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Task 6: Damage Stability Calculations of GOALDS RoPax Designs

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		P.O.Box 300
Customer:	European Maritime Safety Agency,	1322 Høvik
Contact person:	Mr. Sifis Papageorgiou	Norway
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Task and objective: This report contains the results of a recalculation of the damage stability for the RoPax designs developed in the GOALDS project under consideration of the new s-factor to account for water on deck effects as defined at SLF55 and agreed at SDC1.

Prepared by:	Verified by:	Approved by:
Henning Luhmann	Anna-Lea Routi	Odd Olufsen
Mike Cardinale	Rodolphe Bertin	

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Reference to part of this report which may lead to misinterpretation is not permissible.

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1	2015-05-23	Initial issue	See list of authors	Anna-Lea Routi Rodolphe Bertin	
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3	2015-07-02	Corrections after receiving comments from EMSA	See list of authors		Odd Olufsen

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1 PREFACE

This report is a deliverable according to the Framework Service Contract Number EMSA/OP/10/2013. This is the third study commissioned by EMSA related to the damage stability of passenger ships. The previous studies focused on ro-ro passenger ships.

This study aims at further investigating the damage stability in an FSA framework in order to cover the knowledge gaps that have been identified after the finalization of the previous EMSA studies and the GOALDS project.

The project is separated in to 6 studies:

- Identification and evaluation of risk acceptance and cost-benefit criteria and application to risk based collision damage stability
- Evaluation of risk from watertight doors and risk based mitigating measures
- Evaluation of raking damages due to groundings and possible amendments to the damage stability framework
- Assessment of cost effectiveness or previous parts, FSA compilation and recommendations for decision making
- Impact assessment compilation
- Updating of the results obtained from the GOALDS project according to the latest development in IMO.

The project is managed by DNV-GL and is established as a joint project which includes the following organisations:

Shipyards/designer:

Euroyards representing: Meyer Werft, Meyer Turku, STX-France and Fincantieri

Knud E. Hansen AS

Operators:

Royal Caribbean Cruises

Carnival Cruises

Color Line

Stena Line

Universities:

National Technical University of Athens

University of Strathclyde

University of Trieste

Consultants:

Safety at Sea

Software manufacturer:

Napa OY

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4 ABBREVIATIONS

A: Attained index calculated in accordance with SOLAS 2009. Ch.II-1

DL: light service draught

DP: partial draught

DS: maximum subdivision draught

FRBDAM: residual freeboard after damage

GAP: General Arrangement Plan

GM: metacentric height

GOALDS: **GOAL** based **D**amage **S**tability

GT: Gross tonnage

IMO: International Maritime Organisation

LSA: Life Saving Appliances

PFAC: p-factor according to SOLAS Ch.II-1

POB: Persons on board

R: Required Subdivision Index in accordance with SOLAS 2009, Ch.II-1

SFAC: s-factor according to SOLAS Ch.II-1

SNEW: revised s-factor defined at SLF55 and agreed at SDC 1

T: draught

TR: trim

WCOEF: Weighing coefficient according to SOLAS, Ch. II-1

WOD: Water on deck

5 EXECUTIVE SUMMARY

The Ro-Pax sample ships designed in GOALDS have been analyzed with regard to the new s-factor to accommodate the effect of accumulated water on the ro-ro deck after a collision. The designs are a large cruise ferry usually deployed in the Baltic and a typical mid-sized Ro-Pax ferry, with the main focus on cargo capacity. The effect of the new s-factor on these two ships is small with regard to the attained index. However translated into the required reduction of cargo or additional ballast water in order to comply with the stability limits the effect is already significant.

The loss of index for these two sample ships has been also compared with the calculations done in task 1 of the EMSA3 project and the results are in line with each other.

It has been proven that the method itself is robust and can be easily used during the design of ro-pax vessels.

6 ABSTRACT

The new s-factor defined at SLF55 and agreed at SDC1 has been applied to two sample ships. An influence on the attained index of about 1-2% could be found. This rather small impact on the index can be explained due to the fact that the sample ships are already defined to comply with SOLAS Ch.II-1 as well as the Stockholm agreement. Many of the investigated damages, approximately 70-80% have better GZ properties than required by the new s-factor.

However this new s-factor seems to make it more difficult to design ships just at the limits of the intact stability criteria. The damage stability requirements are more restrictive.

7 INTRODUCTION

During the 55th session of the IMO sub-committee Stability, Loadline and Fishing (SLF55) in January 2013 the SDS working group discussed lengthy how the effect of accumulated water could be considered in the current SOLAS Ch. II-1 framework [ref 1].

The discussions resulted in a compromise found and agreed in the working group, however this compromise was not adopted by the sub-committee due to interventions of a number of delegations. The final decision was postponed to SDC1 to allow a further discussion. At SDC1 in January 2014 the proposal of the SDS working group agreed at SLF55 was finally accepted and will be incorporated in the revision of chapter II-1 of SOLAS. [ref 2]

The EC funded research project GOALDS investigated a number of sample ships with regard to a risk based damage stability. In this context 2 ropax vessels have been designed and calculated [ref 3].

Work package 6 of the EMSA 3 study has the task to recalculate these GOALDS ropax sample ships according to the new approach to consider water on deck and investigate in particular those damages, where a reduction of S could be found.

8 BACKGROUND

Since the adoption of the new probabilistic frame work for damage stability there have been concerns raised if this standard also covers the stability requirements for ro-ro passenger ships. In particular the equivalence of SOLAS2009 compared with SOLAS90 in combination with water on deck as defined in the Stockholm agreement (directive 2003/25/EC) has been questioned.

The change from a deterministic concept in damage stability requirements (SOLAS90 and Stockholm Agreement) towards the probabilistic approach with the harmonization leading to the revised SOLAS II/1 (SOLAS2009) is the main reason, why it is so difficult to compare both damage stability regimes.

The deterministic approach defines a small number of explicit damages which needs to comply with a defined set of criteria. This defines a GM/KG limiting curve and describes the stability level to be complied with. Damages outside the explicit set of damages are not investigated and it is uncertain, if the ship may survive such damage or not. The limitation on damage cases outside the B/5 line also implies a high risk of progressive flooding through pipes and ducts situated inside the B/5 line, for damages outside the defined damage extent.

The probabilistic approach requires the investigation of a very large number of possible damages in addition to some deterministic elements. From the large number of damages, which covers a penetration depth up to B/2 and a length up to 60m, a certain percentage needs to be survived. This percentage is defined in the required index R. This probabilistic calculation, together with the deterministic requirements as defined in regulation 8 and 9, result also in a GM/KG limiting curve.

It is an agreed procedure to judge stability questions on GM limiting curves, during ship design and operation, for intact and damage stability problems. Therefore the comparison of GM requirements is always a simplified but suitable method to compare different stability requirements.

9 S-FACTOR

9.1 Existing s-factor according to SOLAS2009

The current s factor is described in SOLAS Reg.II-1/7-2 as the minimum of $s_{final}*s_{moment}$ and $s_{intermediate}$.

S_{final} is defined as follows:

$$S_{final,j} = K \cdot \left[\frac{GZ_{max}}{0.12} \cdot \frac{Range}{16}\right]^{\frac{1}{4}}$$

Where: GZmax is not to be taken as more than 0.12m

Range is not to be taken as more than 16°

K = 1 if $\theta_e \leq \theta_{min}$

K = 0 if $\theta_e \geq \theta_{max}$

$$K = \sqrt{\frac{\theta_{max} - \theta_e}{\theta_{max} - \theta_{min}}}$$

Where: θ_{min} is 7° for passenger ships and 25° for cargo ships

θ_{max} is 15° for passenger ships and 30° for cargo ships

The selection of GZ (0.12m) and Range (16 deg) is based on the HARDER statistics [ref. 4] as shown in the following diagrams and does not differentiate between conventional passenger or cargo ships

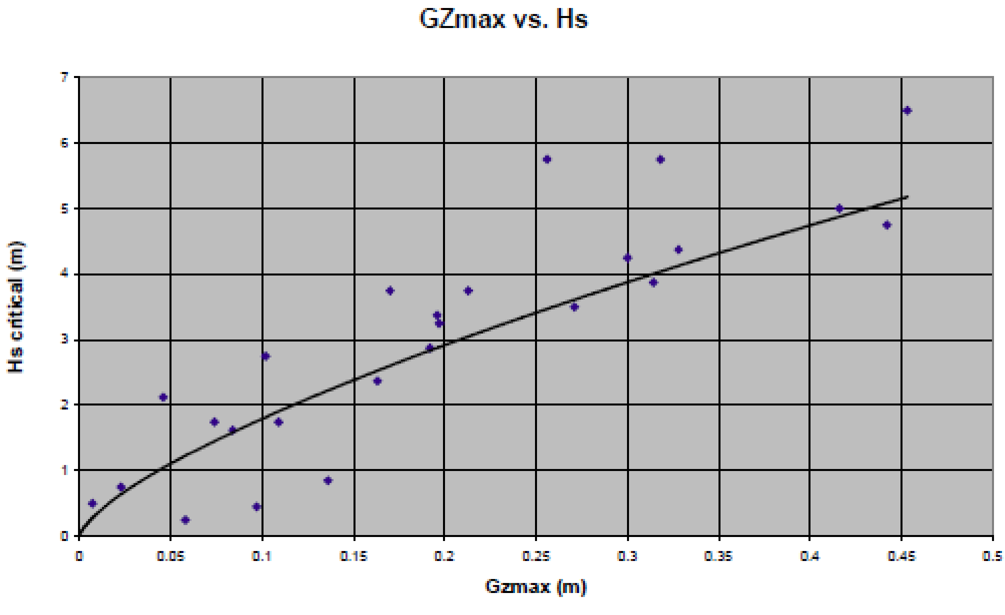

Figure 1 Relation critical wave height and GZmax (HARDER)

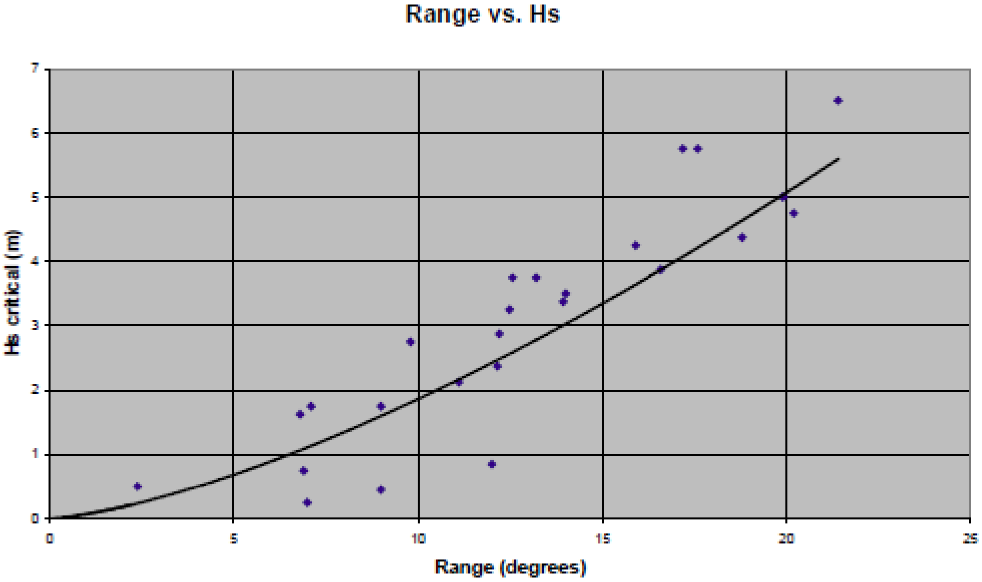

Figure 2 Relation critical wave height and Range (HARDER)

Further studies following the HARDER project have shown that for ro-ro passenger ships the results of model tests showed a significant difference [ref 5].

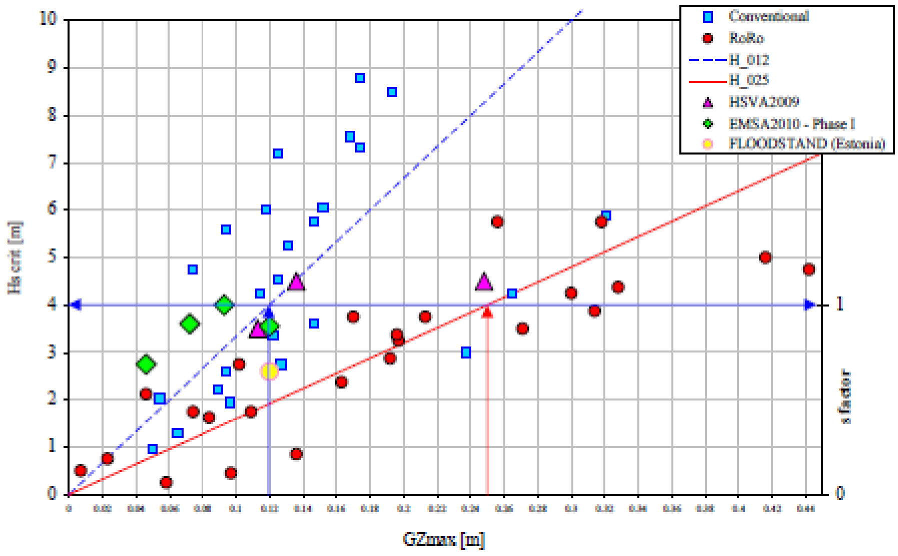

Figure 3 Relation between wave height and GZmax (EMSA2 Study)

9.2 New s-factor definition

The new s-factor has been defined in such a way, that for those damages which involves a ro-ro cargo hold, the GZ and Range requirements have been increased for the final stage of flooding to achieve s=1.

Following definition has been agreed:

The current s factor is described in SOLAS Reg.II-1/7-2 as the minimum of $s_{final}*s_{moment}$ and $s_{intermediate}$.

S_{final} is defined as follows:

$$Sfinal, j = K \cdot \left[\frac{GZmax}{TGZmax} \cdot \frac{Range}{TRange}\right]^{\frac{1}{4}}$$

Where:

GZmax is not to be taken as more than TGZmax;

Range is not to be taken as more than TRange;

TGZmax = 0.20 m, for ro-ro passenger ships each damage case that involves a ro-ro space,

= 0.12 m, otherwise;

TRange = 20°, for ro-ro passenger ships each damage case that involves a ro-ro space,

= 16°, otherwise;

$K = 1$ if $\theta_e \leq \theta_{min}$

$K = 0$ if $\theta_e \geq \theta_{max}$

$$K = \sqrt{\frac{\theta_{max} - \theta_e}{\theta_{max} - \theta_{min}}}$$

Where: θ_{min} is 7° for passenger ships and 25° for cargo ships

θ_{max} is 15° for passenger ships and 30° for cargo ships

The same formulation of the s-factor is to be used when applying regulation II-1/8 for minor damages.

10 GOALDS SAMPLE SHIPS

10.1 Large RoPax

The ship is a large modern cruise ferry with a ro-ro deck for trucks and trailers, a large lower hold for cars and an additional car deck within the superstructure. The cargo handling is based on a drive-through concept with large stern ramps and a bow door and ramp on the bulkhead deck. The access to the other cargo areas is provided via internal ramps.

In addition a hoistable car deck is provided to allow for sufficient car capacity.

The ship is designed as an overnight ferry with a large number of cabins and suitable public rooms, like restaurants, shopping areas, conference center, lounges and a spa area.

The propulsion concept is based on a twin screw plant with CPP and 4 geared main engines. 4 auxiliary diesel generators are provided to supply the energy for the hotel services. The anticipated service speed is with 21.5 kn in the medium range of similar vessels, however the actual service speed may vary with the specific service.

10.1.1 Main dimensions

Table 1 Main dimensions

Length over all	Approx 229m
Length between perpendiculars	214.32 m
Subdivision length	227.97 m
Breadth	32 m
Subdivision draught	6.70 m
Height of bulkhead deck	9.70 m
Number of passengers	3300
Number of crew	200
Gross tonnage	70000
Deadweight	6900 t
No of cabins	1000
Lanemeter	1500
No of cars	1000

The vessel is designed to comply with SOLAS2009 and the Stockholm Agreement, as well as the latest Safe return to port requirements according SOLAS Reg. II-2/21 and 22.

The LSA capacity is based on short-international voyage with limited space in lifeboats and the remaining capacity in state-of-the-art marine evacuation systems (MES).

For environmental protection no fuel tank is located at the shell, in any case the required fuel oil tank protection according MARPOL Reg. 12a is complied with.

10.1.2 General Arrangement / Layout

The layout of the vessel can be seen in the general arrangement plan in the figure below.

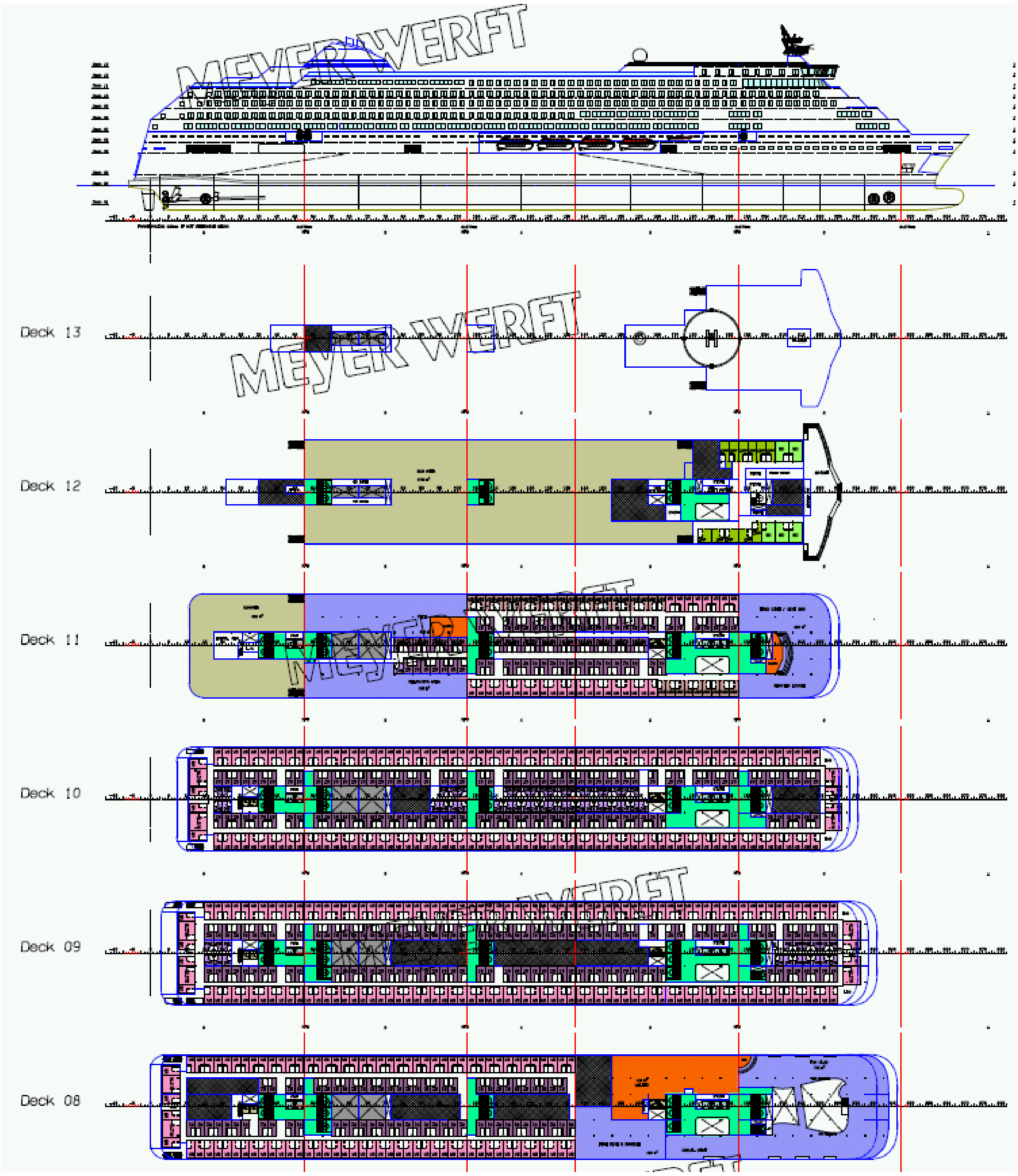

Figure 4 GAP upper part

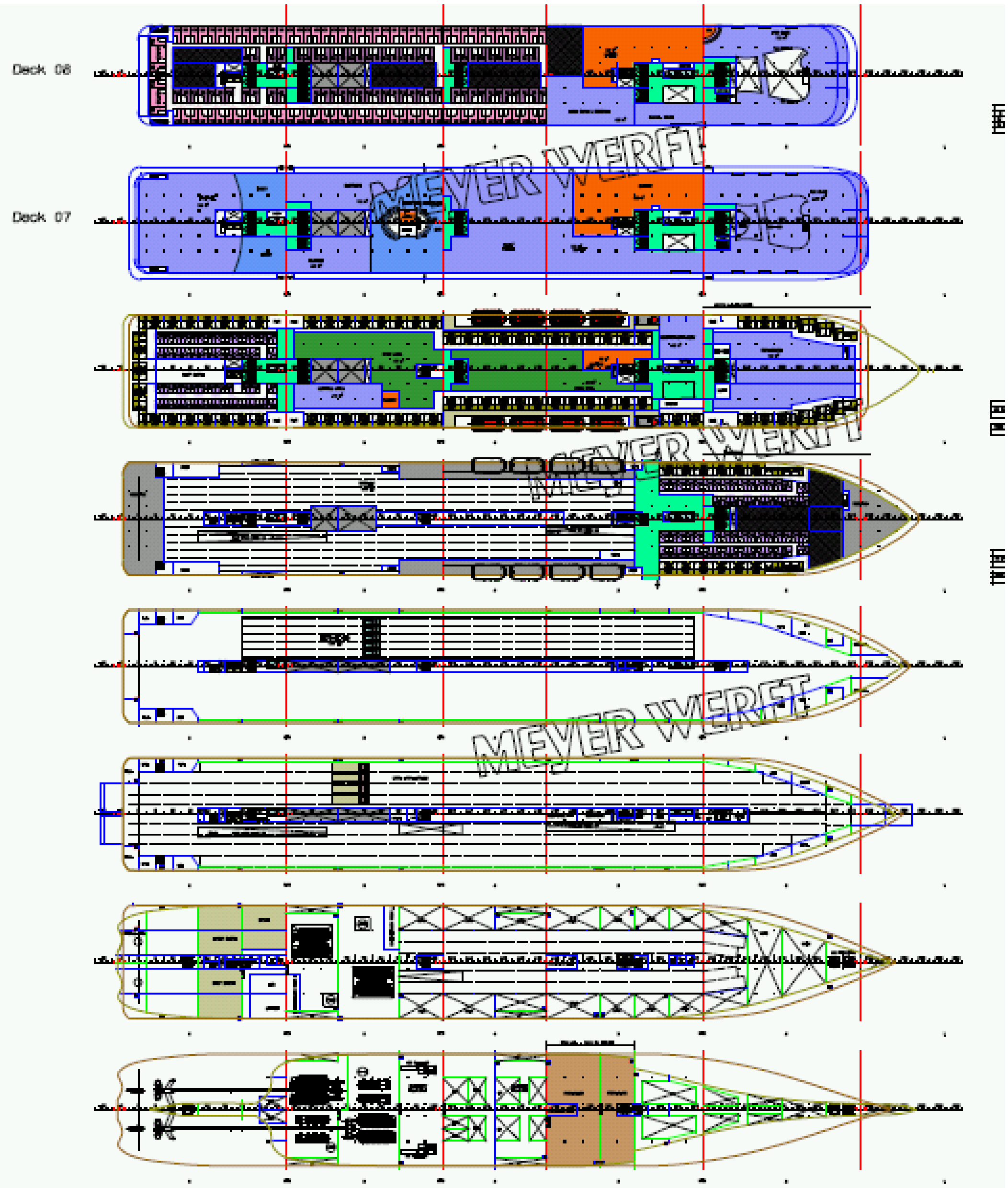

Figure 5 GAP lower part

The layout of the tanks can be seen in the figure below, where a preliminary tank arrangement is shown. It should be noted, that only the major tanks have been modelled, a real ship would have many more smaller tanks, in particular in the engine room area, however these tanks are not significant for intact and damage stability calculations.

