

Maximum Run-up on the Movable bed of Uniform Materials

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ABSTRACT

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The characteristics of maximum run-up on the movable bed of various medium materials were investigated in this study. Six different medium diameters of uniform materials ($D_{50} = 0.15, 0.54, 1.02, 1.39, 2.68$ and 4.84 mm respectively) were used to construct the movable bed with a slope of $1/15$ within the wave flume. In these experiments the topographical profile, wave shoaling and run-up were measured over various durations by generating irregular waves over 20 types of wave conditions. The effects of wave duration and medium diameter on the maximum run-up were initially analysed, with the results showing that under the same wave conditions the foreshore slope and maximum run-up on the movable bed would become steeper and higher with increasing wave duration before the topographical profile tended to stabilise. Hence, the varied profile of the movable bed should be measured at the various wave durations and used to estimate the height of maximum run-up. It is shown that the relative maximum run-up $R_{max}/H_{s,0}$ decreased as the medium diameter of the movable bed increased. Furthermore, considering the influence of roughness factor on the movable bed, a modified factor was led to MASE's empirical formula (1989) and was used to effectively estimate the maximum run-up on the movable bed.

ADDITIONAL INDEX WORDS: *Equilibrium beach profile, equivalent slope, roughness, wave duration.*

INTRODUCTION

The height of wave run-up would be influenced by several factors such as wave conditions, water depth, permeability and roughness at the bed as well as the topographical shape in the shallow water etc. Research on wave run-up on the slope, the effects of the incident wave and the smooth slope and surface roughness had already been investigated in detail; for example, SAVILLE (1956), AHREN (1981), MASE (1989), VAN DER MEER and STAM (1992), HEDGE and SRINIVAS (1995). In regard to the effect of the topography at the shallow depth, the concepts of equivalent slope were proposed to analyse the wave run-up on the composite slope (DE WAAL and VAN DER MEER, 1992; VAN GENT, 2001; MASE, MIYAHIRA and HEDGES, 2004).

Most previous research on wave run-up focussed on the fixed bed. The studies about the influence of roughness or permeability on the wave run-up were largely limited to the case of the dyke. This study investigates the maximum run-up on a movable bed with various uniform materials by carrying out a series of irregular wave model tests within a 2D wave flume. In the experiments the profile change, wave shoaling and run-up were measured over various durations for more than 20 types of wave conditions. The effects of wave duration and medium diameter on maximum run-up were then analysed and discussed.

EXPERIMENT SET-UP

The physical model tests were carried out in a $40 \text{ m} \times 1 \text{ m} \times 1.2 \text{ m}$ wave flume at The Department of Hydraulic and Ocean Engineering, National Cheng Kung University. A beach with a

slope of $1:15$ had been constructed within the wave flume, beginning 18.6 m from the wave generator. For all tests, the water depth was maintained at 80 cm in the constant depth section. A schematic diagram of the experimental arrangement is shown in Figure 1.

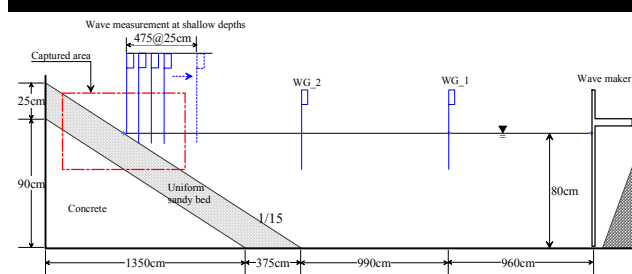


Figure 1. Schematic diagram of the experimental arrangement

In the tests, six different medium diameters of uniform materials ($D_{50} = 0.15, 0.54, 1.02, 1.39, 2.68$ and 4.84 mm respectively) had been used to construct the uniform bed at a slope of $1/15$ in the wave tank. Figure 2 shows the distribution of grain sizes for the six different medium diameters of uniform materials. The wave periods were in the range of $1.2 \sim 1.9$ sec, with the wave steepness being between 0.01 to 0.05 .

