Ro-ro Passenger Vessels Survivability - a study of three different hull forms considering different Ro-ro-deck subdivisions.

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Synopsis:

Based on the newly defined Stockholm Agreement's water on deck criteria model tests where carried out aiming at a better understanding of the critical water height on the ro-ro deck.

For this purpose three differently aged vessel types with respectively different operating freeboards have been included in this study. The results achieved are shown and discussed.

1. Background

Legislative Activities have finally calmed down that had been pushed forward by the tragic losses of ro-ro passenger the most recent of which had been the Estonia. The drastic measures newly required are being put into place now. Once they will be completely in place, time will proof their effectiveness.

Legislative tools dedicated to ro-ro passenger vessels cover other than a set of 1995 SOLAS Amendments, IMO Resolutions requiring the upgrading of shell doors scantlings and their securing as well as a Regional Agreement on a specific damage stability standard applicable to ships travelling in the North and Baltic Seas.

With regard to damage survivability it should be noted that the amended SOLAS [1] requirements and the Regional agreement [2] enforce an increase in standard that will become mandatory to both new and existing passenger vessels. One of the newly installed criteria is a survivability standard that requires to show sufficient residual stability even with accumulating water on the damaged ro-ro deck. The respective legislation does allow to chose showing compliance with this standard either by calculation or by model tests. In both cases the regional agreement does give detailed procedures which are to be complied with.

The scope of this research project (sponsored by BMBF[1]) was to find a better understanding of the critical amount of water on deck relative to the existing trading practice and eventual upgrading of the ship types. Thus three existing hull forms that had been built in accordance with different subdivision and survivability standards due to their individual keel laying and or reconstruction dates were chosen as sample ships. It was anticipated that some kind of subdivision of the ro-ro deck would become necessary during the course of the proposed upgrading and the effect of such subdivision on the survivability of these hull forms was to be studied.

2. Hydrostatic Evaluation of the Sample Ships

Today's subdivision standard is based on the SOLAS 1974 requirement that has been considerably amended after 1988. Up to 1988 for any passenger ship compliance had to proven with existing intact stability criteria the requirement of floodable lengths and certain damage stability criteria. Usually the damage stability requirements would be the crucial criteria and the designs freeboard. Both the intact stability criteria and the floodable length requirement have not been reconsidered while the damage stability criteria had been amended by a requirement of a residual stability standard. As usual this new standard became applicable to new ships and showed a remarkable influence on the designs.

Ro-ro passenger ferries operating in the Baltic and North sea areas are required to comply with a survivability standard that includes the flooding of the ro-ro (bulkhead) deck. The requirement is that acceptable residual stability standards are to be maintained even with a certain flooding height $(h_W \leq 0.5m)$. Compliance with this standard can either shown by model testing or calculation.

Technically, two different survivability standards for new and existing ro-ro passenger ferries can not be justified. Consequently the amended standard became mandatory also to existing vessels.

The vessels chosen for this project are considered to be typical representatives of the kind used in this area:

1. Ship A

   This ship was built in accordance with SOLAS 74/83 standard. Her subdivision below the

[1] German Ministry for Research and Technology

bulkhead deck consists of a relative high number of transverse bulkheads combined with some longitudinal subdivision. The operating freeboard is minimised by making use of cross flooding that decrease or eliminate heeling angles in damaged condition. In this case the criteria of non-submerging the margin was the governing criteria as residual stability standards had not been imposed.

2. Ship B

   Although this ship had been built prior to ship A, with regard to survivability standards she presents a later design standard since she was completely re-built when entering a different service after the 1988 SOLAS amendments came into force. With this conversion in accordance with SOLAS 74/88 she features a very similar subdivision below the bulkhead deck, the operating freeboard was remarkably increased due to the requirement of a minimum heeling lever curve in damaged condition.

3. Ship C

   This vessel was only designed when the new standard had already been established. Her subdivision below the bulkhead deck is governed by longitudinal bulkheads located at B/5 measured from the shell. Not all of these are equipped with cross flooding ducts. Respectively heeling angles in the damaged water lines are not eliminated although they are legally limited.

