#### Flow Structures in Swash Zone

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### Abstract

In order to understand the external and internal flow structures of broken waves on a sloping bottom, a special design of run-up gauge combined with LDV measuring system is used to detect the velocity fields of run-up and run-down in our experiments. According to the experimental results, it is found that the heights of run-up and run-down are mainly determined by incident wave steepness. The dimensionless heights of run-up, run-down and the related swash length for different wave breakers are also discussed respectively. In addition, the elaborate measurements of flow structures, turbulent intensity and Reynolds stress in swash zone are also analyzed in this paper.

## Introduction

The internal and external flow fields of swash zones were investigated on plunging breakers and spilling breakers. To understand the transformation processes of broken waves is of great importance for predicting wave-induced currents and sediment transport in the swash zones. Many researches, such as Hunt (1959), Battjes (1974), Kemp and Plinston (1968) and Fuhrboter (1986), have reported on the external flow fields in the swash zones, of which the relations between the uprush lengths, backwash lengths and wave conditions were proposed. On the other hand, only few researches have paid attention on the internal flow fields. Miche (1944) assumed that the uprush and backwash is a symmetrical cycle and obtained a formula to evaluate the run-up velocity. Kemp and Plinston (1974) proposed a model to calcuate the velocities of surging breakers. Kato and

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Matsuno (1986) used a high-speed camera to obtain the velocity profiles of the first broken wave from the taken images of released hydrogen bubbles.

The objective of this paper is to investigate the flow structures of swash zones. The uprush lengths, the backwash lengths and the velocities of broken waves along a slopping bottom are detected by a special design of run-up gauge combined with LDV measuring system, and the comparison between our experiments and previous studies are made in this paper. Furthermore, the turbulent intensity and Reynolds stress induced by the different wave breakers are also discussed.

### Experiments

The experiments were carried out in a wave flume of 950 cm in length, 70 cm in depth and 30 cm in width as shown in Fig. 1. Only one slope condition, 1/15, was conducted throughout the experiments. The wave body being very thin in swash zones, therefore, the velocities have to be measured by a 2-D laser Doppler velocimetry. Besides, a capacitance gauge leaning parallel with the sloping bottom was used to measure the uprush and backwash lengths. In order to avoid capillary effects, the gauge was carefully designed and installed on the sloping bottom until the recording signals were good performance.



Fig. 1 The Sketch of Wave Flume

The processes of run-up and run-down are recorded by capacitance gauge, and the relating velocity measurements are detected simultaneously by LDV system in this experiment. The typical spilling and plunging breakers are generated in wave flume.

All the test conditions and the arrangements of measured points are shown in Fig. 2. The shoreline, where the still water surface and the slopping bottom intersected, is defined as the origin of X axis, and the origin of Z axis is defined at the local bottom boundary upward.



CASE	T(sec)	H(cm)	$H_0/L_0$
B1	1.62	4.4	0.010862
B2	0.88	4.6	0.040604
B3	1.45	8.5	0.027647
B4	1.21	7.9	0.037627
_B5	1.20	3.6	0.014631
B6	0.91	8.3	0.063636
B7	1.04	6.4	0.042648
B8	1.33	4.7	0.018340
B9	1.60	4.3	0.011052
B10	1.10	10.4	0.059587

Fig. 2 Sketch of the arrangements of measured points

Based on the dimensional analysis, we obtained that the dimensionless run-up (Ru/H) and dimensionless run-down (Rd/H) are function of  $H/gT^2$ , H/L h/L,  $v\sqrt{gH}$  and tan $\theta$  respectively. Where, H is the incident wave height, T is wave period, L is wave length, h is water depth, v is water particle velocity and  $\theta$  is the angle of sloping bottom. Therefore, three kinds of water depths and the appropriate wave conditions are made in the experiments.

## **Results**

The flow fields of swash zone being so furious and chaotic that traditional analysis methods, such as the phase averaged method and the inverse fast Fourier transform method, are subject to overestimate or underestimate the turbulent components. It is consequent that a weight moving average method combined with modified phase average method is used to analyze the experimental data.

The results show that the uprush lengths are mainly associated with the incident wave steepness. For the both types of breakers, the dimensionless uprush height,  $R_u/H_o$ , decreases as the wave steepness increases, as plotted in Fig. 3. In addition, the dimensionless downrush height, Rd/H<sub>o</sub>, decreases as wave steepness increases for  $H_0/L_0>0.03$ , however, for  $H_0/L_0<0.03$ , the dimensionless downrush height decreases

as wave steepness decreases. The comparison between the experiments and the previous studies are displayed in Fig. 4. From the above two figures, the relationship between dimensionless height difference of  $(R_u - R_d)/H_o$  and wave steepness is plotted in Fig. 5. It shows that the experimental results are coincided with the empirical formula proposed by Battjes (1974) and Shuto (1984).



