RECESSION BY RANDOM WAVES: INSIGHTS FROM PHYSICAL MODELING OF CONSOLIDATED SANDY BLUFF

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INTRODUCTION

Coastal bluffs are dynamic landforms that recede due to various physical processes (Kamphuis, 1990). Understanding these processes is essential for effective bluff erosion management. This research investigates the physical mechanisms governing sandy bluff recession under random waves and fluctuating water levels.

Wave action generates hydraulic pressures on the bluff, removing sediment and undermining stability. Toe erosion from wave impact causes undercutting and basal failures. Higher water levels increase hydraulic loading and erosion, while lower levels expose the bluff to more wave action (Buckler & Winters, 1983; Carter et al., 1987). Soil properties significantly affect the erosion response (Arabi & Farhadzadeh, 2019; Arabi & Farhadzadeh, 2022; Farhadzadeh et al., 2022). This paper presents an experimental study of a compacted sandy beach-bluff under random wave actions. The evolution of the bluff profile was monitored along with flow, porewater pressure, and moisture content. The findings provide insight into the complex interactions governing bluff recession.

MATERIALS AND METHODS

Experimental Setup

The bluff recession experiment was conducted in Stony Brook University's Coastal and Hydraulic Engineering Research Laboratory's integrated wave and current flume–a 25 m x 1.5 m x 1.5 m flume with a piston-type wavemaker. Equipped with an active wave absorption system, the flume generated various incident waves.

Bluff Geometry

The mid-scale sandy beach-bluff model was constructed in the flume. The sandy beach was 1.34 m long with a 1:10 slope. The bluff, approximately 1 m tall with a 1V:0.3H slope, had a width of 0.778 m at the bottom and 0.60 m on top. A buttress ensured stability. Figure 1 shows the initial profile of the beach-bluff model.

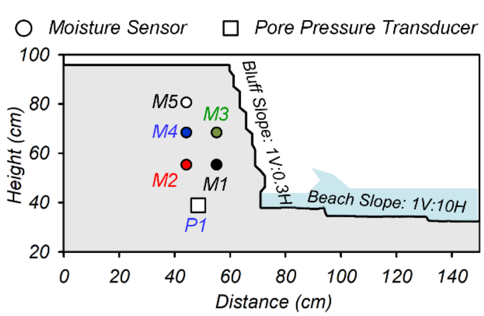

Figure 1: geometry of beach and bluff profile setup and instrumentation setup

Material Characteristics

Local sand was used to construct the bluff model. The particle size distribution indicated a median size (D_{50}) of 0.25 mm. The specific gravity (G_s) was 2.65, and the maximum dry density (ρ_d) was 1.62 gr/cm³. Additionally, the material's optimum water content (ω_{opt}) was ~ 9%. The soil was air-dried, mixed with water based on the optimum water content, and homogenized for 12 hours. Compacted in layers within the wave flume, the bluff achieved a dry density (ρ_d) of 1.62 gr/cm^3. The specimen had a void ratio (e) of 0.64 equivalent to a relative density (D_r) of 0.8.. Figure 2(a) shows the completed bluff model.

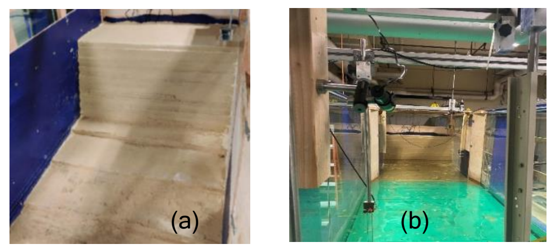

Figure 2: Bluff model. (a) Finished specimen, (b) Overview

Test Procedure

Random waves, generated based on TMA spectrum, acted on the beach and bluff. The water level fluctuations were measured using several resistive wave gauges. Figure 3 shows the sample power spectral density of the measured water levels. The instrumentation setup for the sensors installed in the bluff is shown in Figure 1. These sensors recorded the time history of moisture and pore water pressure inside the bluff. A Laser projector and a camera, mounted on the wooden side wall, monitored the bluff during the test to non-intrusively capture the bluff profile evolution (Figure 2(b)). The initial and final beach profiles were scanned using a bed profiler.