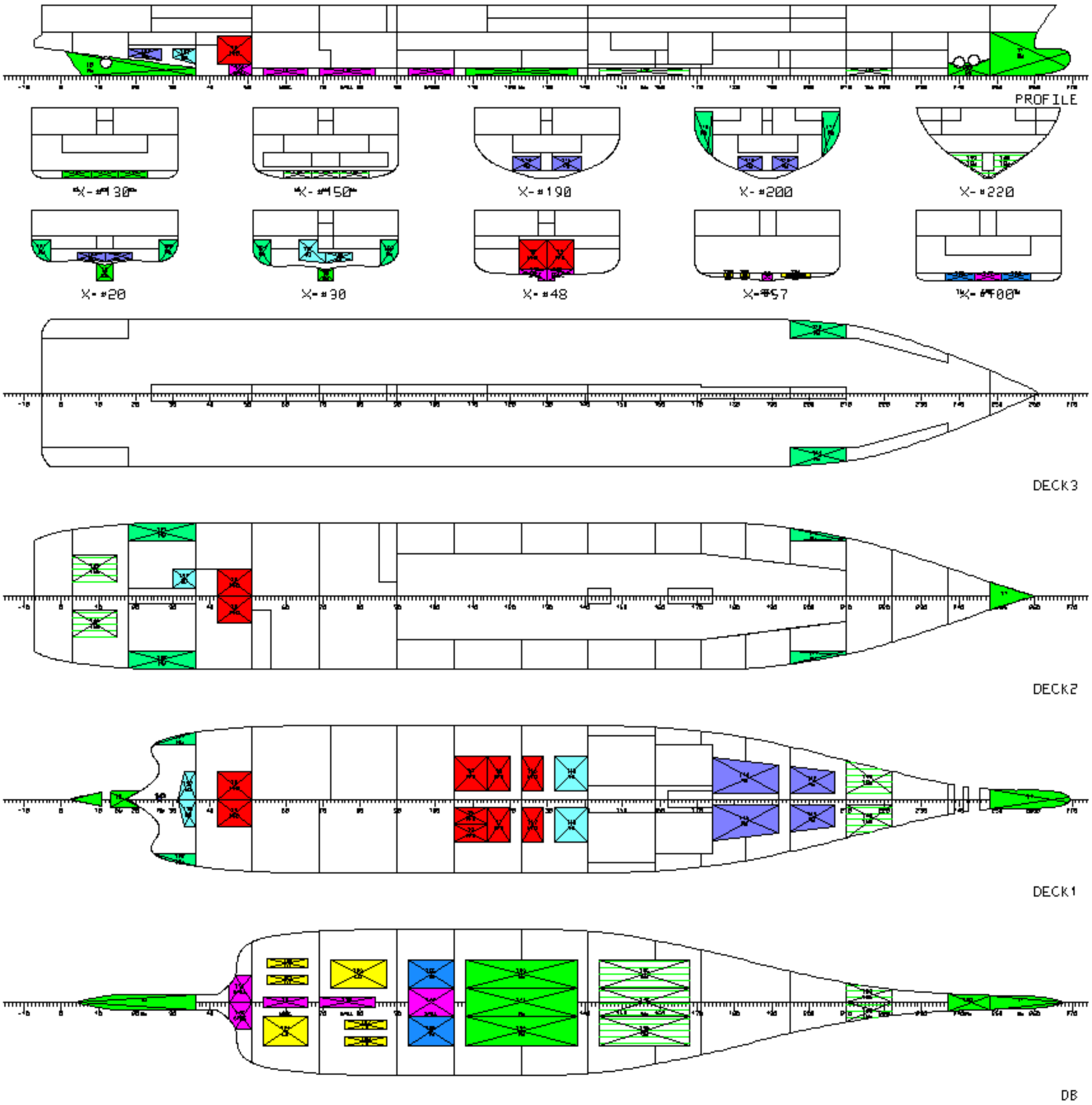

Figure 6 Tank Arrangement

10.1.3 Watertight Subdivision

The watertight subdivision follows the needs from the functionality of the spaces, e.g. the size of the lower hold as well as the size of the main engine rooms.

Due to redundancy requirements as defined in SOLAS Reg.II-2/21 and 22, the engine rooms are quite large and cause special attention for damage stability. The voids spaces around the large lower hold are designed in such a way to allow instantaneous symmetrical flooding. The heeling water tanks are located outside the lower hold area, to minimize heel after damage.

Deck 3 is the main cargo and bulkhead deck. Between deck 3 and 5 there are smaller buoyant spaces at the very end of cargo space to provide additional buoyancy. The access to these spaces is usually not needed during normal voyages but only during loading and unloading. Therefore these spaces can be closed watertight, without applying escape routes.

As required by SOLAS there is no access from the ro-ro deck downwards, the minimum height of any opening is 2.5m above the deck. The hatches to the ramps leading to the large lower hold as well as to the provision area are assumed to be watertight.

The ship is provided with a continuous double bottom with a height of more than B/20.

The figure below shows the watertight subdivision and the damage zones used in the SOLAS2009 calculation of the attained index.

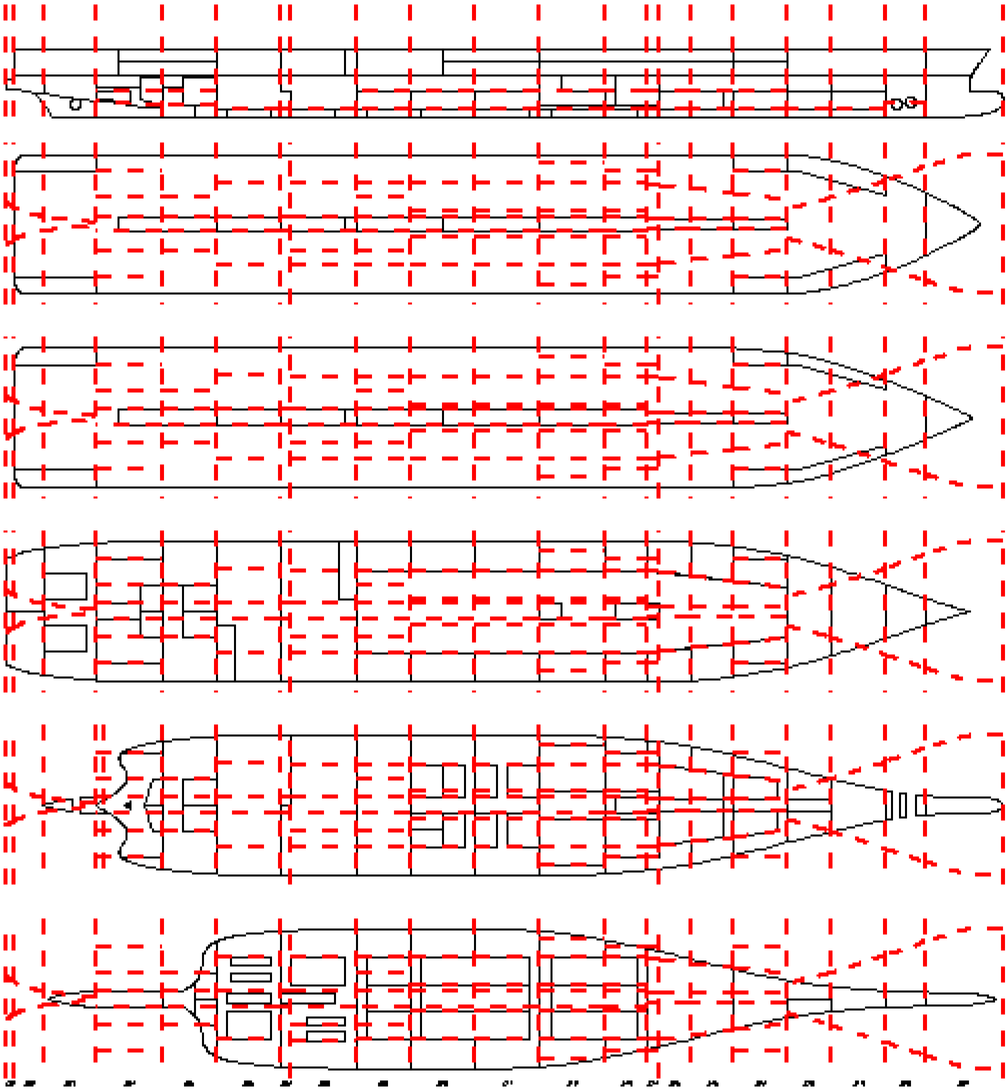

Figure 7 Watertight subdivision

10.2 Medium RoPax

The vessel is a Ro-Ro passenger ship designed for short international voyages. The vessel is twin screw with bulbous bow and an aft skeg.

The General Arrangement Layout provides fast cargo loading/unloading for passenger and good simultaneous flow cargo, passengers, stores and necessary services.

The vessel is fitted with three trailer decks: main (DK3) and upper (DK4) trailer deck and lower garage (DK2) below the main deck.

A hoistable car deck is arranged on the upper car deck; the aft panel is used as ramp. For entrance of cars and trailers, the Vessel is fitted with side hinged bow doors and bow ramp and also fitted with two combined stern ramps. Access to the upper deck loading is arranged from the main deck via a tiltable ramp and to lower garage deck via one fixed ramp with ramp cover.

Deck 3 (main deck) is designated as the freeboard deck and it is watertight.

The vessel is fitted with four diesel engines. Each set of two engines is coupled to one gear box with clutch couplings integrated in the gear for engaging/disengaging of the engines, connected to shaft line and propeller.

10.2.1 Main dimensions

Table 2 Main dimensions

Length over all	Approx 183m
Length between perpendiculars	162.85 m
Subdivision length	182.0 m
Breadth	27.6 m
Subdivision draught	7.1 m
Height of bulkhead deck	9.80 m
Number of passengers	2080
Number of crew	120
Gross tonnage	Abt. 36000
Deadweight	5000 t
No of cabins	180
Lanemeter	1950 m
No of cars	670

The vessel is designed to comply with:
- SOLAS consolidated edition 2009 (all rules in force for keel laying at 31/12/2009)
- MARPOL 73/78 with following amendments (including addition to regulation 12A)
- International Load Line Convention 1966 and following amendments
- ICE CLASS

10.2.2 General Arrangement / Layout

The layout of the lower deck of the vessel can be seen in the figure below.

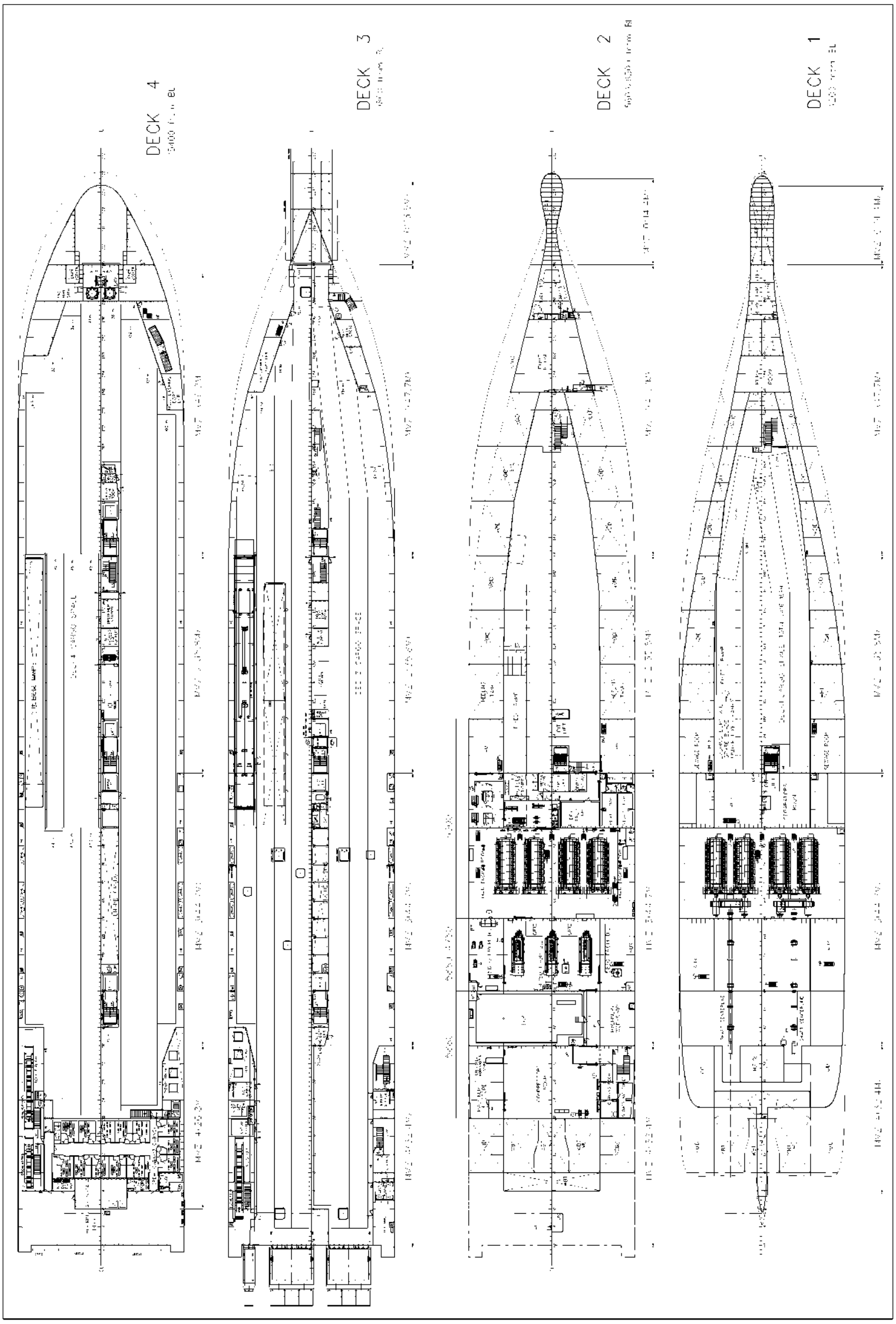

Figure 8 GAP lower part

10.2.3 Watertight Subdivision

The ship has 17 watertight compartments, separated by 16 main transversal bulkheads. The lower hold is located within compartments from 8 to 13 where the transversal bulkheads are arranged on the side rooms only. Weathertight doors capable to sustain a head of water of 2.5m are used on the main Deck (deck 3) for the side casing connected to the garage space.

The ship is provided with a continuous double bottom with a height of 1.4 m therefore more than the required B/20.

For SOLAS2009 calculations the ship has been divided by 19 damage zones and a safe area (width 2.92m) has been arranged in the central part of the ship from zone no.4 up to zone no.15. That area is needed to arrange pipes and duct that cannot be closed by means of watertight valves.

The figure below shows the watertight subdivision used in the SOLAS2009 calculation of the attained index.

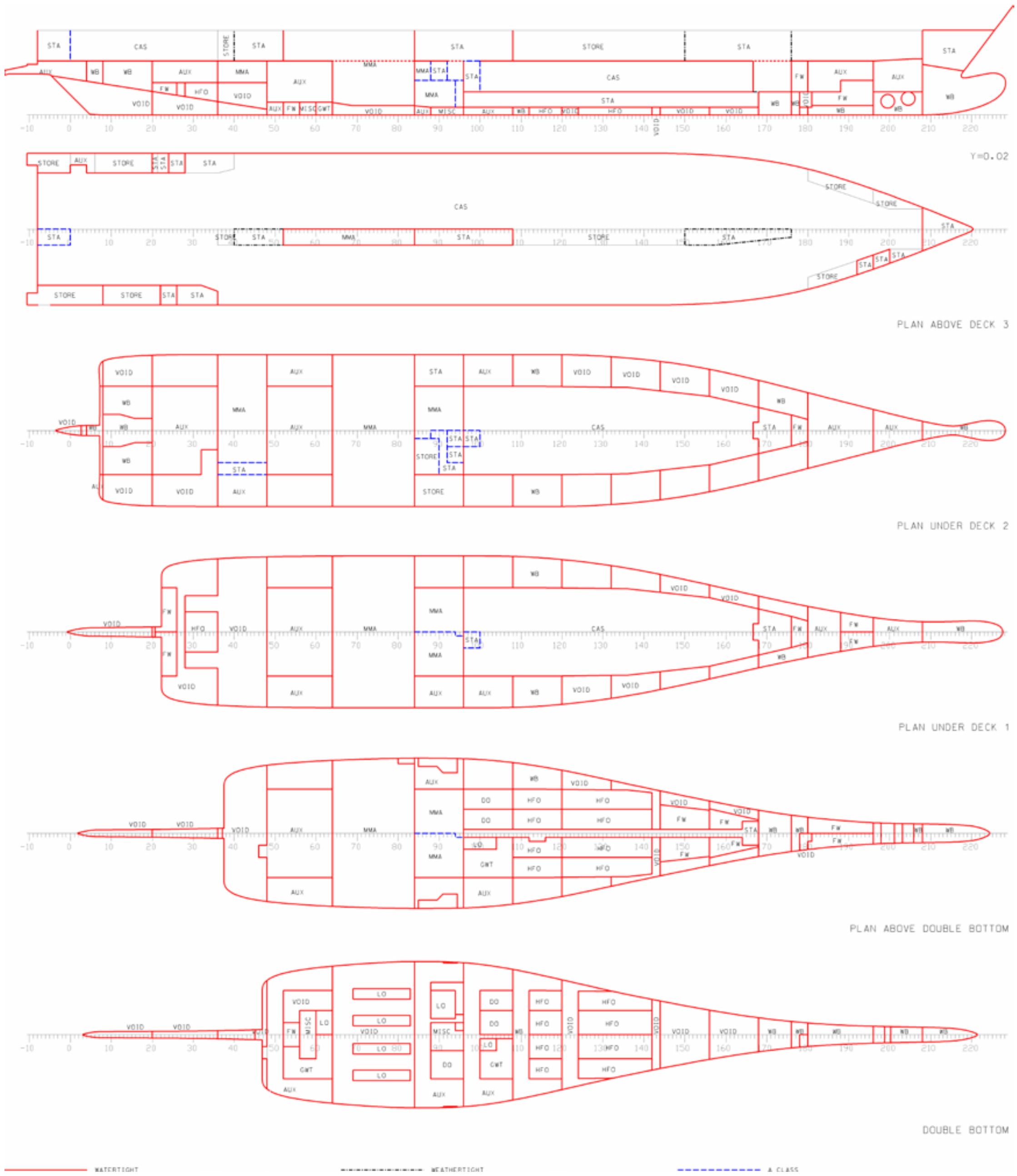

Figure 9 subdivision

11 DAMAGE STABILITY RESULTS

11.1 Results for the Large RoPax

11.1.1 Results according to SOLAS 2009

The results of the damage stability calculation according to SOLAS2009 are as follows:

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	227.971 m
Breadth at the load line	32.000 m
Breadth at the bulkhead deck	32.000 m
Number of persons N1	1200
Number of persons N2	2296
Required subdivision index	R = 0.83296
Attained subdivision index	A = 0.83512

The distribution of the index for the different draughts and damages from both sides are:

INIT	DAMTAB	T	GM	A/R	A	A*WCOEF	WCOEF
DL	DAMP	6.08 m	4.46 m	1.0556	0.8793	0.0879	0.1
DL	DAMS	6.08 m	4.46 m	1.0525	0.8767	0.0877	0.1
DP	DAMP	6.45 m	4.00 m	0.9918	0.8262	0.1652	0.2
DP	DAMS	6.45 m	4.00 m	0.9992	0.8323	0.1665	0.2
DS	DAMP	6.70 m	4.14 m	0.9802	0.8165	0.1633	0.2
DS	DAMS	6.70 m	4.14 m	0.9876	0.8226	0.1645	0.2
						0.8351	

The distributions on the multi-zone damages are shown in the table below:

Multizone Damages

DAMAGES	W*P*V*S	W*P*V
1-ZONE DAMAGES	0.2961	0.2962
2-ZONE DAMAGES	0.3266	0.3490
3-ZONE DAMAGES	0.1503	0.1931
4-ZONE DAMAGES	0.0486	0.0793
5-ZONE DAMAGES	0.0135	0.0341
A-INDEX TOTAL	0.8351	0.9517

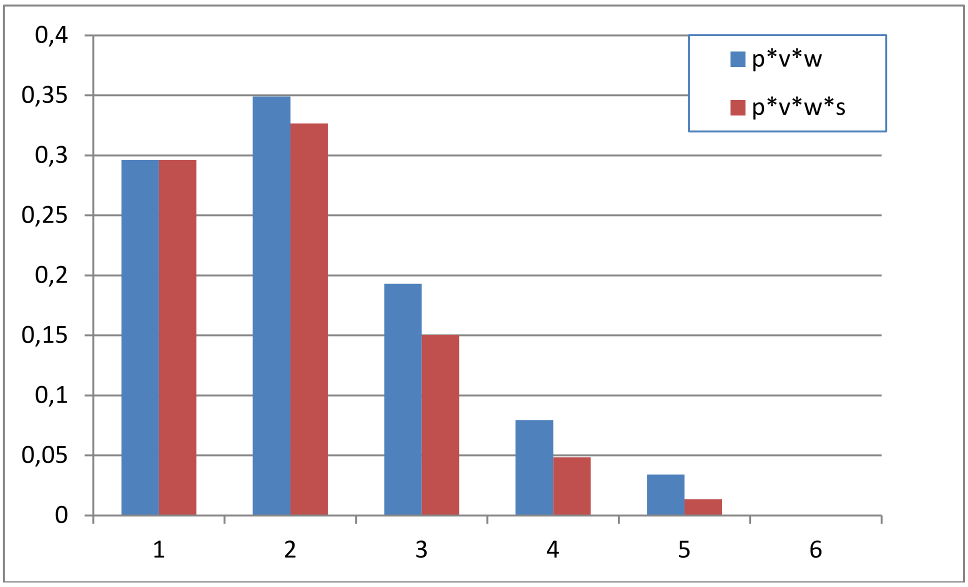

Figure 10 Attained Index for multi-zone damages

From the table above it can be seen that not all possible damage cases are considered in the index calculation. This is a usual approach to allow some dedicated area close to the centre line of the ship to be used for open systems and ducts, which may cause significant progressive flooding in a case of damage.

