ISSW 2013 - Session on ship stability and design implication

Interpretation and design implications of probabilistic damage stability regulation.

Luc Lemoine, Fabrice Mahé, Nicolas Morisset, Rodolphe Bertin

STX France SA

ABSTRACT

The adoption of resolution MSC.216(82) (SOLAS 2009) has had widespread implications on the design of passenger ships which have led to significant improvements in their safety with respect to the risk of flooding.

The development of this new regulation has been an opportunity to completely re-evaluate the way of calculating damage stability which has resulted in a much more rigorous and thorough methodology to evaluate the damage stability of ships, especially for passenger ships. Furthermore, the adoption of a probabilistic method has tremendously increased the amount and complexity of the work required by the designer to ensure compliance to the rule.

Besides the more typical work on subdivision and hydrostatic calculations, this new regulation which considers that any compartment may be flooded has had a significant impact on other parts of ship design such as piping and ventilation ducts. This implies that other design departments in the shipyard need to be involved from early design stages to detailed studies and verifications on board.

To this end, a calculation methodology with adapted calculation tools have been developed at STX France. The first implementations of the rule performed by STX France have highlighted that some calculation parameters are subject to interpretations and that further clarifications of the rules, including the explanatory notes are necessary to apply it.

The goal of this paper is to explain how the rule may be applied in order to achieve a level of safety consistent with the intent of the rule, thereby ensuring that different design strategies which respect these guidelines, may lead to the identical safety level.

INTRODUCTION

Development of SOLAS 2009 [IMO resolution MSC.216(82)] has been a long process during which different parties have been involved : representatives from Administrations, Classification Societies, Universities, ship owners and shipbuilders.

Harder project gave the basis for the formulation of probability and survival factor.

Finally, the required index was been based on calculations of attained index for test ships fulfilling SOLAS 90 requirements.

STX France has been involved in these test calculations, which provided an opportunity to identify practical difficulties in the interpretation of this new regulation.

Applications on new ships designed by the yard have necessitated long discussions with Classification Societies which highlighted the fact that the explanatory notes are not sufficient and need further clarification on some aspects.

EVOLUTION OF DAMAGE STABILITY REGULATION

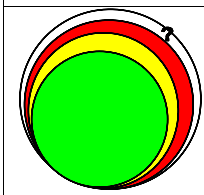
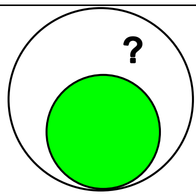
The original aim of SOLAS 2009 new regulation was not to increase the safety level but to reach an equivalent safety level as with SOLAS 90 rules, while resolving some weak points of previous regulation. Indeed, because only a limited number of pre-determined damage cases needed to be studied in the deterministic approach, it was possible to optimize a ship to fulfil SOLAS90 criteria (most of damage cases close to the required survivability) while reducing the overall safety level of the ship. The SOLAS 2009 is much more representative of the safety level of the ship.

The purpose was also to have the possibility to use the damage stability calculations within a risk analysis approach in order to be in line with last IMO recommendations which advocate the use of a probabilistic approach.

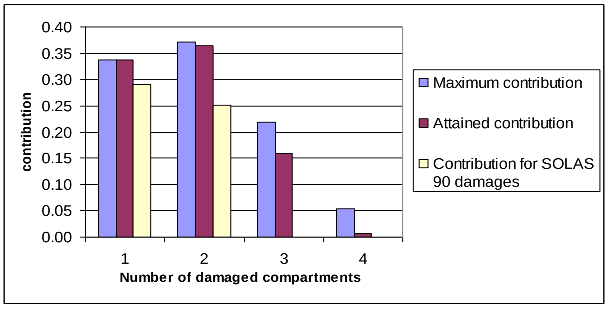
Probabilistic damage stability is based on the calculation of all possible damage cases, each of which is given a probability factor and a survival factor for all initial loading condition. This calculation results in an attained index, which reflects the overall safety level of the ship.

Contrarily to deterministic approach of SOLAS 90, the probabilistic approach highlights the fact that the ship can sink for a certain number of damage cases. The situation is in fact identical to that of the previous deterministic method, where a significant part of possible damage cases were in fact not studied :

Principle of calculated and surviving damages according to regulation (graph not scaled):

SOLAS 2009	**SOLAS 90**
Green : s=1 ; surviving damage cases	Green : surviving 1 or 2 compartments damage cases
Yellow : 0<S<1; survivability reduced	
Red : s=0 ; not surviving damage cases (ship may not sink)	
White : not calculated cases – situation unknown	White : not calculated cases – situation unknown. More than two compartments flooded
	

On a large cruise ship (over 6000 persons on board), it has been checked that the one and two compartments damages when limited in penetration to B/5 contribute only to 0.54 in attained index. Such a large passenger ship designed for SOLAS 90 could also sustain some damages extending over more than two compartments or beyond B/5 limit and it has been established from previous studies that this type of ships may achieve an attained index of 0.70 to 0.75. However, it must be noted that these results do not take into account possible progressive flooding for damages extending beyond the B/5 limit, so they may be overestimated. For this ship, fulfilment of R index of 0.861, necessitates having 78% contribution for 3 compartments damages and 15% contribution for 4 compartments damages. These values correspond to compartments referred to in SOLAS 90, and may include damages extending over up to 5 “subdivision zones” for 3 compartments damages.



CALCULATION PRINCIPLES ACCORDING TO STX FRANCE INTERPRETATIONS

INSTANTANEOUS FLOODING IN LESS THAN 60S

In the explanatory notes of rule 7-2.2 it is mentioned:

§5 […] "If complete fluid equalization occurs in 60 s or less, it should be treated as instantaneous and no further calculations need to be carried out. Additionally, in cases where s_{final} = 1 is achieved in 60 s or less, but equalization is not complete, instantaneous flooding may also be assumed if s_{final} will not become reduced. In any cases where complete fluid equalization exceeds 60 s, the value of $s_{intermediate}$ after 60 s is the first intermediate stage to be considered."

