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Comparison of two different secondary flow correction models for depth-averaged flow simulation of meandering channels

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Abstract

Several secondary flow correction models have been proposed in the literature to account for the 3d flow characteristics of secondary flow which is often lost in depth-averaged hydrodynamic model. In this paper two typical correction models are selected as representatives which are Lien (L) and Bernard (B) models. And one singular bend channel and one meandering channel are applied to evaluate their performances in flow simulation. The simulation results in water surface level and longitudinal velocity distributions across sections of L and B model are compared with that of traditional depth-averaged model with no correction (N model). The results show that the water surface level of B model is a bit higher than that of the other models in the two flumes. As for velocity simulation results, B model performs best by comparison with the other two models, especially when the channel bends become complex. B and L model mainly improves the velocity simulation results around the wall region. The velocity distributions of L model become irrational in flow simulation of the complex meandering channel. While B model works well in sharply curved channel and complex meandering channel. Therefore, B model is applicable for flow simulation in meandering channels. The analysis of the distribution of correction terms of B model demonstrate that the correction term is at the same order of the viscosity stress term and the maximum values of it are around the wall region which enabled the redistribution of the longitudinal velocities.

Keywords: bend; meandering; depth-averaged model; secondary flow; dispersion stresses; numerical modeling

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1. Introduction

Nomenclature

A_s, D_s	empirical coefficient of B model (A_s =5.0, D_s =0.5 used in this paper)
C	Chezy factor ($m^{1/2}/s$)
C_f	Friction factor
g	gravitational acceleration (m/s^2)
H	water depth (m)
h_1	metric coefficients in ζ- directions
h_2	metric coefficients in η- directions
$\vec{n}$	unit vector normal to the vector
Q	discharge from inlet (m^3/s)
Ω	streamwise vorticity (s^{-1})
ρ	water density (kg/m^3)
R_c	radius of channel centerline (m)
r_s	radius of streamline curvature (m)
r	radius of channel geometry (m)
S	the distance from inlet (m)
S_ζ	correction (dispersion) terms in ζ- direction (m^2/s^2)
S_η	correction (dispersion) terms in η- direction (m^2/s^2)
τ_s	secondary shear stress ($kg/(m \cdot s^2)$)
Δt	time interval (t)
$\vec{u}$	depth-averaged velocity vector (m/s)
u	longitudinal velocity (m/s)
U	longitudinal depth- averaged velocity (m/s)
U_0	the mean velocity from inlet (m/s)
V	transverse depth-averaged velocity (m/s)
v	transverse velocity (m/s)
v_e	eddy viscosity (m^2/s)
w	the width of channels (m)
y	distance from left bank (m)
ζ	orthogonal curvilinear coordinates in streamwise axis and transverse axis
η	orthogonal curvilinear coordinates in streamwise axis and transverse axis
Z	water surface elevation (m)

Helical flow or secondary flow which was a main characteristic of meandering river has been studied by many researchers [1~3] via field observation, laboratory experiments, theoretical and numerical methods. It causes a transverse flow and products additional bed shear stress which are responsible for the redistribution of the downstream momentum and a transverse bedload sediment transport respectively. [4] More importantly, the secondary flow plays an important role on the lateral channel evolution. [5~7] Most researches about secondary flow have been concentrated on singular bend in laboratory scale. However, the nature meandering rivers always trend to be continuous with several bends.

As numerical models can provide more detailed information than field measurements and experiments, various numerical models have been used to simulate curved channel flows. Despite 3d numerical models are more favorable to simulate the three dimensional flow features, 2d numerical models remain practical for investigation of long-term and large-scale dynamics process. However, the vertical structure of the flow is lost due to the depth-integration of the momentum equations so that the secondary flow effects on flow field are neglected. In order to account for these effects in 2d numerical model, various correction models have been proposed by many researchers. [8~11]