# Time-Dependent Sediment Flux Within the Bottom Boundary Layer

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## INTRODUCTION

The flow field within the bottom boundary layer (BBL) has been a long time research subject for scientists concerned with fluid dynamics. Researchers understood that the sediment entrainment mechanism is strongly related to the flow field in the area close to the bed and that flow field calculation is a key in the sediment transport phenomena. However, the characteristics of the flow inside the BBL are somehow different from the classical one-directional steady flow conditions due to the oscillatory movement caused by wave action.

Another major problem facing the researchers dealing with the boundary layers flow field and sediment transport modelling is the scarcity of experimental, both field and laboratory, data to which the results of the numerical or analytical models to be compared with. The problem is mainly due to: (1) the limitations of the present measuring equipment and techniques used to sample the data in the highly turbulent flow regime and (2) the high concentrations of sediment particles which prevents accurate measurements in the area close to the bed. Most of the laboratory experiments for the BBL were performed using an added roughness to the bottom, without the presence of the sediments and only the flow field was measured and analyzed. For the existing laboratory data sets for the BBL, most of them obtained in oscillatory water tunnels, sediment concentration measurements were time-averaged values with only a few cases for time-dependent concentration measurements, and with no time-dependent sediment flux measurements. Measuring the time-history of sediment particle velocities also proved to be a difficult task to achive.

The present paper is presenting the results of a numerical model capable of computing the time-history of sediment flux inside the BBL. New laboratory data are used to verify the numerically obtained results and the validity of the model is discussed.

## SEDIMENT TRANSPORT MODEL

The 2DV (two-dimensional vertical) sediment transport model consists of two modules: (1) the *Hydrodynamic Module* and (2) the *Sediment Concentration Module*.

The **Hydrodynamic Module** is capable of computing the time-dependent flow field inside the boundary layer using the Navier-Stokes equations in their Reynolds averaged form

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

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

where $u$ and $w$: the horizontal and vertical components respectively of the Reynolds-averaged velocity vector inside the bottom boundary layer, $\tau_{zx}$: the Reynolds shear stress, $\rho$: the water density and $u_o$: the horizontal free stream velocity at the upper edge of the bottom boundary layer.

The **Sediment Concentration Module** is based on the two dimensional convection-diffusion equation and gives the time-dependent sediment concentration inside BBL.

$$\frac{\partial c}{\partial t}+\frac{\partial (uc)}{\partial x}+\frac{\partial (wc)}{\partial z}=\frac{\partial (w_s c)}{\partial z}+\frac{\partial}{\partial x}\left(\varepsilon_s\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial z}\left(\varepsilon_s\frac{\partial c}{\partial z}\right) \qquad (3)$$

where $c$: the equi-phase mean sand concentration, $u$, $w$: the equi-phase mean velocity components calculated in the hydrodynamic module for the bottom boundary layer, $w_s$: the mean fall velocity of sand and $\varepsilon_s$: the turbulent diffusion coefficient. An important assumption is that the eddy viscosity coefficient, $\nu_T$, used in the Hydrodynamic Module and the diffusion coefficient, $\varepsilon_s$, used in the Sediment Concentration Model are set to be equal. The eddy-viscosity is time-invariant but it varies vertically throughout the thickness of the BBL.

$$\nu_T=\kappa (u_*)_{\max} z=\varepsilon_s \qquad (4)$$

where $\kappa$: the Karman constant with a value of 0.4, $(u_*)_{\max}$ the maximum value of the friction velocity and $z$: the vertical elevation taken from the bottom. The diagram of the numerical model is presented in Fig. 1.

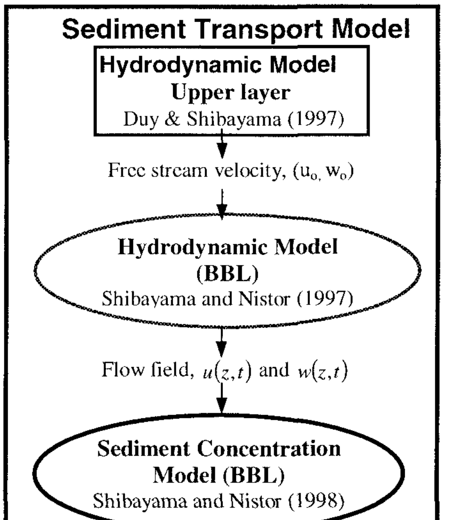


Fig. 1. Calculation of the time-dependent sediment flux inside the bottom boundary layer.

Another important assumption was that the velocity of the sediment particle is equal to the velocity of the fluid particle.

Having obtained the values of the time-dependent velocity flow and time-dependent concentration field, the sediment flux, $\phi(z,t)$, is calculated as

$$\phi(z,t)=u(z,t)c(z,t)/\rho_s \qquad (5)$$

where: $\rho_s$ : the sediment density. The time-dependent values of the sediment flux are compared to the laboratory data of Katopodi *et al.* (1994).

