International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 29, No. 3, September 2019, pp. 257–268; https://doi.org/10.17736/ijope.2019.ts18

http://www.isope.org/publications/publications.htm

Experimental Study and Method of Sloshing Model Test Considering Gas-Liquid Density Ratio

Yangjun Ahn and Yonghwan Kim*
Department of Naval Architecture and Ocean Engineering, Seoul National University
Seoul, Korea

Sang-Yeob Kim
Ship & Offshore Technology Center, Korean Register
Busan, Korea

This paper presents a methodology and the results of sloshing model tests considering gas-liquid density ratio. Experiment materials of conventional sloshing model tests needed to be altered for more proper scaling. Experimental methods for handling alternative gas mixture were introduced to match the density ratio. The described methods were practical, and accurately estimated the density ratio in the model tank. To illustrate the effects of the density ratio, extensive regular tests had been conducted with two rectangular models by regular sinusoidal excitations: one for the impulse pressure comparison, and the other for the local flow comparison. Obvious effects of the density ratio had been investigated.

INTRODUCTION

Sloshing in LNG carriers can lead to large impact loads on a containment system. It is important to assess these impact loads for the adequate design of the cargo containment systems. Because of the stochastic and highly nonlinear characteristics of sloshing, an experimental approach has been mainly used and recommended by ship classification societies (American Bureau of Shipping, 2006; Bureau Veritas, 2011; Det Norske Veritas, 2006; Lloyd's Register, 2009). Methodologies and their developments have been illustrated by the classification societies and primary studies of Gervaise et al. (2009), Kuo et al. (2009), and Kim et al. (2012).

In the application of the experimental approach, scaling the experiment results in the actual design is one of the difficulties. This scaling issue of sloshing model tests has been extensively studied, but a complete conclusion has not been drawn. The Vaschy-Buckingham theorem is a fundamental idea, and many studies have been based on suggesting and identifying dimensionless numbers. Bass et al. (1980) explained that the global behavior of the fluids might be governed by Froude scaling, so that the ullage pressures could be Froude scaled. Local behavior, however, significantly affects sloshing loads on the cargo hold containment systems, and it does need different scaling laws.

To find an appropriate scaling law for the local phenomenon of sloshing, analytic, numerical (Braeunig et al., 2009), and experimental studies have been conducted. Faltinsen and Timokha (2009) organized the initial studies and experiment results. Abramson et al. (1974) and Bass et al. (1980) explained surface tension and viscosity effects, and Frihat et al. (2016, 2017) showed effects of the surface tension and the local behaviors on the sloshing impact pressure. Because the sloshing phenomenon is so complex, the sloshing impact pressure is sensitive to changes in many experimental conditions (Karimi et al., 2015; Frihat et al., 2016). Acoustic scaling including the density ratio was theoretically identified. Acoustic scaling and Froude scaling were relevant to the sloshing problem (Dias et al., 2007). During an impact, a transfer of momentum between liquid and gas occurs, so the density ratio has an influence on the impact pressure. Numerical studies also showed this influence of the density ratio (Dias et al., 2007). Experimental studies were further conducted by Karimi et al. (2016).

The consequences of the experiments have substantiated the importance of the density ratio. A dimensionless number, which consists of the density ratio and polytropic index, was proposed with experimental results (Yung et al., 2009, 2010). Karimi et al. (2016) illustrated breaking wave shapes by offering dedicated captured images as the density ratio varied. The free surface and escape of gas before the occurrence of sloshing impacts were locally affected by the density ratio variation. Maillard and Brosset (2009), and Yung et al. (2010) presented the variation of sloshing impact pressures according to the density ratios. Model tests of the earlier studies, however, were performed under a limited number of test conditions. The influence of the density ratio on the sloshing impact pressures needs to be further described.

This paper presents three parts of a sloshing model test considering the density ratio: an experiment methodology, the influence of the density ratio on the impact pressures, and the influence of the density ratio on the local flow during the impacts. Since conventional sloshing model tests only used ambient air and water, the simple experiment methodology is introduced to consider the gas-liquid density ratio during the sloshing experiments. The details of the introduced experimental method are described. The appropriateness of the experimental method is also analyzed. Second, for various types of sloshing impacts, the magnitudes and shapes of the impact pressures were compared. Forced lateral harmonic motions were studied. The tank was excited for a sufficient time. To generate many different types of sloshing impacts, an extensive number of test conditions were considered. Excitation frequencies were varied at sufficiently small intervals from the minimum frequency to the maximum frequency of each test condition. Filling conditions were also changed from low fillings to high fillings. Two excitation amplitudes for high filling conditions

*ISOPE Member.
Received August 1, 2018; revised manuscript received by the editors January 4, 2019. The original version was submitted directly to the Journal.
KEY WORDS: LNG, sloshing, scaling laws, gas mixture, density ratio.