The main dimensions of the vessels and some general remarks regarding the damage stability calculations are:

Main Dimensions:	Ship A	Ship B	Ship C
length L_s [m]	151.46	177.21	179.5
beam B [m]	29.00	26.00	27.2
height D [m]	8.10 /16.20	8.0 /	8.7 /
draught t [m]	6.40/ 6.20 / 5.90	5.75	6.0
trim [m]	0.0	-1.0 /0.0 / +1.0	-1.0 /0.0 / +1.0
modelled damaged Compartments	9/10 and 11/12	7/8 and 11/12	6/7 and 10/11

All three vessels are narrow and evenly subdivided below the bulkhead deck [figures 1]. All three ships had in their original configuration non watertight divided ro-ro decks.

Each one was subjected to a SOLAS 90 damage stability calculation in order to establish a governing double compartment that was taken into account regarding the "water on deck" criteria.

The Stockholm agreement requires that unless the governing criteria is located within 10% of the mid-length a second double compartment located within this margin has to be demonstrated. Taking this into account the models of all three vessels were built to cover two SOLAS damages over the length. Where the crucial condition turned out to be within the a.m. mid length part the second damage was chosen to be near the vessels shoulder.

For vessels B and C, where the operating freeboard was considered rather large, it was understood that further increase of freeboard would only effect the survivability to become more favourable by allowing for less GM_0 values. In those cases the introduction of trim was considered to be of more interest.

Generally, for all three vessels three different ro-ro deck versions were investigated. Starting point was

Version A the open deck configuration.

In the course of this project. By calculation a variety of different deck subdivision alternatives were considered. Within the scope of this project only two further versions could be expanded on in model testing:

Version E2 with 2 full height bulkheads in transverse ship direction and

Version F with side casings.

In terms of compliance with "SOLAS 90" standard, in the damage stability investigation the side casing version was the version that seemed to best cope with the criteria.

Summarising the scope the research project covered variations of damage location, subdivision on the ro-ro deck and GM as well as draughts and trims respectively.

	Ship A			Ship B			Ship C		
	draught variations			trim variations			trim variations		
	6.4 m	6.2 m	5.9 m	-1.0 m	0.0 m	+1.0 m	-1.0 m	0.0 m	+1.0
GM variations	X	X	X	X	X	X	X	X	X
Sea State realisations	X	X	X	X	X	X	X	X	X

3. Model testing

Within the model tests the model is subjected to a long-crested irregular seaway. The damaged model is free to drift and is placed in beam seas with the damage hole facing the oncoming waves.

The survival criteria in these model tests are such that at least five experiments for each peak period need to be carried out. The test duration shall be such that a stationary state has been reached and a minimum of 30 min. in full scale time are proven. The model is considered to survive when the angles of roll do not reach more than 30° against a vertical axis occurring more frequently than 20%

of the rolling cycles or the steady heeling angle becomes greater than 20°.

To cover the scope of these tests the model has to be such that the hull is thin enough in the damaged areas and the main design features such as watertight bulkheads, air escapes permeabilities and etc. above and below the bulkhead deck can be modelled to represent the real situation.

Each of the models used in this project was built accordingly in GRP and the interior for two damage locations was mostly built of ply wood in suitable size. These two damage locations were chosen in accordance with the SOLAS damage stability as described above. The damage holes were opened successively. Each one sized in accordance with the SOLAS damage and a penetration depth of B/5. Both of the damage locations per ship were subjected to draught or trim variations and to address the critical wave height the GM_L was continuously decreased in order to find the boarder line between safe and capsizing.

This borderline is of course subject to uncertainties that are usually involved in methods that include statistics. The results cover for each tested GM_L the observation survived/ not survived. This statement of result does not cover the residual margin that might exist versus an exact limiting condition on the edge of capsizing. For this reason it would be necessary to evaluate many more runs in testing such capsizing margins to finally achieve the answer to a question of critical "water on deck"-height.

4. Computer Simulations

The scope of this investigation covered also a computer simulation of the relative motions of the damaged ro-ro passenger vessels in the seaway. The software utilised in this respect is based on methodologies developed at the Institut für Schiffbau, Hamburg. (Kröger [3] and Petey [4]) which was expanded and adapted to such model tests by Chang [5]

As an example table 4 and 5 cover the results of simulations for ship A, tables 6 and 7 ship B and tables 8 and 9 ship C respectively. The simulation confirm the outcome of the model testing.

In order to get an improved understanding of the boarder line between safe and unsafe in this context the simulations covered the same scope of GM variations, only in much smaller steps.