In SOLAS 2009, complete flooding in less than 60s is to be verified for all compartments which are assumed instantaneously flooded. Situation with complete flooding of compartments included in breach extent is the first intermediate (or final) stage to be studied. No intermediate phase is studied before 60s.

This instantaneous flooding (in less than 60s) is the first important check that needs to be done at the beginning of the study. This is an essential prerequisite for the splitting of room defined in the ship model used for calculation. This may require a more detailed initial ship model, which can be simplified after checking of instantaneous flooding

Two cases are likely to occur:

- The down flooding or cross flooding areas are large enough to ensure instantaneous flooding of all parts of the compartment.
- Available cross flooding or down flooding section areas are too small to permit a flooding in less than 60s (as in some parts of double bottom). In this case the compartment to be flooded is divided in two or more rooms. The first one is dimensioned to be flooded instantaneously and the other ones are considered flooded at successive stages.

In this second case, the first intermediate stage may have a penalizing effect on the stability if it induces unsymmetrical flooding and cumulative effect of several unsymmetrical flooding may seriously impair the survivability of the ship for the concerned damage cases. Since these cases represent possible flooding situations, they should not be neglected and they have to be integrated in the calculations.

In the cases where instantaneous flooding can not be justified one alternative method consists in evaluating the situation of the ship after 60s and checking that a partial unsymmetrical flooding does not impair the stability. This is permitted by the explanatory note 7-2.2: *"Additionally, in cases where s_{final} = 1 is achieved in 60 s or less, but equalization is not complete, instantaneous flooding may also be assumed if s_{final} will not become reduced".*

However, in our opinion, this method if applied for each compartment separately without any cumulative effect is not sufficient. Indeed, one single unsymmetrical flooding may not impair the stability whereas two or three may lead to ship capsizing.

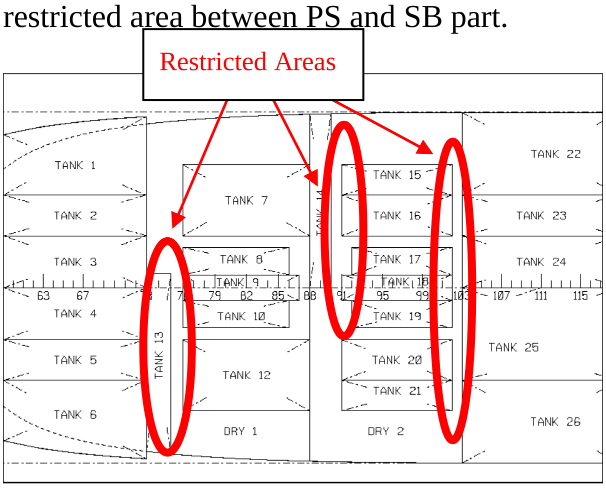
If flooding simulation is used, it should be applied:

- on all compartments separately if the goal is to check its proper flooding in less than 60s
- on all damage cases involving an equalization device, including most penalizing multi-zones damages, contributing to A-index if the goal is to check the situation of the ship after 60s.

As flooding simulations applied on all multi-zones damages require significant calculation resources and time, it is quicker and more conservative to assume unsymmetrical flooding in an intermediate stage and to take it into account in the s factor calculation.

The way instantaneous flooding has been considered in the calculation of attained index is essential for the survivability of the ship and attained index might be overestimated if instantaneous flooding is assumed without proper justification.

If we take the example below of 2 compartments (DRY 1 and DRY 2) with a restricted area between PS and SB part.



Flooding time calculations are done taking into account the flow of water through only 1 frame distance (for DRY 1) or 2 frame distance (for DRY 2) between starboard and portside parts of the compartments.

The type of connection between the SB and PS parts (within the breach, intermediate or final) is then applied in accordance with the flooding time calculated (<60s, between 60s and 600s or >600s)

Damage Case Definition and Flooding Sequence in Relation with Watertight or Non-Watertight Boundaries

One critical step in the calculation process is the definition of all possible damage cases to be studied.

Due to the large number of damage cases to be studied, automatic generation of damage cases has to be done which assumes that well defined assumptions are taken into account.

The generation of damage cases has to take into account two main inputs:

- Possible breach extent to which a probability of occurrence will be affected
- Possible cross flooding and progressive flooding of rooms not directly within the breach extent. Intermediate stages need to be calculated for passenger ships but not cargo ships.

The survival factor calculated for each damage case may be largely dependant on the detailed definition of the damage cases, including the possible successive stages of flooding.

On this point, our opinion is that the regulation and explanatory notes are not sufficiently clear. The principle we apply is to model as close as possible the physical flooding process assuming successive static equilibriums.

One typical example is that of structural non-watertight limits (decks or bulkheads)

The explanatory notes of 7-2.2 states (§2) that they have to be taken into account as they can restrict the flow of water and thus have beneficial or adverse effects on the calculation results. But there is no clear prescription on how they shall be taken into account.

One simplistic approach consists in calculating intermediate flooding stages (with intermediate criteria that are less demanding than final criteria) and one final stage (with final criteria) after collapse of the non-watertight boundary. **The weakness of this approach based on the application of the intermediate criteria is that it assumes without any justification (strength or flood time simulation) that the non-watertight boundary will collapse in less than 10 minutes.**

Another approach is proposed when it is neither proven that the non-watertight boundary will collapse in due time (if it collapse), nor that the cross flooding time has been checked

We consider that no cross flooding will occur during first 10 minutes and therefore that final criteria need to be applied at this first stage. In addition, we consider that the final criteria also needs to be applied to intermediate phases between the two situations.

The most severe case calculated between before and after collapse should be retained in accordance with the wording "beneficial or adverse effects" mentioned in following paragraph of SOLAS 2009:

Chap II-1 Regulation 4: "Where it is proposed to fit decks, inner skins or longitudinal bulkheads of sufficient tightness to seriously restrict the flow of water, the Administration shall be satisfied that proper consideration is given to beneficial or adverse effects of such structures in the calculations."

