CHAPTER 249

Wave Boundary Layer Flows and Pore Pressures in Permeable Beds

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Abstract

The boundary layer flows and wave-induced pore pressures inside porous beds are both investigated in wave tank. Two kinds of porous beds are composed of two different grades of quartz sands which the porosities are 0.437 and 0.472 respectively. According to the experimental results, it is found that the larger pore pressure in permeable bed is induced by the longer wave period, and the pore pressure has an exponential attenuation with the wave steepness increasing.

From the elaborate measurements in the boundary layer, the overshooting induced by wave motion is effected by bed porosity and it becomes smooth. In the experimental cases, the maximum horizontal overshooting occurs at $\tilde{Z}/\delta \approx 1.2$,which is lower than the impermeable case of $\tilde{Z}/\delta \approx 2.7$ obtained by Hwung and Lin (1989). Furthermore, the vertical overshooting has also been found in our experiments.

Introduction

The natural sea beds are usually permeable, however, most investigations about the bottom wave boundary layer flow were conducted on rigid impermeable beds. Longuet-Higgins (1953, 1958), Collins (1963), Jonsson (1966), Kajiura (1968) and so on, analyzed the characteristics of boundary layer flows with linear or nonlinear wave theory in uniform water depth. Furthermore, Du Toit and Sleath (1981), Sleath (1982, 1984, 1987), Hwung and Lin (1989) and other investigators detected the velocity profile of boundary layer on rigid bottom.

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Concerning the pore pressure induced by wave motion in permeable bed, many researchers have paid more attention on the theoretical studies, such as Putnam (1949), Sleath (1970), Liu (1973) and so on. However, only a few of experimental studies has been done in the past years. Therefore, the elaborate experiments including the pore pressure and boundary layer flow in permeable beds have been carried out in this paper.

Experimental set-up

Two different grade of quartz sand of which the porosities are 0.437 and 0.472 respectively, are used in the experiments. The wave flume and related facilities are schematically illustrated in Figure 1. Within the wave flume, a section which 120 cm x 30 cm x 26 cm is filled with quartz sands as the testing section. Four pore pressure transducers are buried inside the porous bed to measure the pore pressure, while a Laser-Doppler velocimetry is used to detect the velocities above the porous bed. The enlargement testing section with the experimental installation are shown in Figure 2.

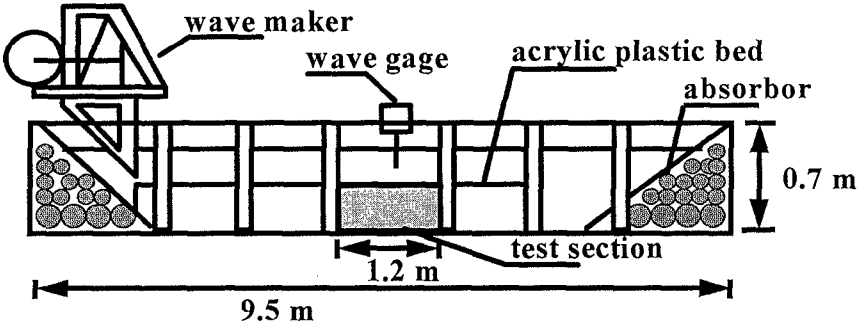


Fig. 1 The layout of wave flume

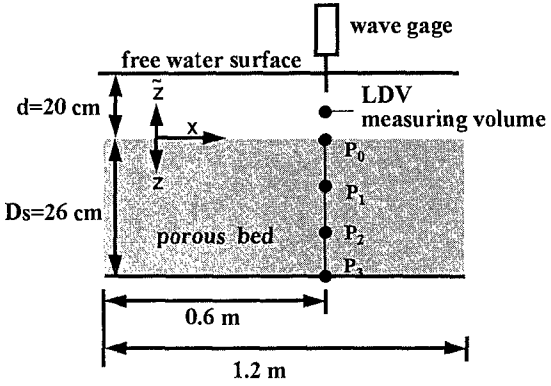


Fig. 2 The installation of test section

Herein, there are three kinds of experimental wave conditions listed in Table-1.

