COMPUTATIONS OF TURBULENCE STRUCTURES IN FREE-SURFACE MIXING LAYERS UNDER DIFFERENT DEPTHS

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The clarification of 2D plane mixing shear layer in an open channel flow is important for various problems. The flow in a mixing shear layer is characterized by vortex formations due to the K-H instabilities. Therefore, it is necessary to predict not only time-mean flow patterns but also the turbulent features, such as turbulence intensities and Reynolds stresses. In shallow open channels, since the dominant flow pattern has basically plane 2D structure, the plane 2D depth-averaged model is likely to be applicable to some extent. Recently, 3D computations have spread with development of personal computers. However, 2D models still hold important position in many engineering fields because of their economic advantage.

In this paper, the non-linear 0-equation type turbulence model proposed by authors is applied to the 2D mixing layers under different depths. The computational results are validated with the results of the laboratory tests by Uijttewall & Booij (2000). The effects of depth to time-mean flow patterns and turbulence structures are investigated through the comparison between numerical and experimental results.

In many depth-averaged models used in previous works, the eddy viscosity coefficient ν_t is usually given by 0-equation type turbulence model, such as

$$\nu_t = \alpha h u_* \tag{1}$$

where u_* and h are a local friction velocity and a local depth, respectively. α is usually given as const. (=0.1 ~ 0.3). However, we proposed a function for α as

$$\alpha(M) = \min\left[0.2,\ 0.3\gamma_k\lambda_p/(1+0.09M^2)\right],\ \mathrm{M} = \max[\mathrm{S},\Omega] \tag{2}$$

where, S / Ω : strain / rotation parameter and γ_k (=2.07), λ_p (=1.07): constants. Eq.(2) was tuned considering realizability and distribution of turbulence intensities in a simple shear flow. Another feature of he present model is a 2nd-order non-linear constitutive equation as

$$-\overline{u_i u_j} = \nu_t S_{ij} - \frac{2}{3}k\delta_{ij} - \lambda_p \frac{h}{u_*} D_t \sum_{\beta=1}^{3} C_\beta \left(S_{\beta ij} - \frac{1}{3} S_{\beta\alpha\alpha}\delta_{ij} \right) \tag{3}$$

$$S_{1ij} = \frac{\partial U_i}{\partial x_\gamma}\frac{\partial U_j}{\partial x_\gamma},\quad S_{2ij} = \frac{1}{2}\left(\frac{\partial U_\gamma}{\partial x_i}\frac{\partial U_j}{\partial x_\gamma} + \frac{\partial U_\gamma}{\partial x_j}\frac{\partial U_i}{\partial x_\gamma} \right),\quad S_{3ij} = \frac{\partial U_\gamma}{\partial x_i}\frac{\partial U_\gamma}{\partial x_j} \tag{4}$$

$$C_1 = 0.4 f_M(M),\quad C_2 = 0,\quad C_3 = -0.13 f_M(M),\quad f_M(M) = (1+0.02M^2)^{-1} \tag{5}$$

We applied the present model to the flow in the laboratory tests by Uijttewaal et al (2000). The schematic diagram of the flow field and the hydraulic parameters are shown in

Fig.1 and Table 1, respectively. Two mixing layers with different water depths (h=67mm and 42mm) are studied.

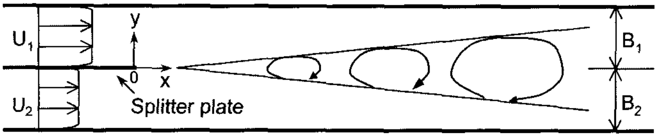


Fig.1 Schematic diagram of mixing layer.

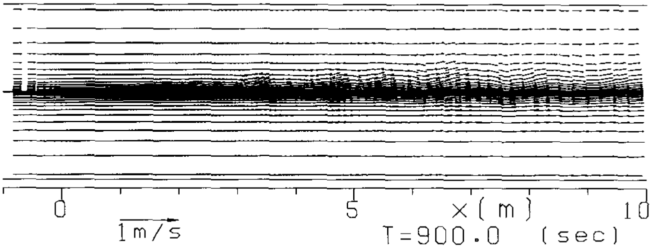


Fig.2 Plane velocity vectors (h=67mm).

