Full-Scale Test and FE Analysis of LNG MK III Containment System under Sloshing Loads

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ABSTRACT

Full-scale impact loading tests have been conducted on MK III CCS through generation of large breaking wave and impact loads. Pressure sensors were positioned in the primary membrane to measure the sloshing impact pressures on the corrugated membrane under different impact loadings, and strain gauges were installed in the insulation system to measure the associated structural response. All these collected data have been employed to validate the sloshing assessment methodology of LNG MK III CCS developed by ABS through numerical simulations. A FE model for MK III layered structure with a corrugated membrane has been developed for nonlinear dynamic FE analysis under sloshing impact pressure. An elastic model is used for stainless steel, foam, plywood, and mastic material properties. A rigid connection option is employed to assemble all components in MK III CCS. In FE analysis, measured pressures have been applied on the corrugated membrane to study the deformation behavior of the insulation system. Strains in the insulation system are computed for comparison with measured data for validation purposes. Both numerical and experimental results show reasonably good consistency. Thus, the ABS sloshing analysis methodology has been validated using full-scale impact test data. Using test and simulation results, the assessment of structural integrity of the LNG MK III CCS has also been carried out based on acceptance criteria.

KEYWORDS: Sloshing loads, LNG cargo containment system, FE analysis, MK III CCS, strength evaluation

INTRODUCTION

Sloshing of LNG cargo due to vessel motion may cause a safety issue for membrane-type containment systems in LNG carriers (LNGC) and offshore FLNG facilities. The LNG MK III containment system (CCS), which is a membrane-type CCS, consists of a thin stainless steel membrane corrugation (primary barrier), primary plywood layer, primary foam layer, triplex (secondary barrier), secondary foam layer, secondary plywood layer, and mastic. Compared to a steel hull structure, MK III CCS is very flexible and the membrane corrugation may be susceptible to deformation under severe sloshing impact loads. In 2008, some deformations of membrane corrugation were observed on board some MK III LNG ships during routine dry dock inspections. Therefore, it is important from a structural safety perspective, to understand the sloshing behavior of MK III CCS including the membrane corrugation under impact loading.

In past years, as a design practice, the comparative method based on existing service experience and previous damage cases had been widely used and accepted in the shipbuilding industry (Shin et al., 2003; Kim et al., 2004). In recent years, as larger LNGCs and FLNG facilities are being built to meet increase capacity demands, it is important to also consider severe loading conditions such as partial filling. Thus, a direct calculation-based strength assessment procedure was employed to evaluate the structural integrity of LNG containment systems under sloshing loads. In this approach, the sloshing model tests are required in the design sea states in order to estimate the sloshing load due to random ship motion, and to provide the design load for the strength assessment of the LNG containment system. ABS (2006) published Guidance Notes on the strength assessment of membrane-type LNG containment systems under sloshing impact loads. The improvement with a patch load approach and the reliability-based approach will be considered in the next revision version, and this revised guidance notes will be implemented in practice through the JDP projects with shipyards. Shin et al. (2006) investigated the dynamic characteristics of sloshing impact loads and dynamic structural response of the LNG containment system using the direct calculation approach. Based on sloshing model test data, the strength of membrane-type LNG MK III and NO 96 containment systems has been evaluated in practice under sloshing impact loads following the ABS methodology (Wang et al. 2006; Wang and Kim 2007; Wang et al. 2009). However, there are some disagreements concerning the application of the sloshing model test data in an actual scenario. First, the rigid wall without containment system is used in sloshing model tests and there is still an issue concerning the use of an appropriate scaling law. A second concern is that the structure response cannot be reflected in model tests.

In this study, full-scale impact tests for simulating sloshing impact phenomena were conducted to evaluate the strength of membrane-type LNG containment systems. Full-scale sloshing tests could provide the time history of impact pressure and its corresponding structural response. In previous work, a NO 96 CCS panel and a concrete cube were tested in full-scale to study hydro-elastic effects and structural deformation behavior. Nonlinear dynamic FE analysis was performed considering fluid-structure interaction. It can be concluded that the ABS methodology has been validated using measured pressure and response (Wang and Shin, 2009). In the same way, based on full-scale tests on the MK III CCS including the membrane corrugation, the pressures measured from full-scale sloshing tests were applied to the layered MK III FE model using the ABS approach. The structural response in the MK III CCS from numerical simulations was compared with that measured from tests. Consequently, the strength of MK III CCS was also assessed based on acceptance criteria. Finally, the ABS approach was validated through