ANALYSIS OF THE APPLICATION OF THE NEW PROBABILISTIC DAMAGE STABILITY RULES PROPOSALS TO EXISTING CRUISE VESSEL DESIGNED FOR THE DETERMINISTIC CRITERIA, SUPPORTED BY STATIC, DYNAMIC CALCULATION AND MODEL TESTS

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ABSTRACT

SLF 46 Committee decided on September 12, 2003 to postpone the application of the revised SOLAS Chapter II-1 parts A, B and B-1 in order to allow further investigation and validation to finalize the revised SOLAS.

As far as, Italian delegation announced at SLF 46 the intention to specifically investigate on the behaviour of large passenger vessels, Fincantieri proposed to develop damage stability calculations and numerical simulations subsequently validated by model tests on selected samples of passenger vessels aiming at verify consistency and to provide guidance to fine tuning of the new IMO propose regulations. A critical analysis of “state of art” of the probabilistic approach for the damage stability calculation utilising the existing probabilistic formulae and possible alternative proposals was performed, applied to four Cruise Vessels range 68000-140000 GRT, one Ferry, one Car Carrier and one Container Ship.

Time domain simulations by "Safety at Sea" and model tests validation of the static calculation have been performed. The aim was to verify consistency and correspondence of the new regulations with the present survivability levels of these ships. The results of this work should therefore provide guidance to the IMO on the appropriate changes necessary to fine-tune the proposed regulations.

Introduction

SLF 46 Committee decided on September 12, 2003 to postpone the application of the revised SOLAS Chapter II-1 parts A, B and B-1 in order to allow further investigation and validation to finalize the revised SOLAS.

As far as, Italian delegation announced at SLF 46 the intention to specifically investigate on the behaviour of large passenger vessels, Fincantieri proposed to develop a critical analysis of “state of art” of the probabilistic approach for the damage stability calculation utilising the existing probabilistic formulae and possible alternative proposals, a series of damage stability calculations and numerical simulations subsequently validated by model tests on selected samples of passenger vessels aiming at verify consistency and to provide guidance to fine tuning of the new IMO propose regulations.

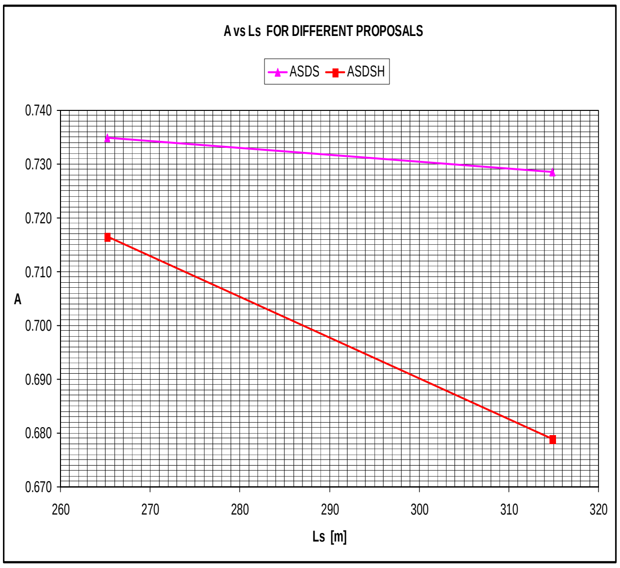
Consequently, in order to improve the knowledge on Subdivision and Damage stability matter, aiming at increase the safety of the ship, especially for the large passenger ship, a huge work of activities started, based on the following list:

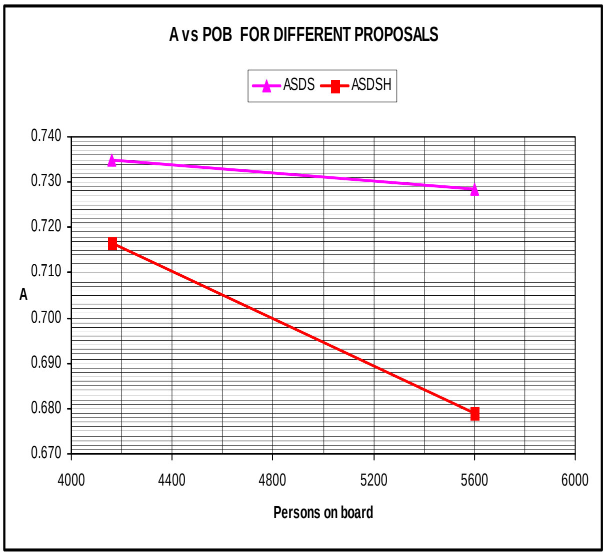
A) Application of the probabilistic formulation, developed by the IS SDS Working group (doc. SLF 47/3/1), on a series of Large Passenger Ships – evaluation of relevant impact and possible redesign.
B) Statistical analysis and formulation of the probability density function for the damage length (doc. SLF 47/3/16).
C) Application of the probabilistic formulation proposal developed by ITALY (doc. SLF 47/3/16) on a series of Large Passenger Ships – evaluation of relevant impact and possible redesign.
D) Model tank test activities to assess the survivability of the SOLAS ship in damaged condition and the consistency of the “s” factor.

