Migration from a prescriptive to a probabilistic rule-making process : evolution or revolution ?

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ABSTRACT:
The content of this paper is the expression of the designer's point of view on the steady migration from a prescriptive to a probabilistic rule-making process. The opportunity is offered by the new harmonized SOLAS chapter II-1 and probabilistic damage stability issues. Some examples are given, starting from the new and demanding design criteria to identify the outstanding problems of harmonization and the effort to be made before reaching a real integration, intended as the possibility of considering the combined effects of the different systems and arrangements and their overall performance on the ship's safety.

This paper is aimed at providing some indications of the passenger ship designer's reaction to the evolution - or revolution - which is in progress in the regulatory framework.
The opportunity is given by the new harmonized SOLAS chapter II-1, to be considered as the most evident evolution of a wider migration from a deterministic to a probabilistic rule-making process.

Some steps - or jumps - are happening more or less gradually. For sure there are many questions still open.

The new regulations for the damage stability are already adopted and will be in force after 1 January 2009, although a significant number of interpretations and assumptions are still to be clarified in the framework of the Explanatory Notes to SOLAS chapter II-1 – parts A, B and B-1.

In parallel, the work is in progress also on the intact stability regulations and also here, considering the outcome of the latest IMO submissions, the probabilistic approach is steadily gathering more and more consensus: the long-term revision of the Intact Stability Code undertaken at SLF with the aim of moving towards a performance-based approach is likely to introduce probabilistic concepts in the estimation of intact ship safety in the near future.

The migration towards a "risk-based / goal-based / performance-based approach" in lieu of the prescriptive approach should - hopefully - imply a better approach to ship's safety and an increased degree of freedom for the designers.

On the other hand, there are several problems to be solved because of the complexity of the methodologies associated to these regulations; moreover several calculation / simulation tools available today are still not fully adequate.

As far as simulation tools are concerned, their inadequacy depends basically on two aspects:

- Inaccuracy: this is typical of fast tools, using a lot of simplification. But even very complex state-of-the-art tools, used both for damage and intact stability calculations, seem to suffer of quantitative inaccuracy;
- Computational effort: this is a critical factor in a "probabilistic and performance-based framework". The need of analysing a huge amount of different combination of variables can make the use of accurate but slow tools absolutely impossible, due to the prohibitive computational time required.

Some might claim that a bad - or hastily defined - probabilistic approach is therefore worse than a "good-ol'deterministic-one". It is to be recalled that the use of "equivalent deterministic loads" based on probabilistic calculation is a common and theoretically well founded practice in many fields of engineering (e.g. the "gust loading factor" in structural/wind engineering).

The origin of the problem is to be searched in the historical incremental approach adopted to define the prescriptive regulations, and it should not be underestimated the simple fact that prescriptive regulations are still valid and used to guide most aspects of ship design. And with a rather good performance in terms of incident / accident prevention or mitigation.

It has been repeatedly said that the incremental approach to prescriptive regulations is the result of the identification of shortcomings in the aftermath of an incident and consequently is preventing the possibility of a better comprehensive approach (just to avoid the abused expression of *holistic approach*) to ship safety design. However this is a typical situation in the engineering practice, associated to the analysis of incidents but also to the progress of innovation, involving new problems that were negligible in previous "old" design (Parametric-roll in containerships or Accumulation of water on deck in Ro-Ro ships are good examples).
As the damage stability rule-making process has clearly evidenced, the matter becomes intricate when trying to harmonise probabilistic regulations in the existing deterministic regulations.

Prescriptive regulations have evolved in parallel for each of the ship's design aspects (e.g. active fire protection, passive fire protection, communications, individual ship systems, load line etc.).
Although there is a good degree of harmonisation in the different SOLAS chapters, there is no real integration, intended as the possibility of considering the combined effects of the different systems and arrangements and their overall performance in case of an incident. The real performance, in terms of safety, is not normally known, so it is difficult to harmonise a goal-based design approach.
Similarly, the alternative design approach - which is explicitly envisaged in SOLAS chapters II-1 and II-2 and being finalised for chapter III - is also based upon the comparison of solutions whose levels of safety have to be first determined and then compared.

