Numerical Modeling of Flow in Open Channel with a Side Concavity

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Abstract

In this article, flow patterns in a channel with a side concavity are studied numerically. The two-dimensional depth-averaged saint venant equations, including the turbulence terms, are solved. The algorithm applies the finite volume method of Roe-TVD with unstructured triangular cells. Three depth-averaged turbulence models, including the mixing length, $k-\varepsilon$ and algebraic stress model (ASM) are used to close the hydrodynamic equations. The numerical results are compared with the available numerical and experimental data. It is clearly shown that the two-dimensional finite volume method of Roe-TVD using the shallow water equations can estimate the flow depth variations and vortices in a side concavity, successfully. It is concluded that by increasing the aspect ratio the water depth enhances within the concavity section and the finite volume method of Roe-TVD with the ASM gives the best results.

Keywords: Roe-TVD Method, Mixing Length Model, $k-\varepsilon$ Model, ASM model, Side Concavity

1. INTRODUCTION

Side concavity structure is one of the facilities leading people to waterfront in normal flow conditions. Several examples of these structures can be found in relatively small rivers. In these rivers with the mean width of about ten to twenty meters, bottom and sides of the concavity may be protected by concrete walls. It is well known that there are significant differences between the velocities of the mainstream and concavity zone.

The flow patterns in a concavity is very complicated, notwithstanding the hydraulic resistance created by installing this structures is not taken into account in the design of channel. Akkerman et al. investigated on the effects of sedimentation and flood water depth after the side concavity in a river, [1]. Flow structures and water exchange in an embayment zone connected to main stream through a conjunction channel were investigated experimentally by Tominaga and Sakaki, [2]. Two dimensional open channel flows with a relatively long side concavity was studied both numerically and experimentally by Fujita et al., [3]. In their numerical simulation, the so called CIP algorithm, a simple mixing length theory was applied for turbulence terms. They concluded that the complex flow structure in the side concavity is a source of flow resistance.

In the present article, we apply the finite volume method of Roe-TVD to simulate the flow pattern in a channel with a side concavity. The multidimensional slope-limiters of Yoon and Kang [4] are employed to achieve the second-order spatial accuracy and to prevent spurious oscillations. For the inspection of the turbulence effects, several depth-averaged versions of the RANS models, such as the two-dimensional mixing length model, $k-\varepsilon$ model and algebraic stress model (ASM), are examined. The experimental data presented by Fujita et al. [3] are used to compare and validate our numerical results.

2. SHALLOW WATER EQUATIONS

The two-dimensional, depth-averaged shallow water equations may be obtained by integrating the 3D Navier-Stokes equations over the flow depth with the assumptions of incompressible fluid, a hydrostatic pressure distribution, a nearly uniform velocity distribution in the vertical direction and a small bottom slope. The conservative form of the depth-averaged shallow water equations with source terms may be written in vectorial form as, [5]:

$$\frac{\partial W}{\partial t}+\frac{\partial F_x}{\partial x}+\frac{\partial F_y}{\partial y}=\sum_{k=1}^{3}G_k \tag{1}$$