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Hamiltonian Boussinesq Simulation of Wave-Body Interaction Above Sloping Bottom

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This paper describes a numerical implementation of a Hamiltonian Boussinesq wave-body interaction for irrotational flow as formulated in van Groesen and Andonowati (2017), with a restriction of one horizontal coordinate and a cross section of the body. Part of the HAWASSI (Hamiltonian Wave-Ship-Structure Interaction) software we developed allows for numerical discretisation of the surface waves using spectral methods. Non-smooth effects from the body-fluid interaction are included in the design of a virtual wave in the body area, which is determined by the boundary conditions on the body hull. Except for a comparison with standard cases in the literature, the performance of the code is shown by comparison with measurements of an experiment on the slow-drift motion of a rectangular barge moored above a sloping beach and interacting with irregular waves, in the barge beam direction, including the infra-gravity waves from the runup on the shore.

INTRODUCTION

This paper describes a numerical implementation of the Hamiltonian Boussinesq wave-body interaction for irrotational flow. In this paper, we are restricted to one horizontal coordinate and a cross section of the body.

When restricted to potential flows, the fluid dynamics can be described only with surface variables: the surface elevation and the potential at the surface. To obtain the explicit expressions, many so-called Boussinesq approximations have been developed. A subclass of approximations based on the Hamiltonian formulation has been described by Zakharov (1968) and Broer (1974). Taking an analytic or numerical approximation of the cumbersome kinetic energy in the Hamiltonian leads directly to the approximate equations for numerical codes (i.e., West et al., 1987) and higher-order spectral methods (Ducrozet et al., 2007, 2012).

The fully coupled interaction of a wave and a floating or fixed structure is often modeled using either a mesh or mesh-free-based computational fluid dynamics (CFD) solver that takes a very long computation time (i.e., Gotoh et al., 2021; Khayyer et al., 2021). For practical use, the CFD solver often uses incident waves from a potential wave kinematic solver for wave generation to make the CFD domain smaller and then shorten computation time; see Bouscasse et al. (2020).

In recent years, we developed software called HAWASSI (Hamiltonian Wave-Ship-Structure Interaction) (LabMath-Indonesia, 2021) that is based on the Hamiltonian formulation for wave dynamics up to the fourth order, and it uses spectral methods for the discretisation. Typical problems with the spectral implementations—in particular, those that deal with varying bottoms and sharply varying structures such as walls—were overcome, and bottom friction and wave breaking were included.

The pseudo-spectral implementation shows very good dispersion above one and two horizontal dimensions with varying bottoms and runups on coasts; the computations are relatively fast (Kurnia and van Groesen, 2014, 2017; van Groesen et al., 2017). Many simulation cases showed good performance when compared with the results of the experiments in laboratory wave tanks (Kurnia et al., 2015, 2018).

In this paper we describe the extension to include the body motions in this HAWASSI software. Just like potential flows, the motion of a rigid body has also a Hamiltonian structure. The challenge is to describe the correct coupled fluid-body interaction as a combined dynamical system, keeping the description of the fluid dynamics restricted to the free surface. This requires the translation of the interaction of the interior flow with the body as an effect at the surface.

The formulation is presented in the next section in detail. In successive sections, we show some standard cases in the literature. In the last section, we compare our simulations with measurements taken from experiments on the slow-drift motion of a rectangular barge moored above a sloping beach in irregular beam waves, as described in Liu et al. (2011).

HAMILTONIAN WAVE-BODY INTERACTION

The equations for the wave-body interactions are of the form of a coupled, causal Hamiltonian system. The Hamiltonian is the sum of the kinetic and potential energy of the fluid and of the body as a rigid body.

The wave dynamics uses the canonical variables: the surface elevation and the surface fluid potential at the free surface. The presence of a rigid body disconnects the free surface; in that interval between the body water line points, at each instant, a virtual

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KEY WORDS: Wave-body interaction, Hamiltonian formulation, diffraction-radiation, focused waves, ringing, coastal wave runup, slow-drift motion.