Permeability of tanks intended for liquids in cruise vessels

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ABSTRACT

One of the objectives of the eSAFE project was to formulate a proposal for permeability to be used for tanks intended for liquids in cruise vessels. This paper provides a summary overview of the main outcomes, in this respect, based on data collected from real loading conditions of cruise vessels. On the basis of collected data, a simplified formulation is derived for the permeability of tanks intended for liquids, depending on the ship draught. The impact of permeability on the Attained Subdivision Index-A is assessed according to the probabilistic damage stability approach prescribed in SOLAS Ch.II-1, Part B.

Keywords: *eSAFE, tanks, permeability, loading conditions, damage stability, SOLAS.*

1. INTRODUCTION

The permeability prescribed by SOLAS Ch.II-1 reg.7-3.1 for tanks intended for liquids is 0 or 0.95 whichever results in the more severe requirement (IMO, 2019).

On the other hand, for cargo compartments (dry cargo spaces, container spaces, Ro-ro spaces, cargo liquids) SOLAS Ch.II-1 reg.7-3.2 defines a different permeability for each draught, as shown in Table 1 (IMO, 2019).

Table 1: Permeability for cargo compartments as defined in SOLAS Ch.II-1 reg.7-3.2.

Spaces	Permeability at draught d_s	Permeability at draught d_p	Permeability at draught d_l
Dry cargo spaces	0.70	0.80	0.95
Container spaces	0.70	0.80	0.95
Ro-ro spaces	0.90	0.90	0.95
Cargo liquids	0.70	0.80	0.95

Comparing the approach used for compartments containing cargo liquids and the approach for tanks intended for liquids, it is evident that there is a great discrepancy. In particular, for passenger ships and, thus, cruise ships, there are no cargo liquid compartments. Therefore, all tanks are considered as "tanks intended for liquids" and the permeability is assumed equal to 0.95 that results in the more severe requirement.

The data of real loading conditions of cruise ships taken from a wide range of vessels (see Figure 1) demonstrate that abt. 83% of the deadweight of a cruise ship is intended for liquids in tanks.

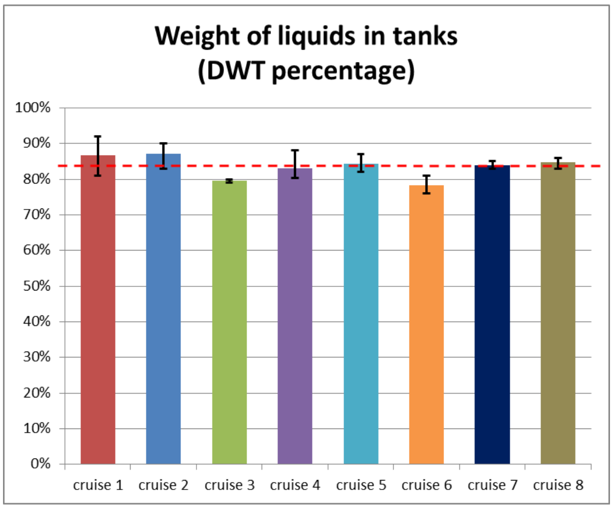

Figure 1: Percentage of deadweight intended for liquids within tanks for cruise vessels of different dimensions (from about 10,000 GRT to more than 200,000 GRT). Intervals reported in the graph for each vessel provide the variation range for different loading conditions according to collected data.

Based on this data, two important facts become apparent:

1) cruise ships never navigate with empty tanks
2) the draught of a cruise ship is strictly related to amount of liquids in tanks

It, therefore, appears that the real permeability of tanks needs a careful investigation.

2. ON BOARD DATA COLLECTION

The first part of the work has been a wide collection of onboard data from 14 cruise ships operating worldwide, with a wide range of dimensions (from about 30,000 GRT to more than 200,000 GRT). This unique collection of data of 317 real loading conditions has been used to obtain a better view of the tanks filling in different operational conditions. For each loading condition, the draughts (aft and fore), the amount of liquids on board for the main tanks purposes and maximum tanks capacity have been provided by the different cruise operators. In particular, the amount of the following liquids has been recorded on board:

- Fuel Oil
- Marine Gas Oil/ Diesel Oil
- Potable Water
- Ballast Water
- Waste Water

Even if the data has not been collected for all tank purposes, the selected categories of liquids cover abt. 90% of the total tank capacity of a cruise ship.

