Tidal Simulation in Loch Linnhe Using a Finite Volume Shallow Flow Model

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ABSTRACT

Tidal flow hydrodynamics near coastlines can be very complex due to the presence of complicated bottom topographies and irregular boundaries. The model described in this paper has been developed for the prediction of tidal flows on a global scale to inform further detailed modeling on a local scale using 3-D methods. This work presents the numerical simulation of tidal flow in Loch Linnhe on the west coast of Scotland. The numerical model adopted solves the two-dimensional shallow water equations using a finite volume Godunov-type scheme directly applied to the complex, but idealized, flow hydrodynamics involved in the different regimes treated. The results are in good agreement with field measurements, which indicates that the model is able to represent the complex tidal conditions in this area convincingly.

KEY WORDS: 2D shallow water equations; finite volume Method Godunov-type scheme; tidal flow modeling; Loch Linnhe.

INTRODUCTION

Researchers and engineers are interested in tidal flow hydrodynamics for many reasons. In recent years, tidal flow hydrodynamics has been studied for the mitigation of any adverse impacts on those people living near coastal areas. In fact, much of the world’s shorelines are subject to severe coastal flooding and serious coastal erosion in the event of storm surges and extreme high tides (e.g. Wolf 2009; Ozer et al. 2000; Ding and Wang 2005). In the context of ongoing climate change, this type of extreme event is becoming more frequent. Another area of application involves the concept of sustainable fisheries, which has also revived the interest in artificial reefs as an alternative solution to marine ecosystem recovery.

In the present instance, the authors are concerned with investigating the flow about artificial reefs that have been installed on the sea bed of Loch Linnhe off the West coast of Scotland. The model described in the following sections concerns the large scale prediction of tidal flows in Loch Linnhe. Further detailed study of the flow about the reefs will be described in a subsequent paper.

LITERATURE REVIEW

Today, an important way of understanding tidal flow hydrodynamics involves the use of computer modeling. There are many models available to evaluate tidal flow based on different numerical methods, such as the Finite Different Method (FDM) (e.g. Garcia and Kahawitha 1986; Fennema and Chaudhry 1989 and 1990), the Finite Element Method (FEM) (e.g. Akanbi and Katopodes 1988), the Discontinuous Galerkin Finite Element Method (DG FEM) as described by Aizinger and Dawson (2002) as well as Yu and Kyozuka (2004), the Finite Volume Method (e.g. Zhao et al. 1994), and the Lattice Boltzmann Method (LBM) (e.g. Chen and Doolen 1998; Zhou 2002; Banda et al. 2009). Specifically, The FVM has the same advantages of simplicity as the FDM and the same flexibility in handling complex domain geometry as for the FEM, and it can be implemented on both structured and unstructured meshes (Aghajanloo et al. 2011).

The FDM has been the most commonly used method so far in tidal flow simulations. The Princeton ocean model (POM) (Casulli and Cheng 1992) used the FDM to solve the primitive three-dimensional flow equations (assuming the hydrostatic pressure distribution in the vertical direction) and has been applied to simulate flooding and drying of tidal mud-flats. Another well-known finite difference tidal flow model has been developed by the Marine Environmental Committee (MEC) in Japan (Yang et al. 2008), which has been widely used by the Japanese Society of Naval Architects and Ocean Engineering to study changes in the water level of the Caspian Sea. Although the finite difference models may predict accurate results for applications where the solution is smooth they are less well adapted for coping with more complex flow hydrodynamics that involve flow discontinuities (Yu and Kyozuka 2004). The FEM based models have also been applied to tidal flow modeling. For example, Walters (1989) compared two finite element models in predicting the North Sea Tides in English Channel. As a finite element based shallow flow model, TELEMAC has been widely applied in coastal simulations (e.g. Jones and Davies 2006; Hervouet 2007). However, similar to the finite difference models, the finite element codes encounter the same obstacles when applied to flow problems. In recent years, the DG FEM has gained popularity in solving the shallow water equations. Although it is less popular, the DG