Generalized Solutions to Several Problems in Open Channel Hydraulics

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Abstract

Open channel flows are the flows having free surfaces that are subject to atmospheric pressure. The solutions of the open channel flows are determined to address a particular issue in hydrology, hydraulics, and engineering. In mathematical and numerical modeling, the open channel flows are usually characterized by a 1-dimensional (1D) model of shallow water equations (SWEs) or Saint-Venant equations, which is reasonably easy to solve compared to a multi-dimensional model. This thesis focuses on the mathematical and numerical modeling of open channel flows locally 1D, addressing dry bed and discontinuities of water surface profiles. The results from each chapter can be summarized as follows.

In Chapter 3, level-set methods applying to the kinematic wave equation governing surface water flows will be discussed. The methods deal with the critical issues arising from the governing nonlinear equations in surface water hydrodynamic included discontinuities in water surface levels and treatment of dry beds or zero water depths. The development of overturning is regulated with singular viscosity regularization (SVR), whose effect is to improve the zeros of the level-set function moving closer to the exact solutions of the shock fronts in dam-break problems. The method is verified with the explicitly known exact positions of primitive dam-break problems, optimizing a parameter of SVR. Then, the computation of the sudden water release from Chan Thnal Reservoir, Kampong Speu Province, Cambodia, into its irrigation canal system with the initially dry bed is simulated as a practical demonstrative example. The proposed method produces the results with free spurious diffusive deformation of water surfaces even if a relatively coarse computational mesh is used. However, the model induces a non-realistic flow propagation downstream. It restricts the flow to remain constant as upstream water depth due to the treatment of the kinematic wave equation as the Hamilton-Jacobi type. To deal with this problem, we consider another method to yield more realistic flow profiles of the dry bed in Chapter 4.

In Chapter 4, the kinematic wave model under the assumption of balanced gravity and friction forces is applied in open channel hydraulics and surface hydrology. There persists a misunderstanding that a discontinuity of a kinematic wave occurs due to a discontinuity of input and then dissipates. The study of this chapter will clarify that a discontinuity can develop without dissipation under the smoothness of all input and provide the numerical solutions of the kinematic wave equation over the dry bed with the varied bed slopes that the case has not been successfully treated in Chapter 3. The frist-order quasilinear partial differential equations theory shows that Cauchy problems for the kinematic wave model have unique measurable and bounded solutions, which are possibly discontinuous. Numerical examples of Case 1 dealing with the practical problem of Chan Thnal Reservoir's irrigational canal system with non-smooth initial data and Case 2 addressing the hypothetical problem with smooth initial data are demonstrated to visualize the fundamental properties of the discontinuous kinematic waves and the non-dissipative shock waves. Both numerical examples are computed with the initial dry bed. Nevertheless, the model is limited to input precisely zero initial condition. Instead, we use a sufficiently small initial condition considered the dry bed case in most literature.

In Chapter 5, it determines water surface profiles of steady open channel flows in a one-dimensional bounded domain Ω, which is one of the well-trodden topics in conventional hydraulic engineering. The characteristics of possibly generalized solutions (GSs) to Dirichlet problems of scalar first-order quasilinear ordinary differential equations, which are of mathematical interest, are proven by the notion of viscosity solution (VS). The VSs are the GSs in the space $L^1(\Omega) \cap L^\infty(\Omega)$. The GSs to some Dirichlet problems are not always unique, and a necessary condition for the non-uniqueness is derived. A concrete example illustrates the non-uniqueness of discontinuous VSs in a modified circular cross-sectional shape channel. The significant results of this chapter will provide a better understanding of the ill-posed problem for the scalar first-order quasilinear ordinary differential equations with Dirichlet boundary conditions.