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Safety Management on Ro-Ro Passenger Ships

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ABSTRACT: To define the safety management on Ro-Ro passenger ship, the wide spectrum of captain's responsibilities should be taken into consideration. One of the important responsibilities is the ship's stability examination. The other measures as the ship's condition, wind on ship with large windage area, rolling characteristics, severe seas etc., are important for ensuring the safe operating of ship, to minimize the risk to the ship, to the personnel and passengers on board , and to the environment. The international convention for the Safety Of Life At Sea – (SOLAS 90) make into fact the continual development of safety standards in the 111 years since the sinking of the Titanic. Important enhancement stability, operational requirements and damage stability requirements were made as a consequence of several disasters at sea: "Torrey Canyon" in 1967 , "Herald of Free Enterprise" in 1987 (183 dead), "Exon Valdez" in 1989, "Braer" in 1993, "Estonia" in 1994 (892 dead).
In particular the dramatic loss of the Ro-Ro/Passenger vessels M/F "Herald of Free Enterprise" in 1987, and M/F "Estonia" in 1994, respectively, has resulted in the international regulation requiring enhanced damage stability requirements for this type of vessels, and in more stringent damage stability criteria adopted on a regional basis by Northern European countries (STOCKHOLM Agreement, 1977).

1 INTRODUCTION

RO-RO / Passenger vessels 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, Dracos Vassalos, 2008), which set to come into force in 2009 . These new regulations based on a wide range of related design parameters, such as the number, positioning and local optimization of transverse bulk-heads, 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. The effects of water on deck and of operational parameters as draught, center of gravity and trim. The current damage stability standard is that a Ro-Ro vessel should be able to sustain damage to any two adjacent compartments.

In northern European countries, an increased standard of damage stability calculations is applied to existing Ro-Ro vessels, known as the STOCKHOLM Agreement, which requires either fulfilment of the deterministic standards of SOLAS' 90 with an additional height of water on 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 Ch. II-1 Pt. B 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) / (displacement) + 0.04 m , taking into account the greatest of the following moments:
   – The wind pressure of 120 N/m^2,
   – The crowding of all passengers to-wards one side of the vessel,
   – The launching of a fully loaded davit-launched survival crafts on one side.

The presented paper describes the results of practical use of the stability calculations and damage stability calculations for the RO-RO/Passenger vessel M/F "Polonia", serving in Southern Baltic.

The said vessel is shown in Fig.1 .

Figure 1 M/F "Polonia" (by UNITY LINE)

2 VESSEL CHARACTERISTICS

2.1 *General*

Twin – screw, roll-on, roll-off, rail-truck-cars-passenger vessel, designated for Świnoujście – Ystad route, is arranged as follows:

– Soft nosed and raked stem with bulbous bow,
– Transom stern,
– Two full length cargo decks of 2 670 m total loading lane length, including lifted car shelves, with 6 railway tracks of effective loading length 740 m on the main deck ,
– Machinery located aft, with 27.5 m of the engine room length,
– Twin controllable pitch propeller propulsion-plant,
– 4 x STORK-WARTSILA medium speed main engines of 15 840 KW total,
– 3 bow thrusters of 1 600 KW each,
– 1 stern thruster of 1 600KW,
– Heeling compensation INTERING system ,
– Three accommodated decks above cargo hold,
– Access to main deck via stern door and shore ramp, and via side doors on Port Side mid ships, and Port Side aft the vessel, using shore ramps,
– Lifted car deck (shelves) on cargo deck,
– Frame spacing of 625 mm.

2.2 *Main particulars*

Main dimensions:

– Length OA	169.90 m
– Depth to 1st superstructure deck	19.95 m
– Length BP	159.00 m
– Depth to upper deck	14.15 m
– Breadth moulded	28,00 m
– Depth to main deck	8,65 m
– Draught designed/scantling	5,90 m/ 6,20 m
– Light ship weight	10 886 T

Table 1. Draught & Deadweight

Item	Draught	Displacement	Deadweight
Summer (1.025 T/m^3)	6.20 m	18 107 T	6855 T

3 CALCULATION OF REQUIRED RIGHTING LEVER

With respect to the criterion 6. described in INTRODUCTION, the following heeling moments has been calculated for different vessel draughts - 5,00 m, 5,50 , and 6,20 m:

3.1 *Moment due to the wind pressure of 120 N/m^2 .*

The results of calculations above moment due to the wind pressure, is presented in Table 2.