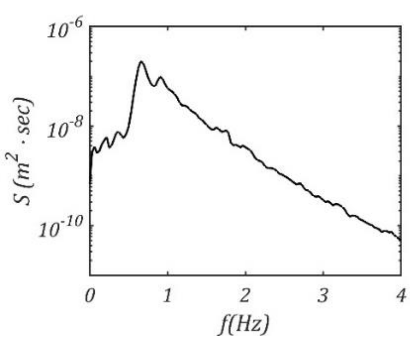

Figure 3: Power Spectral Density (PSD) of waves

RESULTS AND DISCUSSIONS

This study aims to explore the mechanisms driving the recession process and analyze the changes in bluff profiles using a Laser projector-camera system. Figure 4 illustrates the evolution of the beach-bluff profiles during the test. Initially, rapid erosion at the bluff's toe, induced by wave breaking, led to material deposition on the beach. The notch formed at the toe expanded leading to several episodic slope failures including a major failure around t = 39 min. These failures caused sand accumulation in front of the bluff, a temporary protection.

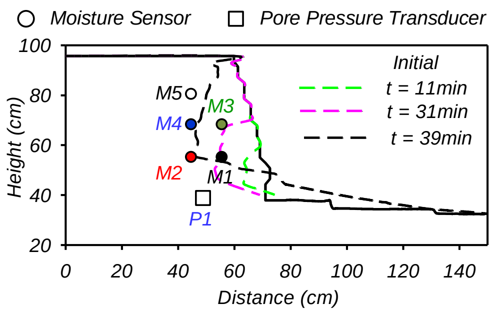

Figure 4: Beach-bluff profile evolution

The moisture content, and in turn, degree of saturation measurements demonstrates a rising trend during the test as shown in Figure 5. The increase in the moisture content led to reduced matric suction and material strength. The pore water pressure also demonstrates an increasing trend at a gradual rate until the major failure occurred at t= 39 min, at which point the pore water pressure spiked rapidly. This spike was followed by a pressure drop as the pore was temporarily drained. The pore water pressure then increased to a new level because of the rise in the hydraulic gradient in the porous medium due to the reduced flow path.

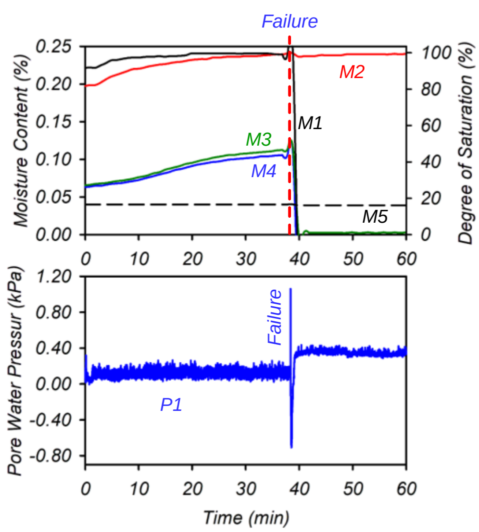

Figure 5: Time series of: (top) measured moisture content/ degree of saturation and (bottom) pore water pressure. Positions of sensors are shown in Figure 1.

CONCLUSIONS

This study delved into the erosion dynamics of consolidated sandy bluffs exposed to random waves and fluctuating water levels through a carefully designed laboratory experiment. The analysis revealed that intersecting processes, including wave impacts and swash flow, pore water pressure fluctuations, and reduced matric suction, triggered bluff failures. The continuous erosion and undercutting of the bluff's toe were identified as the most influential factors leading to episodic collapses. The sandy bluff recession process consisted of minor and major slope failures, with the primary mode of major failure being the tensile failure of overhanging bluff material beyond the reach of up-rushing flow during the runup process. Elevated pore water pressures and reduced matric suction due to wave runup and storm surge further contributed to reduced soil strength and in turn slope stability. In essence, the study provides quantitative data and visual insights into the complex interplay of hydraulic, hydrologic, and mechanical processes steering sandy bluff erosion under wave and surge dynamics.

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