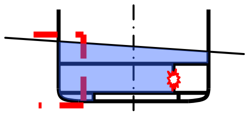
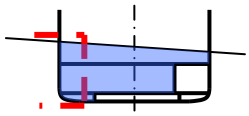
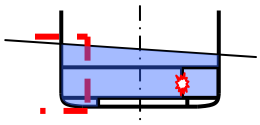
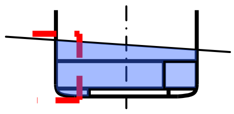
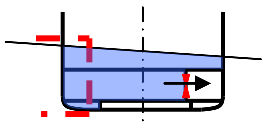
This interpretation is also based on explanatory notes of rule 7-2.2, which clearly indicates that cross flooding time needs to be checked and that: *"In case the equalization time is longer than 10 min,* s_{final} *is calculated for the floating position achieved after 10 min of equalization.[…]"*

This method is not easily implemented in the current Napa release as it requires additional final stages after cross flooding stage, which is currently the last stage in Napa. Specific in house development in Napa Software has been realized to fit this purpose. (See chapter "Implementation in calculation tool")

This calculation assumption leads to a significant improvement of survivability of the ship, as the designer is encouraged to fit all non-watertight boundaries with flooding hatches if the situation before cross flooding is penalizing and to justify proper cross flooding through these hatches in less than 10 minutes as required in reg. 7-2 §2 of SOLAS 2009. This arrangement reduces all cross-flooding times and therefore improves survivability of the ship in case of damage.

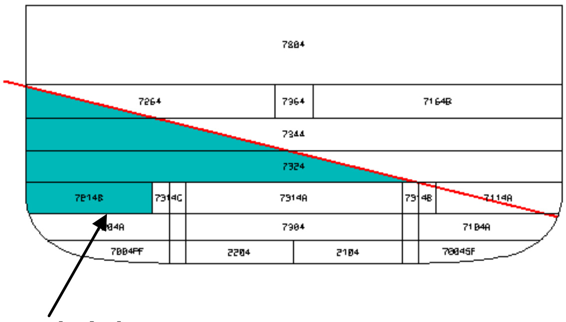
In other words, by calculating the same given arrangement with both methods, a lower attained index will be obtained with the more conservative interpretation and the design will then need to be improved in order to restore the index.

At the end, A-indexes will be identical but the underlying hypothesis are different and the more conservative interpretation leads to safer ships.

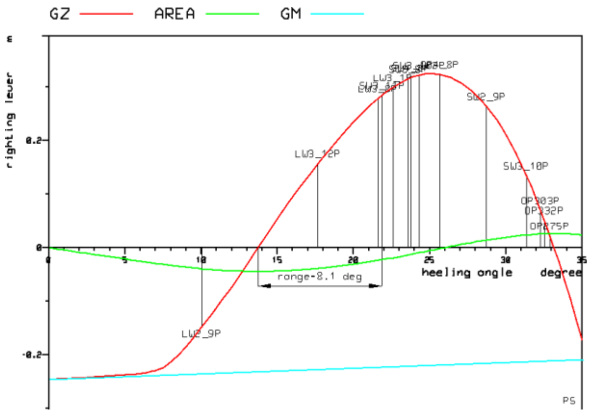
Basic approach	Physical approach
 First flooding stage Calculated with **intermediate** criteria, assuming the non tight boundary will collapse in less than 10min	 First final flooding stage Calculated with final criteria, if it is not proven that the non tight boundary will collapse in due time and no justification of cross flooding time is performed. **Result more penalizing than with intermediate criteria**
 Final flooding stage	 Final flooding stage – time undefined Worst attained index between first and second final stage retained
	If first stage is too penalizing, then a flooding device is fitted in order to ensure cross flooding in less than 10 min  First flooding stage calculated with $s_{intermediate}$ in this case

Example from real case:

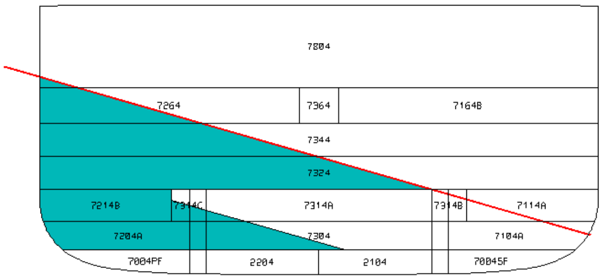
1st stage calculated with <u>final criteria</u> if it is not proven that down flooding occurs in less than 10 min. **Result more penalizing than with intermediate criteria**

