GOAL Based Damage Stability

SEVENTH FRAMEWORK PROGRAMME

GOALDS – Goal Based Damage Stability Objectives and Overview of Results – Relationships to FLOODSTAND

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List of contents

Introduction

- The new probabilistic damaged stability regulations for dry cargo and passenger ships (SOLAS 2009), which entered into force on January 1, 2009, represent a major step forward in achieving an improved safety standard through the rationalization and harmonization of damaged stability requirements.
- There are, however, ***serious concerns*** regarding the adopted formulation for the calculation of the survival probability of *passenger ships*, particularly **for ROPAX and large cruise vessels.**
- The EU funded, FP7 project **GOALDS (Goal Based Damaged Stability, 2009-2012),** responds to these concerns by dedicated research studies using state of the art scientific methods and by formulating a rational regulatory framework, properly accounting for the damage stability properties of passenger ships.

The Project Consortium

1	National Technical University of Athens (coordinator)	NTUA	Greece
2	University of Strathclyde	SSRC	UK
3	Germanischer Lloyd AG	GL	Germany
4	Det Norske Veritas	DNV	Norway
5	Safety at Sea	SaS	UK
6	Lloyds Register of Shipping	LR	UK
7	Hamburg Ship Model Basin	HSVA	Germany
8	Vienna Model Basin	VMB	Austria
9	Danish Maritime Authority	DMA	Denmark
10	Maritime and Coastguard Agency	MCA	UK
11	University of Trieste	DINMA	Italy
12	STX France Cruise SA	STX FR	France
13	FINCANTIERI Cantieri Navali Italiani S.p.A.	FC	Italy
14	MEYER WERFT GmbH	MW	Germany
15	Color Line	CL	Norway
16	Carnival PLC	CAR	UK
17	RCL (UK) Ltd.	RCL	UK
18	STX Finland Cruise Oy	STX FIN	Finland

General Concerns (1)

- The new damage stability standard (SOLAS 2009) being statistical in nature (rather than performance-based) could not satisfactorily cater for the higher level of safety inherently required by innovative **mega-passenger ships**.
- The lack of sufficient data for proper consideration of large passenger ships raised concerns during the harmonization process as to the suitability for the developed standards for damage stability among the IMO delegates, leading to a **strong and explicit recommendation of IMO SLF47 to undertake pertinent research** to address the damage stability standards for these ships.
- Only survivability following ***collision events*** was addressed. A similar formulation for ***grounding accidents*** **was not developed**.
- Within the EU-funded R&D project SAFEDOR (2005-2009), a series of high-level **FSA studies** were performed for cargo and passenger vessels. With respect to cruise and ROPAX vessels both studies concluded that **the risk to human life could be reduced cost-effectively by increasing the required subdivision index**.

General Concerns (2)

- Developing SOLAS 2009 as a new damage stability global standard, the consideration of Water On Deck (WOD) effects on the survivability of ROPAX vessels *was not a prime issue* for IMO-SLF; this was covered however by the Stockholm Regional Agreement; inherently, SOLAS 2009 could not be full equivalent to SOLAS 90 + Stockholm Agreement provisions.
- Developments within SAFEDOR of holistic approaches in dealing with ship safety have revealed that the **risk to human life from flooding** (resulting from collision and grounding accidents) **dominates the safety of passenger ships**.
- Other developments within IMO concerning the safety of large passenger ships, led to concepts of progressively more holistic nature, namely **"Safe Return to Port".**
- Finally, one of the top-agenda items at IMO, namely **Goal-Based Standards** (**GBS**) is targeting in the longer term all ship types, with passenger ships being of course a main target, implicitly again pointing towards the need to sort out the damage stability standard for large passenger ships.

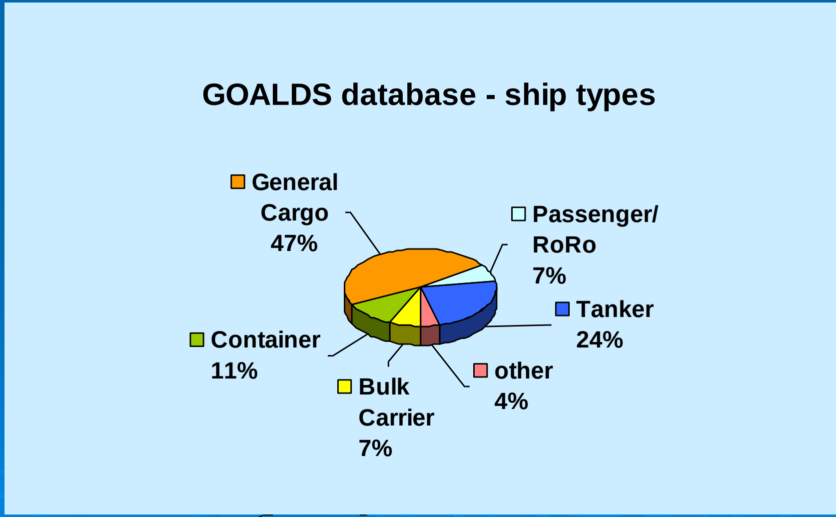
Project GOALDS Objectives

- Enhance collision and grounding casualties database; conduct statistical analysis of data and check validity of current SOLAS 2009 assumptions for passenger ships.
- Develop an enhanced formulation for the survival factor "s" accounting for key design parameters of passenger ships and for the time evolution of flooding scenarios.
- Develop a new survivability formulation for flooding following grounding accidents.
- Integrate collision and grounding survivability formulations into a single framework.
- Validate the new formulations by experimental and numerical analyses.
- Develop a new damage survivability requirement in a risk-based context.
- Evaluate the practicability of the new formulations by a series of ship concept design studies.
- Upon completion, submit results for consideration by IMO (October, 2012).

GOALDS casualty database

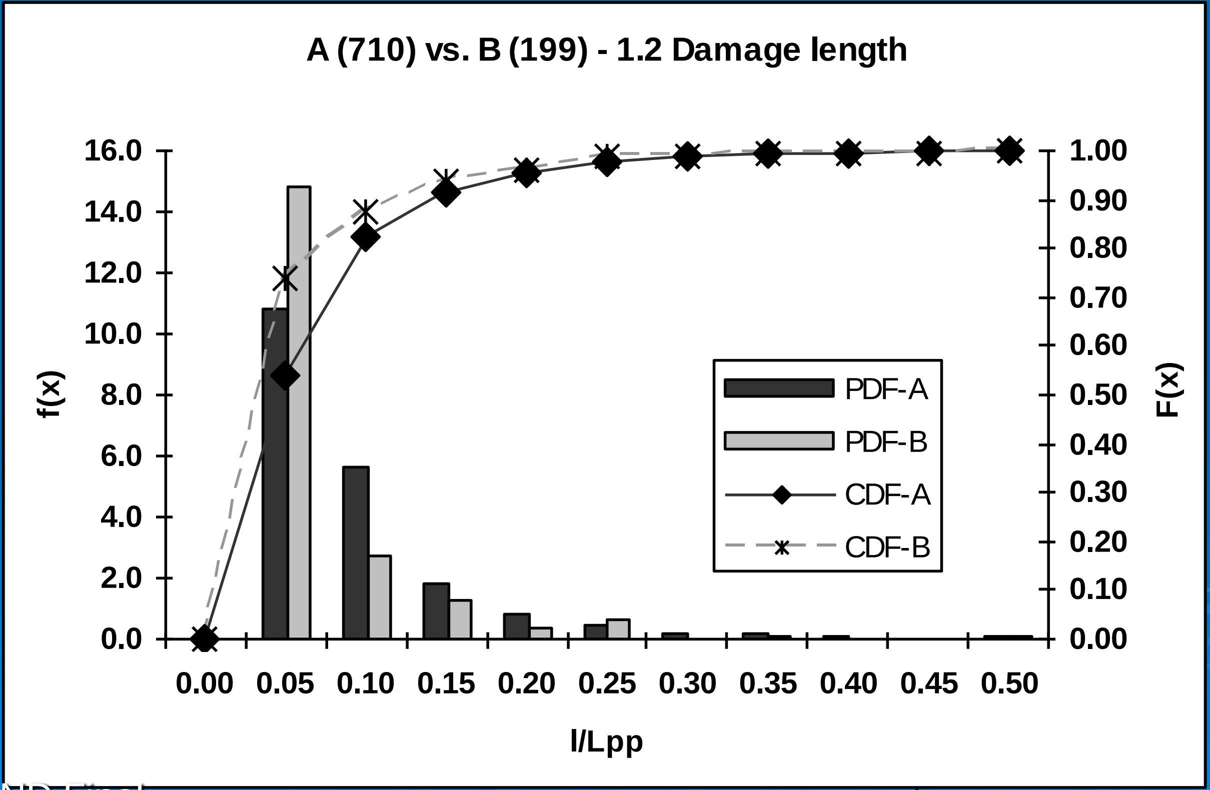
- Casualties (after 2000) were identified through search in the Lloyd's Register IHS (former Fairplay) casualty database (for identifying ships involved in accidents); cross-reference and relationship to class societies' databases
- Total number of casualties used for further statistical analysis: 1527; only 7% of recorded casualties refer to passenger/RoRo ships

	Collision	Grounding	Contact
HARDER	832	312	35
GOALDS	184	160	4
database	**1016**	**472**	**39**