The figure below shows the distribution of the not investigated damages and those damages which contributes to the index and those which have s=0 and do not contribute.

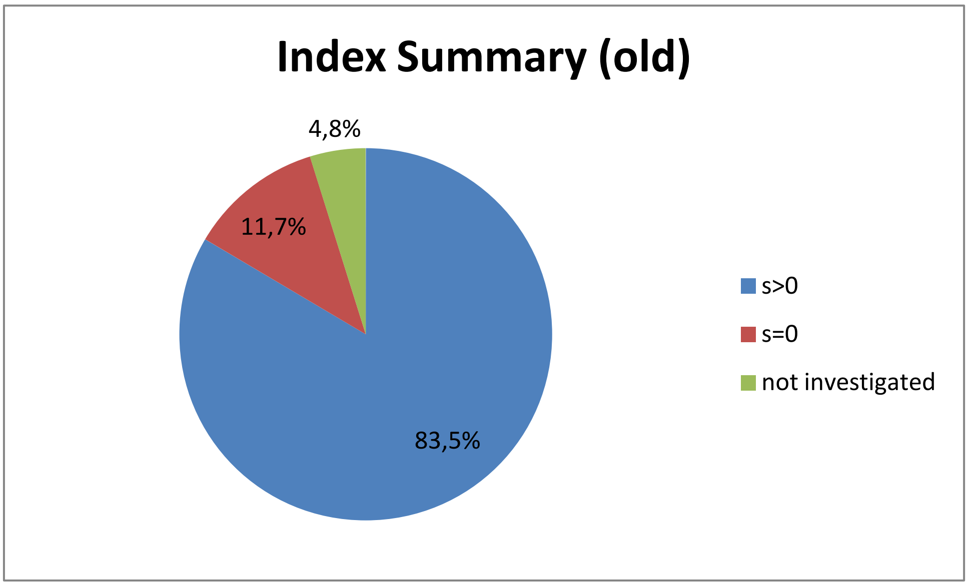

Figure 11 Distribution of s>0 and s=0

Those damage cases which have been investigated have a typical distribution of the achieved s-values. The majority of the damages have s=1 while only about 10% of the damages cannot be survived.

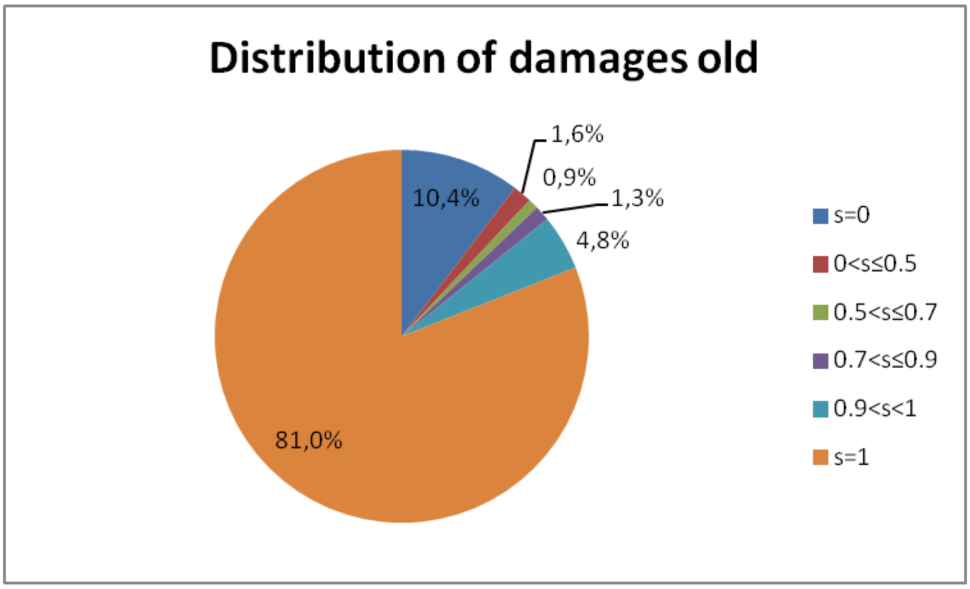

Figure 12 Distribution of s-factor

11.1.2 Results with new s –factor

When applying the new s-factor for the damages where the roro deck is penetrated the attained index is as follows:

Attained index acc. SOLAS 2009 A = 0.83512
Attained index with s-new A = 0.82937

For the different initial conditions the result is

DL:
Attained index acc. SOLAS2009 A = 0.175599
Attained index with s-new A = 0.174757
DP:
Attained index acc. SOLAS 2009 A = 0.331695
Attained index with s-new A = 0.329733
DS:
Attained index acc. SOLAS 2009 A = 0.327826
Attained index with s-new A = 0.324881

The difference between the attained index when using the two calculation methods is very similar for all three draughts.

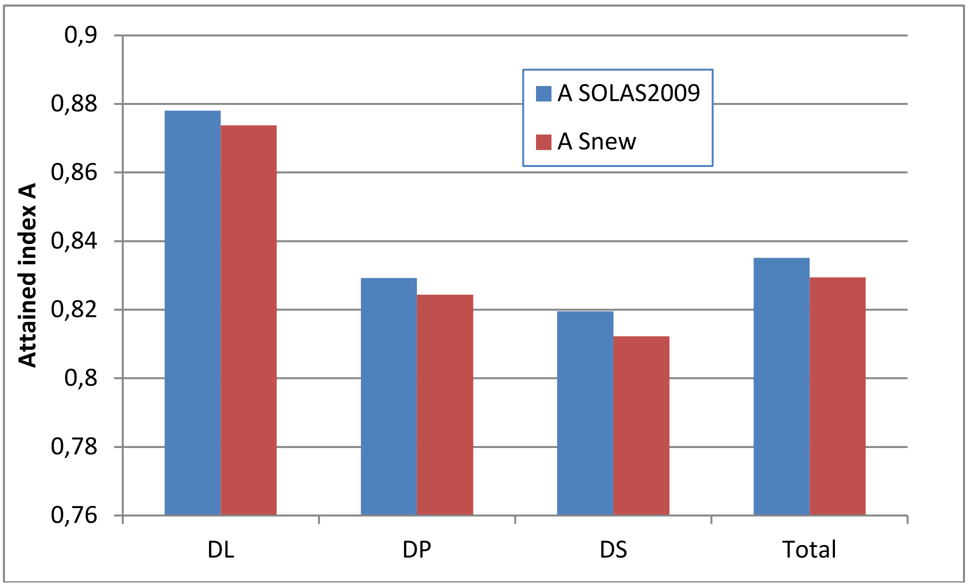

Figure 13 Attained index comparison

The figure below shows the distribution of the not investigated damages and those damages which contributes to the index and those which have s=0 and do not contribute.

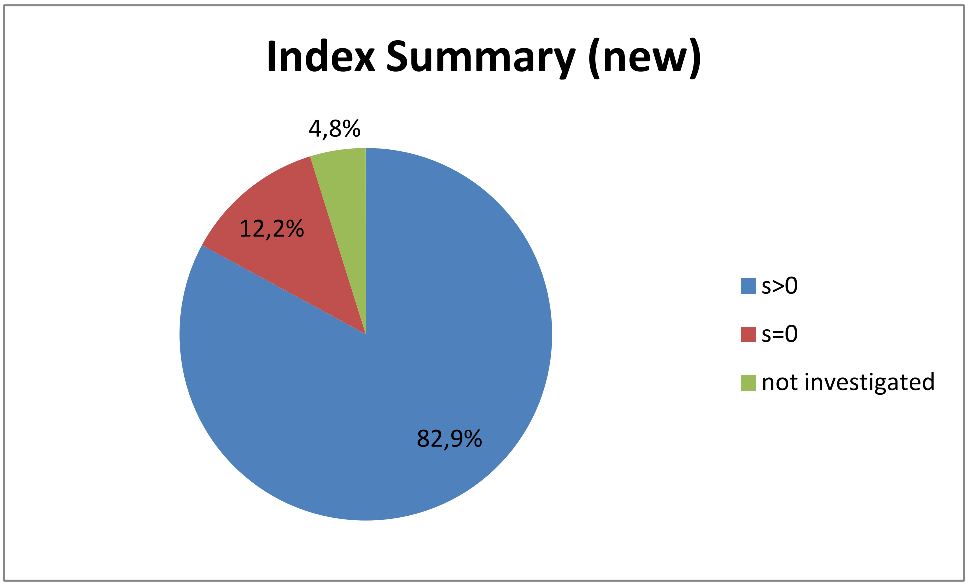

Figure 14 Distribution of s-new

Those damage cases which have been investigated have a typical distribution of the achieved s-values. The majority of the damages still has s=1 while only about 10% of the damages cannot be survived. However compared with the old method the portion of damages with s<1 but s>0 has been increased.

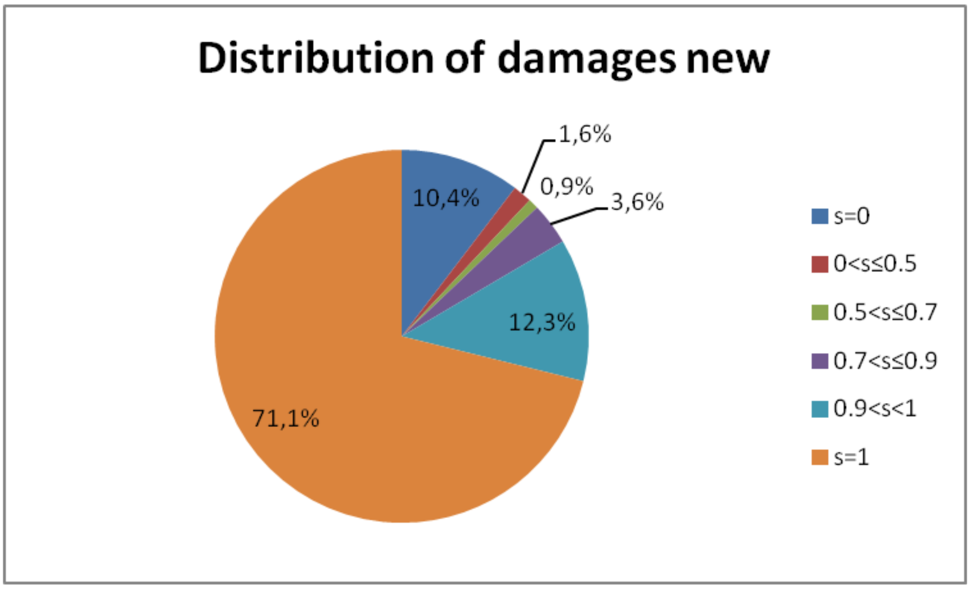

Figure 15 Detailed distribution of s-new

The relatively small impact of the new method on the attained index can be explained with the distribution of damages related to range and GZ.

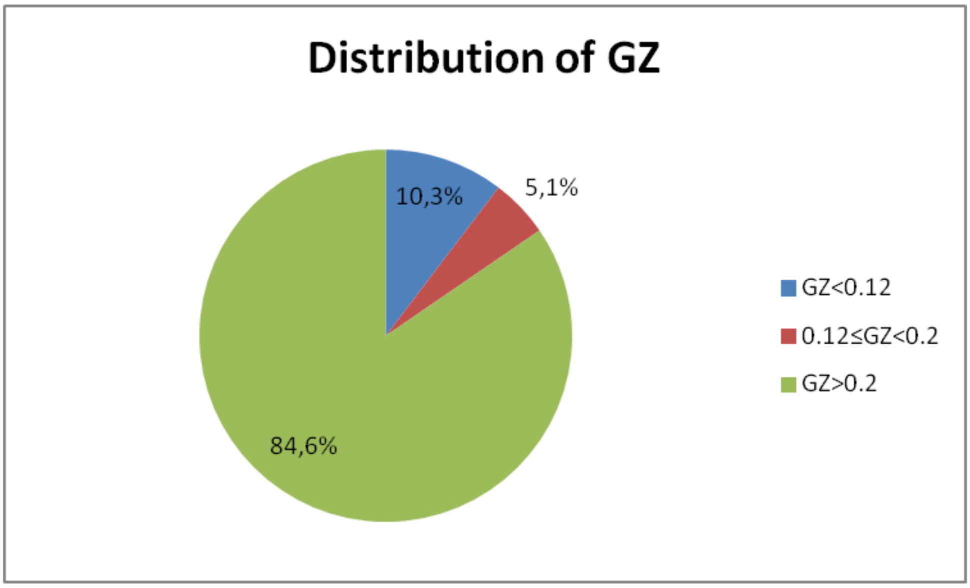

Figure 16 Distribution of GZ values

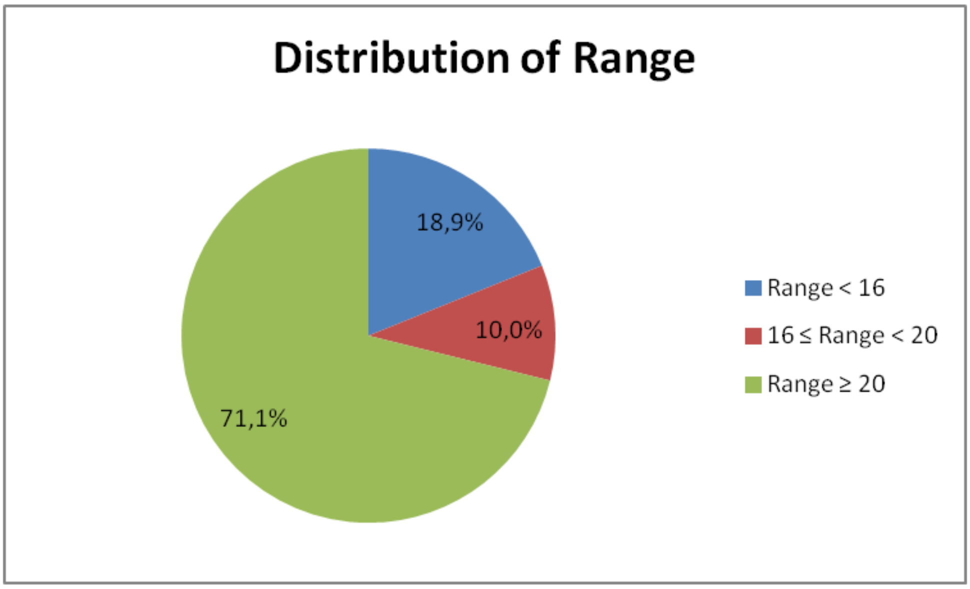

Figure 17 Distribution of Range values

For this ship most of the damage cases already have a higher GZ values and a bigger range than requested by SOLAS2009. Therefore the effect of the raised requirement is marginal.

When calculating the percentages the p-factors have been considered to reflect not only the number of damage cases, but the probability of their occurrence.

11.1.3 GM limiting curves

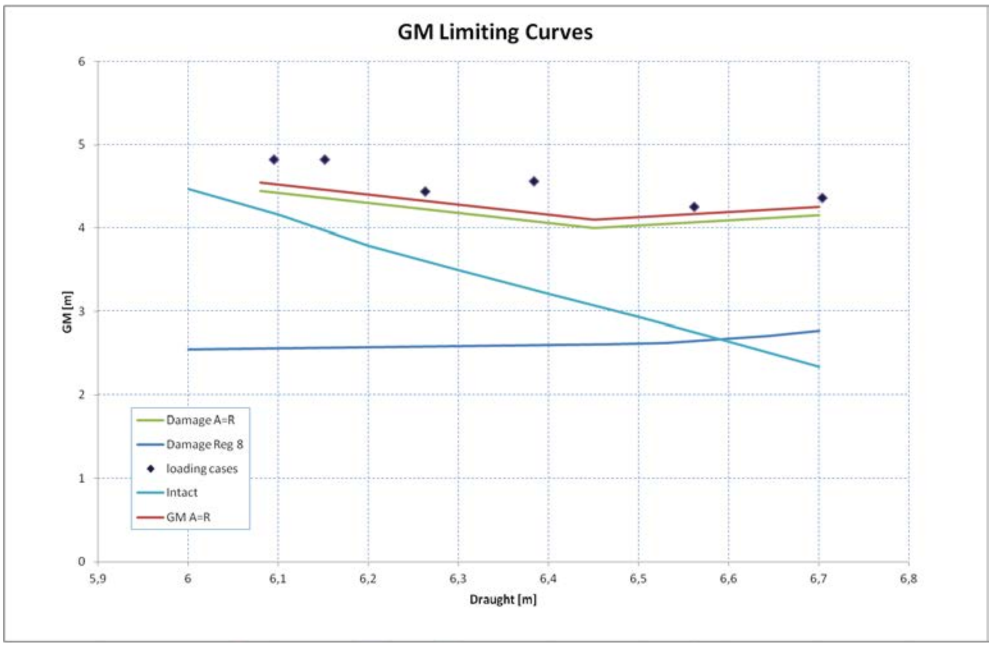

Figure 18 GM Limiting curves

When comparing the GM requirements for the two methods it can be seen that the new s-factor results in raising the GM limiting curve by 10 cm. Although this increase of GM can be covered by the existing loading cases it is a remarkable impact on the design.

To accommodate the same margin on the actual loading conditions versus the limit curve approximately 300t of additional ballast needs to be used.

11.1.4 Comparison of individual damage case

Some damage cases have been investigated in more detail. First of all the effect of the new s-factor formulation is to be demonstrated for a typical damage case involving the large lower hold.

Secondly some of the damage cases, which have an s-factor=1 according the old formulation, but s-new<1 for the new formulation have been investigated. In total, 9.4% of the damage cases fall in this category. When calculating the percentages the p-factors have been considered to reflect not only the number of damage cases, but the probability of their occurrence.

The figure below shows the distribution of damage cases, and their change in s-factor.

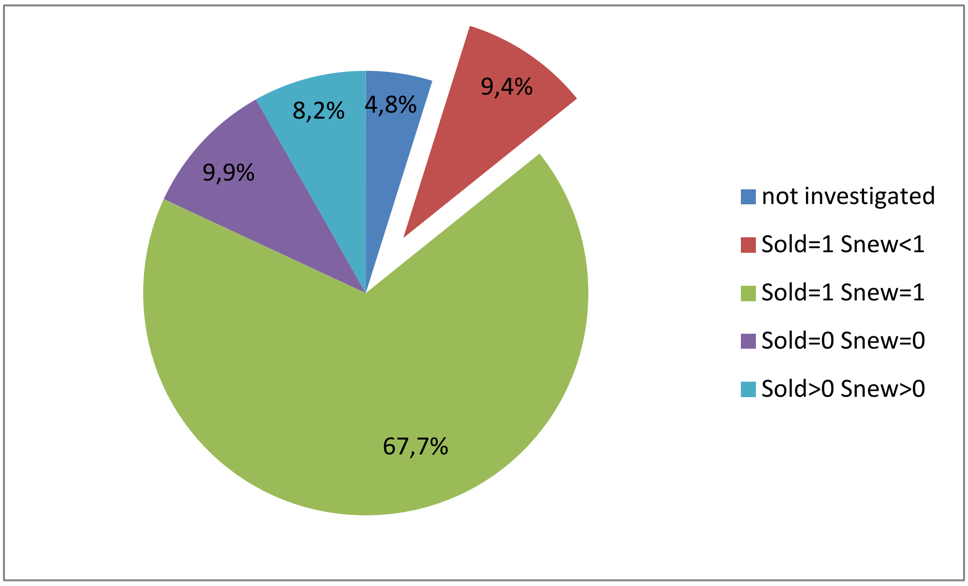

Figure 19 Distribution of change of s

Following damage cases (shown for DS only) have the new s-factor<1 while the old s-factor=1.

