

Boussinesq Cut-cell Model for Wave Scattering from Cylinder in Shallow Water

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This paper presents a Cartesian cut-cell Boussinesq model for simulating nonlinear wave interaction with a curved structure. The Cartesian cut-cell technique permits accurate boundary-fitting of complicated, curved geometries in the numerical domain. A Godunov-type shock capturing scheme is used to solve the Boussinesq-type equations in hyperbolic form in order to provide accurate predictions of strongly nonlinear wave interactions with curved structures in shallow water. The numerical model is used to simulate the interaction of a focused wave with a circular cylinder, and excellent agreement is obtained with data from laboratory experiments conducted in a wave basin.

INTRODUCTION

Numerical models based on the Boussinesq-type equations are becoming widely used to simulate wave transformation in shallow coastal regions and run-up at beaches. Such models can play a key role in design and re-assessment in coastal engineering. Boussinesq (1872) was the first to derive depth-integrated mathematical descriptions of shallow flows that included the influence of vertical accelerations and hydrodynamic pressure. During the past 20 years, considerable efforts have been made to improve the representation of nonlinearity and dispersion by Boussinesq-type formulations (see e.g. Madsen and Sørensen, 1992; Nwogu, 1993; Schäffer and Madsen, 1995; Agnon et al., 1999; Madsen et al., 2002).

Many coastal structures, such as offshore wind-turbine foundations and piers, are composed of vertical surface-piercing circular cylinders. In order to estimate the local wave hydrodynamics and loading on such structures, there is a need to develop Boussinesq-type solvers that can model wave interaction with curved structures. The aim of the present work is to develop a simple, accurate and flexible method for modelling the hydrodynamics of coastal flows in the vicinity of surface-piercing structures of arbitrary plan-form geometry.

The Cartesian cut-cell technique was implemented for body fitting for compressible flow by Yang et al. (1997) and for shallow water flow by Causon et al. (2000) using piece-wise linear segments. Our recent paper on nonlinear shallow water simulation (Liang et al., 2007) updated the method by using ghost-cells to overcome the small time step restriction caused by the presence of very small cut cells that would otherwise have to be merged.

That paper discussed a method for solving the nonlinear shallow water equations on an adaptive cut-cell quadtree grid. For the problem of steady potential flow past a circular cylinder, the Cartesian cut-cell model gave accurate results in close agreement with the analytical solution. The corresponding model, based on a uniform Cartesian grid with a staircase approximation for the curved boundary of the cylinder, produced a spurious rotational wake downstream with the predicted velocity at the shoulder of the cylinder reduced to zero.

This paper presents a Boussinesq-type model based on Cartesian cut-cells for modelling wave interactions with curved coastal structures. The wave flow-field is described by an enhanced set of nonlinear Boussinesq-type equations (Madsen and Sørensen, 1992), which are solved numerically using a Godunov-type finite volume method on Cartesian cut-cell grids. An HLLC approximate Riemann solver is used to evaluate the interface fluxes. Second-order accuracy in time and space is achieved by implementing the MUSCL-Hancock predictor-correction method. The main advantage of this approach is that not only is the proposed scheme conservative, but also no special algorithm is required to simulate discontinuous, or close to discontinuous, flows. The Cartesian cut-cell technique is implemented for accurate boundary-fitting of complex geometries in the numerical domain.

In this paper, physical experiments and numerical simulations are described for focused waves interacting with a vertical bottom-mounted circular cylinder, a typical configuration for an offshore wind-turbine foundation.

Once validated, the numerical model should be useful for providing information on wave loading and other hydrodynamic effects on offshore wind-turbine foundations for design engineers and other researchers. Full details of the model are given in the extended paper in the ISOPE Conference Proceedings (Zang et al., 2007)

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