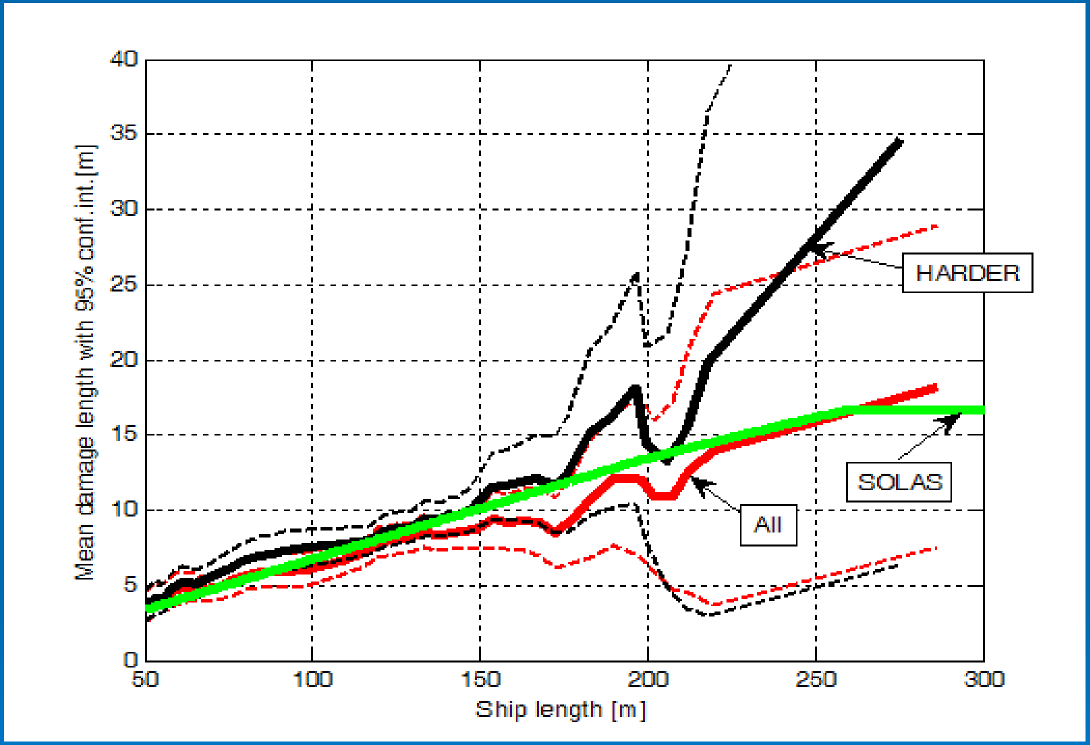


Collision data (1)

- Using data of the last 20 years only (1990-2010), the sample size gets very small (B, 199)
- Therefore the complete data set (A, 710) was used for the statistical analysis



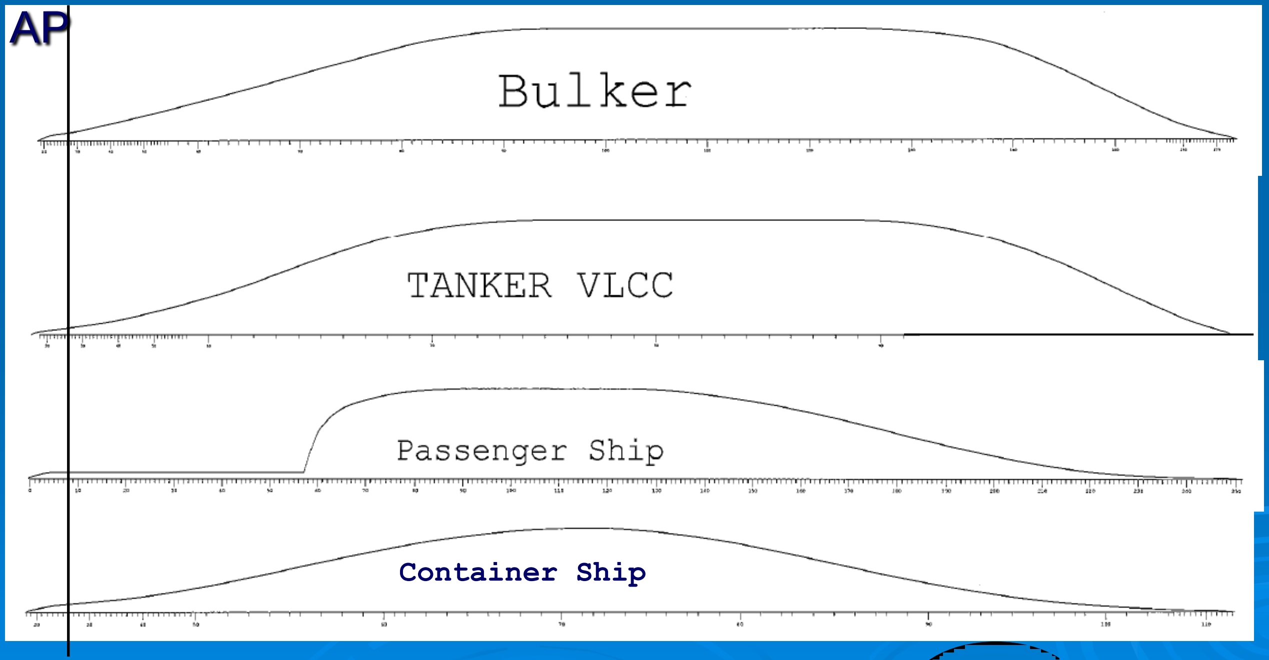
Collision data (2)



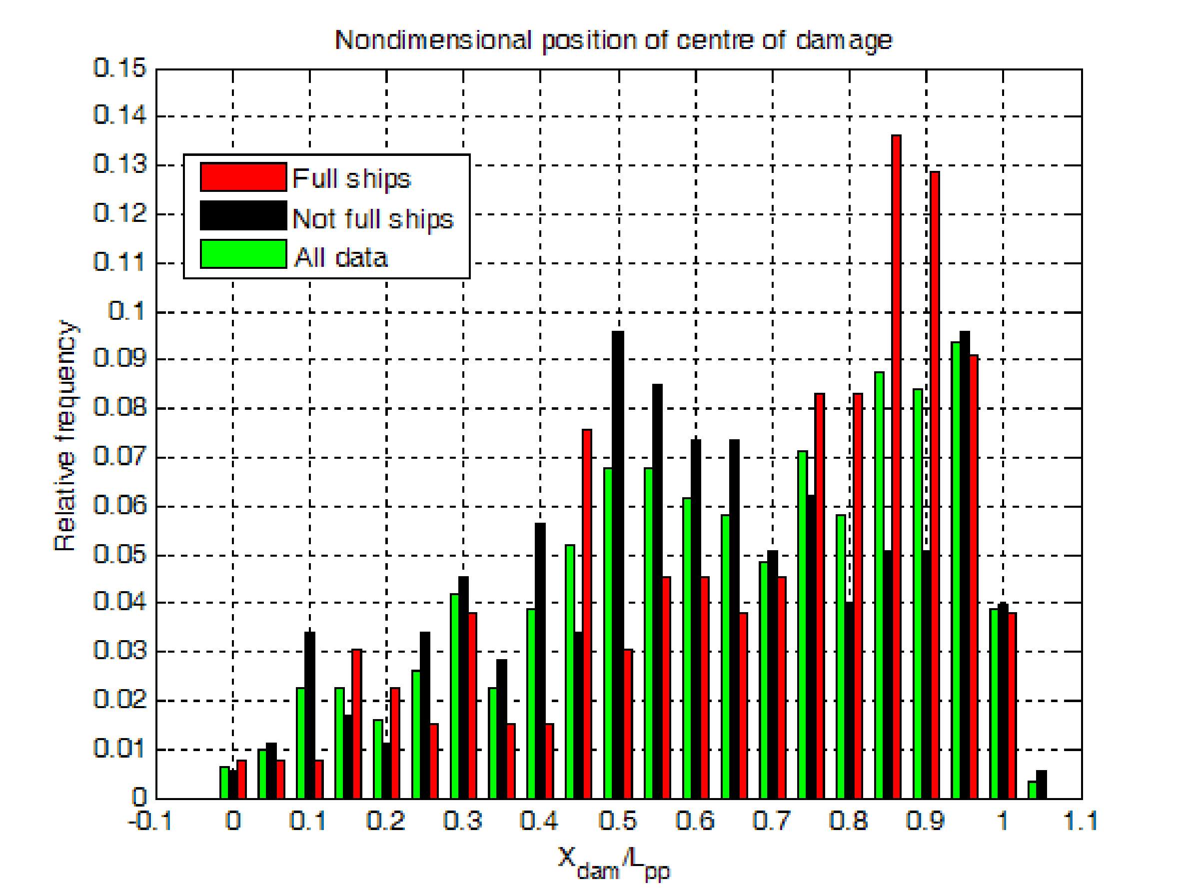
- Comparison of mean value of damage length as a function of the ship length
- Current SOLAS damage length distribution is confirmed!