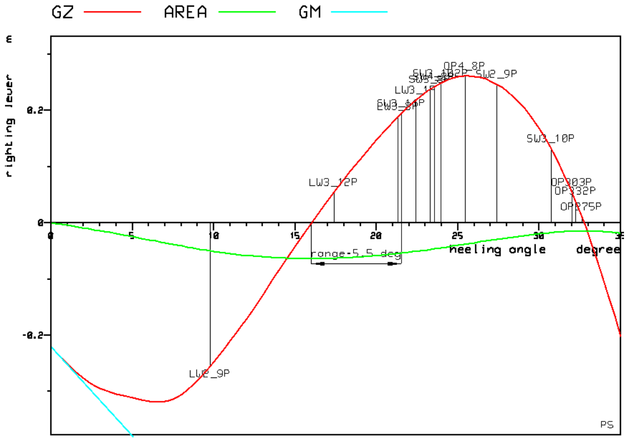


Non tight deck

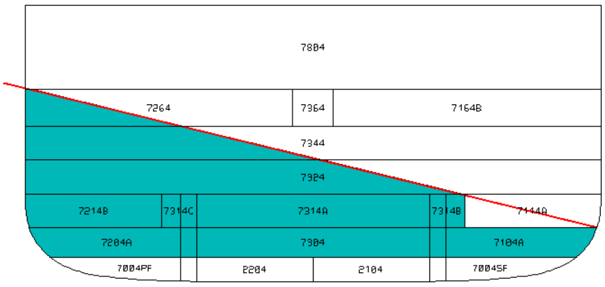


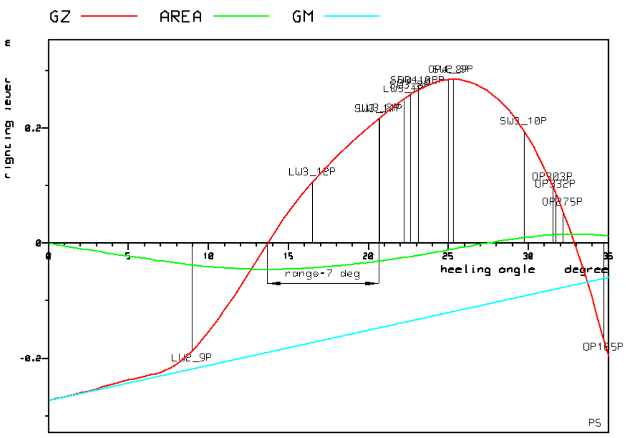
Intermediate phase calculated with <u>final criteria</u> if duration is not justified. Very penalizing phase. s = 0. This phase also illustrates next chapter about multiple free surface effects





Final equilibrium

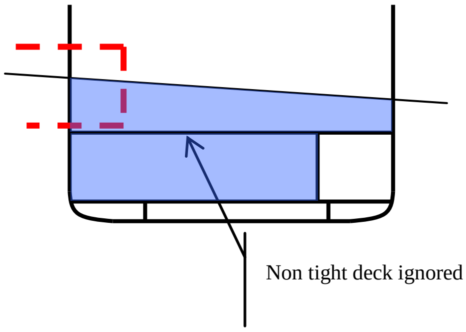




CALCULATION METHODS FOR INTERMEDIATE STAGES OF FLOODING AND MULTIPLE FREE SURFACE EFFECTS

Reg. 7 §6 of SOLAS 2009 mentions : *"In the flooding calculations carried out according to the regulations, only one breach of the hull and only one free surface need to be assumed."*

This could lead to ignore the non watertight boundary by calculating only the final situation represented on the figure here below:

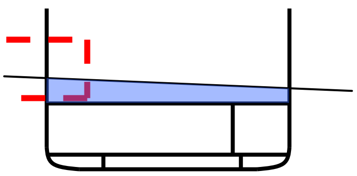


However, this basic approach would be in contradiction with second part of §6 of reg 7: *"However, if a lesser extent of damage will give a more severe result, such extent is to be assumed."*

Accordingly, we consider that the physical phenomena should be modelled and our understanding of the rule is that only one free surface needs to be assumed for water in spaces flooded <u>during the current stage</u>**.**

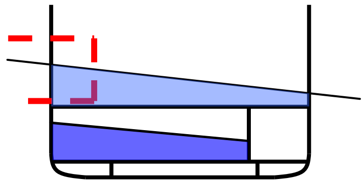
This implies that the following successive stages need to be studied:

Stage 0



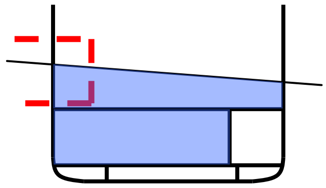
One free surface effect in first stage – even although treated in lost buoyancy method

Intermediate phase of stage 1



- Rooms flooded in first stage treated in lost buoyancy method.
- Added weight method with one common free surface for down flooded rooms in second stage

Final phase of stage 1



All flooded rooms treated in lost buoyancy method.

This interpretation leads to consider that **free surface effects for rooms flooded at a given stage should be superposed with the destabilizing effect of water flooding in the previous stage** and taken into account with lost buoyancy method.

The situation at stage 0 (with intermediate or final criteria depending on flooding time – see part 4.2) and of intermediate phase of stage 1 have an adverse effect on stability and therefore a negative impact on the attained index.

To achieve the same level of attained index as with first simplified approach, the designer needs to reduce flooding times or to find some arrangement to improve the global index. The most straight forward solution is to define large flooding devices in order to justify an instantaneous flooding

Conclusion: s-factor and survivability

These explanations demonstrate that the attained index may be largely dependant on the interpretation and the hypothesis taken to perform the calculations. Rules and explanatory notes still leave room for interpretation which can have a significant impact on attained index (20% to -30% of 1-A).

For a given arrangement, a high attained index will be obtained with favourable assumptions but it will not necessarily reflect a high survivability for the ship.

On the contrary, trying to apply a more physical approach leads first to a lower attained index. Hence, the design needs to be improved in order to increase attained index by:

- facilitating and speeding up the cross-flooding process,
- avoiding or reducing unsymmetrical flooding,
- reducing successive progressive flooding through non tight boundaries, pipes and ducts, …
- finding other ways to improve global attained index in order to compensate for the loss in index.

At the end of this optimization process, the restored A-index might be identical to the one obtained with favourable assumptions, but the underlying hypothesis are different and **the survivability of the ship is actually enhanced.**

Ship 1	Ship 2
Attained index A1 = A2	
Favourable calculation assumptions = **LESS SURVIVABILITY**	More physical calculation assumptions = **SAFER SHIP**

IMPLEMENTATION IN CALCULATION TOOLS

A special Manager has been developed by the STX France with NAPA-Software, including the following possibilities:

- Step by step procedure with verification at each step that all necessary data are updated.
- Visualisation of results and analysis tool to be able to check the results.

This tool also allows us to explain the variations of attained index resulting from modifications or inversely to find the most effective modification which can be done to achieve the required index.

From this experience, we can conclude that the probabilistic method seems very robust. Every evolution in attained index has been explained and progressive evolution is usually observed.

One of the more complex issues is the generation of intermediate stages of flooding. Stages for which a space not directly within breach extent will be flooded are defined in such way as to follow as closely as possible the physical progress of flooding as exposed in previous chapters. This specific manager allows us to specify whether each stage should be considered as "intermediate" or "final" for the calculation of the survival factor. **It is also possible to define successive stages considered as "final". Particularly, a stage is considered as "final" if it is followed by stages which are not certain to occur** (as progressive flooding through piping within the breach extent) or **flooding which may occur within a long or undefined time**

In order to keep results for calculation on the both side of the ship, calculation is made in two distinctive folders.