Table-1 The experimental wave conditions

Test Cases	T (sec)	d (cm)	H (cm)	H/L
Case 1	1.00	20	5.0	0.041
Case 2	0.95	20	7.0	0.062
Case 3	1.20	20	5.0	0.033

Results and Discussions

According to the experimental results, Figure 3 shows the original measurements of water surface elevation and horizontal, vertical velocities. Due to the wave reflection and boundary turbulent effect, we can see the fluctuations are existed in the velocity measurements. And Figure 4 is the original measurements of water surface elevation and the corresponding dynamic pore pressure. It is obviously to see that the dynamic pore pressure is decreasing from surface to bottom.

From the above original measurements, it shows that the length of each wave cycle in wave flume is not exactly the same due to wave reflection. This phenomena will lead to phase time shifting and create a false image of wave component by the phase average method. Therefore, according to the modified phase average method proposed by Hwung *et al.* (1988), the quantities of phase average can be express as

$$\langle Q \rangle = \frac{1}{N} \sum_{j=1}^{N} \tilde{Q}\left(\frac{T_J}{T} \cdot t_i\right) + \overline{Q} \qquad i = 1 \sim M$$

where $\langle Q \rangle$: the quantities of phase average,
$\tilde{Q}$: the quantities of wave component,
$\overline{Q}$: the quantities of time average,
N : numbers of testing wave cycle,
M : numbers of phase time within one wave cycle.

After using the modified phase average method, the water surface elevation, velocities and dynamic pore pressure measurements are shown in Figure 5 and Figure 6 respectively, and the quantities of velocities and dynamic pore pressure at any phase time can be calculated from the above figures.

From the above measurements and analysis, we obtained the relationship between dimensionless pore-pressure attenuation and wave period for the two different quartz sands in Figure 7. It shows that the pore pressure increases linearly as

