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LNG Tank Sloshing Assessment Methodology—The New Generation

J. F. Kuo, R. B. Campbell, Z. Ding, S. M. Hoie, A. J. Rinehart, R. E. Sandström and T. W. Yung
ExxonMobil Upstream Research Company, Houston, Texas, USA

M. N. Greer
ExxonMobil Development Company, Houston, Texas, USA

M. A. Danaczko
ExxonMobil Production Company, Houston, Texas, USA

This paper presents ExxonMobil's evolution of a direct sloshing assessment methodology to resolve several challenging technical issues that are essential for evaluating the integrity of LNG containment systems. Among the most significant developments is the introduction of a probabilistic-based framework that facilitates modeling of the high variability of sloshing impact pressures due to sloshing physics and insulation materials that is inherent in products from natural sources (e.g. plywood, etc.). This probabilistic-based framework also provides the basis for a reliability-based assessment of structural integrity. In addition, this methodology furthered the technical basis of the Scaling Law that supports the use of the sloshing test as the method for prediction of design sloshing loads; addressed tank sloshing and ship motion coupling effects in deriving inputs to drive the sloshing test rig; demonstrated the influence of membrane surface structures on sloshing pressures; and developed limit state structural capacities as a function of a loaded area. The authors are hopeful that this methodology enhances the foundation for achieving continuous safe operation of LNG carriers and enables sound design of offshore LNG loading and receiving terminals.

INTRODUCTION

Over the past 4 decades, the LNG industry has experienced 2 step-changes that produced significant cost savings in delivering LNG. As shown in Fig. 1, the first step-change occurred in the 1970s when scientists and engineers succeeded in increasing capacity of LNG carriers from ~75,000 m^3 to ~130,000 m^3. Jean et al. (1998) reported that sloshing of LNG inside the LNG carrier's insulated tanks was one of the key technical challenges for the step-change. Directionally, with the same number of tanks on an LNG ship, the larger the ship size, the larger the sloshing pressures impacting its tank insulation structures. Thus, maintaining the integrity of the insulated LNG tanks subjected to increased sloshing loads was the primary focus that challenged engineers to realize the step-change. Jean et al. (1998) also reported that, although performance of those LNG carriers has been excellent, some ships' insulation tanks incurred a few damages due to LNG sloshing impacts under both high-fill and partial-fill conditions.

In the late 1970s, the Ship Structure Committee (SSC) of the U.S. National Academy of Sciences initiated an effort by working with a team of experts from the Southwest Research Institute (Cox, Bowles and Bass, 1980) to perform a comprehensive review of worldwide scale-model sloshing loads, and use it to explain what happened to those damaged carriers. Their goal was to use those experiences to improve future LNG carrier designs.

As a part of that effort, the SSC also sponsored additional sloshing tests in order to provide a complete picture of sloshing loads for assessing the integrity of LNG tanks. Along with the developed pressure database presented as a function of the amplitude and frequency of tank excitation, and relative fill range to tank height, etc., the SSC report (SSC-297, 1980) outlined a methodology and detailed analysis flow-chart for ease of applications. Among the contributors to the SSC efforts were the American Bureau of Shipping (ABS), Bureau Veritas (BV) and Det Norske Veritas (DNV). As documented in the SSC-297 report, when applying its proposed assessment methodology, the team of experts succeeded in proving its explanations of those LNG experiences where sloshing impact loads exceeded insulation tank structural capacities. Table 1 is a highlight of the key technical elements from the then state-of-the-art sloshing assessment methodology.

Development of sloshing methodologies in the industry since 1980 has evolved primarily around a deterministic-based framework. One area of improvement is that engineers have been able to conduct sloshing tests of much longer duration (beyond 1,000 cycles) as a result of advancement in computing capabilities

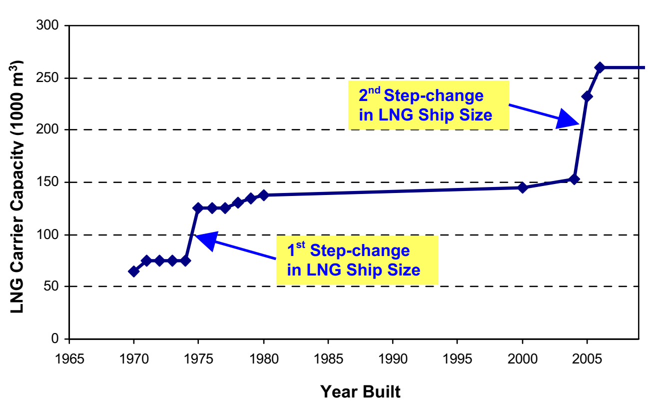

Fig. 1 Recent step-changes in LNG-delivery industry

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KEY WORDS: LNG containment system, LNG tank sloshing, sloshing test, impact dynamics, extreme value statistics, reliability-based structural assessment, offshore LNG terminals.