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Sloshing Assessment of FLNG Cargo Containment System Due to Sloshing Loads in Bimodal Seas: Effect of Wave Intensity

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Sloshing is liquid movement in a container excited by motion. The sloshing flow becomes more violent and results in an intense liquid impact as the excitation period gets closer to the resonance period of the internal liquid. This sloshing impact is the most critical load component in the structural design of a Liquefied Natural Gas (LNG) Cargo Containment System (CCS) of an LNG carrier or Floating Liquefied Natural Gas (FLNG). In this study, the structural assessment of sloshing loads was performed for a two-row Mark III membrane-type CCS of an FLNG. The CCS was designed to be installed in a gas field in northwestern Australia where the wind-sea and swell components were simultaneously measured. Two distinct sea states of special interest were considered for the structural analysis. One included sea states on the contour line corresponding to a 100-year return period in a wave scatter diagram. These sea states are usually used for the prediction of the extreme motions of floaters and are termed extreme sea states. The other included sea states with a high probability of occurrence. These sea states are used for investigating the effect of long-term exposure to sloshing loads on CCS structures. An evaluation of the structural safety of the CCS and hull structures was conducted by the use of a sequence of Computational Fluid Dynamics (CFD)-based scenario screenings, sloshing model tests, and statistical fittings of Utilization Ratios (URs). It was found that all probable sea states had to be fully considered when the screening for the sloshing assessment was performed. Even though the sea states with a high probability of occurrence had smaller significant wave heights than the extreme sea states, they might cause the largest sloshing loads and structural responses.

INTRODUCTION

The new global energy strategy is gradually focusing on natural gas due to economic benefits from conventional petroleum resources. A number of offshore gas reservoirs, which were uninteresting in the past, are now being commercialized, and as a result, new Floating Liquefied Natural Gas (FLNG) development projects related to natural gas production are being executed. In the case of FLNGs, it is not possible to impose restrictions on the filling level of the liquefied natural gas cargo during continuous operation; thus, significantly violent sloshing phenomena can occur. This is in contrast to LNG carriers that operate under restricted filling conditions. Therefore, the sloshing resistance of an FLNG CCS and the adjacent hull structure is one of the most important design parameters for the structural safety of an FLNG.

With respect to the structural design, it is not easy to determine the design sloshing loads absolutely because the LNG sloshing is a highly nonlinear impact phenomenon. Although the model tests can measure the impact pressure, the direct use of the measured pressures in the design is still controversial due to uncertainty regarding the scale effects and cryogenic characteristics. This is why the common practice is to comparatively assess the structural capacities of the CCS of a target vessel and those of a reference vessel, which is proposed by Classification Societies (ABS, 2006; BV, 2011a, 2011b; DNV, 2006).

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KEY WORDS: Sloshing, model test, Floating Liquefied Natural Gas (FLNG), Cargo Containment System (CCS), bimodal seas, wave intensity, contour-line approach, all-sea-states approach, Utilization Ratio (UR), Dynamic Amplification Factor (DAF).

Recently, the rapid development of the fluid-structure interaction technique based on numerical computation has made it possible to simulate easily the structural dynamic response to sloshing impact loads. However, the applicability of this to the design is not mature yet. Therefore, in this study, the one-way fluid-structure interaction approach, which uses measured pressure signals obtained from the model tests directly as loads for the structural analysis, is applied. The following are key parameters for an accurate and practical sloshing assessment using this approach:

- Selection of test cases
- Statistics of measured peak pressures
- Methodology for structural safety assessment

Park et al. (2011) introduced a regular motion-based screening procedure on the basis of critical tank excitation scenarios for the sloshing assessment. A pressure contour map, which is based on a series of two-dimensional (2D) sloshing simulations with 1 degree of freedom (1DOF) regular tank motions, is developed first. Then the isolines of the short-term maximum responses in the sea states of the target years are overlapped on the map. Finally, the probable regular oscillation conditions that are likely to induce high peak pressure can be selected from the map.

Fillon et al. (2011) presented statistical post-processing of sloshing peak pressures obtained from a long-duration sloshing test and found that small changes in the probability level can have a strong influence on the statistical pressure. Thus, 480-hour-long sloshing tests (in the case of partial filling) were performed. As a consequence, the Generalized Pareto Distribution (GPD) was found to be better suited for the extreme pressure distribution of long-duration tests than the frequently used Weibull Distribution.

Kim et al. (2013) presented a study of an FLNG sloshing assessment using a comparative assessment approach. Computational Fluid Dynamics (CFD)-based test scenario screening, model test-based sloshing pressure acquisition, and Finite Element Method (FEM)-based Utilization Ratio (UR) calculations were performed.