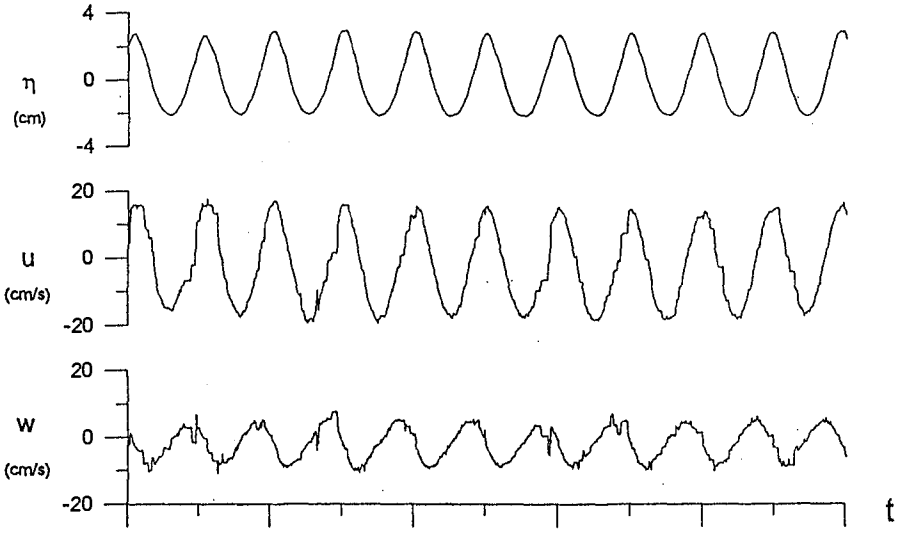


Fig. 3 The surface elevation and velocity measurements

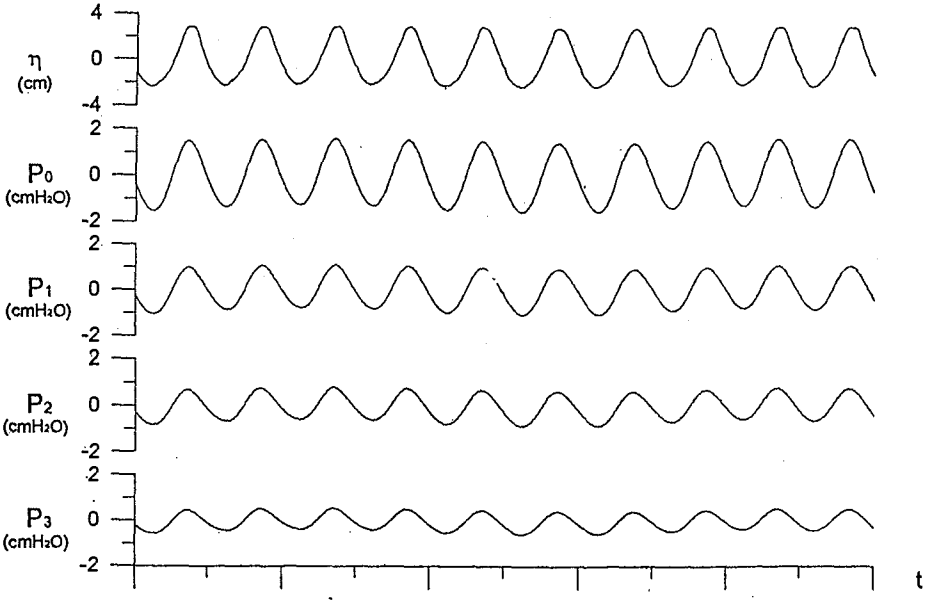


Fig. 4 The surface elevation and pore pressure measurements

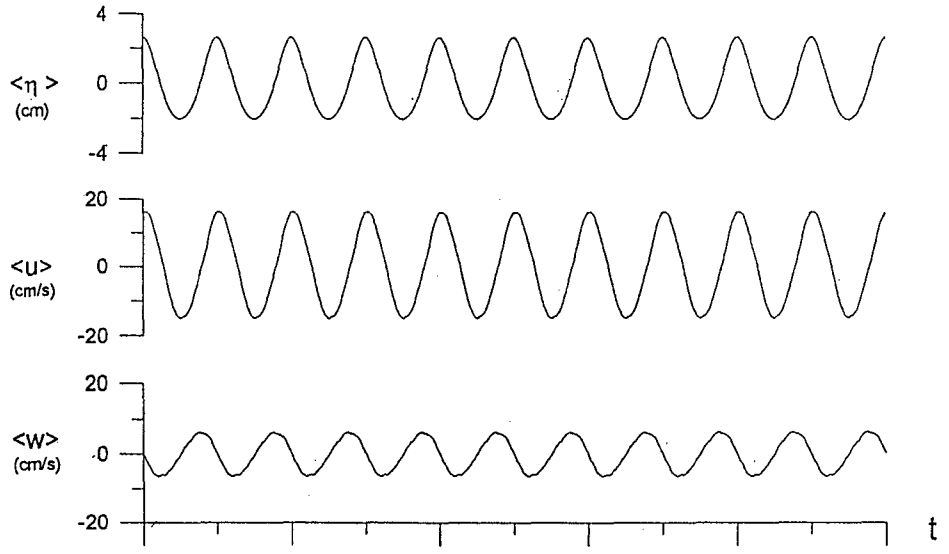


Fig. 5 The surface elevation and velocity measurements of the modified phase average