5. Conclusions

The realisation of the seaway and the accumulated water on deck is shown in figures2 and 3. Due to the a.m. uncertainties the measured accumulated water heights can not be considered representing the critical water height on deck. The scheme of water height measurements are shown in figures 3a.

Figure 2 shows a typical time history of a capsizing. Obviously, the identification of the "critical" water height on deck is judgmental.

In order to produce a better understanding of such critical height of water and in conjunction with earlier survivability test made at the HSVA model basin, it is proposed that the residual stability lever curve is employed to help judge the residual stability margin. It is proposed that the residual area of the heeling lever curve of the respective damage case beyond the measured heeling and rolling angle is used to represent survivability borders. (figure 4)

With regard to improving safety of such existing vessels, and in order to limit the necessary increase in GM to a practicable margin further subdivision versions on the ro-ro deck were investigated. As described above three versions per ship were tested.

As an example the scope of the tested configurations is shown in the following table:

Initial draught	Original configuration Version A		With additional bulkheads Version E2		With side casings Version F	
	L 11/12 GM_L	L9/10 GM_L	L 11/12 GM_L	L9/10 GM_L	L 11/12 GM_L	L9/10 GM_L
6.4 m	-	4.2 m	-	2.3 m	-	2.4 m
6.2 m	3.5 m	4.2 m	1.3 m	2.0 m	1.8 m	2.4 m
5.9 m	2.6 m	3.2 m	1.4 m	1.7 m	1.6 m	1.9 m

The conclusion to be drawn from such result can be summarised as follows:

- the increase in freeboard effects a drastic decrease in GM requirement of the damage case.
- For this vessel not built in accordance with "SOLAS 90" standard the requirement in GM in the original configuration becomes impracticably high.
- Any subdivision introduced on the ro-ro deck significantly influences the survivability of the vessel in damaged condition.
- Other than the calculation the test show better results by the introduction of the proposed two full height bulkheads.

A graphical evaluation of the maximum allowable KG-values are shown in figure 5, 6 and 7.

In case of ship B and ship C the freeboard effect was not considered of the same predominance. A result of the trim variations, however is that obviously small trim angles do have some effect on the GM-requirement.

This is shown for ship B:

Initial trim	Original configuration Version A		With additional bulkheads Version E2		With side casings Version F	
	L 11/12 GM_L	L 7/8 GM_L	L 11/12 GM_L	L 7/8 GM_L	L 11/12 GM_L	L 7/8 GM_L
-1.0 m	2.73 m	-	0.78 m	-	1.54 m	-
0.0 m	2.30 m	1.13 m	1.11 m	1.21 m	1.19 m	1.29 m
1.0 m	-	1.37 m	-	0.96 m	-	1.60 m

The evaluation of Ship C had the following outcome:

Initial trim	Original configuration Version A		With additional bulkheads Version E2		With side casings Version F	
	L 10/11 GM_L	L 6/7 GM_L	L 10/11 GM_L	L 6/7 GM_L	L 10/11 GM_L	L 6/7 GM_L
1.06 m	0.71 m	1.92 m	0.54 m	-	1.11 m	-
0.0 m	1.02 m	1.94 m	1.07 m	1. 24 m	1.20 m	1.83 m
-1.07 m	-	2.10 m	-	1.29 m	-	2.00 m

An overview of the survivability results are shown in table 1, table 2 and table 3

The ship motion, the relative motion between the damage opening and the water surface and the water height on deck were measured during the tests. The most important information is the roll-response which indicates whether or not the vessels is regarded as capsizing or not. Figures 3a show as a section of the measured time and water height records such a typical capsizing. Encountering a group of high waves the vessel is forced to heel to a rather large angle by the load introduced by the collected water on deck. In the following calmer period the vessels recovers very slowly to a more upright position. Another group of larger waves approaching again increases the heeling continuously to lead to the eventually observed capsize. Provided the initial GM is slightly larger the vessel shows better recovering times before encountering the next group of high waves.

Once the critical KG/GM values had been generated as describing the limit between safe and unsafe, the residual stability parameters were calculated. Accordingly the respective maximum lever arms and stability ranges were derived.

The results indicate clearly that the "open deck" Version iterates a larger requirement of residual stability. Both of the subdivided Versions (side casings and two transverse bulkheads), however, showed requirements in a similar order.