Grounding data (1)

- Most significant differences in the grounding casualties of various ship types were found in the *longitudinal centre of damage* X_{dam} , assuming the vessels grouped into 2 main categories (when looking at typical bottom geometry/lines), namely *Full ships* and *Non-full ships*



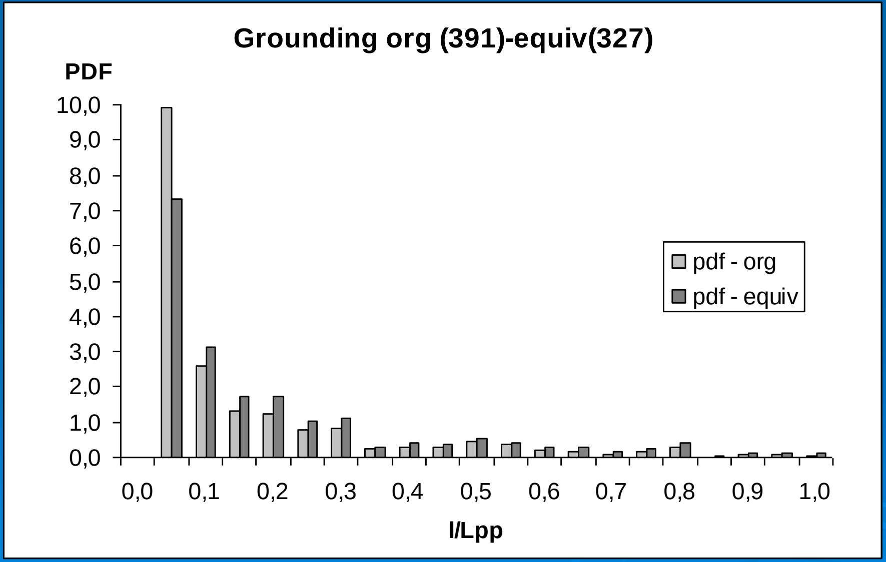
Grounding data (2)

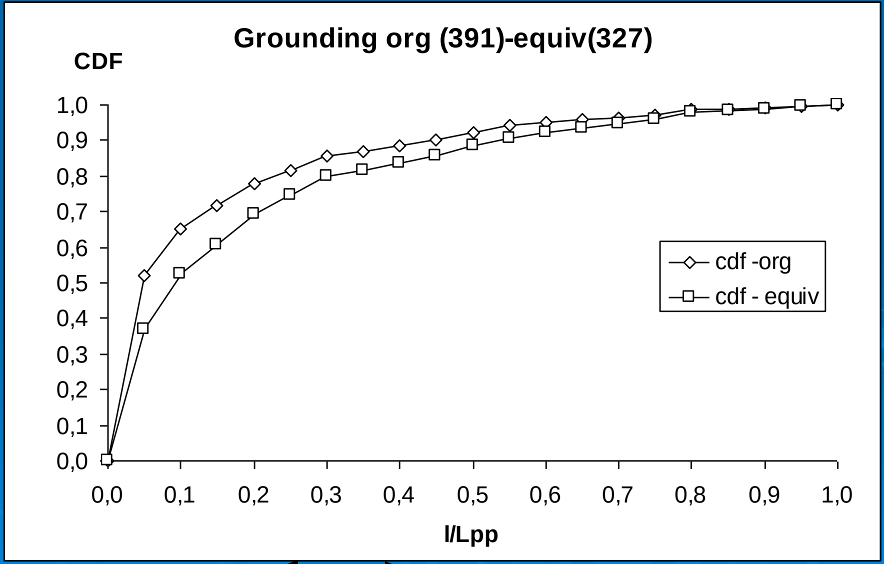


- For *full ships* the centre of damage tends to be in the forward part of the ship
- *Non-full ships* tend to have the centre of damage in the midship section area

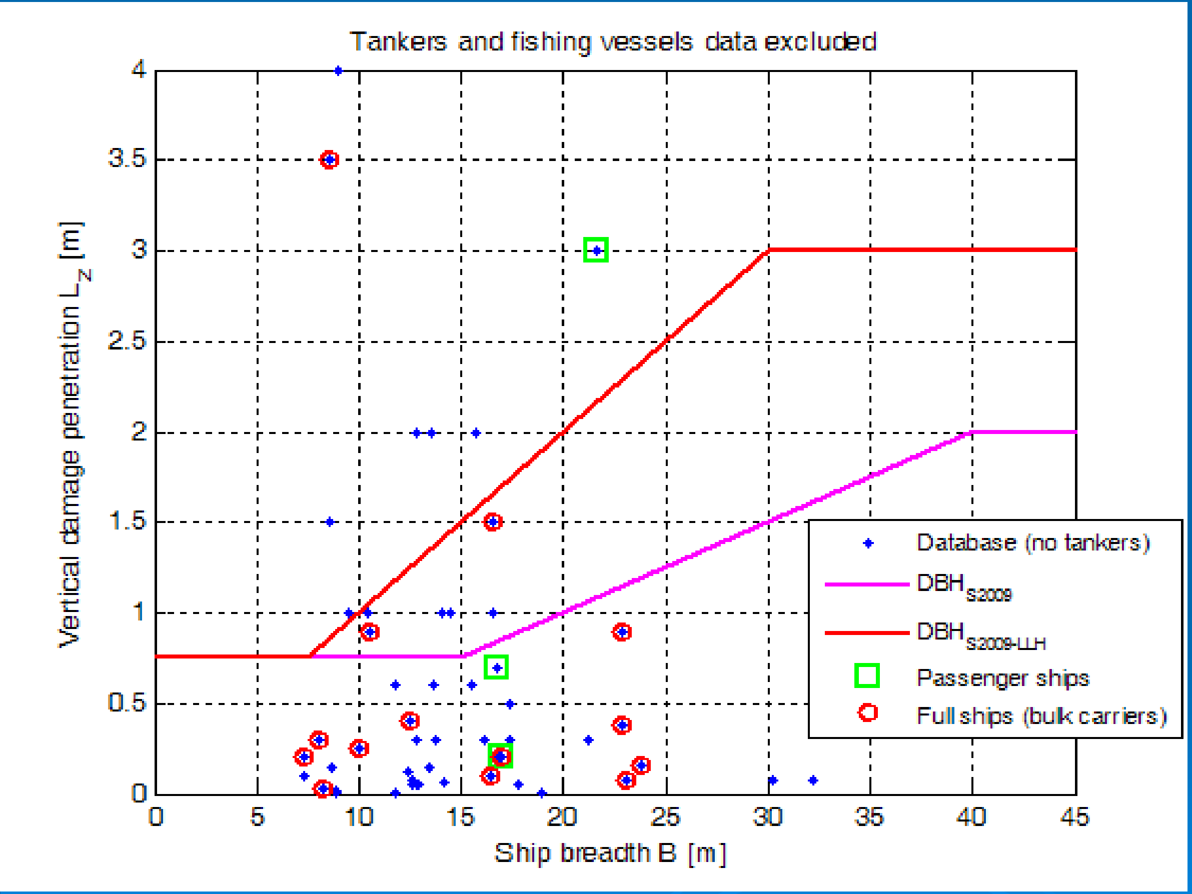
Grounding data (3)

- *Multiple* damages of *one* grounding casualty were interpreted/replaced by *equivalent single* damages (considering multiple damages as individual damages would result in shifting the distribution of bottom damage length to smaller damages)





Grounding data (4)



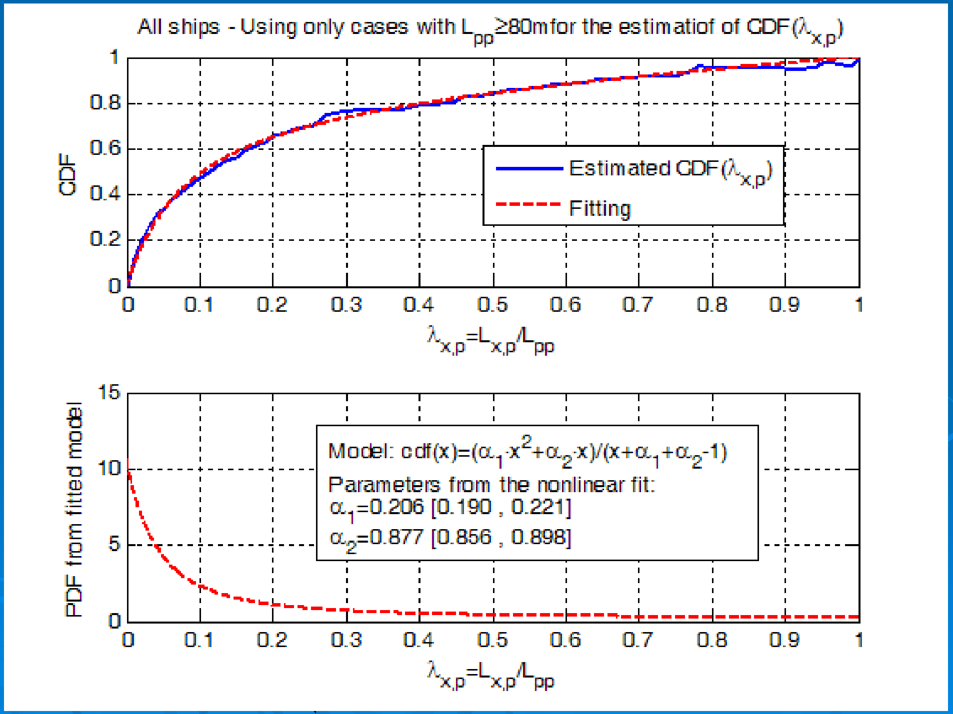
- Penetration depth vs. ship breadth
- The sample lacks satisfactory number of data of passenger and large ships in general (post-panmax)

Sample of results –Grounding damages – All ships

The final result of the GOALDS grounding modelling is a set of distributions for the grounding damage characteristics

- damage position,
- damage length,
- width,
- penetration depth

. Example (all ships): Fitting of distribution for nondimensional potential damage length



Resulting exceedance probabilities

Table 6: Exceedance probabilities (with 95% confidence intervals) for bottom damage characteristics as prescribed in SOLAS.