Table 1. Hydraulic conditions.

	U_1	U_2	B_1	B_2	h (depth)
Case I (large h)	14 cm/s	32 cm/s	150 cm	150 cm	67 mm
Case II (small h)	11 cm/s	23 cm/s	150 cm	150 cm	42 mm

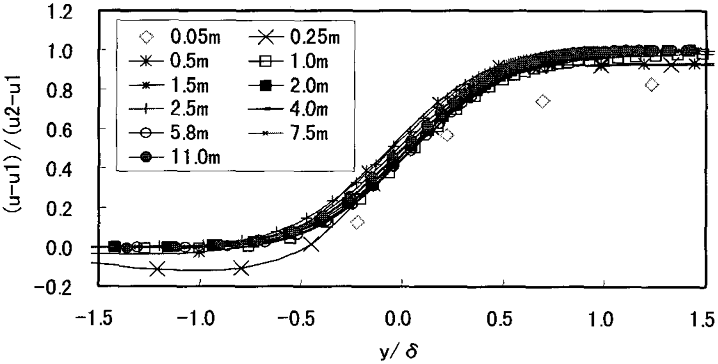
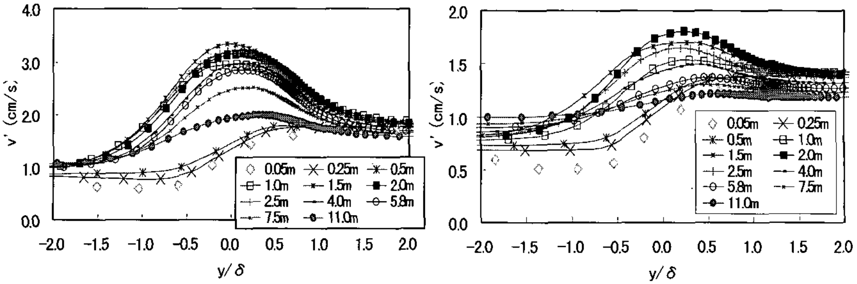


Fig. 3 Non-dimensional velocity profiles at various downstream positions (h=67mm)



(a) Cal. (h=67mm) (b) Cal. (h=42mm)

Fig. 4 Profiles of v'at various positions.

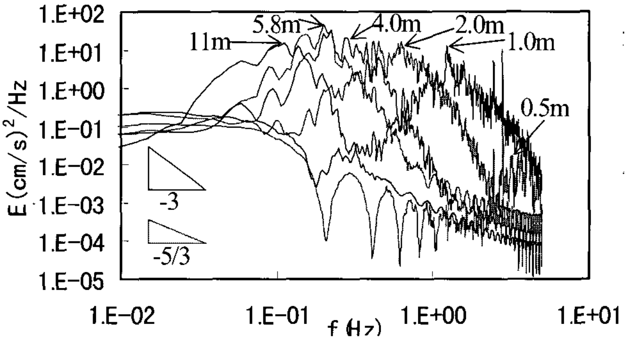


Fig. 5 Spectra of v' along centerline (h=67mm).

Fig.2 shows a snap shot of computed velocity vectors in the h = 67mm case. Large-scale vortex formations due to the shear instability are generated numerically.

Fig.3 shows the time-mean velocity profiles non-dimensionalized by mixing layer thickness in 67mm case. The profiles satisfy the self-similarity except the position at x = 0.05m, where the flow is closely affected by the wake of the splitter plate.

Fig.4 shows the v'-profile. The peaks along the mixing layer decrease as downstream direction. Note that the peaks in h=42mm case dissipate more rapidly than those in 67mm case because the coherent structures in shallower depth are more strongly suppressed by the bed friction.

Fig.5 shows the spectra of v' along the centerline in h = 67mm case. Clear peaks can be seen. The frequency of the peak decreases with downstream distance because multistage of vortex merging occurs.

REFERENCES

Uijttewaal, W. S. J. and Booij, R. (2000). "Effects of shallowness on the development of free-surface mixing layers," *Physics of Fluids*, Vol.12, pp.392-402.