Journal of Fluids and Structures 45 (2014) 66–78

Contents lists available at ScienceDirect

Journal of Fluids and Structures

journal homepage: www.elsevier.com/locate/jfs

Investigation into the effects of petalling on coefficient of discharge during compartment flooding

Y. Li, A.J. Sobey *, M. Tan

Fluid Structure Interactions Group, University of Southampton, University Road, Southampton SO17 1BJ, UK

ARTICLE INFO

Article history:
Received 14 December 2012
Accepted 25 November 2013
Available online 27 December 2013

Keywords:
Compartment flooding
Coefficient of discharge
Damaged structures

ABSTRACT

Ships or risers, among many other marine structures, incur damage even with the best precautions. Whilst these damages can be catastrophic they often lead to scenarios whereby the damaged structure is ailing but not failed. In these scenarios the structure will flood and it is vital that the rate of flooding can be estimated, from a limited knowledge of the damage, so that safety and the environment can be best considered and an economical and effective recovery or repair of the vessel occurs. In an effort to improve the modelling and hence improve the advice available, research has been performed into how petalling, folding of the structure at the edge of the damage, effects the flooding of the structure. Experiments have been conducted on petalled structures and the results are compared to the coefficient of discharge for flat edged damages. The results show that petalling makes a substantial difference to the coefficient of discharge of the orifice flow which is largely dependent on the petalling angle which can both reduce or increase the flow rate dependent on the orientation. However, this difference can be predicted if the type of petalling is known.

1. Introduction

Marine structures can be seriously damaged by, or lost because of, many different causes such as fire, explosion, flooding, structural failure and loss of propulsive power (Tupper, 2004). During these incidents, there is a high likelihood of structural damage with Konopelko (1990) showing that 53% of accidents caused damage to the hull. Each of these damages comes from a different scenario resulting in a large variation of, position and size of damage. Eghtesad et al. (2012) provided a review of a number of cases where damage has been investigated for a range of applications using different fluid modelling methods. Caleyron et al. (2013) summarised the problems associated with modelling leakage through cracks in thin walled structures.

If the damage is below the waterline, it will lead to flooding of the structure. The flooding can have two important consequences: change of buoyancy and stability and reduction in structural strength. This is because when flooding occurs, the reduction in underwater volume will lead to the loss of buoyancy force. The structure will reach a new balanced condition through sinkage, which will affect the stability by changing the position of the centre of buoyancy and also affect the structural strength by deteriorating the loading distribution. During decision making of emergency response, coefficient of discharge, C_d, is commonly used to assess the impact of damage to the stability and structural integrity and therefore it is vital that this value can be accurately determined after damage. Bazsó and Hős (2013) highlighted the difficulties in

* Corresponding author. Tel.: +44 2380 597773.
E-mail address: ajs502@soton.ac.uk (A.J. Sobey).

0889-9746/$ - see front matter
http://dx.doi.org/10.1016/j.jfluidstructs.2013.11.016

estimating this coefficient of discharge finding that the current estimates were not suitable for their calculations for direct spring loaded poppet relief valves.

The time period from the start of flooding to the final equilibrium condition is defined as time-to-flood. In general, the flooding process from the creation of the damage hole can be divided into three main phases (IMO SLF46/INF.3, 2003). Fig. 1.1 provides a brief description of these phases.

The first phase of transient flooding starts as soon as the creation of the damage when the water rushes into the compartment through the opening. It is then followed by the second phase of progressive flooding where the water floods into the undamaged compartments through any openings. If the ship finds an equilibrium condition, the ship will reach a steady state which is the final phase. When evaluating the flooding process Ruponen (2007) showed that flooding ships will experience intermediate stages which can be more dangerous than the final condition, if equilibrium can be found at the final condition. Moreover, in the case of damaged ships, the simulation of the compartment flooding process will provide an estimation of the possible time for abandonment and evacuation.

To explore flooding, Ruponen (2006) performed a series of tests on the progressive flooding of a box-shaped barge. The model contained eight compartments and all of the openings, which represented broken pipes, leaking doors, manholes, and staircases, are simplified to ideal rectangular or circular shapes. All the compartments in the model were open to the external air in order to avoid the air compression. The resulting mean coefficients of discharge, namely, the ratio of actual discharge to the theoretical discharge, are shown in Table 1.1.

Smith (2009) used hydraulic models to measure the coefficient of discharge of an orifice. The experiments were conducted using a model forced with vertical velocity to generate a quasi-steady flow; the assumption made in orifice flow theory. The results showed that with an increase in the orifice size, the coefficient of discharge reduced and the velocity of the water jet also decreased. As the orifice size increased, the effect of model velocity became more significant on the coefficient of discharge. Prohaska et al. (2010) investigated the coefficient of discharge for different orifice sizes in two different sizes of riser pipe. They found the coefficient of discharge to be a function of head height over the orifice, location of the orifice above the floor of the tank and the ratio of the orifice diameter to riser pipe diameter. The coefficient of discharge increases as the ratio between the head height over the orifice and the orifice diameter reduces. For a given size of riser pipe the coefficient of discharge decreased with an increase in the ratio between the heights of the internal and external fluid, if the orifice was above the floor. The coefficient of discharge also reduced as the ratio between orifice diameter and riser pipe diameter increased. Moreover, if the orifice diameter was small compared with the head above the orifice and the height of the orifice above the tank floor, the coefficient of discharge would be constant. Finally it can be to show that, with all of the other variables fixed, the coefficient of discharge was lower for riser pipes of a larger size. Jan and Nguyen (2010) examined the coefficient of discharge for water flow passing through a circular orifice at the bottom of a conical hopper. The results indicated that the larger orifice diameter or higher water head would lead to a smaller coefficient of discharge and the orifice diameter was more important to the coefficient of discharge than the water head. Moreover, the coefficient of discharge for a bottom orifice was larger than for a sidewall orifice under the same test condition. Wood et al. (2010) estimated the coefficient of discharge of orifices with different shapes and areas. The coefficients of discharges were found to vary from 0.452 to 0.725 as a result of different orifice shapes: circles, squares and rectangles; and

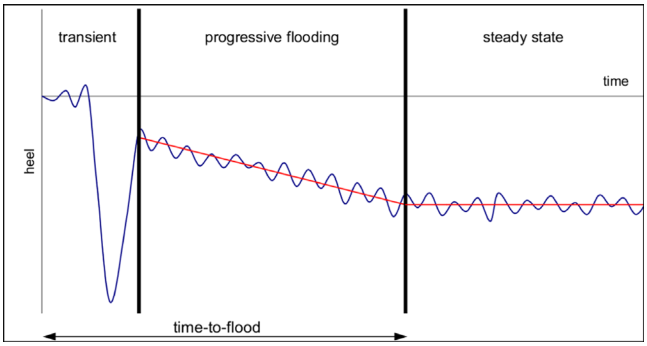

Fig. 1.1. Main phases of the flooding process (Ruponen, 2007).

Table 1.1
Coefficient of discharges for different openings (Ruponen, 2006)

Opening	Mean C_d
Large damage (40 mm × 60 mm)	0.78
Small damage (25 mm × 25 mm)	0.83
Broken pipe (⌀20 mm)	0.80
Partly open door (20 mm × 20 mm)	0.75
Staircase (100 mm × 100 mm)	0.72