Table 3 Damage cases sfac=1 and snew<1

CASE	FRBDAM	PFAC	SFAC	SNEW	RANGE	GZ
DS/P7.1.0	1.55186	0.00062685	1	0.97908	18.3784	0.33138
DS/P9.2.0	2.08183	0.00219224	1	0.99039	19.2419	0.40523
DS/P9.3.0	2.06177	0.00103935	1	0.99005	19.2158	0.40702
DS/P12.3.0	1.58057	0.00467323	1	0.97896	18.3692	0.3441
DS/P12.4.0	1.52067	0.00031022	1	0.97901	18.3728	0.34377
DS/P13.3.0	1.62063	0.00174746	1	0.99968	19.9747	0.38756
DS/P13.4.0	1.55476	7.1133E-05	1	0.99984	19.9874	0.38762
DS/P15.2.0	1.39937	0.00055935	1	0.9942	19.5402	0.35839
DS/P16.2.0	1.32589	0.00119093	1	0.99521	19.6198	0.35494
DS/P17.3.0	1.47696	0.00219226	1	0.96937	17.6596	0.36252
DS/P3-4.2.0	1.3876	0.0103525	1	0.99554	19.6456	0.42484
DS/P3-4.3.0	1.1479	0.00425446	1	0.98031	18.4704	0.38971
DS/P4-5.4.0	0.889528	0.00427306	1	0.9893	19.1576	0.36461
DS/P5-6.1.0	1.26276	0.0141582	1	0.9956	19.65	0.36148
DS/P5-6.2.0	1.21775	0.00568708	1	0.99256	19.4116	0.35497
DS/P5-6.3.0	0.935599	0.00429994	1	0.97128	17.7996	0.30804
DS/P6-7.1.0	1.29122	0.00367361	1	0.97613	18.1574	0.32252
DS/P6-7.2.0	1.28586	0.00215015	1	0.97592	18.1421	0.32205
DS/P7-8.1.0	1.55186	0.0037478	1	0.97908	18.3784	0.33138
DS/P7-8.2.0	1.54977	0.0020471	1	0.97962	18.4188	0.33233
DS/P13-14.3.0	0.980457	4.7511E-05	1	0.94883	16.2097	0.24665
DS/P13-14.4.0	0.980457	0.00126486	1	0.94883	16.2097	0.24665
DS/P13-14.5.0	0.914176	0.00010062	1	0.94899	16.2211	0.24186
DS/P14-15.4.0	1.13533	0.00086763	1	0.98566	18.8768	0.33514
DS/P2-4.1.0	1.70526	0.00301186	1	0.99405	19.5278	0.40653
DS/P2-4.2.0	0.877243	0.00335629	1	0.95613	16.7146	0.31589
DS/P6-8.1.0	1.29122	0.013987	1	0.97613	18.1574	0.32252
DS/P6-8.2.0	1.28586	0.00036184	1	0.97592	18.1421	0.32205
DS/P6-8.3.0	1.18953	0.0100722	1	0.968	17.5601	0.30697
DS/P8-10.1.0	1.3775	0.00791514	1	0.94854	16.1901	0.28447
DS/P13-15.3.0	0.897168	0.0001123	1	0.94883	16.2097	0.24665
DS/P13-15.4.0	0.897168	0.00043273	1	0.94883	16.2097	0.24665
DS/P14-16.3.0	0.903165	0.00012554	1	0.96738	17.515	0.25657
DS/P1-4.1.0	1.70526	0.00235351	1	0.99405	19.5278	0.40653
DS/P1-4.2.0	0.877243	0.00262265	1	0.95613	16.7146	0.31589
DS/P9-12.1.0	1.84172	0.00068518	1	0.97631	18.1707	0.30378
DS/P9-12.2.0	1.66227	0.00114687	1	0.96829	17.5813	0.31016
DS/P10-13.1.0	1.89734	0.00059096	1	0.99757	19.806	0.31656
DS/P10-13.2.0	1.70388	0.00043571	1	0.98859	19.1024	0.32091
DS/P15-18.2.0	0.82947	0.0016173	1	0.96112	17.0665	0.30643
DS/P16-19.1.0	1.05291	0.00052584	1	0.99227	19.3887	0.43344

DS/P16-19.2.0	0.322423	0.00222051	1	0.94697	16.083	0.29217
DS/P17-20.2.0	0.799974	0.00212278	1	0.98321	18.6899	0.41415
DS/P10-14.1.0	1.59332	9.4224E-05	1	0.95928	16.9357	0.21762
DS/P13-17.3.0	1.16908	0.00111078	1	0.99823	19.859	0.35645
DS/P14-18.2.0	0.82947	0.00016441	1	0.96112	17.0665	0.30643
DS/P15-19.1.0	0.491558	0.00020363	1	0.94673	16.0667	0.27764
DS/P16-20.1.0	0.626057	0.00017827	1	0.97064	17.7529	0.36548
DS/P17-21.1.0	1.14422	0.00038008	1	0.99932	19.9458	0.50668
DS/P17-21.2.0	0.345423	0.00160499	1	0.95049	16.3237	0.3389
DP/P7.1.0	1.85247	0.00062685	1	0.99611	19.6902	0.37176
DP/P10.2.0	1.72486	0.00467323	1	0.95443	16.5964	0.31342
DP/P10.3.0	1.69115	0.00031022	1	0.95511	16.6433	0.32027
DP/P11.2.0	1.60952	0.00460212	1	0.95502	16.6373	0.30671
DP/P11.3.0	1.57336	0.0003039	1	0.95589	16.6978	0.31217
DP/P12.3.0	1.91625	0.00467323	1	0.99553	19.6449	0.36189
DP/P12.4.0	1.8569	0.00031022	1	0.99578	19.6643	0.36367
DP/P17.3.0	1.90221	0.00219226	1	0.99116	19.3024	0.38891
DP/P3-4.3.0	1.50325	0.00425446	1	0.99855	19.8843	0.43051
DP/P5-6.3.0	1.22283	0.00429994	1	0.98718	18.9942	0.34634
DP/P6-7.1.0	1.60133	0.00367361	1	0.99561	19.651	0.36969
DP/P6-7.2.0	1.59602	0.00215015	1	0.99557	19.6477	0.36951
DP/P7-8.1.0	1.85247	0.0037478	1	0.99611	19.6902	0.37176
DP/P7-8.2.0	1.85153	0.0020471	1	0.99694	19.7565	0.3737
DP/P13-14.3.0	1.32311	4.7511E-05	1	0.96572	17.3953	0.26821
DP/P13-14.4.0	1.32311	0.00126486	1	0.96572	17.3953	0.26821
DP/P13-14.5.0	1.2579	0.00010062	1	0.96627	17.4348	0.26827
DP/P15-16.2.0	1.15356	0.00040084	1	0.95518	16.6485	0.23594
DP/P15-16.3.0	1.15356	0.00345774	1	0.95518	16.6485	0.23594
DP/P2-4.2.0	1.31518	0.00335629	1	0.97877	18.3549	0.35756
DP/P2-4.3.0	1.00341	0.00151386	1	0.96045	17.019	0.32059
DP/P6-8.1.0	1.60133	0.013987	1	0.99561	19.651	0.36969
DP/P6-8.2.0	1.59602	0.00036184	1	0.99557	19.6477	0.36951
DP/P6-8.3.0	1.49334	0.0100722	1	0.98858	19.102	0.35472
DP/P8-10.1.0	1.63755	0.00791514	1	0.96497	17.3415	0.31397
DP/P13-15.3.0	1.24845	0.0001123	1	0.96572	17.3953	0.26821
DP/P13-15.4.0	1.24845	0.00043273	1	0.96572	17.3953	0.26821
DP/P14-16.3.0	1.31952	0.00012554	1	0.98353	18.7148	0.27831
DP/P1-4.2.0	1.31518	0.00262265	1	0.97877	18.3549	0.35756
DP/P1-4.3.0	1.00341	0.00118295	1	0.96045	17.019	0.32059
DP/P9-12.1.0	2.11303	0.00068518	1	0.98512	18.836	0.31053
DP/P9-12.2.0	1.93222	0.00114687	1	0.97741	18.2529	0.31632
DP/P10-13.2.0	1.97629	0.00043571	1	0.99513	19.6135	0.31945

DP/P15-18.2.0	1.13891	0.0016173	1	0.97706	18.2268	0.31602
DP/P16-19.2.0	0.660499	0.00222051	1	0.96563	17.3887	0.31997
DP/P17-20.2.0	1.14469	0.00212278	1	0.99773	19.8192	0.44608
DP/P10-14.1.0	1.87563	9.4224E-05	1	0.96617	17.428	0.20302
DP/P14-18.2.0	1.13891	0.00016441	1	0.97706	18.2268	0.31602
DP/P14-18.3.0	0.822241	0.00013846	1	0.96033	17.0106	0.2933
DP/P15-19.1.0	0.826575	0.00020363	1	0.96319	17.214	0.29692
DP/P16-20.1.0	0.969545	0.00017827	1	0.98565	18.8767	0.39526
DP/P17-21.2.0	0.700341	0.00160499	1	0.97171	17.8313	0.38071
DL/P8-9.2.0	2.13402	0.00529871	1	0.96218	17.1415	0.35048
DL/P8-9.3.0	2.11021	0.00427816	1	0.96128	17.0776	0.35236
DL/P16-17.3.0	1.84511	0.00031822	1	0.99378	19.5072	0.38538
DL/P16-17.4.0	1.42763	0.00455101	1	0.95822	16.861	0.31683
DL/P17-18.3.0	1.70723	0.00495205	1	0.95956	16.9555	0.37389
DL/P3-5.1.0	1.59128	0.00354374	1	0.99284	19.433	0.40277
DL/P3-5.2.0	0.812072	0.00394901	1	0.95671	16.7556	0.30824
DL/P3-5.3.0	0.812072	3.6403E-06	1	0.95671	16.7556	0.30824
DL/P4-6.1.0	0.833111	0.00513479	1	0.9715	17.8153	0.32316
DL/P7-9.1.0	1.7656	0.00153439	1	0.98055	18.4889	0.34137
DL/P12-14.6.0	1.13964	0.00017463	1	0.94813	16.1622	0.22303
DL/P13-15.5.0	1.43918	0.00338447	1	0.99442	19.557	0.35922
DL/P13-15.6.0	1.37674	0.00044685	1	0.99535	19.6303	0.35971
DL/P2-5.1.0	0.974921	0.00079913	1	0.94901	16.222	0.2793
DL/P6-9.1.0	1.47141	0.00480172	1	0.97868	18.3484	0.33475
DL/P6-9.2.0	1.46789	0.00012275	1	0.97864	18.3453	0.33444
DL/P13-16.4.0	1.29516	0.00038209	1	0.97239	17.8811	0.25485
DL/P1-5.1.0	0.974921	0.00057601	1	0.94901	16.222	0.2793
DL/P9-13.1.0	2.33692	0.00012893	1	0.99284	19.4334	0.32121
DL/P9-13.2.0	2.13693	9.5045E-05	1	0.98436	18.7776	0.32591
DL/P10-14.2.0	2.13414	6.9482E-05	1	0.99578	19.6646	0.29821
DL/P15-19.2.0	0.732376	0.00083413	1	0.9672	17.5025	0.31025
DL/P16-20.2.0	0.867244	0.00075277	1	0.98931	19.1586	0.41791
DS/S9.2.0	2.08183	0.00219224	1	0.99039	19.2419	0.40523
DS/S9.3.0	2.06177	0.00103935	1	0.99005	19.2158	0.40702
DS/S12.3.0	1.58057	0.00467323	1	0.97896	18.3692	0.3441
DS/S12.4.0	1.52067	0.00031022	1	0.97901	18.3728	0.34377
DS/S13.3.0	1.62063	0.00174746	1	0.99968	19.9747	0.38756
DS/S13.4.0	1.55477	7.1133E-05	1	0.99984	19.9874	0.38762
DS/S15.2.0	1.39937	0.00055935	1	0.9942	19.5402	0.35839
DS/S16.2.0	1.32589	0.00119093	1	0.99521	19.6198	0.35494
DS/S17.3.0	1.47696	0.00219226	1	0.96937	17.6596	0.36252
DS/S3-4.2.0	1.35015	0.0103525	1	0.99201	19.3687	0.41669

DS/S3-4.3.0	1.15879	0.00425446	1	0.98107	18.528	0.39189
DS/S4-5.4.0	0.899539	0.00427306	1	0.98976	19.1931	0.36636
DS/S5-6.1.0	1.26276	0.0145217	1	0.9956	19.65	0.36149
DS/S6-7.1.0	1.29122	0.00376479	1	0.97613	18.1575	0.32252
DS/S6-7.2.0	1.21112	0.00205897	1	0.96962	17.6783	0.3098
DS/S13-14.3.0	0.980459	4.7511E-05	1	0.94883	16.2097	0.24665
DS/S13-14.4.0	0.980459	0.00126486	1	0.94883	16.2097	0.24665
DS/S13-14.5.0	0.914177	0.00010062	1	0.949	16.2213	0.24186
DS/S14-15.4.0	1.13533	0.00085921	1	0.98566	18.8769	0.33514
DS/S2-4.1.0	1.69358	0.00301186	1	0.99226	19.3876	0.40234
DS/S2-4.2.0	0.825122	0.00335629	1	0.95137	16.3841	0.30681
DS/S6-8.1.0	1.29122	0.013987	1	0.97613	18.1575	0.32252
DS/S6-8.2.0	1.26544	0.00036184	1	0.97402	18.0013	0.31844
DS/S6-8.3.0	1.18551	0.0054319	1	0.96742	17.5184	0.3057
DS/S6-8.4.0	1.16904	0.00464033	1	0.96606	17.4198	0.30316
DS/S8-10.1.0	1.3775	0.00771785	1	0.94854	16.1901	0.28447
DS/S8-10.2.0	1.35133	0.00019729	1	0.9462	16.0313	0.28063
DS/S13-15.3.0	0.89717	0.0001123	1	0.94883	16.2097	0.24665
DS/S13-15.4.0	0.89717	0.00043273	1	0.94883	16.2097	0.24665
DS/S14-16.3.0	0.903166	0.00012554	1	0.96737	17.5149	0.25657
DS/S1-4.1.0	1.69358	0.00235351	1	0.99226	19.3876	0.40234
DS/S1-4.2.0	0.825122	0.00262265	1	0.95137	16.3841	0.30681
DS/S7-10.1.0	1.36288	0.00058622	1	0.94854	16.1901	0.28447
DS/S7-10.2.0	1.33666	1.4987E-05	1	0.9462	16.0313	0.28063
DS/S9-12.1.0	1.84172	0.00068518	1	0.97631	18.1707	0.30378
DS/S9-12.2.0	1.66227	0.00114687	1	0.96829	17.5813	0.31016
DS/S10-13.1.0	1.89734	0.00059096	1	0.99757	19.806	0.31656
DS/S10-13.2.0	1.70388	0.00043571	1	0.98859	19.1024	0.32091
DS/S15-18.2.0	0.82947	0.0016173	1	0.96112	17.0665	0.30643
DS/S16-19.1.0	1.05291	0.00052584	1	0.99227	19.3887	0.43343
DS/S16-19.2.0	0.322424	0.00222051	1	0.94697	16.0831	0.29217
DS/S17-20.2.0	0.799973	0.00212278	1	0.98321	18.69	0.41415
DS/S10-14.1.0	1.59332	9.4224E-05	1	0.95928	16.9357	0.21762
DS/S13-17.3.0	1.16908	0.00111078	1	0.99823	19.859	0.35645
DS/S14-18.2.0	0.82947	0.00016441	1	0.96112	17.0665	0.30643
DS/S15-19.1.0	0.491558	0.00020363	1	0.94673	16.0668	0.27764
DS/S16-20.1.0	0.626057	0.00017827	1	0.97064	17.7528	0.36548
DS/S17-21.1.0	1.14422	0.00038008	1	0.99932	19.9458	0.50669
DS/S17-21.2.0	0.345423	0.00160499	1	0.95049	16.3237	0.3389

Following damage cases where the original s-factor was 1 but the new s-factor <1 have been investigated in detail. For all the damage cases the lack of range is the criterion, while sufficient GZ is available.

Table 4 Damage cases shown in detail

CASE	FRBDAM	PFAC	VFAC	SFAC	SNEW	RANGE	GZ
DS/P7.1.0	1.55186	0.00062685	1	1	0.97908	18.3784	0.33138
DS/P12.3.0	1.58057	0.00467323	1	1	0.97896	18.3692	0.3441
DS/P5-6.1.0	1.26276	0.0141582	1	1	0.9956	19.65	0.36148

11.1.4.1 Damage DS/P17-18.3.0

This damage DS/P17-18.3.0 is a typical example on how the different formulations for the s-factor contribute to the index.

The extent of the damage and the flooding position can be seen in the figures below.

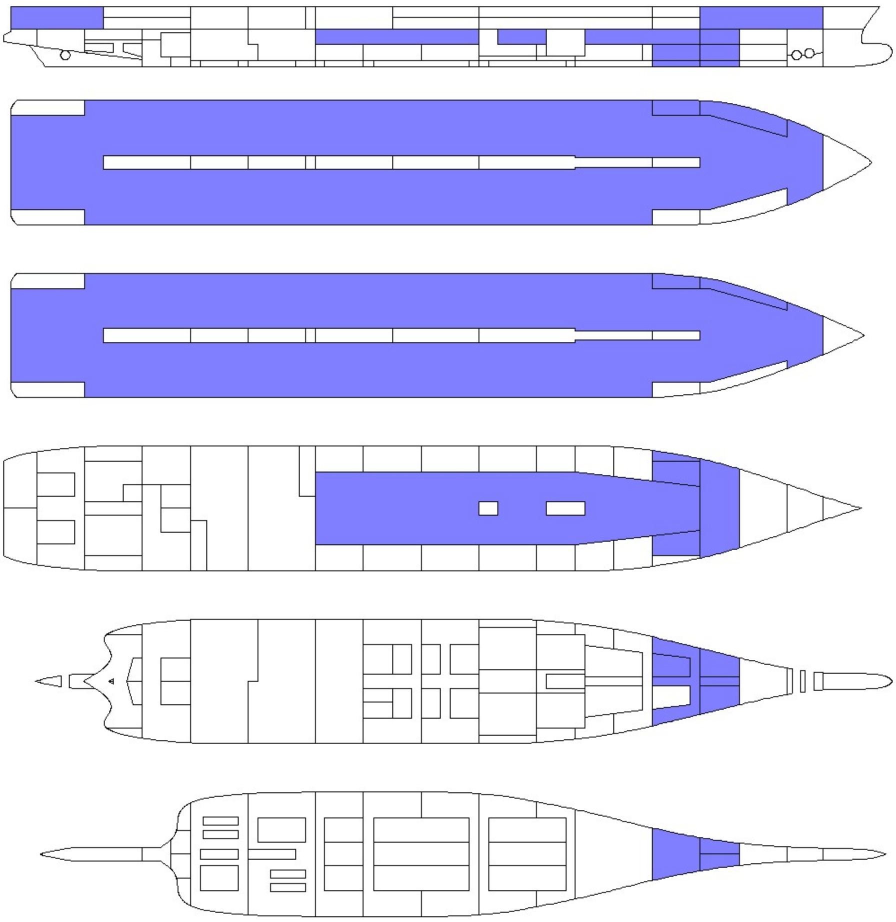

Figure 20 Extent of damage

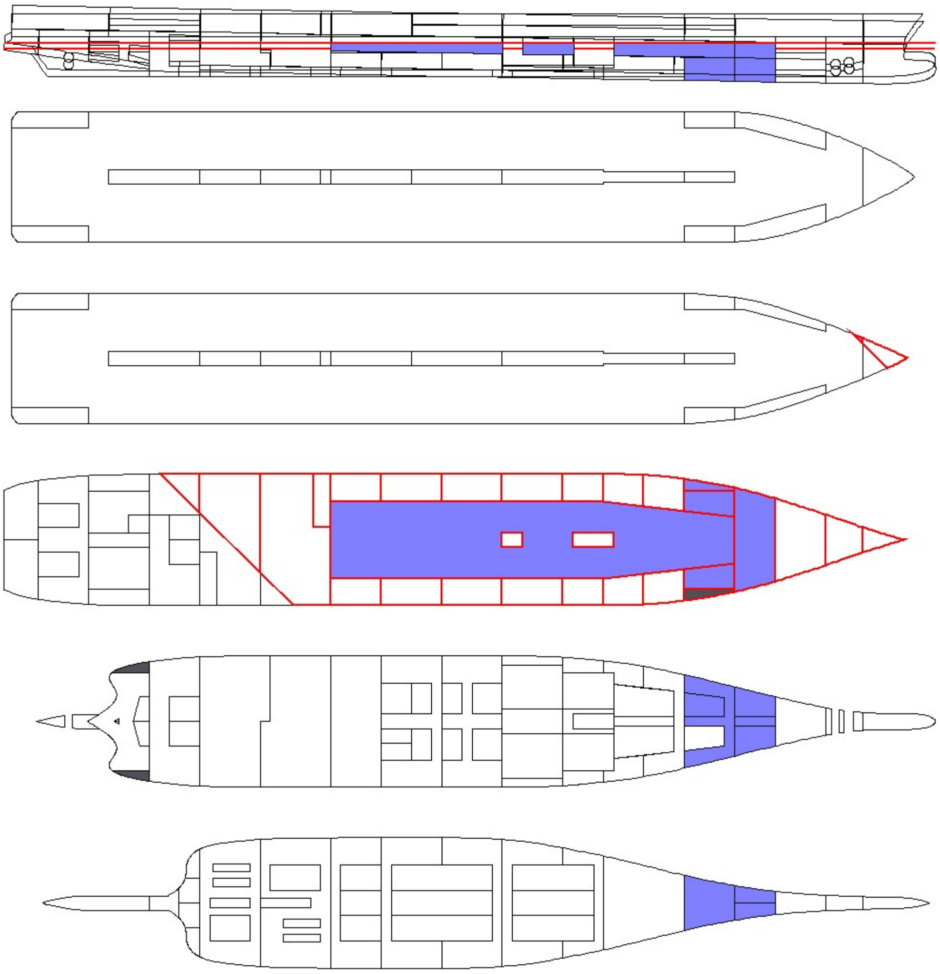

Figure 21 Floating position

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASE	SIDE	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
DS/P17-18.3.	INTACT	EQ	-	6.700	0.000	0.0	-	-	-
DS/P17-18.3.	FIRST	EQ	PS	8.032	-3.781	1.0	3.50	EX91P	-