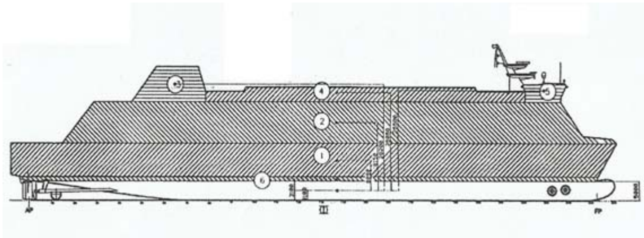


Figure 2 The distribution of windage areas for draught of 5.00 meters

Table 2. Moment due to the wind pressure

Item	Area m2	Wind pr. N/m2	W.force Tons	VCG m	V.Moment Ton.m
Draught: 5.00 m					
Area 1	1486.80	120.00	8.19	8.08	146.95
Area 2	1533.30	120.00	18.76	18.15	340.42
Area 3	148.80	120.00	1.82	28.20	51.33
Area 4	286.50	120.00	3.50	26.06	91.33
Area 5	50.50	120.00	0.62	26.60	16.43
Area 6	194.50	120.00	2.38	3.10	7.38
Sum Area	3700.00		45.27	14.44	653.00
Displacement at draught 5.00m:					13667.00 T
Required GZ = 0.088m					
Draught: 5.50 m					
Area 1	1486.80	120. 00	18.19	7.83	142.41
Area 2	1533.30	120.00	18.76	17.90	335.73
Area 3	148.80	120.00	1.82	27.95	50.87
Area 4	286.50	120.00	3.50	25.81	90.45
Area 5	50.50	120.00	0.62	26.35	16.28
Area 6	112.60	120.00	1.38	3.10	4.27
Sum Area	3618.50		44,27	14.46	640.01
Displacement at draught 5.50m:					15434.00 T
Required GZ = 0.081 m					

Draught 6.20 m

Area 1	1486.80	120.00	18.19	7.48	136.04
Area 2	1533.30	120.00	18.76	17.55	329.17
Area 3	148.80	120.00	1.82	27.60	50.24
Area 4	286.50	120.00	3.50	25.46	89.23
Area 5	50.50	120.00	0.62	26.00	16.06
Sum Area	3505.90		42.89	14.47	620.73

Displacement at draught 6.20m: 18107.00 T
Required GZ = 0.074 m

3.2 *Moment due to crowding of all passengers to-wards one side of the vessel is presented in Table 3*

Table 3. Moment due to crowding of passengers

Item	Area m2	No.	Weight Kg	Tot.Weight Kg	T.Mom Ton.m
Area 1	140.0	4.0	75.0	42000.0	483.0
Area 2	80.0	4.0	75.0	24000.0	240.0
Area 3	30.0	4.0	75.0	9000.0	67.5
Sum Area	250.0				790.5

Draught = 5.00 m Displ. 13667.0 T Required GZ = 0.098 m
Draught = 5.50 m Displ. 15434.0 T Required GZ = 0.091 m
Draught = 6.20 m Displ. 18107.0 T Required GZ = 0.084 m

The above calculations were made for the case of launching of survival crafts in one side of the vessel.

It should be noted that the vessel is supplied with two Marine Evacuation Systems (RDF Ltd) for both, Port and Starboard side, each consisting of dual track evacuation slide, embarkation (landing) platform and 14 liferafts (RDF Ltd), for 50 persons each.

Taking into account the greater of the above heeling moments, the results of calculation of the righting arms are presented in Table 4.