Table 1: Maximum run-up (R_{max}) and foreshore slope (1/N) versus various medium diameters of the movable bed at various durations

D_{50} (mm)	$H_{s,o}$ (cm)	T_o (sec)	Types of equilibrium beach profile	Foreshore slope (1/N)			R_{max} (cm)			Ratio	
				initial	12 hr	20 hr	initial	12 hr	20 hr	$R_{max} (12hr/initial)$	$R_{max} (20hr/initial)$
4.84	7.5	1.2	Deposition	15.0	2.8	2.2	5.0	8.0	9.0	1.60	1.80
2.68	7.5	1.2	Deposition	15.0	2.0	1.8	6.0	12.0	13.0	2.00	2.17
1.39	7.5	1.2	Deposition	15.0	2.1	2.2	8.0	14.0	16.5	1.75	2.06
0.54	7.5	1.2	Neutral	15.0	7.3	6.3	8.0	10.0	10.0	1.25	1.25
0.15	7.5	1.2	Erosion	15.0	5.5	5.7	8.5	8.0	8.5	0.94	1.00
4.84	7.3	1.4	Deposition	15.0	2.0	2.2	8.5	10.5	11.5	1.24	1.35
2.68	7.3	1.4	Deposition	15.0	2.3	2.4	10.0	13.0	15.0	1.30	1.50
1.39	7.3	1.4	Deposition	15.0	2.2	2.2	11.0	14.0	19.5	1.27	1.77
1.02	7.3	1.4	Deposition	15.0	3.1	3.3	9.5	13.0	13.5	1.37	1.42
0.15	7.3	1.4	Erosion	15.0	7.2	7.1	9.0	11.5	12.0	1.28	1.33

In each test run, a CCD video camera (SHOWCASE K-ZC231N) was set near the shoreline to capture the variation of wave run-up, with a rate of 20 frames per second. In the images of wave run-up, the resolution of each pixel was about 5 mm. In the meantime six capacitance wave gauges, each with a resolution of about 0.5 mm, were used to measure the wave height and period in the deep water and the shallow zone by a sampling rate of 20 Hz. The sand profile meter (which had a resolution of about 1 mm) was employed to measure the beach profiles at the durations of 0, 3, 12 and 20 hours in the wave generating procedure.

DISCUSSION

Relationship between maximum run-up and topographical profile change

The relationship between topography profile and various medium diameters was discussed in detail (LAI, KUO and CHIEN, 2005). In this section, two examples with wave conditions of $H_{s,o} = 7.5$ cm, $T_s = 1.2$ sec and $H_{s,o} = 7.3$ cm, $T_s = 1.4$ sec were presented to describe the relationship between maximum run-up versus topographical profile change. The height of maximum run-up (R_{max}), foreshore slope (1/N) in the movable bed of the various medium diameters at the various wave durations and the types of equilibrium profile were shown in Table 1. The types of equilibrium beach profile were analysed by SUNAMURA and HORIKAWA (1974) empirical formula, which was defined as:

$$H_{s,o} / L_o \geq C(\tan \theta)^{-0.27} (D_{50} / L_o)^{0.67} \quad (1)$$

where $H_{s,o}$ is the incident wave height; L_o is the wave length; θ is the bottom slope; and C is a dimensionless constant. For the types of equilibrium beach profile, $C > 8$ is the erosion case; $4 < C < 8$ is the neutral case; and $C < 4$ is the deposition case. Figure 3 shows the schematic diagram of equilibrium beach profile.

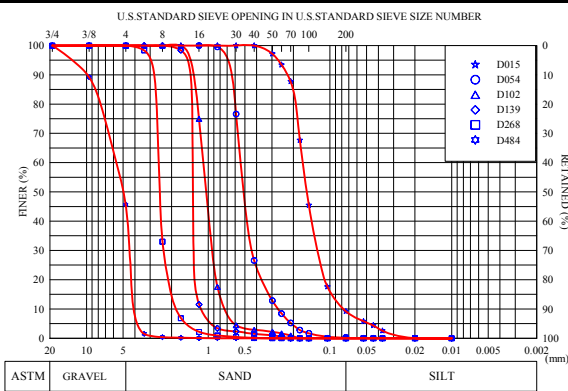


Figure 2. Distributions of grain sizes in six different medium diameters of uniform materials

WAVE AND RUN-UP PROCESSING

The wave data were analysed by the zero-up crossing method and separated into individual waves. The representative values of (T_{max} , $T_{1/10}$, $T_{1/3}$ and T_{mean} , etc.) were then derived from the statistics' wave heights (H_{max} , $H_{1/10}$, $H_{1/3}$ and H_{mean} , etc.) and wave periods method.

