

Hydrodynamic study on ship-to-ship bunkering in waves and shear currents focusing on gap resonances

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Ship-to-ship (STS) bunkering plays a critical role in offshore energy logistics, particularly for floating production, storage, and offloading (FPSO) systems operating in open seas (Zhao et al, 2018). Compared with conventional port-based fueling, side-by-side (SBS) bunkering offers greater operational flexibility but introduces complex hydrodynamic interactions due to the close proximity of vessels. Among these, gap resonance—oscillations of the fluid trapped between adjacent vessels—is a key concern. Under resonant conditions, large free-surface elevations can develop within the gap, leading to increased hydrodynamic loads, violent vessel motions, and potential damage to fuel transfer systems. Understanding the mechanisms governing gap resonance is therefore essential.

While previous studies have examined gap resonance under wave-only (Saitoh et al, 2006) or uniform-current conditions (Ding, 2024), realistic marine environments often involve shear currents, where velocity varies with depth. Such currents can significantly alter wave–structure interactions, yet their influence on three-dimensional gap resonance remains insufficiently understood. This study addresses this gap by numerically investigating the hydrodynamic behaviour of two side-by-side barges subjected to combined wave and linear shear-current conditions in beam seas where resonance effects are most pronounced.

A fully nonlinear three-dimensional numerical wave tank is developed using a CFD framework based on the unsteady Reynolds-averaged Navier–Stokes equations. Turbulence is modelled using the SST $k-\omega$ model, and the air–water interface is captured via the Volume of Fluid method. Incident waves and currents are generated using a stream function approach, extended to incorporate linear shear profiles (Madsen, 2017). The computational domain includes two fixed barges separated by a narrow gap, with refined mesh near the free surface, barge boundaries, and gap region to accurately resolve wave amplification and flow features. Mesh independence is verified to ensure solution accuracy.

Five representative shear-current profiles are considered, including positive, negative, and reversed velocity gradients. Results are compared with wave-only and uniform-current cases. The simulations show that the fundamental standing-wave pattern associated with gap resonance persists under shear-current conditions. However, shear currents significantly modify the resonant response. In general, the maximum wave amplitude within the gap is reduced compared to uniform-current cases, indicating a suppressing effect of velocity

gradients. Nevertheless, localized wave amplification can occur during specific phases of oscillation, demonstrating a strong phase-dependent influence.

The current velocity near the gap entrance is identified as a key parameter controlling wave amplification. Higher entrance velocities tend to enhance resonance, although overall amplitudes remain lower than in corresponding uniform-current scenarios. This suggests that shear-induced mixing and energy dissipation play a role in attenuating resonance. The existence of shear current directly affects both the magnitude and phase of wave-induced loads acting on the barges. Notably, the force difference between the two vessels remains larger than the total system force due to phase differences but is generally reduced in the presence of currents. This indicates that wave–current interactions may alleviate mooring loads compared with wave-only conditions.

In summary, this study provides a comprehensive numerical investigation of gap resonance under combined wave and shear-current conditions. The results demonstrate that while the fundamental resonance mechanism is preserved, shear currents significantly influence wave amplification and hydrodynamic loads. These findings improve the understanding of wave–current–structure interactions in confined marine environments and offer valuable insights for the design and safe operation of SBS offshore bunkering systems.

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