Table 4. Summary of additional heeling levers

Lever due to the wind pressure at draught = 5.0 m 0.088 m
Lever due to the wind pressure at draught = 5.5 m 0.081 m
Lever due to the wind pressure at draught = 6.2 m 0.074 m
Lever due to crowding of passengers at draught = 5.0 m 0.098 m
Lever due to crowding of passengers at draught = 5.5 m 0.091 m
Lever due to crowding of passengers at draught = 6.2 m 0.084 m
Lever due to launching of survival crafts at draught = 5.0 m 0.049m
Lever due to launching of survival crafts at draught = 5.5 m 0.048 m
Lever due to launching of survival crafts at draught = 6.2 m 0.046 m

4 STABILITY CALCULATIONS

In order to improve the ship safety during the sea voyage, the stability calculations are computerized, getting loading dependent issues, such as results of intact stability, longitudinal strength, and damage stability. Some stability calculations for the presented vessel are described below.

4.1 *Loading conditions for stability calculations*

The selected loading condition for stability calculations are shown in Table 5.

Table 5. Loading conditions

FRESH WATER

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
FW30 STORAGE TK. SB	1,000	33,90	33,9	0,93	33,76	1,69	0
FW40 TECHN./BOILER WATER PS	1,000	2,10	2,1	5,61	37,50	-8,15	0
FW44 FOG SPRINKLER SYSTEM	1,000	0,00	0,0	0,00	0,00	0,00	0
TOTAL		36,0		1,20	33,98	1,12	352

HEAVY FUEL OIL

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
HFO12 DAY TK. PS	0,960	28,90	30,1	3,57	76,25	-1,48	0
HFO13 SETTL. TK. SB	0,960	28,90	30,1	3,57	76,25	1,48	0
TOTAL		57,8		3,57	76,25	-0,00	246

STAB-HEELING

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
ST06 STABILIZING TANK	1,000	693,40	693,4	2,55	90,63	0,00	7864
ST07S ANTI HEEL TANK SB	1,000	195,00	195,0	2,28	74,91	12,39	33
ST07P ANTI HEEL TANK PS	1,000	177,00	177,0	2,09	74,90	-12,36	33
ST08 STABILIZING TK.	1,000	875,60	875,6	2,55	75,04	0,00	10009

DIESEL OIL

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
MDO14 DAY TANK	0,860	21,30	24,8	3,75	64,95	-9,67	0
TOTAL		21,3		3,75	64,95	-9,67	1828

SEWAGE

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
MI04 SEWAGE GREY WATER PS	1,000	40,00	40,0	2,56	116,25	-3,33	0
MI05 SEWAGE BLACK WATER SB	1,000	40,00	40,0	2,56	116,25	3,32	0
MI19 SEWAGE/VACUUM TK. PS	1,000	10,00	10,0	3,58	67,50	-7,17	0
TOTAL		90,0		2,67	110,83	-0,80	0

WATER BALLAST

TANK No.	Gamma [t/m3]	WT [t]	V [m3]	VCG [m]	LCG [m]	TCG [m]	MFS [tm]
WB01 FOREPEAK	1,016	0,00	0,0	0,00	0,00	0,00	0
WB02 DEEP TANK	1,016	0,00	0,0	0,00	0,00	0,00	0
WB15 DB TANK	1,016	427,63	420,9	0,57	75,00	0,00	0
WB31 DEEP TK.	1,016	0,00	0,0	0,00	0,00	0,00	0
WB32 DEEP TK.	1,016	288,80	284,3	3,83	14,57	0,00	686
TOTAL		716,4		1,88	50,64	0,00	686

CREW, PROVISION etc.

Description	WT [t]	Frame [-]	Frame [-]	VCG [m]	LCG [m]	TCG [m]
Railwagons Lane 1	0,0	-8	202	10,55	60,30	-10,50
Railwagons Lane 2	0,0	51	230	10,55	85,30	-6,95
Railwagons Lane 3	0,0	-3	241	10,55	74,40	-3,15
Railwagons Lane 4	0,0	39	241	10,55	84,70	3,15
Railwagons Lane 5	0,0	78	230	10,55	93,80	6,95
Railwagons Lane 6	0,0	-8	202	10,55	60,30	10,50
Trailers on main dk	1645,0	0	241	10,60	78,00	0,00
Lorries on upper dk	0,0	-2	243	16,15	80,00	0,00
Trailers on upper dk fwd	1100,0	-2	243	16,15	55,00	0,00
Cars on upper dk fwd	130,0	155	244	15,00	125,00	0,00
Cars on hinged dk	90,0	166	244	17,50	126,00	0,00
Provision&store	10,0	170	180	24,50	109,40	0,00
Spare parts etc	20,0	81	91	6,50	53,50	0,00
Lub&sludge etc.	25,0	81	91	0,85	53,50	0,00
Crew	5,0	26	242	30,00	94,40	0,00
Drivers	0,0	26	242	23,00	87,50	0,00
Passengers	70,0	26	242	23,00	87,50	0,00
Deck 3	0,0	-8	241	10,55	75,00	-0,17
Deck 4	0,0	-8	243	16,15	85,00	0,00
Deck 5	0,0	166	244	17,50	126,00	0,00
TOTAL	3095,0			13,21	73,18	0,00