A) Application of the probabilistic formulation, developed by the IS SDS Working group (doc. SLF 47/3/1), on a series of Large Passenger Ships – evaluation of relevant impact and possible redesign.

The probabilistic formulation contained in the documents 47/3/1 (developed by the Intersessional Correspondence Group) was applied on a series of Large Passenger Ships, ranging from 68000 to 140000 GT.

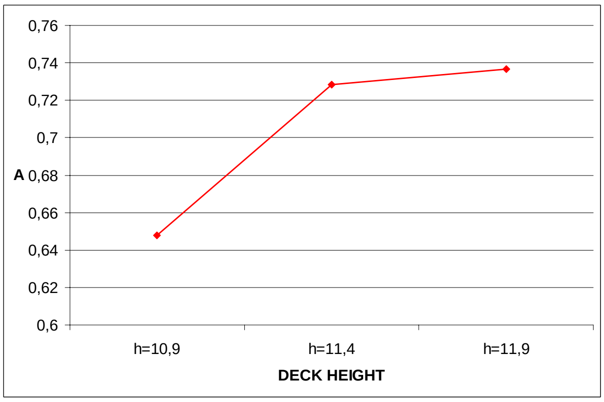
The results showed that the "A" values were significantly lower than 1, decreasing with increase of: ship length, number of persons on board and Gross Tonnage, as results from the following diagram, where is showed the calculations results, performed with the formulation suggested after the Malmoe meeting with (ASDSH) and without heeling moment (ASDS).

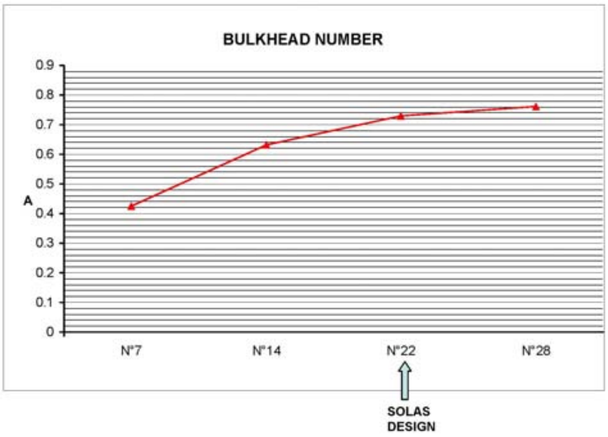




To verify how the value of "A" is influenced by the geometry of the ship, the analysis included the consequences of the bulkhead deck height variation.

Even with a significant increase of the bulkhead deck height, the resulting "A" did never exceed 0.75.





Also the variation in the number of watertight bulkheads was studied : in this case the value of "A" increase with the increase of the nr. of bulkheads, but does not increase significantly after a certain value (0.8). In the figure are showed the results varying the number of bulkhead and the results according to the SOLAS design. The two possible redesign (number of bulkheads and height of bulkheads deck) are the most effective on the possibilities of the designer.

