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Agenda item 4

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DEVELOPMENT OF GUIDELINES ON SAFE RETURN TO PORT FOR PASSENGER SHIPS

Modelling of leaking and collapsing of closed non-watertight doors

Submitted by Finland

SUMMARY

Executive summary:	This document is a summary of full-scale tests of closed fire doors
Strategic direction:	5.1
High-level action:	5.1.1
Planned output:	5.1.1.3
Action to be taken:	Paragraph 5
Related documents:	SLF 47/INF.6 and SLF 53/INF.2

Introduction

1 The research project FLOODSTAND (EU FP7) was briefly introduced in document SLF 53/INF.2 and corrigendum.

1.1 The Work Package 2 (Flooding Progression Model) consists of full-scale experimental and numerical research.

The full-scale tests

2 The tests included several non-watertight door types, such as various different A-class fire doors and B-class joiner doors as well as cold-room doors. Both single and double leaf as well as sliding doors were tested. For most of the tested door types were subjected to water pressure on both sides.

Numerical analysis

3 Some of the test cases were also studied with Finite Element Analysis. The results provided further information on the structural deformation under the floodwater pressure. Based on the measurements the leakage area ratio was determined by using Bernoullis equation.

Findings

4 The collapse pressures and the non-dimensional leakage area ratio coefficients are presented in the annex to this document.

4.1 The collapse pressure value has an apparent effect on the way the flooding progress.

4.2 For many tested doors the leakage area ratio increases practically linearly as a function of the pressure head.

4.3 The leakage area ratio can have a major influence on time-to-flood.

4.4 For hinged doors, the direction of the pressure can have a significant effect on both the leakage area ratio and the critical pressure head for collapsing.

Action requested of the Sub-Committee

5 The Sub-Committee is invited to take note of the information provided.

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ANNEX

Modelling of Leaking and Collapsing of Closed Non-Watertight Doors

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Introduction

The use of time-domain flooding simulation tools has expanded as the computing capacity has increased. The applications vary from simple calculations of cross-flooding time to assessments of time-to-flood or time-to-capsize in damage scenarios with extensive progressive flooding.

It is an undisputable fact that the simulation results depend on the applied input data for the openings. Most notably, the leaking and collapsing of non-watertight structures, such as closed fire doors, can have a very remarkable effect on the time-to-flood. This issue was first raised in SLF 47/INF.6 in 2004, clearly pointing out the need for further research. One of the main objectives of the EU FP7 research project FLOODSTAND was to provide this much needed information.

Typically, the simulation tools are based on Bernoulli's theorem and the pressure losses in the openings are taken into account by applying semi-empirical discharge coefficients. In principle, the flooding rate Q through a small opening can be calculated with the following equation:

$$Q = C_D A_{eff} \sqrt{2gH_{eff}} \qquad (1)$$

where:

C_D	effective discharge coefficient (pressure losses in the opening)
A_{eff}	effective area of the opening (taking into account e.g. leakage)
g	acceleration due to gravity
H_{eff}	effective pressure head

This paper concentrates on proper modelling of the effective area of the opening A_{eff} in leakage condition. Another important aspect is the upper limit of the pressure height H_{eff} when the structure is considered to collapse. This limit value is denoted by H_{coll}.

The previous investigation on the subject, SLF 47/INF.6, was mainly theoretical and the suggested values were only rough approximations. In the present study the results from both dedicated full-scale experiments and FEM calculations are utilized for obtaining more realistic guidelines for modelling non-watertight structures in flooding simulation.

Detailed description of the full-scale tests is given in *Jakubowski and Bieniek (2010)*. These experiments were first of a kind, including detailed measurements of the leakage rates and door deformations. The total number of tested items was 20. The comparative numerical analyses are reported in *Naar and Vaher (2010)*.

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It is also worth noticing that the use of CFD tools, e.g. volume of fluid (VOF) or smoothed particle hydrodynamics (SPH), for simulation of flooding progress does not avoid the need to model the leaking and collapsing of non-watertight structures.

Leakage Area Ratio

In SLF47.INF6 a very simple approach was presented for assessing leakage through non-watertight closed doors in flooding simulation. The effective flooding area of the opening is obtained by multiplying the geometrical (submerged) area with a constant **non-dimensional** leakage area ratio coefficient:

$$A_{ratio} = \frac{A_{leakage}}{A_{submerged}} \qquad (2)$$

where $A_{leakage}$ is the leaking area of the opening that is leaking and $A_{submerged}$ is the area of the submerged part of the whole opening.

Analysis of Results

In the full-scale tests the leakage rate (m^3/s) was measured at different water pressures acting H_{eff} on the door. Based on this, the corresponding leakage area ratio can be calculated by using Bernoulli's equation and a constant discharge coefficient $C_d = 0.6$, *Ruponen and Routi (2011)*.

