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Experimental Comparison of Sloshing Loads on Weather Side and Lee Side for LNG Carrier Cargo Tanks

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This research is based on experience accumulated from projects that have been supported by Korean shipbuilding companies for the past nine years. Earlier sloshing experiments were generally carried out with pressure sensors installed only on the weather side of the models. Recent experiments, however, required the symmetrical placement of sensors on the weather side and lee side. In this paper, an experimental investigation comparing the sloshing impact pressure on the two sides is presented. The pressure data have been locally inspected, and the results are statistically post-processed and compared. It is found that the installation of sensors on both sides can reduce the uncertainty of the experiments.

INTRODUCTION

Assessing the sloshing impacts of liquefied natural gas (LNG) cargo holds has been an important design consideration for LNG carriers. Malenica et al. (2017) recently summarized a current trend of sloshing analysis by describing stochastic and highly nonlinear characteristics of sloshing. Because of the complex nature of sloshing, an experimental approach has been primarily used for its assessment. The experimental approach has been illustrated by the guidance notes of the classification societies American Bureau of Shipping (2006), Det Norske Veritas (2014), Bureau Veritas (2011), and Lloyd's Register (2009) and in numerous studies (Baudin et al., 2013; Diebold and Baudin, 2014; Gervaise et al., 2009; Kuo et al., 2009; Maillard and Brosset, 2009; Mehl et al., 2014; Rognebakke et al., 2009; Wei et al., 2014; Yamamoto et al., 1995). In industrial fields, irregular model tests with six degrees of freedom (6DoF) are practically carried out for 5 hours at real scale (SY Kim et al., 2013, 2017; Y Kim et al., 2013; Oh et al., 2015). Details of the test equipment and test conditions are varied with respect to the project purpose, construction plan, involved classification societies, and many other different conditions.

One piece of test equipment that differs among the model test projects is the sensor arrangement. The number of installed sensors and location of them are varied, although the classification societies suggest that the sensors ideally be placed in almost every location of the cargo hold model to reduce experimental uncertainties. Practical difficulties of cost and time limits and technical issues of the facility and sensor specifications have led to this variation.

When several parts are excluded from the sensor locations suggested by the classification societies, lee-side parts were usually removed with high priority because the wave-induced response motion of the weather side would be more significant than that of the lee side: more severe sloshing loads would be expected on the weather side. Although the sensor configuration is confidential in the industrial projects, a few of these have released information, as can be found in Kim et al. (2012, 2014, 2017) and Ahn et al. (2012). Asymmetric sensor configuration can be also found in the research: Yamamoto et al. (1995) suggested a procedure based on a statistical approach; Graczyk and Moan (2008) investigated a large sample of sloshing pressure signals with two statistical models; Fillon et al. (2012) focused on a proper sampling rate for the sloshing model test; and many other valuable studies (Pastoor et al., 2004; Zalar et al., 2005; Bunnik and Hujismans, 2009) were conducted with asymmetric sensor arrangements.

Whereas the sensor configuration considering only the weather side has been used in many actual projects, no concrete data support that the exclusion of the lee-side sloshing impact pressure would provide experimental results as solid as the ones provided by experiments in which both sides are simultaneously considered.

To provide information that could be used to compare the weather-side and lee-side sloshing loads, several industrial sloshing model tests were selected in the present study. They are first categorized by the wave heading angles. Every model test considered in this study has symmetrical sensor configuration because sloshing loads on the weather side and lee side should be simultaneously compared. All the models are LNG carriers with different capacities larger than 130,000 m^3. The service wave conditions are based on the North Atlantic or the worldwide trade wave scatter diagram (Det Norske Veritas, 2014), and the cargo hold model is the second forwardmost cargo tank that has a conventional hexagonally-shaped membrane tank with upper and lower chamfers.

Basic experimental setup and statistical post-processing procedures are briefly described in the next section. Then, the comparison method is explained to show which side is more critical to the sloshing impact pressure between the weather side and lee side. Next, results compared by considering the wave heading angles are discussed, followed by several key findings as concluding remarks. These findings provide information for the pressure sensor location of the sloshing model test under the test conditions considered in the present paper.

DATABASE PROCESSING

The sloshing model test database of Seoul National University (SNU DB) has been created by conducting various industrial sloshing model tests supported by Korean shipbuilding industries and classification societies. All experiments simulated actual operations of vessels for more than 5 hours at real scale. The

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