II-203 Three-dimensional confluence flow computation using numerically generated grid

Nobuyuki Tamai, Professor S. B. Weerakoon, Graduate Student
Department of Civil Engineering, University of Tokyo.

1. Introduction

Confluences are of considerable importance in river engineering, yet comparatively few studies have been done to unravel the complicated pattern of three-dimensional flow that results as mixing of two streams. In this paper a computational model which is capable of predicting three-dimensional flow in an arbitrary river confluence, using numerical grid generation and coordinate transformation, based on the partially parabollic duct flow assumption, is presented. The model was employed under the same conditions of experiments of Koike(1), Tada(3) and the comparison of results have also been provided.

2. Grid generation and coordinate transformation

Let the physical domain with curvilinear grids be y^i and the transformed domain with orthogonal grids at unit spacings be x^i. The closely orthogonal smooth curvilinear grid is generated to have the required spacings using a quasiconformal mapping technique. First, a rough grid is constructed with the specified spacings by interpolation in y^1, y^2 plane and grid aspect ratio, D is computed by (1). Then equations for orthogonality (2) are solved for new values of y^1, y^2 by double sweeps of TDMA. Repeating the procedure from the computation of D, a smooth and closely orthogonal grid is obtained in y^1, y^2 plane. The extension to third dimension is done by interpolation.

$$g_{11} = \left(\frac{\partial y^1}{\partial x^1}\right)^2 + \left(\frac{\partial y^2}{\partial x^1}\right)^2 \qquad g_{22} = \left(\frac{\partial y^1}{\partial x^2}\right)^2 + \left(\frac{\partial y^2}{\partial x^2}\right)^2 \qquad D = \sqrt{\frac{g_{11}}{g_{22}}} \tag{1}$$

$$\frac{\partial}{\partial x^1}\left(\frac{1}{D}\frac{\partial y^1}{\partial x^1}\right) + \frac{\partial}{\partial x^2}\left(D\frac{\partial y^1}{\partial x^2}\right) = 0 \qquad \frac{\partial}{\partial x^1}\left(\frac{1}{D}\frac{\partial y^2}{\partial x^1}\right) + \frac{\partial}{\partial x^2}\left(D\frac{\partial y^2}{\partial x^2}\right) = 0 \tag{2}$$

3. Basic equations and turbulence model

For incompressible turbulent flows, continuity equation and Reynolds equations are,

$$\frac{1}{J}\left(\frac{\partial J U^j}{\partial x^j}\right) = 0 \tag{3}$$

$$\frac{1}{J}\left(\frac{\partial J U^i U^j}{\partial x^j}\right) + \begin{Bmatrix} i \\ mn \end{Bmatrix} U^m U^n = -g^{ij}\frac{\partial}{\partial x^j}\left(G y^3 + \frac{p}{\rho}\right) + \left(\nu U^i{}_{;}{}^{j} - \overline{u^i u^j}\right)_{;j} \tag{4}$$

where J = Jacobian, U^i = contravariant velocity component, g^{ij} = metric tensor, u^i = contravariant component of turbulent velocity and ; = covariant derivative. Eddy-viscosity concept is applied to express the turbulent stresses, that is,

$$-\overline{u^i u^j} = \nu_t\left(U^i{}_{;}{}^{j} + U^j{}_{;}{}^{i}\right) - \frac{2}{3} g^{ij} k \tag{5}$$

and k-e model is employed to evaluate the eddy viscosity, which is,

$$\frac{\partial}{\partial x^i}\left(J k U^i\right) = \frac{\partial}{\partial x^i}\left(\frac{\nu_t}{\sigma_k} J g^{ij} \frac{\partial k}{\partial x^j}\right) + J\nu_t\left(U_{i;}{}^{j} + U^j_{;i}\right)U^i_{;j} - J\varepsilon \tag{6}$$

$$\frac{\partial}{\partial x^i}\left(J \varepsilon U^i\right) = \frac{\partial}{\partial x^i}\left(\frac{\nu_t}{\sigma_\varepsilon} J g^{ij} \frac{\partial k}{\partial x^j}\right) + J\frac{\varepsilon}{k}\nu_t\left(U_{i;}{}^{j} + U^j_{;i}\right)U^i_{;j} - J c_2 \frac{\varepsilon^2}{k} \tag{7}$$

$$\nu_t = c_\mu \frac{k^2}{\varepsilon} \tag{8}$$

c_μ=0.09, c_1=1.44, c_2=1.92, σ_k=1.0, σ_ε=1.3

4.Solution procedure

Equations (3) to (8) are solved utilising SIMPLE algorithm with hybrid scheme based on the patially parabollic duct flow assumption.