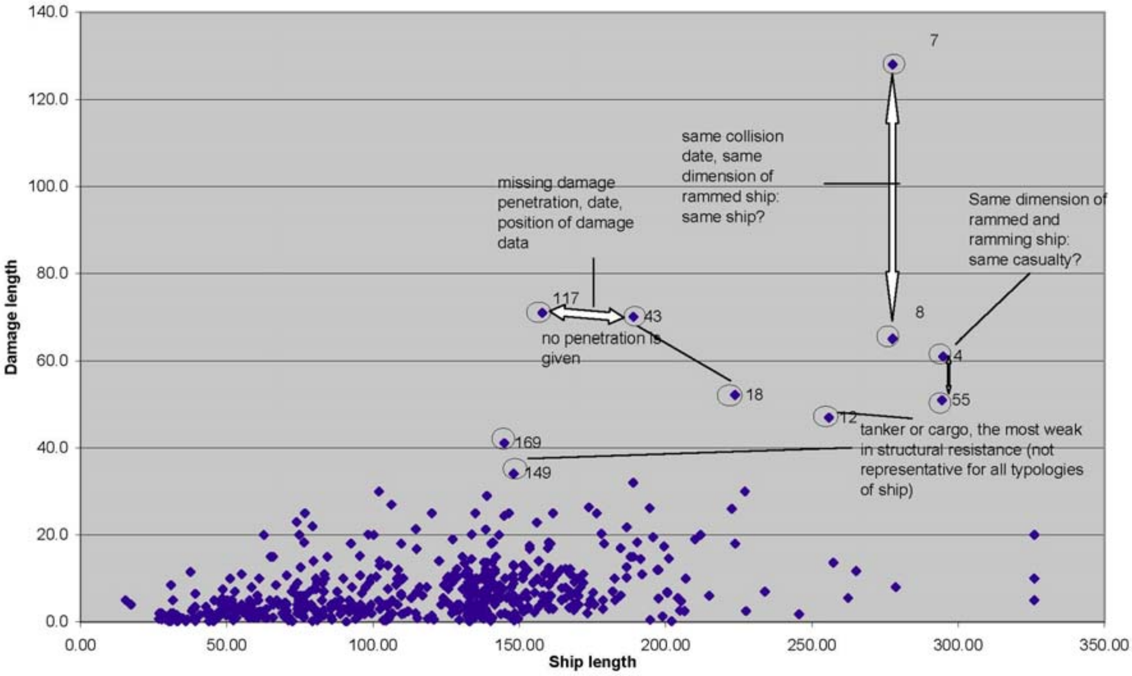
To explain and understand these results, a reanalysis of the statistic damage database was considered necessary and was performed.

B) Statistical analysis and formulation of the probability density function for the damage length (doc. SLF 47/3/16).

The collision database, as selected by the Intersessional Correspondence group on damage stability in 2004, was studied.

The analysis lead to the conclusion that the collision data for ship with length greater than 200 m are too few to derive a reliable statistic formulation.

In fact only 31 data are available from this selection and: 3 are to be disregarded because greater than 60 m, that is the maximum limit for the damage length, as agreed by the IS SDS correspondence group some other seemed not clearly reliable, but were anyhow considered.



Therefore, it was decided to subdivide the collision database in six collections:

ships length between 0 and 50 m,

ships length between 50 and 100 m,

ships length between 100 and 150 m,

ships length between 150 and 200 m,

ships length between 200 and 250 m,

ships length between 250 and 300 m,

to search a better correlation between the damage length and the length of the ship.

The mean value of the damage lengths for each ship category and the mean value of the damage length normalized with the ship length show that:

the dependence of y/L on the Ship length is not constant, as proposed by SLF 46,

y/L decreases with the ship length.

these facts are supported by many data available for ship lengths up to 200 m and could be used to confirm the trend also for ship lengths over 200 m, where the data are few.

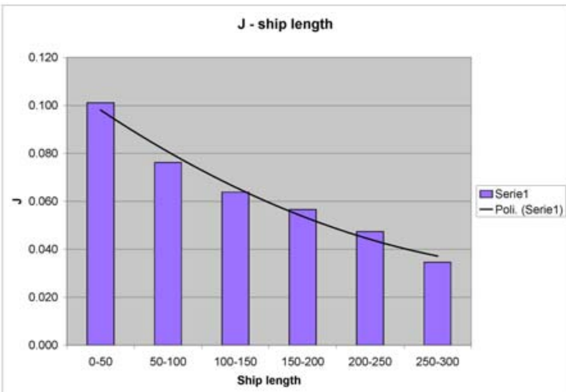
For these reasons, Italy identified a probability density function ("pdf") proposal corresponding to the following requirements:

"Pdf" mean value assuming the same mean value of the damage length for each class of ship length

