Erosion and Recession of Coastal Buffs: Characterizing Erodibility of Bluff Materials under Various Land- and Sea-Based Conditions

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Outline

1. Motivation and Introduction
2. Objectives
3. Results
4. Conclusions
5. Future work

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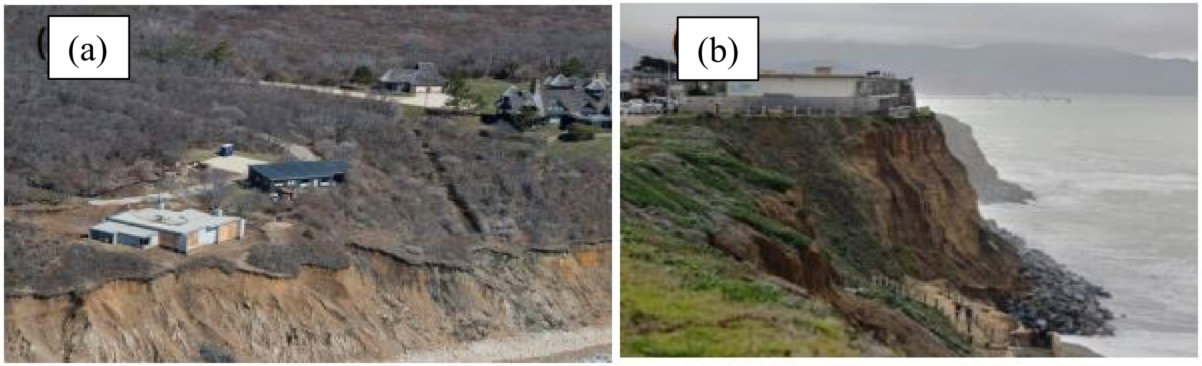
Motivation

Coastal Bluff Recession
Involve a broad range of factors including both sea-based (morphodynamics) and land-based (seepage, runoff, etc.) processes.

- Impossible to recover
- Poses substantial risk to safety of nearby structures and infrastructures
- Has many social, environmental and economic impacts on coastal communities



Bluff Recession in Montauk, NY (image Credit: Photo Credit: Doug Kuntz, Newsday); (b) Pacifica, CA (Image Credit: Credit Eric Risberg/AP)

Location	Bluff portion of total shoreline length (%)
Great Lakes	12
Mid-Atlantic and New England	7
California	72
Oregon	58
Washington	22

In the winter of 2005-2006, bluffs on Long Island's north shore sustained significant erosion for early "nor'easter" storms in October 2005 (State of the Beach, State Reports, NY,Beach Erosion ,Beachapedia, www.beachapedia.org/State_of_the_Beach/State_Reports/NY/Beach_Erosion)

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Bluff Recession in Long Island, NY (Image Credit: Google Earth)

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The Montauk Lighthouse was 297 feet from the edge in 1796 when it was built.
It was 55 feet from the edge in 1967.

Montauk Lighthouse, circa 1900, (Image Credit: Courtesy East Hampton Historical)

Montauk Lighthouse ,2017, NY (image Credit: Google Earth)

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Great Lakes Bluff Erosion

- Bluff constituent materials are mostly till, clay silt

Forcing
- Seiche
- Freeze and thaw
- Precipitation
- Ice impact

Lake Ontario bluff erosion (source: https://fingerlakes1.com, published on Published: 05/10/2017)

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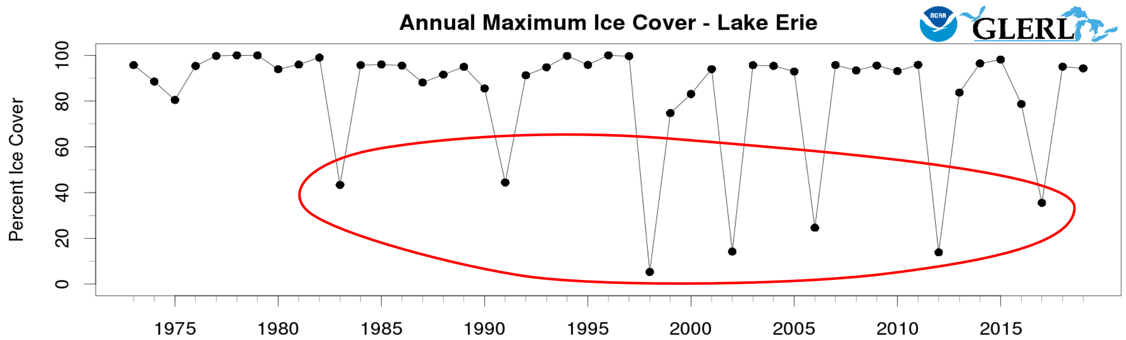
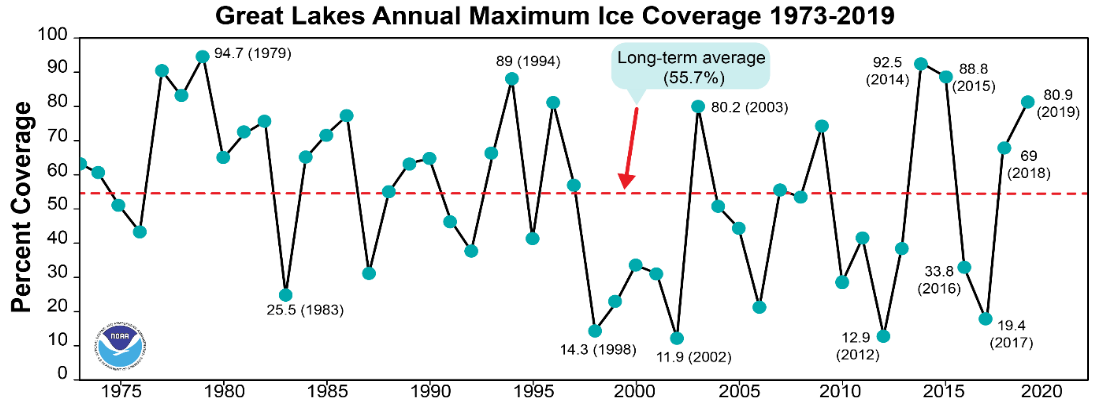
Surface Ice

Annual Maximum Ice Cover (AMIC: maximum lake surface area covered by ice during a given year) was greater than or equal to 75% between 1973 and 2019 with exception of 7 winters





