ABSTRACT

In the process of long-distance ocean transportation, the wave and the tank sloshing have a great influence on the ship motion. The sloshing of the liquid in the tank will produce a large moment to the hull, which may cause the ship to overturn; and the strong impact force of the sloshing on the bulkhead may also cause damage to the hull structure. In this paper, sloshing coupled ship motions are solved numerically in a time domain approach, such as numerical method based on Reynolds-averaged Navier–Stokes (RANS) equation. Through comparison with the experimental data of S175 ship model loaded with tank at zero speed, present numerical methods are validated. Under the head sea conditions with forward speed, the movement effects of ship with or without tank are compared and analyzed. Furthermore, the influence of tank sloshing under different working conditions and the wave contour around ship are systematically studied.

KEY WORDS: wave; tank sloshing; ship motion; RANSE; zero speed; with forward speed

NOMENCLATURE

- L: Ship length (m)
- B: Ship breadth (m)
- T: Ship draught (m)
- D: Ship depth (m)
- XG: Center of gravity position in X direction (m)
- YG: Center of gravity position in Y direction (m)
- ZG: Center of gravity position in Z direction (m)
- l: Tank length (m)
- b: Tank breadth (m)
- d: Tank depth (m)
- h: Liquid level (m)
- ω: Wave natural frequency (Hz)
- λ: Wavelength (m)
- T_e: Wave encounter cycle (s)
- ζ_3: Heave (m)
- ζ_5: Pitch (rad)
- ζ_a: Amplitude (m)
- k: Wave number (m⁻¹)
- g: Gravitational acceleration (m/s²)

INTRODUCTION

With the development technology of liquefied natural gas (LNG) ships and liquefied petroleum gas (LPG) ships, the impact of tank sloshing on ship movements has received increasing attention. During the navigation of such liquid-laden ships in the ocean, multi-degree-of-freedom motions will occur under the action of wind and waves, and the liquid contained in ship tanks will also cause sloshing due to the corresponding movement of the hull. With such sloshing phenomenon, when the frequency of the external incoming wave and the natural frequency of the tank are relatively close, the fluid attack effect caused by its severe resonance phenomenon acts on the bulkhead, which not only has a great possibility of causing serious damage to the bulkhead structure but also increase the amplitude of the motion of the hull. Serious conditions may cause the ship to capsize, which will have a more serious impact on the ship's navigation environment and safety factors.

At present, many scholars have conducted some analysis and research on the coupling effects of tank sloshing and ship motion (Kim, Y, Nam, BW, Kim, DW and Kim, YS., 2007). Based on comprehensive references, the main research methods for the coupling effects of tank sloshing and ship motion are: 1. Theoretical research; 2. Model tests based on real ships; 3. Computational fluid dynamics (CFD) methods. In particular, the recent studies can be categorized into two approaches: 1. Use the frequency-domain method where sloshing flow behavior is under the linear assumption (Kim, Y, Shin, YS and Lee, KH., 2004); 2. Use the time-domain method, which can handle a certain level of nonlinear sloshing flow behavior (Lee, CH and Newman, JN., 2005).

We take the S175 container ship as the object, and uses commercial software STAR-CCM + for numerical simulation based on the experimental data of Shanghai Jiao Tong University (Li, YL., 2014; Li, YL, Zhu, RC, Miao, GP and Fan, J., 2016; Li, YL, Su, M, Li, H, Deng, R, Wang, KP and Hu, Z., 2019). The calculation results are compared with the experimental results to verify the accuracy of the numerical method. In addition, in the case for ship with forward speed, the numerical results of ship with or without tank are compared, and the effect of tank sloshing on ship motion is observed.