Risk Characterization of the Required Index R in the New Probabilistic Rules for Damage Stability

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SUMMARY

The required index of subdivision *R*, is meant to represent relative safety against collision damage and is understood by most to be a safety standard. Using first principles analysis based on the concept of risk this paper shows that the formulation of *R* in the recently adopted probabilistic rules for damage stability demonstrates lack of real understanding of what the probabilistic framework was meant to provide as well as lack of real knowledge of how it all started and what it really *R* represents.

The required index of subdivision

The probabilistic concept of ship subdivision is based on the probabilistic assessment of stability for a multitude of possible damages providing the probability for a ship to survive a hypothetical collision. The said probability is called the (attained) index of subdivision *A*, which is to be less than a required index *R*. In the new regulation the required index has been established based on a sample of existing vessels and is not related explicitly to risk. More specifically, *R* can be characterised as follows [1]:

Index R – Concept:
R is taken to represent an acceptable level of safety standard, derived on the basis of *A*-values of sample ships which have survived all the elements, some of these over their life span. More to the point these ships comply with SOLAS. However, since *A* is related to safety only in a general abstract way, using *R* as a measure of safety requires caution and understanding.

Index R – Calculation:
R is meant to indicate relative safety which might carry some logic for same ship types and as such, it is questionable to use "equivalent safety" principles in its derivation. Moreover, how can we compare the <u>relative safety</u> of two different ship types (one cannot compare relatively car carriers and cruise liners, as the same *A* in both would imply massively different damage stability safety levels)?

An attempt to relate *R* more directly to safety would require the use of risk in its derivation as outlined next.

Using the concept of risk to establish Index R

The expected rate of fatalities per ship year due to collision can be expressed as follows:

$$r_N = NP_{cl}P_{br}(\sum p_i c_i), \qquad (1)$$

where *N* is the number of people on board of the ship, P_{cl} is probability of collision incident per ship year, P_{br} is (conditional) probability of water ingress (i.e. hull breaching), given collision, p_i is probability of flooding a given compartment or compartment group, c_i is (conditional) probability of capsizing of the ship *before* completion of the evacuation process. According to statistics [2], for passenger ships larger than 4000 GRT the probability $P_{cl} = 5.16 \cdot 10^{-3}$, whereas P_{br} is as high as 0.5.
For safe ships the expected rate of fatalities r_N should obviously be not greater than an accepted

rate $(r_N)_{reg}$ that can be figured out from the values accepted in other means of transportation or be established by statistics. For the sake of simplicity it is assumed here that capsizing before the completion of evacuation is associated with the loss of all passengers. In effect, this leads to a conservative estimation of r_N, i.e. the actual value is smaller than that provided by equation (1).

The term in the parentheses $\sum p_i c_i$ represents the expected rate of capsizing $E(c)$ before completion of the evacuation of passengers. This is nothing else than the weighted (averaged) probability of capsizing. Hence, equation (1) can be written in a more abbreviated form:

$$r_N = NP_{cl}P_{br}E(c) \tag{2}$$

Dividing it by P_{cl}, we get

$$NP_{br}E(c) = r_{Nc} \tag{3}$$

where $r_{Nc} = r_N/P_{cl}$ is the expected rate of fatalities per collision to be established by statistics. This quantity can be presented as $r_{Nc} = k(r_{Nc})_{reg}$, where $(r_{Nc})_{reg}$ is a regular rate of fatalities per collision, and k is a coefficient modifying the regular rate, depending on area of operation, with $k > 1$ for regions with an increased risk of collision (density of traffic). Hence,

$$NP_{br}E(c) = k(r_{Nc})_{reg} \tag{4}$$

Regarding the expected probability of capsizing, it can be assumed that

$$E(c) = E(1 - s_{60'}) = 1 - E(s_{60'}) = 1 - A_{60'},$$

Where $s_{60'}$ is the factor s based on 60-minute test runs, with the mean survival time assumed equal to ninety minutes. Hence, equation (4) takes the form

$$NP_{br}(1 - A_{60'}) = k(r_{Nc})_{reg},$$

which yields

$$1 - A_{60'} = k(r_{Nc})_{reg}/NP_{br} \tag{5}$$

The expression on the right-hand side of equation (5) is nothing else then $1 - R_{60'}$. The above equation leads then to the well known form $A_{60'} \geq R_{60'}$. The required index of subdivision is therefore equal to

$$R_{60'} = 1 - \frac{k}{NP_{br}}\left(r_{Nc}\right)_{reg} = 1 - \frac{k}{P_{br}}\left(\frac{r_N}{NP_{cl}}\right)_{reg} \tag{6}$$

The expression in the parentheses presents the expected (regular) rate of fatalities per collision and per person and equals simply a regular value of $(1 - R_{60'})_{reg}$. Hence,

$$R_{60'} = 1 - \frac{k}{P_{br}}\left(1 - R_{60'}\right)_{reg} \tag{7}$$

where,

$$\left(1 - R_{60'}\right)_{reg} = \left(\frac{r_{Nc}}{N}\right)_{reg} \tag{8}$$

Equation (7) indicates how we can account for two important factors affecting the required level of safety, i.e. areas of operation with varying risk of collision and for structures with different crashworthiness. From equation (8) it follows that the required index increases with the number of people on board, which means indirectly – with the size of the ship, which is natural. IMO was then perfectly on the right truck in handling ship safety.

