MORPHOLOGICAL HYSTERESIS OF ARTIFICIAL BEACH UNDER LARGE WAVE CONDITION: AN EXPERIMENTAL INVESTIGATION

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INTRODUCATION

Submerged **A**rtificial sand**B**ars (SAB) are usually implemented on the lower shoreface to protect berms or dunes during storm surges. The lee-effect of SAB is due to its ability in triggering large wave breaking, so that sediment concentration in water column and sediment transport capacity will decrease in the covered areas. Previous studies analyzed the lee-effect and topography evolution of SAB (e.g., Grunnet et al. 2004), however the morphological coupling of SAB and natural profiles is seldom referred.

The morphological connections and sediment budgets between lower shoreface and upper beach have attracted lots of attentions. Aagaard (2014) estimated the sediment transport in lower shoreface with field datasets, which supplies sands to upper beach. Marinho et al. (2020) simulated the sediment budget between bars and berms with a semi-empirical numerical model. However, these studies are limited either by instrumentations or by the scale effect.

In this study, the morphological coupling between SAB located on the lower shoreface and the berm in upper beach is investigated in a well-controlled physical experiment.

EXPERIMENTAL SETUP

Physical experiments are conducted in a wave flume of 50m long, 0.5m wide and 0.8m high. Offshore random waves in JONSWAP spectrum with peak enhancement factor of 3.3 are generated in the fixed water depth of 0.6m. Beach profiles consist of well-sorted natural sands with median grain diameter of 0.23mm.

In the first stage, a quasi-equilibrium berm profile is formed under mild wave conditions. Then the SAB is implemented on the shoreface and a large wave condition is imposed. Significant wave height H_s = 0.15m and peak period T_p = 1.5s are chosen to represent the large wave condition. dimensionless fall velocity is 3.3 (Dean, 1977), which represents storm conditions in several experimental studies (e.g., Eichentopf et al. 2020; Sanchez-Arcilla and Caceres 2017). Table 1 provides the design parameters of SAB in each test.

Table 1 Design parameters of SAB

ID	d_c (m)	s_{off}	Profile measuring moments
C1_1	0.12	0.24	N=0; 300; 600; 1600
C1_2	0.11	0.19	N=0; 300; 600; 1600; 2600
C1_3	0.09	0.25	N=0; 300; 600; 1900; 3900
C1_4	0.07	0.27	N=0; 200; 600; 3600; 6600

In the table, d_c and s_{off} mean water depth over the bar crest and seaward slope of SAB, respectively. N represents the total wave numbers, at the moments of profile measuring. The time intervals are not fixed but adjusted according to the time-varying profile evolution rate. A test will be terminated when little change can be observed visually. The experiment setup is shown in Fig. 1.

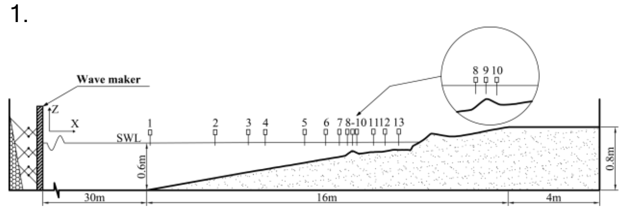

Figure 1 Sketech of experimental setup.

RESULTS

The profile evolution under large wave conditions are provided in Fig. 2. Generally, these four tests present analogous features. The SAB migrates onshore with their shapes dissipating gradually. Berms are well protected at the beginning, while severe erosion occurs when shapes of SAB are significantly decayed. Shoreline retreat and decrease in front of berm are observed at the end of each test. Hence, the lee-effect of SAB is dynamic and affected by the morphology stability of SAB.

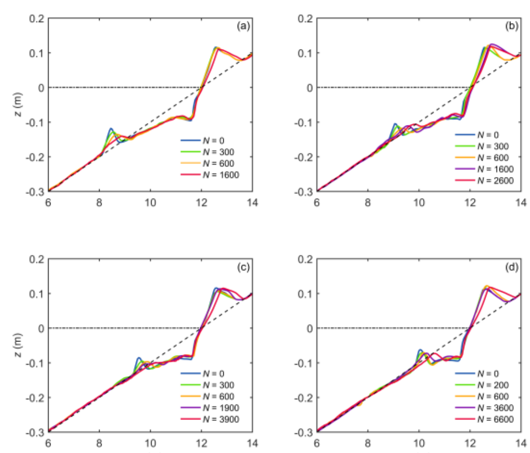

Figure 2 Beach profile evolution of test C1_1 (a), C1_2 (b), C1_3 (c) and C1_4 (d).