In the section of wave run-up analysis, run-up image data were adjusted with a series of processes such as digital transformation, geometric calibration, image reconstruction, time-stack image, image enhancement, edge detection and data extraction, etc (HOLLAND, HOLMAN, LIPPMANN, STANLEY and PLANT 1997; AAGAARD and HOLM, 1989; KUO, CHIEN and LEE 2005; KUO, HAN and CHIEN 2006). The heights of run-up could then be obtained.

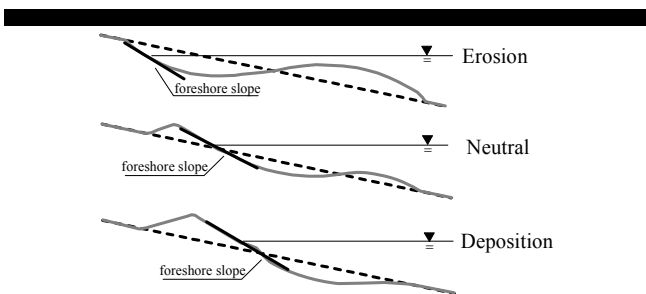


Figure 3. Schematic diagram of equilibrium beach profile

The ratios of maximum run-up at wave durations of 12 and 20 hours versus one at the various medium diameters of the movable bed on the initial topography ($R_{max} (12hr/initial)$ and $R_{max} (20hr/initial)$) were also shown in Table 1. Furthermore, topographical profile change and wave height in the shallow zone at the various durations were plotted respectively for the various medium diameter in Figures 4 and 5 (in different wave periods).

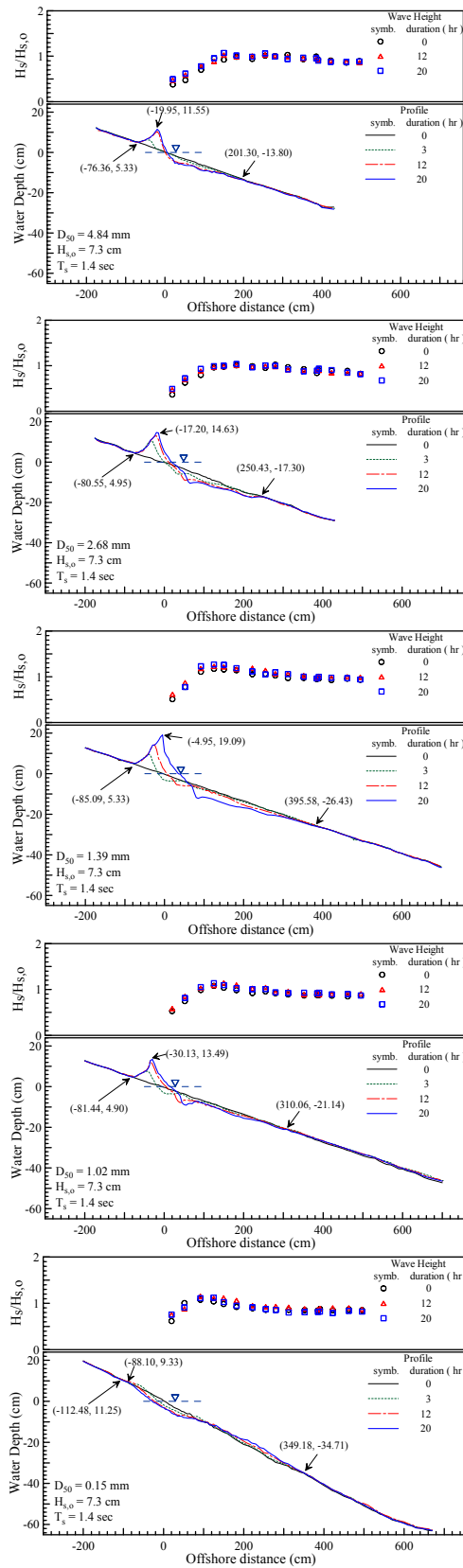
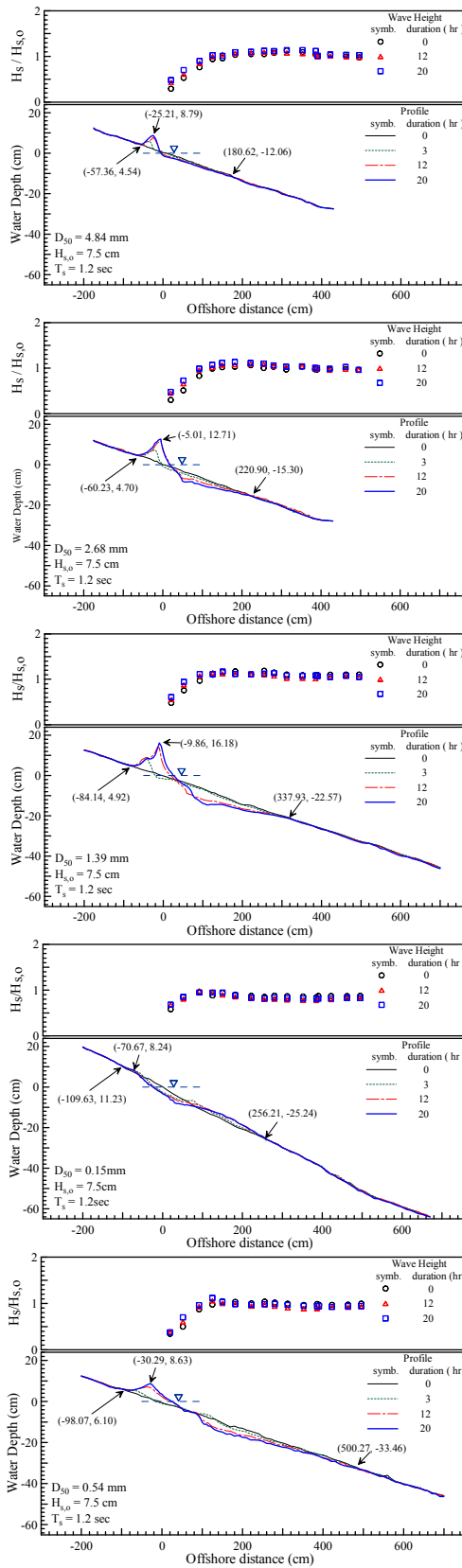