The probabilistic damage stability calculation in NAPA contains many steps, such as creating the subdivision table, generating the damage cases etc., which have to be taken in a logical order. The hierarchical tree structure of the manager contains all the necessary steps to be taken before any results can be obtained.

The intention with this development was also to provide a design tool allowing the person responsible for the stability to **analyse the results by browsing through the many cases which are sorted according to the severity of the damages.**

CONNECTION TABLE DEFINITION

Connections are based on the physical links between two rooms, if they are not separated by a watertight boundary. If rooms are separated by a partially watertight bulkhead, an opening will be defined at the critical point of this partial bulkhead to ensure that no progressive flooding will occur. (GZ curve is limited to the angle at which this opening is submerged.).

Connections are defined between the room within breach extent and another room.

For each connection a stage option needs to be defined to set the flooding order of the different connected rooms and also to set the survival factor to be used at each stage.

If cross flooding is achieved in less than 10 minutes, option is INT1, INT2, …INTn or FIN for the last one. If flooding is achieved in more than 10 min or without time justification, stage option is PROG1, PRO2, …PROGn. Same stage option may be used for two rooms flooded at the same stage.

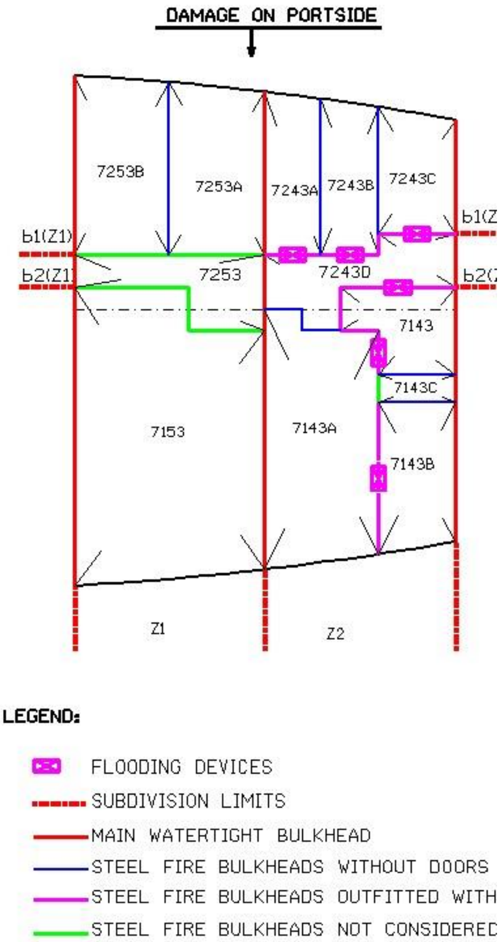
Survival factor for INTn stages are calculated with intermediate criteria.

Survival factor for FIN and PROGn stages are calculated with final criteria.

All these connections are arranged in two tables for portside and starboard damages.

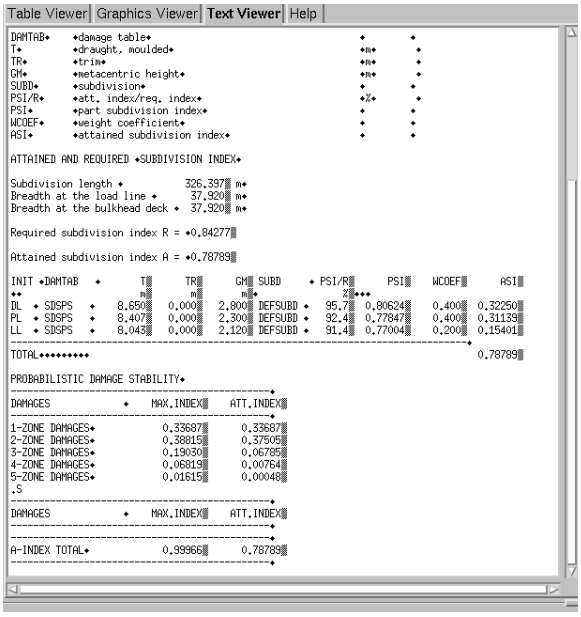
Example of connection table and corresponding arrangement:

	CONN	COMP	OPEN	STAGE
1	R7253B	R7253	Y	PROG1
2	R7253B	R7153	Y	PROG2
3	R7243A	R7243D	Y	INT2
4	R7243A	R7143	Y	INT3
5	R7243A	R7143A	Y	INT4
6	R7243A	R7143B	Y	FIN
7	R7243A	R7143C	Y	PROG1
8				



Presentation and analysis of the results

Summary of the results:



```
Table Viewer | Graphics Viewer | Text Viewer | Help

DAMTAB    damage table
T         draught, moulded              m
TR        trim                          m
GM        metacentric height            m
SUBD      subdivision
PSI/R     att. index/req. index         %
PSI       part subdivision index
WCOEF     weight coefficient
ASI       attained subdivision index

ATTAINED AND REQUIRED SUBDIVISION INDEX

Subdivision length           326.397 m
Breadth at the load line      37.920 m
Breadth at the bulkhead deck  37.920 m

Required subdivision index R = 0.84277

Attained subdivision index A = 0.78789

INIT  DAMTAB      T      TR      GM  SUBD      PSI/R      PSI   WCOEF      ASI
                  m       m       m             %
DL    SDSPS   8.650   0.000   2.800  DEFSUBD    95.7  0.80624   0.400  0.32250
PL    SDSPS   8.407   0.000   2.300  DEFSUBD    92.4  0.77847   0.400  0.31139
LL    SDSPS   8.043   0.000   2.120  DEFSUBD    91.4  0.77004   0.200  0.15401
-------------------------------------------------------------------------------
TOTAL                                                                  0.78789

PROBABILISTIC DAMAGE STABILITY
-------------------------------------------
DAMAGES              MAX.INDEX   ATT.INDEX
-------------------------------------------
1-ZONE DAMAGES         0.33687     0.33687
2-ZONE DAMAGES         0.38815     0.37505
3-ZONE DAMAGES         0.19030     0.06785
4-ZONE DAMAGES         0.06819     0.00764
5-ZONE DAMAGES         0.01615     0.00048
.S
-------------------------------------------
DAMAGES              MAX.INDEX   ATT.INDEX
-------------------------------------------
-------------------------------------------
A-INDEX TOTAL          0.99966     0.78789
-------------------------------------------
```