It should be also considered that this paper was necessarily written before the IMO SLF 48 sub-committee where, hopefully, all the concerns listed hereafter will have already been solved.
Anyway the difficulty conceptually remains for many other design criteria of various ship's systems.

The IMO is making progress in setting broader goals – such as "ship survivability after an incident" (fire, flooding, grounding …), the "ship as her own best lifeboat", the "safe return to port", the "time for an orderly evacuation and abandonment", the "environmentally friendly ship", etc. – but at the same time trying not to complicate too much the regulatory framework.
So the practical difficulties in pursuing a rigorous probabilistic approach on top of deterministic regulations becomes evident, and the solution is necessarily a compromise.

The time required to perform calculations and simulations is normally against the comprehensive global approach to the design, but rapid computing capabilities offered by modern technology are filling this gap.
The real problem is the vast number of variables and assumptions required to tackle the problem. There is a strong possibility of driving to individual and forced conclusions making an improper use of the assumptions along the route. So, at the end, it is questioned if the same results could be obtained in a straight deterministic way, using appropriate safety

margins, as done in the past and in other fields of engineering.

The approach should anyway be selected considering the real possibility of identifying the most dangerous risks that the ship shall potentially face in her operational life, with the purpose of “designing them out” as far as reasonably and economically practicable. The risk is always to be taken "As Low As Reasonably Practicable" (ALARP), even though qualitative words like "low" and "reasonably practical" depend on several aspects, not always technical.

EXAMPLE 1

Impact of new SOLAS chapter II-1 on ship’s system design

The impact of the new SOLAS chapter II-1 on the ship’s systems is fundamental - and the less known.

A complete harmonization process of the applicable SOLAS Regulations would be strongly required. Ship’s systems have a primary importance on safety and operability of the ship, as well as on the Attained Index “A”.

According to the “old” deterministic regulations, the extension of the damage (length, penetration) was determined using only few basic parameters, those normally known from the very beginning of any design process.

According to the “new” probabilistic based approach, the extension of a damage is derived from a statistical analysis, with some deterministic assumptions anyway, defining the probability density function of a damage.

Consequently :

- the B/5 concept, as previously defined, is no longer relevant,
- the margin line concept has become meaningless,
- the pipes which lived a happy existence inside the B/5 zone, find that they are now in danger – or better, have a probability of being in danger.

One might argue that the same pipes inside the same ship which sails on the same route as before should not be more in danger than before.

But the (simple) deterministic rules have changed, replaced by others that, far from being the ultimate truth, are anyway closer to the physical phenomena as derived from a statistical analysis. And are more complex.

So the pipes have to move. At least the big ones. Or even the small, if they are numerous enough to be considered equivalent to the big ones in terms of progressive flooding risk. The safety lies deep inside the ship, where the probability of having an extension of damage up to B/2 drops significantly.

So far, so good. But the pipes involved are many, not only those associated to ship’s essential systems : bilge, ballast, air vents, fuel, oil, heeling, fresh water, sea water, HT and LT cooling, hydraulic controls, lubrication, scuppers, CO_2, fire extinguishing, sewage, grey water, food waste, chilled water, compressed air, steam, air ducts …

On some piping systems it is not allowed to have valves.

Some systems are open circuits (e.g. air vents, black water treatments, scuppers, pipes leading to non structural tanks), other are closed circuits (e.g. steam, compressed air, fire, cooling systems), some do not resist to high pressures, but potentially all of their pipes can cause a progressive flooding.

For sure each system has other specific deterministic rules and regulations to comply with.

Ship’s systems need to be assessed one by one, at least to confirm if their position is OK with the new probabilistic regulations.

They should be positioned in the right place from the beginning.

The problem of the pipes has become a problem of lay-out and positions (see Fig. 1).

Therefore it has become a problem of space in the General Arrangement of the ship.

So it has become a basic design problem.

And without mentioning the systems redundancy and availability in case of a damage, which is a another (parallel) story.