As mentioned above, there is a morphological hysteresis between berm state and large wave impact. The decrease of berm front slope depends on the shape of SAB, indicating a morphological coupling between SAB located on the lower shoreface and berm in the upper beach. In each test, berm changes to adapt to wave conditions. Here, an empirical parameter B incorporating three factors related to berm shapes is defined to reflect berm behavior:

$$B = \frac{1}{3}\left(\frac{\tan b}{\tan b_0} + \frac{\tan\theta}{\tan\theta_0} + \frac{H_b}{H_{b0}}\right) \quad (1)$$

in which, $\tan b$ means berm front slope, $\tan\theta$ is berm rollover, defined as the slope between the positive direction of x axis and the line connection berm highest position to initial shoreline location. H_b is the distance between the highest position of berm to still water level. Subscript 0 means these physical quantities in the initial state. The first term on the right-hand side represents berms slope changes, the second term means berm movement in the cross-shore direction and the last term is berm elevation changes in the vertical direction. B > 1 represents berm accretion compared with the state at the timing of implementation.

Meanwhile, the other empirical parameter A is defined to describe the degree of SAB morphology:

$$A = \left(\frac{s_{off}}{\sqrt{H_0 / L_0}}\right) / \left(\frac{h_c}{h_c + h_{bar}}\right) \quad (2)$$

where H_0 and L_0 represent offshore significant wave height and peak period, respectively. h_{bar} means bar height. the first term in numerator is a surf similarity parameter based on the seaward slope of SAB. This term with a larger magnitude indicates a higher possibility of occurrence of plunging breakers, i.e., onshore sediment transport. The term in denominator represents relative bar height. A smaller magnitude of this term means a smaller h_c or larger h_{bar}, indicating a better lee-effect so that the berm is more likely to be accretive (or not to be eroded). When there is no SAB, s_{off} in Eq. 2 equals natural slope and h_{bar} equals 0, so that A reduces to the classic surf similarity parameter of Battjes (1974).

The morphological coupling between SAB and berm is revealed by the relationship between B and A shown in Fig. 3. The relationship can be formulated by:

$$B = 0.2\tanh(4.1A) + 0.8 \quad (3)$$

Based on this relationship, it is noted B increases with the increasing of A, and gradually tends to be stable. The morphological coupling reveals the berm responses is controlled by the SAB morphology. The berm undergoes less erosion with the protection of SAB which has a smaller h_c and steeper s_{off} under the erosive wave condition. When B is larger than 1 (e.g., for A = 0.37, B = 1.02), the berm is accretive compared with the state before nourishment, indicating there is a morphological hysteresis of berm response to erosive wave impacts, when the morphology of SAB is remarkable. At that time, SAB with a steep s_{off} and a smaller h_c efficiently dissipates the incident wave energy. When SAB morphology has decayed with a milder s_{off} and larger h_c (i.e., with a small A), the morphological hysteresis is vanished and the berm starts to be eroded with a small B.

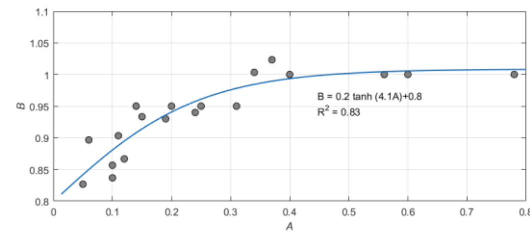

Figure 3 Quantitative relationship between SAB shape and berm morphology

CONCLUSIONS
A series of laboratory experiments are carried out to investigate the SAB beach profile evolution under the erosive wave condition, considering different SAB designs. The responses of SAB and berm as well as their morphological coupling are of special interests.

A morphological hysteresis existing in berm response to erosive wave impacts is found on an artificial beach. The morphological hysteresis is closely linked to the morphological evolution of SAB and indicates a dynamic lee-effect of SAB. An empirical relationship has been proposed to quantitatively describe the strong morphological coupling of SAB and berm. This finding may be useful to optimize the design of shoreface nourishment, e.g., to preserve sand volume during storms.

REFERENCES
Aagaard (2014): Sediment Supply to Beaches: Cross-shore Sand Transport on the Lower Shoreface, Journal of Geophysical Research: Earth Surface, AGU, vol. 119, no. 4, pp. 913-926.

Battjes (1974): Surf Similarity, Proceedings of International Conference on Coastal Engineering 1974, pp. 466-480.

Dean (1977): Equilibrium Beach Profiles: US Atlantic and Gulf Coasts. Department of Civil Engineering and College of Marine Studies, University of Delaware.

Eichentopf, van der Zanden, Cáceres, Baldock, Alsina (2020): Influence of storm sequencing on breaker bar and shoreline evolution in large-scale experiments. Coastal Engineering, vol. 157, pp. 103659.

Grunnet, Walstra, Ruessink (2004): Process-based modelling of a shoreface nourishment, Coastal Engineering, vol. 51, pp. 581-607.

Marinho, Coelho, Larson, Hanson (2020): Cross-shore modelling of multiple nearshore bars at a decadal scale, Coastal Engineering, vol. 159, pp. 103722.

Sanchez-Arcilla, Cáceres (2017): An analysis of nearshore profile and bar development under large scale erosive and accretive waves, Journal of Hydraulic Research, vol. 56, no. 2, pp. 231-244.