Following this, for each loading condition, the normalized draught (*dn*) and the actual global tank permeability (*tperm*) have been calculated.

The normalised draught (*dn*) was introduced in order to allow for a comparison among different ships. For each ship, *dn* was defined as follows:

$$dn = \frac{T_m - T_l}{T_S - T_l} \tag{1}$$

where

- T_s : maximum draught [m] (corresponding to deepest subdivision draught for ships built under SOLAS 2009);
- T_l : minimum draught [m] (corresponding to light service draught for ships built under SOLAS 2009);
- T_m : draught at mid-ship perpendicular [m].

The tanks permeability for each recorded loading condition was calculated by assuming that the liquid loaded within the damaged tanks is totally replaced by sea water. Therefore the actual global tanks permeability is obtained from the following equation:

$$\sum_{i=1}^{n}(\rho \cdot c_i - m_i) = \rho \cdot tperm \cdot \sum_{i=1}^{n} c_i \tag{2}$$

where

- i : index for the i-th tank;
- ρ : sea water density (1.025 t/m^3);
- c_i : capacity of the i-th tank [m^3];
- m_i : mass of liquid within the i-th tank [t];
- *tperm* : actual global tanks permeability.

It follows that:

$$tperm = 1 - \frac{\sum_{i=1}^{n} m_i}{\rho \cdot \sum_{i=1}^{n} c_i} \tag{3}$$

Two example results are shown in Figure 2 and Figure 3, where the global tank permeability versus the normalized draught are shown for each recorded loading conditions of ship n.2 and ship n.5, respectively. From the results in the figures it can be concluded that there is a very good correlation between tank permeability and normalized draught in both cases. A similar result was found for all the other ships (Cardinale et al., 2017).

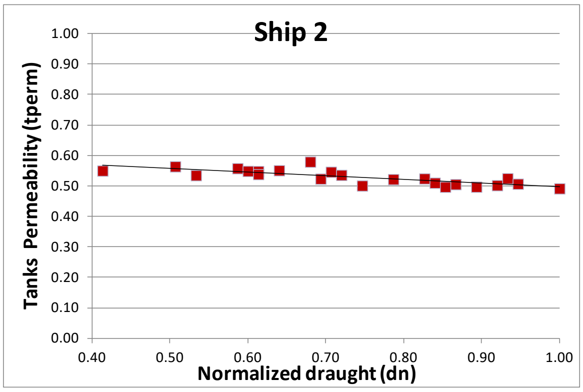

Figure 2: Actual global tanks permeability vs Normalized Draught (cruise ship n.2).

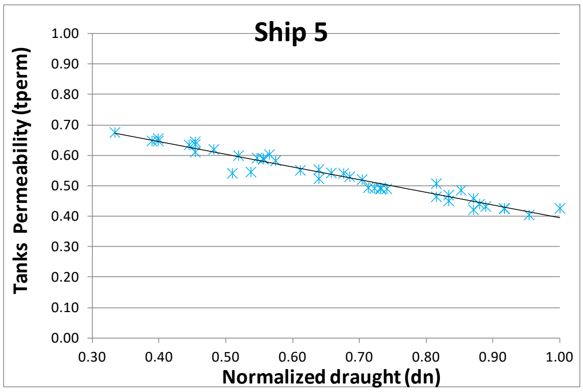

Figure 3: Actual global tanks permeability vs Normalized Draught (cruise ship n.5).

Furthermore, if we look at Figure 4, where all ships are collected in the same graph, we can realise that the SOLAS permeability for tanks is not realistic and very conservative.

