NUMERICAL MODELING OF VERTICAL-2D UNSTEADY FLOW AND SUSPENDED MATERIAL DISTRIBUTION

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There are two kinds of 2D models for the simulation of flow fields in reservoirs and rivers. The horizontal 2D model is usually used when distributions of velocity, temperature and concentration of suspended material along the water depth are relatively uniform. When flow factors along the water depth change obviously and difference in the horizontal directions is small, the vertical 2D model is usually adopted.

In existing vertical 2D models, assumption of rigid-lid or hydrostatic pressure is introduced to treat the free surface, and the bed boundary is simplified as step-like profile. When surface slope is an important factor to drive the flow, computed result using the rigid-lid assumption will differ from actual condition. Hydrostatic pressure assumption will cause error close to orifice. Simplification of bed boundary as step-like profile will bring error in the same way. So it is needed to develop a vertical-2D numerical model, which can overcome these drawbacks. In this paper, using σ-coordinate transformation and VOF, a new vertical 2D unsteady flow and concentration of suspended material distribution model is developed.

In practical simulation, riverbed is not a plane, and free surface always changes with time under unsteady flow, which adds difficulty to the grid generation for the computation. In this paper, σ-coordinate transformation is used to solve this problem.

Free surface flow is very common in engineering. A number of methods have been proposed to track the free surface in numerical simulation. In hydraulic engineering, rigid-lid method is usually adopted to treat the free surface problem in vertical-2D and 3D numerical model. But for the conditions such as steep bed slope, long river reach simulated and unsteady inflow, rigid-lid method is not suitable. In this paper, VOF (Volume of Fluids) is used to simulate the free surface. And it introduces the equation of a fluid volume function $F(x,y,\sigma)$ in σ-coordinate system. When velocity u^{n+1} in new time step has been obtained, F^{n+1} in new time step can be solved from it. Because the gradient of function F reflects the normal direction of free surface, a line, dividing the cell containing free surface into two parts of which fraction of fluid occupied is equal to F, represents the free surface.

For the surface boundary, kinematical condition is the free surface equation and dynamical condition is zero pressure. Zero gradients of both velocity and suspended material concentration at surface are used. For the riverbed boundary, no-slip condition is for flow velocity, and diffusion flux is taken as zero for suspended material. For the inlet boundary, Dirichlet boundary conditions are applied to the variables (u, w, C). For the outlet boundary, stage-discharge relation is used for the flow, and the normal gradient of suspended material concentration is treated as zero. For the initial condition, velocity, concentration and surface slope are given as zero.

SIMPLE algorithm is used in this model. Computational grid is non-uniform rectangle. Scalar variables are set on the cell center and vector variables on the cell faces. Let δx、$\delta\sigma$ as widths of the control volume along longitudinal and vertical directions respectively, the x- and z-momentum equations can be solved. Then by solving the continuity equation in the σ-coordinate system, pressure correction can be obtained. This paper gives the detailed procedure of computation.

On computation of schematic reservoir, longitudinal gradient of the bed is 1/1000 and width is 200m. All the cross sections are rectangular. Bottom orifice is set on the dam. Inflow discharge and stage-discharge relation at outflow section are given, respectively. From modeling results of water surface profiles at different instants, water storage process in the reservoir is as follows. At the beginning, storage volume in the reservoir and inflow discharge are small, water level is low. As the storage volume increase, backwater region gradually extends and surface slope becomes smaller. It is in agreement with storage process of natural reservoir. And by variation of vertical distributions of velocity at different cross sections in the range from 160m upstream to the dam site, it can be seen that the reasonable flow patterns in the reservoir under various in- and out-flow conditions are simulated. So the proposed model can be used to simulate long term changes of free surface, flow pattern in large water body and flood storage process in reservoir.

Further, a natural river-type reservoir is chosen for simulation. The simulated reach is 6.3km long and divided into 132×60 grids, size of grids is about 20~100m in the flow direction and 0.5~2m in vertical. Suspended material concentration of incoming flow is determined by the empirical relation $C_{in} = 0.135Q^{1.46}$ from measured data. Process simulated is from Sep. 1 to Nov. 30. Comparison between computed result and measured data on Sep. 11 and Sep. 27 shows that the computed suspended material concentration distribution both in longitudinal and vertical directions agree with measured data.

Results obtained in this paper made a solid basis for the further development of vertical-2D and 3D non-uniform sediment numerical models. Researches will be reported in forth coming papers.

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