OBSERVATIONS FROM A CONTROLLED DUNE EROSION EXPERIMENT UNDER VARIABLE WATER LEVELS, WAVES, AND INTERNAL DUNE MOISTURE CONTENT

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INTRODUCTION AND BACKGROUND

Dune erosion due to storms is primarily predicted by the use of empirical relationships, for example, when the duneface slope exceeds a certain threshold sand is eroded (SBeach, XBeach); or as a function of wave impact (Larson et al., 2004). However, geotechnical properties also play a role in dune scarp formation. Dry sand is relatively unstable, but as water is added, the tensile strength increases, enabling a vertical duneface to form and reduce slumping. The strength and stability of the sand matrix increases up to 10-15% with increasing water content, and then decreases as the sand matrix becomes saturated and more easily eroded. Hence, it is somewhat surprising that the importance of water infiltration into the dune sand matrix and resulting porewater content have received relatively limited attention within the coastal engineering literature to-date.

Erikson et al (2007) and Palmsten and Holman (2011) were amongst the first authors to hypothesize the effect of infiltration on dune stability, based on their observations from small- and large-scale laboratory experiments, respectively. Dune failure mechanisms including notching, elastic beam failure and shear failures were introduced as a function of sand moisture content. However, throughout both these studies, no direct measurements of infiltration, soil moisture content or pore pressure were obtained during the lab experiments and these hypotheses remain largely untested.

This paper presents new results from a series of controlled laboratory experiments to observe moisture content and pore pressures within an eroding dune, to better understand the importance of wave run-up infiltration to dune erosion under wave attack.

METHODS

Controlled wave flume experiments were performed under variable wave conditions, water levels with respect to the dune toe, and moisture contents of the dune above the capillary fringe. As sediment dynamics are a challenge to scale, in part due to different properties as a function of grain size, a test program was undertaken consisting of 18 unique combinations of 2 wave conditions, 3 water levels, and 3 initial dune moisture contents o. The duration of each test was 4000 waves. Four additional tests were performed for 8000 waves, repeating 2 water levels and 2 initial dune moisture conditions in order to validate the experimental methods, as well observe the eroding the dune to its maximum extent.

The two irregular wave conditions consisted of JONSWAP spectrums with a significant wave height of 0.14m and 0.25m and time periods of 1.1s and 1.5s, respectively. The three still water levels with respect to the dune toe were defined as: Foreshore (below the dune toe), dune toe and one-third dune water levels. The three moisture conditions chosen represented volumetric water contents above the capillary fringe of 0.05, 0.18 and 0.3.

Detailed morphological data was obtained by 2D Lidar Scanning. Wave conditions were measured with two sets of 3-Probe Arrays. Continuous phreatic surface ('water table') measurements and pore pressures within the dune were obtained using two sets of screened, vented pressure transducers mounted in vertical arrays. Wave run-up infiltration and direction measurements of pore moisture content were quantified using Frequency Domain Reflectometry (FDR) moisture probes buried in the actively eroding dune.

RESULTS AND DISCUSSION

Results from these experiments confirm that the still water level with respect to the dune toe is the primary driver of overall dune erosion, followed by the wave conditions and dune moisture content.

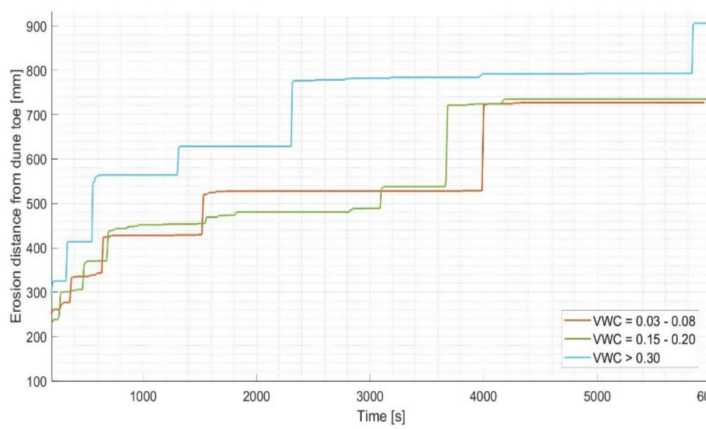

Figure 1 - Dune crest recession across time for the larger wave condition (Hs = 0.25, Tp = 1.5s), foreshore water level and three internal volumetric water contents (VWC). Dune erosion rates can be observed to increase as a function of increasing dune moisture content.

It was observed that dune moisture content directly impacts the rate of erosion of the dune. This observation is attributed to pore-water content having the dual effect of increasing the tensile strength of the sand matrix and also adding weight to the dune face. The latter effect was observed to be of greater influence - resulting in a faster rate of erosion as a function of increasing internal dune moisture content (Figure 1). Geometrical parameters such as the scarp height play a key role in determining the potential effect of dune moisture content on the rate of erosion. As the scarp height increases, more pore-space is available to be filled with water – increasing the relative weight added by the pore-water and the rate of erosion potential of a 'wetter' dune.

For the two lower moisture content conditions (initial VWC 0.05 & 0.18) the dune was observed to retreat backwards following a 4-step erosion process, here referred to as: 1) reflection-dominated scarping, 2) collision-dominated slumping, 3) infiltration-dominated slumping, 4) notching-dominated slumping. As shown in Figure 2, the rate of dune recession throughout this 4-step process followed a logarithmic relationship, whereby most of the erosion happened in the first minutes of each experiment, prominently during the collision-dominated regime (step 2) of erosion. As the beach eroded backwards and upwards reaching the infiltration-dominated regime (step 3), slumping became episodic and was observed to depend more on individual larger wave bores reaching the scarp face and adding weight due to additional infiltration. Notching-dominated slumping (step 4) was observed towards the latter phase of the dune face erosion, when the largest wave bores only managed to reach the scarp toe – slowly propagating a notch until it was deep enough for the scarp above to become unstable and fail – without altering the moisture dynamics of the dune and adding further weight.

The maximum extent of dune erosion by the end of each 4000 wave experiment was observed to be similar for these same two initial moisture content conditions, and could be robustly predicted by the total water level (TWL). Once the beach eroded backwards sufficiently so that the maximum swash tip (TWL) was no longer reaching the eroding scarp toe, no more erosion could occur. After the scarp was formed, both elastic beam and shear type failures were observed throughout testing – with the former being more prominent once notching started to appear.

Figure 2 - A vertical dune scarp under the attack of a larger wave, causing the local water table to rise above the scarp toe and the notching process to begin.

It was observed that the notching process was closely tied to the elevation of the local water table within the dune face. In the highest moisture content test cases (VWC = 0.30) the local water table inside the dune was raised above the scarp toe – liquefying the base of the dune and preventing notching. Conversely, for the low and mid moisture cases (VWC = 0.05 & 0.18), notching commenced once the beach was observed to have eroded landwards and upwards a sufficient distance for the time-averaged water table (or 'mean water level') to be below the toe of the scarp. This resulted in the base of the dune lying in the unsaturated region, which increased its strength and stability. Subsequently, larger wave runup periodically reached the dune face, momentarily raising the water table above the scarp toe, liquefying and eroding a layer of sand (Figure 2),and commencing the notching process. After wave rundown, exfiltration resulted in the local water table returning to the mean water level, leaving the notch more elevated and therefore gaining strength and stability as it re-entered the unsaturated region.

REFERENCES

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