$\Pr\{L_x > L_{x,S2009}\}$	$54.6\%\ [47.6\%, 61.6\%]_{95\%CI}$	Samples:205, Exceeding:112
$\Pr\{L_y > L_{y,S2009}\}$	$18.2\%\ [11.5\%, 26.7\%]_{95\%CI}$	Samples:110, Exceeding:20
$\Pr\{L_z > L_{z,S2009}\}$	$29.1\%\ [17.6\%, 42.9\%]_{95\%CI}$	Samples:55, Exceeding:16
$\Pr\left\{\begin{matrix}(L_x > L_{x,S2009}) \wedge \\ \wedge (L_y > L_{y,S2009}) \wedge \\ \wedge (L_z > L_{z,S2009})\end{matrix}\right\}$	$11.1\%\ [3.7\%, 24.1\%]_{95\%CI}$	Samples:45, Exceeding:5
$\Pr\left\{\begin{matrix}(L_x > L_{x,S2009}) \vee \\ \vee (L_y > L_{y,S2009}) \vee \\ \vee (L_z > L_{z,S2009})\end{matrix}\right\}$	$64.4\%\ [48.8\%, 78.1\%]_{95\%CI}$	Samples:45, Exceeding:29

Survivability of Passenger Vessels Re-engineering the s-factor (1)

What is the s-factor?

- *traditional* (SOLAS, B-1, Reg. 25-4): *probability of survival a collision damage after flooding of a compartment or group of compartments*
- *new approach* (GOALDS): *It is a measure of probability of surviving collision damage after flooding in seaways over min. 30min*:

$$s(t=30\min \mid H_S)=\int_0^\infty dH_S \cdot f_{H_S|coll}(H_S)\cdot F_{surv}(t=30\min \mid H_S)$$

Key issues (SOLAS 2009):

•Inaccuracy in survival prediction

•Problems in accounting for unconventional subdivision and stability-enhanced WT envelope

•Lack of reference to WOD accumulation and to the “classical” concept of freeboard

•No distinction made to different modes of ship loss/capsize

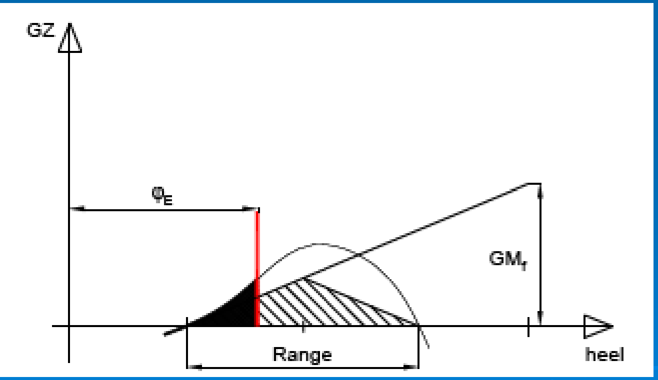
Survivability of Passenger Vessels
Re-engineering the s-factor (2)

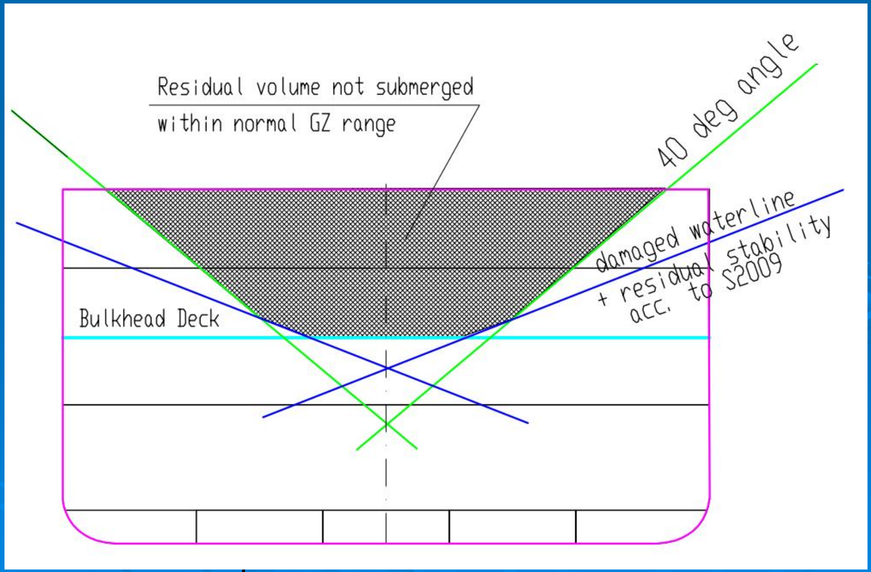
Proposed new formula for the s-factor of passenger ships

Determine critical significant wave height:

$$H_{S\,crit} = \frac{A_{GZ\,E}}{\frac{1}{2} GM_f \cdot Range} V_R^{1/3}$$

GM$_f$: GM in flooded equilibrium condition
V$_R$: residual volume of WT compartments (total volume of intact hull minus total volume of damaged compartments).

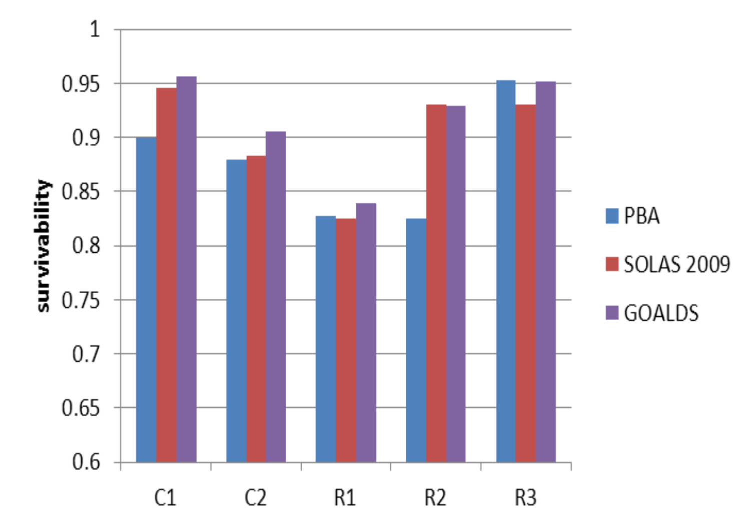




Survivability of Passenger Vessels
Re-engineering the s-factor (2)

Evaluate probability of surviving collision damage over min. 30 min:

$$s(H_S) = \begin{cases} e^{\left(-e^{\left(0.16-1.2 H_{S\,crit}\right)}\right)}, & \forall\left(A_{GZ}, V_R, Range, k > 0\right) \\ 0, & otherwise \end{cases}$$



Comparison of attained index of subdivision calculated for sample RoPax and cruise vessels (SSRC)

	PBA	SOLAS 2009	GOALDS
C1	0.900	0.946	0.957
C2	0.880	0.883	0.905
R1	0.827	0.825	0.840
R2	0.825	0.930	0.929
R3	0.953	0.931	0.952

[1] Performance-Based Assessment by means of numerical simulations with Monte Carlo Sampling

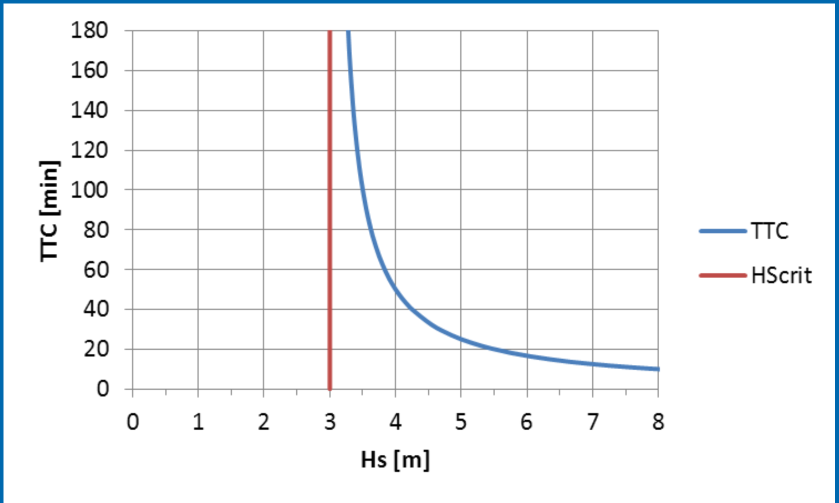
Time To Capsize TTC

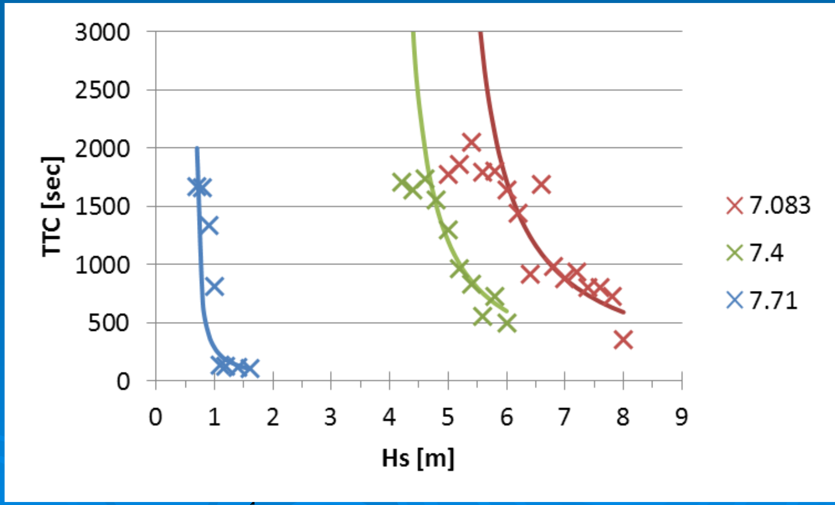
- TTC gets infinite for $Hs<Hs_{crit}$
- For $Hs>Hs_{crit}$, TTC decreases hyperbolically