Detailed results:

Maximum index and attained index obtained are detailed for each zone or combination of zones. Presentation of results are provided in two ways (list and bar-graph)

Attained subdivision index ATTINDEX (weighted result) and indices obtained for each initial condition (ATTDL, ATTPL, ATTLL) are presented in detail for each group of n combined zones. (See example below for 2 zones damaged). **The attained index can be easily compared with the potential maximum attained index for each group and in this way, group of damage which don't fulfil "s" = 1 can be detected.**

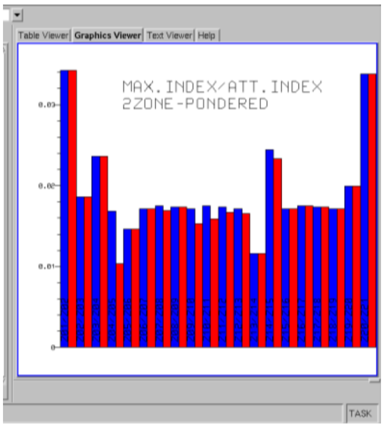
ATTAINED INDEX FOR 2 ZONE DAMAGED

*MAX.INDEX - INDEX DL/PL/LL - ATT.INDEX *

ZONE	MAXINDEX	ATTDL	ATTPL	ATTLL	ATTINDEX
Z01/Z02	0.03423	0.03423	0.03423	0.03423	0.03423
Z02/Z03	0.01861	0.01861	0.01861	0.01861	0.01861
Z03/Z04	0.02361	0.02361	0.02361	0.02361	0.02361
Z04/Z05	0.01686	0.01033	0.01033	0.01033	0.01033
Z05/Z06	0.01462	0.01462	0.01462	0.01462	0.01462
Z06/Z07	0.01716	0.01716	0.01716	0.01716	0.01716
Z07/Z08	0.01749	0.01646	0.01700	0.01749	0.01688
Z08/Z09	0.01738	0.01734	0.01738	0.01724	0.01733
Z09/Z10	0.01716	0.01632	0.01529	0.01326	0.01530
Z10/Z11	0.01749	0.01690	0.01633	0.01281	0.01585
Z11/Z12	0.01738	0.01696	0.01676	0.01599	0.01669
Z12/Z13	0.01716	0.01658	0.01669	0.01624	0.01655
Z13/Z14	0.01162	0.01162	0.01162	0.01162	0.01162
Z14/Z15	0.02446	0.02312	0.02337	0.02376	0.02335
Z15/Z16	0.01716	0.01716	0.01716	0.01716	0.01716
Z16/Z17	0.01749	0.01749	0.01749	0.01749	0.01749
Z17/Z18	0.01738	0.01738	0.01738	0.01738	0.01738
Z18/Z19	0.01716	0.01716	0.01716	0.01716	0.01716
Z19/Z20	0.01996	0.01996	0.01996	0.01996	0.01996
Z20/Z21	0.03379	0.03379	0.03379	0.03379	0.03379
TOTAL	0.38815	0.37677	0.37592	0.36989	0.37505

A Bar-graph such as the one presented bellow, helps the user to detect the zones, where the maximal attainable index is not reached :

Blue bars correspond to the maximum index (P factor * V factor). Red bars correspond to the attained index (P factor * V factor * S factor)



DAMAGE ANALYSIS TOOLS (Quick damage checking branch)

Using quick damage checking branch by browsing trough the current result table, each damage case results can be detailed and stability parameters used for 'S' calculation check.

For example, according to the bar-graph presented above, group Z07/Z08 of the two adjacent zone calculation has been selected for more detail analysis.

All the damage cases in the pre-selected group are sorted according to their potential contribution to total attained index.

A column represents **loss of contribution for each damage** (PFAC * VFAC * (1-SFAC) * WCOEF). Damages are sorted in descending order so the damage inducing the maximum loss of index is presented on the top of this table.

DAMAGE CASE TO BE CHECKED.

This main sub-item is employed to check in detail the damage selected among the previous results.

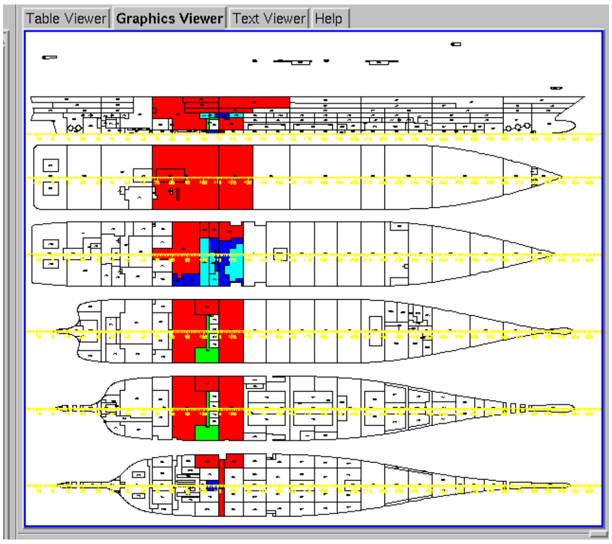
In the following example, default damage case DL/damp7-8.1.0 has been chosen to study smaller SFAC value retained in the global calculation. The result is 0.93702 for the equilibrium phase of the final stage.