Based on the known dependency of the stability parameters on B/T and the observation that the deck area involved (i.e. length and beam of the wetted ro-ro cargo area) and trim have large impact. Therefore, it is proposed to use these geometric features to describe the residual stability characteristic.

$$GZ^* = GZ_{MAX} * \frac{T}{B} * \frac{1}{(1.368 - \exp(-(A_{RO}/bL)^2)) * (0.2 + \exp(-(57.3 * \Delta T/L)^2))}$$

$$F_b^* = (F_b + B/2 * \sin\Phi_{Stat}) / \varsigma_{\omega sig}$$

For Version A all three hulls are shown in figure 4a versus the freeboard.

6. Nomenclature

A_{RO}	flooded area on RoRodeck
B	beam
b	breadth of the damaged compartment on deck
D	height up to freeboarddeck
dT	initial trim (undamaged)
ΔT	trim in damaged condition
E	area under the righting lever arm curve
F_b	residual freeboard at damage location
GM_o	metacentric height in the initial condition
GM_L	metacentric height in damaged condition
GZ	righting lever
L_{pp}	length between perpendiculars
T	draught
T_p	wave period
V	buoyant volume
$\zeta_{\omega\ sig}$	significant wave elevation
ϕ	heeling angle

7. References

[1] The International Convention for the Safety of Life at Sea (SOLAS) 1974 including all relevant amendments

[2] Regional Agreement concerning specific stability requirements for ro-ro passenger ships ("Stockholm Agreement") published as IMO Circ. Letter 1891 dated 29th April 1996.

[3] Kröger, H.P., Rollsimulation von Schiffen, Schiffstechnik 33 (1986)

[4] Petey, F., Ermittlung der Kentersicherheit lecker Schiffe im Seegang, Schiffstechnik 35 (1988), 155-172

[5] Chang Bor-Chau, On the capsizing safety of damaged ro-ro ships by means of motion simulation in waves, Int. Symposium Ship Safety in a Seaway: Stability, Manoeuverability, Nonlinear Approach, Kaliningrad 1995