More adherence of the "pdf" to the statistical data

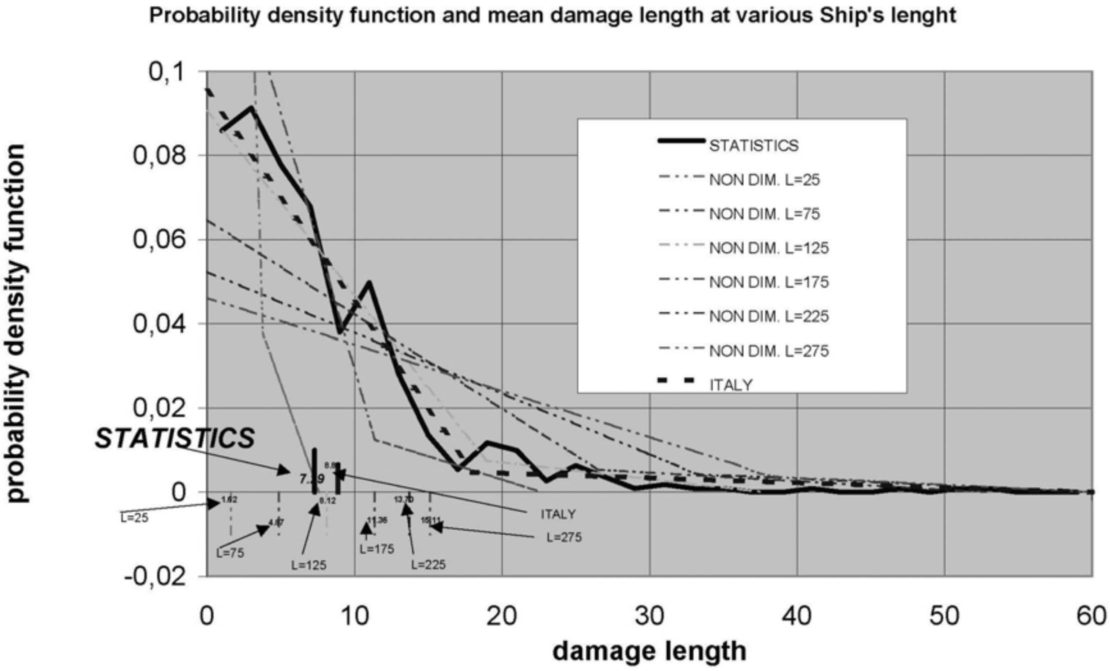
length / sh	0-50	50-100	100-150	150-200	200-250	250-300	300-350	tot.	tot. %
0-2	30	30	31	2	2	0	0	95	0.171
2-4	15	43	24	16	3	0	0	101	0.182
4-6	6	31	31	15	2	1	1	86	0.155
6-8	2	14	37	18	4	0	0	75	0.135
8-10	1	9	23	8	0	1	0	42	0.076
10-12	1	10	27	15	1	1	1	55	0.099
12-14	0	1	15	14	0	1	0	31	0.056
14-16	0	5	5	4	1	0	0	15	0.027
16-18	0	0	1	5	0	0	0	6	0.011
18-20	0	2	4	5	2	0	0	13	0.023
20-22	0	3	5	2	1	0	1	11	0.020
22-24	0	2	0	1	0	0	0	3	0.005
24-26	0	1	4	2	0	0	0	7	0.013
26-28	0	0	1	2	1	0	0	4	0.007
28-30	0	0	1	0	0	0	0	1	0.002
30-32	0	0	1	0	1	0	0	2	0.004
32-34	0	0	0	1	0	0	0	1	0.002
34-36	0	0	1	0	0	0	0	1	0.002
36-38	0	0	0	0	0	0	0	0	0.000
38-40	0	0	0	0	0	0	0	0	0.000
40-42	0	0	1	0	0	0	0	1	0.002
42-44	0	0	0	0	0	0	0	0	0.000
44-46	0	0	0	0	0	0	0	0	0.000
46-48	0	0	0	0	0	1	0	1	0.002
48-50	0	0	0	0	0	0	0	0	0.000
50-52	0	0	0	0	0	1	0	1	0.002
52-54	0	0	0	0	1	0	0	1	0.002
54-56	0	0	0	0	0	0	0	0	0.000
56-58	0	0	0	0	0	0	0	0	0.000
58-60	0	0	0	0	0	0	0	0	0.000
scartate				2		3			
tot	**55**	**151**	**212**	**110**	**19**	**6**	**3**	556.00	
media	2.527	5.715	8.264	10.109	12.895	22.667	12.333	7.71	
J	**0.101**	**0.076**	**0.066**	**0.058**	**0.057**	**0.082**	**0.038**		

								sino a 300 m
tot	**55**	**151**	**210**	**109**	**18**	**4**	**0**	547.00
media	2.527	5.715	7.981	9.899	10.667	9.500	12.333	7.29
J	**0.101**	**0.076**	**0.064**	**0.057**	**0.047**	**0.035**	**0.038**	



