EXAMINATION OF EXISTING MODELS FOR FLUID LAGRANGIAN INTEGRAL TIMESCALE SEEN BY SUSPENDED SEDIMENT

XUDONG FU[1] and GUANGQIAN WANG[2]

[1] Associate Professor, Dept. of Hydraulic Engineering,
Tsinghua University, Beijing 100084, P. R. China.
(Tel: +86-10-62797071, Fax: +86-10-62772463, e-mail: xdfu@tsinghua.edu.cn)
[2] Professor, Dept. of Hydraulic Engineering,
Tsinghua University, Beijing 100084, P. R. China
(Tel: +86-10-62781748, Fax: +86-10-62772463, e-mail: dhhwgq@tsinghua.edu.cn).

Knowledge of vertical diffusion of suspended sediment is essential for reasonably determining suspended sediment transport in open-channel flows. Conflicting evidences on the relationship between sediment diffusivity and fluid eddy viscosity have advanced two-phase formulations of sediment-laden flows in recent years. However, no effort has been made to examine the assumptions that have been introduced into modeling fluid Lagrangian integral timescale seen by suspended sediment. This paper aims at examining existing formulations of this timescale through a kinetic-model-based simulation of sediment vertical diffusion.

The study employed Fu and Wang's (2003) kinetic model for simulation of suspended sediment diffusion. For two-dimensional, uniform and steady open-channel flows, the momentum equation for the vertical direction is derived from the kinetic model as follows:

$$\varepsilon_{yy}\frac{\partial C}{\partial y} = -\omega C + \tau_p C\left(F_L - d\left\langle v_y' v_y'\right\rangle / dy\right) \qquad (1)$$

where ω is sediment settling velocity, C is sediment volumetric concentration, τ_p is sediment relaxation time, F_L is fluid-induce lift force, $\langle v_y' v_y'\rangle$ is sediment y-normal stress, y is vertical coordinate, and the sediment diffusivity for the vertical direction, ε_{yy}, is defined as

$$\varepsilon_{yy} = \tau_p \left\langle v_y' v_y'\right\rangle + \alpha\tau_p \left\langle u_y' u_y'\right\rangle \qquad (2)$$

where $\langle u_y' u_y'\rangle$ is fluid y-normal stress; α is a coefficient associated with particle-turbulence interaction and takes the following form:

$$\alpha = \frac{T_{Lp}}{\tau_p}\frac{T_{Lp}}{T_{Lp} + \tau_p} \qquad (3)$$

where T_{Lp} is fluid Lagrangian integral timescale seen by suspended sediment and needs to be accurately quantified for characterizing sediment vertical diffusion.

Three existing formulations of T_{Lp}, named as Model 1, Model 2 and Model 3, respectively, were examined by comparison with Graf and Cellino's (2002) concentration data, see Figure 1. Model 1 did not take into account the inertia effect (IE) and the crossing trajectories effect (CTE), i.e. $T_{Lp} = T_L$, where T_L is Lagrangian integral timescale of the carrier fluid. As a result, Model 1 overestimated the sediment concentration profile. The predicted value of the depth- averaged ratio ($\bar{\gamma}$) of $\varepsilon_{yy}/\nu_{ft}$ (ν_{ft} is fluid eddy viscosity) was greater than but close to unity for the small sand (d_p = 0.135 mm) used in the experiment. Obviously, Model 1 could not reproduce the experimental finding of $\bar{\gamma} < 1$.

Model 2 is an extension of Model 1 through accounting for the CTE. In the case of Model 2, accounting for the CTE predicted an improved but still overestimated concentration profile. The predicted $\bar{\gamma}$ value was distinctly smaller than unity, which agreed with the measured data although the predicted value was much higher. On the other hand, as the shear velocity u_* increased, the predicted value of $\bar{\gamma}$ increased and had a tendency of approaching unity. This was not supported by the experimental data, implying that the IE should also be included.

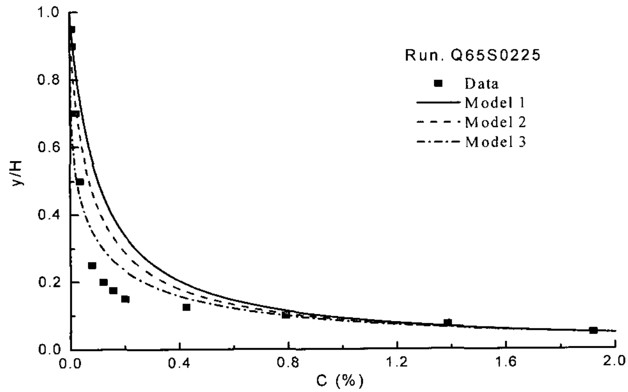

Fig. 1 Comparisons of predicted concentration profiles with Graf and Cellino's (2002) data

No model that accounts for both the IE and the CTE has been proposed for turbulent open-channel flows. This study modified and then examined Wang and Stock's (1993) model that was originally developed for isotropic turbulence. This modified model was referred to as Model 3, which could predict much reasonable result. This examination suggested that: (1) the kinetic model coupled with a reasonable formulation of T_{Lp} could satisfy the requirements of quantifying various effects on sediment vertical diffusion; (2) Further exploration of turbulence structure of the carrier fluid would be desired for improving characterization of sediment diffusion process.

REFERENCES

Fu, X. D., and Wang, G. Q. (2003). "Kinetic model of particulate phase in dilute solid-liquid two-phase flows," *Acta Mech. Sinica*, Vol. 35, No. 6, pp. 650-659 (In Chinese).

Graf, W. H., and Cellino, M. (2002). "Suspension flows in open channels; experimental study," *J. Hydraul. Res.*, Vol. 40, No. 4, pp. 435-447.

Wang, L. P., and Stock, D. E. (1993). "Dispersion of heavy particles by turbulent motion," *J. Atmos. Sci.*, Vol. 50, pp. 1897-1913.