International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 30, No. 3, September 2020, pp. 308–317; https://doi.org/10.17736/ijope.2020.hc18

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A Flux Source Method for Ship Wave Generation in a Boussinesq-type Wave Model

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A moving flux source is modified to predict ship waves by using NOWT-PARI (NOnlinear Wave Transformation model by the Port and Airport Research Institute), taking into account the expandability of setting ship navigation channels and applicability for representative ship shape in a harbor. The fluxes on a slender-ship sailing are generated with two functions approximating ship shape: a modified parabolic function and an interpolation of Lewis form. Through several sets of numerical simulations reproducing ship waves measured in model experiments, a tuning parameter related to the ratio of ship width and length to computational mesh size is introduced in order to secure independence of the calculation accuracy of ship waves from a spatial resolution.

INTRODUCTION

In harbor tranquility analysis, the distribution of wave heights inside a harbor is usually estimated with a numerical wave transformation model that considers wave diffraction around breakwaters and wave reflection on seawalls. Recently, a number of different nonlinear wave transformation models (e.g., Boussinesq-type) have been used to simulate the wave field in shallow water. Although Peregrine (1967) derived Boussinesq-type equations for varying bathymetry, early Boussinesq-type equations (e.g., Abbott et al., 1978) were applied to the calculation of short waves by considering only linear dispersion over a uniform bottom in relatively shallow water. Subsequently, the linear dispersion characteristics in intermediate water depth were improved with the dispersion enhancement coefficient $B = 1/21$ by Madsen et al. (1991). Madsen and Sørensen (1992) then modified the dispersion terms, with $B = 1/15$ applied for varying bathymetry. Nwogu (1993) also derived Boussinesq-type equations with respect to the representative water depth z_α where the horizontal velocity was defined. Although $z_\alpha = -0.531h$ (h is the settled water depth) was originally recommended, it was confirmed that the linear dispersion characteristics approximated by Nwogu's equations corresponded to those of Madsen and Sørensen's equations when $z_\alpha = -0.553h$ (Hirayama, 2007).

On the basis of Nwogu's equations and their derivatives, some numerical codes, such as FUNWAVE (Wei and Kirby, 1995) and COULWAVE (Lynett and Liu, 2002), were developed. Similarly, the NOnlinear Wave Transformation model by the Port and Airport Research Institute (NOWT-PARI) was proposed by Hirayama (2002) on the basis of Madsen and Sørensen's equations. These numerical codes have been expanded so as to deal with bottom friction and wave breaking, as well as wave runup and rundown, by referring to some representative papers on the modeling of wave transformation to Boussinesq-type equations (e.g., Madsen et al., 1997a, 1997b; Kennedy et al., 2000). Therefore, NOWT-PARI, which can reproduce wave transformations in a harbor and a coastal area in random seas as well as other numerical codes, has already been widely used to estimate harbor tranquility.

In recent times, the tranquility in busy ports and harbors has been affected not only by storm waves propagated from outside but also by harbor waves that are generated because of ship navigation. Although ship-induced waves are not usually counted in the wave height exceedance probability inside the harbor, because they are rarely significant for mooring vessels, they may affect the maintenance of dikes, revetments, and seawalls along rivers, waterways, and the coast. For this reason, Nascimento et al. (2009) modified FUNWAVE by incorporating a moving pressure source to simulate the effect of a moving ship hull. After the description of a pressure term was improved by Bayraktar Ersan and Beji (2013), David et al. (2017) conducted numerical experiments with their Boussinesq model, BOSZ, to investigate how pressure distribution and ship speed affect the characteristics of wave parameters such as amplitude and period, as well as wake patterns. Tanimoto et al. (2000) and Dam et al. (2006, 2008) implemented a moving flux source using the slender-ship approximation (Chen and Sharma, 1995) in a Boussinesq model governed by Madsen and Sørensen's equations. And they reproduced the propagation of soliton waves (primary waves generated at the ship's front) and secondary waves following behind the ship observed in model experiments (Kurata and Oda, 1985), while a model ship sailed at various velocities and in shallow depth channels.

In the case of simulating ship-induced waves by recreating moving flux sources, the sailing direction should be set along a grid axis of computational boxes, although the layout of navigation channels in actual ports and harbors would be arbitrary. And the ship shape should be approximated to line symmetry between the bow and the stern, although a ship would generally have a different bow shape to stern shape. Therefore, in this study, the moving flux source that is transplanted to NOWT-PARI is modified by considering the expandability of setting ship navigation channels and the applicability for representative ship shapes in a harbor. To implement this, the center line of the hull, from the bow to the stern, is drawn by an arrangement of computational

Received February 12, 2019; updated and further revised manuscript received by the editors September 1, 2019. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-eighth International Ocean and Polar Engineering Conference (ISOPE-2018), Sapporo, Japan, June 10–15, 2018.

KEY WORDS: Ship-induced wave, slender-ship, moving flux, Lewis form, NOWT-PARI, Boussinesq-type model, harbor tranquility.