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Model experiments of the transient response to flooding of the box shaped barge

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ABSTRACT

Coupling of the flooded water and ship motions was studied experimentally. Roll decay tests for one flooded compartment and transient abrupt flooding tests were performed for the box shaped barge model. The tests were conducted to obtain information on the flooding process for the development of numerical tools and to provide validation data. Quantitative values on the effect of flooded water on the roll damping were obtained. Flooded water behaves in a different manner in undivided and divided compartments. Flooded water in divided compartment increases roll damping significantly. In undivided compartment roll damping was high at low amount of flooded water. For higher amounts damping was of the same order as for the intact model. Initial flooding is a complex process where the ship and flooded water motions are coupled. Propagation of the flooding water inside the compartment, at a dam-break type abrupt flooding, was studied by tracking the surface of the flooded water. An image processing algorithm was used to obtain the tracked surface. Flooded water volume and its center of gravity were estimated from the tracked surface. Different internal layouts of the flooded compartment can lead to a totally different roll response. The inflooding jet plays an important role in the response in case of the undivided compartment. While, for a divided compartment, asymmetric flooding due to the obstructions causes high heel angle on the damage side.

1. Introduction

The overall risk assessment of the marine traffic is dependent on the validity of underlying sub-models (Goerlandt and Kujala, 2014; Ståhlberg et al., 2013). Collision between ships or grounding are the most common reasons for the loss of hull integrity and consequent flooding (Montewka et al., 2014). Understanding about the flooding process together with the ship response is one of the most important elements of existing risk models aiming at the improvement of the maritime traffic safety (Goerlandt et al., 2014). The flooding process can be divided into three stages; transient, progressive and steady state (Ruponen, 2007). The transient phase occurs right after the damage creation. Water starts to enter the ship through the damage opening. Inflow at this stage can be fast depending on the damage geometry. On the progressive stage the flooding continues through the internal openings of the ship. Transient and progressive stages are often referred to as the intermediate

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stages of flooding. At these stages the flooding process is complex depending, among many factors, on hydrostatical and geometrical characteristics of the ship (Khaddaj-Mallat et al., 2011). A large passenger vessel may lose its stability during the transient and intermediate stages of flooding (Vassalos et al., 2004).

The intermediate stages of the flooding include the impact of the inflow momentum and the flow propagation inside the compartment (Journée et al., 1997). Ship motions, floodwater movements and the progression of the flooding are strongly coupled. Asymmetric flooding due to obstructions in the compartment can cause a significantly high transient roll on the damage side or even capsize at the initial stage (Spouge, 1985; Vredeveldt and Journée, 1991; Santos, 2002; Macfarlane et al., 2010). For a compartment free of obstructions a jet due to the inflooding pushes the water to the opposite side and roll angles to the opposite side of the damage are observed in the model tests (Ikeda and Ma, 2000; de Kat, 2001; Ikeda and Kamo, 2001; Ikeda et al., 2003). Roll motion to the opposite side of the damage can slow down the inflooding by lifting the opening above the sea surface (Ikeda and Ma, 2000). The ship may experience a high roll angle either on the damage or on the opposite side depending on the initial water motions in the flooded compartment.

The coupling of the ship motions and liquid sloshing has been studied in the context of liquid transportation (Journée, 1997; Faltinsen and Timokha, 2009) specially related to the LNG tanks (Zhao et al., 2014). Essential differences, in the case of the damaged ship compared with the sloshing in liquid transportation, are the changing amount of water in the compartment and often lower fill height per tank breadth ratio at all stages of flooding. Intact and damaged ship motion response in waves have been studied by Armenio et al. (1996a,b), Chan et al. (2002), Korkut et al. (2004) and Begovic et al. (2013). They observed smaller roll motion response for the damaged ship than for the intact ship. In a numerical and experimental study of the damage ship motions in waves by Lee et al. (2007) it was concluded that more investigation is needed on the flooded water motions and progression inside the compartments. Free roll decay tests of the damaged ship (de Kat et al., 2000; Papanikolaou, 2001; Papanikolaou and Spanos, 2004; Lee et al., 2012) have showed that flooded water increases both damping and the period of the roll motion. In the previous studies the complex coupled flooded water motions have been observed to cause nonharmonic and damped roll response. Bouscasse et al. (2014a,b) performed experimental and theoretical study on the energy dissipation due to water motions. The internal layout of the damaged compartment has an important effect on the flooded water progression and motions (Veer and de Kat, 2000; Veer et al., 2004; Khaddaj-Mallat et al., 2012). Water exchange between the compartments through non-watertight openings in a harmonic motion of the compartment has been studied by Manderbacka et al. (2014). The beginning of the flooding resembles a dam-breaking problem which has been widely studied both numerically and experimentally (Lobovský et al., 2014). However, the damaged ship response complicates the problem.

The aim of this study is to provide quantitative data on the damping and flooded water motions in the damaged ship. In this paper a thorough set of measurements on simplified ship geometry is presented. Model proportions of external/internal dimensions, stability and inertia properties are relevant to a real ship. Coupling of the ship roll response to the water motions is studied by performing roll decay tests for flooded ship. The inflooding process at the initial stages of the flooding is carefully studied by transient flooding tests. Inflooding water kinematics is studied by tracking the water surface and estimating the flooded water volume and location of its center of gravity. This information is of utmost importance when validating the computational tools. The effect of the compartment layout and initial stability has been studied by performing tests with two different compartments and two different initial stabilities. Air flow and compression may further complicate the flooding process (Palazzi and de Kat, 2004; Ruponen et al., 2013). In this study the air compression effect is eliminated by having all flooded spaces fully ventilated. The geometry of the compartment layout had been made as simple as possible in order to concentrate and reveal the importance of different phenomena in flooding case. The simplified geometry facilitates comparison to computational models for validation purposes. The measurements reveal the importance of the flooded water motions on the response of the model.

This paper adds to the existing literature by providing systematic study on the damping effect of the flooded water. Furthermore quantitative data of the water motions at transient stage was obtained. Small values of flooded water can dampen the roll very fast if the sloshing natural frequency is close to the ship natural roll frequency. In this case the flooded water acts like a passive anti-rolling tank. Flooded water in the compartment with obstructions dampens the roll motion very efficiently. For the compartment with obstructions the increase in the amount of flooded water increases the damping.

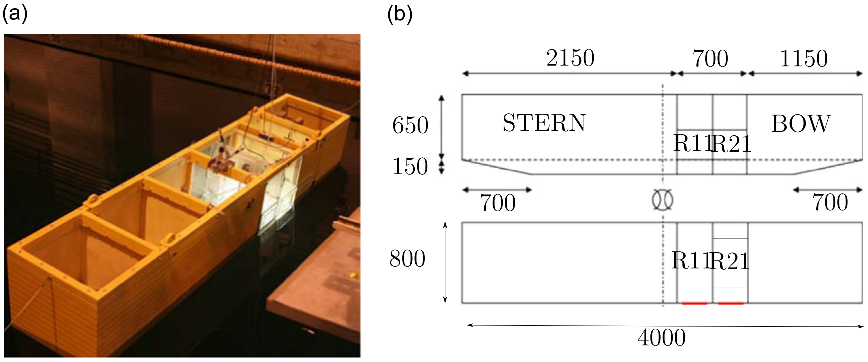

Fig. 1. Box-shaped-barge model. (a) Model in tank. (b) Overall dimensions of the model and compartment locations (Ruponen, 2006).