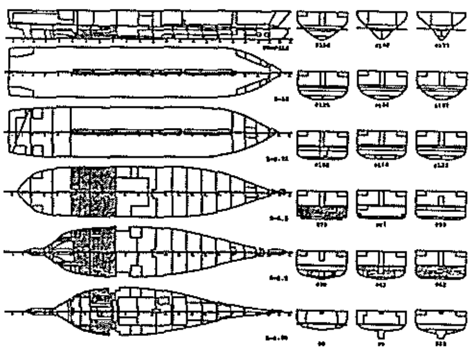

Figure 1A: Subdivision of Ship A Version A Damage Case 11/12

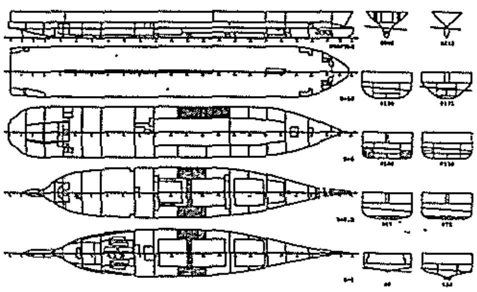

Figure 1B: Subdivision of Ship B Version A Damage Case 7/8

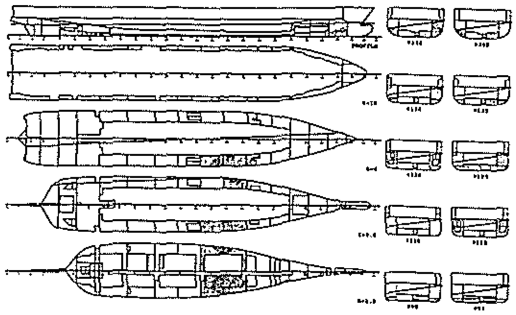

Figure 1 C: Subdivision of Ship C Version A Damage Case 6/7

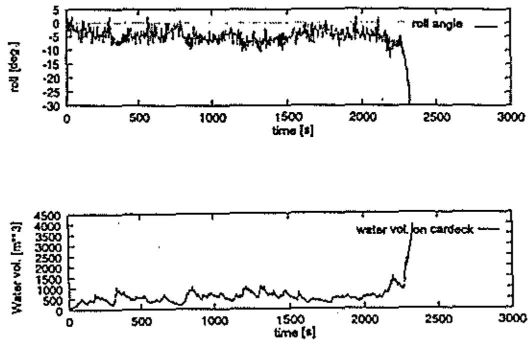

Figure 2: Typical Capsize Scenario

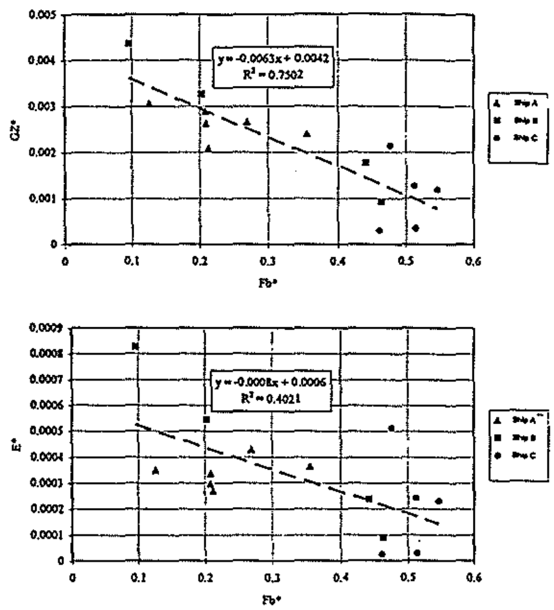

Figure 4a: Standardised maximum lever arm and area curves demonstrated as a function of freeboard

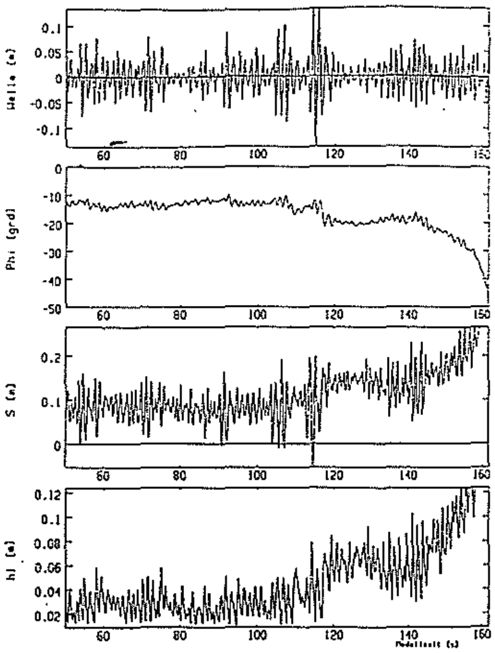

Figure 3a.1: Section of time records measured for a capsizing situation

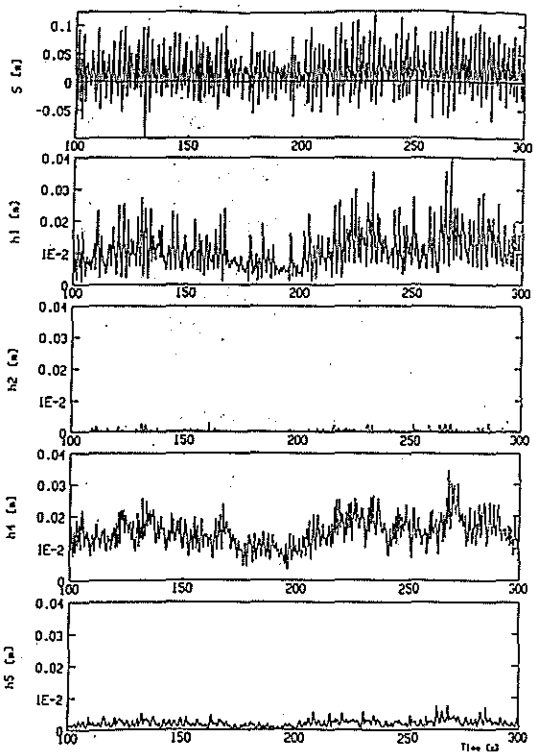

Figure 3a.2: Section of time records of water height

Table 4: Number of tests resp. simulation runs N and number of observed capsizing incidents N_c Ship A; damage case 9/10; no trim