Equation (7) defines the required index of subdivision R without the need for any test calculations that are normally carried out for a sample of existing ships, frequently designed without sufficient concern for ship safety in the damaged condition. Be it as it may, with the help of equation (7), the R-index can now be established objectively, with the help of statistics only. This would deliver an index, providing a *desired* level of safety rather than a conventional level. Whether such an index could be accepted by society, it is a different story but at least we would know the ultimate goal to be achieved in the area of damage stability safety.

Rulemaking

As can be seen, equation (8) is in the form much the same as adopted by IMO in its resolutions. Assuming, for instance, that the expected rate of fatalities per collision r_{Nc} to be at a level of 40 (persons), the following is obtained:

$$(1 - R_{60'})_{reg} = 40/N$$

For N = 1000, this formulation yields $(1 - R_{60'})_{reg} = 0.04$, a far smaller rate of loss due to collision damage than by current formulations used by IMO instruments. Indeed, such a high level of safety is entirely feasible at reasonable cost, only if safety considerations are taken into account at the concept stage of ship design (risk-based design methodology), [3].

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It is felt unreasonable to keep r_{Nc} constant, irrespective of N – the total number of people on board the ship. Ideally, the level of safety against collision damage should be the same, regardless of the ship size. This is the case, if r_{Nc} varies in proportion to N, which is clearly seen from equation (8). Due to practical reasons, however, this is not realistic, as when the size of ship increases, greater survivability is achievable at marginal cost. This is why greater safety is required for larger ships.

Since by the nature of things r_{Nc}/N – the relative rate of fatalities cannot be constant against N, for this reason IMO assumes for r_{Nc}/N the following expression:

$$r_{Nc}/N = a/(b + N), \qquad (9)$$

where a and b are constants, both positive.

Therefore, using equation (9), yields

$$(1 - R_{60'})_{reg} = a/(b + N) \qquad (10)$$

The relative fatality rate r_{Nc}/N, as given by equation (9), decreases monotonically versus N, i.e. for smaller ships r_{Nc}/N is higher than for larger ships. It follows from this equation that

$$r_{Nc} = aN/(b + N) \qquad (11)$$

which means that on the whole r_{Nc} increases monotonically but with a decreasing rate, when N increases. When N tends to infinity, then $r_{Nc} = a$. The constant a has thus the meaning of the asymptotic value for the expected rate of fatalities per collision for ships with infinitely large number of passengers.

The other constant is given by the equation:

$$b = N(a - r_{Nc})/r_{Nc} \qquad (12)$$

from which it follows that $r_{Nc} < a$ in order to keep the constant b positive. Assuming, for instance, the asymptotic value a = 200 (fatalities per collision), for N = 1000 the values of b as function of r_{Nc}, are shown below:

Table 1

r_{Nc}	b
50	3000
67	2000
80	1500
100	1000

As can be seen from equation (12), if r_{Nc} is proportional to a, than the constant b does not change. For a = 200 and b = 1000, regular values of the index vary from 0.80 to 1, for N varying from 0 to ∞. For instance, for N = 1000, $R_{60'} = 0.90$, while for N = 4000, $R_{60'} = 0.96$. Whereas for a = 400 and the same value of b = 1000, the index vary from 0.60 to 1 and the differences of the index from a value of 1 doubles. In both cases regular values of the index are much higher than those currently required by IMO instruments. If the index R is to be positive for any N, then this requirement yields $a \leq b$.

Deriving from the foregoing, of crucial importance for rulemaking is the knowledge of merely one quantity – the asymptotic value of fatalities per collision $(r_{Nc})_\infty = a$ for the largest passenger ships. This value could be established with the help of statistics in conjunction with some theoretical analysis, as statistics can contain insufficient amount of data; for example an investigation using numerical simulations of survivability and passenger evacuation providing as output survival and evacuation times, a comparison of which will enable estimates of fatality rates to be made. The constant b governs the rate of chance of R relative to N. The higher b, the more flat the R-curve is.

If all the consequences of collision are to be accounted for, the number N has to be increased somehow to reflect the loss of the ship. For this purpose IMO uses indirectly a ship size factor F_s, not termed as such yet, which is a linear combination of the subdivision length of the ship L_s and the total number of persons on board the ship N. This factor could be defined as $F_s = 4L_s + N$. The number N in the foregoing equations should simply be replaced by the ship size factor F_s.