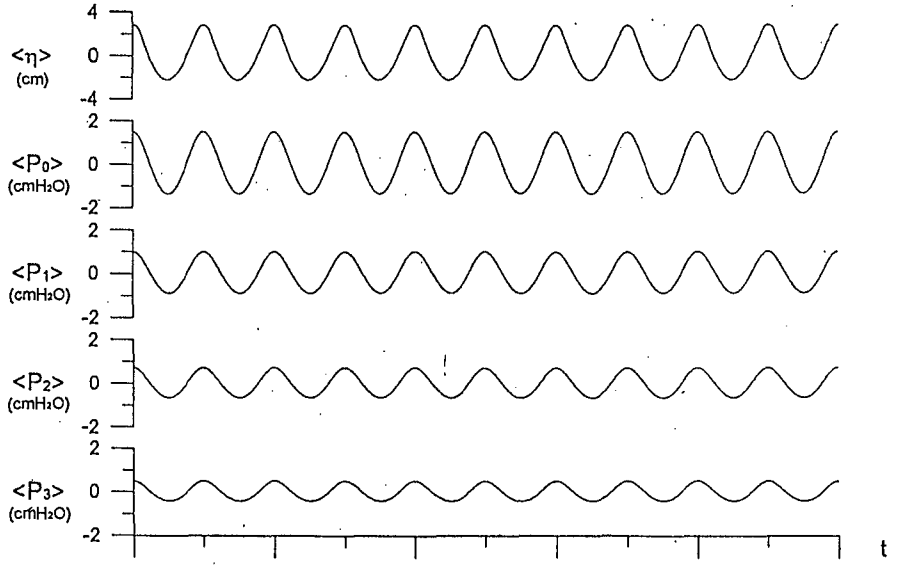


Fig. 6 The surface elevation and pore pressure measurements of the modified phase average

wave periods increasing, and the larger porosity bed has larger pore pressure at the same permeable depth. Besides, Figure 8 shows the relationship between dimensionless pore pressure attenuation and wave steepness. From the results, we found that the pore pressure decreases as wave steepness increasing, and it seems to have an exponential attenuation in this figure.

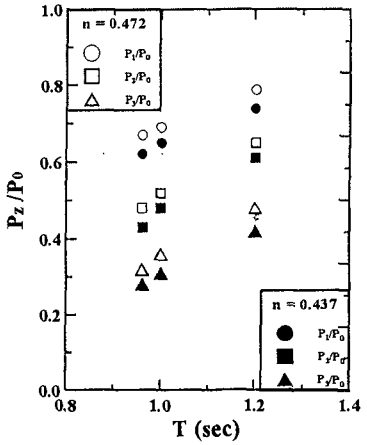


Fig. 7 The relationship between pore pressure attenuation and wave period

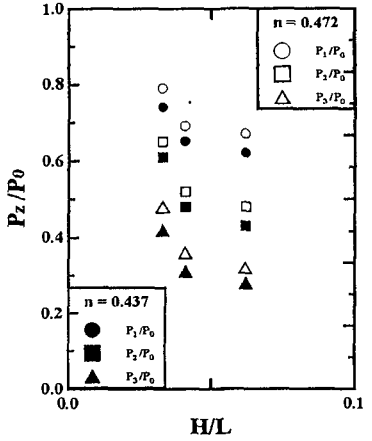


Fig. 8 The relationship between pore pressure attenuation and wave steepness

In addition, we also made the comparison between the dynamic pore pressure and previous theoretical studies as shown in Figure 9. We see that it has similar variation for the measurements and theoretical values, however, there is a little difference at the bottom due to the reflection of rigid bed.