initial draught T [m]	damage GM_L	Test N	Test N_c	Simulation N	Simulation N_c	Test N	Test N_c	Simulation N	Simulation N_c
	Open deck				(Version A)				
5.9	3.83	2	-	2	-	-	-	4	-
	3.45	2	-	2	-	-	-	4	-
	3.25	2	-	8	-	-	-	8	-
	3.22	-	-	4	1	-	-	4	1
	3.17	-	-	8	1	-	-	4	2
	3.12	-	-	4	1	-	-	8	4
	3.06	1	1	8	1	-	-	8	5
	3.02	-	-	4	2	-	-	-	-
6.2	4.44	2	-	2	-	-	-	4	-
	4.14	-	-	8	-	-	-	8	-
	4.09	2	1	8	2	-	-	4	2
	4.05	-	-	8	3	-	-	8	2
	4.00	-	-	4	1	-	-	4	2
	3.95	1	1	4	1	-	-	4	2
	3.73	1	1	4	4	-	-	4	4
6.4	4.50	-	-	8	-	-	-	-	-
	4.45	-	-	8	1	-	-	8	-
	4.40	-	-	-	-	-	-	4	4
	4.31	2	-	4	4	-	-	4	4
	4.10	1	1	4	4	-	-	4	4
	3.60	1	1	4	4	-	-	4	4
	3.03	1	1	4	4	-	-	4	4
	Side casings				(Version F)				
5.9	2.52	2	-	4	-	-	-	4	-
	2.17	2	-	4	-	-	-	4	-
	1.78	2	1	4	-	-	-	8	-
	1.69	-	-	8	-	-	-	8	-
	1.64	-	-	4	2	-	-	8	-
	1.59	-	-	-	-	-	-	8	1
	1.44	-	-	4	2	-	-	-	-
6.2	2.69	2	-	4	-	-	-	4	-
	2.30	2	1	4	-	-	-	4	-
	2.20	-	-	8	-	-	-	4	-
	2.10	-	-	4	-	-	-	4	-
	2.00	-	-	8	-	-	-	8	-
	1.90	-	-	8	-	-	-	8	-
	1.85	-	-	8	1	-	-	8	1
6.4	2.82	2	-	4	-	-	-	4	-
	2.62	2	-	4	-	-	-	4	-
	2.40	2	-	4	-	-	-	4	-
	2.20	-	-	8	-	-	-	8	-
	2.10	-	-	8	-	-	-	8	-
	2.00	-	-	8	-	-	-	8	-
	1.96	-	-	8	1	-	-	8	1
	With transverse bulkheads				(Version E)				
5.9	2.04	2	-	4	-	-	-	4	-
	1.91	-	-	8	-	-	-	8	-
	1.86	-	-	8	2	-	-	4	2
	1.81	-	-	4	3	-	-	4	3
	1.74	2	-	8	3	-	-	4	4
	1.70	-	-	4	3	-	-	4	4
	1.65	-	-	4	2	-	-	-	-
	1.55	1	1	4	1	-	-	4	4
	1.45	-	-	4	4	-	-	-	-
6.2	2.70	2	-	4	-	-	-	4	-
	2.37	2	-	4	-	-	-	4	-
	2.24	-	-	8	-	-	-	8	-
	2.21	-	-	4	2	-	-	4	1
	2.13	-	-	4	4*	-	-	4	4
	2.04	2	-	4	4	-	-	4	4
	1.90	1	1	4	4	-	-	4	4
6.4	2.81	2	-	4	-	-	-	4	-
	2.57	2	-	8	-	-	-	4	-
	2.46	-	-	8	-	-	-	8	-
	2.40	-	-	8	3	-	-	8	1
	2.34	2	-	4	4	-	-	4	4
	2.10	1	1	4	4	-	-	4	4

Table 5: Number of tests resp. simulation runs N and number of observed capsizing incidents N_c Ship A; damage case 11/12; no trim