https://www.glerl.noaa.gov/data/ice/#historical

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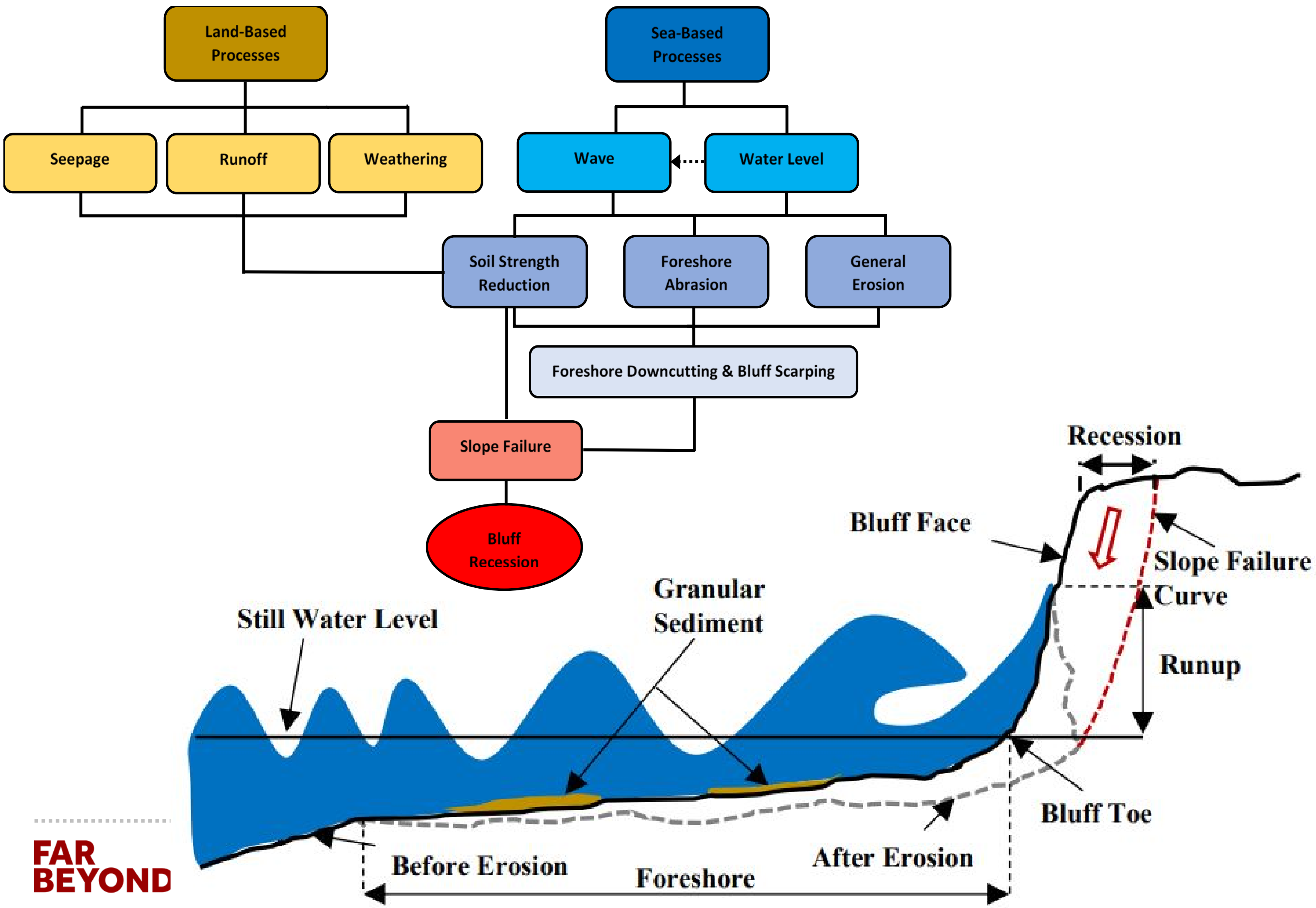
Bluff Erosion - Introduction

Important Processes



Objectives

The present work is the result of extensive laboratory experiments on the effects of the **fine content, relative density, and water content** of constituent material on the erosion of low fine content soil for both flat and sloping bottoms and bluffs. This research consists of two inherently related components:

Understanding and characterizing the erosion of **sloping beach and recession of bluff** under breaking wave and surge actions.

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Material and Method

Soil Sample Collection and Geotechnical Testing

- Sample materials were taken from Montauk bluffs, on south shore of Long Island, NY.
- The Montauk bluffs are predominantly sandy, steep or event vertical with a height ranging from about 6 m to more than 30 m.
- Bluffs are constantly being eroded by wave and surge attacks from Atlantic Ocean.

Montauk Point Bluff

Material and Method

Geotechnical Testing

- Index tests
- Atterberg limit test
- Triaxial test
- Sieve analysis
- Proctor tests

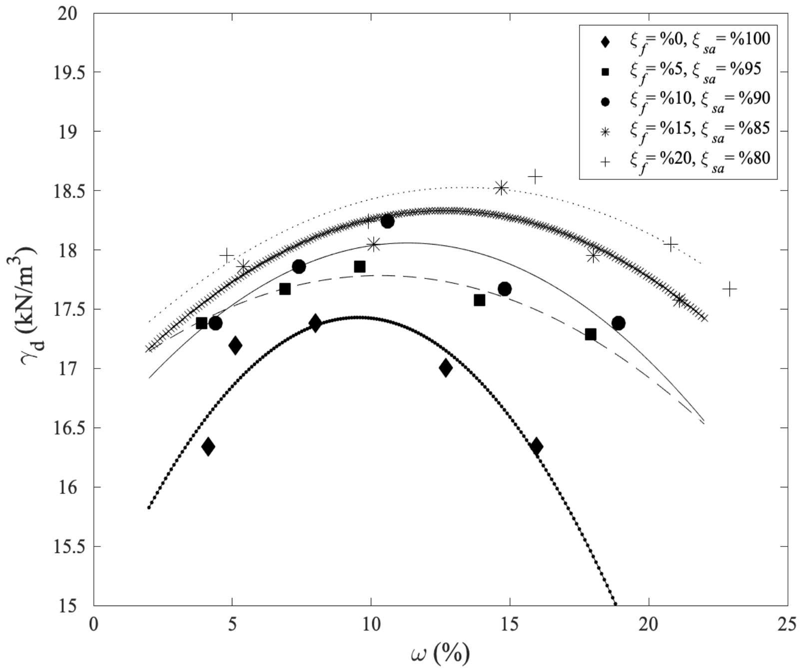
Parameter	Value
D_{10}	0.075 mm
D_{30}	0.3 mm
D_{50}	0.35 mm
Fine content (FC)	8-12 %
Specific Gravity (G_s)	2.52-2.56
Water Content (w)	4-17%
Dry Density (γ_d)	1.43 (gr/cm^3)
Void Ratio (e)	0.36-0.64
Minimum Void Ratio (e_{min})	0.30
Maximum Void Ratio (e_{max})	0.68
Relative Density (D_r)	0.1-0.86
Optimum Water Content (w_{opt})	11-13%
Plasticity Limit (PL)	18.2-21.1%
Liquid Limit (LL)	35.7-36.7%
Plasticity Index (PI)	14.6-18.5%

- Target properties (20 Samples)
  - Fine Content % 0, % 5, % 10, % 15, and %20
  - Water Content %7 and Optimum water content
  - Relative Density, %39 and %68

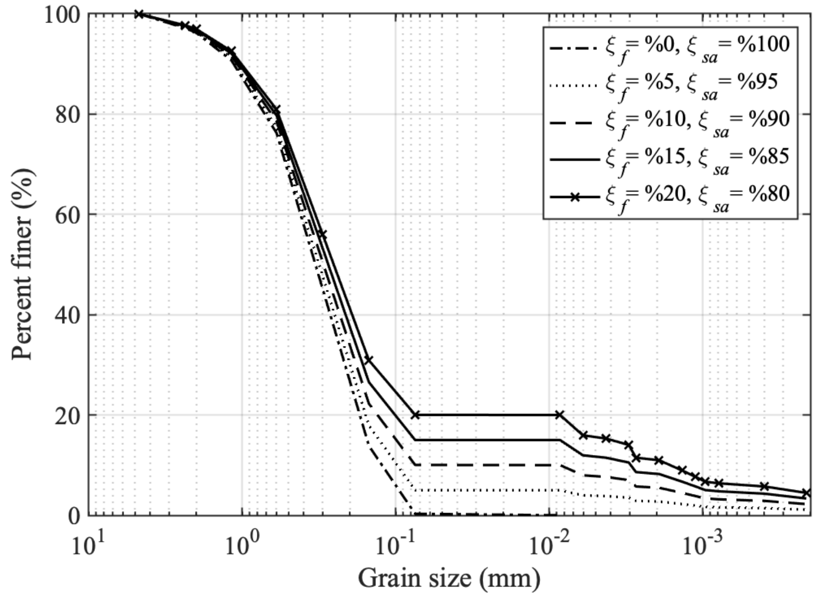
Material and Method

Geotechnical Testing

- Sieve analysis and proctor test was performed for five samples with different fine contents. (ξ_f = % 0, % 5, % 10, % 15, and %20)
- Gravel removed with sieve No.4