5.Results and comparisons

The qualitative agreement between the experimental distribution (Koike) of turbulent quantity,u_{rms}in fig.(2) and the computed distribution of turbulent kinetic energy in fig.(3) is satisfactory. The mean flow quantities in the mixing layer was also in good quantitative agreement.

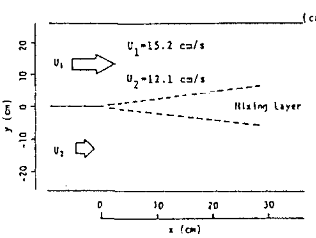

Fig.1. Layout diagram

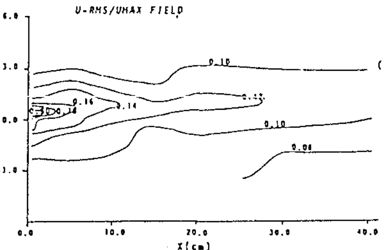

Fig.2. Experimental

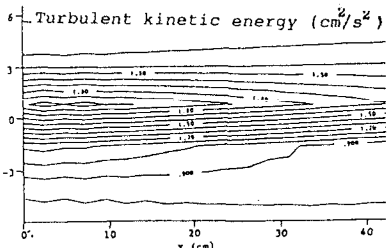

Fig.3. Computed

The model was employed for a confluence of 60 with a levee and comparison with the experimental results (Tada) is satisfactory as in fig.(5) and fig.(6).

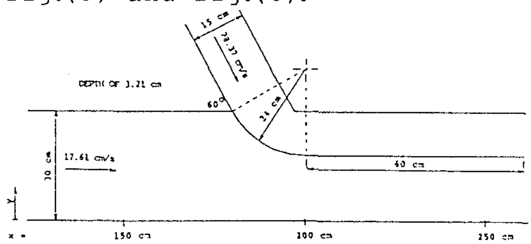

Fig.4. Layout diagram

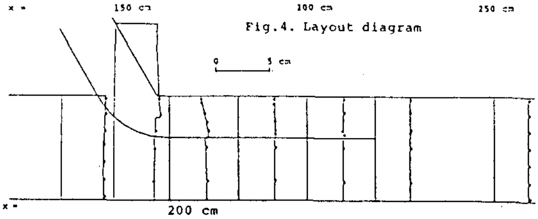

Fig.5. Flow depth variation

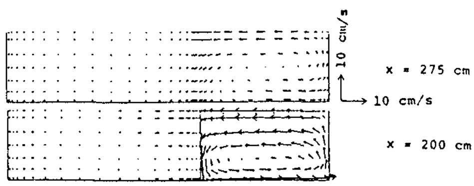

Fig.6. Secondary flow

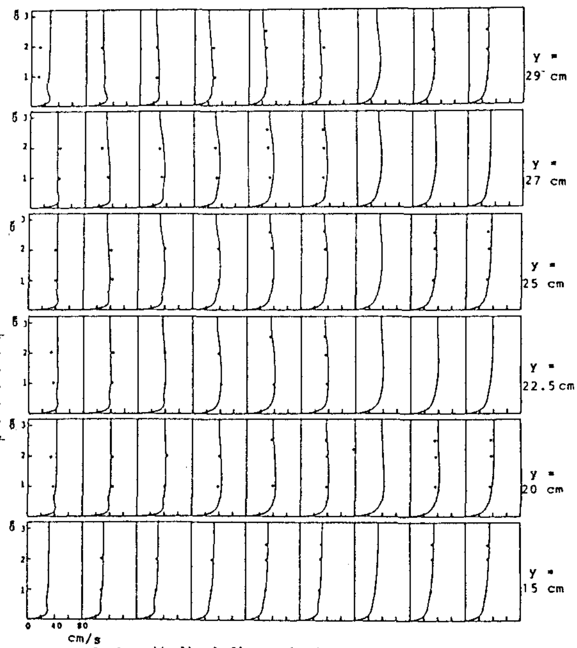

Fig.7. Longitudinal flow velocity profiles at x = 200,215,235,265,270,280,325,380 and 480 cm

6.Conclusions

1. By the proposed method of numerical grid generation and coordinate transformation an arbitrary confluence can be tackled.
2. The computational model based on k-e turbulence model has reproduced all important features in a confluence satisfactorily.
3. The roleof the levee in reducing the secondary currents in the main channel and facilitating gradual mixing of two streams can be emphasized.

7.References : 1. Koike A., M.E.Thesis (1986),Kyoto univ.

2. Patankar S.V., Numerical Heat Transfer and Fluid Flow,Hemisphere
3. Tada H., Experimental reports (1987), Osaka College of Technology.