Ship length category	**Mean damage length**	Normalised damage length
ship between 0 e 50 m:	2,53 m	y/L = 0,101
ship between 50 e 100 m:	5,72 m	y/L = 0,076
ship between 100 e 150 m:	7,98 m	y/L = 0,064
ship between 150 e 200 m:	9,90 m	y/L = 0,057
ship between 200 e 250 m:	10,67 m	y/L = 0,047
ship between 250 e 300 m:	9,50 m	y/L = 0,035

Dependence of the normalised damage length according to the Ship length



C) Application of the probabilistic formulation proposal developed by ITALY (doc. SLF 47/3/16) on a series of Large Passenger Ships – evaluation of relevant impact and possible redesign.

		ITALY PROPOSAL				
	MAX. ATT.	ATTAINED	MAX. ATT.	ATTAINED	MAX. ATT.	ATTAINED
GRT	68000		109000		139000	
Ads						
1 ZONE	0,531570	0,531475	0,424810	0,422675	0,430020	0,427375
2 ZONE	0,365930	0,347900	0,327270	0,317350	0,338790	0,326400
3 ZONE	0,059500	0,038150	0,147530	0,129675	0,142150	0,125775
4 ZONE	0,026790	0,011600	0,049830	0,034275	0,048070	0,037100
5 ZONE	0,013080	0,002675	0,038340	0,007325	0,023430	0,012475
TOT	0,996870	0,931800	0,987780	0,911300	0,982460	0,929125

Tab.1

	SLF 47/3/1 PROPOSAL					
	MAX. ATT.	ATTAINED	MAX. ATT.	ATTAINED	MAX. ATT.	ATTAINED
GRT	68000		109000		139000	
Ads						
1 ZONE	0,358480	0,358475	0,243500	0,242400	0,21795	0,216900
2 ZONE	0,339880	0,323275	0,25083	0,242800	0,23639	0,225625
3 ZONE	0,187180	0,118275	0,176007	0,147800	0,18608	0,144425
4 ZONE	0,077750	0,033700	0,124803	0,074825	0,12446	0,085775
5 ZONE	0,029780	0,006075	0,06164	0,026175	0,10011	0,052050
TOT	0,993070	0,839800	0,856780	0,734000	0,864990	0,724775

Tab. 2

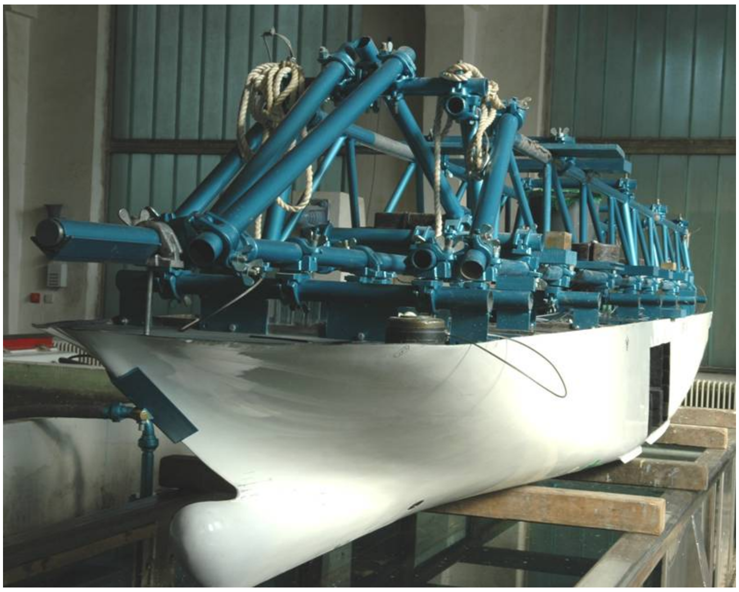
The proposed “pdf” formulation was applied and tested on three large cruise ships.
The obtained subdivision index “A” on such ships, as expected :
is higher, increases with the ship's length for the two larger ships that have a similar subdivision.
The calculated A index for the three cruise ship for the deepest subdivision draught, according to the proposal presented in this document, compared with the A index calculated according to the document SLF 47/3/1, are reported in the table 1 and 2.