Dry unit weight vs. water contents of sediment mixture with different fine (ξ_f)and sand content (ξ_s)



Grain size distributions (GSD) of soil mixtures prepared for the tests

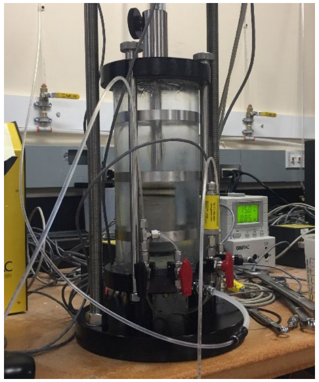
Material and Method

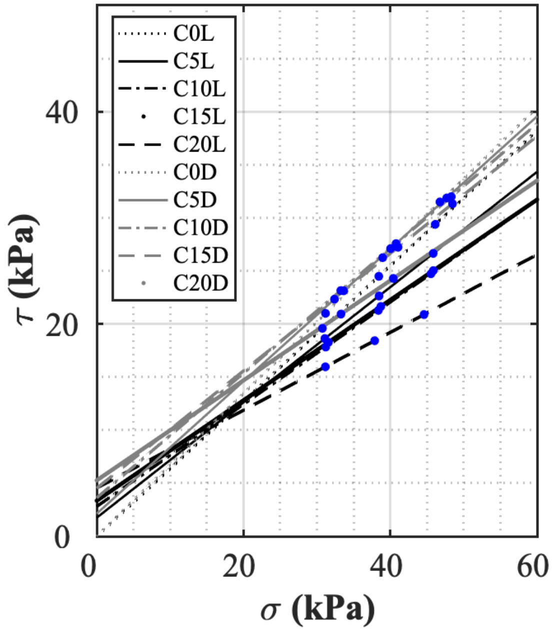
Geotechnical Tests

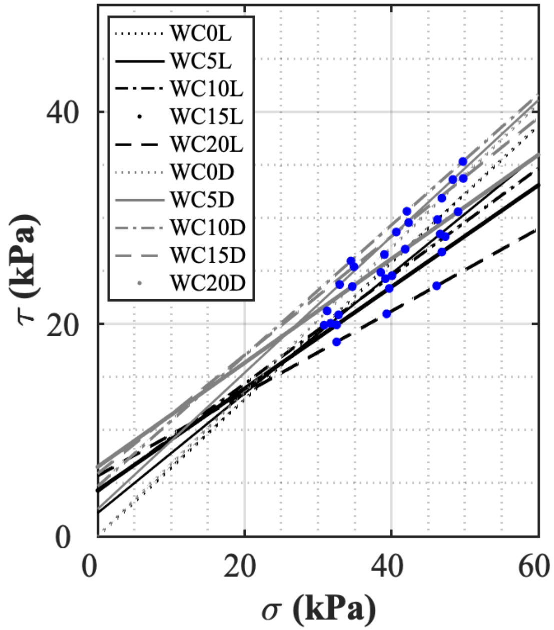
- Shear strength parameters, C' and ϕ', were determined using the CU triaxial test. A linear Mohr-Coulomb failure envelop fitted to the test results.

$$\tau = c' + \sigma'_n * \tan(\phi')$$

Shear stress, τ, as a function of the effective cohesion, c', the effective coefficient of internal friction, tan ϕ', and the effective normal stress σ'_n.







Mohr-Coulomb failure envelope

Material and Method

Test Sample Specifications

Composition (ξ_f, ξ_{sa}), water content (ω), relative density (D_r), bulk density (ρ_b) and shear strength properties(C', ϕ') of tested samples

No.	Name	ξ_f (%)	ξ_{sa} (%)	ω (%)	D_r(%)	ρ_b(kg/m^3)	C'(kPa)	ϕ'(°)
1	C0L	0	100	7	39	1776	0	33
2	C5L	5	95	7	39	1776	1.01	31.2
3	C10L	10	90	7	39	1776	2.17	26.5
4	C15L	15	85	7	39	1776	3.2	26.4
5	C20L	20	80	7	39	1776	5.12	22.1
6	C0D	0	100	7	68	1927	0	34.3
7	C5D	5	95	7	68	1927	1.95	32.1
8	C10D	10	90	7	68	1927	3.47	31.3
9	C15D	15	85	7	68	1927	4.23	29.7
10	C20D	20	80	7	68	1927	4.93	27.2

Material and Method

Test Sample Specifications

Composition (ξ_f, ξ_{sa}), water content (W), relative density (I_D), bulk density (ρ_b) and shear strength properties(C', ϕ') of tested samples

No.	Name	ξ_f (%)	ξ_{sa} (%)	ω (%)	D_r(%)	ρ_b(kg/m^3)	C'(kPa)	ϕ'(°)
11	WC0L	0	100	9.5	39	1817	0.00	33.3
12	WC5L	5	95	10.2	39	1829	1.26	32.8
13	WC10L	10	90	11	39	1842	3.25	27.2
14	WC15L	15	85	12.8	39	1872	4.12	26.7
15	WC20L	20	80	13.2	39	1879	5.17	22.4
16	WC0D	0	100	9.5	68	1972	0.00	34.6
17	WC5D	5	95	10.2	68	1985	2.24	32.4
18	WC10D	10	90	11	68	1999	4.16	32.3
19	WC15D	15	85	12.8	68	2031	5.20	30.1
20	WC20D	20	80	13.2	68	2039	5.96	27.6

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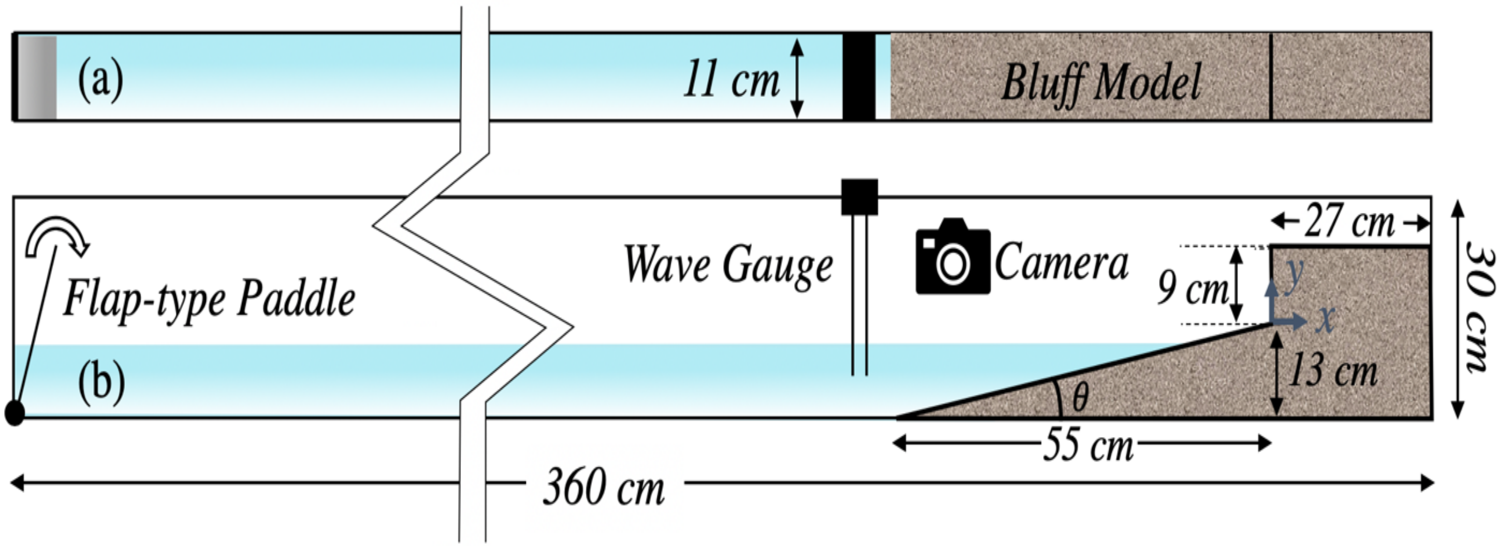
Material and Method