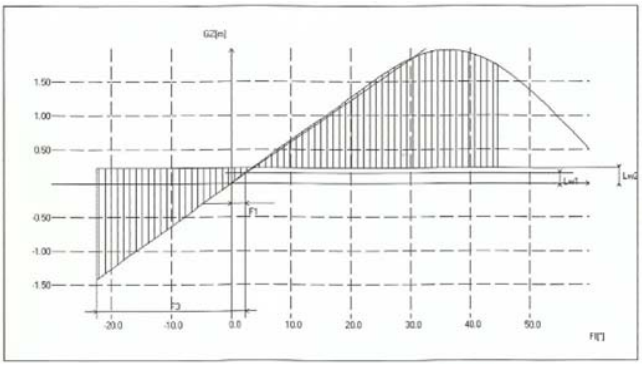
TOTAL DEADWEIGHT

Description	WT [t]	VCG [m]	LCG [m]	TCG [m]
Liquids in Tanks	2862,5	2,35	73,25	0,00
Vehicles	0,0			
Crew, Provision etc.	3095,0	13,21	73,18	0,00
TOTAL	5957,5	7,99	73,22	-0,00

CASE: 07 LOAD-10

Description	WT [t]	VCG [m]	LCG [m]	TCG [m]
Light Ship	11252,0	12,50	76,64	0,01
Total Deadweight	5957,5	7,99	73,22	0,00
TOTAL	17209,5	10,94	75,45	0,00

4.2 *The results of stability calculations*



Fi	5	10	20	30	40	50	60	70
GZ	0.318	0.637	1.264	1.844	1.926	1.378	0.491	-0.598

Figure 3. The righting levers curve.

Stability Criteria	Actual	Required
GZmax value	GZmax = 1.97 m	0.20 m
GZmax angle	Fi = 36.25°	30.00°
Metacentric height corr.	GMc = 3.51 m	2.98 m
Area under GZ up to 30°	A30° = 0.493 mrad	0.055mrad
Area under GZ up to 40°	A40° = 0.835 mrad	0.090mrad
Area between 30°-40°	A30°-40°=0.342mrad	0.030mrad
Angle of heel due to crowding of passengers	Ap = 0.93°	10.00°
Angle of heel due to turning	At = 3.17°	10.00°
IMO Weather Criterion	K = 2.198	1.00
Heeling lever of lateral wind force	Lw1 =0.148 m	
Angle of roll to windward due to wind action	F1 = 24.74°	
Angle of downflooding	FiD = 44.6°	
List	Fi = 0.1°	

5 DAMAGE STABILITY CALCULATIONS

For the loading conditions described in section 4, two damage situations has been simulated. First of them concerns the flooding of dry spaces and water ballast tank in fore part of the double bottom and section below the main deck of the vessel: dry space (SP01) in double bottom, deep tank (WB02) and dry space (SP03).

The double bottom compartments layout is shown in Fig. 3. The water ballast tanks are marked green colour, dry spaces are white, fuel and oil tanks are red and grey, and fresh water tanks are blue.

The results of calculations the hypothetical cases of damage some of double bottom compartments are presented in this paper.

The results has been obtained by use of the vessel's stability calculation software.

5.1 *Case of damage in fore part of the vessel*

In this case only 3 compartments in fore part of the vessel has been damaged. The vessel in this state has a good stability and will float in equilibrium position. The damage stability complies with criteria of SOLAS'90 and STOCKHOLM Agreement.