Figure 4. Distribution of wave height and topographical profile change at the various durations ($H_{s,0} = 7.5$ cm, $T_s = 1.2$ sec)

Figure 5. Distribution of wave height and topography profile change at the various durations ($H_{s,0} = 7.3$ cm, $T_s = 1.4$ sec)

Table 1 and Figures 4 and 5 show that most types of equilibrium profile are in the case of deposition, except the medium diameter of 0.15 mm. Under the same wave conditions the foreshore slope gradually became steeper and the maximum run-up on the movable bed became higher, as the wave duration before the topographical profile reached equilibrium. As the topographical profile tended to stabilise, the foreshore slope and the maximum run-up approached a constant. This appeared to change with variations to the foreshore slope on each wave duration.

From the variations of wave height and topography in the shallow zone, the breaker zone was moved slightly toward the shoreline. The topography in the shallow zone was eroded to make the foreshore slope steeper; the height of maximum run-up on the movable bed then increased. This indicates that the height of maximum run-up will change with the characteristics of foreshore status. Hence, the varied profile of the movable bed should be measured at the various wave durations and used to estimate the height of maximum run-up.

Comparison of maximum run-up between the movable bed and the fixed bed

In order to find the discrepancy of maximum wave run-up between the movable bed and the fixed bed, the maximum run-up for various medium diameters at the various wave durations were used to compare with the results of MASE (1989) that were studied on the fixed bed.

The empirical formula of maximum run-up by MASE (1989) is shown as Equation (2)

$$R_{max} / H_{s,o} = 2.32 \times \xi_o^{0.77} \quad \xi_o \leq 3 \tag{2}$$

where $H_{s,o}$ is the incident wave height; ξ_o is the surf similarity parameter or the Iribarren Number, defined as follows:

$$\xi_o = \tan \alpha / \sqrt{H_{s,o} / L_o} \tag{3}$$

where α is the angle of the slope (or the angle of equivalent slope) measured from the horizontal; and L_o is the wave length.