Wave Flume Test Program

- Monochromatic waves generated using flume's flap-type paddle
- Instantaneous water surface elevation measured using a resistive wave gauge
- Beach and bluff profile Evolution recorded using GoPro Hero 5 Black



Schematic of Experimental Setup

Material and Method

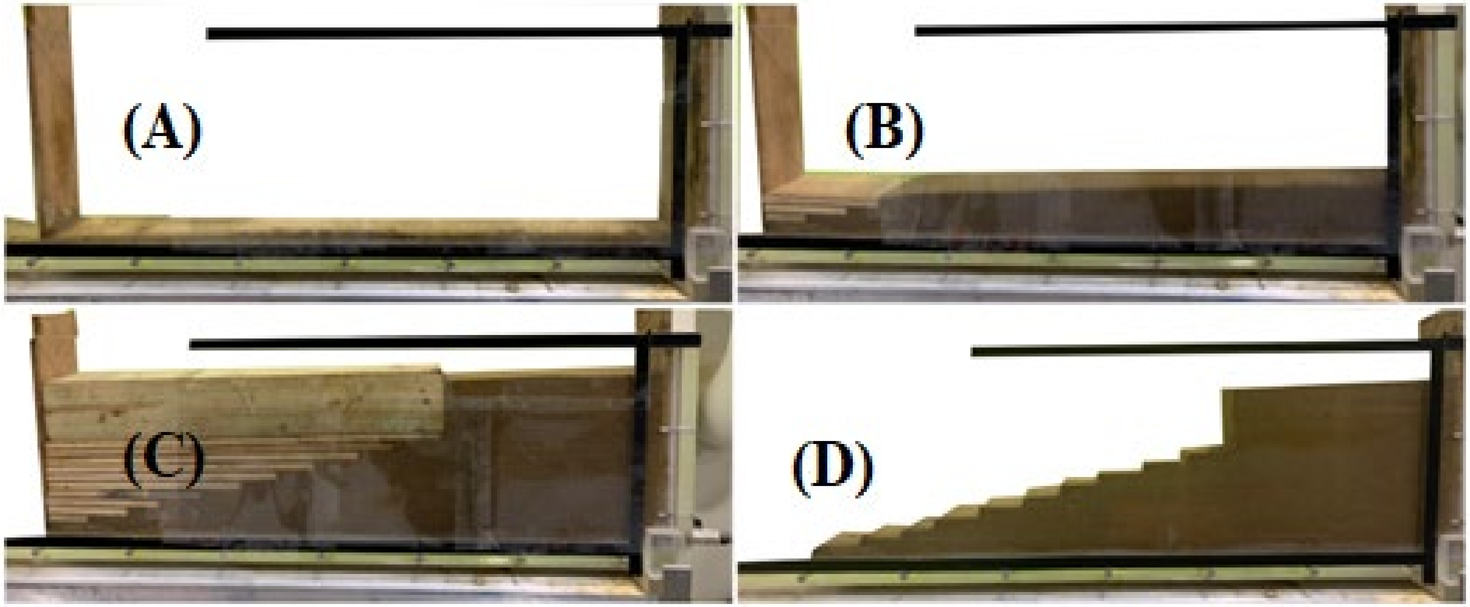
Sample preparation

A. Oven dried and sieved through No. 4 to remove gravel
B. Sieve the soil and adjust the fine content
C. Measure the specific mass to reach the target density
D. Mix soil with specific amount of water to reach target water content
E. Compact the sample to reach the target density

Material and Method

Bluff model construction

- The collected soil was air dried and passed through a No.4 sieve.
- The samples with the target mixture of fine grains and sand were prepared.
- Water was added to the soil and mixed in a mixer to reach a homogenous moisture. The soil moisture was monitored during the mixing process using a METER Group EC-5 soil moisture sensor.
- Before constructing the sample, the flume sidewalls were lubricated using grease to reduce the friction between the walls and the soil mixture, minimizing the wall effect.
- The beach and bluff were constructed layer by layer up to the bluff crest; each layer was compacted to the target density.



Images of the bluff model construction procedure

Material and Method

Wave Flume Test Program

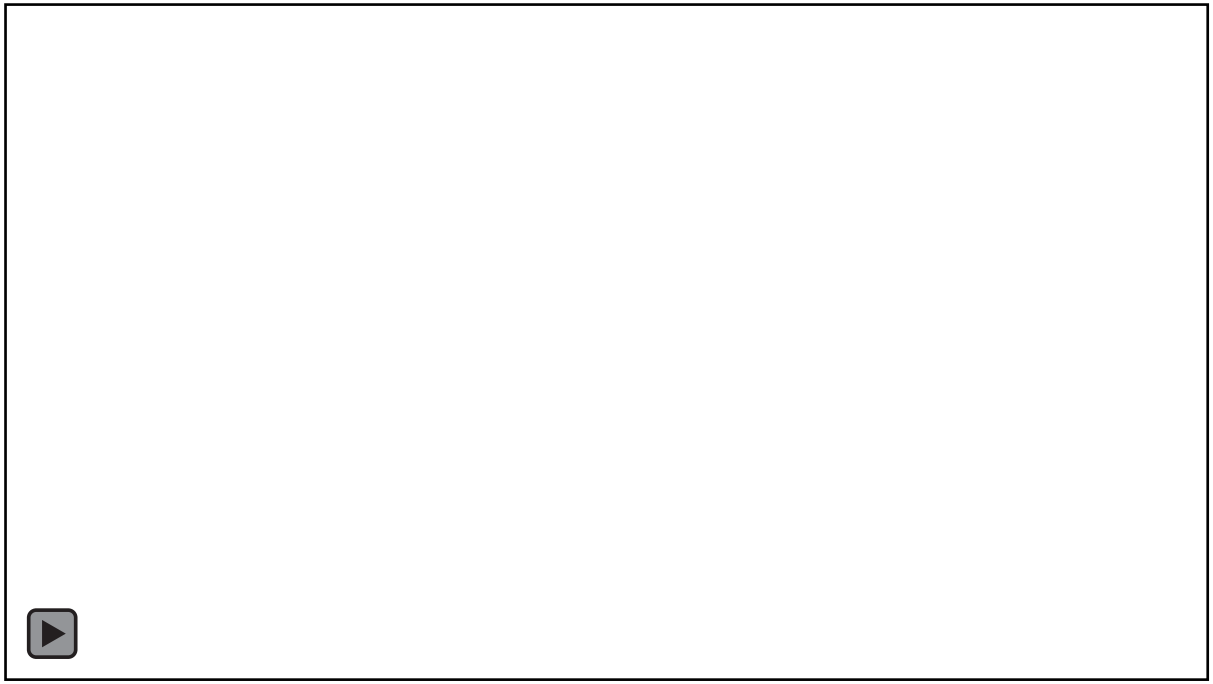
Water Levels and Wave Characteristic

- The test started after 12 hour of submerging the sample in the water.
- Each test had three stages with one cm increment in water level.

