유체-구조 연성 해석을 이용한 LNG 운반선 방열시스템의 내슬로싱 성능 평가

Evaluation of sloshing Resistance Performance of LNG Carrier Insulation System by Fluid-Structure Interaction Analysis

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Abstract

In the present paper, the sloshing resistance performance of an LNG carrier insulation system is evaluated by fluid-structure interaction (FSI) analysis. For this analysis, the arbitrary Lagrangian Eulerian (ALE) method is adopted to accurately calculate the structural behavior induced by internal LNG motion of a KC-1 type LNG carrier cargo tank. In addition, the global-local analysis method is introduced to reduce computational time and cost. The global model is built from shell elements to reduce the sloshing analysis time. The proposed novel analysis techniques can potentially be used to evaluate the structural integrity of LNG carrier insulation systems.

Keywords: Hydroelastic analysis; Fluid-structure interaction (FSI) analysis; KC-I type LNG carrier cargo tank; Sloshing; Arbitrary Lagrangian Eulerian (ALE) method.

1. Introduction

For several decades, the sloshing phenomenon and sloshing-induced structural response have been analyzed under separate mechanical viewpoints when six-degree-of-freedom movements are applied to the vessel tank. In most research on the sloshing problem, the fluid is regarded as a uniform flow, and fluid characteristics under a sloshing motion is not exactly considered(Brebbia et al., 1984; Shepel and Smith, 2006). FSI analysis has gained attention for addressing sloshing-induced structural response problems(Morand and Ohayon, 1995). In addition, when used in conjunction with novel computational methods such as the arbitrary Lagrangian Eulerian (ALE) method. And FSI analysis takes a huge amount of computational time. In order to overcome this problem, the global-local analysis method was introduced(Mao and Sun, 1991; Cho and Lee, 2003).

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2. Sloshing Phenomenon of LNG Carrier Insulation System

2.1 Hydroelastic Problem of LNG Carrier Insulation System

2.1.1 LNG Carrier Insulation System

The membrane-type cargo tank encounters the severe sloshing problem. Therefore, it is essential to guarantee the structural safety of the cargo tank during design and fabrication. Hence, analyzing the structural behavior using classical structural mechanics, finite element analysis, etc., is not an easy task. Therefore, in this study, the structural behavior including the hydroelastic response was analyzed with the unified FSI analysis technique.

2.2 Global - Local Analysis Technique

In global - local analysis, the global analysis is carried out prior to the local analysis. By using approximate mechanical information of the global structures such as the reaction force, the displacement can be obtained. Based on this information, local analysis of the region of interest is then performed. In local analysis, the FE model is fabricated as a real structural/material model, and specific mechanical information of specific regions can finally be acquired.

2.3 Simplified FE Model of Anchor Section

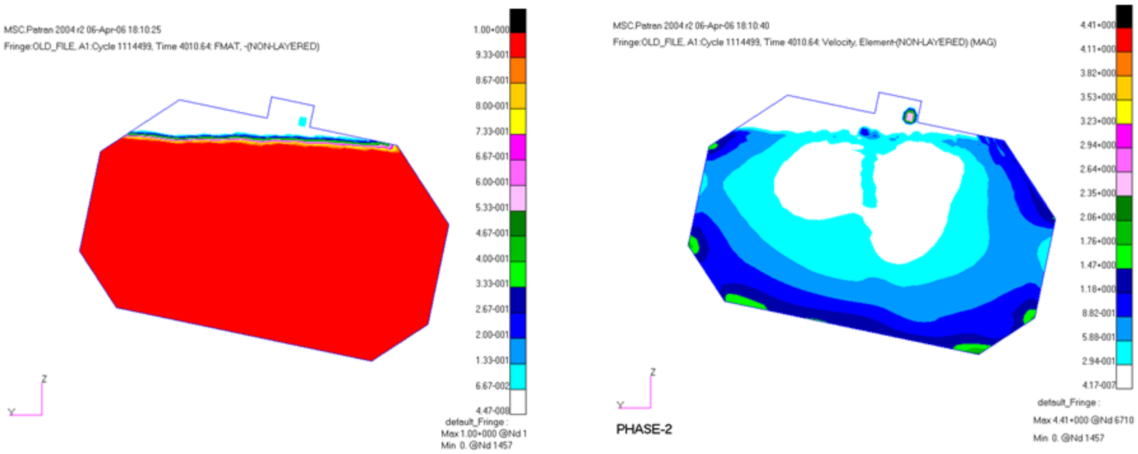
The anchor combines the R-PUF and membrane firmly. The surface of the anchor is made of SUS 304L, and inside is filled with R-PUF. The anchor has extremely complex lamination structures. In order to save the computational time and cost, the simplified FE model of the anchor section was introduced in this study. The two kinds of analysis scenarios were adopted. Case A is the general FE model, which was fabricated by using element refinement. The connection area between the membrane and anchor was established as surface-to-surface contact. In case B, the upper side of the anchor was eliminated for fast calculation.