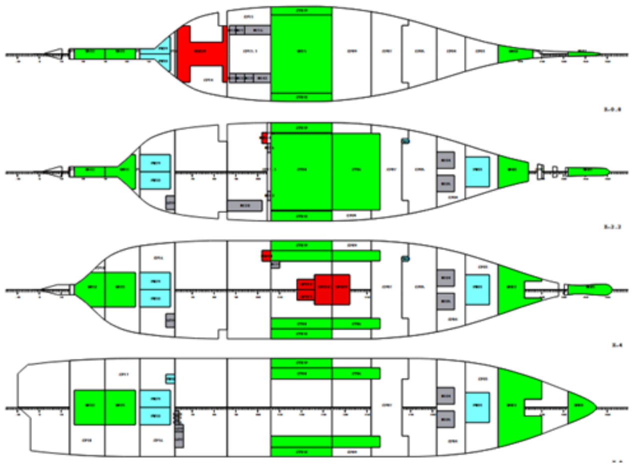


Figure 4. The ship compartments layout [7]

The ship's compartments to be damaged as per case 5.1, are presented in Fig. 5.

The results of stability calculations for damage case 5.1, are presented in Table 5. When the water will be on the train deck, the stability results correspond also with criteria of SOLAS '90 and STOCKHOLM Agreement.

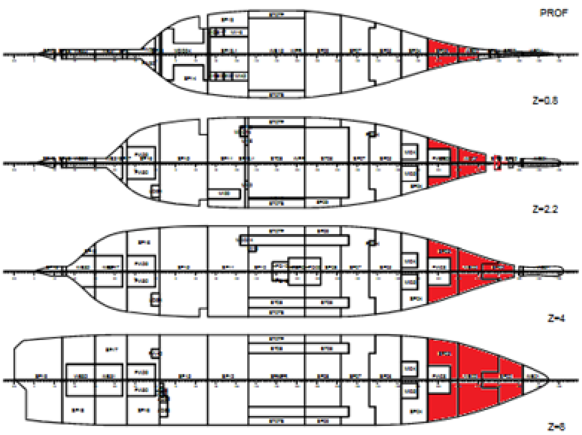
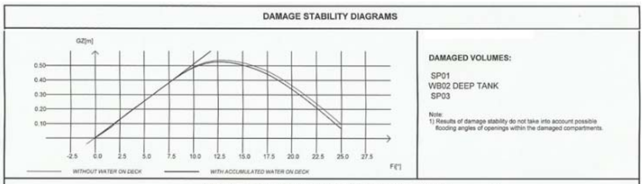


Figure 5. Horizontal section of flooded compartments Case 5.1

The results of stability calculations for damage case 5.1, are presented in Table 5.

Metacentric heigh GMc = 2.9 m.
GZ max = 0.54 m with no water on the train deck, but with water on the train deck
GZ max = 0.53 m.
The Freeboard = 1.19 m.

Table 5. Stability data for case 5.1



RESULTS OF CALCULATIONS: NO WATER ON DECK/ WITH WATER ON DECK

Tm = 6.41/6.41 [m]	Ta = 5.36/5.36 [m]	Tf = 7.46/7.46 [m]	t = 2.10/2.10 [m]	GM = 2.90/2.90 [m]	Flo = -0.08/-0.08 [°]	hw = 0.03 [m]
Fb = 1.19/1.19 [m]	Xfr = 121.9/121.9 [m]		Flr = 25.1/25.0 [°]	A = 0.151/0.144 [mr]	GZn= 0.539/0.528 [m]	

Fi[°]	-2.5	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	25.0	
NO WATER ON DECK												
GZ[m]	-0.122	0.004	0.130	0.257	0.384	0.491	0.538	0.521	0.463	0.364	0.096	
WITH WATER ON DECK												
GZ[m]	0.000	0.000	0.130	0.257	0.384	0.487	0.528	0.505	0.442	0.339	0.065	
Pw[t]	0.0	0.0	0.8	0.1	0.4	5.6	13.3	21.3	28.2	33.8	41.6	
Yw[m]/Zw[m]	0.00/0.00	0.00/0.00	9.03/8.63	13.26/9.05	12.92/8.70	11.34/8.94	10.94/9.18	10.27/9.24	9.82/9.76	9.39/10.09	8.59/10.82	

5.2 *Case of damage in the middle sections of the vessel*

This case corresponds the flooding of dry spaces in the midship's part of the double bottom of the vessel : SP 13, SP 14, SP 15 and SP 11-12.

