Wet Drop Impact Response Analysis of Cargo Containment System in Membrane-type LNG Carrier using FSI Technique of LS-DYNA

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ABSTRACT

While the structural safety assessment of Cargo Containment System (CCS) in membrane type LNG carriers has to be carried out in consideration of sloshing impact pressure, it is very difficult to figure out its dynamic response behaviors due to its very complex structural arrangements/materials and complicated phenomena of sloshing impact loading. In this study, diverse parametric studies for the 2D water entry problem of symmetric wedges were carried out using ALE2D option of LS-DYNA code and validated with wet drop test results, and wet drop impact response analyses of Mark III membrane-type LNG CCS were performed again using Fluid-Structure Interaction (FSI) analysis technique of LS-DYNA code in considering the effects of the corrugation flexibility for the enhancement of shock response analysis technique accuracy.

KEY WORDS: Structural Safety Assessment; Cargo Containment System (CCS); Sloshing; Wet Drop Analysis, ALE2D Option; Fluid-Structure Interaction (FSI); LS-DYNA; MARK III Membrane-type CCS.

INTRODUCTION

As the cargo tank size and configuration of Liquefied Natural Gas carriers (LNGC) and LNG Floating Production Storage Offloading (LNG-FPSO) vessels grows in response to the global increase in demands for LNG and the necessities of its economical transportation, impact loading from sloshing may become one of the most important factors in the structural safety of LNG Cargo Containment Systems (CCS). The most important structural safety criterion for membrane-type LNGC and LNG-FPSO is likely to be the leakage of LNG from damaged CCS under impact loadings from sloshing. Guidance notes on the strength assessment have been suggested under the sloshing impact loads, involving the ultimate strength of MARK III membrane-type CCS component materials (ABS, 2006).

To ensure a reasonable and reliable safety assessment of CCS, its criteria should be established for the large deformation and strength of its components and their shock failure characteristics under impact loadings from sloshing, with consideration of their cryogenic material properties. It is necessary to develop the sloshing analysis techniques to achieve more accurate and correct predictions of impact loading on the CCS, and moreover it is urgent to improve them in the situation of recent incidents of sloshing damages on CCS in LNGC (Hine, 2008).

It is very difficult to figure out its dynamic response behaviors due to its very complex structural arrangements/materials and complicated phenomena of sloshing impact loading. In addition to the sloshing experiment and simulation using tank models, wet drop test and simulation have also been carried out for the development of its original technique and exact understanding of the characteristics of dynamic response behavior of CCS structure under sloshing impact pressure (Chung et al., 2006; Kim et al., 2008). Our laboratory conducted the wet drop simulations of Mark III membrane-type LNG CCS and also validated their simulation responses through a series of wet drop experiments using FSI technique of LS-DYNA code (LSTC, 2007) for the enhancement of shock response analysis technique accuracy and for more exact understanding of the characteristics of its dynamic response behavior under sloshing impact pressure (Lee et al., 2008a and 2008b).

Fluid-structure interaction problems, such as sloshing and slamming etc., could be conveniently simulated by moving mesh algorithm and overlap capability of grid to structure mesh using the multi-material Arbitrary Lagrangian Eulerian (MMALE) formulation and the Euler–Lagrange coupling algorithm of LS-DYNA code. Volume of Fluid (VOF) method is adopted for solving a broad range of nonlinear free surface problems and coupling algorithm is more suitable for the FSI problems with very complicated deformable structure, where fluid grid can overlap the structural mesh. 2D version of ALE option, ALE2D (LSTC 2009), was developed, which enables to investigate diverse parametric studies due to much computational time save, where, shell and beam elements are used instead of solid and shell ones, respectively.

Wet drop tests for water entry of two-dimensional symmetric wedge sections and a ship stern section were performed to estimate impact loads for use in the stern slamming assessment of modern containerships (Yang et al., 2007), and numerical simulations were also performed for the investigation of the validity of a commercial CFD code FLUENT (FLUENT, 2006; Yum et al., 2008; Lee et al., 2009). These two-dimensional water entry experimental results of symmetric wedges could be suitable for the validation of FSI analysis technique of LS-DYNA code and for the diverse parametric studies for the wet drop simulation of CCS.

The corrugation damages of MARK III membrane-type have been reported under the severe sloshing loading conditions, and its damages, such as buckling and bending, were also happened by the jet flow and impact pressure in the wet drop tests (Kim et al., 2008; Noh et al.,...