$$TTC = \frac{a}{(Hs - Hs_{CRIT})}\ [min]$$

The parameter ***α*** varies with Hs_{crit}

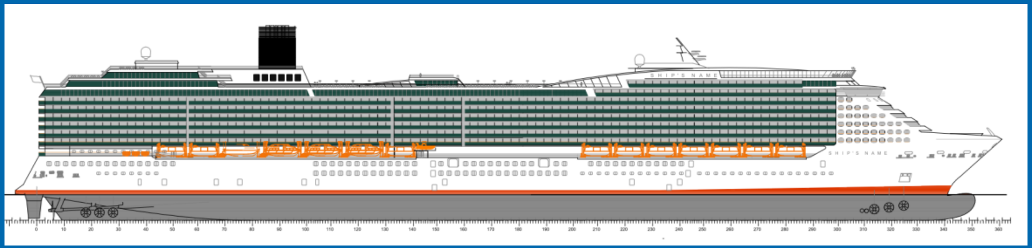
More details: see presentations by SSRC at GOALDS year 2 public WS, Oslo, Oct. 2011, http://www.goalds.org

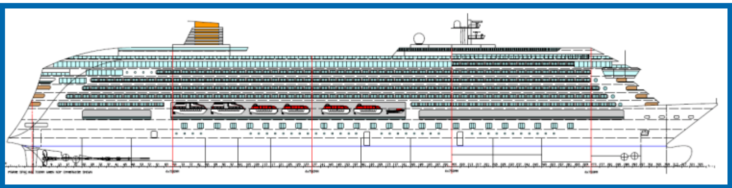


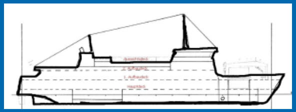


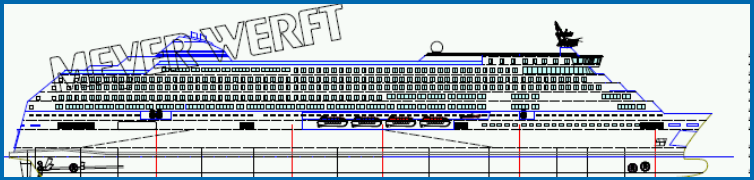
Validation of new s factor and exploration RCOs for 6 Sample Ships

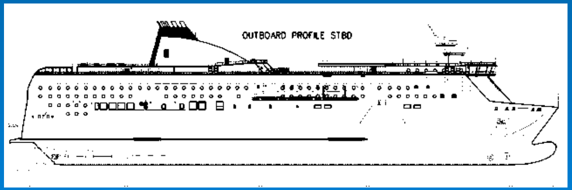
- Cruise ships
  - Large
  - Medium
  - Small
- Ropax
  - Large
  - Medium
  - Small
- Design teams
  - Shipyard
  - Shipowner
  - Class society
  - Flagg administration
  - University laboratory





