MULTIPHASE MODELING OF LOCAL SCOUR IN LONG CONTRACTION

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The contraction of a watercourse is typically induced by hydraulic structures, such as bridge piers, abutment and barrages. The channel contraction leads to the increase of flow velocity and free surface deformation due to the reduction of cross-section which may result in local scouring in the contracted zone of the open channel. The increase in depth in an a long contraction can be calculated from the equations of motion and continuithy for sediment and water[1]. In this study, a local scour in a long contraction is numerically invesitygated through multiphase computational fluid dynamics (CFD) modeling with rheological model for non-Newtonain sediment layer.
A Multi-phase flow model for simulation of the interaction of water flow and sediment bottom in the channel contraction was developed, which is based on three-dimensional Navier-Stokes equations incorporated with multiphase transport equations and employed a viscoplastic models for water-saturated sediment flows. The governing equations for the flow are the unsteady, incompressible filtered Navier-Stokes equations. The interfaces of water, air and water-solid mixture fluids are captured by means of the multiphase volume of fluid (VOF) method which is capable of modeling flows in complex free surface geometries. The location of the free-surface and interface of fluids are obtained by the VOF variable. The contribution of three fluid velocities to the evolution of the free surface and interface is proportional to the corresponding phase fraction, and the volume fraction is used to determine the fluid properties.
The governing equations are solved numerically by the finite volume method. Overall fully second-order-accurate setup both in time and in space is used for the simulation. The generalized second-order-accurate backward, implicit, differencing scheme is used to evaluate the time derivatives. Spatial discretization for the convective term is achieved using the central differencing schemes. One of the major difficulties in the VOF method is ensuring the transport of sharp interfaces without artificial numerical diffusion or dispersion. In the VOF model, the boundedness of volume faction is maintained by utilizing a bounded central differencing scheme combined with a solution procedure referred to as multi-dimensional universal limiter for explicit solution. The rheological behavior of the water and sediment mixture is approximated by a modified Herschel-Bulkley model. The delayed detached eddy simulation is used to compute subgrid-scale eddy viscosity of turbulent flow. Sufficiently refined computational mesh and appropriate boundary conditions are essential to accurately reproduce the dynamical interaction of water phase and solid-water mixture phase in the multiphase, turbulent modeling.
A series of laboratory experiments had been carreid out by Dey and Raikar [2] in a 12 m long, 0.6 m wide and 0.7 m deep rectangular flume. In the experiemnt, a 3 m long, 0.3 m deep, rectangular contraction model containing sediment is installed at 6 m downstream of the flume inlet as seen in Fig. 1. A numerical flume, of which the configurations are identical to the experimental ones, is generated to reproduce the experimental measurements. Among a series of experiments with different contraction ratios, sediments and flow conditions [1], a measurement observed for the contration ratio $\tilde{b}\ (= b_2/b_1)$ of 0.4, median diameter of sediment d_{50} of 2.54 mm, approaching bulk mean velocity of 0.568 m/s and the upstream flow depth of 0.1286 m. The Reynolds number and Froude number based on the approaching velocity and flow depth are 71,000 and 0.506, respectively.
Numerical results show that the multiphase CFD model is successfully applied to resolve propagation of sediments wave and local scour in a long contraction of the open channel. Fig. 2 shows snapshots of free surface and bed deformation at three different instants. Numerical solutions well reproduce the experimental measurements in terms of overall shape of free surface and the bed evolution.

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References

[1] A. J. Raudkivi, Loose Boundary Hydraulics, A.A. Balkema, Rotterdam, Netherlands, 1998.

[2] S. Dey and R. V. Raikar, Scour in Long Contractions, Journal of Hydraulic Engineering, Vol. 131, No. 12, pp. 1036-1049, 2005.