IMO proposals

In IMO resolution A.265 (VIII) the required index has the form:

$$R = 1 - \frac{1000}{(4L_s + N) + 1500} \tag{13}$$

It is worth noting that IMO makes no distinction between the regular and complete index R. Therefore, IMO proposals can be treated as for the regular part of R. The expression in the parentheses is nothing else than the ship size factor F_s. The constant b is taken 1500 instead of 1000, which is reasonable, as can be seen in Table 1, whereas the asymptotic value of fatalities a = 1000, seems to be definitely excessive. The above index varies from 1/3 to 1, for F_s varying from 0 to ∞. If the asymptotic value of fatalities is reduced and taken at a *desired* level a = 600, it leads to the following expression:

$$R = 1 - \frac{600}{(4L_s + N) + 1500} \tag{14}$$

varying from 0.60 to 1, for F_s varying from 0 to ∞. In the most recent proposal (SLF 47/17), however, the required index is proposed in the form:

$$R = 1 - \frac{5000}{(L_s + 2.5N) + 15225} = 1 - \frac{2000}{\left(\frac{2}{5}L_s + N\right) + 6090} \tag{15}$$

where $F_s = 0.4L_s + N$ is the ship size factor. The above index varies from 0.672 to 1, for F_s varying from 0 to ∞. Modifications made by SLF 47 render the R-curve very flat, as can be seen in Figure 1, which increases the indices for smaller ships substantially whilst diminishing slightly for large ships, with $F_s > 3000$. Because of the flat run of this curve, the relative rate of fatalities r_{Nc}/N is pretty constant in this case, as can be seen in Figure 2. Bearing in mind that the proposal by SLF 47 reduces the effect of ship size on the index and provides smaller indices for large ships, it is evident that equation (15) was calibrated with large ships in mind, to make it easier to meet a reduced standard of safety for those ships, compared to the original IMO proposal. The effect of this modification is clearly illustrated by doubling the asymptotic value of fatalities, taken as 2000 instead of 1000 in the original proposal.

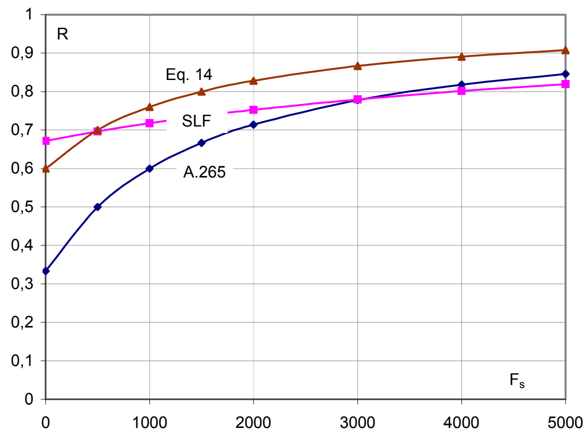

Figure 1: IMO proposals for the index R

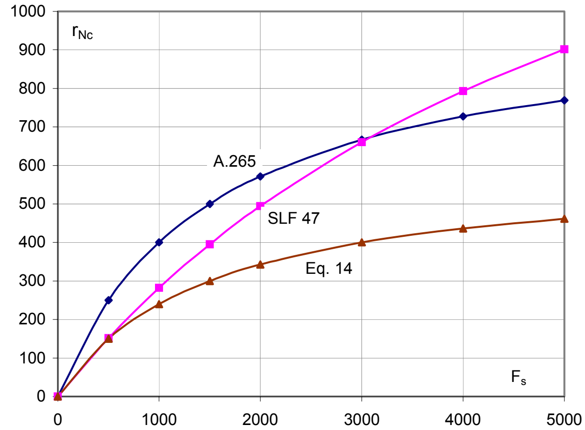

Figure 2: Rate of fatalities per collision r_{Nc}

For any formulation on R, as given by equation (10), a unique rate of fatalities per collision is assigned, as given by equation (11). Such values of r_{Nc} are plotted in Figure 2. It is almost certain that IMO is unaware that such a relation exists at all. Equation (8) can be viewed as providing a *desired* level of safety in terms of acceptable fatalities. To establish how this relates to reality requires statistical data on r_{Nc}.

Concluding remarks

It is obvious that in the long process of IMO rule making, initial assumptions are often overlooked, thus leading to formulations which defy logic, lead to unrepresentative levels of safety and more worrying could undermine safety. The formulation for the R-index in the recently adopted probabilistic rules for damage stability calculations appears to be one such case.

References

[1] Vassalos, D: "A Risk-Based Approach to Probabilistic Damage Stability", 7th International Stability Workshop, Shanghai, China, November 2004.

[2] Vanen, E., and Skjong, R.: "Collision and grounding of passenger ships – risk assessment and emergency evacuation", ICCGS, 2004.

[3] Vassalos, D: "Passenger Ship Safety – Containing the Risk", SNAME, Greek Section, Athens, June 2005.