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Wash wave effects on ships moored in ports

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ABSTRACT

A ship moored in a port is subjected to both the sea waves and the wash waves produced by nearby passing ships. A hybrid numerical model is proposed to estimate the transient response of a moored ship exposed to the two types of waves. The hybrid method is based on the combination of 3-D Rankine source method and impulse response theory. The 3-D Rankine source method is applied to address the wash waves and the wave-structure interactions. The transient response is subsequently simulated in time-domain with the impulse response theory. The transient effect produced by the wash wave impact loads is found to be dependent on the sea waves induced response. The transient effect becomes less significant when the sea waves induced response is strong and vice versa. Besides, the propagation distance of wash waves has a limited influence on the transient response due to the dissipation feature of the divergent wash waves. The transient response in stochastic sea waves is also investigated, which is dominated by the resonant frequency, the sea wave frequency and the wash wave varying frequency.

1. Introduction

A ship moored in a port is subjected to complicated external loads, which may induce strong motions of the moored ship. When the motions become very large, marine operations must be terminated and the downtime will be consequently increased. For the safety of operation, the motions of a moored ship in a port should be investigated carefully.

Kwak et al. [1] proposed a computational method to estimate the motions of a moored ship taking into consideration of the harbour resonance. The simulation results with and without harbour resonance were compared. Sakakibara and Kubo [2] investigated the low-frequency motions of a moored ship inside ports induced by the harbour resonance. Rosa-Santos et al. [3] examined how the type of fender influenced the mooring tension of a moored ship at an exposed port terminal. Xiong et al. [4] studied the shallow water effect on the motions of a moored barge with both numerical and experimental methods. The second order difference frequency force was incorporated to capture the long-period motions of the barge realistically. A critical depth for shallow water effect was clarified. In a port or coastal region, the sea waves will propagate from deep water to shallow water and the port geometry also has an influence on the wave propagation. A very popular method for wave propagation is the combination of a phase resolving wave model and a boundary element method. Bingham [5] came up with a new computational technique to predict the wave-induced motion of a moored ship. Modified Boussinesq theory was used to assess the transformation of the waves when they propagate from deep water zone to the port. The corrected waves were subsequently used to obtain the hydrodynamic interactions. Van der Molen and Wenneker [6] developed a combination of the Boussinesq-type wave model and the time-domain panel model to predict the motions of a moored ship in open sea. The calculation procedures were very like those applied in [5]. However, the effect of port boundaries (which cause wave reflection) was not considered in their works. Jiang et al. [7] combined the Boussinesq's equations and the slender-body theory to investigate the wake produced by a ship. The Boussinesq's equations were used for the far-field flow and the slender-body theory was applied for the near-field flow. They showed that the wash wave pattern depends a lot on the ship speed and bottom topography.

Apart from the incident sea waves, a passing ship also causes the moored ship to move. Vantorre et al. [8] carried out model tests to investigate the hydrodyanmic interaction between a moored ship and a passing ship during overtaking operation. A model test program was launched by Mousaviraad et al. [9] to investigate the effect of configurations, speed and heading angle on ship-to-ship interactions in calm water and waves. Both works proved that the moored ship is subject to considerable hydrodynamic loads due to the passing effect induced by the other ship. Alongside with model test method, analytical and empirical approaches have been developed as well, most of which are based on the slender-body theory. Brix [10] proposed an empirical formula to estimate the maximum values of the longitudinal and the transverse forces acting on a moored ship induced by another passing ship,which is not applicable to very high speed problem. Wang [11]

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Fig. 1. The wash waves produced by an advancing ship. (Google Map. https://www.google.co.uk/maps/@1.2841423,103.7517161,382m/data=!3m1!1e3?hl=zh-CN).

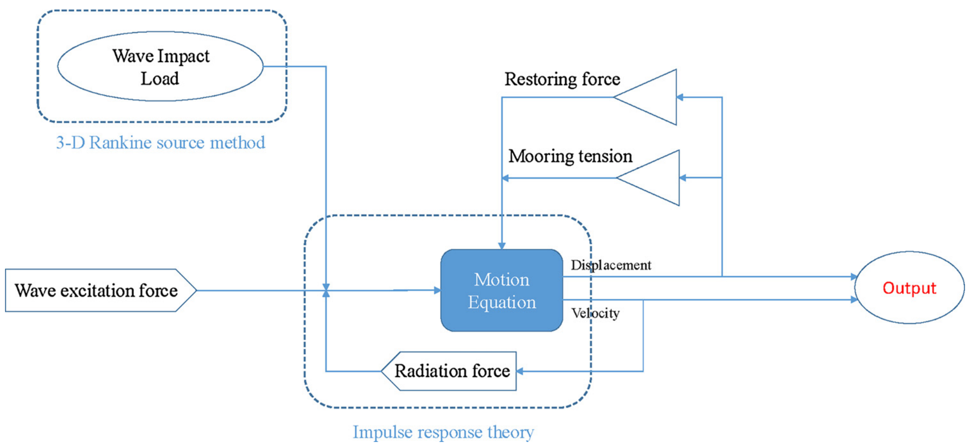

Fig. 2. Sketch of the hybrid numerical model.

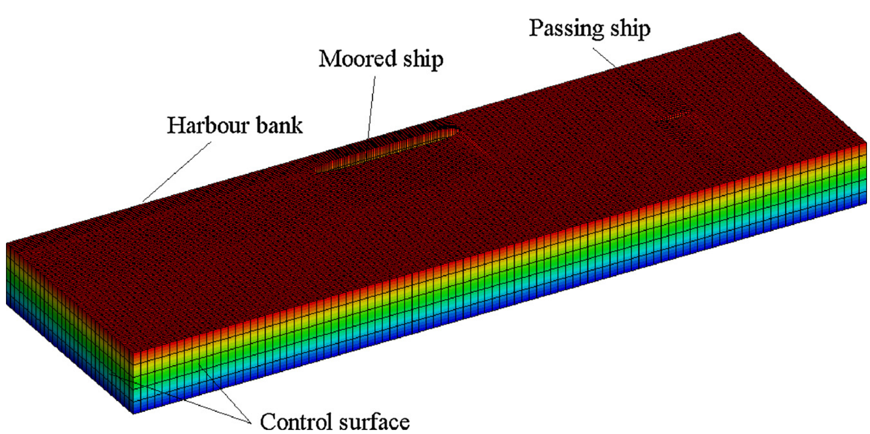

Fig. 3. Boundary of fluid domain.

developed an analytical solution to the unsteady interaction of two slender floating bodies with a propagation angle of yaw. Nevertheless, the free surface disturbance was not considered in his model. Apart from the model test and the analytical approaches, the numerical simulation method is also adopted by researchers in the study of ship-to-ship interaction. Pinkster [12] studied the wash effects of passing ships in ports. The reflection of long waves due to the interaction of wash wave and geometry of the port was considered. Yuan et al. [13] proposed a de-coupled numerical model to assess the ship-to-ship interaction during overtaking operation in shallow water. A modified Sommerfeld radiation condition taking into account the Doppler shift effect was proposed and thereby their model is applicable to very low speed problem where the scattered wave could propagate in front of the advancing ship. Xu and Zou [14] used a high-order panel method to predict hydrodynamic force on a moored ship induced by a passing ship in shallow water. Calculations were conducted with different water depths and lateral distances between the two ships. An advantage of their method is that the numerical damping caused by the configuration of meshes is limited so that only a few meshes were distributed on the water surface.

Until now, the majority of the studies on the response of a moored ship induced by a passing ship are based on the assumption that the two