This damage case has following s-factors:

According SOLAS 2009: s=0.8963

According SLF55 s=0.7768

Based on following GZ curve:

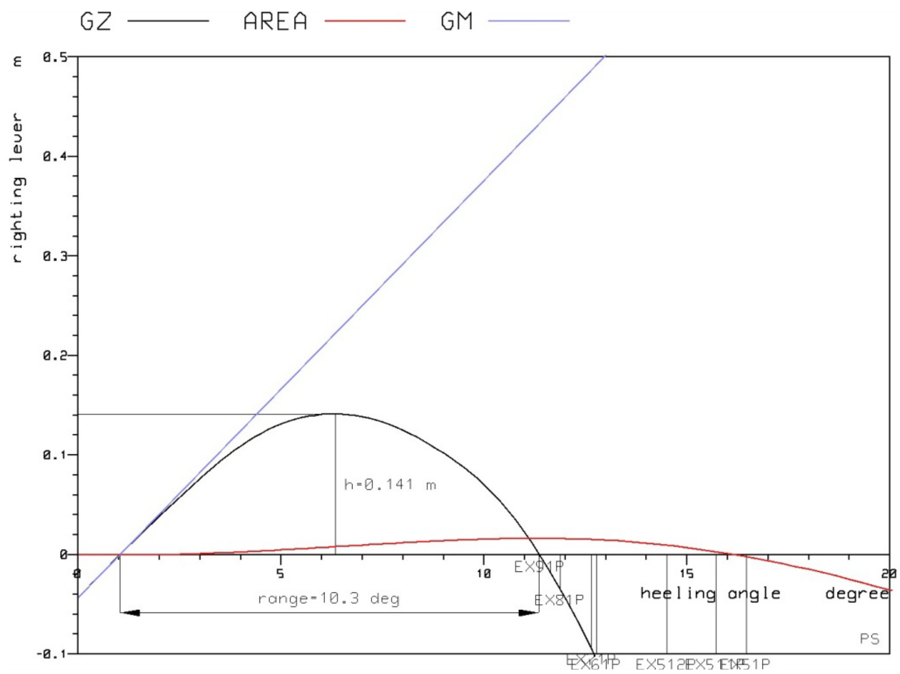

Figure 22 GZ curve

Although this case is still a survivable condition with a significant difference in the s-factor the overall contribution to A is small, as the corresponding p-factor for this damage is only 0.00495. The resulting delta A is only 0.594E-3.

11.1.4.2 Damage DS/P7.1.0

The extent of the damage and the flooding position can be seen in the figures below.

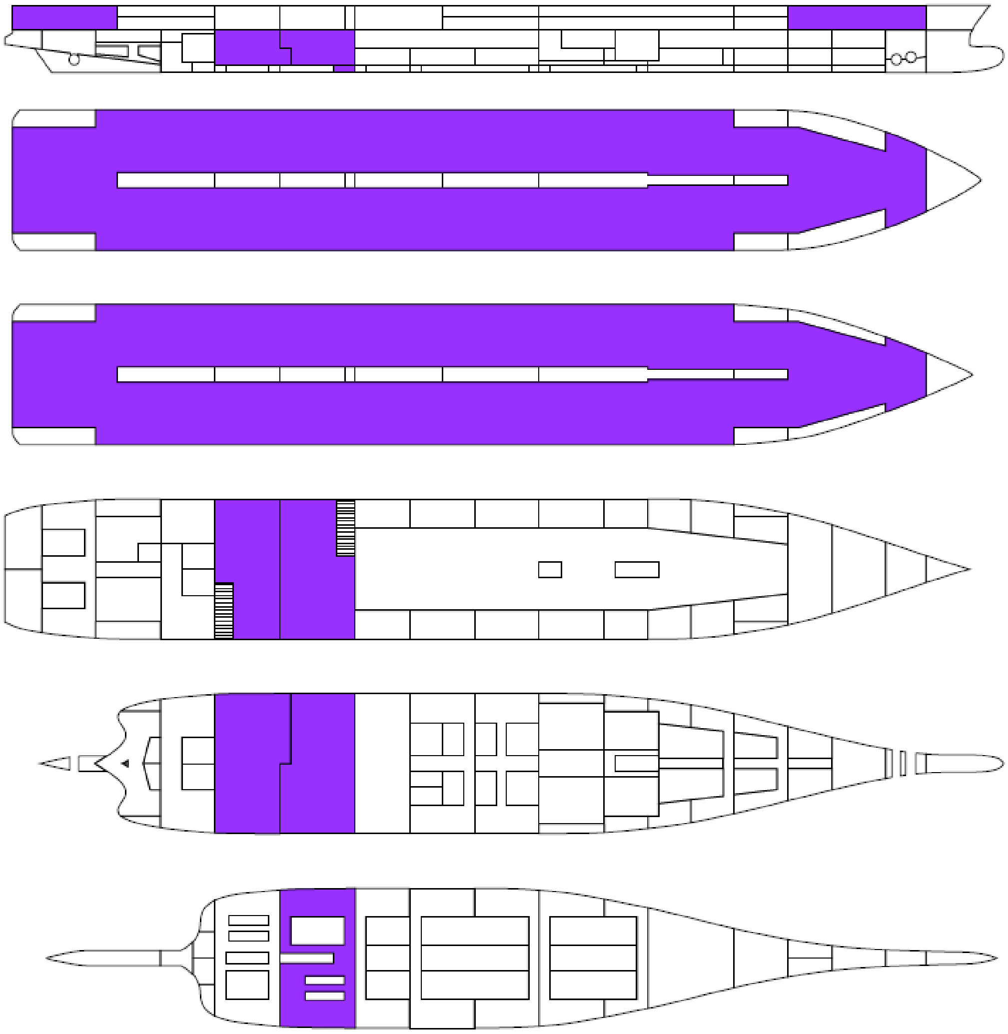

Figure 23 Extent of damage

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASE	SIDE	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
DS/P7.1.0	INTACT	EQ	-	6.700	0.000	0.0	-	-	-
DS/P7.1.0	FIRST	EQ	SB	7.516	2.197	0.0	4.81	EX51S	-
DS/P7.1.0	INT1	EQ	SB	7.557	2.313	-0.2	4.73	EX51S	-

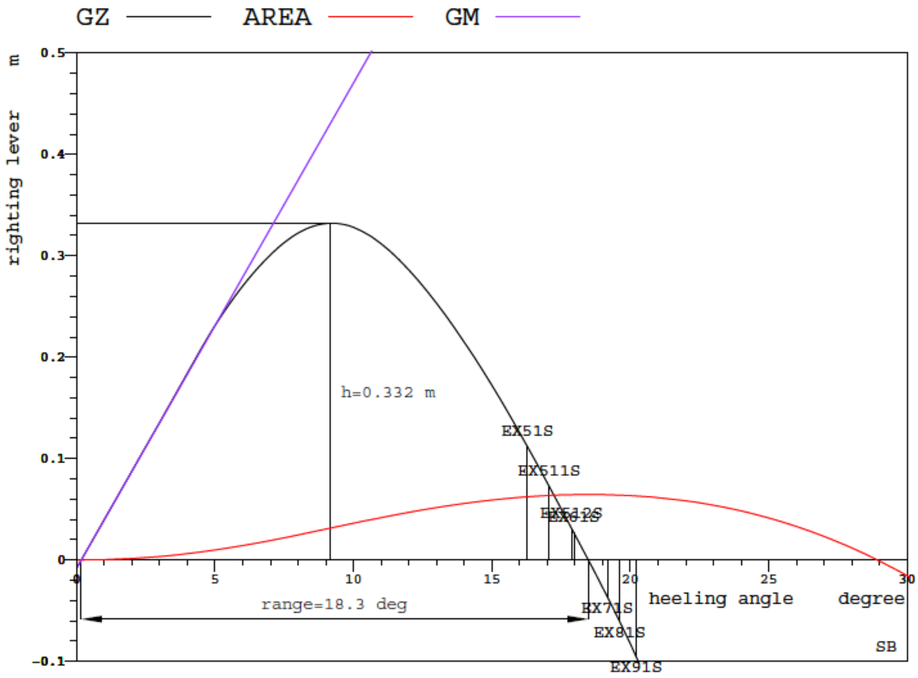

Figure 24 GZ curve

11.1.4.3 Damage DS/P12.3.0

The extent of the damage and the flooding position can be seen in the figures below.

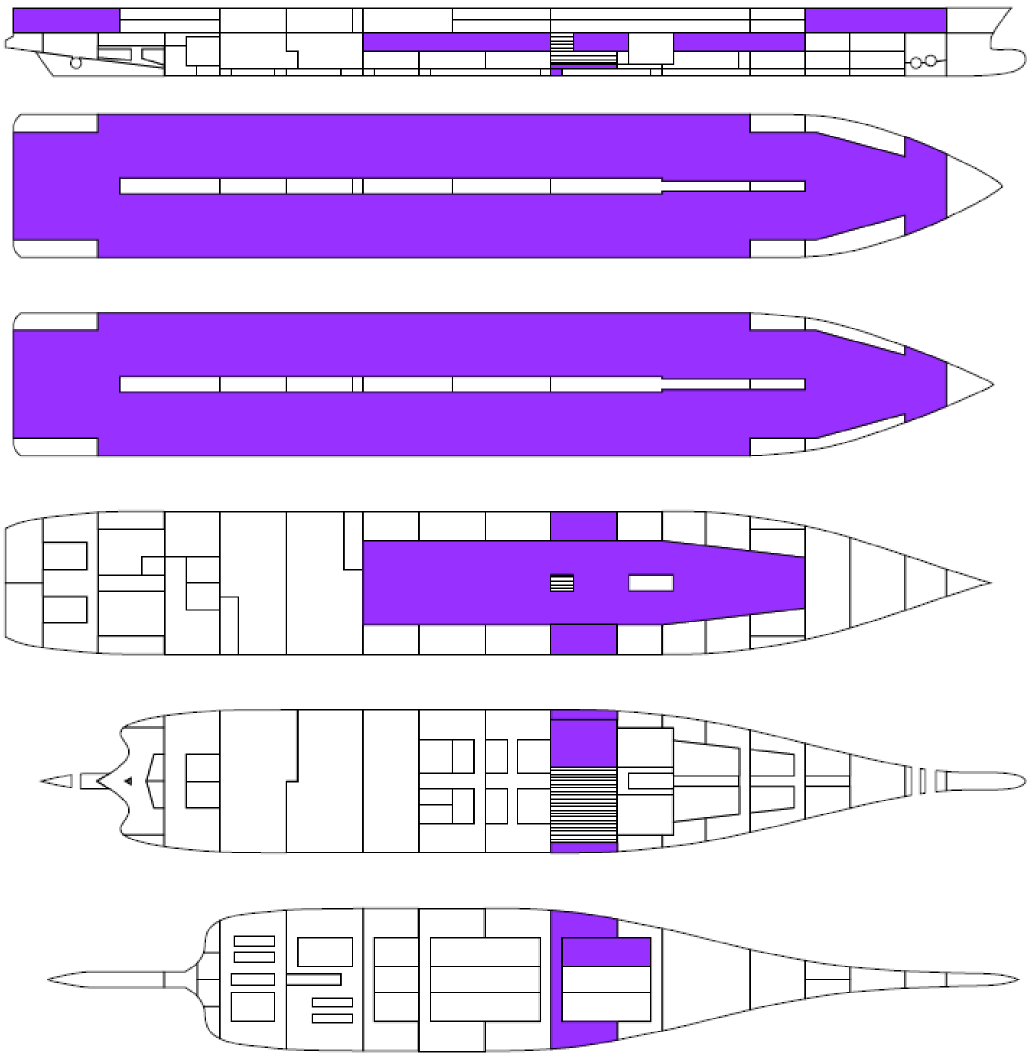

Figure 25 Extent of damage

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASE	SIDE	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
DS/P12.3.0	INTACT	EQ	-	6.700	0.000	0.0	-	-	-
DS/P12.3.0	FIRST	EQ	PS	7.554	-1.553	2.5	4.03	EX91P	-
DS/P12.3.0	INT1	EQ	PS	7.605	-1.640	2.5	3.97	EX91P	-
DS/P12.3.0	INT2	EQ	PS	7.696	-1.779	0.8	4.32	EX91P	-

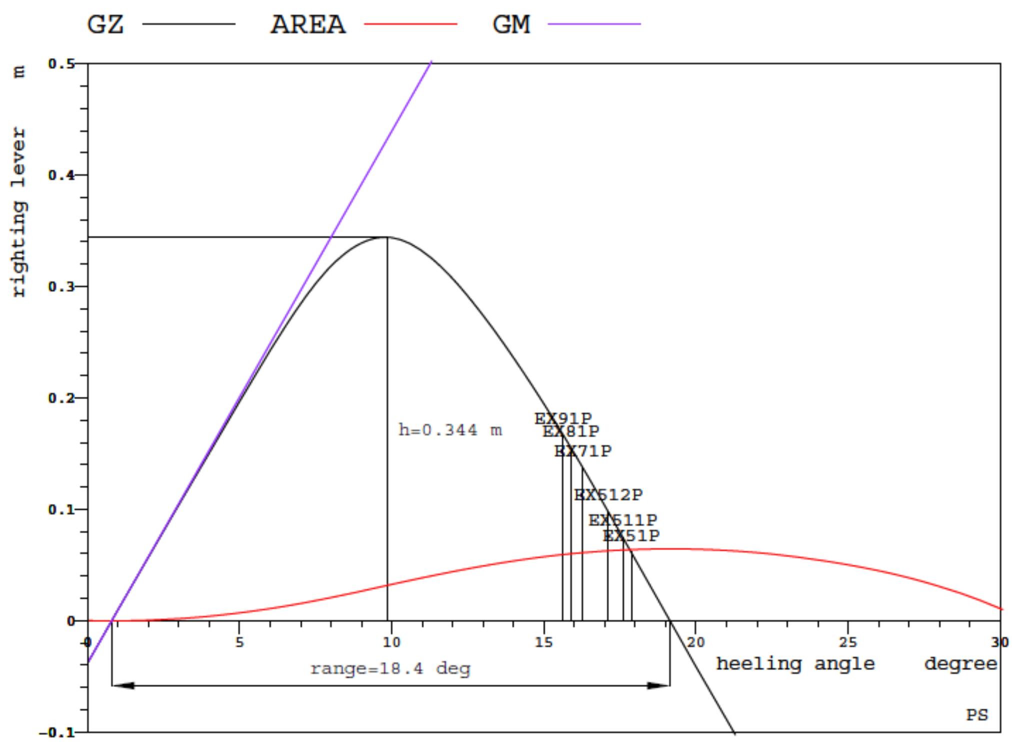

Figure 26 GZ curve

11.1.4.4 Damage DS/P5-6.1.0

The extent of the damage and the flooding position can be seen in the figures below.

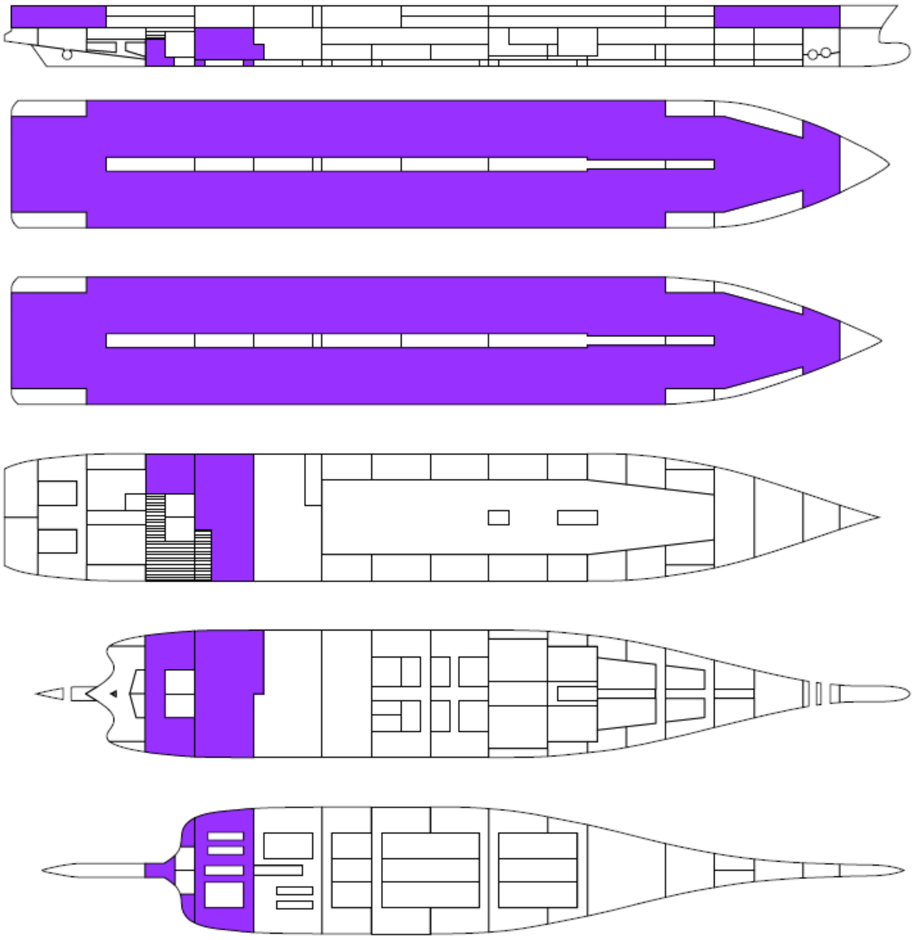

Figure 27 Extent of damage

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASE	SIDE	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
DS/P5-6.1.0	INTACT	EQ	-	6.700	0.000	0.0	-	-	-
DS/P5-6.1.0	FIRST	EQ	PS	7.260	2.365	2.0	4.54	EX51P	-
DS/P5-6.1.0	INT1	EQ	PS	7.305	2.556	0.7	4.81	EX51P	-

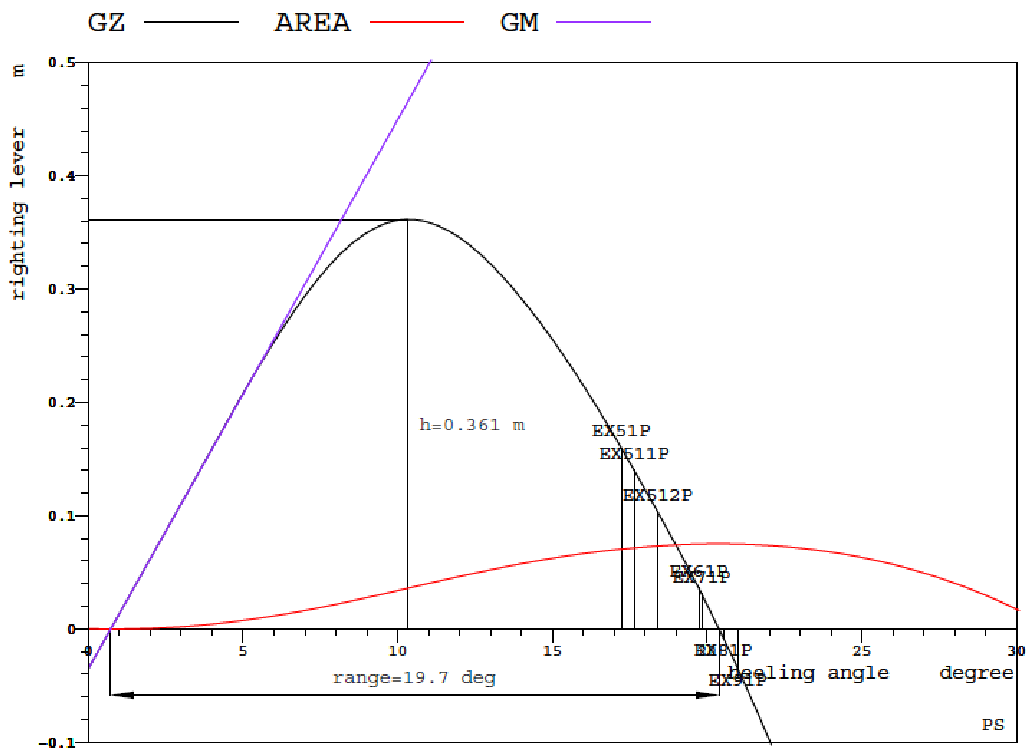

Figure 28 GZ curve

11.2 Results for the medium RoPax

11.2.1 Results according to SOLAS 2009

The results of the damage stability calculation according SOLAS2009 are as follows:

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length	182.0 m
Breadth at the load line	27.6 m
Breadth at the bulkhead deck	27.6 m
Number of persons N1	660
Number of persons N2	1540
Required subdivision index	R = 0.79804
Attained subdivision index	A = 0.80984

The distribution of the index for the different draughts and damages from both sides are:

INIT	T	GM	A/R	A	WCOEF	A*WCOEF
DL	6.10 m	2.70 m	1.13	0.90033	0.2	0.18007

DP	6.70 m	1.90 m	0.99	0.79295	0.4	0.31718
DS	7.10 m	2.00 m	0.98	0.78149	0.4	0.31260
						0.80984

The distribution on the multi-zone damages is shown in the table below:

Multizone Damages		
DAMAGES	W*P*V*S	W*P*V
1-ZONE DAMAGES	0.31966	0.32067
2-ZONE DAMAGES	0.32182	0.34717
3-ZONE DAMAGES	0.13161	0.18346
4-ZONE DAMAGES	0.02995	0.06568
5-ZONE DAMAGES	0.00679	0.02781
A-INDEX TOTAL	**0.80984**	**0.94478**

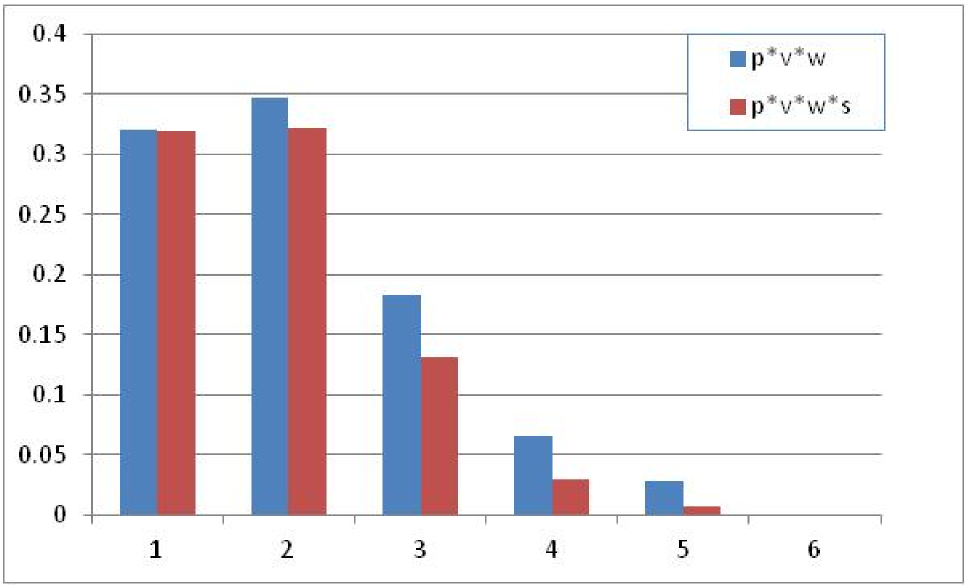

Figure 29 Attained Index for multi-zone damages

From the table above it can be seen that not all possible damage cases are considered in the index calculation. This is a usual approach to allow some dedicated to be used for open systems and ducts, which may cause significant progressive flooding in a case of damage.

