Effects of internal cylinders on natural sloshing frequencies of a 3D rectangular tank

Chongwei Zhang, Peng Su, Dezhi Ning
State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology.
Dalian, Liaoning Province, P. R. China

ABSTRACT

A semi-passive sloshing mitigation technique that takes advantage of movable structures in the tank is considered. Hydrodynamic characteristics of the 3-D rectangular tank with a cylindrical floating structure are investigated. A numerical model is established based on boundary element method (BEM) to predict natural sloshing frequencies and corresponding modes for these liquid tanks. The influence of the geometry parameters, including the position, draught and radius of the floating cylinder on the natural sloshing frequency of the liquid is analyzed. It is also found that the anti-sloshing floating structure works better for a shallower water tank.

KEY WORDS: boundary element method; liquid sloshing; natural frequency; anti-sloshing; resonance.

INTRODUCTION

The natural gas with environmental advantages over other fossil fuels has become increasingly significant in meeting the world’s energy needs. However, a great proportion of the present natural gas reserves is located below the offshore seabed. The floating liquefied natural gas (FLNG) facility is an attractive technology proposed for the offshore gas exploitation. Compared with conventional natural gas facilities, the FLNG facility has advantages on initial cost and construction time. Many existing designs have taken the FLNG facility as a giant floating vessel moored above an offshore natural gas field. During the operation, the natural gas is chilled onboard into the liquefied natural gas (LNG) and stored in several huge tanks below the deck. Then, the produced LNG is offloaded to LNG carriers and transported to the land. Unless docking for inspection, the FLNG is continuously moored at the location for around 20-25 years, so that it can experience any complex sea state with any fill in tanks during the period of service. The vessel motion induced by external ocean waves could easily cause the violent liquid sloshing in partly filled tanks and threaten the safety of the platform structure. Thus, designing effective sloshing mitigation or anti-sloshing techniques are of great significance for structural safety of LNG tanks.

At present, many existing anti-sloshing techniques are mainly designed for conventional liquid cargo tanks. These techniques can be divided into the active and passive types. The active anti-sloshing technique relies on external power control and sensors for real-time feedback of the liquid state. Bubble injections (e.g., Hara and Shibata, 1986) or dynamic baffles (Hernandez and Santamarina, 2012) may be used to achieve real-time adjustment of hydrodynamic characteristics in the tank and to weaken the effects of sloshing. However, the complex machinery system of active techniques normally indicates high maintenance costs, which should also be considered in practical applications. Especially for the flammable and explosive LNG cargo, using electric power in an LNG tank put the platform in a great danger.

Passive anti-sloshing techniques do not require an extra electricity supply. The energy dissipation of the liquid sloshing is achieved with the help of fixed structures inside the tank. At present, a number of theoretical, experimental and numerical studies on the passive anti-sloshing technique can be found. For example, Wang et al. (2013) analyzed the anti-sloshing effects of annular baffles in a cylindrical tank; Xue et al. (2017) carried out the experimental study on hydrodynamic characteristics of different anti-sloshing baffles in the square tank; Jung et al. (2012) studied effects of the vertical anti-sloshing bulkhead installed on the tank bottom; Wei et al. (2015) considered the vertical screen structure on the bottom of the tank; Yu et al. (2017) carried out an experimental study on the anti-sloshing method with double vertical baffles on the free surface; Zhang (2015) proposed a tank design based on wedged geometry, aiming to avoid the simultaneous occurrence of sloshing resonances in all tanks of an LNG carrier. The above anti-sloshing techniques based on internal baffles have been widely adopted by oil or chemical tankers. However, for the LNG tank whose internal surface is covered by a smooth invar membrane, installing dense baffles is likely to damage mechanical properties of the membrane and potentially cause a leakage of the tank.

Some researchers have proposed a semi-passive anti-sloshing technique...