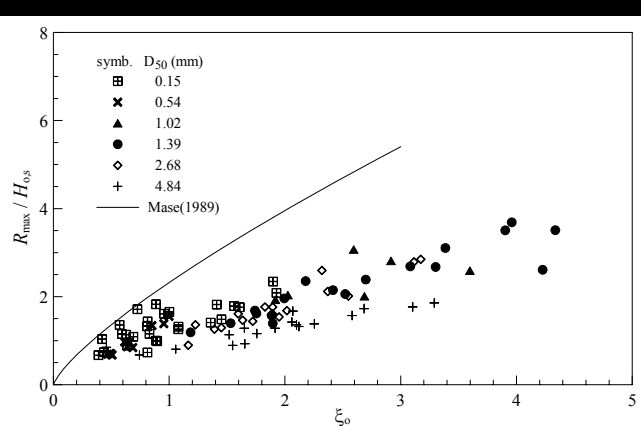


Figure 6. Relative maximum run-up $R_{max}/H_{s,o}$ for the movable bed with those on the fixed bed calculated by Mase (1989)

Figure 6 shows the comparison between maximum run-up ($R_{max}/H_{s,o}$) on the movable bed with those on the fixed bed. The equivalent slope of surf similarity parameter on the fixed bed was taken as the initial slope (1/15), while the equivalent slope of the movable bed at each duration was calculated with the varied foreshore slope by SAVILLE's method (SAVILLE, 1958). As the

results show, all the data of $R_{max}/H_{s,o}$ on the movable bed were obviously smaller than those on the fixed bed as calculated by MASE (1989). For the relationship between $R_{max}/H_{s,o}$ and the medium diameter of the movable bed, $R_{max}/H_{s,o}$ decreased as the medium diameter of the movable bed increased. Therefore, due to the effect of roughness the relative maximum run-up on the movable bed would be influenced by the type of profile (including berm and foreshore slope).

To find the effect of roughness on maximum run-up for various medium diameters of the movable bed, the equivalent slope of equilibrium profile at each wave duration was taken into Equation (2) to calculate the maximum run-up on the smooth slope. Next, the influence factor of roughness for wave maximum run-up was considered as γ_f , defined as follows:

$$\gamma_f = (R_{max})_{exp.} / (R_{max})_{smooth} \tag{4}$$

The results of roughness factor versus relative medium diameter ($D_{50}/H_{s,o}$) were shown in Figure 7. There was a tendency for the roughness factor to decrease with increasing relative medium diameter. The relationship between the roughness factor and relative medium diameter could preliminarily be regressed, as follows:

$$\gamma_f = 0.245 \times (D_{50} / H_{s,o})^{-0.141} \tag{5}$$

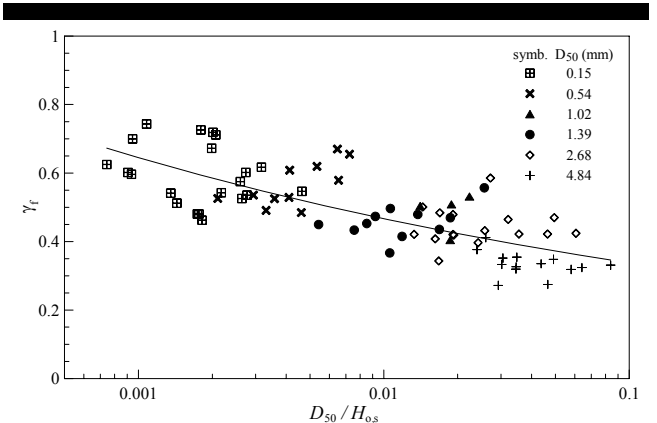


Figure 7. The relationship between roughness factor and relative medium diameter ($D_{50}/H_{s,o}$)

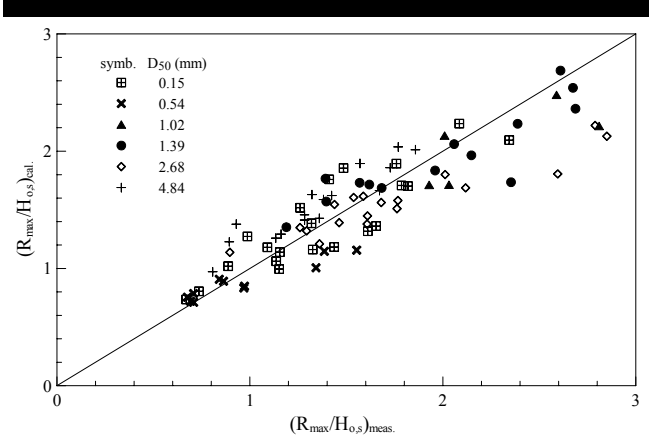


Figure 8. Comparison of relative maximum run-up in Equation (6) with the experimental data