Case of vessel's damage, presented in point 5.2 corresponds the situation of the stability loss when the water is accumulated on Ro – Ro deck. The damaged volumes of the vessel are located in the double bottom and below of the main deck of the midships are shown in Fig. 6.

With no water on the Ro – Ro deck the vessel has a small stability margin, but she will float in equilibrium position. The stability is however not sufficient to comply with criteria of SOLAS'90.

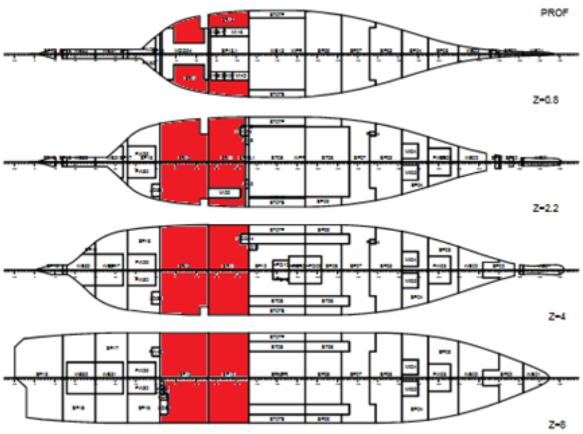
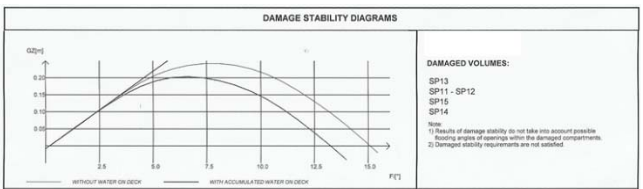


Figure 6. Horizontal section of flooded compartments Case 5.2

Table 6. Stability data for case 5.2



RESULTS OF CALCULATIONS: NO WATER ON DECK/ WITH WATER ON DECK

Tm = 6.93/6.93 [m]	Ta = 7.94/7.94 [m]	Tf = 5.93/5.93 [m]	t = -2.00/-2.00 [m]	GM = 2.61/2.61 [m]	Flo = 0.18/0.18 [°]	hw = 0.13 [m]
Fb = 0.64/0.64 [m]	Xfr = -2.5/-2.5 [m]		Flr = 14.9/13.1 [°]	A = 0.040/0.030 [mr]	GZn= 0.242/0.203 [m]	

Fi[°]	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	25.0		
NO WATER ON DECK												
GZ[m]	-0.008	0.105	0.205	0.243	0.218	0.131	0.006	-0.143	-0.305	-0.663		
WITH WATER ON DECK												
GZ[m]	-0.008	0.105	0.189	0.199	0.147	0.039	-0.101	-0.263	-0.436	-0.788		
Pw[t]	18.1	0.9	21.3	61.5	102.3	135.7	159.7	180.3	194.6	193.3		
Yw[m]/Zw[m]	0.00/8.69	12.47/8.68	11.60/8.84	10.61/9.09	9.90/9.37	9.26/9.69	8.69/10.06	8.26/10.44	7.92/10.83	6.59/11.25		

6 CONCLUSIONS

Results of stability and damage stability calculations, presented in this paper are getting knowledge of practice in simplified stability information for the master. It's a very important element of safety management on the Ro -Ro Vessel.

Author of the paper, having the practice as the master of M/F "Polonia", is also experienced that absolute safety doesn't exist, and a large number of safety measures are difficult to execute.

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 a vessel sinks or staying afloat.

The case 5.1, regarding to the damage of the forespaces of the vessel, is testifying that the vessel is staying afloat, even if 40 tons of sea water is flooding the main deck.

The case 5.2 corresponds to the sinking of the vessel due to the damage of four spaces in the midship. The 190 tons of the sea water is coming to flood the main, open un-subdivided deck.

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 (1997).

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