Experimental Investigation of Non-similarity Slamming Phenomena in Geometrically Similar Tanks

Zhi-jun Wei and Qian-jin Yue
Department of Engineering Mechanics, Dalian University of Technology
Dalian, Liaoning, China

In this paper, the non-similarity sloshing-induced slamming phenomena in geometrically similar Gaztransport & Technigaz (GTT) membrane-type floating liquefied natural gas (FLNG) facilities are investigated. The experiments were conducted in three scaled prismatic tanks at scales of 1/20, 1/40, and 1/60 with roll excitation, and the impact pressure was measured. The experimental results demonstrate that the kinematic free-surface behavior, time traces, and spatial distribution of the impact pressure during a single roll wave impact exhibit non-similarity in the three geometrically similar tanks. Furthermore, the quantitative statistical analysis of the impact pressure and impact rise time indicates that Froude’s law yields conservative estimates for the slamming force in the tank by using the same experimental media.

INTRODUCTION

The challenge of designing floating liquefied natural gas (FLNG) facilities has attracted considerable attention from both the offshore gas exploration industry and academia. Floating above the deep water or marginal gas fields, the FLNG system is designed to produce, liquefy, store, and transfer liquefied natural gas (LNG). Consequently, it needs large volume tanks, a large amount of deck space, and easy maintenance. Gaztransport & Technigaz (GTT) membrane-type cargo containment systems (CCSs) have an advantage over other types of CCSs for FLNG facilities. They afford the maximum utilization of the ship’s space, making use of the ship’s support structure. However, due to cost efficiency and low-temperature preservation considerations, one drawback to the GTT membrane CCS is the capability of the thin insulation layer to bear liquid impact. Furthermore, one significant difference between the LNG CCS and FLNG CCS is that the FLNG system has no restriction for filling conditions (American Bureau of Shipping, 2010). Liquid tends to slosh in a partially filled tank. These slosh-generated loads have a considerable influence on the tank and support structure design. The slamming force has long been of interest to designers and researchers because it has resulted in structural local damage and liquefied natural gas leakage during LNG shipping (Abramson et al., 1974; Gavory and De Seze, 2009). Thus, it is essential to determine the slamming force caused by violent liquid movements in partially filled tanks in the design of CCSs for FLNG facilities.

Both theoretical and numerical methods have limitations in predicting rapid overturning or the strongly nonlinear free surface with large amplitude slamming and complicated tank shapes, which is reported by many researchers (Abramson et al., 1974; Lee and Choi, 1999; Faltinsen and Timokha, 2009). The experimental approach is efficient and accurate in revealing the complicated physical phenomena during liquid sloshing. Monitoring the slamming force of CCS prototypes for in-service LNG carriers is expensive, difficult, and dangerous. Furthermore, it is difficult to eliminate uncertain factors that are not relevant to the slamming force in prototype experiments (Malenica et al., 2009). Hence, few prototype tests have been conducted, and there is little public information on such tests because of commercial conservation. The scaled model test is a practical approach for filling in the gaps between theoretical, numerical methods and prototype experiments. The slamming pressure obtained by the sloshing model test is processed to identify the most critical slamming force on the containment system structure. Although many sloshing model studies have been conducted, the effect of scaling remains unclear (Faltinsen and Timokha, 2009).

Froude and geometric scaling have traditionally been used to convert a model force to prototype scale because it is generally accepted that the slamming force is dominated by gravity (Faltinsen and Timokha, 2009). However, during the slamming process the impact pressure is extremely sensitive to local flow phenomena such as liquid splashing, trapped air, jets of aerated liquid, and capillary waves, which cannot be considered by existing scaling laws based on Froude and Euler scaling (Bass et al., 1985; Yung et al., 2009). Bogaert et al. (2010) compared the global flow in two scaled flumes under a single wave impact to assess the global physical phenomena of the slamming process. Lafeber et al. (2012) developed three elementary loading processes (ELPs) to describe the physical phenomena of the local flow in two scaled flumes during a single wave impact. However, few studies have investigated the effect of scaling on the slamming force caused by long-term excitation in GTT membrane-type tanks. Kim et al. (2012) studied the slamming force in two three-dimensional (3D) GTT-type models under irregular motion. Their results indicated that Froude’s law is appropriate for modeling the slamming force. Furthermore, Karimi et al. (2013) reported a statistical comparison of the slamming pressure in two two-dimensional (2D) GTT model tanks at a filling level of 20%. Due to the complicated physical phenomena during liquid slamming, both the free-surface profile and impact pressure exhibit non-similarity even in geometrically scaled tanks. The studies noted above did not systematically study the non-similarity of the physical phenomena, spatial distribution, and magnitude and rise time of the impact pressures in the geometrically similar GTT model tanks (Bogaert and Brosset, personal communication, December 8, 2014).

The main goal of this paper is to study the non-similarity slamming phenomena in 2D geometrically similar GTT membrane-type model tanks in an FLNG facility. An extensive series of experiments was conducted in three scaled tanks at a filling level...