Experimental investigation of the influence of short-crested seas and swell on sloshing-induced impact loads

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ABSTRACT

The assessment of structural strength of membrane tanks onboard ships to transport liquefied natural gas is generally based on sloshing-induced impact loads. These loads are usually determined via model tests for the ship sailing in short-crested wind seas having a cos\(^2\) spreading. The influence of swell is usually neglected. In the present study, we experimentally investigated sloshing loads resulting from ship motions in long- and short-crested pure wind seas and combinations of wind seas and swell. Impact loads and counts were correlated with wave spreading functions, tank filling levels, and tank natural sloshing frequencies. Results emphasized that short-crested seas increased the impact loads for highly filled tanks. Additionally, swell had a significant influence on sloshing-induced impact loads.

KEY WORDS: Slamming; experiments; design loads; short-crested seas; swell.

INTRODUCTION

Over the past decades, the rising consumption of natural gas required new transport technologies. Consequently, the transport of liquefied natural gas (LNG) in membrane tanks became prominent. Thus, transporting liquefied gas in membrane tanks will likely be of major interest in the future. However, the accelerating shift to renewable energies could decrease the usage of natural gas as it might be replaced by green hydrogen. For transport and storage, hydrogen can be bound as ammonia, which can be liquefied at -33 °C. In principle, membrane tanks can also be used to contain ammonia.

The design of membrane tanks is usually based on determining the expected sloshing loads acting on tank walls. These loads depend on the LNG carrier’s motions under critical sea conditions and are usually obtained by performing experimental model tests using a model tank. Here, critical sea conditions consider severe sea conditions which also have a high probability of occurrence during operation. The accurate determination of design loads depends on initial assumptions of seaways encountered by the ship. According to the International Maritime Organization (2014) and Det Norske Veritas (2022), sloshing tests must cover all relevant tank filling levels. This is challenging because all tank fillings during offshore loading and unloading scenarios must be accounted for. Additionally, relevant encounter angles between the ship and the predominant wave direction as well as all relevant wave heights must be studied (Det Norske Veritas, 2021). Waves should be considered short-crested when estimating ultimate limit states for standard filling ranges (< 5% ; > 95%), but they can be assumed long- or short-crested for other tank fillings. However, so far no recommendations for sea conditions have been specified when considering fatigue limit states. Additionally, there are no specifications if swell must be considered when testing sloshing-induced impact loads. Thus, model tests often consider only wind sea.

Analogously, short-crested seas having a cos\(^2\) spreading are predominantly used in literature to evaluate sloshing-induced impact loads. Ryu et al. (2016) calculated motions of a Floating Production Storage and Offloading (FPSO) vessel with a two-row tank arrangement using Inverse Fast Fourier Transformation (IFFT). They assumed the seaway to be long-crested and fitted its spectrum to sea conditions of the Northwest Australian Sea. The group performed model tests for one of the FPSO’s LNG tanks to obtain sloshing loads. Park et al. (2011) numerically predicted sloshing loads based on long-crested seas focusing on the evaluation of the structural integrity of a membrane tank. Paik et al. (1998) used a Volume-of-Fluid (VoF) method to simulate full-scale sloshing resulting from long or short-crested seas. However, they did not elaborate a comparison of the impact loads resulting from excitation by long- and short-crested seas.

Many publications on sloshing impact loads do not address in particular whether long- or short-crested seas are considered. However, publications not mentioning the directional wave spreading most likely consider short-crested seas and a cos\(^2\) spreading. For example: Park et al. (2021) numerically investigated sloshing impact loads on a prismatic tank and applied cyclic peak stresses to analyse fatigue. Kim et al. (2013), studying a floating natural gas liquefaction plant with a two-row containment system, experimentally determined sloshing loads for a finite element analysis to assess the structural strength of the cargo containment system. Sandström et al. (2007) and Kuo et al. (2009) addressed the experimental determination of sloshing-induced loads on membrane tanks to assess their strength integrity and safety aspects. Park et al. (2014) developed a membrane tank for unrestricted filling levels and performed experiments with filling levels prone to sloshing. Wang et al. (2009) experimentally studied the impact pressures of a tank of a 138K LNG carrier and applied a finite element method to analyse the strength of the cargo containment system.

Due to the short history of membrane tanks and corresponding sloshing