Resonant Waves in the Gap Between Two Ships by Fully-Nonlinear Simulation

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HIGHLIGHT
The objective is to accurately predict nonlinear waves in the gap between FLNG and LNG carrier during side-by-side offloading. We aim to determine the relative importance of free-surface nonlinearity verse viscosity effects on gap wave heights and hydrodynamic loads and motions of ships near the resonant frequencies of the gap. Fully-nonlinear simulations based on a quadratic boundary element method are used to investigate this problem. The comparison between numerical simulations and laboratory experiments shows that the linear solution significantly over-predicts the wave height in the gap near the resonant frequency while the fully-nonlinear solution (without viscous effects) matches well the experimental measurement. It is found that it is free-surface nonlinearity rather than viscous effect that controls the resonant wave motion in the gap between FLNG/LNG carriers during side-by-side operations.

1 INTRODUCTION
Understanding and prediction of the hydrodynamics of resonant wave motions in the gap between two neighboring objects is of fundamental interest and practical importance in offshore industry and marine operations. Most of the theoretical and computational studies have been conducted in the context of linearized potential flow theory with a focus on the prediction of the resonance frequencies and the associated free-surface wave profiles (e.g. Faltinsen, 1978; Molin et al, 2002; Chen and Yang, 2001). Comparisons with experimental data have shown that the wave height and ship motion amplitude in the vicinity of resonance frequencies are generally largely over-predicted by the linear potential-flow theory. One hypothesis to improve the prediction is to account for the viscous damping effect in the linear potential-flow models (e.g. Newman, 2004; Chen, 2005). Benchmark experimental data is needed to determine the artificial damping coefficient. This approach would be invalid and ineffective if other physical factors such as free-surface nonlinearity also significantly influence the wave motion near the resonance frequencies.

Free-surface nonlinearity has been known to play a significant role in the resonant wave motion in two-dimensional moonpools (e.g. Vinjie, 1991; Kristiansen and Faltinsen, 2010; Wang et al, 2011). Recent studies have been extended to the general three-dimensional problems but focusing on special situations such as nonlinear wave radiation (Ma et al 2013) and nonlinear wave diffraction in beam sea (Feng and Bai 2015). In the present study, we investigate the general three-dimensional resonant wave motion problem by fully-nonlinear numerical simulations with a focus on the quantification of free-surface nonlinear effects on resonant wave motions in the gap between two stationary or freely-floating ships under general incident wave conditions.

2 APPROACH
A fully-nonlinear time-domain numerical simulation of fluid-body interaction is applied to predict the diffracted and radiated wave fields as well as ship motions in response to the action of incident waves. The numerical

simulation is based on the potential flow formulation with the use of a quadratic boundary element method (QBEM) and accounts for fully-nonlinear interactions among surface waves and multiple ships. A mixed Euler-Lagrangian (MEL) approach is used to track the instantaneous positions of the free surface and bodies. The validity and effectiveness of this fully-nonlinear simulation capability has been well established for a variety of steep/overturning wave dynamics and nonlinear wave-body interaction problems (e.g. Liu et al, 2001; Yan and Liu, 2011). To understand the effects of free-surface nonlinearity on the resonant gap wave motion and body response, both linear and fully-nonlinear simulations are performed and compared. To access the importance of free-surface nonlinearity effect verse viscous effect, linear and fully-nonlinear numerical simulations without the inclusion of viscous effects are compared with the laboratory experiments of Pauw (2006).

3 RESULTS

The configuration of two ships in the experimental setup of Pauw (2006) is shown in Fig. 1a. The two ships are identical. The length, beam and draught of the ships are 270 m, 44 m and 11 m, respectively. The deck depth of the ship is 25 m. The water depth is 37.5. The details of ship hull form are given in Pauw (2006). In the numerical simulations, the same ship hull geometry and configurations of the ships are used. A sample QBEM elements used in simulations are displayed in Fig. 1b. In the simulations, various incident wave conditions (with different incident angles, wave frequencies, and wave steepness) and different gap widths are considered. Fig. 2 compares the time histories of the total wave elevation at the center of the gap near the resonance frequency obtained from the linear and fully-nonlinear computations of the diffraction problem in head sea. It is seen that the nonlinear solution approaches the steady state much faster than the linear solution.

In Fig. 3, the wave amplitude RAO at the center of the gap between two ships (with gap width=32 m) obtained by simulations is compared with experimental data of Pauw (2006) in the neighborhood of the resonance frequency. The result is for the diffraction problem under the head sea condition. It is seen that the fully nonlinear solution matches the laboratory experiments well while the linear solution largely over-predicts the resonant wave heights. Since viscous effects are not considered in the simulation, the comparison indicates that the free-surface nonlinearity plays a dominant role in suppressing wave resonance in the gap between two ships. The results with different gap widths and incident angles and freely-floating ships are also obtained and will be presented in the workshop.