But, very often, the lay-out and the other design features of pipes (size, location, diameter, pressure etc.) are defined much later in the design, so that it is very difficult to assess the consequences of a damage : at detailed design stage the consequences could be unpredictable and cause major modifications.
The study of each single configuration would lead to impracticable and endless design verifications.

Time consuming calculations would be reduced if considering bilge pumping capability; the quantity of water that can be drained by the bilge system is anyway limited, therefore main piping routes should not cross watertight compartments or be segregared by means of (remote controlled) valves.
According to this interpretation the bilge system, to mitigate the effects of the flooding envisaged by (probabilistic) damage criteria, should have a (deterministic) redundancy either in the pumping system (quantities, locations) and in piping lay-out (e.g. ring distribution rather than a single line), so that a single failure or damage is not going to compromise the pumping capacity in each compartment.

As far as the valves are concerned, these would be required for open systems (e.s. sewage or gray water), to segregate the compartments where the (non structural) collecting tanks are located.

Air vents or other systems cross-connected with empty tanks or void spaces that could be flooded, mainly if located near the side shell should have segregation valves, closed in case of an emergency but kept open during normal operation of the system.
This configuration should be particularly considered on ships featuring a central route for several piping systems on the tank top, because in case of damage all the tanks connected to those pipes would be flooded.
On cruise ships, the air vents are normally within the same compartment of the tank, but on their upper part run vertically, close to the side shell. In this case, the connected tanks would be flooded also for damages with a penetration less than B/5. The use of valves would allow a better design flexibility, but with an increased cost of the ship.

There is a serious risk that preliminary (optimistic) design assumptions would require a revision at a later stage, after the detailed design phase of the piping systems is completed, with the necessity of running again long calculations and finding additional mitigation actions or stability margins, which may be difficult to implement.
It should also to be noted that the terms of reference of an ongoing DE intersessional correspondence group include *"the consideration of which limits are essential to different systems due to penetration risk (in collision or in grounding) and whether the limit B/5 is still valid for them"*. Expected completion date : report to DE 49 (2006).

Lessons to be learnt :
- Ship's systems definition and lay-out have become basic design aspects,
- Their level of detail is not normally known when needed,
- The rules regulating these fields are separate and derived from different origins.

EXAMPLE TWO
Escape Routes from Flooded Compartments
The term "Horizontal evacuation route" referred to in SOLAS chapter II-1, reg.7-2, 5.2.2 does not exist in SOLAS chapter II-2.

All definitions and criteria contained in SOLAS chapter II-2 and the FSS Code are referred to fire protection aspects. The whole escape route concept in SOLAS is associated to fire only (cause, effect, risk, dimensioning, scenario, acceptance criteria, active and passive protection, ventilation etc.). Multiple events, such as fire and flooding, are against the whole rule-making criteria of the SOLAS Convention. Since there are no specific requirements for escape routes in case of flooding, it is questioned if these aspects are amendments to the Convention and not simply interpretations or Explanatory Notes.

The design of horizontal and vertical escape routes from any flooded compartment are new requisites aimed at filling the gap of previous regulations born in the framework of fire protection or functional requirements of watertight subdivision.
The regulations are not yet clearly defined but must be consistent with the approach of the revised SOLAS chapter II-1. And all other SOLAS chapters as well, which are defined according to prescriptive criteria.

Anyway the Attained Index is sensibly influenced by the lay-out and design criteria of escape routes.
The original calculation of the sample ships did not take systematically into account the internal escape routes arrangement - new different interpretations would probably require some reconsiderations of the Attained index of the sample ships used in the regression analysis to define the required index “R”.

The design is also heavily influenced by the design criteria of watertight and splash-tight doors. The use of doors which are to be kept closed when the ship is sailing might adversely impact the ship operation (circulation of crew, passengers, baggage, provisions, spares, etc.).

