PREDICTION OF WAVE RUN-UP AFFECTED BY DUNE SCARP: A LARGE-SCALE TWO-DIMENSIONAL MOVABLE BED EXPERIMENT

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INTRODUCTION

Korean beaches have suffered erosion due to coastal development. Recently, the South Korean government has initiated efforts to restore the dune system for a beach on the west coast of Korea. Coastal sand dunes serve as natural barriers against extreme waves caused by climate change and rising sea levels. To design effective artificial sand dunes, understanding the erosion and restoration mechanisms of coastal dunes is crucial. Hence, the COastal sand Dune Experiment in Korea (CODEK), a large-scale two-dimensional movable bed experiment, was conducted to investigate these mechanisms. This study focuses on observing wave run-up affected by dune erosion, particularly the dune scarp during a storm. Wave run-up is a vital parameter for assessing the vulnerability of coastal beaches, dune systems, and structures to dynamic wave action. The aim of this study is to analyze the wave run-up on the dune scarp based on experimental results and propose ways to enhance prediction accuracy using an existing empirical formula.

LARGE-SCALE MOVEABLE BED EXPERIMENT

A large-scale wave flume (100m (L) x 2m (W) x 3m (D), partially glass-walled flume) was used to replicate a simplified representative natural dune and beach profile at a 1:4 scale from the west coast of South Korea.

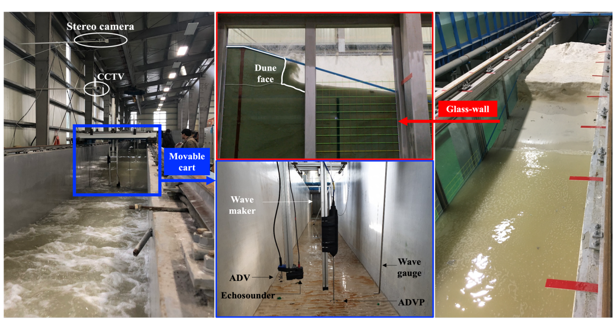

Figure 1 - Overview of the large-scale moveable bed experiment

To fill the flume, Silica sand which D_{50} is 0.15 mm was used. An entire storm event, including a post-storm, was also simulated in the flume. In order to replicate a single storm event, the significant wave height and water level progressively rise from storm condition 1 (SC1) until they reach their peak values at storm condition 3 (SC3). Subsequently, they sequentially decrease two steps (storm condition 4 and 5) until the recovery condition **(Table 1)**. Instruments such as capacitance-type wave gauges (WG), electromagnetic current meter, acoustic Doppler velocimeter (ADV), acoustic Doppler velocimeter profiler (ADVP), and echosounder were equipped to measure the hydrodynamics of the entire dune and beach system.

Table 1 - Incident wave condition of the experiment

Storm condition	Water level (m)	Hs (m)	Tp (s)	Td (hr)
Initial	1.46	0.14	2.92	0.75
SC1	1.54	0.32	3.18	1.50
SC2	1.62	0.56	3.47	1.50
SC3	1.7	0.67	3.81	6.25
SC4	1.62	0.57	3.76	1.50
SC5	1.54	0.32	3.91	1.50
Recovery	1.46	0.14	3.72	14.00

Especially, an WG, an ADV, an ADVP, and an echosounder are mounted on the movable cart (Figure 1) to obtain wave and characteristics of all possible areas indicated in Figure 2. Bed surveys were conducted at 20 cm intervals, and stereo cameras were set up in the swash zone to capture water surface elevation and wave run-up using Level Stuff, Echosounder, and Laser Range Finder. Figure 2 illustrates the bed profile following each storm condition. For shallow water region (swash zone), a set of stereo cameras was set up to capture water surface elevation and wave run-up. The area covered by stereo camera is indicated in Figure 2.

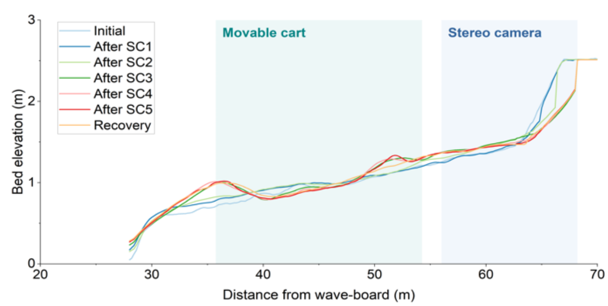

Figure 2 - Bed profile after each storm condition and measurement area by movable cart (green) and stereo camera (blue)

RESULTS AND CONCLUSIONS

The dune experienced erosion, resulting in the formation and retreat of the dune scarp from SC1 to SC3, representing the most significant erosive phase. During the initial phase of the storm (SC1), the dune face started to slump, gradually expanding the slumping area. In SC2, the dune scarp became distinctly formed, and the dune scarp toe was clearly recognizable. Further retreat of the dune scarp occurred during the most erosive event, SC3 (see Figure 3). As the dune eroded and the dune scarp was formed and retreated (SC1-SC3), wave run-up values exceeding two percent, denoted as R2%, occurred on the dune scarp. Stereo imagery was used to extract the wave run-up, and R2% was calculated. In the subsequent stages, as the storm weakened (SC4 and SC5), swash motion primarily occurred on the foreshore slope rather than the dune scarp, and there was no additional retreat of the dune scarp or dune erosion.

