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A study on leakage and collapse of non-watertight ship doors under floodwater pressure

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ABSTRACT

The flooding of a damaged ship is a time-dependent process that is significantly affected by the non-watertight structures inside the watertight compartments. For certain ship types, like passenger ships, such structures form a complex internal subdivision. Time-domain simulation is the most realistic approach to calculate progressive flooding in damage stability analyses, but it is necessary to use a simplified method for modelling the leakage and possible collapse of the non-watertight structures. This paper presents unique full-scale tests and advanced finite element analyses, conducted to determine the leakage and collapse characteristics of various typical non-watertight structures, when subjected to water pressure. The obtained results are carefully analysed, and a simplified method for modelling the leakage of closed doors for time-domain flooding simulation is presented. For all tested doors leakage started practically immediately when immersed. Various deformation and collapse mechanisms were observed, and often the leakage increased with larger pressure head due to the deformation of the door. The collapse pressure heads varied between 1.0 *m* and 3.5 *m*; the cold room door having the largest value. Guideline values for typical non-watertight doors were derived based on the obtained results.

1. Introduction

Damage stability of a ship is based on watertight subdivision of the hull. This subdivision is usually composed of several transverse watertight (WT) bulkheads, tank top and bulkhead deck together dividing the ship into several watertight compartments, SOLAS 2009 [1]. Also other watertight decks and longitudinal bulkheads can be used. If there is a breach in the hull, for example due to a collision or grounding, consequent flooding is normally limited to a certain number of compartments due to this watertight subdivision. Therefore, with a proper subdivision and watertight integrity, the ship should not sink or lose its stability and capsize after damage. However, the bulkheads cannot ensure unconditional safety if the damage is large enough.

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The watertight compartments of a ship can be further subdivided into smaller rooms with non-watertight decks and bulkheads. This is typical especially for passenger ships. The different levels of subdivision are illustrated in Fig. 1. As a result of this structural complexity, the flooding of such compartments may contain transient asymmetric flooding, Spouge [2]. In addition, Manderbacka and Ruponen [3] have recently noted that the internal structures can have a significant effect, especially on the transient roll motion immediately after flooding starts. In some cases, this may lead to capsize or significant heeling during the flooding process, even if the ship would survive the full flooding of all the damaged compartments. Thus, some intermediate stage(s) of flooding may be even more dangerous than the final condition after flooding has equalized.

The risk of capsize during the intermediate stages of flooding is recognized also in the international regulations for damage stability. The Explanatory Notes to the SOLAS II-1, IMO Resolution MSC.281(85) [4], Regulation 7–2.2, under sub-heading: Intermediate stages of flooding, state that:

> “Where intermediate stages of flooding calculations are necessary in connection with progressive flooding, they should reflect the sequence of filling as well as filling level phases”. And further that: “Such calculations consider the progress through one or more floodable (non-watertight) spaces. Bulkheads surrounding refrigerated spaces, incinerator rooms and longitudinal bulkheads fitted with non-watertight doors are typical examples of structures that may significantly slow down the equalization of main compartments.” These requirements have proven to be a challenge for the ship designers, especially for smaller ships where rooms for different purposes must be fitted to same watertight compartments, Spigno et al. [5].

The real sequence of flooding can only be calculated with time-domain simulation. During the past decades, several simulation tools have been developed, e.g., Spanos and Papanikolaou [6], Jasionowski [7], Santos et al. [8], van't Veer et al. [9,10], Ruponen [11–13]), Schreuder et al. [14], Dankowski [15], Manderbacka et al. [16], Lee [17] and Rodrigues and Guedes Soares [18]. These methods use Bernoulli's equation for calculation of the water flow through the openings. Time-domain flooding simulation has already proven to be an efficient tool for cross-flooding calculations, Ruponen et al. [19] and accident analyses, e.g. Dankowski et al. [20] and Krüger [21]. However, complex flooding scenarios in passenger ships often involve also flooding through non-watertight subdivisions. Therefore, full-scale experiments were conducted with EU FP7 research project FLOODSTAND, Jalonen et al. [22], in order to obtain new insight and data on this specific field of fluid-structure interaction.

The prerequisite for using flooding simulation to analyse intermediate stages of flooding is that the size and location of all openings are known with reasonable accuracy. The internal subdivision inside a watertight compartment can be divided into A and B-class structures, based on the level of fire integrity, as defined in SOLAS Chapter II-2 Regulation 3, IMO (2009) [1]. Especially for A-class structures that are constructed of steel, it is very likely that these bulkheads are practically watertight. However, the various doors in the A-class bulkheads (see Fig. 2) are not watertight and thus, allow leakage, and if the water pressure is further increased the whole door may collapse. There may also be other openings, e.g. for cables and pipes, but the present study focuses on the non-watertight doors. The B-class structures are weaker, and notable leakage is expected to be possible also through the walls, not only at the doors.

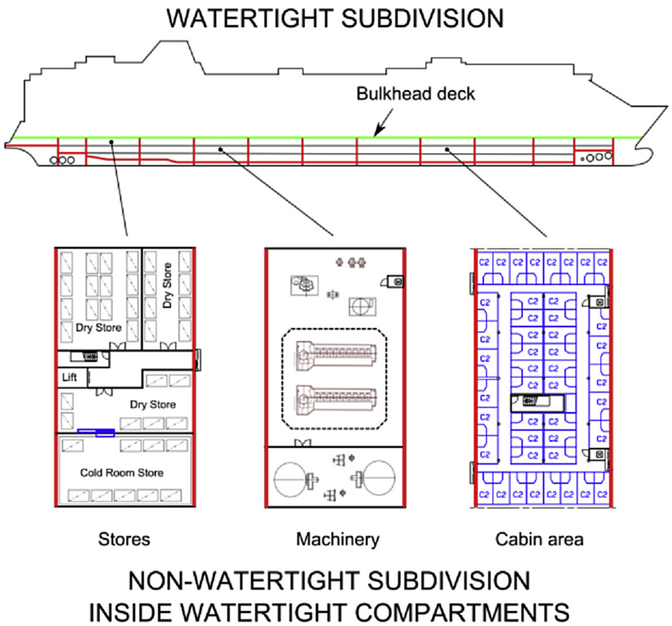

Fig. 1. Watertight subdivision of a passenger ship with three examples of non-watertight subdivision in some WT compartments.