The problem of the escape routes from flooded compartments is a problem of lay-out and position (see Fig. 2).
Therefore it is a problem of space in the General Arrangement of the ship.
So it is a basic design problem.
Protected escape routes should be located deep inside the ship, exactly where the pipes should be.
The ideal escape routes should be located in centreline.
The ideal pipes should be located in centreline.
The ideal engine casing should be located in centreline.
The ideal lifts should be located in centreline.
The ideal MVZ stairtowers should be located in centreline.
…how big should the centreline be?

EXAMPLE THREE
Life Saving Appliances (LSA)
The selection of LSA and their design should be linked to the subdivision and damage stability criteria, or in other words to the ship survivability, which is depending on several probabilistic parameters (in design and operation).

The necessity of abandoning the ship is a consequence of the survivability of the ship after a damage.
An “unsinkable” ship needs not to be abandoned.
Very safe ships should have the possibility of relaxing the requirements on LSA.
At present the Required Index “R” refers to the number of person on board, but the number of those not in conventional lifeboats is multiplied by 2, thus penalising the “R” index.

Everything works under the (deterministic) assumption that lifeboats are the safest LSA. Is that always true ?
SOLAS chapter III and the LSA Code are written in accordance with conventional deterministic rules.
The lifeboats and their davits require anyway a much larger space in comparison with other alternative LSA.
The problem of LSA is a problem of lay-out and position.
Therefore it is a problem of space in the General Arrangement of the ship.
So it is a basic design problem.

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One might argue that all the examples made so far are redundant statements: it might be obvious that, eventually, everything is a design issue, so designers should stop to fuss about and work to harmonise the existing SOLAS chapters.

The work is in progress, analysing innovative designs and exploring new methodologies in dedicated research projects (SAFEDOR, just to mention one), aimed at understanding and implementing the new performance-based requirements.

In the slow but steady migration toward performance-based regulations, several IMO instruments such as the Protocol of 1988 relating to the International Convention on Load Lines, Annex I to MARPOL , IGC Code, IBC Code and others are being considered for their revision under probabilistic principles, taking into account their inter-relationship with other regulations.

A final and good example of the new attitude towards ship design and the impact of the new performance-based requirements is the *"time for orderly evacuation and abandonment",* defined as *the time beginning when the casualty threshold is exceeded until all persons have safely abandoned the ship, in which the ship remains viable for this purpose.*

The implications of this topic either on the rule making process and on the ship design are now in the scope of work of several IMO sub-committees and working groups, in the framework of passenger ship safety.
This concept is depending on the definition of *casualty threshold*, which is preliminary identified as *the amount of damage a ship is able to withstand, according to the design basis, and still safely return to port* and supporting the concept that the ship will remain viable for at least 3 hours (deterministic) to allow for safe, orderly evacuation and abandonment in the event that a casualty exceed the threshold.

There is a huge amount of work to be done to properly consider and implement this requirements on future ships, and for sure there are many aspects not explicitly addressed by current regulations :