The higher values coming from the proposal presented in this document, ranging from 0.9 to 0.94, may be explained considering the higher weight for the maximum attained index for the one and two zone damaged, in line with the statistic data.

In the light of the evidence given by document SLF 47/3/16, the subdivision index “A”, obtained with a more appropriate damage length distribution function, is evidencing the good safety level of the most recent cruise vessels. This is validated by the campaign of experimental tests.

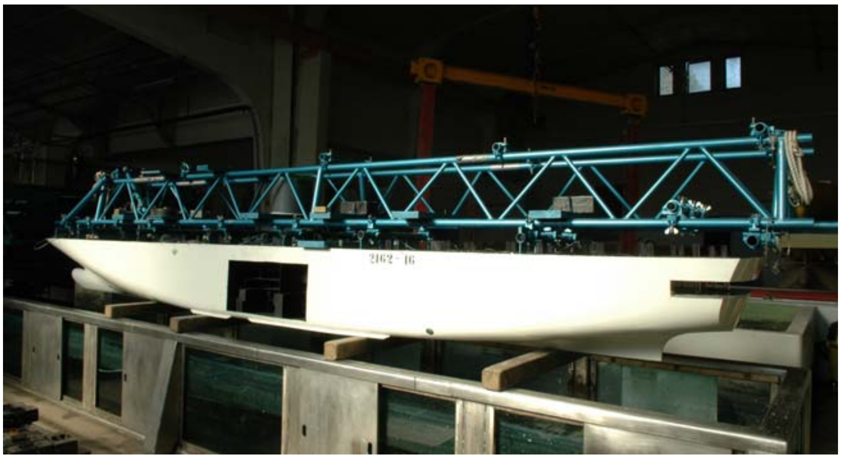
D) Model tank test activities to assess the survivability of the SOLAS ship in damaged condition and the consistency of the “s” factor.

The model used is that of a standard SOLAS 90 design of a cruise ship, of approximately 110000 GRT. It was built in scale l : 40 with a Lpp = 6.055 m Loa= 7.25 m B = 0.90 m T = 0.21 m Displacement = 805.22 kg.



The tests include calm water and irregular sea states, for a two and three compartment flooding.
Transient phases and progressive flooding have been observed and recorded for a duration of at least one hour, in ship scale, to asses the final calm water equilibrium and behaviour in irregular sea, increasing the sea state up to 7.
After a check of the principal parameters, a comparison of intact GZ curve was made with the theoretical calculations obtained with NAPA and PROTEUS, extensively used to study the damage survivability.
The comparison of the righting lever curve of the model in flooded condition with the correspondent static calculation, demonstrated the correct modelling of the compartments as well as volume, centre of volume and permeability of the physical model.
In the final condition, the heeling angle, draft and trim were compared with the static calculation, demonstrating a good correlation.

An interesting result was the maximum rolling angle in irregular sea, found to be very low also for sea state 7, showing the good behaviour of large cruise vessels due to their high natural rolling period - about 30 seconds in the intact condition, far from the resonance period of incoming beam waves.
Different wave directions did not affect much the rolling behaviour.
The motions of the model were checked also with different damage sizes, but the results did not significantly changed.
A test of KG variation was done, to check the survivability with a very low value of maximum residual GZ - below SOLAS 90 criteria - corresponding to a survivability index less than 1 according to the damage stability probabilistic formulation contained in SLF 47/3/1.



Also those tests showed the good survivability of the ship.
Finally, a 3 compartment damage test was done - although the ship was designed according to SOLAS 90 - testing a damage length of more than 33 m and a flooded length of about 50 m, (i.e. 50% more than SOLAS 90 maximum flooded length).
In irregular sea, the ship model with a stability corresponding to the operative loading condition, survived with significant wave height up to 4-5 m (sea state 6).
It is underlined that the ship survived - without water on bulkhead deck :

- in the worst damage scenario of two compartments with irregular sea up to 6-7 m of significant wave height

- for a three compartment flooding, with 4-5 m of significant wave height - although the ship was not designed for these assumptions, well beyond SOLAS 90.

The ship demonstrated high survivability, although in the probabilistic damage stability calculations the survivability index was less than 1 for these damages!

These results, proving the high safety standards of large cruise ships are to be taken into account in the present and future regulations for the ship survivability in damage conditions.