The figure below shows the distribution of the not investigated damages and those damages which contributes to the index and those which have s=0 and do not contribute.

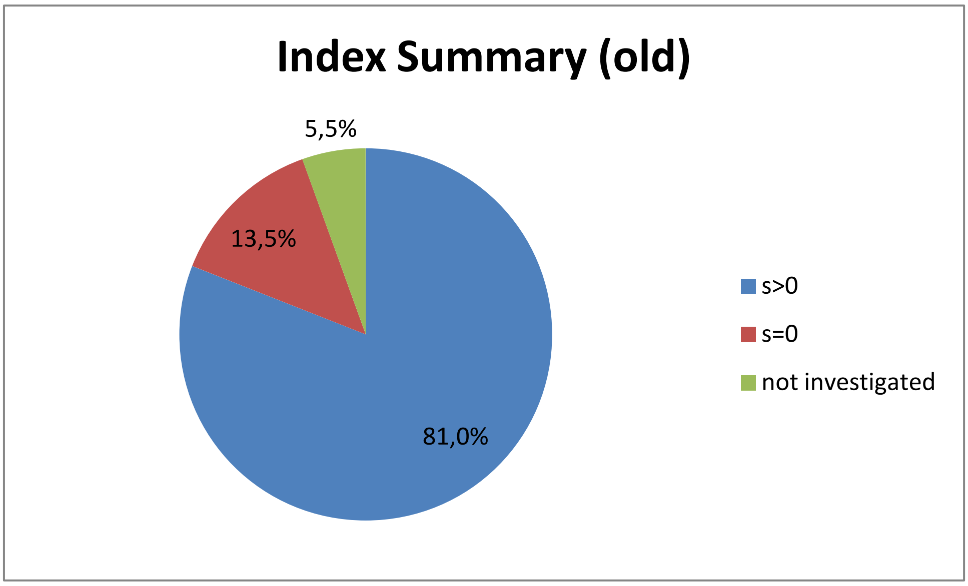

Figure 30 Distribution of cases where s>0 and s=0

Those damage cases which have been investigated have a typical distribution of the achieved s-values. The majority of the damages have s=1 while about 13% of the damages cannot be survived.

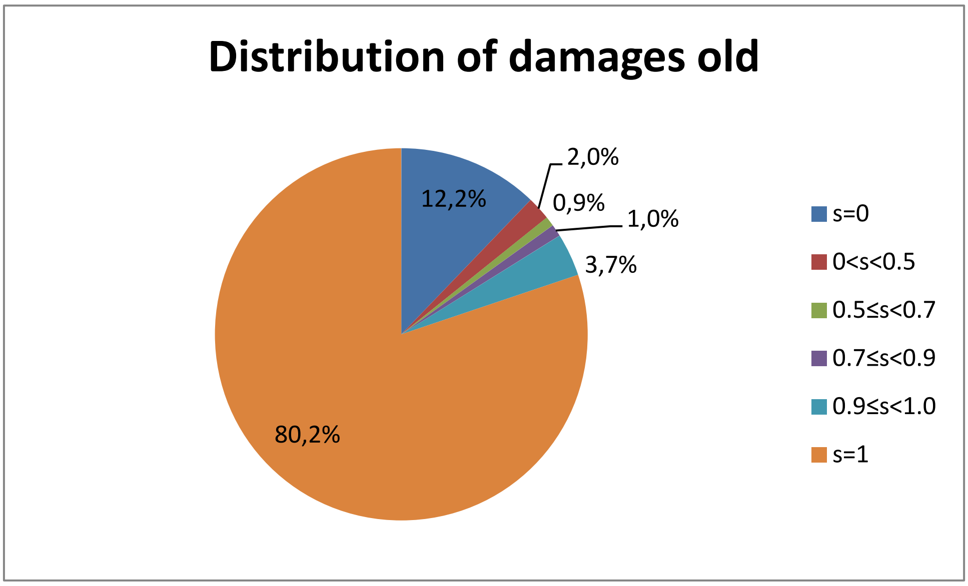

Figure 31 Distribution of s-factor

11.2.2 Results with new s –factor

When applying the new s-factor for the damages where the roro deck is penetrated the attained index is as follows:

Attained index acc. SOLAS2009 A = 0.80984
Attained index with s-new A = 0.80255

For the different initial conditions the result is

DL:
Attained index acc. SOLAS 2009 A = 0.90033
Attained index with s-new A = 0.89794
DP:
Attained index acc. SOLAS 2009 A = 0.79295
Attained index with s-new A = 0.78742
DS:
Attained index acc. SOLAS 2009 A = 0.78149
Attained index with s-new A = 0.76998

The difference between the calculation methods for the attained index is higher at the deepest and partial subdivision draught where the initial GM value is lower compared to lightest draught therefore a lower value of GZMAX has been obtained.

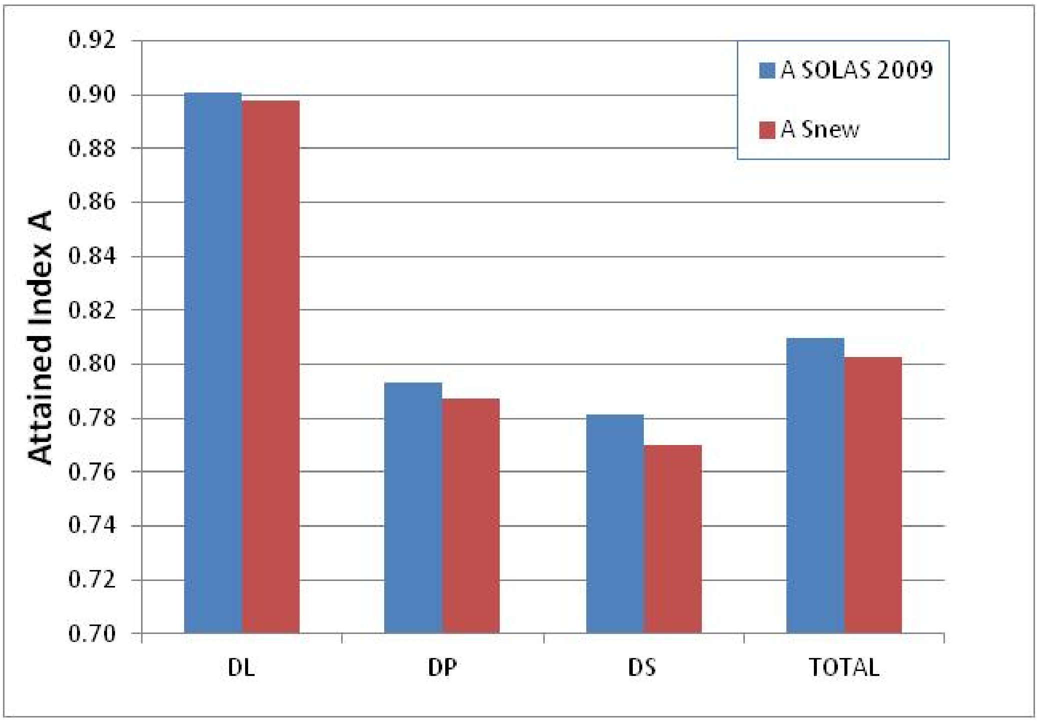

Figure 32 Attained index comparison

The figure below shows the distribution of the not investigated damages and those damages which contributes to the index and those which have s=0 and do not contribute.

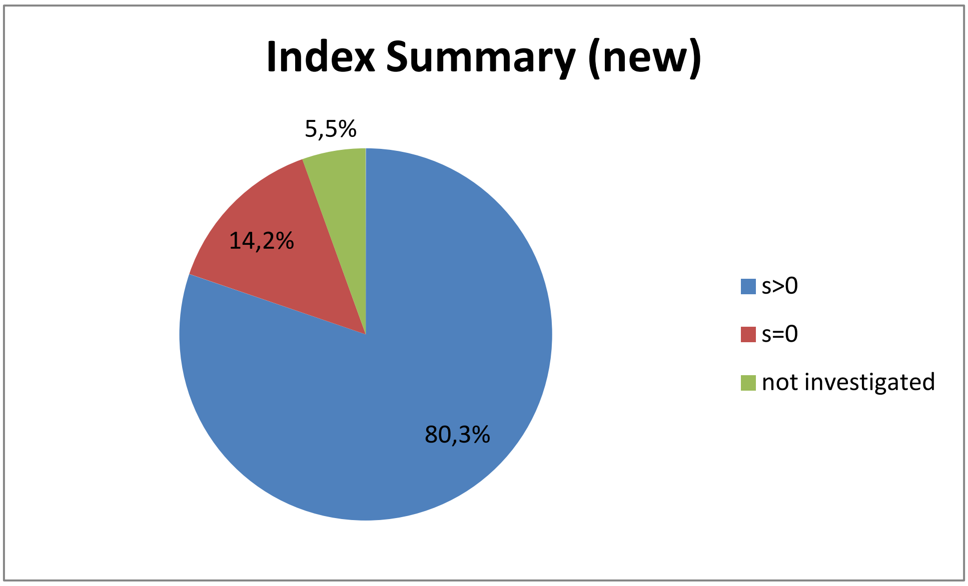

Figure 33 Distribution of s-new

Those damage cases which have been investigated have a typical distribution of the achieved s-values. The majority of the damages still has s=1 while only about 12% of the damages cannot be survived. However compared with the old method the portion of damages with 0.9≤s<1 but has been increased from 3.7% to 11.4% and portion with s=1 has been reduced from 80% to 70%.

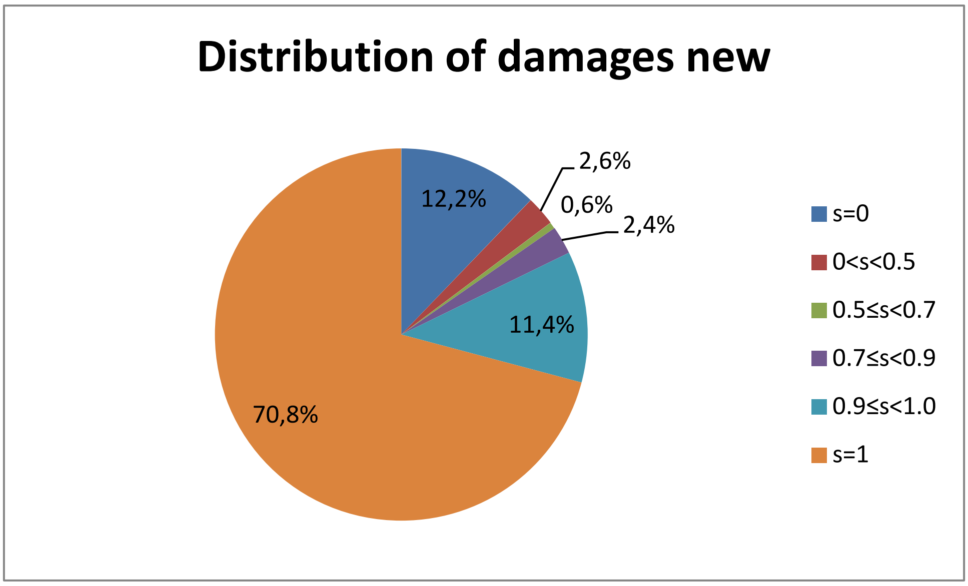

Figure 34 Detailed distribution of s-new

The relatively small impact of the new method on the attained index can be explained with the distribution of damages related to range and GZ.

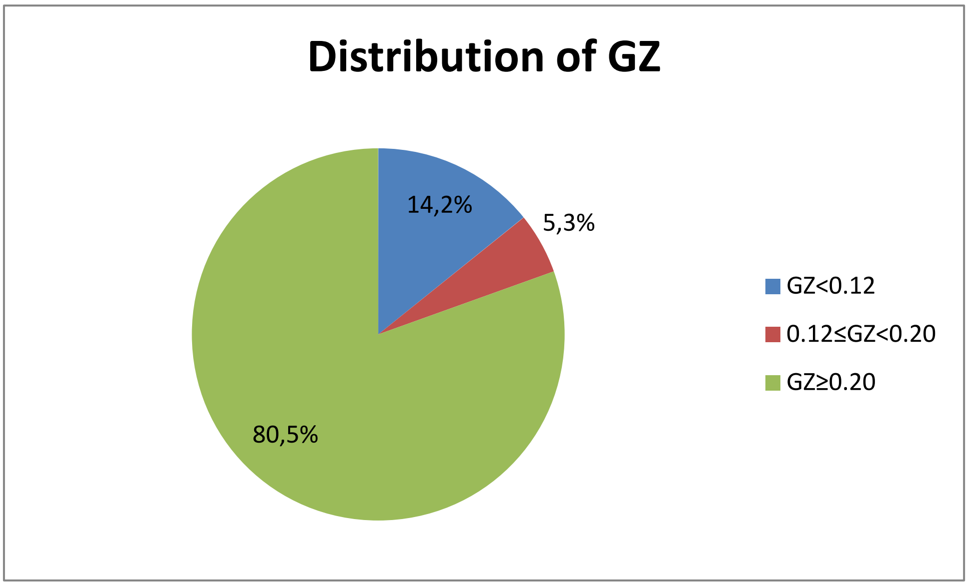

Figure 35 Distribution of GZ values

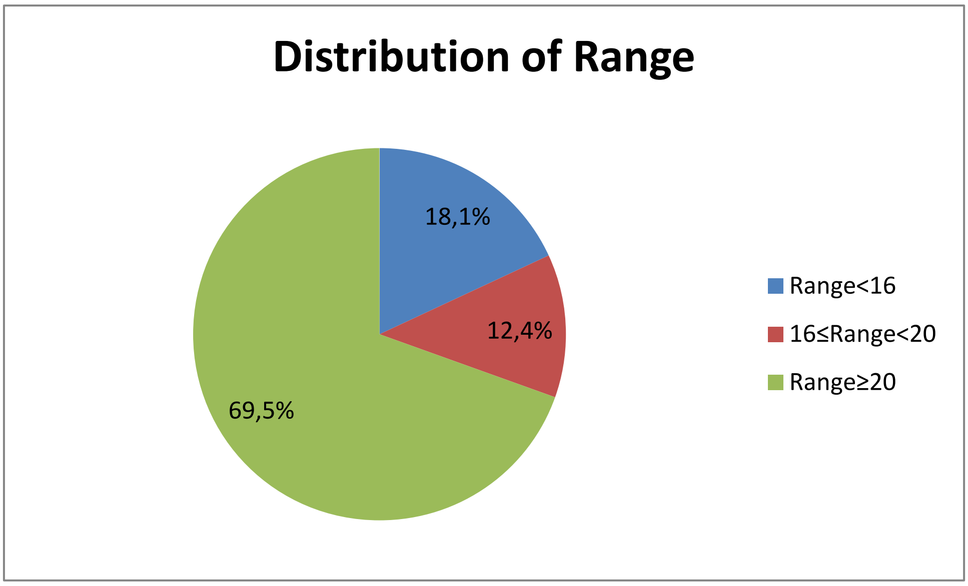

Figure 36 Distribution of Range values

For this ship most of the damage cases already have a higher GZ values and a bigger range than requested by SOLAS2009. Therefore the effect of the raised requirement is marginal.

When calculating the percentages the p-factors have been considered to reflect not only the number of damage cases, but the probability of their occurrence.

11.2.3 GM limiting curves

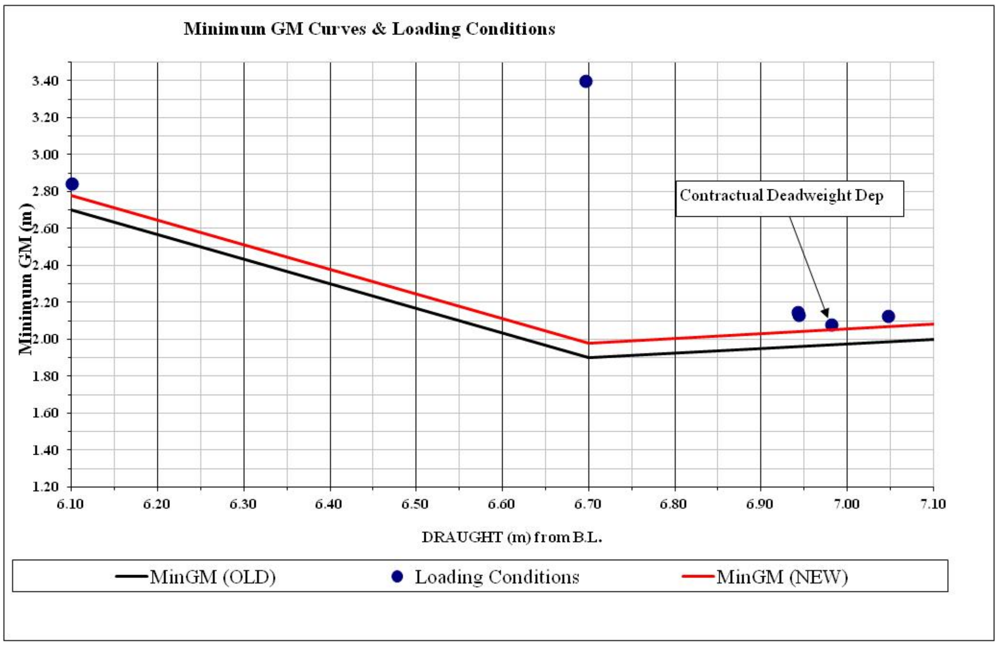

Figure 37 GM Limiting curve

When comparing the GM requirements derived from the two methods it can be seen that the new s-factor results in raising the GM limiting curve by 8 cm.

Although the original loading conditions are just above the new GM limiting curve the effect cannot be neglected. To maintain a similar margin to the limit curve a reduction of cargo of approximately 100t on the upper trailer deck.

11.2.4 Comparison of individual damage cases

Some damage cases have been investigated in more detail. First of all the effect of the new s-factor formulation is to be demonstrated for a typical damage case involving the large lower hold.

Secondly some of the damage cases, which have an s-factor=1 according the old formulation, but s-new<1 for the new formulation have been investigated. In total 8.8% of the damage cases which falls in this category. When calculating the percentages the p-factors have been considered to reflect not the number of damage cases, but the probability of occurrence.

The figure below shows the distribution of damage cases, and their change in s-factor.