Stage		1	2	3
Water	depth (d, cm)	11.5	12.5	13.5
Wave	height (H, cm)	4.5	5.8	6.7
	period (T, s)	0.5	0.5	0.5
	length (L, cm)	38.7	39.1	39.5
	steepness (H/L)	0.12	0.15	0.17
	surf similarity (ξ)	0.60	0.53	0.48
	breaker type		Plunging	

Duration of test for each Stage was 12 hours

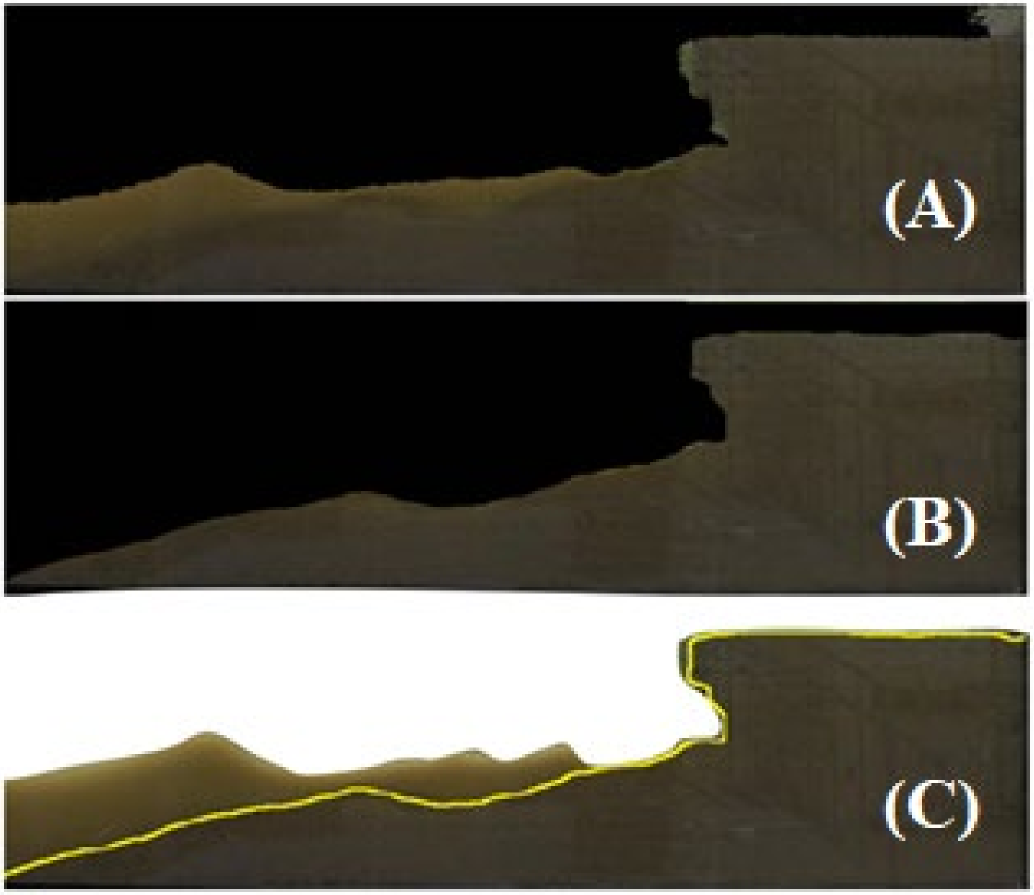
Time-lapse of bluff failure



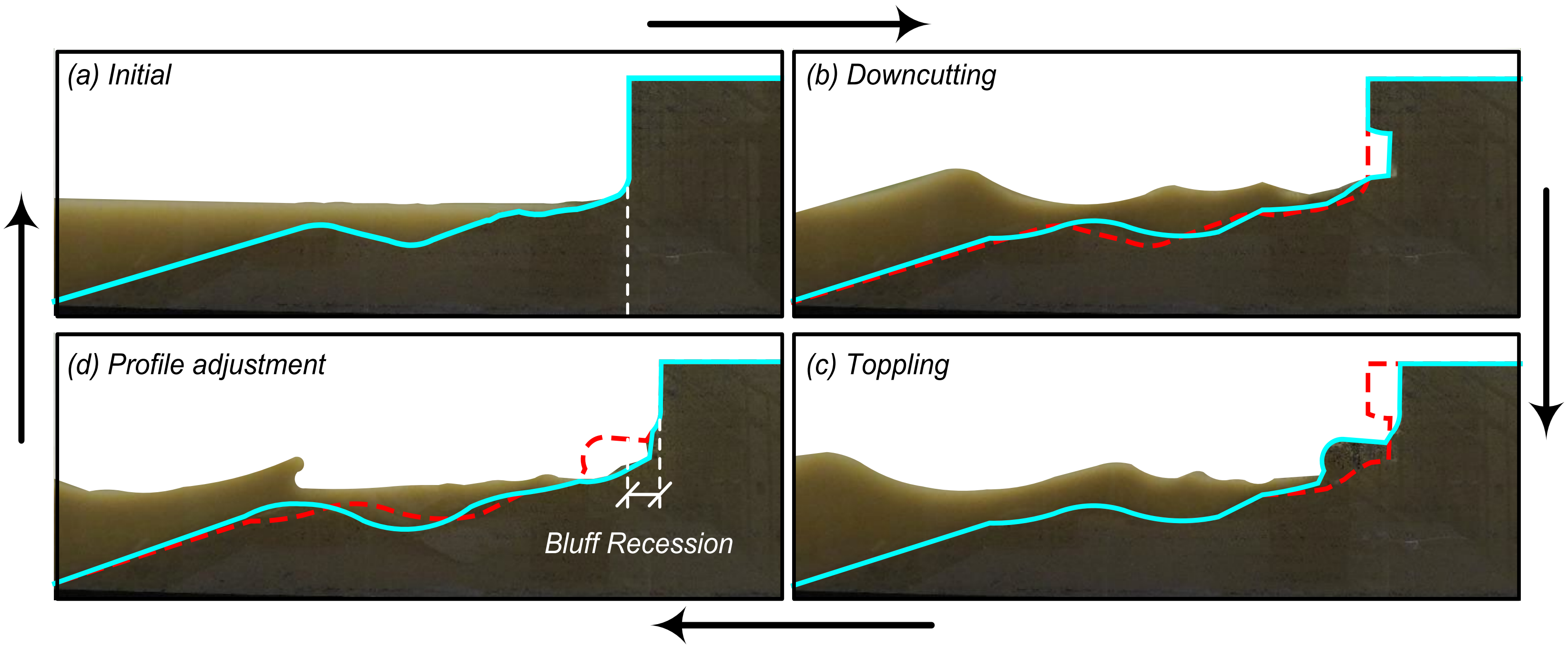
Material and Method

Data Analysis
Image Processing

- Image Processing utilized by three different toolbox in MATLAB R2017a.
- First camera has been calibrated and then images were wrapped.
- Secondly, beach and bluff edges were captured using a color threshold technique (A).
- Then, image region analyzer used to delete the noises.
- Finally, Image segmentation technique was used to eliminate farther edge of the bluff visible due to camera angle relative to the bluff (B).