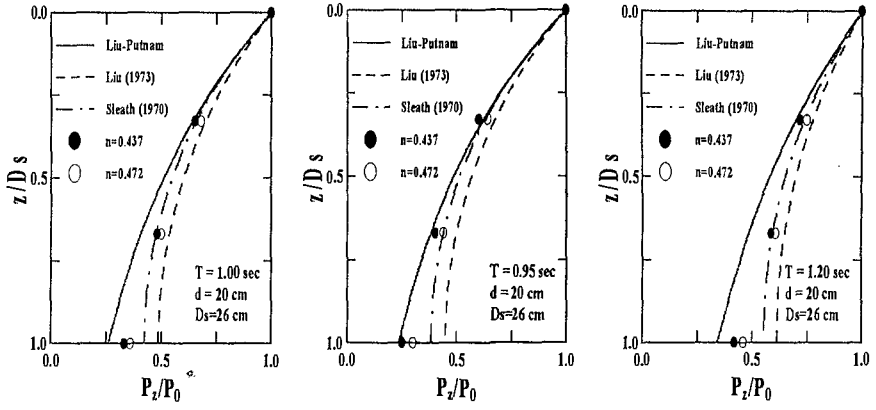


Fig. 9 The comparison between pore pressure measurements and theoretical values

In order to understand the boundary flows on permeable beds, a two-dimensional LDV system was employed to detect the horizontal and vertical velocities simultaneously. Figure 10 shows the horizontal velocity distributions on the permeable bed of porosity is 0.437 at seven different time phases. We can see that it also has overshooting in the boundary layer at $\tilde{Z} / \delta \approx 1.2$, and it is less than on rigid smooth bottom which the overshooting is at $\tilde{Z} / \delta \approx 2.7$ obtained by Hwung and Lin (1989). Figure 11 shows the horizontal velocity distributions on the permeable bed of porosity is 0.472 at different time phases. And the overshooting phenomena disappears in this larger porosity case.

Further, the extreme horizontal velocity distributions of all experiments are plotted in Figure 12, we can see that the overshsooting phenomena in the boundary layer is clearer in shorter wave period and the overshsooting disappears in longer wave period. The another cases of the extreme horizontal velocity distributions on the permeable bed of porosity is 0.472 as shown in Figure 13. From the comparison with Figure 12, we see that the boundary layer flows are more uniform in larger porosity bed.

Finally, the extreme vertical velocity distributions in bottom boundary layer on the permeable beds are shown in Figure 14 and Figure 15 respectively. It is interesting to see that the velocity in lower layer are larger than in upper layer within the boundary layer, and the velocities are more scattering due to the effect of vertical low passing through the porous material. From the vertical velocity distribution, we found the overshooting phenomena also occurs in porous bottom boundary layer.

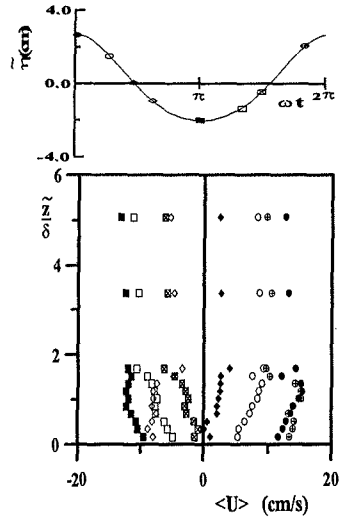


Fig. 10 Case 1, The horizontal velocity distributions on permeable bed of n=0.437