PROBABILISTIC DAMAGE STABILITY

ZONE	CASE	STAGE	PHASE	SIDE	PFAC	VFAC	SFAC
Z07/Z08	DL/DAMP7-8.1.0	INT1	EQ	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	FIN	1	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	FIN	2	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	FIN	EQ	PS	0.01069	1.00000	0.93702
Z07/Z08	DL/DAMP7-8.1.0	PROG1	1	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	PROG1	2	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	PROG1	EQ	PS	0.01069	1.00000	0.98967
Z07/Z08	DL/DAMP7-8.1.0	PROG2	1	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	PROG2	2	PS	0.01069	1.00000	1.00000
Z07/Z08	DL/DAMP7-8.1.0	PROG2	EQ	PS	0.01069	1.00000	0.99111

DAMAGE DEFINITION

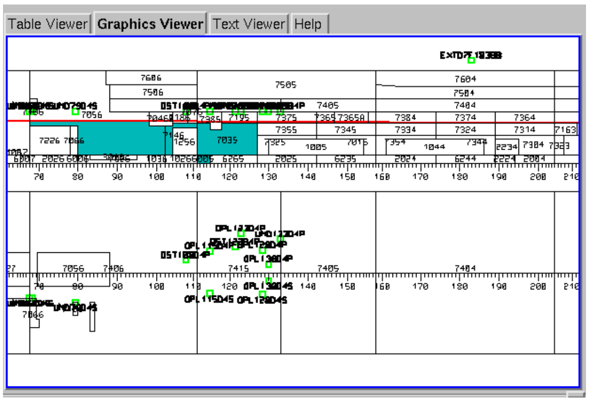
Damage definition can be checked using this sub-item. Damage stages are plotted with different colours. RED colour shows the compartments included in the inboard penetration of the considered b value and damaged in the first stage. Other stages are in accordance with the connection table.



STAGE AND PHASE TO BE CHECKED.

According to the damage selected in the previous items, this tool has been provided to browse through the stage and phase to be able to determine which stability parameter leads to reduction of s factor.

Floating position :



With this tool, an opening which must not be immersed can be detected easily. More information concerning the poor 'S' value of this stage can be found using the last sub-items of this branch.

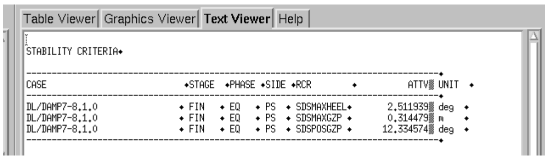
Criteria check :

With this sub-item the three criteria used for the 'S' calculation are shown in the text viewer:

MAXHEEL, MAXGZP, POSGZSP

In our example case, it is very easy to detect a lack of POSGZ due to unprotected opening too close to the final waterline.

POSGZP= 12.334574 deg. < required 16 deg. necessary to obtain S=1.

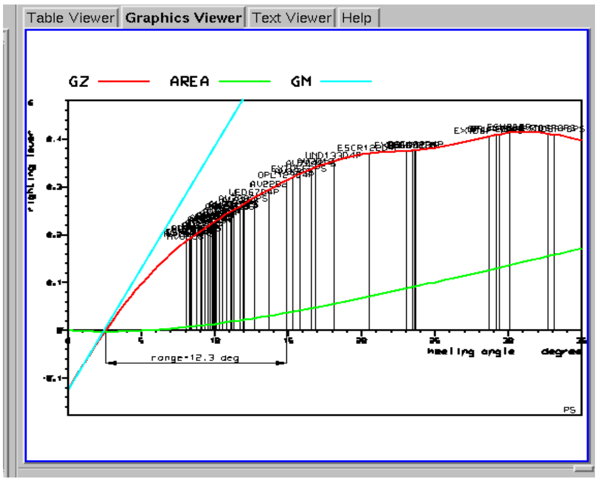


STABILITY CRITERIA

CASE	STAGE	PHASE	SIDE	RCR	ATTV	UNIT
DL/DAMP7-8.1.0	FIN	EQ	PS	SDSMAXHEEL	2.511939	deg
DL/DAMP7-8.1.0	FIN	EQ	PS	SDSMAXGZP	0.314479	m
DL/DAMP7-8.1.0	FIN	EQ	PS	SDSPOSGZP	12.334574	deg

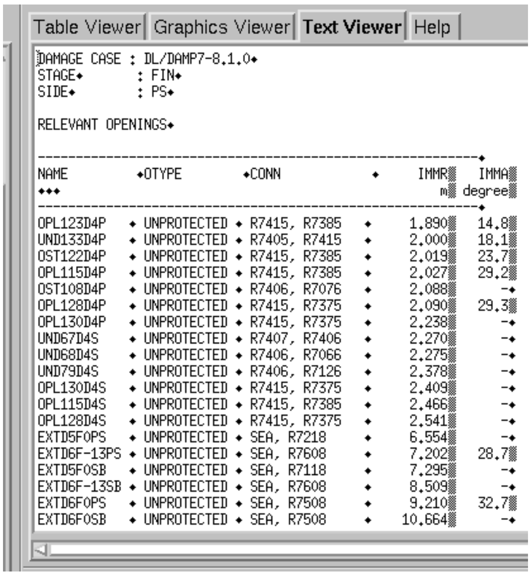
Involved opening can be found using GZ curve diagram or relevant opening list.

GZ curve diagram :



Relevant opening:

Openings are sorted according to their type and value of immersion angle IMMR. In our present case, OPL123DAP is the opening concerned.



