International Journal of Offshore and Polar Engineering
Vol. 14, No. 4, December 2004 (ISSN 1053-5381)
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A Simplified Moving Boundary Treatment in the MEC Model

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ABSTRACT

Aimed at providing a simple yet stable method of dealing with a moving boundary problem, a simplified treatment is proposed in the Marine Environmental Committee (MEC) ocean model, which combines 3-dimensional hydrodynamic multi-layers with a shallow water layer. Tidal current around general geometries such as the long shore and the sinking island can be simulated effectively.

INTRODUCTION

In tidal simulations, most researchers make great efforts to deal with complicated geometries in order to get precise results. It is even more difficult when there exist quite a tidal flat (the long shore effect) whose length could be several kilometers in only a few meters' tidal height, and/or very shallow water that exposes its bottom during low tide to form an island that will be submerged during flood tide (the island effect); these are situations where the topologies of meshes will be changed. It requires a numerical model to be precise and stable enough for the simulation of this kind of moving boundary problem.

The above problem usually involves cells being flooded or dried during the calculation, which arises in a wide range of free-surface hydraulics problems, such as tidal floods, dam breaks and overland flow of precipitation. Techniques to handle these problems include deformable computational meshes, modified equations in very shallow regions (e.g. Meselhe and Holly, 1993) and shock capturing schemes (e.g. Tchamen and Kawahita, 1994). Akanabi and Katopodes (1987) gave a brief summary of the problems encountered in the numerical simulation of flood waves propagating on a dry bed. Khan (2000) developed a finite element model for the flow over a frictionless horizontal surface, and reported the smooth and rough surface of the horizontal and sloping laboratory channel and numerical oscillations at the front of the surge. Beffa and Connel (2001) reported numerical oscillations when cells switch from dry to wet and vice versa. George and Stripling (1995) represented the local bathymetry in each cell by a sloping facet rather that by a flat bed so as to eliminate the numerical shocks in the 2-dimensional tidal flow in their finite volume model. This showed a need for work on the model development for large-scale and complex natural rivers and flood-plain flow simulations. Vemulakonda and Scheffner et al. (1997) used a 2-D finite-element, long-wave hydrodynamic model, ADCIRC-2DDI (Westerink et al., 1992), to study coastal surges. The wet/dry algorithm operates on a fixed grid with wet and dry nodes inside it, and additional restrictions were applied in order to minimize numerical noise. Brufau (2001) used a special treatment for dealing with wetting-drying fronts over inclined beds so as to avoid numerical error, since the upwind treatment of the bottom variations is not enough to assure mass conservation.

As for numerical ocean models, Grades (1993) showed a generalized form called the s-coordinate system from which other coordinate systems can be derived. For example, the so-called sigma coordinates (Blumberg, 1987, and others) and z-level systems (Bryan, 1969; Cox, 1984; and others) are special cases of the s-coordinate system. The Marine Environmental Committee (MEC) in Japan has developed an ocean model (MEC, 2000 and 2001) which falls into the z-level system. This model is indeed a 3-D multi-layer model that combines the global hydrostatic model with the local, full 3-D one.

The original MEC ocean model does not include the moving boundary treatment. In this paper, a simplified practical method is adopted to treat the problem. First, the regions will be covered by a very thin layer of water, with the artificial layer working as a special bottom boundary during the whole simulation. Then the layer is joined to the uppermost layer of the 3-D hydrostatic MEC model, forming a *shallow water layer*. The deduction of the discretization shows a unified way to combine this layer with the lower layers. The wave elevation is expressed explicitly in the internal domain while the coastline is implicit, which eliminates the need for tracing the position of tidal front, and is quite robust judging from our numerical experiment.

3-D HYDROSTATIC MEC MODEL

First, we'll briefly describe the 3-D hydrostatic part of the MEC model (MEC, 2000, 2001). Given a coordinate system $oxyz$ with its origin o on the mean sea surface, axis x eastward, y northward and z upward, the governing equations under the hydrostatic assumption are:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z} = fv-\frac{1}{\rho}\frac{\partial p}{\partial x}+A_M\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right) \tag{1}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z} = -fu-\frac{1}{\rho}\frac{\partial p}{\partial y}+A_M\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right) \tag{2}$$

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Received October 22, 2003; revised manuscript received by the editors June 8, 2004. The original version (prior to the final revised manuscript) was presented at the 13th International Offshore and Polar Engineering Conference (ISOPE-2003), Honolulu, Hawaii, USA, May 25–30, 2003.
KEY WORDS: Moving boundary, ocean environment, tidal current, wetting and drying process.