Some examples of the results are presented in Figure 1 and Figure 2. For most of the tested structures the leakage area ratio increases practically linearly as a function of the pressure height. However, for some test specimen the maximum flow rate of about 90 l/s was achieved at relatively low pressure, and thus the function of A_{ratio} had to be determined from a very limited set of measurements points. Consequently, the approximation of a constant A_{ratio} was selected e.g. for the sliding A-class fire doors. A comprehensive analysis of all tested structures is presented in *Ruponen and Routi (2011)*.

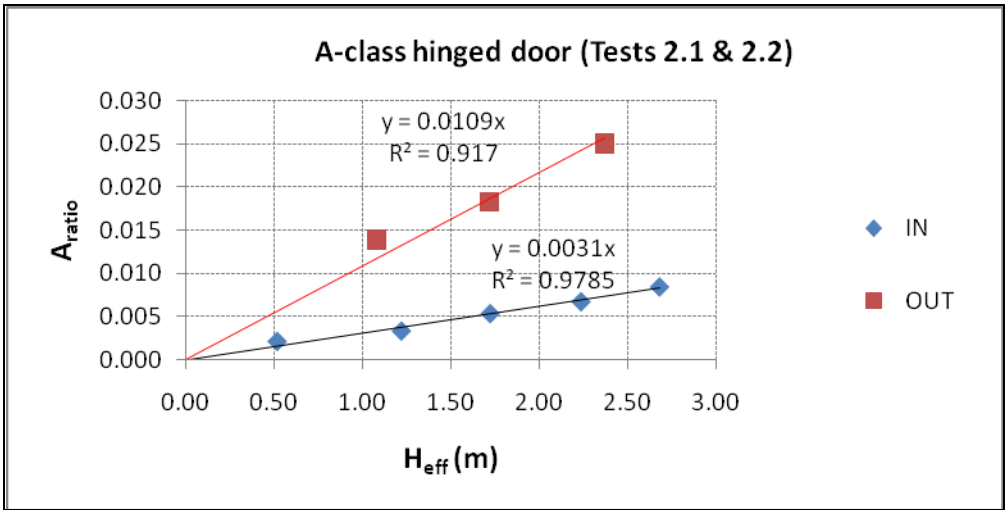

Figure 1: Calculated area ratio as a function of pressure height and linear regressions for A-class hinged door for two directions (pressure into and out from the doorframe)

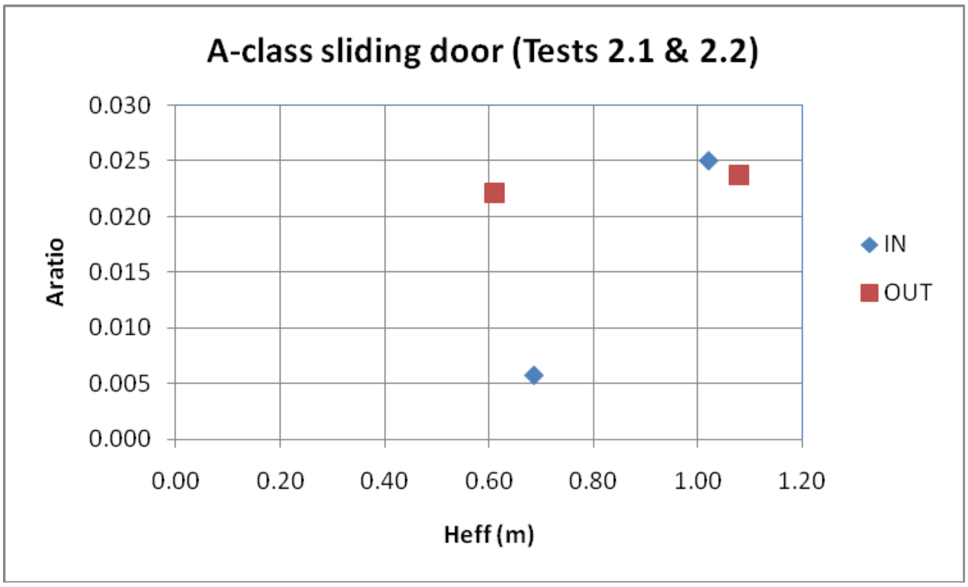

Figure 2: Calculated area ratio as a function of pressure height for A-class sliding door for two directions (pressure into and out from the doorframe)

Guideline Values

If possible, experimental data for the exact door arrangement should be used. Alternatively, dedicated FEM calculations are also recommended. However, these tests and computations are very expensive and thus a more generalized data is needed.

Rough guidelines for modelling leaking and collapsing of various non-watertight structures in flooding simulation are presented in Table 1. The data is highly generalized and based on very small set of test items. If the actual item significantly differs from the tested items, a more dedicated analysis (tests or calculation) is highly recommended.

Guideline values are presented also for the B-class joiner doors, but based on the observations from the full-scale tests it seems to be justified to exclude most of the B-class boundaries in flooding simulation models. However, some B-class boundaries may be necessary for proper treatment of free surfaces and asymmetry during the flooding process.

It seems that for all tested doors and panels, the leaking starts at very low pressure head. Consequently H_{leak} = 0 m is recommended for the simulations. On the contrary the tested window was found out to be watertight to the maximum pressure that could be achieved in the test facility. This supports the generally used assumption that windows on the lower decks are excluded from the flooding simulations.

