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Representation of Linear Terrain Features in 2D Free Surface Models using Ghost-Fluid Method

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ABSTRACT

Decision Support Systems (DSS) for evaluating the loss-of-life, socio-economic impact of rural and agricultural damage due to floods caused by the failure of water control infrastructures, such as dams and levees, rely heavily on the use of robust and accurate numerical models that can simulate realistic flood scenarios.

In engineering practice, the use of a Digital Elevation Model (DEM) directly as a regular mesh with grid lines extending along North-South and East-West directions eliminate the need for mesh generation and offer other advantages, especially in the post treatment of data using GIS software. Despite these obvious advantages, the use of a DEM as computational mesh has also drawbacks. Typical cell sizes of DEMs for flood simulations may vary from 10m to 100m, or larger, depending on the availability of the data and the size of the area to be modeled. At this range of resolution various linear terrain features, such as roads, railroads, levees, etc., which may considerably influence the propagation and extent of the flood, cannot be captured adequately due to their small width. Using an irregular triangular mesh is possible but lacks the practical advantages offered by DEM.

The present paper discusses the use of Ghost-Fluid Method (GFM) ([1]) for taking into account the effect of linear terrain features in the 2D cell-centered conservative upwinding finite volume scheme proposed in [2]. The GFM is a special form of a class of techniques called Immersed Boundary (IB) methods, which have long been used for representing irregular computational boundaries on regular grids. A general review of IB methods and GFM can be found in [3]. We have chosen the GFM since its implementation into the existing 2D Finite Volume code is quite straightforward. Moreover, unlike other cut-cell methods, the GFM does not require any particular treatment of small cells to avoid violation of the CFL condition.

In the present implementation, the linear feature is represented by a polygon (immersed boundary) that cuts through the regular cells of DEM as shown in Fig. 1a. A cell can only be cut by a single straight

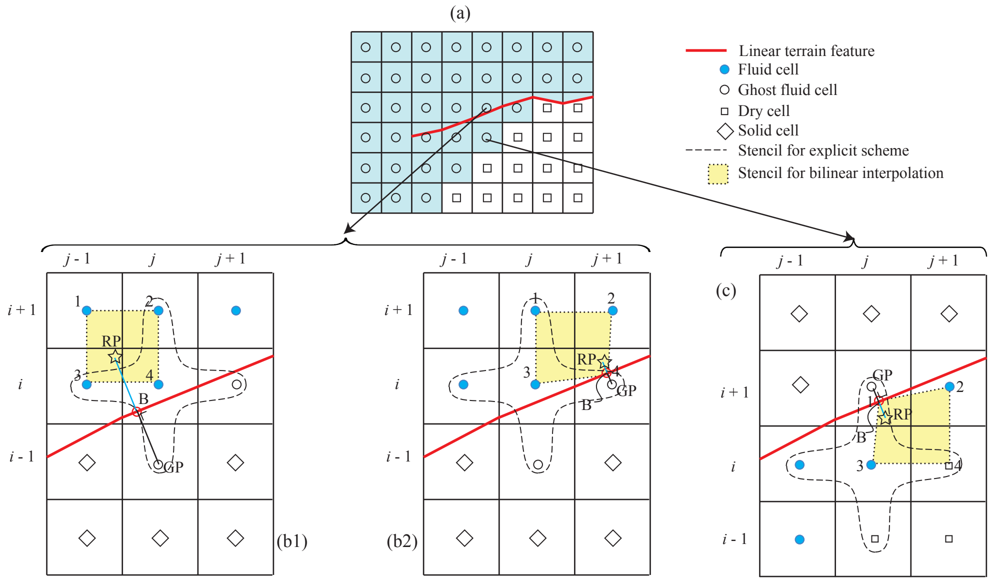

Figure 1: Regular DEM grid with a linear terrain feature and description of ghost fluid method

line. Since water may go around the linear feature, the water is allowed to flow on both sides of the cut cells, which is a unique feature of the present implementation.

On the internal boundary we will impose: $Q_n = 0$, $dQ_t/dn = 0$ and $dh/dn = 0$, where n and t are the normal and tangential directions (to the internal boundary), Q_n and Q_t are the normal and the tangential component of the discharge and h is the water depth.

When calculating a cell, the boundary condition at the immersed boundary is imposed by defining the cell across the immersed boundary as a ghost cell (GP in Fig 1.b1, b2, and c). Using a suitable approximation, the values of the unknowns at the ghost cell are computed in a way to enforce the desired conditions on the boundary. Since the water can be on both sides of the obstacle, the above described procedure has to be carried out on both sides of the barrier creating two layers of ghost cells (one on the right and one on the left of the internal boundary); this implies that a given cell can be both a ghost-cell and a fluid cell depending which side of the internal boundary is being processed. Fig. 1 shows the selection of ghost cells and interpolation stencils for calculating two fluid containing cells located across an immersed internal boundary. Let RP be the "mirror" point of GP with respect to the interior boundary; the value in RP can be calculated by means of a bilinear interpolation using values in points 1,2,3 and 4; finally the value in GP can be extrapolated using the values in RP and the boundary condition (i.e. the value in point B).

The effectiveness of the proposed algorithm has been verified on academic and on real world cases.

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