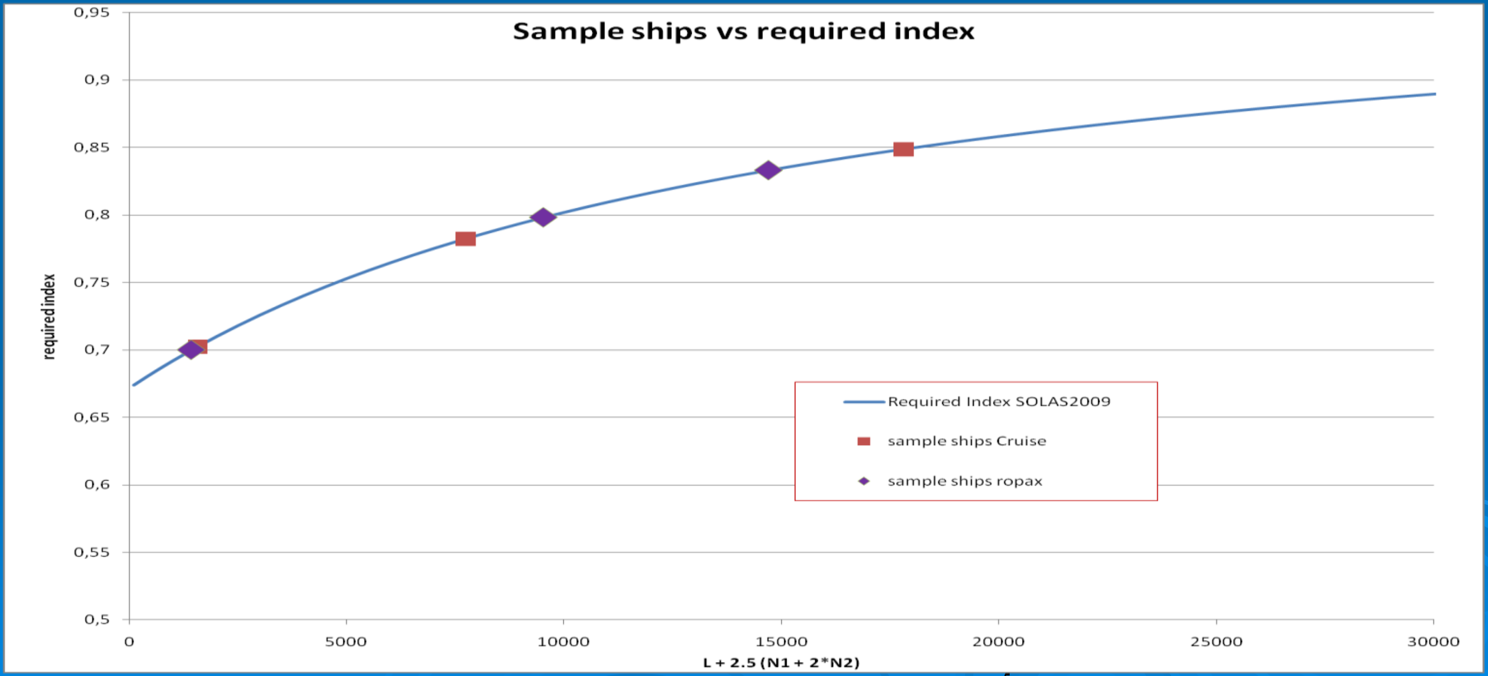






Range of Sample Ships

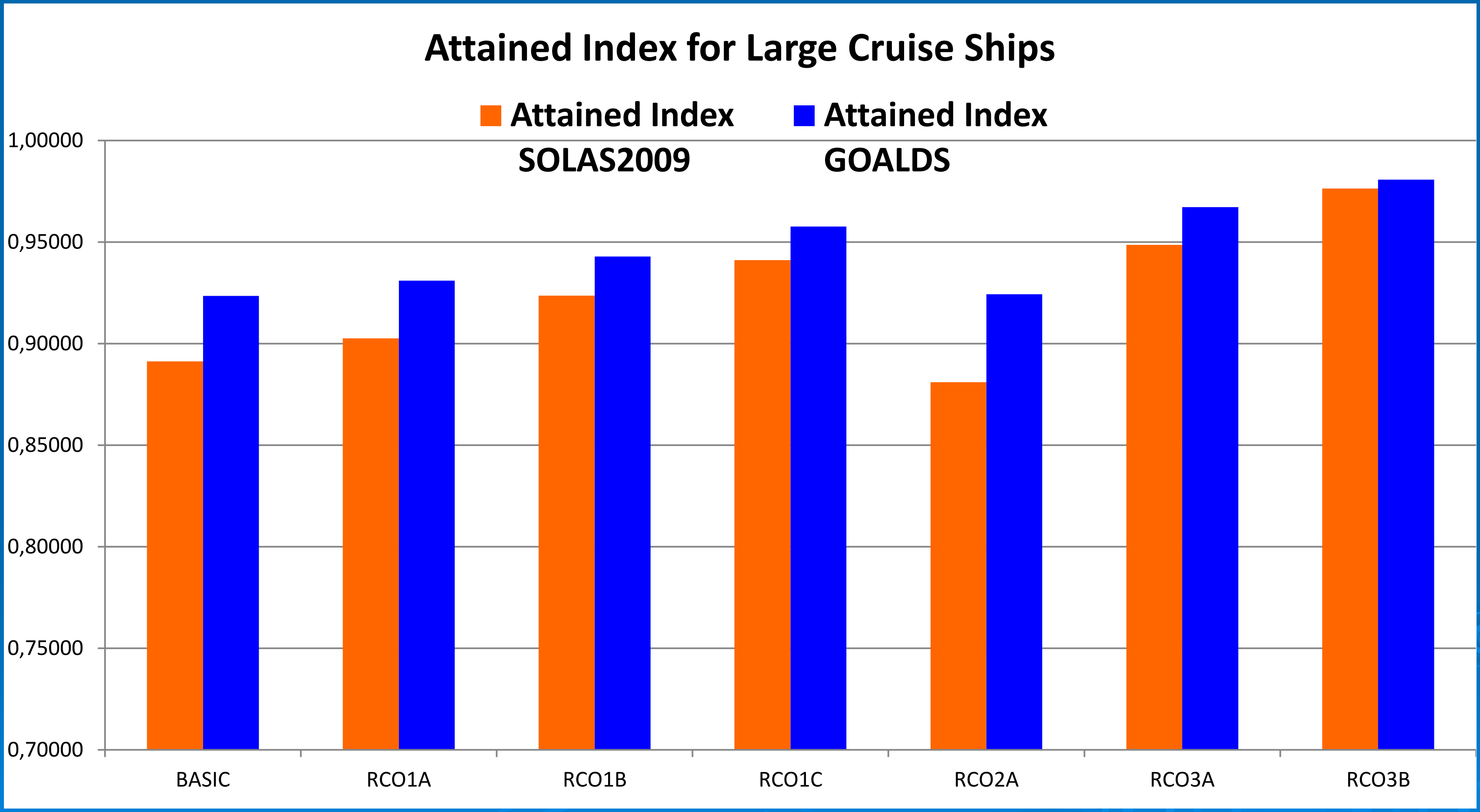
- Wide range of ship sizes covered
- Very large cruise ships (>150000GT) were not considered (max. 125000GT, Ls = 316m, 5600 POB)
- Small ships also not fully explored, but sample includes lower SOLAS limit (min. Ls = 80m, max. 800 POB)



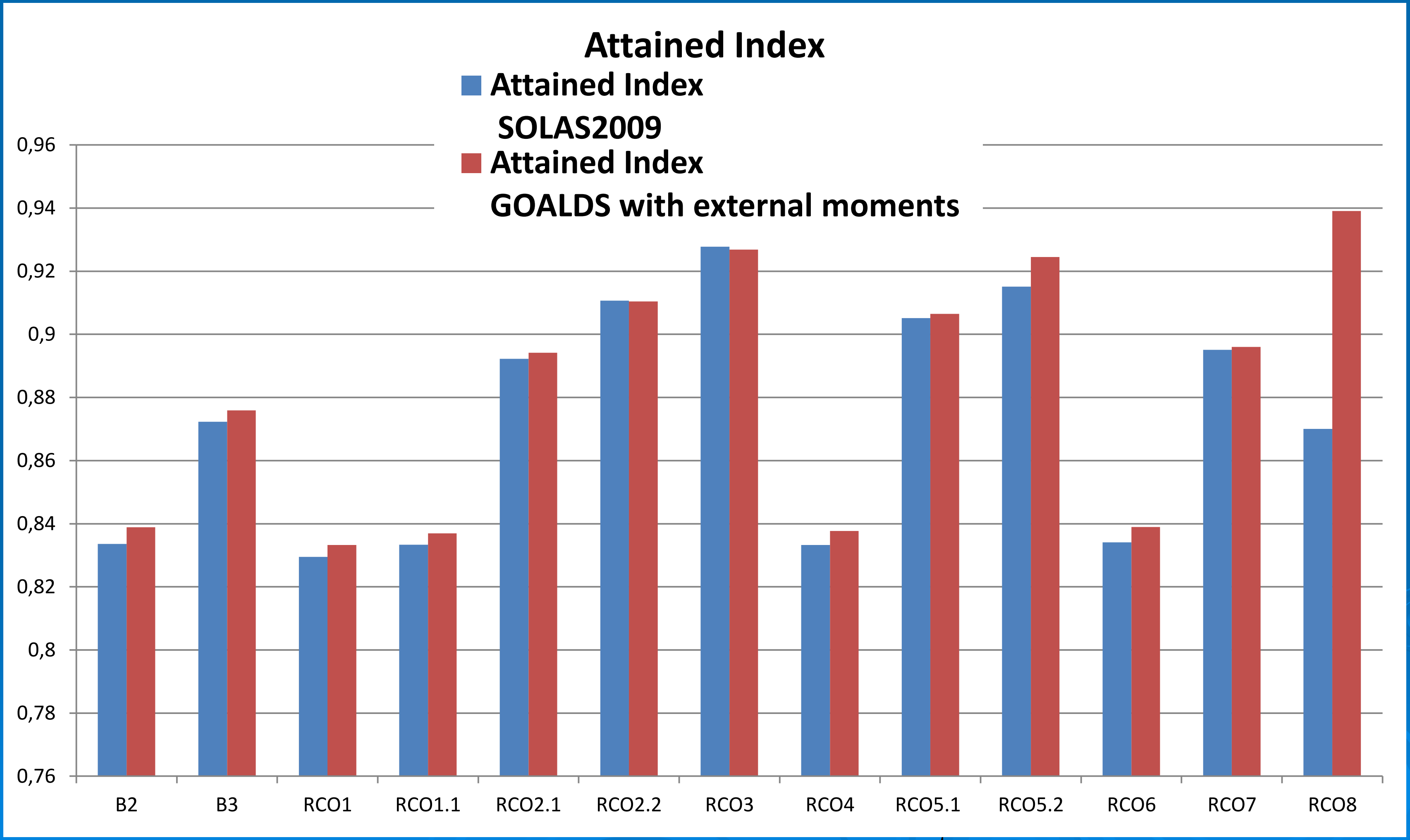
Sensitivity studies and exploration of Risk Control Options

- RCOs developed jointly by individual design teams (one team/ship)
- Basic ship requirements were kept constant
- Typical examples of variation:
  - Change of freeboard
  - Change of breadth
  - New subdivision
  - Additional watertight volume above bulkhead deck
  - Combination of measures
- Calculation of Attained Index
  - According SOLAS 2009
  - According GOALDS new s factor for passenger ships
- Rough estimation of costs of design changes

Attained index for RCOs (large cruise ship)



Attained index for RCOs (large RoPax)



Conclusions from new s factor validation

- SOLAS2009 and GOALDS index show similar tendency; *values of resulting A indices are comparable*
- GOALDS index gives enhanced credit for WT spaces above BHD and “effective“ freeboard
- RoPAx ships: LLH damages appear to have only a small contribution to the A index (abt. 6-7%), but impact on ship‘s survivability for individual damage scenarios may be significant

Experimental Studies - Objectives

- To gather damage stability data on passenger vessels to augment the existing database against which the new formulation of ‘s’ factor can be tested.
- To contribute to the accumulation of a substantial body of experiential and experimental data in order to increase the confidence in the methods and algorithms used to estimate the damage stability characteristics of vessels.

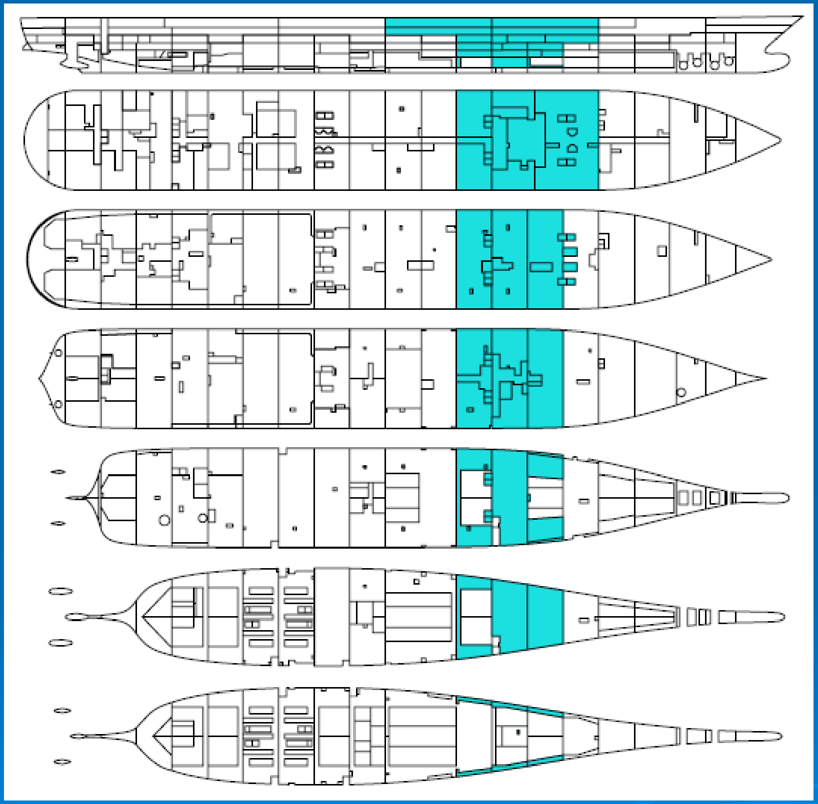
More details: see presentations by HSVA and VMB at GOALDS year 2 public WS, Oslo, Oct. 2011, http://www.goalds.org

