論文の内容の要旨

Abstract of Dissertation

Experimental and Numerical study on Sheetflow Sediment transport under Skewed-asymmetric Waves and Currents

(流速と加速度の非対称性を有する波動と流れのもとでのシートフロー漂砂に関する研究)

レ　プオン　ドン

In recent years, sheetflow sand transport regime has attracted the attention of many coastal engineers and scientists as it is predominant in the surf zone. Sheetflow conditions develop when the near bed velocity is large enough to wash out sand ripples and transport sand in a thin layer with high sand concentration along the bed. This sand transport regime involves very large net transport rates and thus results significant changes of the beach topography.

When waves propagate to the nearshore zone, their shapes gradually change primarily owing to the combined effects from wave shoaling, breaking, and nonlinear interactions. As waves enter the shallow water; their shapes evolve from sinusoidal to the pure velocity asymmetric waves with sharp crests separated by broad, flat wave trough in intermediate water depths. As waves continue to shoal and break, they transform through asymmetrical, pitched-forward shapes with steep front faces in the inner surf, to a pure acceleration asymmetric waves (pitched-forward) near the shore. In addition to the change of wave shapes, the interaction of nearshore waves and currents is also an indispensable hydrodynamic element in coastal regions. For example, the offshore-ward near-bottom current, referred to as undertow, develops to compensate the onshore flux caused by waves. This type of waves-currents interaction, however, is quite weak. In contrast, a strong interaction can be observed in the vicinity of river mouth. The existence of different wave shapes and their interactions with different magnitude currents may lead to the different sediment transport behaviors. Many laboratory studies have been conducted in the oscillatory flow tunnels with sinusoidal, pure asymmetric velocity waves and pure asymmetric acceleration waves. However, it is hardly found any experiment conducted with the combined velocity-acceleration asymmetric waves and with strong opposing currents. Thus, new prototype scale laboratory tests (53 tests) using different wave shape conditions with and without the presence of strong opposing currents were performed. These experiments were motivated by the fact that most natural waves in surf zone produce mixed skewed-asymmetric oscillatory flows

(Ruessink et al., 2009) and sand transport at the river mouth is influenced by the interaction of nearshore waves and strong river discharge.

Experimental results reveal that in most of the case with fine sand, the “cancelling effect”, which balances the on-/off-shore net transport under pure acceleration/velocity asymmetric waves and results a moderate net transport, was developed for combined asymmetric-skewed shaped waves. However, under some certain conditions (T > 5s) with coarse sands, the onshore sediment transport was enhanced by 50% under combined asymmetric-skewed waves. Additionally, the new experimental data under collinear waves and strong currents show that offshore net transport rate increases with decreasing velocity skewness and acceleration skewness.

Image analysis technique was employed to investigate major aspects of sediment transport under asymmetric-skewed waves and currents. Measured maximum erosion depths were found larger for shorter wave periods and for wave profiles with shorter time to maximum velocities. This suggested that faster flow acceleration could produce higher bed shear stress. In addition, it is found that the presence of a strong steady current which results in larger ratio u_c/u_w also increases the sheetflow layer thickness. It is because the appearance of currents in the opposite direction with waves could enlarge the available time length for flow erodes the sand bed and raises up sand to the maximum possible elevation. Thus, as a consequence it enlarges the sheetflow layer thickness.

A two phase flow model with calibrated turbulence closure terms was employed to get further insight sand transport mechanism. The simulated results agree well with observations. Analysis of forces acting on sand precisely shows that an increase of flow acceleration will increase applied forces on sand particles and hence the sand velocity travelling in the upper sheetflow layer. However, inside the pick-up region, due to high sand concentration, sand motions will be absorbed by the intergranular stress and as a result it increases the bed shear stress. In addition, the mobile bed effect were also confirmed by the two phase flow model and the Nikuradse bed roughness that is often estimated as of the order of the sheetflow layer thickness appears to be corrected.

Taking into account the effects of mobile bed and the flow acceleration, empirical formulas have been proposed to estimate bed shear stress, the maximum erosion depth and the sheetflow layer thickness. Sand transport mechanism was investigated by comparing the bed shear stress and the phase lag parameter for each half cycle. The “phase lag parameter” was modeled as the ratio between the sheetflow layer thickness and the settling distance. By analyzing the temporal brightness distribution at different elevations which corresponds to the distribution of suspended sand concentration, it is precisely found that phase lag is considered to be significant once it value exceeds 0.9. In such circumstances, the so-called “cancelling effect”, will occur. In contrast, in cases phase lag is small; the bed shear stress plays a more fundamental role as it causes an onshore enhancement for mixed shaped waves.

The new net transport rate measurements were compared with several net transport rate models (i.e, Watanabe and Sato, 2004; Silva et al., 2006; Van der A et al., 2010) and found that those approaches fails to deliver an accurate prediction. The reason is pointed out due to the inappropriate estimates of the representative suspension height in their models. Thus the new estimation for sheetflow layer thickness was incorporated in a new net transport rate model, based on Watanabe and Sato’s concept. The new model has been examined with comprehensive sheetflow experimental data and prediction skill over a wide range of hydraulics and sediment conditions shows that the new model fulfills for practical purposes and can be integrated into numerical morphodynamic models.