, as it is shown in Figure 7.

The damaged compartments are located between frames

#63 and #121, and they correspond with Water Ballast Tank No 8 and Dry Tank No 6 of the analyzed ship. The permeability of these two tanks equals 0.95.

Inboard penetration equals 4.80 m, and flooded volume is 2 852.2 m^3**.**

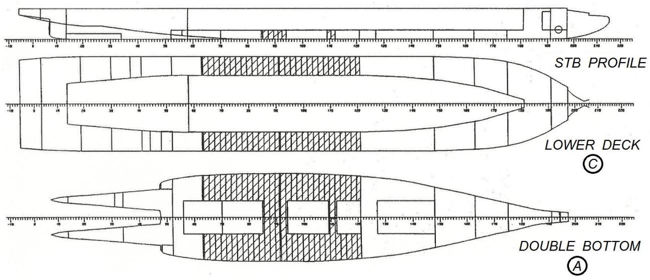

Figure 7. Two compartments damage.

FLOATATION CONDITIONS of ship in this case of damage are as follows:

Table 3

Draught			Trim	Heel	GM
Aft	Midships	Forward			
6.70 m.	6.68 m.	6.65 m.	0.05 m.	0.4 deg.	0.34 m.
Maximum righting arm (max. GZ)				0.03 m.	
Heel angle at GZ max.				5.0 deg.	
Range of GZ curve				7.7 deg.	

CRITICAL OPENINGS:

Table 4

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	1.17 m.	0.08 m.
Door 3 rd. Deck	50	1.89 m.	0.21 m.
Bow door	197	1.22 m.	0.07 m.

In this case the ship 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.

The Case of three compartments has been damaged in forward part of the Ro-Ro / Passenger ship is presented in Figure 8.

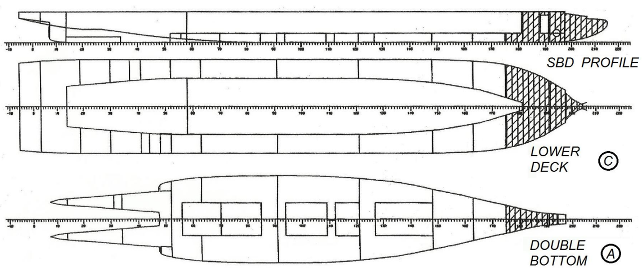

Figure 8 Three compartments damage.

The damage compartments are as follows: Water Ballast Tank with permeability of 0.95, Bow Thruster Room with permeability 0.85, and Forepeak Water Ballast with permeability of 0.95. The damaged spaces are located between frames #175 and #215. Penetration inboard is 4.80 meters which corresponds to flooded volume of 720.7 m³.

FLOATATION CONDITIONS of ship in this case of damage are as follows:

Table 5

Draught			Trim	Heel	GM
Aft	Midships	Forward			
5.21 m.	6.06 m.	6.90 m.	-1.70 m.	0.0 deg.	1.40 m.
Maximum righting arm (max. GZ)				0.21 m.	
Heel angle at GZ max.				10.0 deg.	
Range of GZ curve				15.9 deg.	

CRITICAL OPENINGS:

Table 6

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	2.74 m.	0.08 m.
Door 3 rd. Deck	50	3.05 m.	0.21 m.
Bow door	197	1.05 m.	0.07 m.

In the above case, the ship has a good stability. She will float in equilibrium position. The stability complies with the SOLAS'90 criteria.

The Case of four compartments to be damaged.

In presented case of the Ro-Ro/ Passenger ship damage, the following compartments has to be flooded: Water ballast tank, Starboard Side Dry Tank, Engine room, and Starboard Side

Bilge Water Tank. All tanks permeability is equal of 0.95. The permeability of the engine room equals of 0.85.

The presented case is shown in Figure 9.