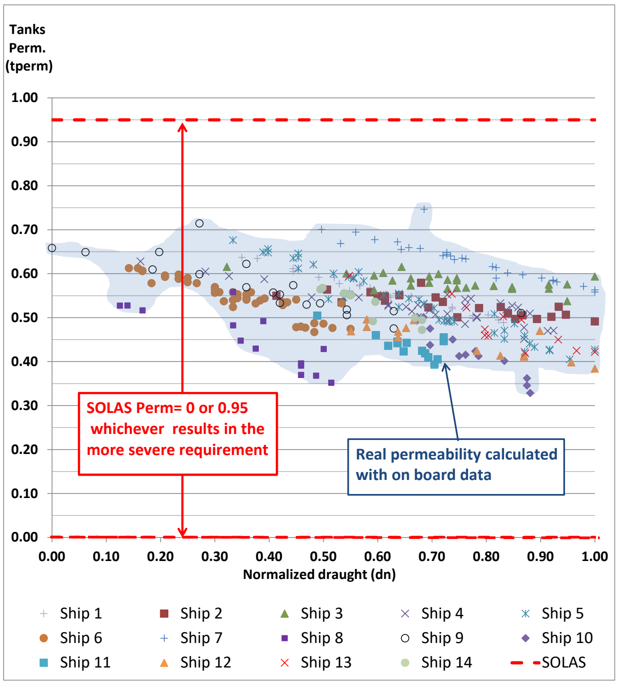

Figure 4: Actual global tanks permeability vs Normalized Draught (all ships).

3. NEW PROPOSAL FOR TANKS PERMEABILITY

A different tank permeability could be defined for each ship based on its real operating loading conditions, but these conditions are not known at the design stage. Therefore, a formula based on data available at an early design stage is needed.

Considering the approach used in SOLAS Ch.II-1 reg.7-3.2 for dry cargo spaces, container spaces, ro-ro spaces and cargo liquids (see Table 1), a similar approach can be used for permeability of tanks intended for liquids on cruise ships, instead of the presently used worst case between 0 or 0.95. Indeed, the calculations of real permeability with results shown in Figure 2, Figure 3 and Figure 4 are sufficient to justify such a different approach. Moreover, "other figures for permeability may be used if substantiated by calculations" as stated in SOLAS Ch.II-1 reg.7-3.3, with more clarifications provided in the relevant Explanatory Notes (IMO, 2017).

A simple proposal is shown in Figure 5, where a linear regression is used to define the permeability of tanks as a function of the normalised draught.

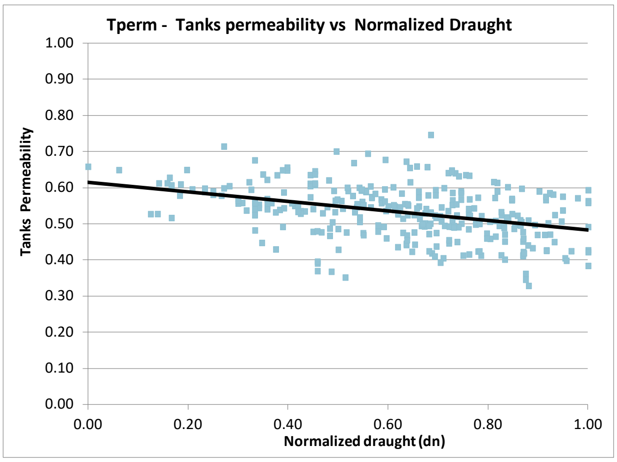

Figure 5: Proposal of regression for tanks permeability.

The proposed formulation takes the following analytical form (Cardinale et al., 2017; Luhmann et al., 2018a,b):

$$Tperm = 0.61 - 0.13\frac{T - T_{min}}{T_{max} - T_{min}} \qquad (4)$$

where:

- $Tperm$: tanks permeability;
- T : mean draught of the initial condition to be calculated [m];
- T_{min} : minimum draught according to stability booklet [m] (corresponding to light service draught for ships built under SOLAS);
- T_{max} : maximum draught according to stability booklet [m] (corresponding to

deepest subdivision draught for ships built under SOLAS).

The notation *Tperm* is used in (4) to differentiate between the permeability directly determined from the on-board data (*tperm*, see (2)) and the permeability from the regression.

This proposal will result in the following values of the tanks permeability (*Tperm*) at the three calculation draughts for attained index calculation defined in SOLAS:

- 0.61 at light service draught (dl);
- 0.53 at partial subdivision draught (dp);
- 0.48 at deepest subdivision draught (ds).

