II－68 Fluid and Sediment Particle Velocity Distribution in the Bottom Boundary Layer

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INTRODUCTION

With respect to sediment transport modelling, the most important part of the flow is the bottom boundary layer through which the main flow influences the bed. The flow inside the bottom boundary layer is a complicated phenomenon, and the physical mechanism is not entirely understood at present. Few models have been proposed in order to simulate the hydrodynamic field in the bottom boundary layer and some of them still have problems in describing the real flow field in this area.

Due to practical difficulties involved with field experiments, only laboratory experimental work on bottom boundary layer has been carried out in recent times. Because of the difficulty of making measurements in the very thin layer near the bed, a highly sensitive equipment and measuring techniques are required. A very limited number of experiments are assumed to be truly reliable.

The purpose of this paper is to estimate the validity of a numerical model used to obtain the hydrodynamic field in the bottom boundary layer and compare it to the latest laboratory results and analyze the effect of sediment presence in the fluid on the hydrodynamic field.

THEORETICAL CONSIDERATIONS

The numerical model is developed to obtain the velocity profile inside the bottom boundary layer by Shibayama and Duy (1995). The flow inside the bottom boundary layer is assumed to be two-dimensional and the effect of breaking of waves is calculated by eddy-viscosity model. The governing equations for the flow in the region close to the bed are

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}-\frac{1}{\rho}\frac{\partial \tau_{zx}}{\partial z}=\frac{\partial u_e}{\partial t}+u_e\frac{\partial u_e}{\partial x} \qquad (2)$$

where x is positive in the direction of wave propagation, z is positive upward, t is the time, (u,w) is the Reynolds-averaged velocity vector inside the boundary layer, τ_{zx} is the Reynolds shear stress, ρ is the water density and u_e is the horizontal free stream velocity at the top of the boundary layer. In Eq. (2), the viscous stresses are neglected since they are very small compared to the Reynolds stresses under turbulence. Since the terms in the right hand side of the previously mentioned equation represent a kind of forcing factor as a result of the water motion outside of the boundary layer, it is therefore necessary to get the information regarding the free-stream velocity vector (u_e, w_e) both for the space and time variation. The values are obtained applying the model of Shibayama and Duy (1994) based on the 2DV Reynolds equations. The solution of this wave model (the time series of free stream velocities) is imposed as an upper boundary condition to solve the boundary layer flow.

The vertical boundary conditions for the bottom layer model are $u=0$ and $w=0$ at $z=0$ and $u=u_e$ and $w=w_e$ at $z\to\infty$ while at the shoreline and at the offshore boundary the horizontal velocity is assumed to have a logarithmic profile.

The Reynolds shear stress, τ_{zx} is expressed as

$$\tau_{zx}=\rho\nu_T\frac{\partial u}{\partial z} \qquad (3)$$

where ν_T represents the eddy viscosity. Since the variation of the latter is still not clearly understood, it was assumed that it is time-invariant and included in the model as

$$\nu_T=\kappa u_* z \qquad (4)$$

where κ is the Karman constant $(\kappa=0.4)$, u_* the friction velocity and z is the vertical elevation from the bottom. The friction velocity u_* is determined as

$$u_*=\sqrt{0.5 f_w u_{em}^2} \qquad (5)$$

in which f_w is the friction factor and u_{em} is the maximum horizontal free stream velocity.

COMPARISON BETWEEN NUMERICAL AND LABORATORY DATA

For the cases of the bottom boundary layer, the validity of the mathematical models can hardly be assessed because of the limited number of measurements available. Only a limited number of experiments dealing with the hydrodynamics of the bottom boundary layer have been performed. Ribberink et al. (1994) have investigated the full scale reproduction of the wave flow in the Large Oscillating Water Tunnel (LOWT) of Delft Hydraulics in Holland. During a set of experiments termed E1, non-linear second order Stokes waves were generated in the tunnel above a sandy bed ($d_{50}=0.21$ mm). The results of the measurements included time-series of intra-wave measurements of sediment concentrations, flow velocities and grain velocities in the sheet flow regime using advanced measuring techniques and equipment (laser Doppler velocity flow meters and high speed video recordings) . The authors analyzed data and obtained thus the equi-phase mean values for the time-series data. The grain velocities in the thin sheet flow layer were measured from detailed high speed video recordings (HSV).

