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Evaluation of sloshing resistance performance for LNG carrier insulation system based on fluid-structure interaction analysis

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ABSTRACT: *In the present paper, the sloshing resistance performance of a huge-size LNG carrier's insulation system is evaluated by the fluid-structure interaction (FSI) analysis. To do this, the global-local analysis which is based on the arbitrary Lagrangian-Eulerian (ALE) method is adopted to accurately calculate the structural behavior induced by internal LNG sloshing of a KC-1 type LNG carrier insulation system. During the global analysis, the sloshing flow and hydrodynamic pressure of internal LNG are analyzed by postulating the flexible insulation system as a rigid body. In addition, during the local analysis, the local hydroelastic response of the LNG carrier insulation system is computed by solving the local hydroelastic model where the entire and flexible insulation system is adopted and the numerical analysis results of the global analysis such as initial and boundary conditions are implemented into the local finite element model. The proposed novel analysis techniques can potentially be used to evaluate the structural integrity of LNG carrier insulation systems.*

KEY WORDS: Hydroelastic analysis; FSI analysis; KC-1-type LNG carrier insulation system; Sloshing; ALE method; Global-local analysis.

INTRODUCTION

As the demand of natural resources such as natural gas and oil are tremendously increased, the huge size carrier such as liquefied natural gas (LNG) carrier is fabricated in nowadays. In accordance with this phenomenon, a lot of risk factors such as sloshing problem, crack propagation problem in midship section are emerged. Among these, the sloshing problem is considered as one of the most catastrophic problems since the structural failure of the LNG carrier leads to not only leakage of LNG but also tremendous loss of human and financial resources.

In order to overcome this problem, i.e., the insulation system which is consisted of lots of composites and austenitic stainless steels is adopted such as MARK-III-type, NO-96-type, KC-1-type insulation system. Among these, the KC-1-type insulation system which is fabricated by shipbuilding companies of Korea is designed to sustain the leakage of LNG as well as structural failure. Figs. 1 and 2 show the schematic of the membrane-type LNG carrier and the KC-1-type insulation system. This insulation system encounters the severe sloshing loads during its oversea operation. Hence, it is essential to guarantee the structural safety of the insulation system during its design and fabrication.

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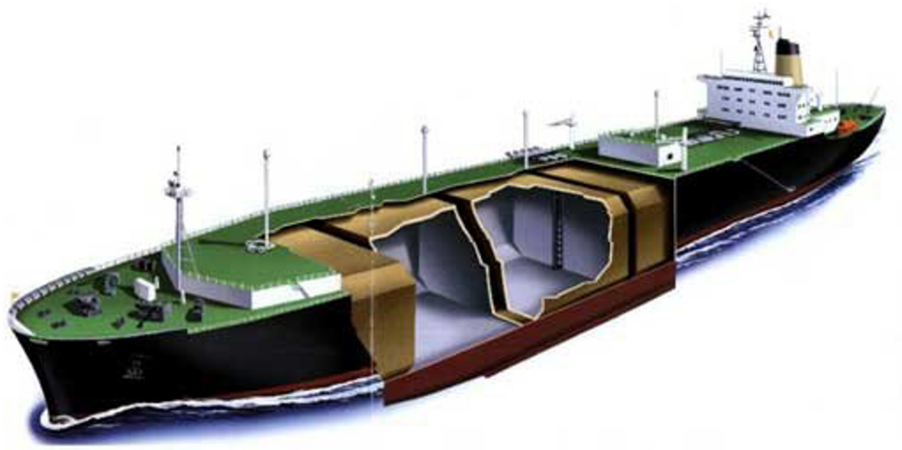

Fig. 1 Membrane-type LNG carrier with insulation system.

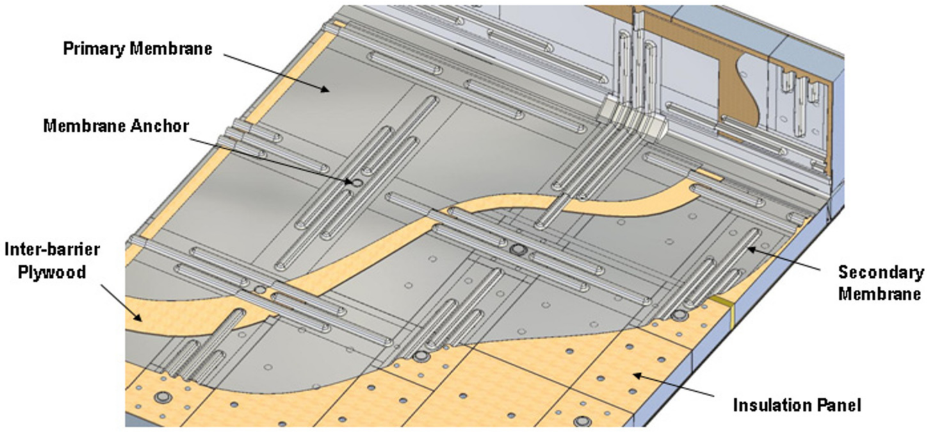

Fig. 2 Schematic of KC-1-type LNG carrier's insulation system.

For several decades, the hydroelastic analysis under sloshing has been analyzed by computational methods. In other words, the hydrodynamic pressure distributions as well as wave characteristics near the boundary condition are successfully evaluated based on finite element method (FEM) (Valtinsen, 1974; Nakayama and Washizu, 1980; Wu et al., 1998). However, in these researches, the structural response and behavior is not focused on, because the container is postulated as a rigid body and the interactive effect between interior fluid and exterior container is ignored. It is considered that the tremendous computational time and cost would be demanded when the structural deformations and interactive methods are adopted.

As an alternative method, the global-local basis fluid-structure interaction (FSI) analysis has gained attention for addressing the sloshing-induced structural response problem (Mote, 1971; Mao and Sun, 1991; Cho and Lee, 2003; Cho et al., 2008). In these researches, the structural behavior as well as correlation between internal LNG flow and external container can be considered in a unified formulation. On the other words, the sloshing-induced flow and hydrodynamic pressure can be obtained during the global analysis. In addition, the structural stress/strain and deformation can be estimated during the local analysis. In the process of the local analysis, the container is considered as a deformable body (not a rigid body) and boundary/initial conditions at an arbitrary time are implemented into the local analysis procedures. For this reason, the computational time and cost can be saved during the global-local analysis process.

Hence, in the present study, the global-local method based hydroelastic analysis which is successfully derived by Cho et al. (2008) has been adopted to evaluate the structural safety as well as hydrodynamic pressure induced by interior LNG flow for the KC-1-type LNG insulation system. During the global analysis, the flow motion characteristics such as the flow velocity, hydrodynamic pressure and volume fraction which are used as an initial and boundary condition for the local analysis are obtained. In addition, during the local analysis, the structural behaviors of the actual sized KC-1-type insulation system such as effective stress/strain and deformation are estimated precisely.