4. IMPACT ON THE ATTAINED INDEX

In order to evaluate the impact of tanks permeability on the assessment of cruise ships safety through the attained subdivision index, six initial conditions have been selected for each sample ship of the eSAFE project. Some of these conditions correspond to real operational loading conditions, while additional loading conditions are taken from the stability booklet. This approach has been used both to evaluate the impact in cases where real filling levels for tanks are used and also to cover a wide range of draughts.

The results of these calculations are dependent on the GM of each loading condition. Therefore, considering the scope of the test, three loading cases have been calculated with the actual GM and three with the minimum GM required by SOLAS 2009.

The loading conditions used for each ship are as follows:

- Ship A: two loading conditions from the stability booklet and three real loading conditions;
- Ship B: three real loading conditions;
- Ship C: three real loading conditions;
- Ship D: three loading conditions from the stability booklet.

All the calculations executed on the four cruise ships (Cardinale et al., 2017; Luhmann et al., 2018a) clearly show that there is a significant gap between A index calculated with the real filling level for tanks and A index calculated with empty tanks (perm=0.95 according to SOLAS), especially when calculations are executed, for design purpose, with the GM of limit curve according to SOLAS 2009 (see Figure 6). As expected, this gap generally increases at partial and heaviest draught, as in these cases the global filling level of the tanks is higher compared to lightest loading condition.

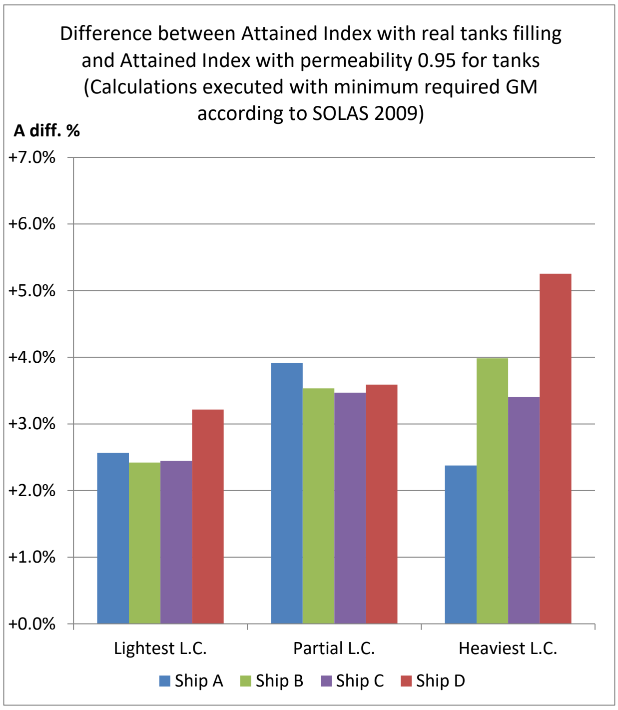

Figure 6: Difference between A index with real filling for tanks vs empty tanks.

Based on these results it is evident that the SOLAS permeability is not realistic for cruise ships and the proposed formula for *Tperm* (equation (4)) has been tested in order to verify its capability to compensate the gap shown in Figure 6.

5. VALIDATION OF THE PROPOSED TANKS PERMEABILITY

The validation of the formula for tanks permeability proposed in section 3 has been performed with two different sets of calculations for each ship. In particular, two different options for permeability of heeling tanks have been calculated:

- Attained Index calculated with permeability 0.95 for heeling tanks and permeability according to *Tperm* (see (4)) for other tanks;
- Attained Index calculated with permeability 0.50 for heeling tanks and permeability according to *Tperm* (see (4)) for other tanks.

Even if the second option (permeability 0.50 for heeling tanks) is much more realistic for cruise ships, also calculations according to the first option have been carried out to evaluate the impact of heeling tanks permeability on the Attained Index.

The calculations executed on the sample ship demonstrated that the *Tperm* formula (4) for tanks permeability is capable to reduce the difference between attained index calculated with real tanks filling and attained index calculated according to SOLAS permeability for tanks (see Figure 7). Furthermore, the results showed that it is necessary to use a permeability of 0.5 for heeling tanks in order to minimize the aforementioned difference, as shown in Figure 8, in particular when calculations are executed with GM of the limit curve.