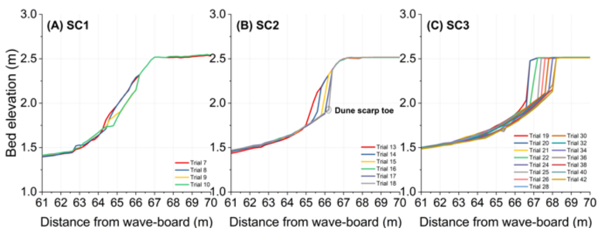

Figure 3 - Dune profile during (A) storm condition 1, (B) 2, and (C) 3

Based on the stereo imagery results, the observed values of R2% remained relatively consistent regardless of varying wave and morphological conditions when it occurred on the dune scarp (Figure 4A). This study also compared the observations and estimations using the empirical formula proposed by Stockdon et al. (2006) (hereinafter referred to as the Stockdon formula), known for its high accuracy in predicting R2% for extreme events (da Silva et al., 2020). Figure 4(B) illustrates the relationship between the dune scarp toe (St) and still water level (SWL) versus R2% with the estimations from previous studies and our experiment, along with the observations of our experiment. Similar to Figure 4(A), the estimated R2% exhibited linearity with the dune scarp toe, while the observed R2% on the dune scarp remained consistent regardless of the location of the dune scarp toe. Moreover, considering only the results of this experiment, the estimated R2% values derived from Stockdon et al. (2006) tended to be smaller than the observed values. Additionally, this study revealed that the dune scarp acted like a vertical embankment seawall, preventing overwash compared to the findings of EurOtop (2018).

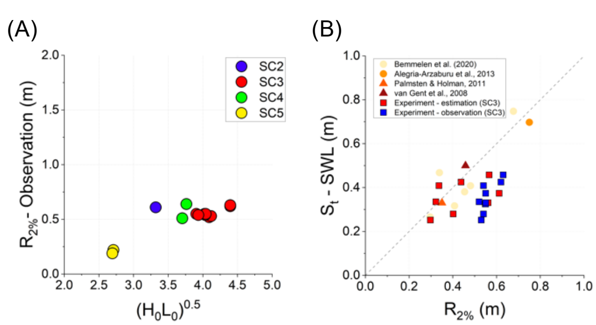

Figure 4 - (A) Observed values of $R_{2\%}$ from stereo camera versus $(H_0L_0)^{0.5}$; (B) Dune scarp toe elevation (S_t) with respect to still water level (SWL) versus estimated values of $R_{2\%}$ for previous studies and our experiment (red diamond) compared to observed $R_{2\%}$ (blue diamond). This figure is originated from Bemmelen et al. (2020)

To improve the accuracy of R2% predictions on the dune scarp, this study recommended incorporating the beach slope, denoted as βB (extending from the still water level to the dune scarp toe), into the Stockdon formula. The suggested parameter, beach slope, proved to be an effective means of predicting R2% (Figure 5).

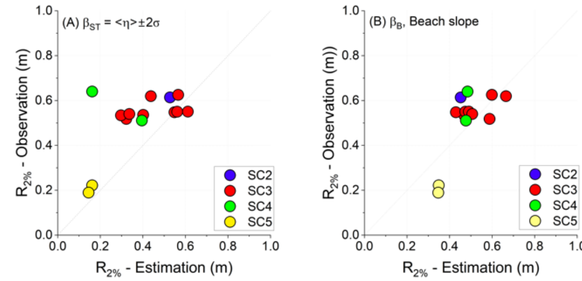

Figure 5 - Comparison observed and estimated $R_{2\%}$ using (A) slope by Stockdon et al. (2006) and (B) Beach slope

When applying the storm impact scale to forecast dune erosion under storm conditions, this research suggests integrating beach slopes (βB) to estimate R2% and staying updated on morphological changes to avoid overestimating dune erosion. Figure 6 demonstrates the different results when the initial bed profile and updated morphological changes with the input of βB were utilized. The incorporation of topographical changes accurately predicted the absence of overwash by the dune scarp acting as a wall in the actual experiment. Consequently, when planning an artificial dune, it is crucial to consider the formation of the dune scarp caused by dune erosion and storms.

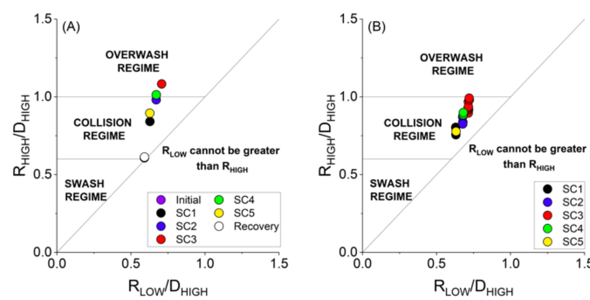

Figure 6 - Storm impact scale using (A) initial bed profile and (B) updated morphological changes

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