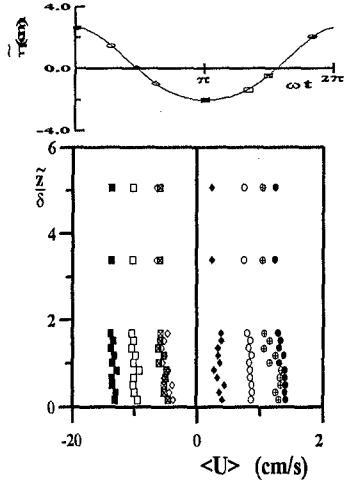
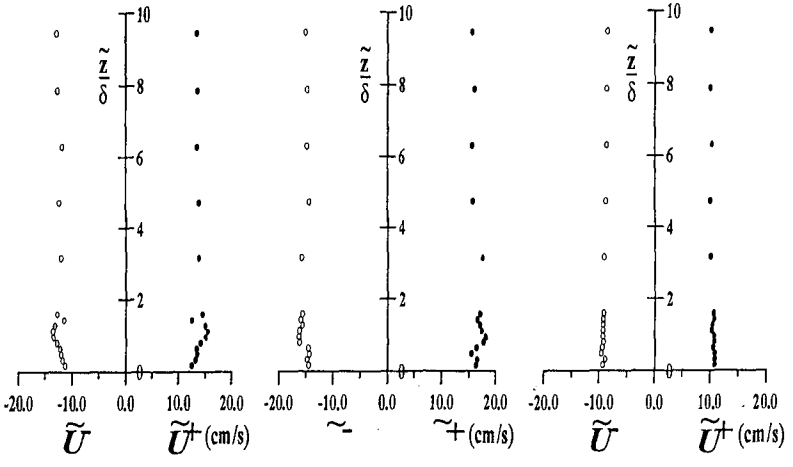
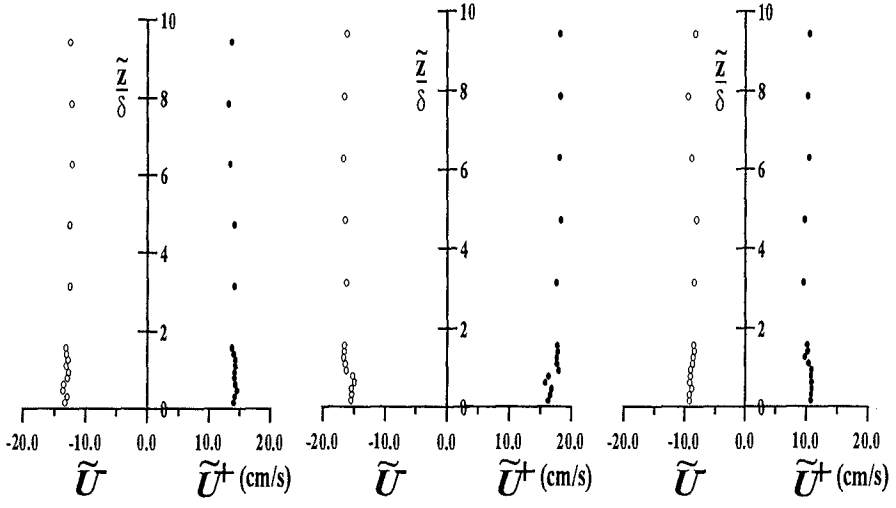


Fig. 11 Case 1, The horizontal velocity distributions on permeable bed of n=0.472



Case 1 Case 2 Case 3

Fig. 12 The extreme horizontal velocity distributions on permeable bed of n=0.437



Case 1 Case 2 Case 3

Fig. 13 The extreme horizontal velocity distributions on permeable bed of n=0.472