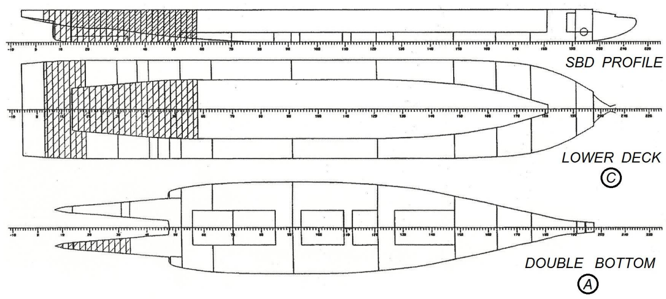

Figure 9. The illustration of four compartments damage.

FLOATATION CONDITIONS of ship in this case of damage are as follows:

Table 7

Draught	Trim	Heel	GM
The ship capsizes due to stability loss			
Maximum righting arm (max. GZ)	0.0 m.		
Heel angle at GZ max.	3.0 deg.		
Range of GZ curve	0.0 deg.		

CRITICAL OPENINGS:

Table 8

	Frame No.	Distance to the waterline	Reduction of distance to the waterline per degree of heel
Stern door	- 6	-6.76 m.	0.16 m.
Door 3 rd. Deck	50	-11.04 m.	0.25 m.
Bow door	197	-2.68 m.	0.15 m.

Extent of damage contains the frames between frame #3 and frame # 58. Inboard penetration equals 4.8 m, and flooded volume reaches the size of 6 767.1 m³.

In this case the ship has no residual stability, and will capsize or sink. The above case of vessel's damage corresponds the situation of the stability loss. The damaged volumes of the vessel are located in the double bottom and below of the main deck of the midships.

Conclusions

Results of 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, giving a clear image of risk when some of ship's compartments have been damaged. In case of damage of two or three compartments the ship has a good or even residual stability, when the much more serious damage creates the stability loss. The results of the above calculations are giving 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.

The process of 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 computer program 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 full loaded conditions of the analyzed Ro-Ro / Passenger ship.

Biography

Marek Szymonski is the Master Mariner and Professor in the Naval Academy of Gdynia, Poland. He used to be the commanding officer of biggest Polish Ro-Ro/passenger ferries M/F "Polonia" and M/F"Gryf" , serving on Baltic Sea for the last 14 years.

He used to be the Professor of Maritime Universities of Szczecin and Gdynia, too. He has published several articles in academic and scientific journals, participated in several International Conferences and wrote a books about radionavigation, satellite navigation, and safety of sea transportation.

References

[1] IMO Circular letter No.1930 , "Regional agreement concerning specific stability requirements for Ro-Ro passenger ships", London 1996, upublished.

[2] IMO Circular letter No. 1891, "Agreement concerning specific stability requirements for ro-ro passenger ships udertaking regular scheduled International voyages between or to or from designated ports in North West Europe and the Baltic Sea", London 1996, unpublished.

[3] Vassalos Dracos, Papenicolau Apostolos, " Stockholm Agreement - Past, Present, Future ", Society of Naval Architects. 2002, Vol. 39, No 3, pp. 137-158.

[4] D.J. Eyres, 2005, ELSEVIER Butterworth- Heinemann, Ship Construction, Amsterdam, 354 p.

[5] George Simopoulos Dimitris, Konovessis Email, Dracos Vassalos, "Sensitivity analysis of the probabilistic damage stability regulations for Ro-Pax vessels", Journal of Marine Science and Technology, 2008, Volume 13, Issue 2, pp. 164–177 .

[6] Klaas van Dokkum, Hans ten Katen, Tees Koomen, Jakob Pinkster, 2008, Ship Stability, DOKMAR Nederlands, 176 p.

[7] M.Szymonski, Analysis and Eveluation of Manoeuvrability Characteristics of Polish Ferries M/F 'Polonia' and M/F 'Gryf' ,TRANSNAV, The ournal on Marine Navigation and Safety of Sea Transportation, 2013, Vol.7, No 4, Gdynia, December 2013.

[8] Documentation of ro-ro passenger ship M/F 'Kaptan Burhanettin Isim', unpublished.

[9] Documentation of Ro-Ro passenger ship M/F 'Gryf', unpublished.