Public summary

The International Maritime Organization (IMO) defined the process Formal Safety Assessment (FSA) as a structured and systematic methodology, aiming at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost-benefit assessment (MSC-MEPC.2/Circ.12/Rev.2, 2018). The Cost-Benefit Assessment (CBA) is part of the ALARP process (As Low As Reasonably Practicable) and its purpose is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in the previous steps in order to make the risk ALARP. The ALARP process is applicable if initial risk is evaluated to be tolerable. The CBA provides the economic justification of risk mitigating measures. When the risk reduction is outweighing its own costs, all measures evaluated to be cost beneficial with respect to IMO specified thresholds should be considered for amending the regulations. By doing this, the risk level is reduced until no further risk reduction is economically justifiable, i.e. risk is ALARP.

In FLARE, new risk control measures were identified and selected ones were subject of a detailed investigation to calculate their risk reduction potential, costs and benefits. This investigation was performed by applying the RCOs to nine reference vessels, five cruise and four RoPax, and calculating the impact on risk compared to the original design of the reference vessel. The RCOs included internal subdivision, doors, watertight barriers, changes to hull, buoyancy volumes, flooding control and crashworthiness. Risk was calculated in terms of potential loss of life (PLL).

The selection of these sample ships as well as their characteristics have been summarized in deliverable D2.1 (Luhmann et al., 2019). In total 9 sample ships were chosen, six Cruise ships and three RoPax vessel, covering a size range between 11,800 GT and 230,000 GT, and a person on board (PoB) capacity ranging from 478 to 10,000 for cruise ships and from 2,800 to 3,700 for RoPax. These values encompass the whole range of ships currently in operation as well as ships that will be delivered in the near future. Most of these ships are designed to comply with the latest SOLAS amendments (SOLAS2020) and, due to their size, with safe return to port requirements. However, to show the effects on the existing fleet, also two SOLAS90 ships have been included in the sample.

The application of RCOs to reference ships is summarised in Table 1 for “standard” RCOs and in Table 2 for the new crashworthiness option. The fast calculation tool on crashworthiness developed in FLARE facilitates the consideration of structural resilience by evaluating the damage extents after collision and grounding, based of thousands of accident scenarios. By this approach, the enhancement of structural details of the ship’s hull become a measurable design parameter in the damage stability assessment, i.e., enhanced structures can be effective in reducing the breach sizes.

It is noted that the cost-benefit assessments of Crashworthiness enhancements have yet a different level of maturity compared to the RCOs listed above, due to the used simplified approach.

Table 1 Application of RCOs to reference ships

Category	RCO No	No #	1	2	3	5	9	6	7	8	10
		Type	Cruise					RoPax			
			S2020	S2020	S2020	S2020	S90	S2020	S2020	S2020	S2009+SA[1]
Internal subdivision	S1	Watertight bulkhead deck (with WT hatches)			X	X	X				
	S2	Double hull [with 1m] width			X	X					
	S3	Other									
Doors	*D1*	*SWD-door to staircases on the bulkhead deck*									
	D2	Reinforced doors	X								
	D3	Additional doors to bulkhead deck		X[2]			X				
WT-barriers	W1	Foldable sills									
	W2	Coaming surrounding the staircases on the bulkhead deck									
	W3	Foam wall									X
Change of hull	H1	Change of hull, e.g., increase of beam		X							
Buoyancy volumes	B1	Passive/permanent foam	X	X	X	X	X		X	X	X

All RCOs were investigated using the newly developed assessment framework for damage stability of passenger ships.

The cost-benefit assessment was performed using the reviewed cost threshold of $ 8.7 million updated by 2019 economic data (latest available information).

In this deliverable the results of the CBA are summarised considering the FSA requirements as well as uncertainty and sensitivity.

Table 2 Application of Crashworthiness to reference ships

RCO No	No #	1	2	3	5	9	6	7	8	10
	Type	Cruise					RoPax			
		S2020	S2020	S2020	S2020	S90	S2020	S2020	S2020	S2009+SA[3]
C1	B-1: Doubling inner bottom thickness (B00 type damages)									
C2	B-2: Doubling number of inner girders (B00 type damages)								X[4]	
C3	B-3: Steel upgraded to AH36 (B00 type damages)						X			
C4	DH-1: Double hull offset B/20, thickness 12mm (C00 & S00 type damages)			X				X		
C5	DH-2: Double hull offset B/10, thickness 12mm (C00 & S00 type damages)					X		X		