3. Global - Local Hydroelastic Analysis

3.1 Global Analysis

The dimensions of the FE model were 42.84 m × 37.4 m × 27.2 m (length × breadth × height). The filling level (η_R), density (ρ), and volumetric elastic coefficient (K) of the LNG were 95%, 500 kg/m^3, and 1.44GPa, respectively. The analysis was carried out using MSC.Dytran. The variables of the angular velocity were defined as a = 3.87° amplitude and ω = 2π/5.5 (rad/s) angular frequency(Cho and Lee, 2004).

The computational analysis time was from 0 to 4014 s(Cho and Lee, 2004). The time increment was △t = 3.598E-03 (s), and the corresponding number of iterations was 1,115,508. The maximum pressure occurred when the time was at 35 ms. The maximum angle of the free surface was 22.1°. Fig. 14 shows the LNG volume fraction and flow at 4010 s. The maximum velocity and hydrodynamic pressure were 1.26 m/s and 0.142 MPa, respectively.

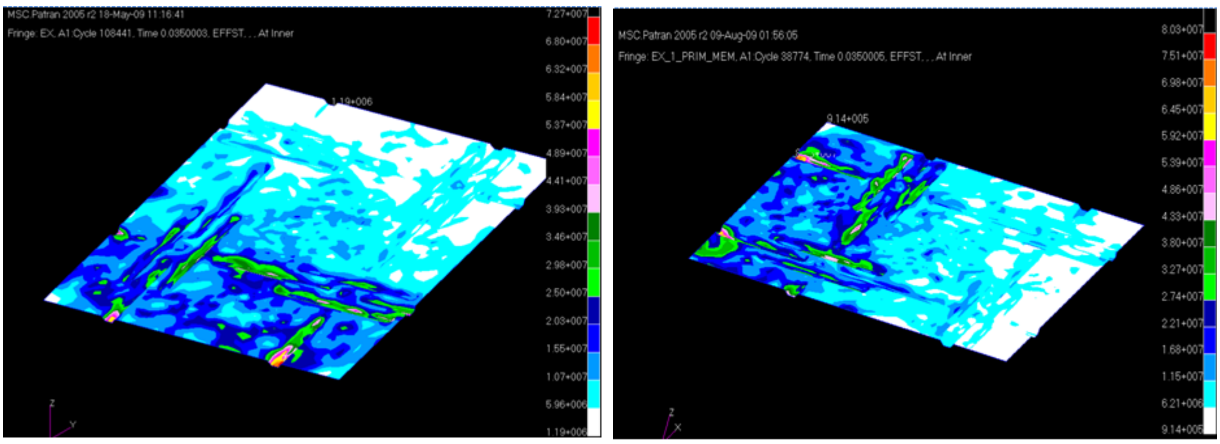


(a) (b)

Fig. 1 Global analysis results at t=4010 s: (a) LNG volume fraction and (b) LNG flow

3.2 Local Analysis

Based on the data of the global analysis results, the local analysis was carried out. Figs. 3 (a) (b) show the local analysis results of the effective stress contour regarding cases A and B. In both cases, the maximum effective stress occurred in the membrane region at 35 ms. The specific value of the maximum effective stress is listed in Table 2. The differences between each case were found to be quite small; therefore, it is reasonable to choose the case B type anchor model during local analysis.



(a) (b)

Fig. 2 Effective Stress contour of KC-1 model (a) case A (b) case B

Table 1 Maximum effective stress at 35 ms (Unit: MPa)

	Case A	Case B
Membrane	72.7	80.30
Plywood	4.60	5.31
Top plywood	2.95	2.73
R-PUF	0.28	0.30
Bottom plywood	3.83	3.95
Mastic	1.71	1.75
Hull	16.1	16.5

4. Concluding Remarks

In this study, the sloshing resistance performance for the KC-1 type LNG carrier insulation system was evaluated by FSI analysis. The research results are listed below.

- FSI analysis was carried out based on the well-known arbitrary Lagrangian Eulerian method, and other novel techniques for FSI analysis were introduced.
- The flow velocity, pressure, and volume fraction of the KC-1 cargo internal LNG can be precisely calculated during the sufficient sloshing time based on the global analysis method. In addition, a shell-type element was adopted for the huge KC-1 cargo, which made it possible to reduce computational time and cost.
- The effective stress of the structural element of the KC-1 cargo can be accurately obtained based on the global analysis results. Moreover, in order to reduce the computational time, a simplified model was introduced.
- Although validation of the analysis results through a comparison of the experiments was not carried out, the proposed global - local analysis technique can potentially be used as a robust integrity assessment technique for LNG carrier insulation systems.

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