Sloshing Assessment of FLNG Cargo Containment System due to Sloshing Loads in Bi-modal Seas
- Effect of Wave Intensity

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ABSTRACT
Sloshing is the liquid movement in the container excited by the motion. The sloshing flow becomes more violent and results in intensive liquid impact when the excitation period gets closer to the resonance period of internal liquid. This sloshing impact is the most critical load component in the structural design of LNG Cargo Containment Systems (CCSs) of LNG carriers or FLNGs.

In this study, the structural assessment was performed against sloshing loads for a two-row Mark I II membrane type CCS of FLNG. She was designed to be installed in Northwestern Australia gas field where the wind sea and swell components are simultaneously measured. Two distinct sea states are considered for structural analysis. One is the sea states on the contour line corresponding to 100-year return period in wave scatter diagram. These sea states are usually used for the prediction of extreme motions of floater and termed extreme sea states. Another is the sea states that have high probability of occurrence. The latter is considered to investigate the effect of the long term exposure on sloshing loads. Evaluation of the structural safety of CCS and hull structure was conducted in sequence of CFD-based scenario screening, sloshing model tests and statistical fittings of Utilization Ratios (URs).

In conclusion, it was found that all of probable sea states had to be fully considered at screening for the sloshing assessment. Even though the sea states with high probability of occurrence have smaller significant wave heights than extreme sea states, those sea states might cause the largest sloshing load.

KEY WORDS: Sloshing; Model test; FLNG; Cargo Containment System (CCS), Bi-modal seas, Wave intensity, Contour line approach, All sea states approach, Utilization Ratio (UR), Dynamic Amplification Factor (DAF).

INTRODUCTION
New energy strategy gradually focuses on natural gases due to economic benefits from conventional petroleum resources. A number of uninterested offshore gas reservoirs in the past are being commercialized recently and the FLNG development projects related to the natural gas production are actively executed. In case of FLNGs, because it is not possible to impose the restriction of the filling level on liquid natural gas cargo for continuous operation rather than LNG carriers which operate with restricted filling condition, more significantly violent sloshing phenomena can occur. Therefore, the sloshing resistance of FLNG CCS and adjacent hull structure is the one of most important design parameters for the structural safety of the FLNG.

For the structural design, it is not easy to determine the design sloshing loads absolutely, because the LNG sloshing is highly nonlinear impact phenomena. Although the model tests can measure the impact pressure, the direct use of the measured pressures as design purpose is still controversial due to uncertainty on scale effect and cryogenic characteristics. That is why the comparative assessment performing the comparison of structural capacities of the CCS of target vessel with ones of the reference vessel proposed by Classification Societies (ABS, 2006, BV, 2011a-2011b and DnV, 2006) is widely used as the common practice.

Recently rapid development of fluid-structure interaction technique based on numerical computation makes it possible to simulate the structural dynamic response against sloshing impact loads easily. However, the applicability in design is not mature yet. Therefore, in this paper, the one-way fluid-structure interaction approach which uses the measured pressure signals obtained from the model tests directly as loads for structural analysis is applied. The followings are key parameters for the accurate and practical sloshing assessment in 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 of critical tank excitation scenarios for sloshing assessment. A pressure contour map based on a series of 2 D sloshing simulations with 1 DOF regular tank motions is developed firstly, and then the isoline of the short-term maximum responses in the sea states of target