GOALDS Ships Tested

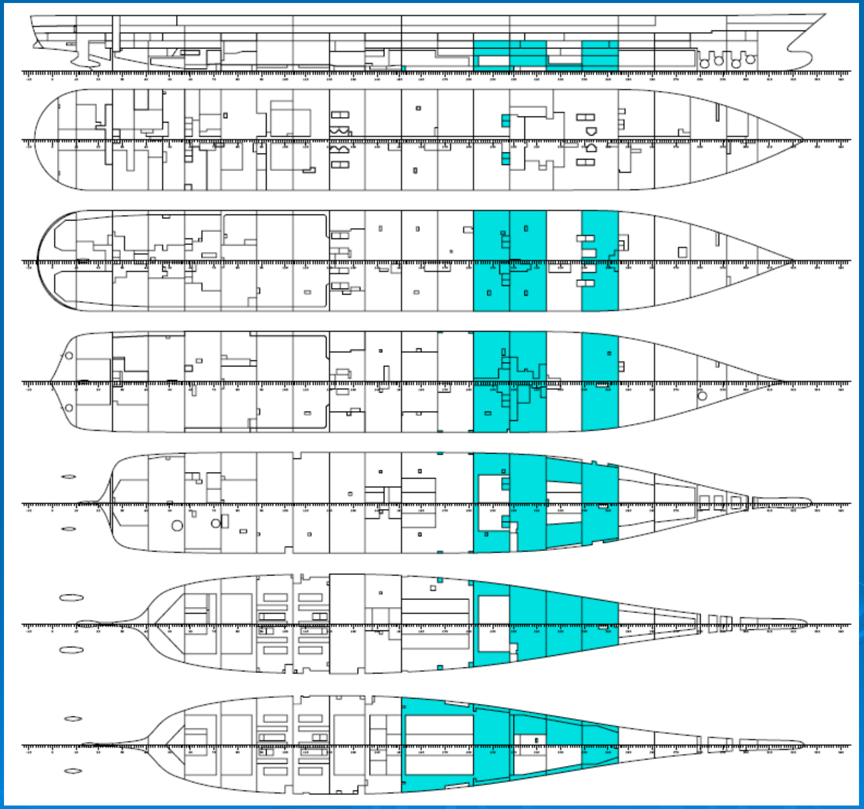
Ship	LBP (m)	B (m)	Ts (m)	Δ (t)	PAX	Tank
Ropax 1	176	25	6.55	16,558	1400	HSVA
Ropax 2	89	16.4	4	3,445	622	HSVA
Cruise 1	274.7	38.6	8.6	62,459	3840	VMB
Cruise 2	260.6	32.2	8.0	45,025	2500	VMB

Typical Test Damages (C1)

Collision Damage

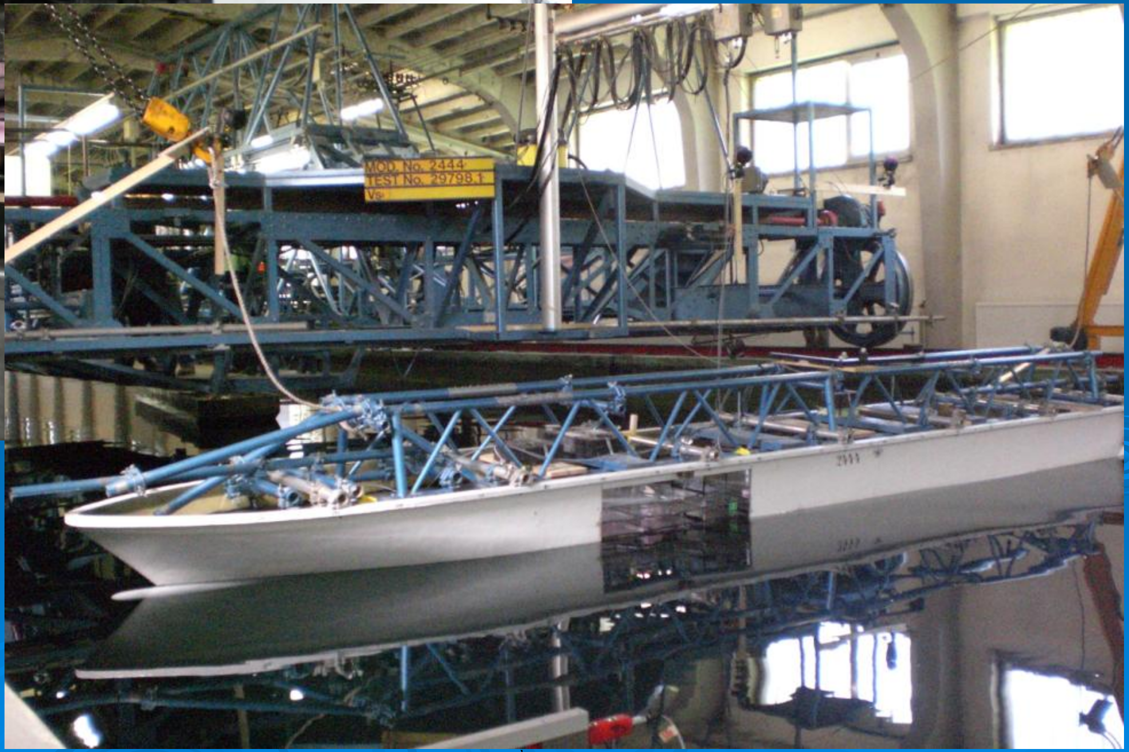


Grounding Damage



Model Set Up (C1) - VMB

Model in position



GOALDS Integrated Risk Model

- Objective
  - To establish risk based damage stability requirements *covering collision and grounding accidents* based on cost-benefit analyses
  - To be expressed as the level of a ***required index R as function of POB/persons on-board (or PLL…)***
  - It should cover ships carrying passengers and of types:
    - Cruise/Passenger ships
    - RoPax /RoPax-Rail ships
    - L over 80m
    - (No HSC)

GOALDS Risk Model

- The project developed specific tailored risk models (event trees) for collision and grounding accidents
- Basis for the risk analysis and eventually for the determination of the new R-Index:
  - Updated accident frequencies (1994 – 2010)
  - Update of dependent probabilities on the basis of IHS, LMIU, GOALDS and GISIS casualty data
  - Integration of new attained Index A in the risk model
  - Cost/benefit assessments of design variants (Risk Control Options) on the basis of the improved/new attained index A for sample cruise and RoPax ships.

Risk model – GOALDS Benchmarking

Benchmarking:

…understood as a *validation process* through comparison of the GOALDS risk model with alternative or other known other risk models, as well as with relevant historical data (for the same types of sample ships and accidents).

Key elements of GOALDS benchmarking:

- Study of consequences of collision and grounding (fatalities per shipyear and for lifecycle)
- Study of effects of alternative assumptions in the risk model (sensitivity studies of ensuing parameters)

Parameters affecting statistical analysis

- Important parameters affecting the results of risk analysis:
  - Extent of casualty data (limited sample)
  - Use of different time intervals (periods) for investigation
  - Difference in reporting/recording of accidents (under-reporting of non IACS ships)
  - Use of different samples for fleet at risk (all passenger ships, only IACS, only ships > 80 m, exclude High Speed Craft , ...)
  - Use of different databases (different sample of raw data)
  - Classification of accident's severity by database provider
    e.g.: *collision between a 105 m Cruise vessel and a fishing vessel of 100 GT is classified as serious for the Cruise vessel*
  - Use of different risk models (consideration of different accident scenarios)
  - Relevance of accident data (accident type, sample ship technology, loading and environmental conditions)
- Detected differences in frequencies and probabilities of occurence between GOALDS and previous work can be explained from the above

Analysis of consequences

- From relevant accident records in the GOALDS casualty database *for all passenger ships* (period 1990 to 2010):
  - Collision:
    - *No total loss*
    - *No fatalities* registered for struck passenger ship (4 fatalities in one case of striking vessel)
  - Grounding:
    - 4 cases of total loss
    - One case led to 0.1% fatality rate and
    - one case of total loss of overaloaded ship in very extreme weather conditions ('typhoon in Philippines') with a fatality rate of 94% (*relevance of this accident may be disputed*).

Modeling of fatalities in case of sinking

- Two different approaches (models) were considered:
  - Model A: Consider the outcome of sinking events *independently from accident type* (*initiating event may be other than collision or grounding*) -> ship capsizes without possibility of orderly evacuation ("< 30 min") or remains stable (not sinking)
  - Model B: Use of expert judgements based with respect to the time for evacuation; estimation of time to sink/capsize and relationship to realistic fatality numbers (considering all survivors); us of experience from numerical simulations (TTC) and of historical data (fatality rates)
- Model A was presented at an early stage in GOALDS:
  - Results to 100% fatalities, when the ship sinks/capsizes (1-A).
- Model B, similar to a model used in previous FSA studies (SAFEDOR):
  - Fatality rates depend on how fast the sinking/capsizing take place and other parameters (proximity to shore, etc).

