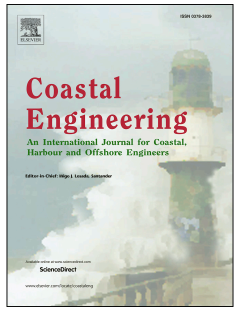
Accepted Manuscript



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PII: S0378-3839(18)30069-3

DOI: 10.1016/j.coastaleng.2018.08.014

Reference: CENG 3417

To appear in: *Coastal Engineering*

Received Date: 20 February 2018

Revised Date: 31 July 2018

Accepted Date: 21 August 2018

Please cite this article as: Judge, F.M., Orszaghova, J., Taylor, P.H., Borthwick, A.G.L., A 2DH hybrid Boussinesq-NSWE solver for near-shore hydrodynamics, *Coastal Engineering* (2018), doi: 10.1016/j.coastaleng.2018.08.014.

A 2DH hybrid Boussinesq-NSWE solver for near-shore hydrodynamics

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Abstract

This paper presents a numerical model that simulates the nearshore circulation and the propagation of waves in two horizontal dimensions (2DH) across the coastal zone, from intermediate depth to zero depth. Pre-breaking, wave propagation is calculated using a Boussinesq equation set with enhanced dispersion characteristics, discretised using second-order central differences and solved using the conjugate gradient method with fourth order Runge-Kutta time integration. In the breaker zone, the Boussinesq dispersive terms are gradually switched off, and the resulting non-linear shallow water equations solved using a finite volume MUSCL-Hancock scheme with an HLLC approximate Riemann solver. Broken waves are treated as hydraulic bores. A wetting and drying algorithm models the moving wet/dry front at the shore. Waves are generated by a line of independently moving piston paddles which are represented through a linear mapping, stretching and compressing the grid in the region of the paddles. Model verification tests include wave sloshing in a frictionless basin, seiching in a parabolic basin with bed friction, solitary wave propagation over a horizontal bed, and the interaction of a solitary wave with a conical island. After calibration, the model simulates the generation of wave-induced currents by regular waves as they interact with sinusoidal and tricuspate beaches, and the propagation of a uni-directional focused wave group over a plane beach. Results are compared against previously published laboratory data. The validation tests confirm that the 2DH model reproduces several important coastal hydrodynamic phenomena including wave-induced currents and multi-component wave packets. The model can thus be used to replicate wave basin experiments, and could be extended to multi-directional waves, leading to a better understanding of hydrodynamic processes in shallow coastal waters.

Keywords: Boussinesq; shallow water; finite differences; finite volume; nearshore circulation; focused wave group.

1 Introduction

The Boussinesq equations (originally formulated by Boussinesq in 1872 [1]) represent an inviscid depth-averaged approximation of the Navier-Stokes equations. Over the past 50 years, Boussinesq-type models have become increasingly popular, due to their ability to represent adequately the main physical processes at the shore, while remaining relatively computationally efficient, compared to Navier-Stokes CFD solvers.

Early Boussinesq models based on the classical equations derived by Peregrine [2] were limited to modelling very long waves, because of the weakly nonlinear, weakly dispersive nature of the governing equations, i.e. $O(\mu^2) = O(\epsilon) << 1$, where the dispersion parameter μ is the ratio of mean water depth to wavelength and the nonlinearity parameter ϵ is the ratio of the wave amplitude to mean water depth. Madsen and Sørensen [3] improved the dispersive properties of the classical equations by applying a linear operator to the momentum equation that resulted in higher-order dispersive contributions, while retaining only third-order derivatives. This led to an equation set valid for relative water depth up to $\mu = 0.5$. Nwogu [4] also achieved improved dispersion characteristics without increasing the order of the governing equations, by formulating the equations in terms of a chosen

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