DAMAGE CASE : DL/DAMP7-8.1.0
STAGE : FIN
SIDE : PS

RELEVANT OPENINGS

NAME	OTYPE	CONN	IMMR m	IMMA degree
OPL123D4P	UNPROTECTED	R7415, R7385	1.890	14.8
UND133D4P	UNPROTECTED	R7405, R7415	2.000	18.1
OST122D4P	UNPROTECTED	R7415, R7385	2.019	23.7
OPL115D4P	UNPROTECTED	R7415, R7385	2.027	29.2
OST108D4P	UNPROTECTED	R7406, R7076	2.088	--
OPL128D4P	UNPROTECTED	R7415, R7375	2.090	29.3
OPL130D4P	UNPROTECTED	R7415, R7375	2.238	--
UND67D4S	UNPROTECTED	R7407, R7406	2.270	--
UND68D4S	UNPROTECTED	R7406, R7066	2.275	--
UND79D4S	UNPROTECTED	R7406, R7126	2.378	--
OPL130D4S	UNPROTECTED	R7415, R7375	2.409	--
OPL115D4S	UNPROTECTED	R7415, R7385	2.466	--
OPL128D4S	UNPROTECTED	R7415, R7375	2.541	--
EXTD5F0PS	UNPROTECTED	SEA, R7218	6.554	--
EXTD6F-13PS	UNPROTECTED	SEA, R7608	7.202	28.7
EXTD5F0SB	UNPROTECTED	SEA, R7118	7.295	--
EXTD6F-13SB	UNPROTECTED	SEA, R7608	8.509	--
EXTD6F0PS	UNPROTECTED	SEA, R7508	9.210	32.7
EXTD6F0SB	UNPROTECTED	SEA, R7508	10.664	--

IMPACTS ON GENERAL DESIGN OF THE SHIP

The goal is to have a rigorous evaluation of the consequences of a breach in the ship hull in order to:

- minimise as far as possible its extent (watertight/weathertight internal integrity of the ship) or
- account for every supplementary flooding that may occur in the damage definition and thus in the calculations.

The first step is to limit the flooding to the compartments within the breach by defining watertight and weathertight boundaries. Below bulkhead deck, watertight bulkheads or decks are fully watertight. Above bulkhead deck partial watertightness may be sufficient and the following limits need to be defined for each bulkhead or deck :

- Watertight limits which are based on the worst situation at equilibrium, and during intermediate stages of flooding
- Weathertight limits correspond to the lowest limits for unprotected openings. These are determined by the envelope of water level achieved at the equilibrium state for the cases used in the calculation of survival factor, (as defined in SOLAS Chapter II-1, regulation 7-2).

This has a consequence on ship design aspects taken into account by the different trades in the shipyard :

- The scantling of the watertight bulkheads and decks (steel structure department). According to regulation 2 of chapter II-1 of SOLAS, watertight decks or bulkheads have to sustain the head of water in the worst situation at equilibrium, and during intermediate stages of flooding. Only damage cases contributing to the attained index are considered. For scantling of bulkheads, the cases to be considered are only those that involve flooding on one side of the bulkhead. For scantling on decks, cases to be considered are damages that involve only spaces above the deck, or partly above the deck. Doors or hatches in these decks or bulkheads will be scantled with the same criteria.
- The pipes and ducts routing :
  - Bulkhead penetrations will be unprotected, or weathertight or watertight, depending on the zone they are penetrating
  - Specific routing strategies may be adopted when the network crosses a weathertight or watertight boundary, in order to prevent progressive flooding. This item is developed in details here after.
- The flooding analysis may have widespread impacts on the general arrangement :
  - Position of escape routes
  - Watertight doors below bulkhead deck
  - Position and/or type of the doors above bulkhead deck, as for bulkhead penetrations
  - Geometry of rooms to minimise unsymmetrical flooding and ascertain their instantaneous flooding

PREVENTION OF PROGRESSIVE FLOODING THROUGH PIPES OR VENTILATION DUCTS.

Identification of progressive flooding:

In early design phase, it is necessary to identify systems which can lead to progressive flooding of rooms that are not within breach extent. A distinction may be made between:

- systems with openings in the flooded compartment as ventilation ducts, air vent or scuppering systems

- systems crossing the flooded compartment in a watertight envelope

For the second case, the risk of progressive flooding is analysed only when the pipe or duct is within breach extent.

Prevention of progressive flooding (design phase):

When the consequences of the induced progressive floding lead to an unacceptable situation (low survival index, high probability of occurrence), the network design is adapted by:

- Installing a loop and defining an unprotected opening at the highest point
- Fitting a non return valve, remote controlled valve or normally closed valve adjacent to the opposite side of the limiting bulkhead if not within the connected room

Alternative routing or de-design of the network design have to be developped if no acceptable solution is found.

Checking (during detailed design phase and construction)

Verifications of duct and pipe routing are required on the detail drawings and finally on board to insure that the ship matches the assumptions made in the damage stability calculations.

- A check list is established to identify all specific measures taken to prevent progressive flooding :
- A list of valves and their position
- Position of high points in the systems

Spot checks by measurement on board are done. If discrepancies are found, corrective measures need to be taken or position of points taken into account in the calculations are updated, depending on impact on attained index.

These informations are also part of the stability documentation as a guidance for further modifications which may be done during the life of the ship.

CONCLUSION:

The complexity of probabilistic approach to damage stability, can lead to consider only the final global result for the attained index. STX France has developed a dedicated calculation tool to perform and analyze the stability calculation step by step.

In theory, the attained index should fully reflect the survivability level of a ship. This is roughly the case but one has to admit that rules and explanatory notes still give room for different interpretations, which may have significant impacts on the calculation assumptions and therefore on the attained index.
More comprehensive explanatory notes may come in the future but in the mean time, it is our opinion that it is necessary to model as much as possible the real physical flooding process which may result in several possible scenarios. As a general rule, the more penalising assumptions are retained in order to ensure the level of safety intended by the rule.

On the other hand, a simplistic application of the rule may be insufficient and could lead to a lower level of ship survivability. It is thus necessary to encourage a safety culture beyond mere compliance with regulatory requirements, as recommended in the conclusions of the IMO Symposium on Future Ship Safety held on 10 and 11 June 2013.

List of References

Resolution MSC.217(82) Adoption to the International Convention for the Safety Of Life At Sea.

Resolution MSC.218(85) Explanatory notes to the SOLAS chapter II-1 Subdivision and damage stability regulations

Lemoine Luc, STX France S.A. “Norwegian Epic PERFORMANCE”. Submission for R.I.N.A.-conference held in feb 2011