1 SA = Stockholm Agreement
2 RCO marked in RED level 2 calculations are performed
3 SA = Stockholm Agreement

C6	DH-3: Double hull offset B/30, thickness 12mm (C00 & S00 type damages)		X			X	X	X	X	
C7	DH-4: Double hull offset B/20, thickness 7mm (C00 & S00 type damages)							X		
C8	DH-5: Double hull offset B/20, thickness 17mm (C00 & S00 type damages)				X[4]			X		
C9	DS: side shell thickness + 10mm (S00 type damages)	X								
Combinations				S2-B1[4]	B1-C8	B1-C6	C3-C9		C5-C6	D3-B1[4]
				S2-C4Errore. Il segnalibro non è definito.		C5-C6[4]			B1-C5-C6	

In synthesis:

- All but two RCO (Ship #7 C4) proposed in FLARE are cost effective in reducing the risk, expressed as PLL. It is noted that such detailed cost-effectiveness evaluation is always ship specific;

- The adoption of RCOs is easier and more cost effective when implemented at early design stage, The engineering cost can be minimised when distributed on new series of ships (I.e., one prototype followed by several sisterships). However, this would limit the benefits to new ships only;

- Some of the RCOs are also applicable to existing ships without requiring comprehensive redesign or structural work. Risk reduction effect of these RCOs, e.g., foldable sills (1), coamings surrounding staircases (W2), and their cost efficiency has been demonstrated. Based on a sensitivity analysis that has been performed it was shown that this result is valid even when investment and operating costs vary by a large amount. Especially in times when energy and material costs are unstable the FLARE results are therefore still meaningful;

- Crashworthiness is opening a new range of options to properly consider the effectiveness of structural resilience on damage stability assessment, thereby increasing the design space available, I.e., providing more flexible design options to minimise the consequences of collision or grounding. The considerations made on the applicability to new or existing ships is valid also for the structural modifications required to improve the ship crashworthiness (higher steel grade, increased scantlings, additional structural elements, double hull…). A variety of structural enhancements has been considered and the effects on risk have been calculated. The positive impact of the structural modifications on the size of the hull breaches is obvious, in particular for long raking damages in bottom and side grounding events. However, the quantification of the effect on the nine sample ships was yet pre-mature, because the effects of the structural modifications on the breach dimensions were based on the Crashworthiness Calculation Tool applied to only one ship, for which the structural design data were available, and quantifying the effects

[4] RCO marked in RED level 2 calculations are performed

to the other sample ships by applying scaling factors. Nevertheless, assuming that the range of breach reduction factors of the reference design are of correct magnitude, the results have shown the significant potential impact of structural changes to reduce the hull breach dimensions. Although it is debatable how these findings may be extrapolated in a generic way, it is concluded that the Crashworthiness method applied in FLARE to a number of reference designs should be further investigated by applying it to a larger sample of demonstrator ships and calculating the associated costs. This should provide the basis for a future accurate cost-benefit assessment of crashworthiness and subsequent consideration in the regulatory framework, if justified;

In conclusion, a new framework has been applied to passenger ship damage stability assessment, using risk in terms of PLL as metric instead of key performance indicators. Among others, this new framework offers the advantage of linking the two essential aspects of passenger ship safety: damage stability (ship's survivability after flooding accidents) and evacuation from the ship (before sinking or capsizing). This link between SOLAS chapters II-1 and III offered by the new framework is considered to be an important conclusion that should be submitted to IMO, inviting all relevant stakeholders to use this new framework and get more experience, with a view of introducing further future amendments to SOLAS damage stability requirements on the basis of a risk-based assessment concept, as used in other safety-critical industries.

Based on the results of FLARE investigations it is recommended to:

- Further investigate the crashworthiness approach and the quantification of its effects in the damage stability assessment, e.g., following an alternative design process;
- Open current IMO framework for considering RCOs as investigated in this study;
- Consider the application of adequate RCOs to existing fleet; and,
- Further examine the new risk-based framework for passenger ship damage stability assessment and discuss the introduction of risk as the metric used.

REFERENCES

Luhmann, Henning, Anna-Lea Routi, Mike Cardinale, Rodolphe Bertin, Gijs Streppel, Juha Kujanpä, 2019: Sample Ships – Overview. Deliverable 2.1 https://www.flare-project.eu/images/D2.1_overview_sample_ships_final_20210215.pdf

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