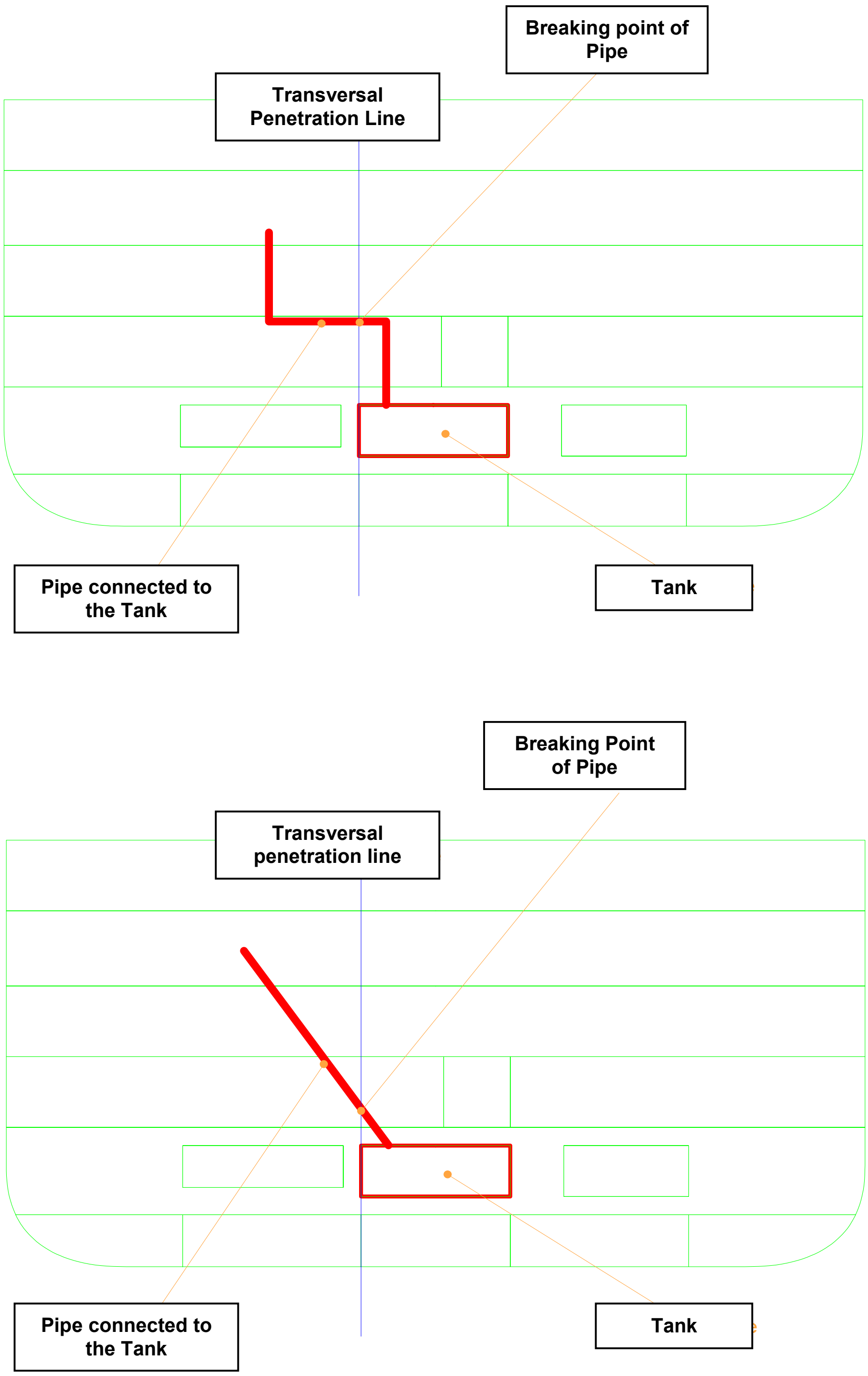
- definition of "level of safety";
- level of safety associated to existing regulations;
- real performance of ships in damage conditions and rough weather – effective reserve of stability and buoyancy;
- time-to-flood aspects, progressive flooding;
- human elements;
- structural capability of sustaining extensive damage;
- real ship's system availability;
- etc.

There is a general consensus that time-to-flood analyses are new and complex tools that will provide useful information on the "time to remain habitable", but that much time and work will be required to develop, agree and standardize these procedures to the point where they could be used in a SOLAS regulatory application. The problem will always be the evaluation of time-to-flood, due to the complexity of the simulation and the quantity of assumptions to be made, so it is not practically possible in the present stage to introduce directly such a requirement in the probabilistic concept.
In parallel, analyses to demonstrate the same degree of safety of alternative solutions should be encouraged; qualitative and quantitative analyses are considered as the core process in a typical complete assessment of an alternative design, which should be supported in its process also by model tests and simulations, to gain more experience. In addition, in a "performance-based" framework, where the level of safety is to be addressed (and proved) from a global point of view, a very effective and bi-directional liaison is expected between

designers and authorities (Classification Societies, Flag Administrations, etc.).

These specific aspects need to be further clarified, e.g. working on some Guidelines to take into account the functional requirements for the designer, with an adequate level of detail.
And there is still a long way to go, discussing with spirit of cooperation and open minded approach the methodology and the results among all stakeholders.