Table 1: Rough guidelines for modelling doors and boundaries for flooding simulation, the values marked with an asterix (*) are estimations that are not based on experimental or FEM results *(Ruponen and Routi, 2011)*

Type	direction	H_{leak} (m)	A_{ratio}	H_{coll} (m)	Notes
Light watertight door	into	–	–	8.0*	minimal leaking at lower pressures, full collapse likely for $H > 8$ m; note that only direction "out" was tested
	out	–	–	8.0	
A-class sliding	into	0.0	0.025	1.0	almost constant leakage area ratio
	out	0.0	0.025	1.0	
A-class hinged	into	0.0	$0.02 \cdot H_{eff}$	2.5	A_{ratio} depends on the gap size
	out	0.0	$0.03 \cdot H_{eff}$	2.5	A_{ratio} depends on the gap size
A-class double leaf	into	0.0*	0.025*	2.0*	**Not tested!** Assumed to be independent on direction
	out	0.0	0.025	2.0	Collapsing could not be tested due to high leaking, value based on FEM
Cold room sliding door	into	0.0	$0.01 \cdot H_{eff}$	3.5	Only one direction tested; collapsing pressure height assessed with numerical methods
	out	0.0*	$0.01 \cdot H_{eff}$*	3.5*	
B-class joiner door	into	0.0	$0.03 \cdot H_{eff}$	1.5	panels around the door will fail first, A_{ratio} expression is very approximate
	out	0.0	0.03	1.5	door is distorted, A_{ratio} increases slowly
Windows	–	–	–	> 18	can be excluded in simulations

Sensitivity Analysis

A systematic sensitivity analysis has also been carried out within the FLOODSTAND project, *Karlberg et al. (2011)*, using three different flooding cases and a modern large passenger ship design and the NAPA Flooding Simulation tool, *Ruponen (2007)*. The previous research, such as *van't Veer et al. (2004)*, indicated that there are certain critical openings, such as fire doors to staircases. The applied input parameters for pressure losses and leaking for these openings can have a very notable effect on the simulation results. The main observations from the sensitivity study are given in the following.

In the performed simulations, no parameter variation whatsoever seemed to have any significant effect on the maximum transient heel. The same conclusion could be drawn even with an extensive and asymmetric flooding case. On the other hand, the applied parameters had notable effects on the time-to-flood and on the progress of flooding and the heeling after the transient phase. For example, variation of discharge coefficient C_d affected directly the flooding time and indirectly the collapses of doors.

Variation of critical pressure head for collapse had the most apparent effect on the way the flooding progressed. In this way it affected the nature of the heeling behaviour, but it also had an effect on the flooding rate and thus on the time-to-flood.

Leakage area modelling had a clear effect on the time-to-flood. This effect became apparent after the early flooding phases when most of the flooding was based on leaking through closed doors. If the variation of A_{ratio} did not have an effect on the collapse of doors, the consequent effects especially on heel were practically non-existent.

In a flooding case, where most of the flooding is leaking through closed doors the applied leakage area ratios have a significant effect on the time-to-flood. E.g. underestimation of this coefficient by 50% can lead to up to 50% overestimation in the time-to-flood. However, the effects on the behaviour flooding (e.g. order of flooded compartments) were minimal. Thus the conservative approach is to use slightly too large leakage area ratios in order to avoid the over-estimation of time-to-flood.

Conclusions

Further research on leakage and collapse of different kinds of typical non-watertight structures in ships is still needed. This should include more full scale tests. Especially, repetition tests are needed in order to find out possible statistical variations. The performed tests with hinged A-Class doors showed that in some cases a very notable variation is possible. Thus special attention should be paid on different A-class fire doors and cold room doors/walls since these structures were found out to notably affect the flooding progression. The gap size under the door can have a significant effect on the leakage through the door. Moreover, the leakage area coefficient was found out to be the most important parameter in the performed sensitivity analysis.

The present study is limited to flow conditions, where the leaking water through the structure discharges freely into air. In real flooding case also a situation, where the leaking structure is partly or even fully submerged is also likely. Therefore, further studies on the effect of flow condition on leakage and collapsing is also highly recommended.

Finally, it is noteworthy that the tested structures (A-class doors, B-class walls and doors, cold room doors, etc.) were found out to collapse or become significantly damaged under rather low pressure heights. This implies that on lower decks of the ship these structures have only a small effect on the progress of flooding within the damaged watertight compartment. However, up-flooding through staircases and flooding on the decks near the waterline are more complicated.

Disclaimer

The guidelines, presented in this paper, are based on the experimental and numerical research in the WP2 of the project FLOODSTAND. It should be noted that the set of tested items was rather limited. Consequently the presented guidelines are highly generalized, and to some extent, still based on assumptions and simplifications, as well as on the particular design and materials studied. This fact should be taken into account when using the presented values in time-domain flooding analyses. If newer or more reliable data is available, it should be used instead of these guidelines.

Acknowledgement

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