Results and Discussions



Cycle of bluff downcutting, toppling and beach adjustment

Results and Discussions

Recession and recession rate of the bluff's crest for cases with dry water content

Case Name	Case No.	Fine Content ξ_f(%)	Water Content ω (%)	Relative Density D_r(%)	Bulk Density γ (kg/m^3)
C0L	1	0	7	39	1776
C5L	2	5	7	39	1776
C10L	3	10	7	39	1776
C15L	4	15	7	39	1776
C20L	5	20	7	39	1776
C0D	6	0	7	68	1927
C5D	7	5	7	68	1927
C10D	8	10	7	68	1927
C15D	9	15	7	68	1927
C20D	10	20	7	68	1927

Results and Discussions

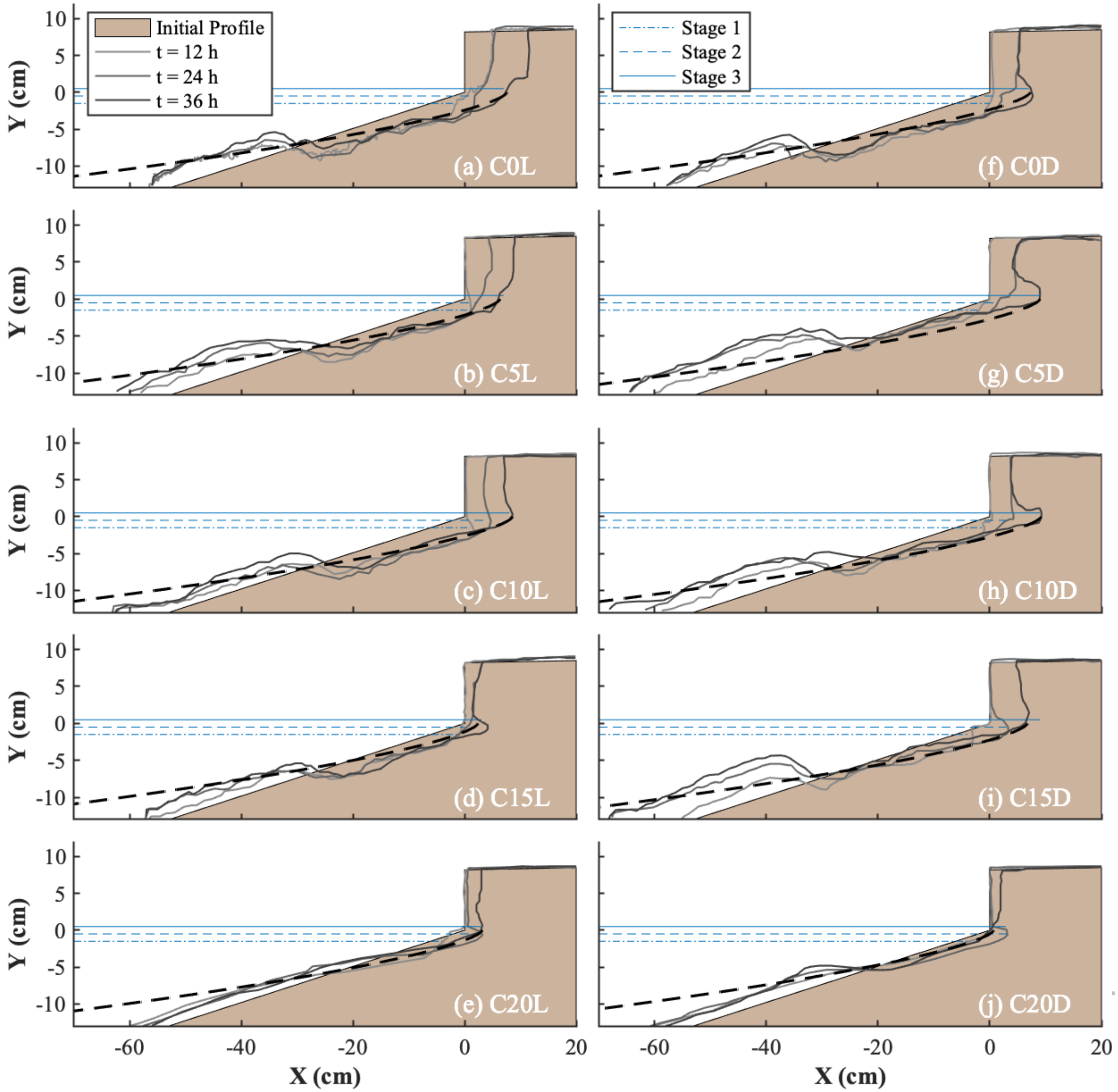
Recession and recession rate of the bluff's crest for cases with optimum water content

Case Name	Case No.	Fine Content ξ_f(%)	Water Content ω (%)	Relative Density D_r(%)	Bulk Density γ (kg/m^3)
WC0L	11	0	9.5	39	1817
WC5L	12	5	10.2	39	1829
WC10L	13	10	11	39	1842
WC15L	14	15	12.8	39	1872
WC20L	15	20	13.2	39	1879
WC0D	16	0	9.5	68	1972
WC5D	17	5	10.2	68	1985
WC10D	18	10	11	68	1999
WC15D	19	15	12.8	68	2031
WC20D	20	20	13.2	68	2039

Results and Discussions

Erosion and Recession Processes

Cross-shore profiles for different time steps and for cases with dry water content