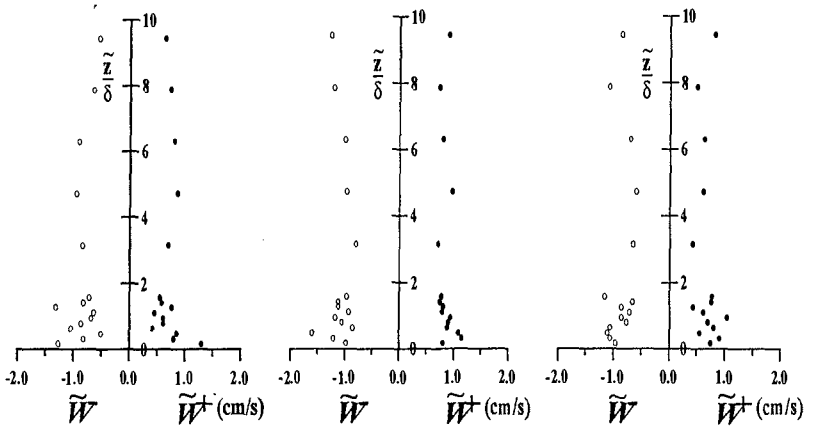


Fig. 14 The extreme vertical velocity distributions on permeable bed of n=0.437

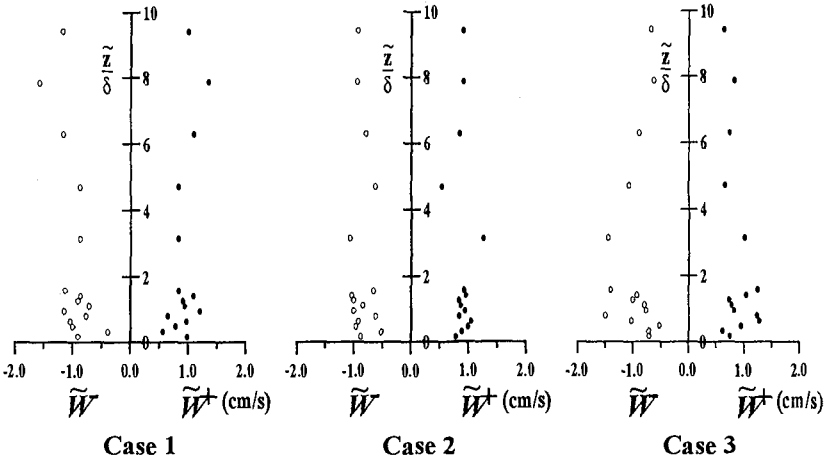


Fig. 15 The extreme vertical velocity distributions on permeable bed of n=0.472

Conclusions

The results summarized above indicate that the permeability of the bottom would result in interesting phenomena in wave boundary flows and dynamic pore pressure. Some remarkable conclusions would be described as follows:

1. In permeable beds, the larger pore pressure is induced by the larger wave period, and the dynamic pore pressure decreases exponential with the wave steepness increasing.

2. On the same wave condition, the larger porosity bed has larger dynamic pore pressure.

3. In the boundary layer, the horizontal overshooting induced by wave motion is influenced by bed porosity and becomes smoother. In our experimental cases, the maximum horizontal overshooting occurs at $\tilde{Z}/\delta \approx 1.2$, which is lower than the impermeable case of obtained by Hwung and Lin (1989).

4. From the vertical velocities measurements, we found that the vertical overshooting phenomena also occurs within bottom boundary layer.

References

1. Longuet-Higgins, M.S. (1953): Mass transport in water waves, Phil. Trans. Royal Society of London, Series A, No. 903 Vol. 245, pp. 535-581.

2. Longuet-Higgins, M.S. (1958): The mechanics of the boundary-layer near the bottom in a progressive waves, Proceedings of the 6th International Conference of Coastal Engineering, pp. 184-193.

3. Collins, J.I. (1963): Inception of turbulence at the bed under periodic gravity waves, J. Geophysical Research, Vol. 68, pp. 6007-6014.

4. Jonsson, I.G. (1966): Wave boundary layers and friction factors, Proceedings of the 10th International Conference of Coastal Engineering, pp. 127-148.

5. Kajiura, K. (1968): A model of the bottom boundary layer in water waves, Bull. Earthquake Research Inst., Vol. 46, pp. 75-123.

6. Du Toit and J.F.A. Sleath (1981): Velocity measurements close to rippled beds in oscillatory flow. Journal of Fluid Mechanics, Vol. 112, pp.77-96.

7. Putnam, J.A. (1949): Loss of wave energy due to percolation in a permeable seabed, Trans. Am. Geo. Un., 30, pp. 349-356.

8. Sleath, J.F.A. (1970): Wave-induced pressure in beds of sand. J. Hyd. Dvi., ASCE, 96, HY2. pp.367-378.

9. Liu, P.L.F. (1973): Damping of water waves over porous beds. J. Hyd., Div., ASCE, 99, HY12, pp.2263-2271.

10. Sleath, J.F.A. (1984): ***Sea Bed Mechanics.*** John Wiley & Sons, Inc. Press.

11. Hwung H.H., S.C. Wang and C. Lin (1988): The investigation of turbulent characteristics in the surf zone by LDV, Proceedings of the 10th Conference on Ocean Engineering in Republic of China, pp. 17-34.

12. Hwung, H.H. and C. Lin (1989): The experimental study on the boundary layer flow of waves propagating on a sloping bottom, The Chinese Journal of Mechanics, Vol.5, No.1, pp.67-76. (in Chinese)