initial draught T [m]	damage GM_L	Test N	Test N_c	Simulation N	Simulation N_c	Test N	Test N_c	Simulation N	Simulation N_c
	Open deck				(Version A)				
5.9	4.45	2	-	4	-	2	-	4	-
	3.24	2	-	4	-	2	-	4	-
	2.65	5	-	8	-	5	-	8	-
	2.60	-	-	8	-	-	-	-	-
	2.55	-	-	8	2	-	-	-	-
	2.49	5	1	8	4	5	-	8	-
	2.45	-	-	-	-	-	-	8	-
	2.40	-	-	-	-	-	-	8	3
6.2	3.76	2	-	4	-	-	-	4	-
	3.65	-	-	8	-	-	-	-	-
	3.60	-	-	4	1	-	-	-	-
	3.55	-	-	4	2	-	-	-	-
	3.45	-	-	4	4	-	-	-	-
	3.33	2	1	4	4	-	-	8	-
	3.30	-	-	-	-	-	-	4	3
	2.48	1	1	4	4	-	-	4	4
	Open deck 1° additional heeling towards the waves				(Version A)				
5.9	3.24	2	-	4	-	2	-	4	-
	2.95	-	-	8	-	-	-	-	-
	2.90	-	-	8	2	-	-	-	-
	2.85	2	1	4	1	2	-	8	-
	2.80	-	-	-	-	-	-	8	-
	2.75	-	-	-	-	-	-	8	1
	Side casings				(Version F)				
5.9	1.93	2	-	4	-	-	-	4	-
	1.67	-	-	8	-	-	-	-	-
	1.62	2	-	4	3	-	-	8	-
	1.57	-	-	-	-	-	-	8	2
	1.48	2	1	4	3	-	-	4	2
6.2	2.42	-	-	4	-	-	-	-	-
	2.22	-	-	8	-	-	-	-	-
	2.17	-	-	4	3	-	-	8	-
	2.12	2	-	4	4	-	-	4	2
	1.83	2	-	4	4	-	-	4	4
	1.40	-	-	4	4	-	-	-	-
	With transverse bulkheads				(Version E)				
5.9	2.32	2	-	4	-	-	-	4	-
	1.94	2	-	4	-	-	-	4	-
	1.56	2	-	4	-	-	-	4	-
	1.45	2	-	4	-	-	-	4	-
	1.39	-	-	8	-	-	-	-	-
	1.34	-	-	8	-	-	-	8	-
	1.29	-	-	8	1	-	-	8	-
	1.24	-	-	-	-	-	-	4	2
6.2	1.66	2	-	4	-	-	-	4	-
	1.57	-	-	8	-	-	-	8	-
	1.52	-	-	8	2	-	-	4	2
	1.47	-	-	4	3	-	-	4	3
	1.37	2	-	4	3	-	-	4	4
	1.09	1	1	4	4	-	-	4	4

Table 6: Number of tests resp. simulation runs N and number of observed capsizing incidents N_c
Ship B; damage case 11/12; Initial draught t = 5,75m

initial trim dT [m]	damage GM_L	Test N	Test N_C	Simulation N	Simulation N_C
	Open deck			(Version A)	
0.	2.44	-	-	8	-
	2.39	-	-	8	2
	2.34	5	-	8	3
	2.26	2	2	8	8
	2.19	1	1	8	7
-1.0	3.02	2	-	8	-
	2.87	2	-	8	-
	2.77	-	-	8	-
	2.74	-	-	8	2
	2.71	2	1	8	3
	Side casings			(Version F)	
0.	1.94	2	-	8	-
	1.64	2	-	8	-
	1.44	-	-	8	-
	1.39	-	-	8	5
	1.34	2	-	8	5
	1.16	1	1	8	8
-1.0	2.47	2	-	8	-
	2.24	2	-	8	-
	2.02	2	-	8	-
	1.79	2	-	8	-
	1.67	-	-	8	-
	1.62	-	-	8	4
	1.57	2	-	8	5
	1.30	1	1	8	8
	With transverse bulkheads			(Version E)	
0.	1.77	3	-	8	-
	1.47	2	-	8	-
	1.17	2	-	8	-
	1.07	-	-	8	-
	1.02	1	1	8	1
-1.0	1.38	2	-	8	-
	1.16	2	-	8	-
	0.93	2	-	8	-
	0.83	-	-	8	-
	0.78	-	-	8	-
	0.73	2	-	8	4
	0.65	1	-	8	5