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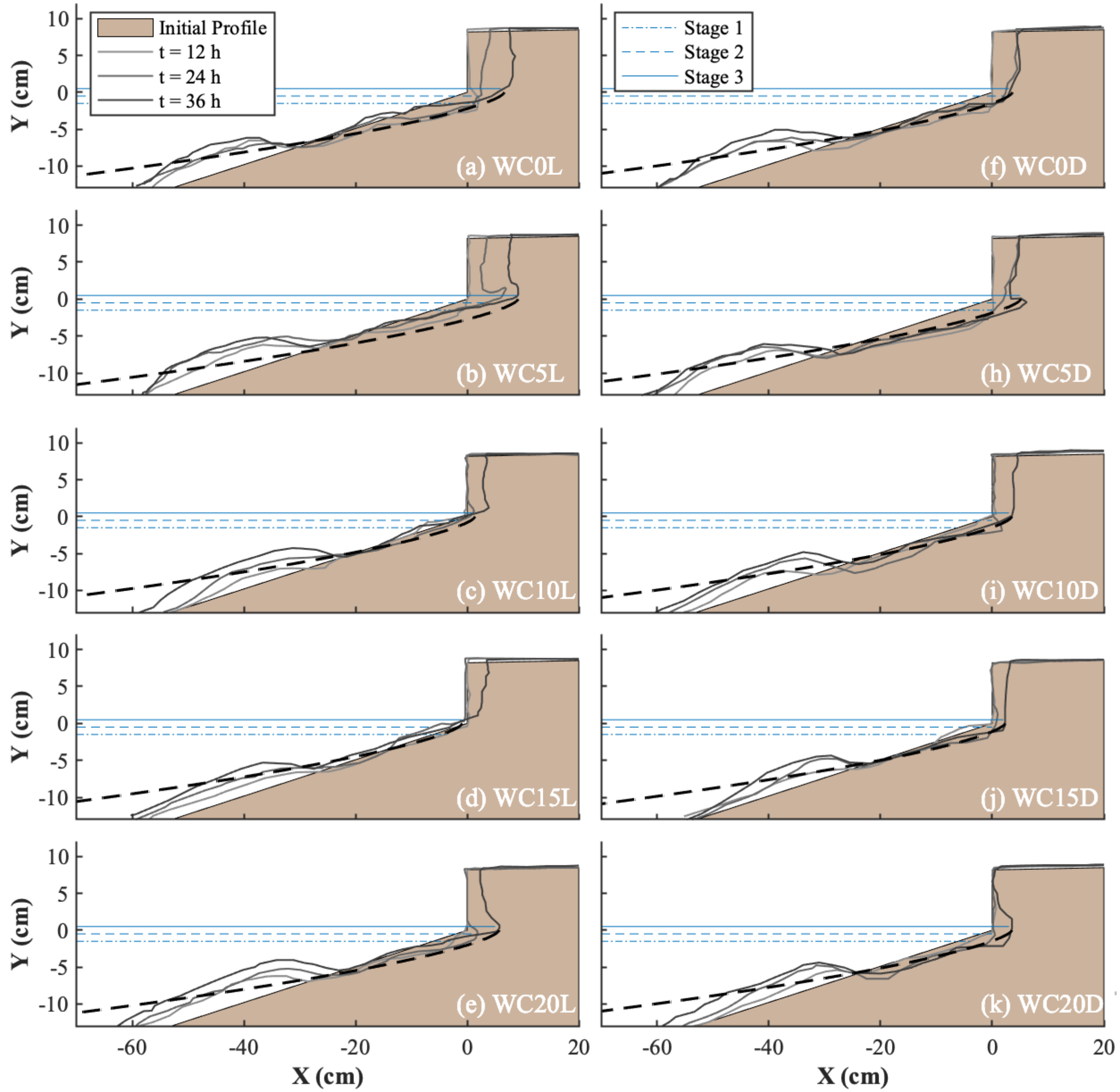
Results and Discussions

Erosion and Recession Processes

Cross-shore profiles for different time steps and for cases with optimum water content



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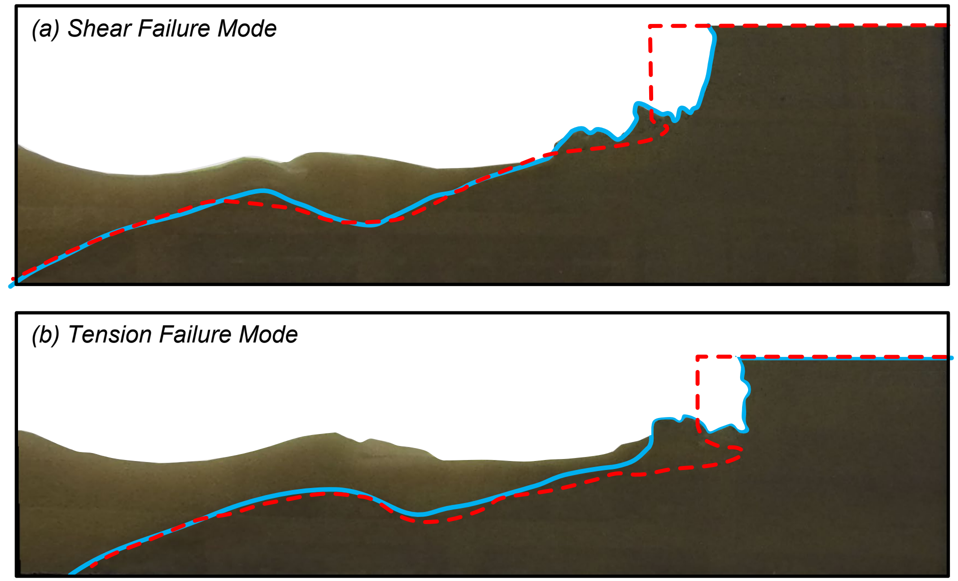
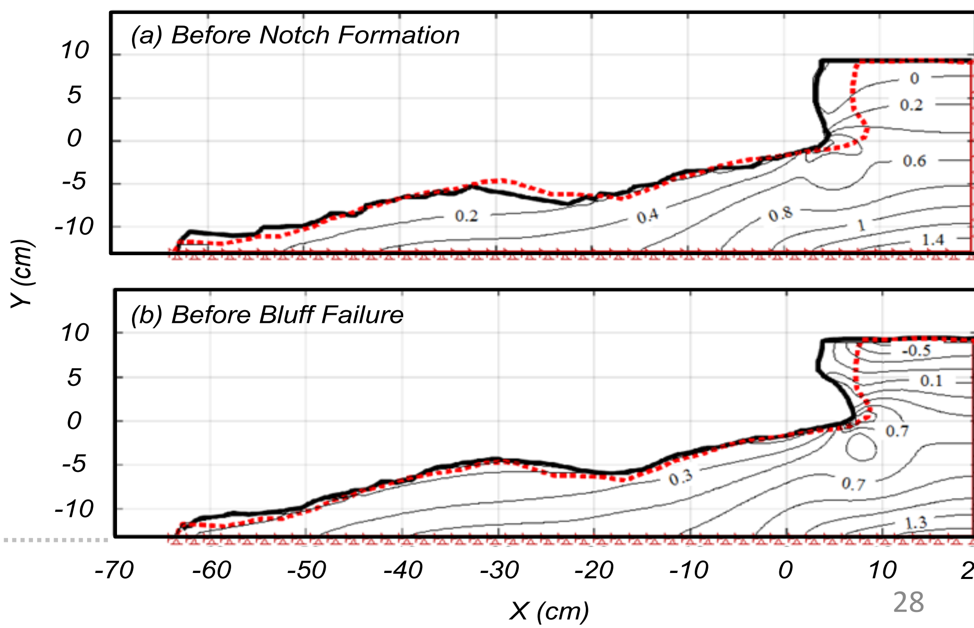
Results and Discussions

Stability Analysis of Eroded Bluff

- Sample images of observed shear and tension failure modes.



- A series of linear-elastic, finite-element method (FEM) analyses was carried out using the commercially available finite element program SIGMA/W.
- Pre-failure distribution of minor principal stress (σ_3) for Case C10L, at Stage 3. (a) before formation of notch, (b) before failure.