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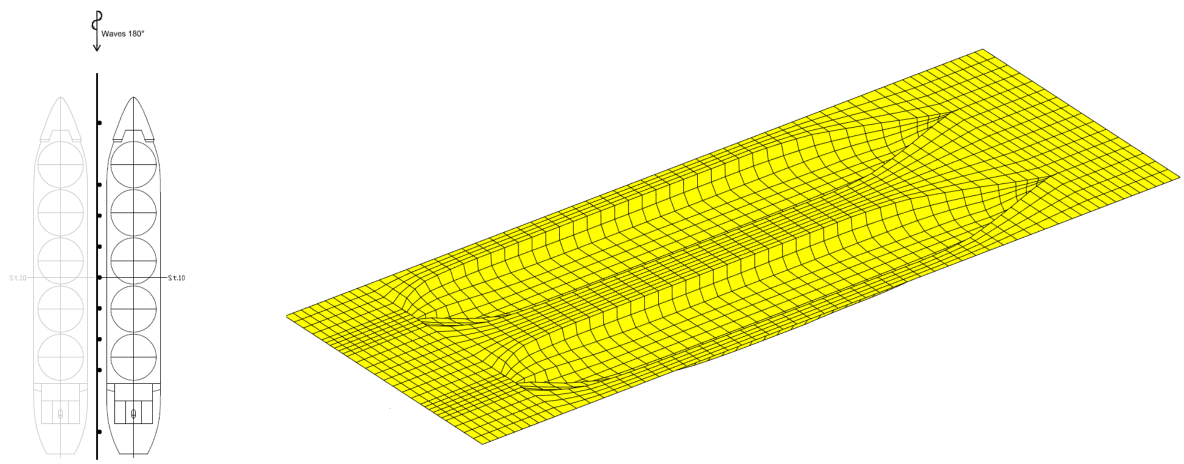

(a) (b)

Fig. 1. (a) Configuration of two ships in the experimental setup, and (b) sample QBEM computational grids.

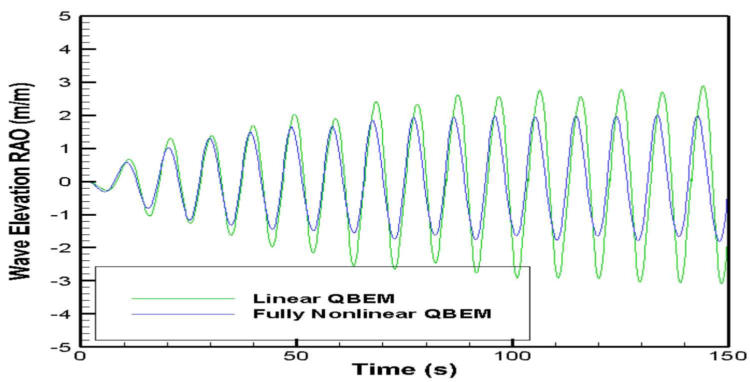

Fig. 2. Time history of the total wave elevation at the center of the gap between two ships obtained from linear and fully-nonlinear simulations. (Gap width = 32m, incident wave steepness kA=0.05, head sea, diffraction problem).

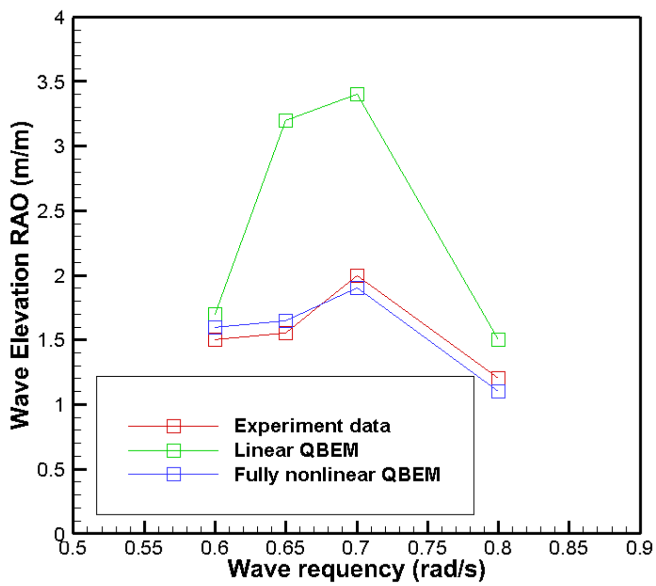

Fig. 3. Comparison of total wave elevation RAO (at the center of the gap) in the neighborhood of the resonance frequency among the linear and fully-nonlinear simulations as well as experimental data. Fully-nonlinear solution compares excellently with the experimental data. (Gap width =32m, kA=0.05, head sea, diffraction problem).