Experimental Study of Sloshing Load on LNG Tanks for Unrestricted Filling Operation

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ABSTRACT

This paper presents a numerical and experimental study of sloshing loads on liquefied natural gas (LNG) vessels. Conventional LNG carriers with membrane-type cargo systems have filling restrictions from 10% to 70% of tank height. The main reason for such restrictions is high sloshing loads around these filling depths. However, intermediate filling depths cannot be avoided for most LNG vessels except the LNG carrier. This study attempted to design a membrane-type LNG tank with a modified lower-chamfer shape that allows all filling operations. First, numerical sloshing analysis was carried out to find an efficient height of the lower-chamfer that can reduce sloshing pressure at partially filled conditions. The numerical sloshing analysis program SHI-SLOSH was used for numerical simulation; this program is based on SOLA-VOF. The effectiveness of the newly designed tanks was validated by 1:50-scale three-dimensional tank tests. A total of two different tanks were tested: a conventional tank and modified tank. As test conditions, various filling depths and wave periods were considered, and the same test conditions were applied to the two tanks. During the tests, slosh-induced dynamic pressures were measured around the corners of the tank wall. The measured pressure data were post-processed and the pressures of the two different tanks were statistically compared in several ways. Experimental results show that the modified tank was quite effective in reducing sloshing loads at low filling conditions. This study demonstrated the possibility of all filling operations for LNG cargo containment systems.

KEY WORDS: Sloshing, LNG cargo containment system, all filling operation, lower-chamfer

INTRODUCTION

In the construction of large liquefied natural gas (LNG) carriers, there are growing needs for technical development for sloshing loads; this is closely related to the design and strength assessment of the LNG cargo containment system. For newly built LNG vessels, the cargo systems can be largely divided into two categories. The first type is the independent type. Independent tanks are completely self-supporting and can be constructed of flat surfaces or with a spherical/cylindrical shape. These types of tanks have stronger resistance to slosh-induced force, which is one of the key parameters in the design of LNG cargo. However, recent trends favor using the membrane tank rather than the independent tank. Such tendency occurs because the membrane type, which has a prismatic tank shape, has less unnecessary void space.

LNG carriers with a membrane cargo containment system generally have tank filling restrictions between 0.10H and 0.70H (where H is the internal tank height). The main reason for the restriction is the high sloshing pressures at approximately 0.20H to 0.40H filling (Macdonald, 2008; Pastoor et al., 2004; Zhao et al., 2004). However, for other LNG vessels, which are required to process the production, offloading, and regasification, intermediate filling depths cannot be avoided. Therefore, despite the high construction cost, there is no choice but to adopt the independent type for LNG vessels such as LNG-shuttle regasification vessels (LNG-SRVS) and floating LNG (FLNG).

Several studies have addressed the development of sloshing reduction devices installed inside prismatic LNG cargo (Anai et al., 2010; Kim et al., 2013b). Although these studies had a positive outcome in sloshing reduction, adoption of such special devices is meeting many obstacles in real ship applications such as safety checks and application costs. Therefore, it would be highly advantageous if sloshing pressure could be reduced by simple change of tank shape with the same insulation system.

This study attempted to develop a membrane-type LNG tank design that enables all filling operations by changing the shape of the lower-chamfer. The main objective was reducing the sloshing pressures of the conventional tank at approximately 0.30H filling, which is known as the most critical filling depth condition for sloshing loads. First, numerical sloshing analysis was carried out to design the lower-chamfer height. Irregular sea simulation was carried out using a total of four different tank designs, including the conventional type tank. The numerical sloshing analysis program used for this study is SHI-SLOSH which is based on SOLA-VOF (Ha et al., 2002; Park et al., 2006).