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II －309 Evaluation of velocity near bed in meandering compound open channel flow

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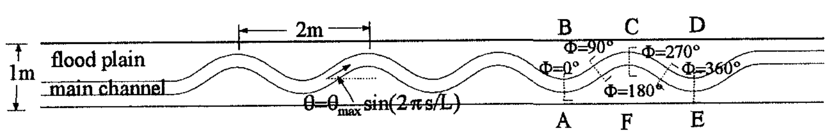
1. Introduction

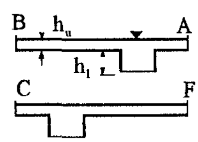
It is well-known that secondary currents generated by streamline curvature and non-uniformity of flow cause excess local scouring near outer bank and accordingly point bar formed near convex bank in a meandering river course. At this stage, most of bed variation simulations are incorporated with evaluation of depth-integrated water flow. The information on the flow near bed is then obtained by empirical method based on the depth-averaged streamline, friction velocity, etc.[1] Such an approach can work well in some case, e.g., mild meandering channel with simple cross-section, outer area far from hydraulic structure, etc. Where channels are of meandering compound shape, however, flow is so complicated that velocity near the main channel bed cannot be represented correctly by current empirical approaches because of greater changes of water depth, hydraulic roughness, flow intensity, streampath and so on between main channel and flood plains. Result obtained by the streamline method may be wrong even if the bulk feature of flow is reproduced well[2]. In this study results of velocity near bed simulated numerically by different approaches are reported.

2. Brief description of the simulation

Numerically generated boundary-fitted orthogonal curvilinear coordinates for fitting local channel path and all horizontal boundaries completely and a sigma transformation in order to follow free water surface and bed topography (ξ, η, σ, t) are employed. Governing equations for water flow referred by present method are 3-D Reynolds equations with the Boussinesq approximation so that the influence of variable density appears only in the buoyancy term, which are continuity equation and three momentum equations in ξ, η, σ components and are expressed as the forms in (ξ, η, σ, t) system[3]. Boussinesq's eddy-viscosity concept is employed and different turbulence closures, including 0-equation model, standard k-ε closure[4] and modified k-ε closure, are applied to evaluate the turbulent shear stress. With the 0-equation approximation, eddy viscosity coefficients in horizontal plane (ν_t) and vertical direction (ν_{tz}) are written as $\nu_t = \alpha h u_*$ and $\nu_{tz} = \alpha_z h u_*$, respectively, in which h=water depth, u_*=friction velocity, α and α_z are the dimensionless constant. In the modified k-ε model, transport equations for k and ε are the same as the standard one except $\nu_{tz} = \sqrt{h/B}\,\nu_t$, herein B= channel width. In several cases, hydrostatic pressure approximation is assumed. The governing equations are rebuilt and solved by a special implicit finite difference scheme. The continuity equation, incorporated with relationships between velocity components and water surface level resulted from the horizontal (ξ, η) momentum equations, is solved firstly to obtain the advanced water surface level. In the case with hydrodynamic pressure calculation, then equation for hydrodynamic pressure deviation from the hydrostatic formed according to the momentum equations is solved. Thereafter the momentum equations are solved to get the advanced velocity with the new water surface (and hydrodynamic pressure). In the case with the hydrostatic pressure approximation, vertical velocity is calculated by integrating the continuity equation. Finally k and ε are computed to obtain new eddy viscosity. Thus one cycle of computation is finished and the procedure is repeated until convergence conditions are reached.



(a) Plan-view



(b) Cross-sections

Fig.1 Sine-generated meandering compound channel (θ_{max}=35°, L=2.2m, the slope=0.009)

The method is employed to evaluate flow in meandering compound open channel. Plan-view of calculation domain and its cross-sectional shape are shown in fig.1. The flume is 12m long and 1m wide with a central located sine-generated meandering main channel (the width=20cm and the depth h_l=3cm). 141x42 grids are set on the horizontal directions. 16 layers are made non-uniformly in the vertical direction in which 9 layers are below the floodplain and 7 over that. Discharge at the entrance and water surface level at the exit are specified as the open boundary conditions for the computation. At the wall boundaries, the velocity normal to the bank is equal to zero and the tangential component, conforming to the resistance law, is not zero. The initial conditions correspond to the initial value in boundary conditions.

