別　紙　　　　　その１

論　文　の　内　容　の　要　旨

論文題目　　　Laboratory Experiments and Numerical Simulation on Sheetflow Sediment Movement

(和訳　シートフロー漂砂に関する実験と数値シミュレーション)

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Coastal processes include various aspects of surface wave and bottom sediment movement together with the interaction between them. Among them, sand transport is an essential link in the coastal morphodynamics related to the change of bottom topography. The present study is motivated by the increase in beach instabilities corresponding to the erosion and accretion courses around the world, and focuses on the cross-shore sand transport under various wave and current flow conditions in the sheetflow regime. Sheetflow transport develops under storm conditions when the Shields parameter becomes large (0.8-1.0) enough to wash out sand ripples and the bed turns to plane again. A thin layer (~ 1 cm) with high sand concentration is moving in a sheet along the bed.

The primary aim of the present study is twofold. The first objective is to increase insight in cross-shore sand transport processes under sheetflow conditions through physical experiments. The second objective is to apply the insight from experiments to develop a new theoretical model for numerical simulation through a two-phase flow conception on describing the cross-shore sediment movement.

Experimental approach

Sheetflow experiments were performed in the oscillatory flow water tunnel applying the pure sinusoidal wave condition. Two series of experiments were carried out with mobile sand beds consisting of well-sorted sand with different medium grain sizes: 0.21 mm and 0.3 mm. By using image analysis, which overcomes the demerits introduced by intrusive measurements, the timedependent as well as the maximum erosion depths for different flow conditions were estimated. In addition, one specified experiment was carried out in order to investigate the sediment concentration distribution and grain velocity variation. The experimental processes were recorded using a high-speed video camera.

From the experimental measurements, the erosion depth in the sheetflow transport varies significantly and never returns back to zero during one wave period. Temporal variation of the erosion depth is significant under the conditions of large velocity amplitude and short wave period. The relative maximum erosion depth is found related to the maximum Shield parameter linearly with a large linearity coefficient for fine sand.

Although the free-stream velocity is sinusoidal, the suspended concentration is asymmetric with large concentration values in the deceleration phase. The duration of the suspension is generally longer than sedimentation process reflecting the asymmetry in turbulence. The phase lag between concentration and free stream velocity is important for sediment movement and increases with the elevation.

The sediment velocity is determined using a PIV technique on the successive images. A sudden decrease in the bottom horizontal sediment velocity profile is observed at the beginning of acceleration phases corresponding to the sedimentation of a large amount of sand particles. Turbulence intensity is strong around maximum velocities and weak around flow reversals, which is consistent with the suspension and deposition processes.

Numerical simulation

Taking into account the sediment movement mechanism observed from the experimental study, a new two-phase flow model for fluid phase and sediment phase, was set up based on the conservation of mass and momentum in horizontal and vertical directions.

Compared with the practical quasi-steady and semi-unsteady models as well as traditional one-dimensional vertical models, the two-phase flow models are sophisticated models and circumstantiate the interactions between fluid and grain, the collision among grain particles, and can describe the sediment movement from the stationary sand bed, into the high-concentration sheetflow layer, and then upwards into the dilute suspended layer. Various forces, like the interaction force between the fluid and water, the intergranular stress among the sand particles, the turbulent stress in the fluid, the sediment diffusivity and pressure gradient are specified in the two-phase flow model. Reasonable numerical integrations together with the suitable boundary and initial conditions for simulation were proposed. The two-phase flow model proposed in the present study includes six governing equations with six unknown variables. The finite difference method is employed to solve these coupled nonlinear differential equations.

Preliminary descriptions on the model's results show the capability of the two-phase flow model for sediment movement simulation under the sheetflow conditions. It was found that anti-phase behaviour for concentration profiles together with large vertical concentration gradient was estimated in the sheetflow layer. Horizontal velocity difference between the fluid and sand is small with the largest discrepancy appearing in the sheetflow layer. At the bottom layer, the vertical instantaneous sediment velocity profile presents an upwardly convex ")(" shape in the low region and downwardly convex "()" tendency in the above region within one wave period. In the suspended layer, the magnitude of fluid velocity is always larger than that of sand velocity in the acceleration phase, and smaller in the deceleration phase. As for vertical velocity distribution, the upward flow is simulated around the initial bed level for fluid phase where significant decrease on the sand falling velocity can be observed. In the suspended layer, the sand falling velocity approaches to the free settling velocity of a single sand particle. Further discussions on the force terms governing the sand movement demonstrate that in the bottom sheetflow layer the intergranular stress gradient plays an important role for sand movement, whilst the pressure gradient affects the sediment dynamics significantly in the upper sheetflow region due to the counteraction between intergranular stress gradient and drag force. In the suspended layer, the drag force and pressure gradient are more crucial for sand movement.

The model's validation was carried out by comprehensive comparison between numerical simulation and experimental measurement. This included the verification on a large amount of up to date experimental data: Horikawa *et al.* (1982) for pure sinusoidal flows, Ribberink and Al-Salem (1995) for pure sinusoidal and asymmetric waves, Dohmen-Janssen (1999) for combined wave/current flows, O'Donoghue and Wright (2004a, 2004b) for asymmetric wave conditions and Liu and Sato (2005) for pure sinusoidal flows.

The comparison was carried out based on four aspects: the temporal and spatial sediment concentration configurations together with the mean concentration profiles, the detailed fluid and sand velocities profiles together with the mean velocity profile for combined wave/ current flows, the information on sediment flux structure and the net transport rate for combined wave/current flows and asymmetric wave conditions. The simulated solutions represent the main characteristics of sediment movement satisfactorily for most of the experimental cases. Overestimation on the net transport rate for combined wave/current flows is found, especially for fine sand with large current/wave velocity ratio cases. After some suitable modification on the expressions for eddy viscosity and sand diffusivity, the simulated net transport rate for asymmetric wave conditions is rather well compared with several previous empirical formulae. Both the magnitude and direction of the net transport rate can be estimated from the present model with an agreement by a factor of 2, especially for fine sand cases with an offshore directional net transport.