Table 7: Number of tests resp. simulation runs N and number of observed capsizing incident N_c
Ship B; damage case 7/8; initial draught t = 5,75m

initial trim dT [m]	damage GM_L	Test N	Test N_C	Simulation N	Simulation N_C
	Open deck			(Version A)	
0.	2.31	5	-	8	-
	1.72	2	-	8	-
	1.67	-	-	8	-
	1.62	-	-	8	8
	1.44	2	-	8	7
	1.38	2	-	8	8
+1.0	2.10	2	-	8	-
	1.79	2	-	8	-
	1.74	-	-	8	-
	1.69	-	-	8	-
	1.64	-	-	8	5
	1.49	1	1	8	8
	Side casings			(Version F)	
0.	2.27	2	-	8	-
	1.96	2	-	8	-
	1.77	2	-	8	-
	1.68	-	-	8	-
	1.63	-	-	8	2
	1.58	2	1	8	4
+1.0	2.27	2	-	8	-
	1.89	2	-	8	-
	1.68	-	-	8	-
	1.63	-	-	8	2
	1.58	1	1	8	7
	With transverse bulkheads			(Version E)	
0.	2.13	2	-	8	-
	1.75	2	-	8	-
	1.44	2	-	8	-
	1.29	2	-	8	-
	1.19	-	-	8	-
	1.14	-	-	8	5
+1.0	1.55	2	-	8	-
	1.31	2	-	8	-
	1.11	-	-	8	-
	1.06	-	-	8	6
	1.01	2	-	8	8

Table 8: Number of tests resp. simulation runs N and number of observed capsizing incidents N_c
Ship C; damage case 10/11; initial draught t = 6,0m

initial trim dT [m]	damage GM_L	Test N	Test N_C	Simulation N	Simulation N_C
	Open deck			(Version A)	
0.	2.16	5	-	8	-
	1.62	2	-	8	-
	1.48	-	-	8	-
	1.43	-	-	8	2
	1.33	-	-	8	3
	1.23	-	-	8	2
	1.08	2	-	8	2
	0.3	2	1	8	5
+1.04	1.53	2	-	8	-
	1.12	2	-	8	-
	0.75	-	-	8	-
	0.70	-	-	8	2
	0.11	2	-	8	4
	Side casings			(Version F)	
0.	1.90	2	-	8	-
	1.42	2	-	8	-
	1.37	-	-	8	1
	1.27	-	-	8	7
	1.17	2	2	8	7
+1.04	1.78	2	-	8	-
	1.54	2	-	8	-
	1.14	2	-	8	-
	1.09	-	-	8	-
	1.04	-	-	8	5
	With transverse bulkheads			(Version E)	
0.	2.03	2	-	8	-
	1.74	2	-	8	-
	1.35	2	-	8	-
	1.25	-	-	8	-
	1.15	-	-	8	-
	1.05	-	-	8	-
	1.00	-	-	8	-
	0.95	-	-	8	1
+1.04	1.68	2	-	8	-
	1.31	2	-	8	-
	0.56	2	-	8	-
	0.51	-	-	8	-
	0.46	-	-	8	3

Table 9: Number of tests resp. simulation runs N and number of observed capsizing incidents N_c
Ship C; damage case 6/7; Initial draught t = 6,0m

initial trim dT [m]	damage GM_L	Test N	Test N_C	Simulation N	Simulation N_C
	Open deck			(Version A)	
0.	2.49	5	-	8	-
	2.05	2	-	8	-
	1.95	-	-	8	-
	1.90	-	-	8	2
	1.77	1	1	8	2
+1.08	2.33	2	-	8	-
	2.07	2	-	8	-
	1.90	1	1	8	-
	1.78	-	-	8	-
	1.68	-	-	8	-
	1.63	-	-	8	-
	1.58	-	-	8	1
-1.07	2.47	2	-	8	-
	2.24	2	-	8	-
	2.15	-	-	8	-
	2.08	1	1	8	2
	Side casings			(Version F)	
0.	2.31	2	-	8	-
	2.12	2	-	8	-
	2.01	-	-	8	-
	1.96	2	-	8	2
	1.85	2	1	8	3
-1.07	2.29	1	-	8	-
	2.19	-	-	8	1
	2.14	-	-	8	3
	2.09	2	-	8	5
	1.95	1	1	8	6
	With transverse bulkheads			(Version E)	
0.	2.00	2	-	8	-
	1.82	2	-	8	-
	1.63	2	-	8	-
	1.43	-	-	8	-
	1.38	-	-	8	-
	1.33	-	-	8	1
-1.07	2.20	2	-	8	-
	2.00	2	-	8	-
	1.83	2	-	8	-
	1.65	2	-	8	-
	1.45	-	-	8	-
	1.40	-	-	8	-
	1.35	-	-	8	3