Abstract

Hydraulic engineers faced with complex practical and theoretical hydrodynamic or morphodynamic processes look forward to computational modelling as an elegant and cost-effective tool for finding a solution. However, while doing so, one is often encountered with issues pertaining to the applicability or efficiency of a particular numerical model in simulating a given flow problem. This research work presents a comprehensive and systematic study on the implementation of 1D/2D depth-averaged hydrodynamic and morphodynamic models and coupled 2D RANS-VOF turbulence models for simulating a collection of hydraulic flow phenomena chosen from laboratory and field applications as described below.

The depth-averaged morphodynamic model is applied for simulating the failure of non-cohesive granular dams due to overtopping, incorporating an equilibrium model of sediment transport, based on the flux form of the Exner equation. The effect of a steep bed slope of the dam face is taken into account in both the hydrodynamics and sediment transport equations and solved using a well-balanced high-resolution finite volume algorithm. The equilibrium model outcome is compared with results obtained from existing non-equilibrium models and also validated against experimental data. A Serre-Green-Naghdi (SGN) model is developed for simulating positive surge wave propagation. Numerical treatment of SGN equations coupled with eddy viscosity type wave-breaking scheme is discussed and the necessity of using an overall fourth-order accurate schemes is demonstrated. The deficiencies of the weak-nonlinearity assumption of Boussinesq type models are shown. The results produced by the proposed model appear to be at par with Large-eddy simulation solutions. The non-hydrostatic flow field for an undular surge wave is experimentally measured and compared with the model estimations. Weak undular hydraulic jump is simulated using a 2D RANS-VOF model. Turbulence is modelled using the k–ω Shear Stress Transport (SST) turbulence model. The proposed model is seen to accurately reproduce the key free-surface characteristics and the velocity and pressure fields corresponding to undular jumps. The model is also successful in reproducing the bottom recirculation region below the first wave crest for undular jumps with a partially developed boundary layer at the jump toe, which agrees well with the experimental observations. Submerged flows over barrage weirs is analysed using a 2D RANS-VOF model coupled with the RNG k-ε equations. Numerical simulations are performed for a wide range of hydraulic conditions for deriving reliable correlations corresponding to submerged flows over barrage weirs. The piezometric gauging technique is proposed as a more accurate alternative to the commonly recommended free-surface gauging technique for quantifying the discharge reduction factor of such weirs for submerged conditions. A 2D depth averaged model for simulating tidal bores in the River Hooghly, India is presented. A high-resolution well balanced finite volume scheme is used to solve a pre-balanced formulation of the 2D SWE. The model is validated by comparing the results with field data. The study bears relevance from a practical engineering viewpoint, as tidal bores considerably impact shipping along the river and affect the vessels' berthing at the riverine port at Kolkata.

Overall, the studies presented in the thesis highlight that computational models can provide new insights about complex hydraulic flow problems that are routinely encountered in the real world. It is hoped that the studies accomplished in this work will enrich the field of computational hydraulics for a better understating of practical hydraulic engineering problems.

Keywords: Finite volume method; CFD; RANS-VOF; SGN model; Undular flows; Sediment transport; Tidal bore; Barrage weir.