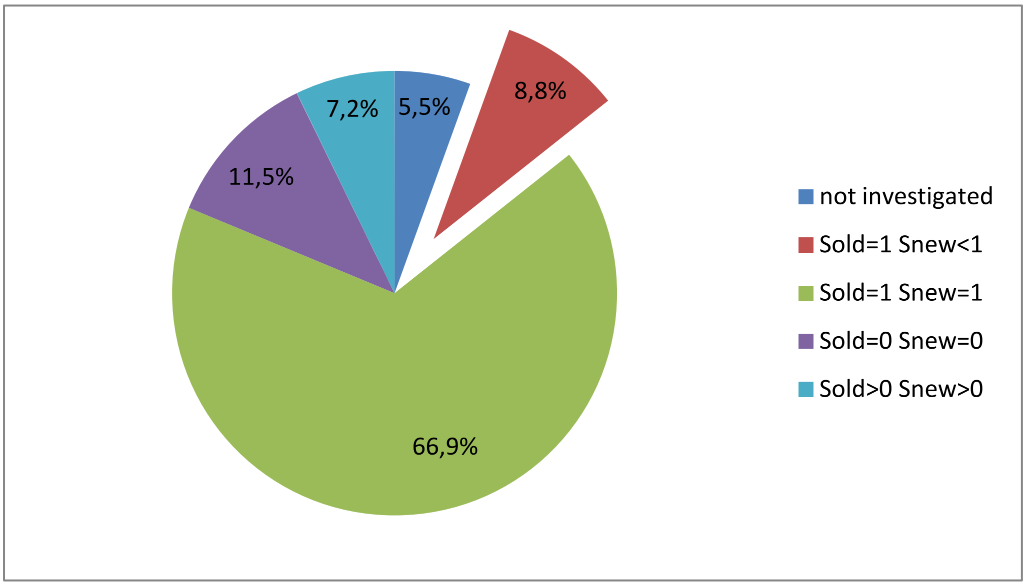

Figure 38 Distribution of change of s

Following damage cases where the original s-factor was 1 but the new s-factor <1 have been investigated in detail. For all the damage cases the lack of range is the criterion, while sufficient GZ is available.

Table 5 Damage cases where sfac=1 and snew<1

CASE	PFAC	VFAC	SFAC	SNEW	0	RANGEF	GZMAXR
DL/DP9-10.2.0	0.00472	0.62051	1	0.99056	0	19.3	0.361
DL/DP9-10.3.0	0.00186	0.62051	1	0.98473	0	18.8	0.354
DL/DP9-10.4.0	0.00046	0.62051	1	0.98635	0	18.9	0.359
DL/DP11-12.2.0	0.00012	0.62051	1	0.95555	0	16.7	0.269
DL/DP12-13.2.0	0.00022	0.62051	1	0.99295	0	19.4	0.281
DL/DP12-13.3.0	0.00419	0.62051	1	0.99295	0	19.4	0.281
DL/DP12-13.4.0	0.00040	0.62051	1	0.97229	0	17.9	0.258
DL/DP12-13.5.0	0.00210	0.62051	1	0.97229	0	17.9	0.258
DL/DP13-14.3.0	0.00421	0.62051	1	0.98586	0	18.9	0.274
DL/DP13-14.4.0	0.00189	0.62051	1	0.96520	0	17.4	0.247
DL/DP7-9.4.0-2	0.00033	0.62051	1	0.99184	0	19.4	0.313
DL/DP7-9.5.0	0.00043	0.62051	1	0.99080	0	19.3	0.325
DL/DP7-9.6.0-2	0.00021	0.62051	1	0.99184	0	19.4	0.313
DL/DP1-4.5.0	0.00001	0.62051	1	0.99895	0	19.9	0.241
DL/DP3-6.4.0	0.00093	0.62051	1	0.98025	0	18.5	0.218
DL/DP3-6.5.0	0.00118	0.62051	1	0.98025	0	18.5	0.218
DL/DP3-6.6.0	0.00034	0.62051	1	0.98025	0	18.5	0.218
DL/DP3-6.7.0	0.00036	0.62051	1	0.97790	0	18.3	0.220
DL/DP3-6.8.0	0.00047	0.62051	1	0.96986	0	17.7	0.212
DL/DP9-12.1.0-4	0.00236	0.62051	1	0.96307	0	17.6	0.196
DL/DP10-13.1.0-3	0.00234	0.62051	1	0.92818	0	16.6	0.179

DL/DP11-14.1.0-1	0.00234	0.62051	1	0.97227	0	17.9	0.200
DL/DP1-5.5.0	0.00001	0.62051	1	0.99895	0	19.9	0.241
DL/DP12-16.1.0-1	0.00104	0.62051	1	0.98524	0	22.6	0.188
DP/DP10.2.0	0.00193	0.68205	1	0.94638	0	16.0	0.233
DP/DP14.2.0	0.00224	0.68205	1	0.96648	0	17.5	0.232
DP/DP15.2.0	0.00170	0.68205	1	0.97844	0	18.3	0.251
DP/DP15.3.0	0.00023	0.68205	1	0.96254	0	17.2	0.218
DP/DP2-3.5.0	0.00389	0.68205	1	0.97880	0	18.4	0.211
DP/DP2-3.6.0	0.00055	0.68205	1	0.97476	0	18.1	0.207
DP/DP2-3.7.0	0.00010	0.68205	1	0.97123	0	17.8	0.209
DP/DP2-3.8.0	0.00023	0.68205	1	0.97123	0	17.8	0.209
DP/DP3-4.1.0	0.00523	0.68205	1	0.99266	0	19.4	0.221
DP/DP3-4.2.0	0.00273	0.68205	1	0.99266	0	19.4	0.221
DP/DP3-4.3.0	0.00003	0.68205	1	0.94378	0	17.3	0.184
DP/DP5-6.2.0-2	0.00154	0.68205	1	0.97094	0	20.8	0.178
DP/DP5-6.3.0-2	0.00232	0.68205	1	0.97094	0	20.8	0.178
DP/DP5-6.4.0-2	0.00109	0.68205	1	0.97094	0	20.8	0.178
DP/DP6-7.2.0	0.00585	0.68205	1	0.99198	0	19.4	0.266
DP/DP6-7.3.0	0.00296	0.68205	1	0.99150	0	19.3	0.269
DP/DP7-8.1.0-2	0.01827	0.68205	1	0.98732	0	19.0	0.213
DP/DP7-8.2.0-2	0.00088	0.68205	1	0.98732	0	19.0	0.213
DP/DP7-8.3.0-1	0.00829	0.68205	1	0.95453	0	16.6	0.213
DP/DP7-8.4.0-1	0.00151	0.68205	1	0.95334	0	16.5	0.215
DP/DP7-8.5.0	0.00280	0.68205	1	0.95273	0	16.5	0.231
DP/DP8-9.1.0-2	0.01496	0.68205	1	0.98817	0	19.1	0.255
DP/DP8-9.2.0-2	0.00072	0.68205	1	0.98817	0	19.1	0.255
DP/DP8-9.3.0-2	0.00799	0.68205	1	0.97847	0	18.3	0.279
DP/DP8-9.4.0	0.00153	0.68205	1	0.97824	0	18.3	0.315
DP/DP8-9.5.0-2	0.00071	0.68205	1	0.97847	0	18.3	0.279
DP/DP10-11.1.0-3	0.01104	0.68205	1	0.96743	0	17.5	0.221
DP/DP11-12.1.0-1	0.01104	0.68205	1	0.96217	0	17.1	0.208
DP/DP1-3.5.0	0.00719	0.68205	1	0.96869	0	17.6	0.206
DP/DP1-3.6.0	0.00132	0.68205	1	0.96260	0	17.2	0.199
DP/DP1-3.7.0	0.00028	0.68205	1	0.96260	0	17.2	0.199
DP/DP1-3.8.0	0.00067	0.68205	1	0.96260	0	17.2	0.199
DP/DP3-5.1.0	0.00370	0.68205	1	0.99266	0	19.4	0.221
DP/DP3-5.2.0	0.00189	0.68205	1	0.99266	0	19.4	0.221
DP/DP3-5.3.0	0.00002	0.68205	1	0.94378	0	17.3	0.184
DP/DP4-6.2.0-2	0.00109	0.68205	1	0.97094	0	20.8	0.178
DP/DP4-6.3.0-2	0.00138	0.68205	1	0.97094	0	20.8	0.178
DP/DP4-6.4.0-2	0.00039	0.68205	1	0.97094	0	20.8	0.178
DP/DP4-6.5.0-2	0.00098	0.68205	1	0.97094	0	20.8	0.178

DP/DP13-15.1.0	0.00618	0.68205	1	0.96585	0	20.7	0.174
DP/DP15-18.1.2	0.00150	0.00113	1	0.99803	0	19.8	0.212
DP/DP15-18.1.0	0.00150	0.68092	1	0.99803	0	19.8	0.212
DP/DP15-18.2.2	0.00015	0.00113	1	0.99803	0	19.8	0.212
DP/DP15-18.2.0	0.00015	0.68092	1	0.99803	0	19.8	0.212
DP/DP15-18.3.2	0.00001	0.00113	1	0.95142	0	18.5	0.177
DP/DP15-18.3.0	0.00001	0.68092	1	0.95142	0	18.5	0.177
DP/DP16-19.4.3	0.00091	0.00113	1	0.99948	0	20.0	0.236
DP/DP16-19.4.0	0.00091	0.68092	1	0.98959	0	19.2	0.231
DP/DP16-19.5.3	0.00101	0.00113	1	0.99948	0	20.0	0.236
DP/DP16-19.5.0	0.00101	0.68092	1	0.98959	0	19.2	0.231
DP/DP16-19.6.3	0.00000	0.00113	1	0.99948	0	20.0	0.236
DP/DP16-19.6.0	0.00000	0.68092	1	0.98959	0	19.2	0.231
DP/DP15-19.1.3	0.00117	0.00113	1	0.92585	0	17.8	0.165
DP/DP15-19.1.0	0.00117	0.68092	1	0.92585	0	17.8	0.165
DP/DP15-19.2.3	0.00012	0.00113	1	0.92585	0	17.8	0.165
DP/DP15-19.2.0	0.00012	0.68092	1	0.92585	0	17.8	0.165
DS/DP4.2.0	0.00066	0.72308	1	0.99989	0	20.0	0.260
DS/DP4.3.0	0.00009	0.72308	1	0.99989	0	20.0	0.260
DS/DP11.1.0-1	0.00946	0.72308	1	0.99802	0	19.8	0.294
DS/DP2-3.2.0	0.00231	0.72308	1	0.97144	0	17.8	0.203
DS/DP2-3.3.0	0.00209	0.72308	1	0.97144	0	17.8	0.203
DS/DP2-3.4.0	0.00037	0.72308	1	0.95469	0	17.3	0.192
DS/DP3-4.1.0	0.00523	0.72308	1	0.95551	0	17.4	0.192
DS/DP3-4.2.0	0.00273	0.72308	1	0.95551	0	17.4	0.192
DS/DP4-5.2.0	0.00111	0.72308	1	0.99989	0	20.0	0.260
DS/DP4-5.3.0	0.00130	0.72308	1	0.98804	0	19.1	0.305
DS/DP4-5.4.0	0.00033	0.72308	1	0.98804	0	19.1	0.305
DS/DP4-5.5.0	0.00071	0.72308	1	0.98735	0	19.0	0.306
DS/DP5-6.1.0-2	0.00799	0.72308	1	0.95539	0	19.1	0.175
DS/DP5-6.2.0-2	0.00154	0.72308	1	0.91399	0	18.2	0.153
DS/DP5-6.3.0-2	0.00232	0.72308	1	0.91399	0	18.2	0.153
DS/DP5-6.4.0-2	0.00109	0.72308	1	0.91399	0	18.2	0.153
DS/DP6-7.1.0	0.01361	0.72308	1	0.98894	0	19.1	0.251
DS/DP7-8.1.0-2	0.01827	0.72308	1	0.95664	0	16.8	0.206
DS/DP7-8.2.0	0.00088	0.72308	1	0.95357	0	16.5	0.231
DS/DP8-9.1.0-2	0.01496	0.72308	1	0.95348	0	16.5	0.245
DS/DP8-9.2.0-2	0.00072	0.72308	1	0.95348	0	16.5	0.245
DS/DP9-10.1.0	0.01104	0.72308	1	0.99216	0	19.4	0.270
DS/DP1-3.1.0	0.00416	0.72308	1	0.96258	0	17.2	0.203
DS/DP1-3.2.0	0.00389	0.72308	1	0.96258	0	17.2	0.203
DS/DP1-3.3.0	0.00348	0.72308	1	0.96258	0	17.2	0.203

DS/DP1-3.4.0	0.00062	0.72308	1	0.94300	0	16.6	0.191
DS/DP3-5.1.0	0.00370	0.72308	1	0.95551	0	17.4	0.192
DS/DP3-5.2.0	0.00189	0.72308	1	0.95551	0	17.4	0.192
DS/DP4-6.1.0-2	0.00561	0.72308	1	0.95539	0	19.1	0.175
DS/DP12-14.1.0	0.00618	0.72308	1	0.88743	0	17.4	0.142
DS/DP13-15.1.0	0.00618	0.72308	1	0.92561	0	18.2	0.161
DS/DP14-16.1.0	0.00625	0.72308	1	0.98731	0	19.1	0.199
DS/DP14-16.2.0	0.00004	0.72308	1	0.96067	0	18.2	0.187
DS/DP14-16.3.0	0.00000	0.72308	1	0.96067	0	18.2	0.187
DS/DP15-17.1.0	0.00737	0.72308	1	0.98259	0	18.6	0.213
DS/DP15-17.2.0	0.00005	0.72308	1	0.93640	0	17.3	0.178
DS/DP16-18.3.2	0.00023	0.00113	1	0.98452	0	18.8	0.227
DS/DP16-18.3.0	0.00023	0.72195	1	0.98452	0	18.8	0.227
DS/DP16-18.4.2	0.00164	0.00113	1	0.98629	0	18.9	0.219
DS/DP16-18.4.0	0.00164	0.72195	1	0.97859	0	18.3	0.215
DS/DP16-18.5.2	0.00182	0.00113	1	0.98629	0	18.9	0.219
DS/DP16-18.5.0	0.00182	0.72195	1	0.97859	0	18.3	0.215
DS/DP15-18.1.2	0.00150	0.00113	1	0.89644	0	16.7	0.155
DS/DP15-18.1.0	0.00150	0.72195	1	0.89644	0	16.7	0.155
DS/DP15-18.2.2	0.00015	0.00113	1	0.89644	0	16.7	0.155
DS/DP15-18.2.0	0.00015	0.72195	1	0.89644	0	16.7	0.155
DS/DP16-19.1.3	0.00241	0.00113	1	0.97911	0	18.4	0.218
DS/DP16-19.1.0	0.00241	0.72195	1	0.97911	0	18.4	0.218
DS/DP16-19.2.3	0.00025	0.00113	1	0.97911	0	18.4	0.218
DS/DP16-19.2.0	0.00025	0.72195	1	0.97911	0	18.4	0.218
DS/DP16-19.3.3	0.00013	0.00113	1	0.90026	0	16.1	0.163
DS/DP16-19.3.0	0.00013	0.72195	1	0.90038	0	16.1	0.163

Following damage cases where the original s-factor was 1 but the new s-factor <1 have been investigated in detail. For all the damage cases the lack of range is the criterion, while sufficient GZ is available.

Table 6 Damage cases shown in detail

CASE	PFAC	VFAC	SFAC	SNEW	0	RANGEF	GZMAXR
DS/DP6-7.1.0	0.01361	0.72308	1	0.98894	0	19.1	0.251
DL/DP13-14.4.0	0.00189	0.62051	1	0.96520	0	17.4	0.247

11.2.4.1 Damage DS/DP6-7.1.0

This damage DS/DP6-7.1.0 is a typical example showing how the different formulation for the s-factor contributes to the index. In this case the Ro-ro deck is damaged but the lower hold is undamaged. The extent of the damage and rooms open to sea are shown in the figure below. The room connected in the cross-flooding stage is indicated by orange colour and the rooms connected in the A-Class stages have been indicated by pink and green colour.

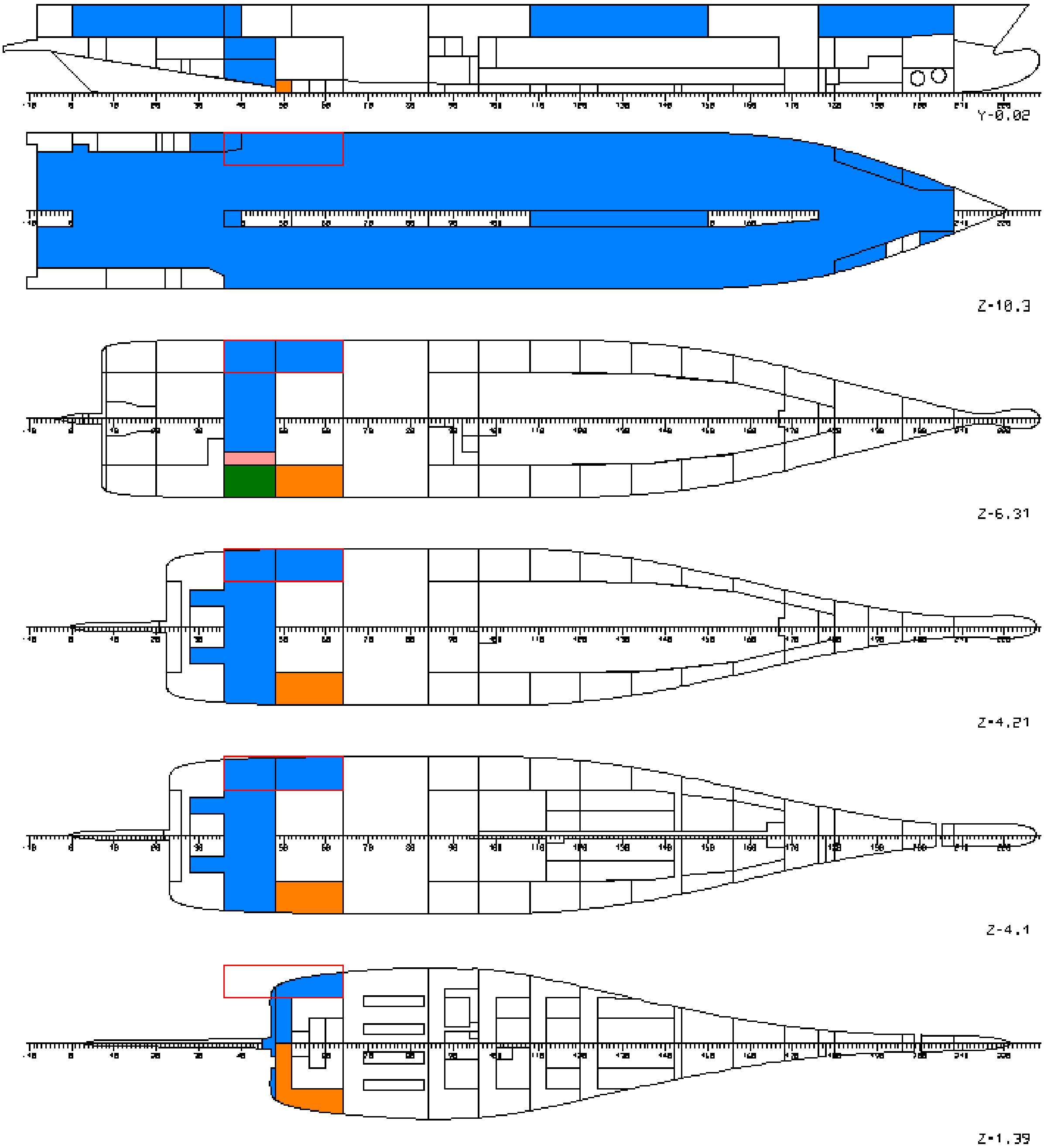

Figure 39 Extent of damage

The flooding position in the final stage of flooding can be seen in the figure below

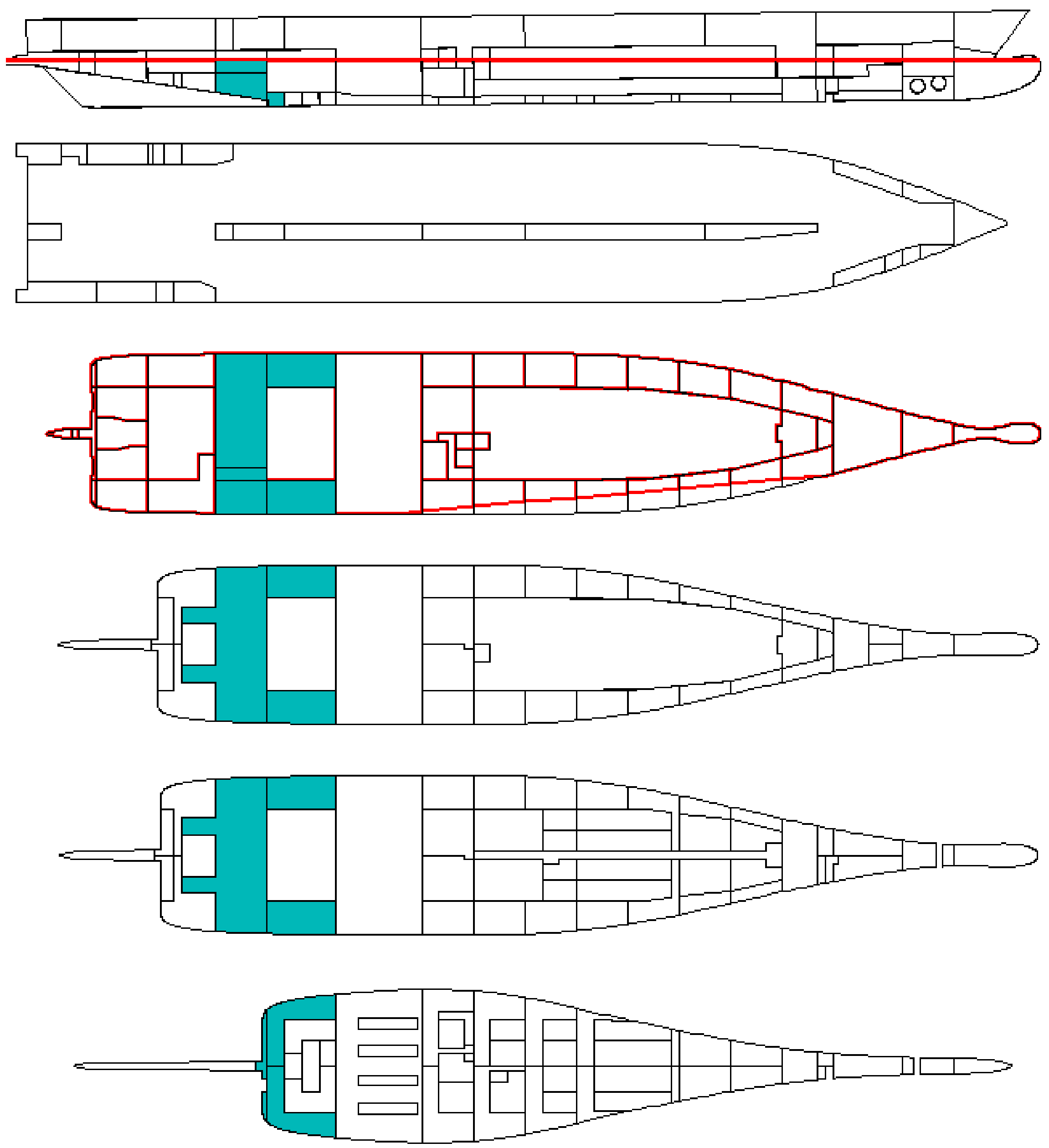

Figure 40 Floating position

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASIDE	T m	TR m	HEEL degree	SFACTYPE	FLOPEN	RANGEF degree	GZMAXR m
DS/DP6-7.1.0	INTACT	EQ SB	7.10	0.00	0.0	-	-	30.0	0.87
DS/DP6-7.1.0	1	1 PS	7.13	0.14	-1.5	NONE	OD#26.1P	28.5	0.84
DS/DP6-7.1.0	1	2 PS	7.25	0.65	-4.1	NONE	OD#12.1P	25.9	0.71
DS/DP6-7.1.0	1	EQ PS	7.35	1.31	-7.6	NONE	OD#12.1P	8.7	0.09
DS/DP6-7.1.0	CROSS	EQ PS	7.50	1.43	-1.7	INTERMEDIATE	OD#12.1P	17.1	0.25
DS/DP6-7.1.0	CROSS60s	EQ PS	7.45	1.39	-4.5	INTERMEDIATE	OD#12.1P	14.3	0.20
DS/DP6-7.1.0	#1	1 PS	7.41	1.36	-6.0	INTERMEDIATE	OD#12.1P	11.6	0.14