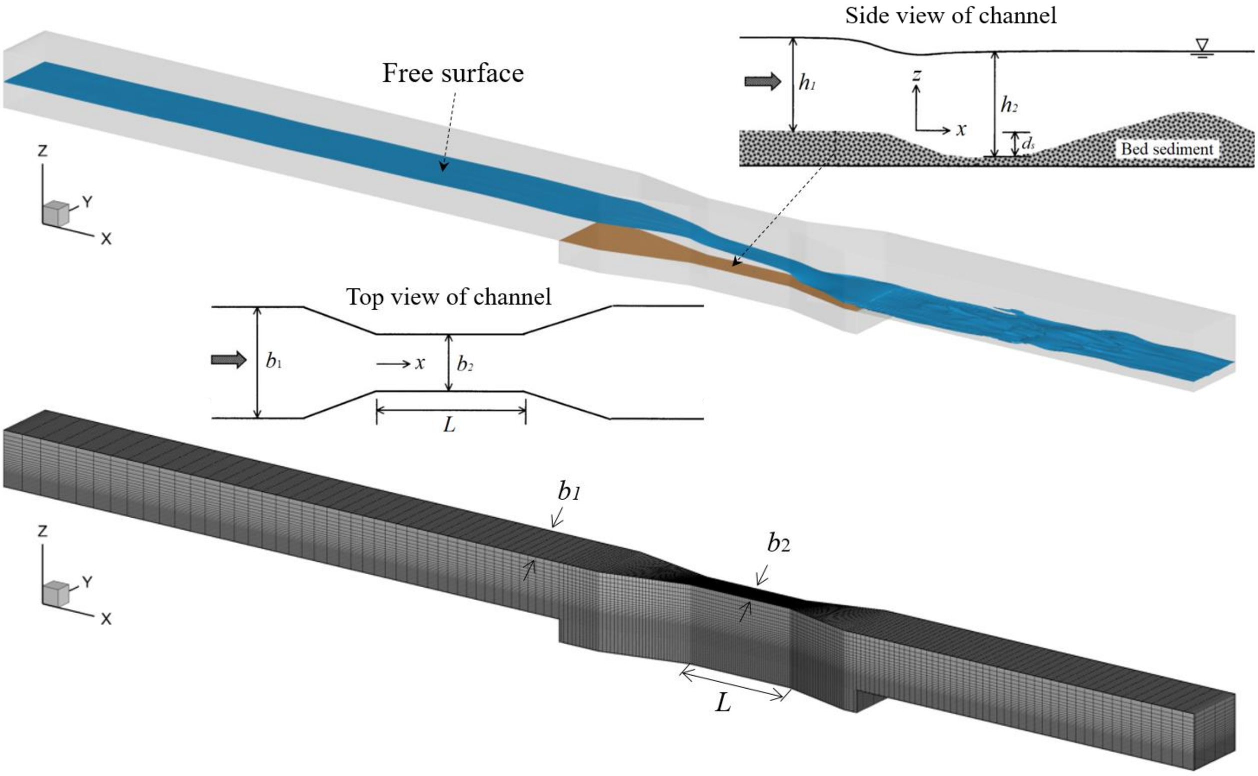

Figure 1: Schematic of a long rectangular channel contraction experimentally investigated by (Dey and Raikar, 2005) and computational mesh

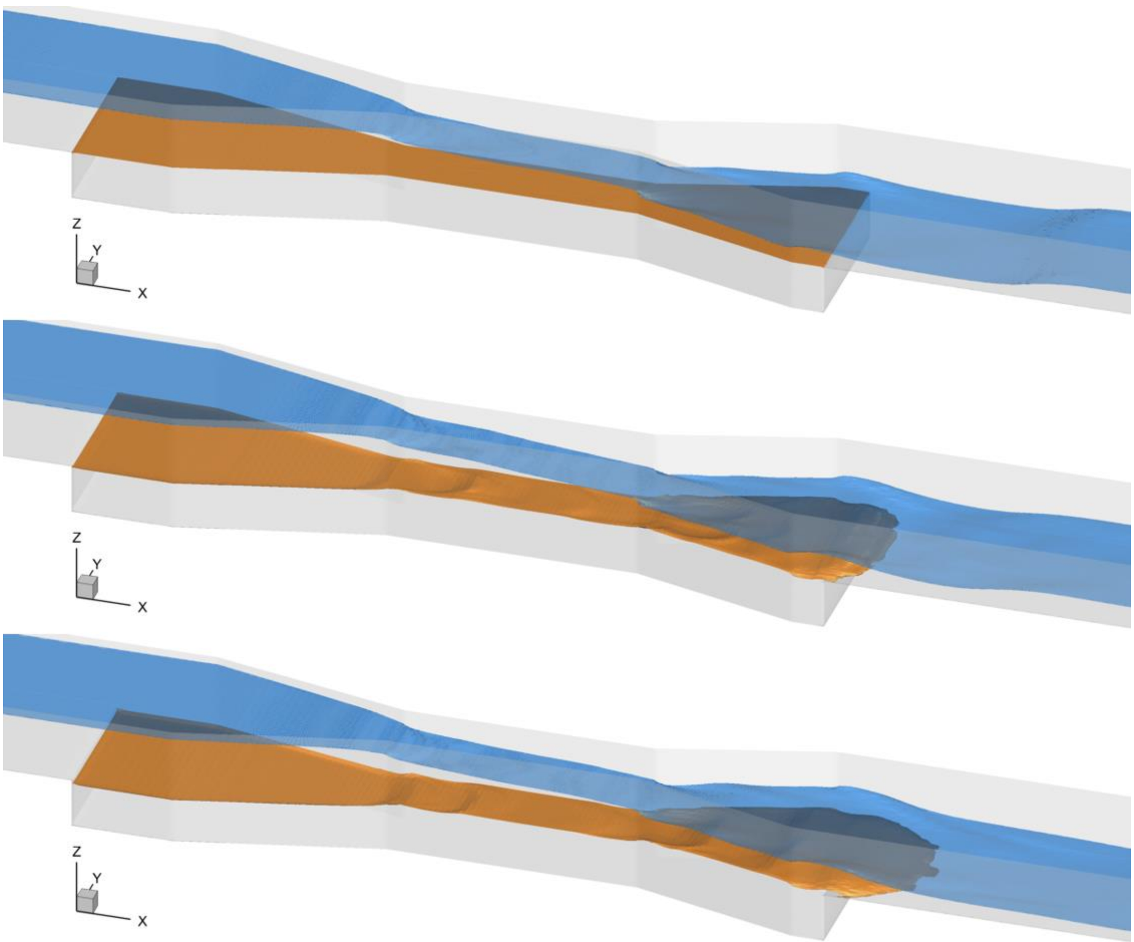

Figure 2: Computed free surface and sand bed deformation at subsequent three time instants: *t* = 0 s (*upper*), *t* = 120 s and *t* = 300 s (*lower*)