Fig. 1 - Example 1 - Impact of new SOLAS chapter II-1 on ship's system design



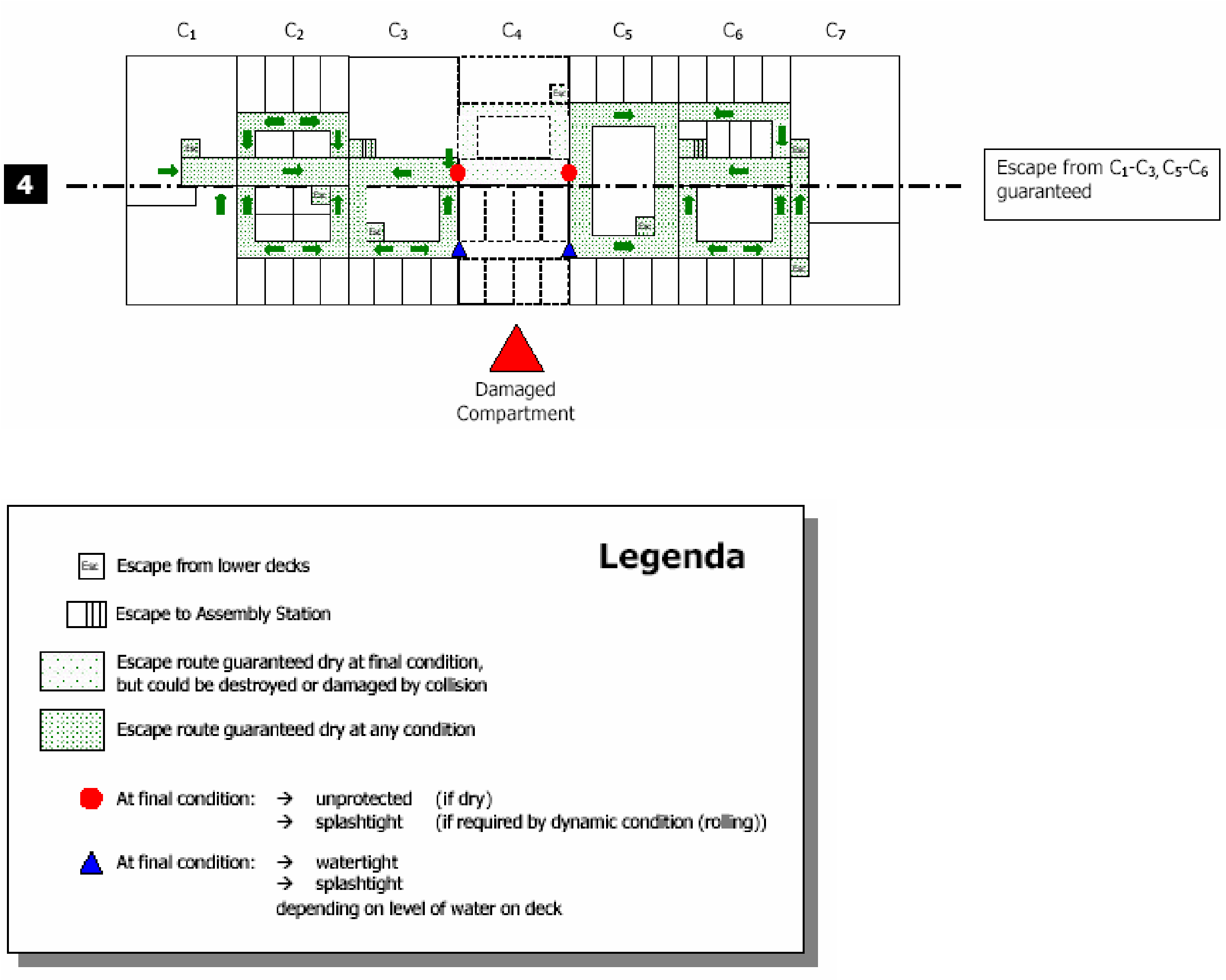


Fig. 2 – Example 2 - Escape Routes from Flooded Compartments