DS/DP6-7.1.0	#1	2	PS	7.47	1.41	-3.5	INTERMEDIATE	OD#12.1P	16.1	0.24
DS/DP6-7.1.0	#1	EQ	PS	7.51	1.45	-1.4	INTERMEDIATE	OD#12.1P	17.4	0.25
DS/DP6-7.1.0	#2	1	PS	7.42	1.38	-5.5	INTERMEDIATE	OD#12.1P	12.3	0.16
DS/DP6-7.1.0	#2	2	PS	7.49	1.44	-2.7	INTERMEDIATE	OD#12.1P	17.4	0.27
DS/DP6-7.1.0	**#2**	**EQ**	**SB**	**7.53**	**1.52**	**0.2**	**FINAL**	**OD#0.1S**	**19.1**	**0.25**

This damage case has following s-factors:

According SOLAS 2009: s=1

According SLF55 s=0.98894

Based on following GZ curve for the final stage of flooding (#2):

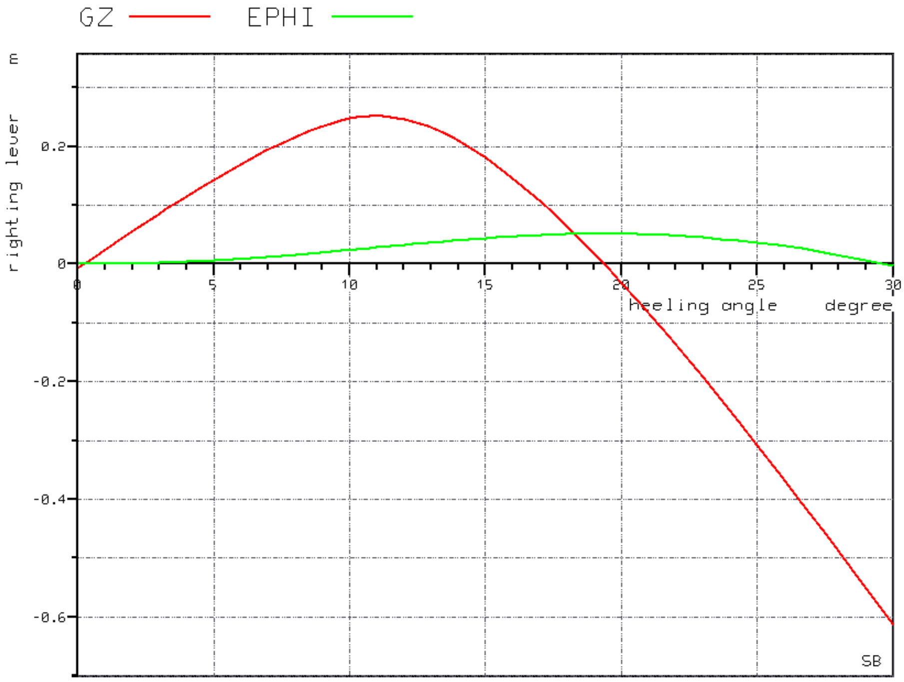

Figure 41 GZ curve

The showed case is a typical example of effect of the new s formula when the ro-ro deck is damaged. The resulting delta A due to this damage case is -0.0000435.

11.2.4.2 Damage DL/DP13-14.4.0

This damage DL/DP13-14.4.0 is a typical case where the Ro-ro deck and the lower hold are damaged. The extent of the damage and rooms open to sea are shown in the figure below. The rooms connected in the cross-flooding stage have been filled by orange color.

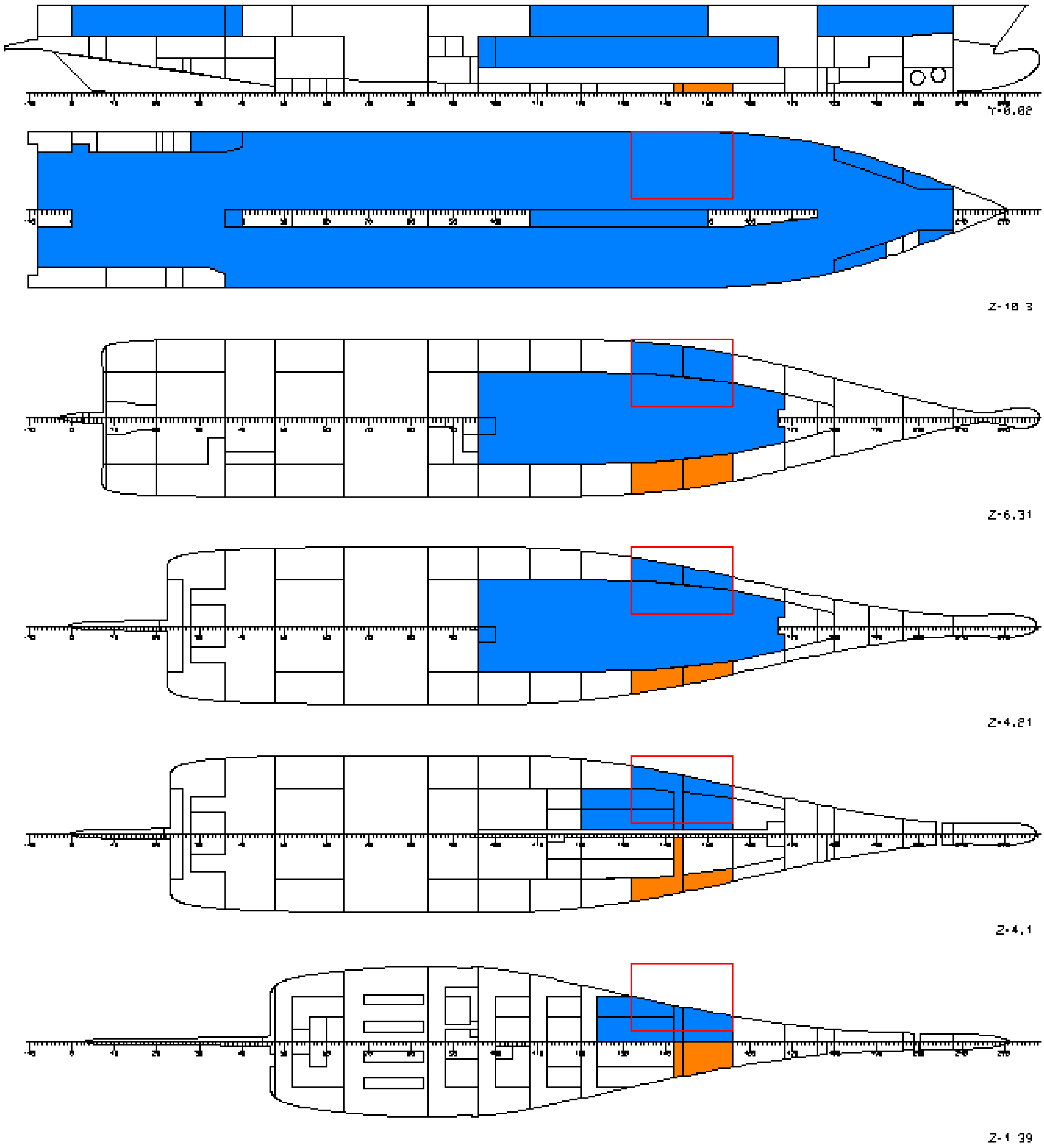

Figure 42 Extent of damage

The flooding position in the final stage of flooding can be seen in the figure below.

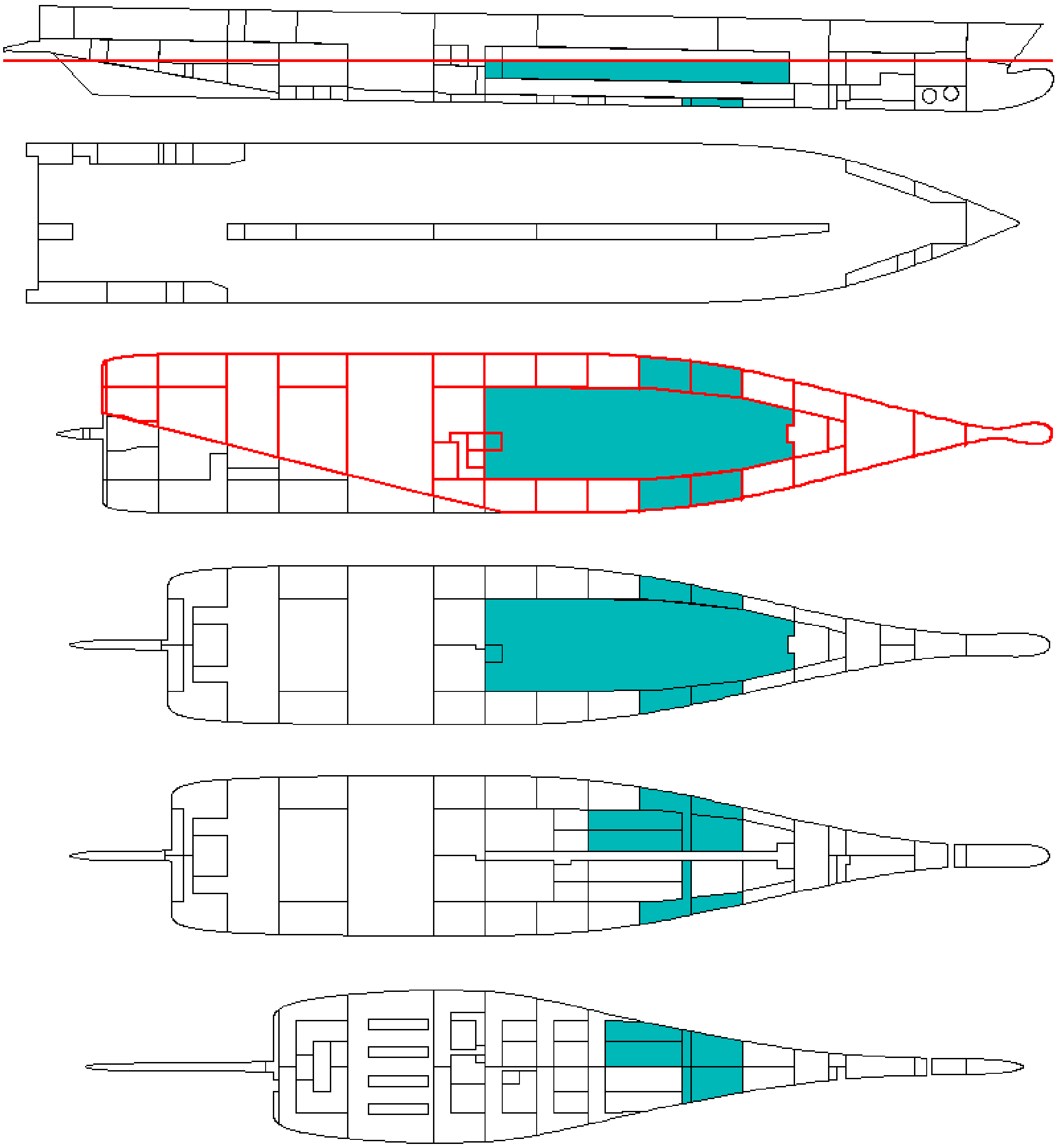

Figure 43 Floating position

The corresponding floating position is

FLOATING POSITION

CASE	STAGE	PHASIDE	T m	TR m	HEEL degree	SFACTYPE	FLOPEN	RANGEF degree	GZMAXR m
DL/DP13-14.4.0	INTACT	EQ SB	6.10	0.50	0.0	-	-	30.0	1.05
DL/DP13-14.4.0	1	1 PS	6.32	-0.07	-1.5	NONE	OD#26.1P	28.5	0.99
DL/DP13-14.4.0	1	2 PS	6.63	-0.98	-4.4	NONE	OD#26.1P	25.6	0.80
DL/DP13-14.4.0	1	EQ PS	7.10	-2.47	-8.6	NONE	OD#26.1P	11.5	0.15
DL/DP13-14.4.0	**CROSS**	**EQ PS**	**7.37**	**-2.86**	**-4.1**	**FINAL**	**OD#26.1P**	**17.4**	**0.25**
DL/DP13-14.4.0	CROSS60s	EQ PS	7.29	-2.75	-5.7	INTERMEDIATE	OD#26.1P	16.6	0.26

This damage case has following s-factors:

According SOLAS 2009: s=1

According SLF55 s=0.96520

Based on following GZ curve for the final stage of flooding (CROSS):

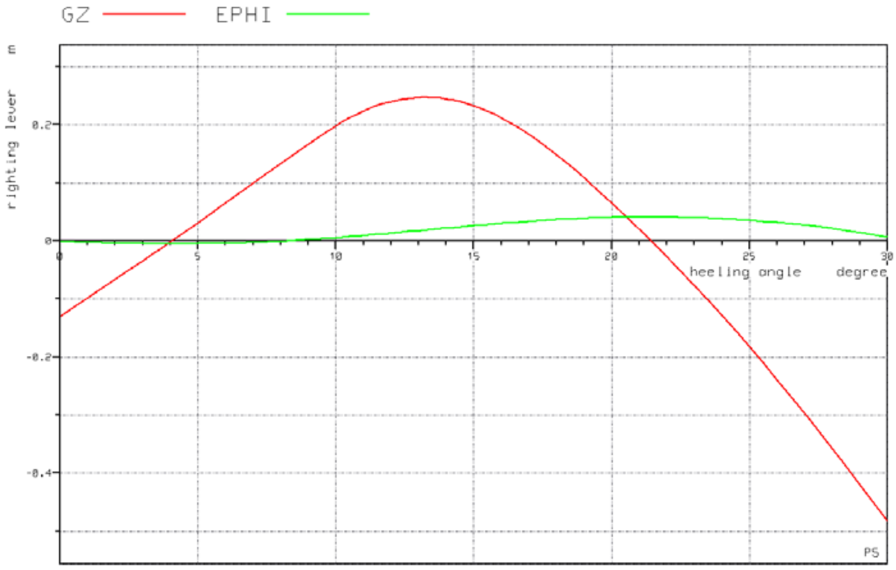

Figure 44 GZ curve

This case is a typical example showing the effect of the new s formula when the ro-ro deck and the lower hold is damaged. The resulting delta A due to this damage case is -0.0000082.

11.3 Results for other sample ships

In this project a few other RoPax ships have been investigated in task 1 including the analysis of risk control options.

In addition to the recalculated GOALDS RoPax sample ships the results for these ships using the index calculation according to SOLAS Ch.II-1 compared with the application of the new snew factor are shown here to provide additional information about the implication of the s-factor. It should be noted that the purpose of this table is to show the effect of the new s-factor on the required index. For some of the sample ships the GM requirements from other regulations may be higher than for the required index, e.g. regulation 8 for the small ropax ships.

A detailed analysis of individual damage cases has not been done for these sample ships as it is outside the scope of this project.

Table 7 Results of Task 1 sample ships

Ship	Required Index R	Attained index A SOLAS2009	Attained index A New s-factor
GOALDS large RoPax	0.8330	0.8351	0.8294
GOALDS medium RoPax	0.7980	0.8098	0.8025
Task 1 Baltic RoPax Basic	0.8300	0.8527	0.8326
Task 1 Baltic RoPax (optimized)	0.8300	0.9195	0.9152
Task 1 Med RoPax	0.778	0.852	0.83982
Task 1 Small RoPax Original	0.7214	0.7740	0.7225
Task 1 Small Ropax Optimised	0.7214	0.8426	0.8426
Task 1 Small Ropax (DE) Original	0.7279	0.7648	0.7491
Task 1 Small ropax (DE) Optimised	0.7279	0.8708	0.8601

The diagram below shows all results in a graphical way. It can be seen that the influence of the new s-factor for the optimized designs is much smaller. The reason is obvious, there are more damage cases with higher GZ and Range values and the impact of the new s-factor gets marginal.

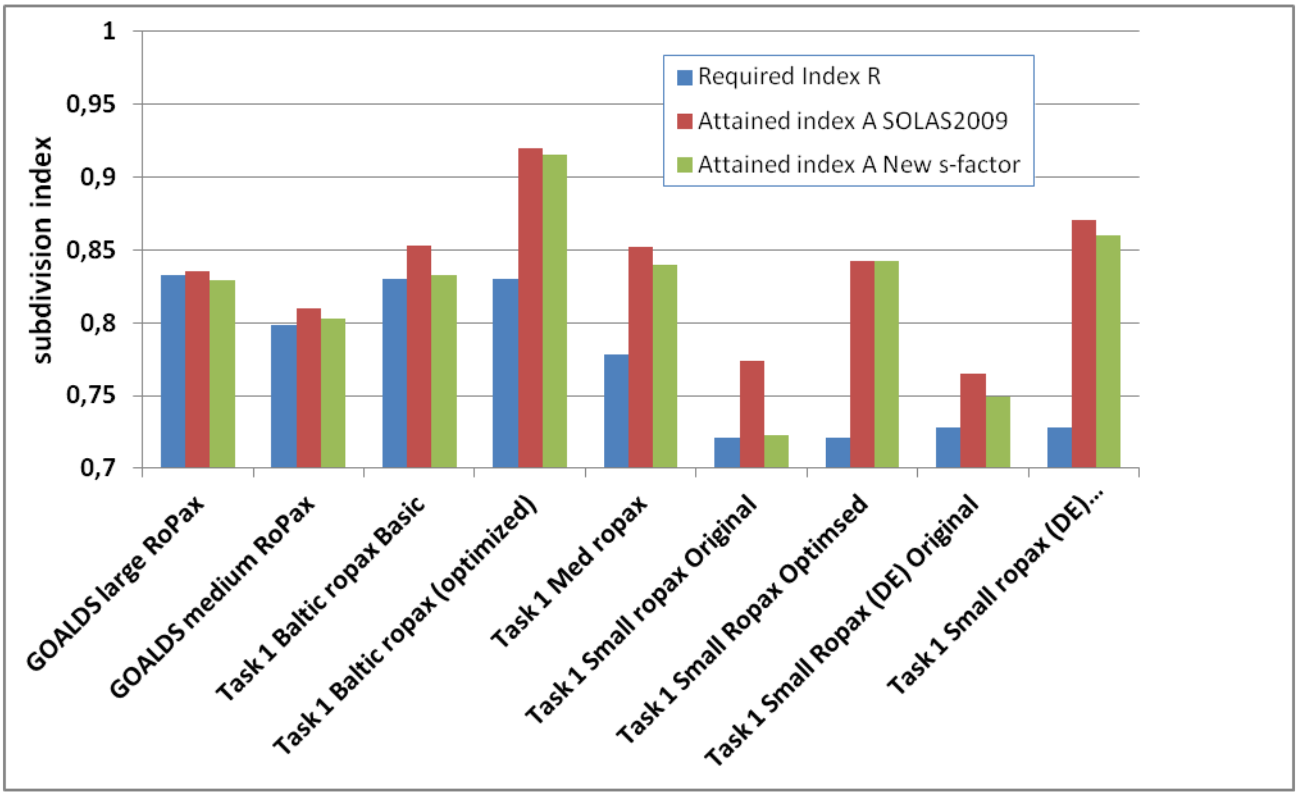

Figure 45 Comparison of old and new s-factor

12 CONCLUSIONS

The analysis of the GOALDS Ro-Pax sample ships for the new s-factor showed a rather small impact on the attained index. However transferring this impact to a change of GM requirements the estimated increase of GM-Limiting curve by 8-10 cm results in a significant loss of cargo or additional ballast has to be carried.

The background for the rather small impact on the index is that these ships are already designed according SOLAS2009 and the Stockholm Agreement and there is only a small portion of damages, which have GZ properties within the limits between 16 and 20 degrees of range and 12 and 20 cm of maximum GZ. The majority of the investigated damage cases have already higher GZ values than requested by the new s-factor. However, the minimum GM values are even higher than to comply with the requirements of SOLAS90 and Stockholm agreement

13 REFERENCES

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/4/ IMO, London, 2002: Investigations and proposed formulations for the factor "s": the probability of survival after flooding, SLF 45/3/3

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