3. Result and analysis

Keywords: Meandering compound channel, 3-D simulation, velocity near bed, turbulence closure, hydrodynamic pressure
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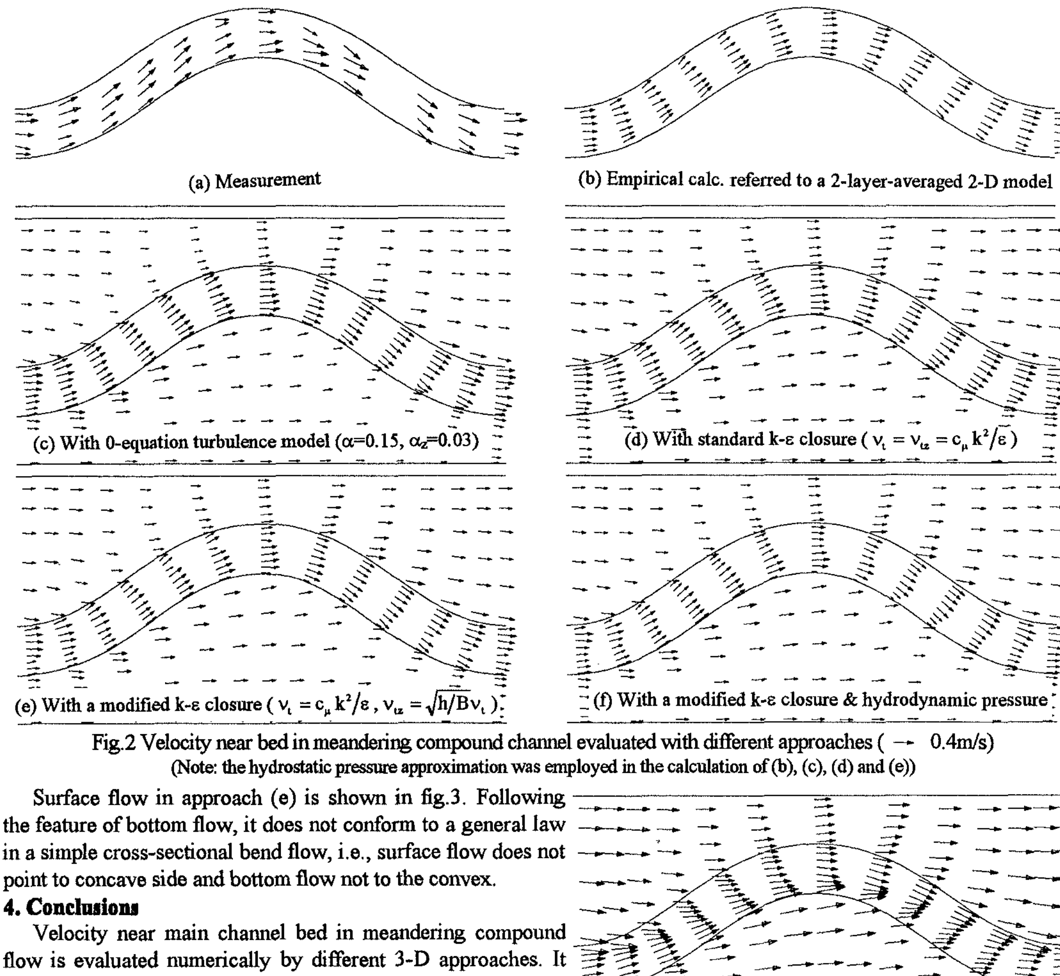
Results on the case for discharge of 7.15 l/s and mean water depth of about 4.4cm in main channel are discussed. Fig.2(a) shows the experimental data for velocity near main channel bed. It shows a typical feature of bottom flow, i.e., it does not points consistently to convex side around the main channel bend flex, though its precision is not so good in some locations. Result in fig.2(b) is calculated by Liu's approximation(5) according to a two-layer-averaged 2-D computation(2). The result is better a little than that evaluated by depth-averaged streamline method(2), but it cannot represent the chief feature yet. Results computed by different 3-D approaches are displayed in fig.2(c)~(f). The feature can be simulated reasonably with the 0-equation closure as well as the modified k-ε approach. It may be deduced, however, that the result simulated by the latter with or without hydrostatic pressure approximation can reproduce much better such a distinct feature of main channel bottom flow though magnitude of computational results is smaller than the measurement because of possibly inconsistent vertical location for the comparison.



(a) Measurement (b) Empirical calc. referred to a 2-layer-averaged 2-D model

(c) With 0-equation turbulence model (α=0.15, α_z=0.03) (d) With standard k-ε closure ($\nu_t = \nu_{tz} = c_\mu k^2/\varepsilon$)

(e) With a modified k-ε closure ($\nu_t = c_\mu k^2/\varepsilon$, $\nu_{tz} = \sqrt{h/B}\,\nu_t$) (f) With a modified k-ε closure & hydrodynamic pressure

Fig.2 Velocity near bed in meandering compound channel evaluated with different approaches (→ 0.4m/s)
(Note: the hydrostatic pressure approximation was employed in the calculation of (b), (c), (d) and (e))

Surface flow in approach (e) is shown in fig.3. Following the feature of bottom flow, it does not conform to a general law in a simple cross-sectional bend flow, i.e., surface flow does not point to concave side and bottom flow not to the convex.

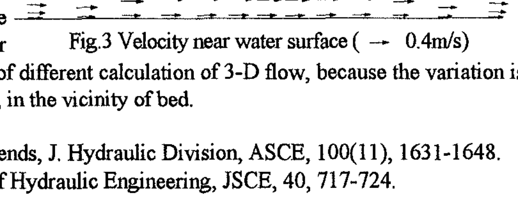


Fig.3 Velocity near water surface (→ 0.4m/s)

4. Conclusions

Velocity near main channel bed in meandering compound flow is evaluated numerically by different 3-D approaches. It cannot be reproduced correctly by current simple empirical methods and a better description may be gained by a modified k-ε turbulence closure with or without hydrostatic pressure approximation. It can be anticipated that there is a greater difference among simulation results of bed variation by means of different calculation of 3-D flow, because the variation is closely related to sediment transport, both its rate and direction, in the vicinity of bed.

5. References

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