# Laboratory observations of turbulence and bed shear stress in the swash zone

［課程博士・論文博士共通］

# 博士学位論文内容要旨
# Abstract

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| 論文題目<br>Title | Laboratory observations of turbulence and bed shear stress in the swash zone<br>遡上帯における乱れおよび底面剪断応力に関する研究 | | |


This study presents detailed investigations of hydrodynamics of the flow induced by dam-break bores on an impermeable smooth slope with the main aim to improve the understanding of swash processes that characterizes the beach evolution.

As pointed out by many previous studies, the processes occurring at the edge of swash zone and in the initial stages of uprush and final stages of backwash may be the most important with regard to sediment transport but are most difficult to measure. To shed some light on these issues, laboratory experiments were carried out to resolve the velocity field evolution from the near initial uprush phases to the very late backwash phases in the upper swash zone. To this end, a high-resolution Particle Image Velocimetry (PIV) technique was specially developed. The current advanced PIV system was designed to achieve high temporal resolution using a continuous wave laser together with a high speed CCD camera capable of imaging 2000 frames per second so as to capture more instants of the short-lived upper swash event. Based on the fact that large vertical velocity gradients and small bed-normal velocities characterize the bottom boundary layer flow, a rectangle interrogation window with a longer dimension in the stream-wise direction and a smaller dimension in the span-wise direction compared with that used in previous studies were adopted to give a dense spatial resolution. The accuracy was improved by applying an iteration cross-correlation scheme based on adaptive Fast Fourier Transformation (FFT) algorithm which can accelerate the computation and overcome the circularity limitation of the normal FFT. With the aid of the spatial-temporal-resolved PIV system, velocity field in the aforementioned complicated flow conditions was successfully measured for the first time. No previous studies were done in such shallow swash zone because of the technique limitations.

The measured velocities then were ensemble-averaged based on at least 50 events to obtain the mean velocity distribution. The vertical structure of the velocity was investigated according to the mean even and an individual event that selected randomly. The backwash duration is longer than the uprush duration (85%) showing the natural characteristics of asymmetry in time in the swash zone. The velocity profiles are similar to previous studies with a typical shape of turbulent flow near the bed in the uprush phases and a wall-jet like flow in the backwash phase; the measured peak uprush velocity is larger than the measured peak backwash velocity (80%). Because of the high resolution, phase lead that the lower water reverses direction firstly with respect to the upper layer water flow is firstly found to last for nearly the whole backwash in the upper swash zone. This is very different from what have been observed in the inner swash zone, where the phase lead phenomenon only exists for a short time from the start of the backwash. One explanation is related to the fact that in the upper swash location there is not enough time for the backwash flow to reestablish the velocity profile especially for the upper layer flow. This will have important effects on the sediment transport since the suspend sediments gain from the lower location cannot be carried back resulting relative accretion here. Near-zero velocities close to the bottom in conjunction with lager velocities away from the bottom reveal that bottom boundary layer exists almost during the whole swash event. The properties of highly unsteady and

nonuniform complicates the finding of a clearly identifiable free stream velocity, thus leading to the difficulty in using the typical methods that employed in the steady flow to define the boundary layer thickness. Based on past studies, boundary layer thickness was determined by three methods so-called: log-profile based method, velocity gradient based method, and vorticity based methods. The results obtained from the three methods are consistent: the boundary layer thickness increases rapidly with the arrival of the incident bore and reaches the peak before flow reversal, then vanishes during the flow reversal and begins to increase again from the start of the backwash and finally becomes depth-limited during the late backwash phases because of the shallow water depth.

Although there is no consensus on decomposition method of turbulence, it is widely acknowledged that turbulence plays an important role in sediment transport. Ensemble average method and moving average method both were used to evaluate turbulent kinetic energy (TKE). Based on the ensemble average method, peak uprush TKE is 2 times larger than peak backwash TKE. In the early uprush, the TKE shows similar level in the near surface and close to the bottom, indicating a similar contribution of bore-generated turbulence and bed-generated turbulence. After the early uprush, both the surface and bed TKE injects into the water column, resulting a max TKE in the middle water layer. With surface TKE dissipating along the wave propagating, the TKE in the surface is about 60% of that near the bed in the mid to late backwash phases. Seen from the view of moving average method, peak uprush TKE is also 2 times larger than peak backwash TKE. However, both in the uprush and backwash, the surface TKE is only 15% of that near the bed, suggesting that in the shallow swash zone the bed-generated turbulence is dominant. Moreover, the depth-averaged TKE in the uprush and backwash using the moving average method is about 50 times smaller than that using ensemble averaging. By inspecting the PIV images and the corresponding velocity field visually and taking into account the measurement location, it seems that the result of moving average method is more reliable since the bore-related turbulence should only affect for a short period near the bore-collapse location.

Bed shear stress estimation is still debatable since there is no perfect formula that takes the characteristics of unsteady and nonuniform into consideration without any simplifications. Among others, the log-law method originally formulated for steady flows is the one that widely used mainly because it is easy to apply and can give acceptable results. In this study, bed shear stress is extensively studied using log-law, momentum integral and linear fitting methods. Results show that log-law estimates are of one order larger than other two methods and based on log-law peak uprush bed shear stress is about 2 times smaller than that in the backwash, which is contrast to previous results. The discrepancy is largely attributed to the different measurement locations. The corresponding friction coefficient is similar to previous studies, with a mean value of 0.018 during the uprush and 0.023 during the backwash. In the uprush, the friction coefficient varies dramatically, but it is almost constant during the backwash.

Detailed laboratory measurements of velocity field in the water column, especially within the bottom boundary layer in the upper swash zone were successfully measured using the high-resolution PIV technique. Extensive discussions were made on the velocity profiles, boundary layer thickness, turbulence distribution, and bed shear stress evolution. These novel results provide new insights into the swash processes when the local water flow is extremely shallow. Experiments considering the roughness and permeability with corresponding numerical models of phase-depth-resolving should be carried out to further extent the understanding of swash zone in the future.