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Investigation of Two-layer Liquid Sloshing by Using the Consistent Particle Method

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The two-layer sloshing of water and diesel oil is studied numerically by using the consistent particle method (CPM). CPM is a projection-based particle method with the distinct feature of having consistency and high-order accuracy in computing spatial derivatives. A validation against published experimental data is conducted. Then, the two-layer sloshing under sway-only and coupled sway-heave excitations is studied. For the coupled excitation cases, it is found that the sum/difference of sway and heave frequencies being close to the odd multiple of the system's natural frequency induces secondary violent sloshing even when both excitations are further away from the natural frequency.

INTRODUCTION

With the global shortage of resources, the demand for liquefied natural gas (LNG) keeps growing, and by 2035, the gas is projected to supply the largest share of energy demand growth and over 40% of growing demand (Shell Global, 2020). Compared with traditional LNG systems, the floating liquefied natural gas (FLNG) facility integrates the functions of production, storage, processing, and transportation, saving in gross cost. Therefore, FLNG is getting more market share in the LNG industry. The integrated capability of FLNG in production and storage also implies that the filling level in an FLNG tank can vary from very shallow to very high. Previous studies on sloshing have suggested that the wave impact pressures and loads induced by middle-filling sloshing can be very violent (Luo et al., 2020), which may cause localized damage to the tank structure (Wang, 2010) or global instability to the ship (Luo, Koh, and Bai, 2016). For the safe design of FLNG vessels, therefore, the sloshing features in FLNG tanks—especially the resonant scenarios in middle-filling levels—need to be thoroughly investigated.

Many studies investigated the sloshing induced by one-degree-of-freedom excitations such as horizontal (Chen and Wan, 2019; Liu et al., 2021; Shimizu et al., 2018; Xue et al., 2020; Zheng et al., 2014), vertical (Calderon-Sanchez et al., 2021; Jin et al., 2021), or rotational (Bulian et al., 2014; English et al., 2021) excitation, as well as by coupled excitations. Among the three categories, although works on vertical excitation are relatively fewer, some interesting studies have been reported. For example, Faraday (1831) found that resonance occurs when the frequency of the vertical excitation is twice the sloshing system's natural frequency, and such a resonant scenario was termed the Faraday wave. Benjamin and Ursell (1954) derived the equation for the Faraday wave based on the potential flow theory and analyzed parametric sloshing theoretically. Bredmose et al. (2003) studied sloshing excited by horizontal and vertical motions experimentally. A flat-topped wave crest with almost vertical sides was observed and reproduced via numerical simulation. More recently, Ning et al. (2012) identified the triggering conditions of the first- and second-mode resonance induced by vertical excitation through numerical simulations. Serván-Camas et al. (2016) conducted seakeeping analyses by considering the internal sloshing induced by the sway and heave excitations through a coupled smoothed particle hydrodynamics–finite element method (SPH-FEM) model. Jin et al. (2021) investigated mode 1 to mode 5 Faraday waves under vertical excitations and found that these modes could be triggered by two times the nth natural frequency of the sloshing system. A research project funded by the European Union, Sloshing Wing Dynamics (SLOWD) has focused on liquid sloshing under large-amplitude vertical accelerations; one of the recent outcomes of this project is the study by Calderon-Sanchez et al. (2021), who investigated the energy dissipation and interaction force between the fluid and tank resulting from vertical sloshing based on SPH simulation.

In FLNG tanks, the sloshing phenomenon of multilayer liquids exists in, for instance, the "wash tank," which is designed for preprocessing mixed oil and seawater before separating them. An immiscible emulsion fluid is added into the wash tank to increase production and processing efficiency. This leads to the multilayer

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KEY WORDS: Consistent particle method, two-layer sloshing, coupled excitation, resonance, projection-based particle method.