Fig. 3 The relationship between dimensionless uprush height and wave steepness

Fig. 4 The relationship between dimensionless downrush height and wave steepness



Fig. 5 The relationship between dimensionless height difference and wave steepness

Regarding the internal flow fields, Kemp and Plinston (1974) indicated that the whole water body moves, either shoreward or seaward, in the same direction in swash zone for surging breakers. While in our experiments of plunging breakers and spilling breakers, they show that both shoreward and seaward directions of flows are existent in swash zone simultaneously. The velocity profiles of different phases along the sloping bottom for plunging breakers are shown from Fig. 6(a) to 6(e). The different phases shown are referred to the locations of the wave tip where 6(a) is the phase of run-up beginning at t/T = 0.0, 6(b) is the phase of run-up moving at t/T = 0.18, 6(c) is the phase of approaching the highest run-up at t/T = 0.42, 6(d) is the phase of beginning backwash at t/T=0.6, and 6(e) is the phase of backwash at t/T=0.9. Furthermore, it is obvious that at  $X/L_i = -0.05$  where is located in the initial run-up region, most of the velocity profiles are moving on-shore except around the phase of t/T=0.42. This is resulted from the set-up of wave breaking. At the location of  $X/L_i = 0.00$ , it has similar phenomena, while the velocity profile is moving offshore only between the phase of t/T = 0.42 and t/T = 0.6. However, at  $X/L_i = +0.05$  where is located in the end of run-up region, most of the velocity profiles are moving offshore except from t/T=0.18 to t/T=0.42 are onshore.



Fig.6 Velocity profiles at different phases (case B7)

In order to obtain the relevant flow structures in swash zone, the on-shore extreme velocity profiles,  $\langle U \rangle^+$ , offshore extreme velocity profiles  $\langle U \rangle^-$ , horizontal mean velocity prifiles, U, and vertical mean velocity profiles,  $\overline{W}$ , of spilling and plunging breakers are plotted in Fig. 7 and Fig. 8 respectively. Herein, it is found that both of spilling and plunging breakers, the on-shore extreme velocities are larger than the offshore extreme velocities and the horizontal mean velocity profile is moving shoreward in the initial runup region. However, the offshore extreme velocities are larger than on-shore extreme velocities and the horizontal mean velocity profile is moving seaward in the end of runup region. Generally speaking, the uprush of the water body is mainly related to the onshore velocity and the phase celerity, while on the other hand, the offshore velocity and the gravity determine its backwash. The exchanges between kinetic energy and potential energy during the uprush and the backwash stages are of reason. Thus a retardation of velocities along the uprush process is expected, and vices versa. Fig. 9 shows that the mean velocities and the onshore extreme velocities decrease as x/Li increases. An interesting result is that the offshore extreme velocities also decrease as  $x/L_i$  increases, which do not follow our intuition to exhibit an opposite tendency with the onshore ones. Yet the backwashing water body is evidently not only controlled by the gravity but the propelling of the subsequent uprush water body which must be also taken into account.



Fig. 7 Extreme velocity profiles and mean velocity profiles at different locations on sloping bottom (case B7,  $H_0/L_0 = 0.042648$ )



Fig. 8 Extreme velocity profiles and mean velocity profiles at different locations on sloping bottom (case B8,  $H_0/L_0 = 0.018340$ )

The turbulent flow in swash zone is created by wave breaking, bottom boundary and the mixing during the processes of uprush and backwash. According to LDV measurements, the Reynolds stress of plunging and spilling during the wave period are displayed in Fig. 10 and Fig. 11 respectively. It is evident that the maximum Reynolds stress almost occurs at the phase of backwash stage, and the Reynold stress of plunging breaker is bigger than that of spilling breaker.



Fig. 9 The onshore, offshore extreme velocities and the mean velocities along the slopping bottom (case B2)



Fig. 10 The Reynolds stress during a wave period (plunging  $H_0 / L_0 = 0.01834$ )



Fig. 11 The Reynolds stress during a wave period (spilling  $H_0 / L_0 = 0.05958$ )

# **Conclusions**

The swash height and the velocities of broken waves along a slopping bottom are recorded and analyzed. The remarkable conclusions are as follows:

- 1. The run-up heights decrease as the wave steepness increase for the both types of breakers.
- 2. The moving direction of the water body of a spilling-plunging breaker shows that both shoreward and seaward movements are existent simultaneously either in the uprush or backwash stages, which is not consistent with that of a surging breaker described by Kemp and Plinston(1974).
- 3. The mean velocities, the onshore extreme velocities and the offshore extreme velocities all decrease as  $x/L_i$  increases.
- 1. The maximum Reynolds stress almost occurs at the phase of backwash stage, and the Reynold stress of plunging breaker is bigger than that of spilling breaker.

# References

- 1. Hunt, I. A. (1959), Design of seawalls and breakwaters, Proc. ASCE, 85, ww3, pp.123-152.
- 2. Battjes, J. A. (1974), Surf Similarity, Proc. 14th Coastal Engineering Conference, pp.466-479.
- 3.Kemp, P. H., Plinston, D. T. (1968), Beaches produced by waves of low phase difference, Proceeding of ASCE, Journal of Hydraulics Division, pp.1183-1195.
- 4. Fuhrboter, A. (1986), Model and prototype tests for wave impact and run-up on a uniform 1:4 slope, An Int. Journal for Coastal Harbor and Offshore Engineering, vol.10, pp.49-84.

- 2. Kemp, P.H., Plinston, D. T. (1974), Internal velocities in the uprush and backwash zone, Proc. 14th Coastal Eng. Conf., pp.575-585.
- Kato K. and A. Mano, (1986), Velocity measurement in Wave Tip Running Up on a Dry Bed, Proc. of Coastal Engineering, JSCE, vol.33, pp.76-79.
- 7. Shuto, N. (1967): Run-up of long waves on a sloping beach, Coastal Engineering in Japan, Vol. 10 pp. 23-38.
- 8. Nadaoka, K., Kondoh, T. (1982): Laboratory measurements of velocity field structure in the surf zone by LDV, Coastal Engineering in Japan, Vol. 25 pp. 125-145.