Many of the numerical models dealing with sediment transport are calculating the sediment flux as a product of sediment concentration and velocity of sediment particle. The hydrodynamic modules usually calculate the fluid velocity field without considering the presence of sediment in the fluid. However, the majority of them assume as a simplification that the sediment particle has the same speed as the fluid particle. For the case of suspended sediment the assumption might hold to a better degree. For the case of the high sediment concentration in the region near the bed (bottom boundary layer), due to sustained sediment particle interaction and high viscosity of sediment-fluid mixture, assuming same values for water and sediment particles might be unrealistic. Therefore, a trial has been made in order to compare the results of the hydrodynamic numerical model with the actual sediment particle velocity.

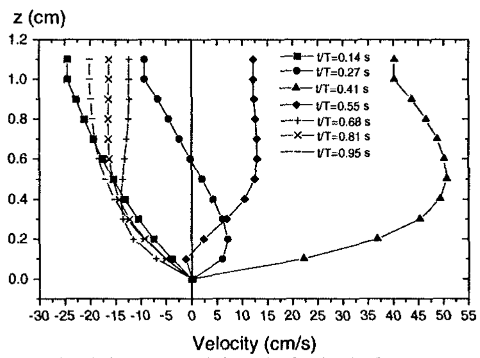

Fig. 1: Water particle velocity in the bottom boundary layer (BBL) - computation

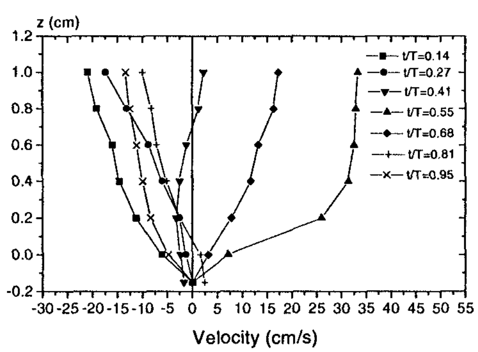

Fig. 2: Sediment particle velocity in the bottom boundary layer (BBL) - lab.experim.

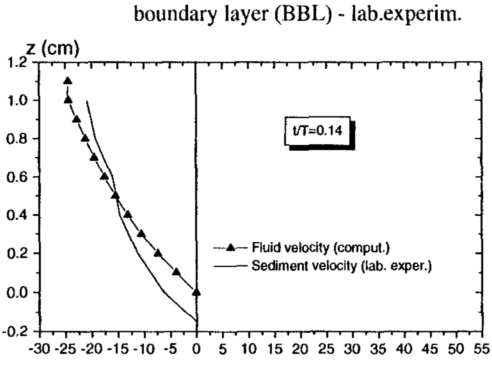

Fig. 3: Comparison between water and sediment particle velocities in the BBL

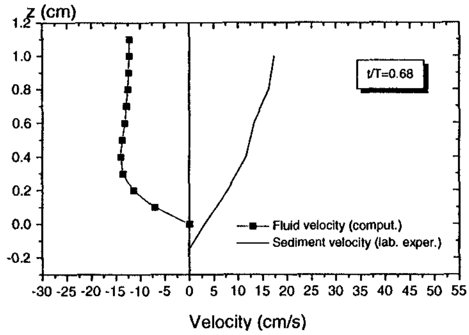

Fig. 4: Comparison between water and sediment particle velocities in the BBL

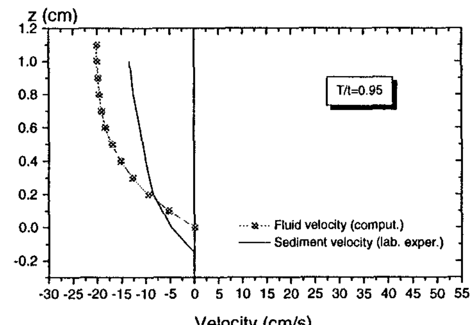

Fig. 5: Comparison between water and sediment particle velocities in the BBL

The comparison reveals the differences between the velocities of water and sediment particles during one wave cycle. At the beginning of the wave cycle the differences are practically not present, with an increasing value of the relative time (t/T), a different pattern can be observed. By the end of the wave period, the sediment particle velocity seems to get closer to the water particle one. Several reasons could be the cause of this behavior. First, the inertial force acting on the sediment particle is leading to obviously smaller values of their velocity. Secondly, the differences between water and sediment velocities appear especially during high gradients of water particle velocity, that is during the onshore directed movement in the wave cycle, while for the end of the wave cycle, velocities tend to have the same magnitude. One reason might be the smaller velocity gradients during the second half of the wave period. Thirdly, another explanation could be that the eddy viscosity used in the numerical model should be modified so as to include the real behavior of the fluid-sediment mixture.

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