Comparison PLL - Collision

Initial freq.	L	A	People capacity	PLL			
				Risk model A		Risk model B	
1/ship year	m			1/ship year	Per ship (30 yrs.)	1/ship year	Per ship (30 yrs.)
Cruise							
6.99 10^{-3}	170	0.73	1000	$1.49 \cdot 10^{-1}$	4.47	$2.52 \cdot 10^{-2}$	0.76
	200	0.77	2000	$2.54 \cdot 10^{-1}$	7.62	$4.31 \cdot 10^{-2}$	1.29
	290	0.80	3000	$3.31 \cdot 10^{-1}$	9.93	$5.63 \cdot 10^{-2}$	1.69
	290	0.82	4000	$3.97 \cdot 10^{-1}$	11.9	$6.67 \cdot 10^{-2}$	2.00
RoPax							
7.78 10^{-3}	150	0.75	1000	$2.12\ 10^{-1}$	6.35	$8.33 \cdot 10^{-2}$	2.50
	170	0.79	2000	$3.56\ 10^{-1}$	10.7	$1.37 \cdot 10^{-1}$	4.11
	210	0.82	3000	$4.57\ 10^{-1}$	13.7	$1.74 \cdot 10^{-1}$	5.22
	210	0.85	4000	$5.08\ 10^{-1}$	15.2	$2.02 \cdot 10^{-1}$	6.05

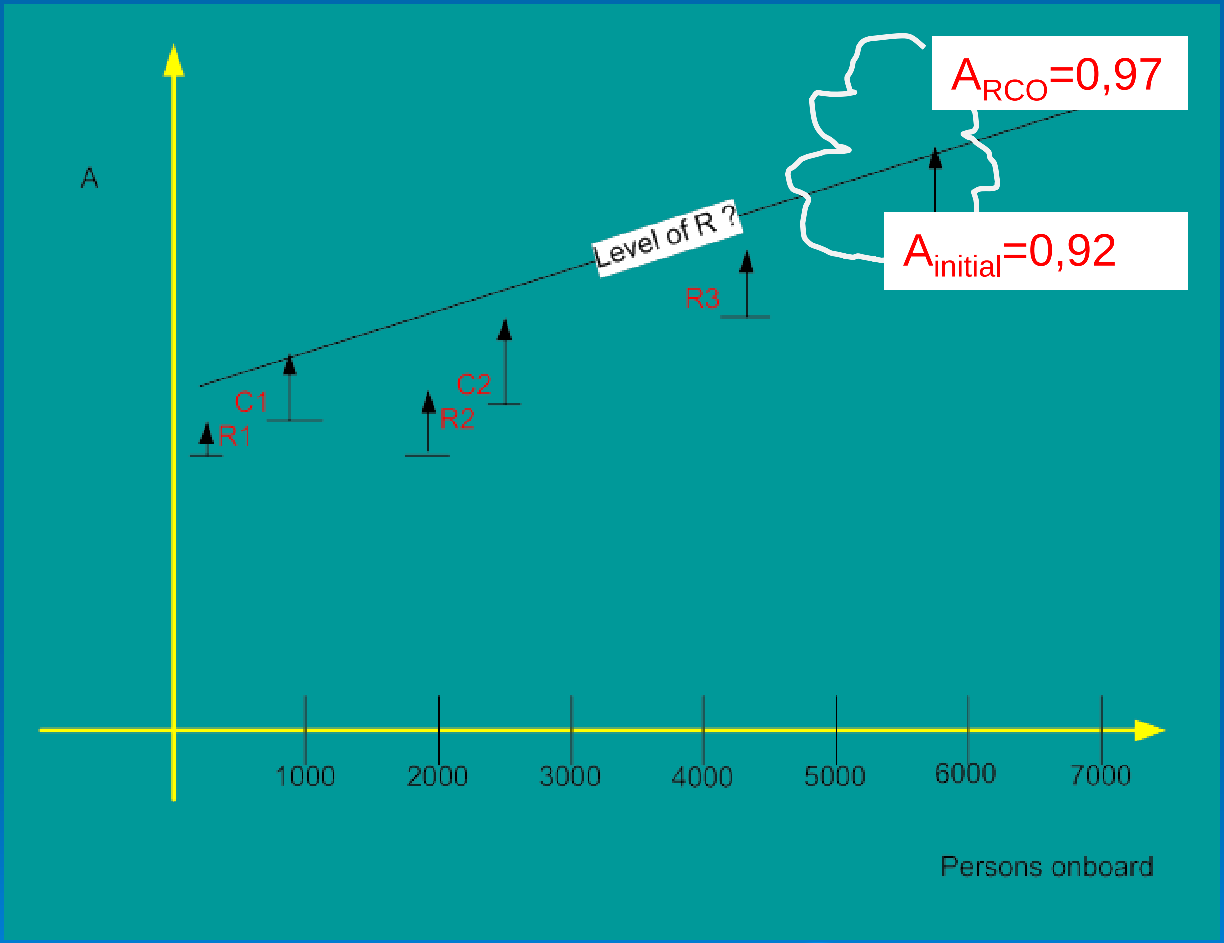
Conclusions/Recommendations/risk model

- The *uncertainities* in accidental causal data (due to very small statistical sample) and in the recorded consequences are recognised.
- Assumptions entailing 100% fatality rates in case of sinking/capsize, as laid down in the assessed model A, can be seen as an extreme case scenario and not representing the likely outcome.
- It is however acknowledged that when people could survive rapid ship sinking/capsize accidents, this is not a consequence of orderly evacuation
- The risk model should reflect the closest feasible the experience from relevant historical data and take into account realistic fatality rates depending on whether the ship sinks/capsizes fast or slowly, what greatly depends on the damage scenario, ship's properties, proximity to the shore and environmental parameters.

Methodology for R index

From GOALDS (WP3)	Sample ship calculations	Assessments
Factors p and v	Initial design	
s-factor	RCOs	$GrossCAF = \frac{\Delta C}{\Delta R}$
	ΔA , ΔR, ΔC & ΔB	$NetCAF = \frac{\Delta C - \Delta B}{\Delta R}$

Proposal of a new level of R index



Example:

The resulting A_{RCO} may be used for proposing a value of R for ships carrying that number of persons onboard. This requirement will correspond to a ship in the ALARP region of relevant FN-FSA, when applying relevant risk acceptance and cost criteria defined in the IMO FSA Guidelines.

Innovative ship concept designs

The impact of the new formulation for the probabilistic damage stability evaluation on the design and operational characteristics of characteristic ROPAX and cruise vessels is being currently studied more systematically

- Two already developed design multi-objective optimisation design procedures/software tools (NTUA-SDL and US-SSRC), encompassing the parametric design and multi-objective optimisation of ROPAX and cruise vessels, were adapted to the new damage stability standard proposed by GOALDS.
- Five (5) available yard designs were selected, namely one small ROPAX, two large ROPAX and two large cruise ships; they will be redesigned through formal multi-objective optimisation and elaboration by the formed 5 design teams, consisting of one shipyard, one class society, one operator, one flag state and one university laboratory.
- The watertight subdivision will be optimized for enhanced survivability, according to the new probabilistic damaged stability concept, considering building cost and efficiency in operation.
- Results of these studies will be presented at a GOALDS workshop planned in May 2012 (Hamburg) seeking to receive feedback from the end users, before concluding the design exercise in WP6 and providing feedback for the final dissemination of the project results and the submission to IMO.

Relationships of GOALDS to FLOODSTAND (1)

- Both projects address the survivability of passenger ships after flooding due to (collision or/and grounding) damages
- Focus of GOALDS is on improvement of ship design on the basis of improved damage stability regulations (‘*passive safety measures*’)
- Focus of FLOODSTAND is on improvement of operational procedures/crisis management (‘*active safety measures*’)

Relationships of GOALDS to FLOODSTAND (2)

- Both projects have certain important cross-references/links referring to
  - Estimation/modeling of Time to Capsize (TTC)
  - Estimation/modeling of Time to Evacuate (TTE)
  - Effect of Semi-Watertight Doors on Survivability
- Important conclusions from both projects appear to be (*personal opinion*)
  - In cases of ship loss the Time to Capsize (TTC) appears very short and not sufficient for an orderly evacuation
  - In view of this, both the *passive and operational safety of passenger ships* needs to be enhanced by
    - *Enhanced subdivision requirements, especially for mega passenger ships*
    - *Introduction of improved/innovative life saving appliances*
    - *Improved training of crew regarding (ISM and STCW codes)*
      - *Evacuation procedures in emergency*
      - *Navigation in restricted waters*
      - *Familiarization with ship's technology and working environment*

GOALDS year 3 dissemination Activities

Papers expected to be presented at the following international conferences and IMO

- 11th International Marine Design Conference IMDC2012 (Glasgow, June 2012)
- 12th International Conference on Stability of Ships and Ocean Vehicles STAB 2012 (NTUA-Athens, September 2012)
- IMO-SLF final report (London, October/Nov. 2012, for January 2013) – Intermediate reports issued in October 2010 and 2011

GOALDS: Year 3 Public Workshop (final)
STAB2012, September 23-28, 2012, Athens (NTUA)
http://stab2012.ntua.gr

GOALDS Web Site & Contacts

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http://www.goalds.org/

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