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Model experiment on the dynamic process of oil leakage from the double hull tanker

Jinshu Lu [a,*], Zhenbo Yang [a], Haoxiao Wu [a], Wenfeng Wu [a], Fengchen Liu [a], Song Xu [a], Hao Yang [b], Shiqiang Yan [b]

[a] Maritime College, Zhejiang Ocean University, Zhoushan, Zhejiang Province, China
[b] School of Engineering and Mathematical Sciences, City University London, UK

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A B S T R A C T

This paper presents an experimental investigation on oil leakage from the double hull tanker (DHT). It is designed to explore the dynamic process of oil leakage from bottom-rupture hole of DHT. The experimental test shows the leakage resistance mechanism of ballast tank space. The behavior of oil leakage from damaged DHT and dynamic features of flow in the overall process are demonstrated from experimental results. The overall process of oil leakage is divided into free-leakage and resistance-leakage stage according to the corresponding power to study the dynamic features of oil-water flow inside or outside the tank. The corresponding dominated factors of oil leakage in different stage are also pointed out, and the unsteady Bernoulli's equation is used to verify experimental results. Meanwhile, viscous effect in leakage process is discussed and the importance of hydrodynamic features associated with the mechanism of oil leakage is explored from experimental results.

1. Introduction

Double hull tanker (DHT) design was regulated in 1992 by the International Maritime Organization (IMO) for the purpose of minimizing oil leakage in an event of a casualty (Yamaguchi and Yamanouchi, 1992). It was widely accepted that DHT is the most effective design to reduce oil leakage from a damaged tanker due to collisions and groundings in the past twenty years. So far, many experimental and numerical investigations on DHT in incidental scenarios have been carried out by different researchers. The effect of emulsification on oil leakage from damaged tanker in a series of model tests with different kinds of oil has been explored (Simecek-Beatty et al., 2001, 2003). The model which could determine the process of oil leakage due to changes of gravity and wave pressure caused by movements of vessel or waves on the surface was developed (Fthenakis et al., 2003). Meanwhile, numerical analysis and probabilistic methodology have been used to investigate the behavior of oil leakage. (Hart and Hancock, 1992; Daidola et al., 1997; Smailys and Mindaugas, 2006). However, oil leakage is clearly a dynamic and unsteady procedure, the explorations on oil leakage from damaged DHT have not been found in literature. The investigations on oil leakage from single hull tanker can be found in only a few papers among the available publications (Tavakoli et al., 2008, 2009, 2010, 2011, 2012). The hydrodynamic features of oil and water flow during this process have been confirmed in these investigations on single hull tanker. The ultimate volume of oil leakage due to accidental groundings or collisions could be provided in these aforementioned explorations. As these explorations were mainly based on the steady or quasi-steady assumption and focused on the ultimate amount of oil outflow or water inflow, the dynamic behaviors and the viscous effect on oil leakage have not been explored. Numerical simulation is the effective tool to capture the hydrodynamic features of oil leakage from oil tankers (Lu et al., 2010; Xiao et al., 2010; Krata et al., 2012), such as the Moving Particle Semi-Implicit method (MPS) (Koshizuka and Oka, 1996) as well as the PNU-MPS approach (Lee et al., 2011). The references cited above only focused on the single hull tanker (SHT), and the corresponding numerical studies related to DHT are rarely seen in literature, partially due to the complexity caused by the narrow ballast space in DHT compared with SHT. The oil-water flows from grounded tank of DHT was simulated by the program 'Flow-3D' without considering the viscosity of fluid (Peter and Lin, 1994) and the numerical investigations on oil leakage from grounded or collided cargo tankers with different hull structures (including

* Corresponding author.
E-mail address: ljs_ljs@zjou.edu.cn (J. Lu).

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DHT) was conducted with 2D model (Tavakoli et al., 2008; Lee et al., 2011). Nevertheless, most of the aforementioned investigations were restricted by two-dimensional condition or neglect of viscous effect, which leads to irrational numerical results, especially for flow flux (Cheng et al., 2010).

Obviously, in order to predict the behavior of submerged oil leakage and propose optimal designs to reduce the volume of oil leakage to sea, it is necessary to understand leakage resistance mechanism of ballast tank space. Relying on the model experiment, detailed investigation on the dynamic process of oil leakage from DHT was presented by analyzing flow features. Configurations of two broken holes (puncturing through two hulls) located on the bottom of tank (Tavakoli et al., 2010, 2011) were used to reflect the grounding incidents, respectively, and model tank is fixed and initially located in still water basin. The focus of the paper is to explore the factors of oil leakage from cargo tank. The Unsteady Bernoulli's equation is used in predicting volume of oil leakage from cargo tank. Based on the data from model test, the process of oil leakage into basin is presented and the behavior of ballast tank capturing oil from cargo tank is illustrated based on the hydrodynamic features of flows. More importantly, viscosity effect is considered in this exploration.