Therefore, considering the influence of factors for roughness on the movable bed, the relationship between relative wave maximum run-up and the surf similarity parameter could be modified as Equation (6)

$$R_{\max} / H_{s,o} = 2.32 \times \gamma_f \times \xi_{eq}^{0.77} \quad \xi_{eq} \leq 3 \quad (6)$$

where ξ_{eq} is the equivalent surf similarity parameter. Figure 8 shows the results of relative maximum run-up calculated by Equation (6) compared with the experimental data. Most data on relative maximum run-up in Equation (6) could be considered to give good estimates.

CONCLUSION

In this study, the characteristics of maximum run-up on the movable bed versus the topography profile change at the various wave durations and medium diameters had been investigated. The main results were summarised as:

Under the same wave conditions, the foreshore slope gradually became steeper and the maximum run-up on the movable bed became higher with increasing wave duration before the topographical profile reached equilibrium. This indicates that the height of maximum run-up will change with the characteristic of foreshore status. Hence, the varied profile of the movable bed should be measured over the various wave durations and used to estimate the height of maximum run-up.

The comparison between $R_{\max}/H_{s,o}$ on the movable bed and those on the fixed bed, which were calculated on the initial slope (1/15) by MASE's empirical formula of maximum run-up (1989), shows that all the data of $R_{\max}/H_{s,o}$ on the movable bed were notably smaller than those on the fixed bed. This appeared that maximum run-up would be influenced by type of profile (including berm and foreshore slope) and roughness.

With the relationship between relative maximum run-up ($R_{\max}/H_{s,o}$) and the medium diameter of the movable bed, it is shown that there was a tendency for the roughness factor to decrease with increasing relative medium diameter ($D_{50}/H_{s,o}$) as Equation (5). Therefore, MASE's formula could be modified as Equation (6) to estimate the maximum run-up on the movable bed.

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LITERATURE CITED

- AAGAARD, T. and HOLM, J. 1989. Digitisation of wave run-up using video records. *Journal of Coastal Research*, 5, 547-551.
- AHRENS, J.P. 1981. Irregular wave run-up on smooth slopes, CETA No. 81-17, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, VA.
- DE WAAL, J. and VAN DER MEER, J.W. 1992. Wave run-up and overtopping on coastal structures. Proceedings of the 23rd Conference on Coastal Engineering, pp. 1756-1771.
- HEDGE, A.V. and SRINIVAS, R.P. 1995. Effect of core porosity on stability and run-up of breakwaters. *Ocean Engineering*, 22, 149-152.
- HOLLAND, K. T., HOLMAN, R. A., LIPPMANN, T. C., STANLEY, J. and PLANT, N. 1997. Practical use of video imagery in nearshore oceanographic field studies. *IEEE Journal of Oceanic Engineering*, 22, 81-92.
- KUO, C.A., CHIEN, C.H. and LEE, M.C. 2005. Wave profile measurement by the overlooking image in wave flume. *The Seventh Regional Symposium, PACON 2005* (Changhua, Taiwan). (in press)
- KUO, C.A., HAN, K.P. and CHIEN, C.H. 2006. Application of digital image processing to identify run-up water profile on seawall. *Proceedings of the 28th Ocean Engineering Conference in Taiwan* (Kaohsiung, Taiwan), pp. 521-526. (in Chinese)
- LAI, J.W., KUO, C.T. and CHIEN, C.H. 2005. A preliminary study on shingle beach profile change with the small-scale model. *The Seventh Regional Symposium, PACON 2005* (Changhua, Taiwan). (in press)
- MASE, H. 1989. Random wave run-up height on gentle slope. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 115, 649-661.
- MASE, H., MIYAHIRA, A. and HEDGES, T.S. 2004. Random wave run-up on seawalls near shorelines with and without artificial reefs. *Coastal Engineering Journal*, 46, 247-268.
- SAVILLE Jr., T. 1956. Wave run-up on shore structures. *Journal of the Waterways Division*, 82, 925-1-925-14.
- VAN DER MEER, J.W. and STAM, C.M. 1992. Wave run-up on smooth and rock slopes of coastal structure. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 118, 534-550.
- VAN GENT, M.R.A. 2001. Wave run-up on dikes with shallow foreshores. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 127, 254-262.