LOG-WAKE LAW IN TIME-DEPENDENT AND DEPTH-VARYING OPEN-CHANNEL FLOW

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Unsteady depth-varying open-channel flows are really observed in flood rivers. We can use some valuable experimental database of flood-simulated open-channel flows which were measured accurately by laser Doppler anemometers (LDA). However, these LDA measurements are comparatively difficult to be conducted in flood-simulated open-channel flows with strong unsteadiness because of various limitations of experimental instruments and flumes. So, in the present study, a low-Reynolds-number type $k-\varepsilon$ model involved with a function of unsteadiness effect was developed and some numerical calculations were conducted using the Volume of Fluid (VOF)method as a free-surface condition of flood. The present calculated values were in good agreement with the existing LDA data in the whole flow depth from the bed to free surface, which is described by the log-wake low. This calculation model could predict the phase-averaged of velocity distributions and the time-variations of wall shear stress and flow depth reasonably. In particular, these calculations are able to explain well the log-wake law, in which the wake-strength parameter Π varies with time more significantly, as the unsteadiness becomes larger.

In a low-Reynolds-number type $k-\varepsilon$ model, the eddy viscosity, ν_t, is given then by

$$\nu_t = C_\mu f_\mu \frac{k^2}{\varepsilon} \tag{1}$$

C_μ is the model coefficient, and f_μ is the damping function due to the viscous effect by the wall.Although the model coefficient, C_μ, in (1) is really a constant $(C_\mu = C_{\mu steady} = 0.09)$ in steady flows, it may not be guaranteed whether the value of C_μ itself can be applied even to flood-simulated unsteady open-channel flows without any modification. Nevertheless, we tried to conduct some tentative calculations by assuming C_μ as the fixed constant of $C_{\mu steady} = 0.09$ in flood-simulated open-channel flows. Unfortunately, these results were not in good agreement with the experimental data as the unsteadiness became larger, as will be mentioned later (see Fig.2). In order to overcome these difficulties, Sanjou & Nezu (2004) developed the new function of unsteadiness effect, f_U, which is described by

$$C_\mu \equiv C_{\mu steady} \cdot f_U(T) = 0.09 f_U(T) \tag{2}$$

$$f_U(T) \equiv 1 - C_U \left(\frac{\partial h}{\partial T}\right) \cdot \alpha^m \tag{3}$$

in which, $\hat{h} \equiv h/h_b$ and $T \equiv t/T_d$. $\hat{h}$ is the time-dependent water depth normalized by the base water depth, h_b, that is one before the flood. T is the time normalized by the duration flood time, T_d, from the base flow depth, h_b, to the peak flow depth, h_p. m is the model constant. α is the unsteadiness parameter proposed by Nezu *et al.*(1997). The value of C_U and *m* were determined by comparison with the existing experimental data of Nezu *et al.*(1997) and Nezu & Onitsuka(2001). In this study, five kinds of hydraulic cases with different unsteadiness were calculated under the same condition as the LDA data of Nezu *et al.*(1997) and Nezu & Onitsuka(2001).

Fig. 1 shows the phase-averaged distributions of mean velocity, $U(y;t)$, in the base and peak stages of $T = 0$ and 1.0. Fig. 1 indicates the result of large unsteadiness case of $\alpha = 0.0031$. It should be noticed that the value of U^+ for $y^+ \geq 30$ obeys a linear relation to $\log y^+$ in the inner layer irrespective of the phase T. On the other hand, the wake component in the outer layer of $0.2 \leq y/h \leq 1.0$ was observed in such a large unsteadiness case in the peak stage of $T = 1.0$. These properties are observed in the both of the present calculation and measured data. In order to reveal the unsteadiness effect on the log-wake law, Fig.2 shows the variations of a wake strength parameter Π, the value of which were evaluated from the best-fittings of calculated values to log-wake law with $\kappa = 0.412$ shown in Fig.1.). Of particular significance is that the value of Π increases with an increase of α, and approaches a limit value at an extremely high unsteadiness. It is also recognized that the calculation with no consideration of unsteadiness function of (3) cannot predict the experimental data reasonably at higher unsteadiness of $\alpha \geq 10^{-4}$. It is therefore said strongly that the present calculated values are in good agreement with the existing experimental data measured with LDA in the whole flow depth from the viscous sublayer to the free surface in the open-channel flows included with large unsteadiness.

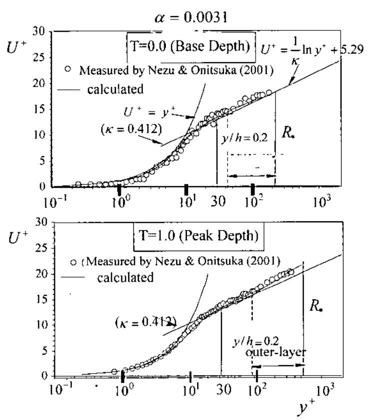

Fig. 1 Distributions of phase-averaged velocity

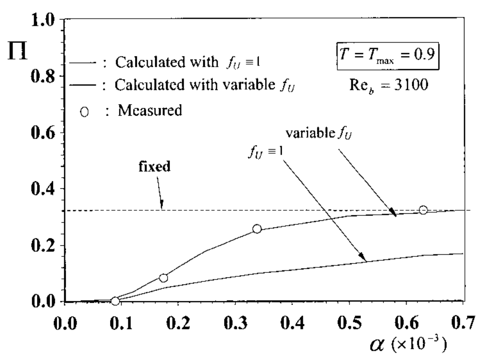

Fig. 2 Variation of Π with α

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