2. Experimental design

Similarity principles considering both Froude number and Reynolds number are adopted to achieve kinematic and dynamic similarity (Tavakoli et al., 2008). Vegetable oil with density of 915 kg/m^3 and viscosity of 3.2×10^{-5} m^2/s was chosen as the model oil. The density and the kinematic viscosity of water are 998 kg/m^3 and 1.0×10^{-6} m^2/s, respectively.

2.1. The model tank

A model tank was built at 1/40 scale of a typical tank which takes a side section of VLCC ignoring details of internal support structures inside ballast tank (Thomae, 1995; Karafiath, 1992). Similar to the previous investigations (Karafiath, 1992), a J-shape ballast tank (sketched in Fig. 1 (a)) was used. The height, breadth and the length of the external tank are 0.75 m, 0.5 m and 0.55 m, respectively. The whole model is made of watertight plywood and glass for the purpose of visual observations. The thickness of the glass wall is 1 cm. The height of the bottom ballast space and the width of the side ballast space are 0.06 m. Two coaxial circular holes with diameter of 0.02 m were drilled on internal and external bottom hull, representing the rupture of the tanker (*H1* in Fig. 1(b)). The dimensional error of scale model in this paper is $\pm 2 \times 10^{-3}$ m.

2.2. The basin

The height, breadth and the length of the external basin are 1 m, 1.2 m and 2 m, respectively. Meanwhile, the drain holes were arranged on the same height of model tank's draft as shown in Fig. 2 (a) to ensure a fixed draft of model tank in the process of experiment. The model test was carried out in a controlled environment with temperature of 10 ± 3 °C.In the experiments, the hole on the external hull (referred to as external hole) and the hole on the internal hull (referred to as internal hole) were drilled to simulate the puncturing rupture. The model tank was fixed in a water basin as illustrated in Fig. 2 (a).

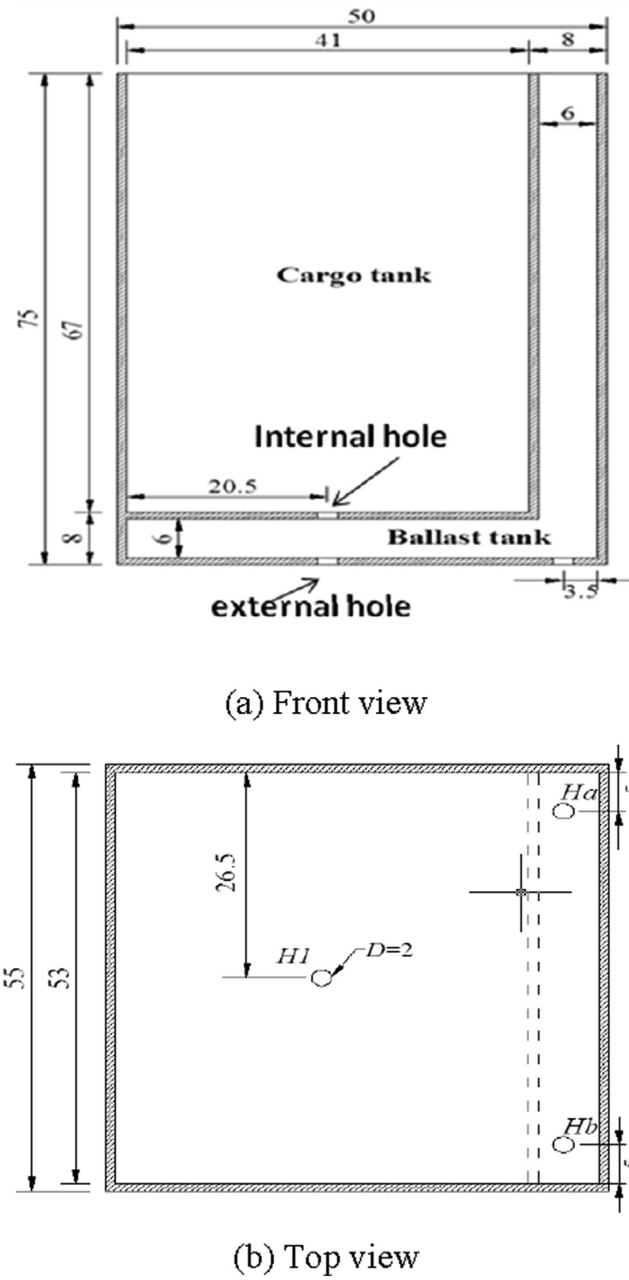

Fig. 1. Dimensions of model tank (a) and location of the hole (b) (unit: cm).

3. Test setup

3.1. Experimental system

Mechanical gates driven by the heavy object were designed and utilized to close/open holes so as to ensure the repeatability of test. As two coaxial circular holes were drilled on internal and external bottom hull, representing the rupture of the tanker, before oil leakage from cargo tank, the coaxial circular holes are plugged by two plugs. In order to avoid the effect of turbulence caused by human factors on whole flow field, fixed pulleys were adopted and arranged in appropriate position of the frame (Fig. 2) to make sure that the plugs are pulled out vertically and smoothly.

Equipments used to observe the leakage phenomenon and measure the data of liquid level or pressure are shown in Fig. 3