## VERIFICATION OF THE THEORETICAL MODEL

Measurements of sediment flux inside the bottom boundary layer have been hardly reported in literature. The reasons already were mentioned. The most up to date and reliable data the authors considered were the ones performed by Katopodi *et al.* (1994) at Delft Hydraulics, using a Large Oscillating Water Tunnel. The measurements were carried out for oscillatory flow conditions, on a sandy bed with sand particle diameter of $d_{50} = 0.21\,\mathrm{mm}$. The oscillation period for the analyzed case was $T = 7.2\,\mathrm{sec}$ while the thickness of the boundary layer was found to be $\delta = 20\,\mathrm{mm}$. The time-dependent sand flux was calculated multiplying the measured sand particle velocity with the sand concentration (both were time-dependent measured values). The sediment particle velocity was measured using HIV (High Speed Videorecordings) while the time-dependent sand concentration inside the BBL was measured using a CCM (Conductivity Concentration Meter). The results of the measurements are presented in Fig. 2.

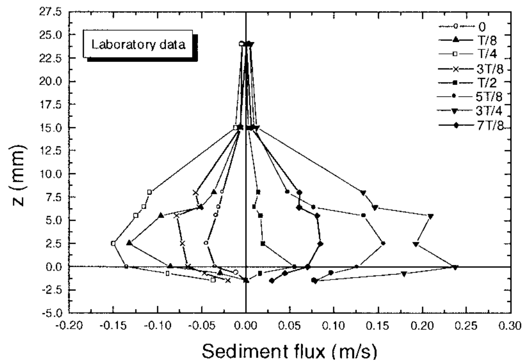


Fig. 2. Measured, phase-averaged sediment flux inside BBL (Katopodi *et al.*, 1994)

The numerical model assumes that the velocity of the fluid and sediment particle is the same. Therefore, the sediment flux (numerically calculated) presents some differences from the one calculated using laboratory data. Figures 3, 4 and 5 show the comparison between the numerically determined sediment flux values and the ones resulted from the laboratory data, for different phases within one period.

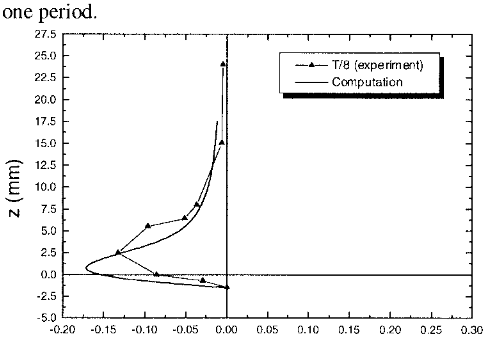


Fig. 3. Comparison between computed and laboratory determined sediment flux inside BBL

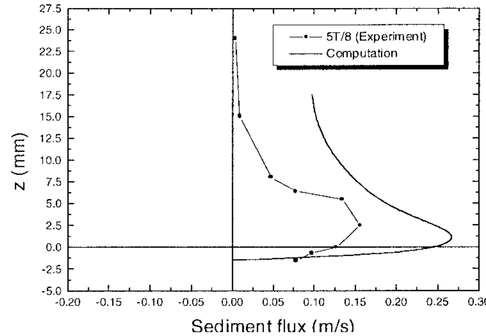


Fig. 4. Comparison between computed and laboratory determined sediment flux inside BBL

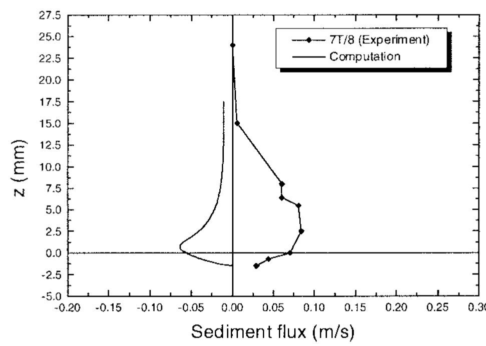


Fig. 5. Comparison between computed and laboratory determined sediment flux inside BBL

Several conclusions can be drawn as a result of the present comparison. One could notice the evolution of differences between the sediment flux computed values and the measured ones. If for the beginning of the wave period there is good agreement between the computed and measured values, with an increased value of the relative time (t/T), an larger phase lag occurs between the plotted data. The authors attribute the phenomenon to the followings. **Firstly**, the assumption made on the equality between the fluid and sediment particle velocities. This assumption might be questionable for the BBL area where the high regime of sediment particles interaction might reduce their energy and implicit their velocity, which will decrease, compared to the fluid particle velocity. **Secondly**, the sediment particle, due to its mass, experiences a "delay-time" caused by the inertial force acting on it. Inertial forces are large inside the BBL due to the strong velocity gradients leading consequently to large accelerations acting on the sediment particles.

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