To cover any different filling of the heeling water tanks during operation, it is necessary to calculate the damages on both sides, port and starboard sides.

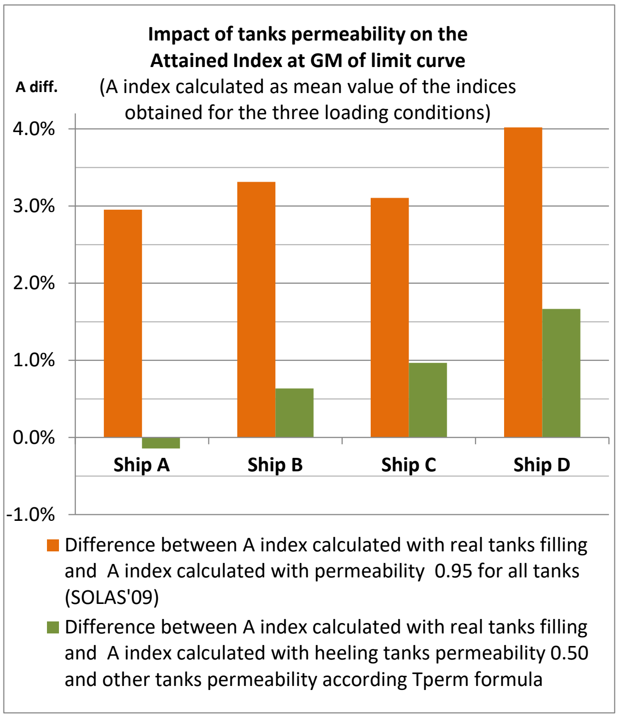

Figure 7: Impact of tanks permeability on A index at GM of limit curve.

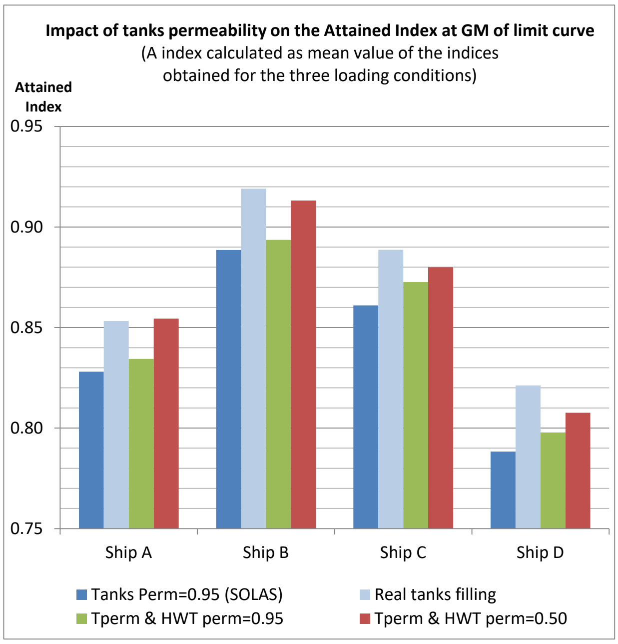

Figure 8: Impact of tanks permeability on A index at GM of limit curve.

6. CONCLUSIONS

The data collected on board (14 cruise ships and 317 loading cases) demonstrate that the SOLAS permeability for tanks is not realistic for cruise ships and it represents a very conservative approach in A-Index calculation.

Furthermore, the results showed that there is a good correlation between tanks permeability and normalised draught; based on this correlation, a simple formula for permeability (*Tperm*), based on linear regression, has been proposed to be applied for all tanks (excluding heeling tanks) of cruise ships.

To evaluate the impact of tanks permeability, the attained index has been calculated for some loading cases of a set of sample ships, using real tanks permeability. The results showed that the difference between A index calculated with the real tanks filling and A index calculated with empty tanks (perm=0.95 according to SOLAS), is significant (from 2.4% to 5.3%), when calculations are executed using GM from the limit curve.

A second round of calculations carried out by using the proposed formula for permeability, showed that the difference between A index calculated with the real tanks filling and A index calculated with empty tanks can be significantly reduced by using a permeability of 0.5 for heeling tanks combined with the value *Tperm* from the proposed formula for the other tanks.

ACKNOWLEDGEMENTS

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DISCLAIMER

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