Results and Discussions

Stability Analysis of Eroded Bluff

Summary of failures characteristics

Case No.	Stage No.	Fine Content (%)	Packing	Water Content	Failure Mode	Crest Recession (cm)
1	1	0	Loose	Dry	Shear	5.74
1	3	0	Loose	Dry	Shear	5.98
2	2	5	Loose	Dry	Shear	4.51
2	3	5	Loose	Dry	Shear	4.57
3	2	10	Loose	Dry	Tension	3.73
3	3	10	Loose	Dry	Tension	3.82
4	2	15	Loose	Dry	Tension	3.44
5	3	20	Loose	Dry	Tension	3.05
6	2	0	Dense	Dry	Tension	5.22
7	2	5	Dense	Dry	Tension	4.20
8	2	10	Dense	Dry	Tension	3.78
9	3	15	Dense	Dry	Tension	4.33
10	3	20	Dense	Dry	Tension	2.30
11	2	0	Loose	Optimum	Tension	3.93
11	3	0	Loose	Optimum	Tension	4.03
12	2	5	Loose	Optimum	Tension	3.84
12	3	5	Loose	Optimum	Tension	3.93
13	3	10	Loose	Optimum	Tension	3.37
14	3	15	Loose	Optimum	Tension	3.22
15	3	20	Loose	Optimum	Tension	2.98
16	2	0	Dense	Optimum	Tension	4.90
17	2	5	Dense	Optimum	Tension	4.52
18	3	10	Dense	Optimum	Tension	4.32
19	3	15	Dense	Optimum	Tension	3.10

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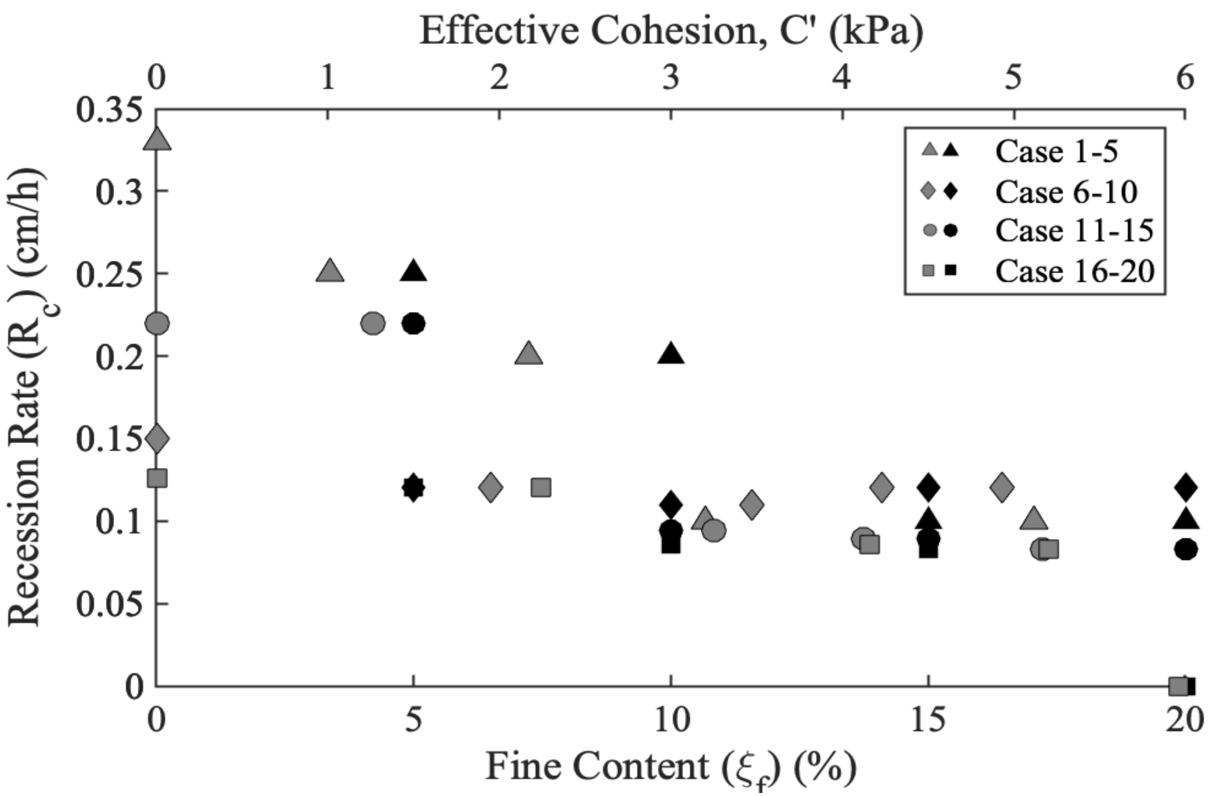
Results and Discussions

- Recession rate reduces with fine content and cohesion of the soil.
- For a given fine content or cohesion, recession rate is significantly influenced by relative density



Bluff recession rate (R_c) versus fine content (ξ_f) and effective cohesion (C')

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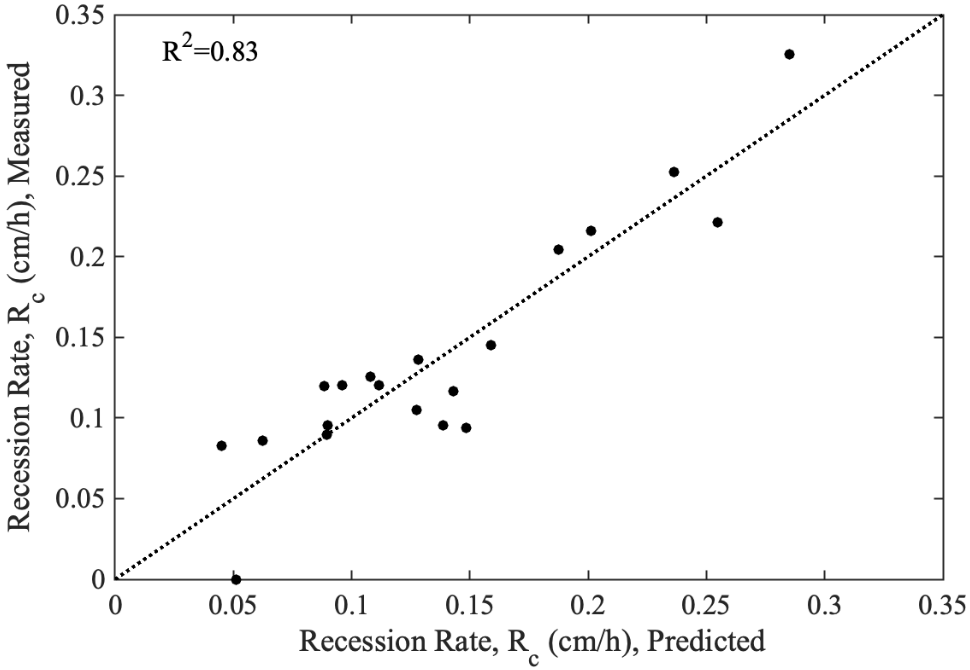
Results and Discussions

Bluff Recession Rate:

$$R_c = 0.51 + \xi_f(-0.0182 + 0.00023 D_r) - 0.0044\, D_r - 0.0087\omega$$

- The variables in this equation are in percentage.



Comparison of measured and predicted recession rate as a function of fine content, relative density, and water content

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Conclusions

- The mixture with **higher resistant force** shows the **lower erosion rate** for bluff failure.
- The erosion of the beach and bluff with the looser soil and fine content less than 10% lead to **two bluff failure events** throughout the test, while the bluff with the denser soil as well as that with the looser soil but with the highest fine content tested underwent only **one failure**. This observation is aligned with the result of the erodibility test.
- The bluff recession rate decreased as the fine content and density of the soil increased. This **reduction** was more pronounced for the **looser soil** than that of the denser one; the density overshadowed the impacts of the fine content on the recession process which is similar to the result of the initiation of erosion test
- For the cases with **optimum water content**, in general, the recession of the crest reduced compare to the cases with dry water content. These results show that the soil mixture with optimum water content has higher strength and it agrees with the results of initiation of erosion tests.
- As the beach and bluff profile reached a relatively **equilibrium profile** toward the end of each Stage, the rise of water level lead to further nearshore beach erosion and bluff recession until a new equilibrium condition is achieved.
- An **empirical relationship** including the **fine content, relative density** and **water content** was proposed for the prediction of the bluff recession rate.

Future work

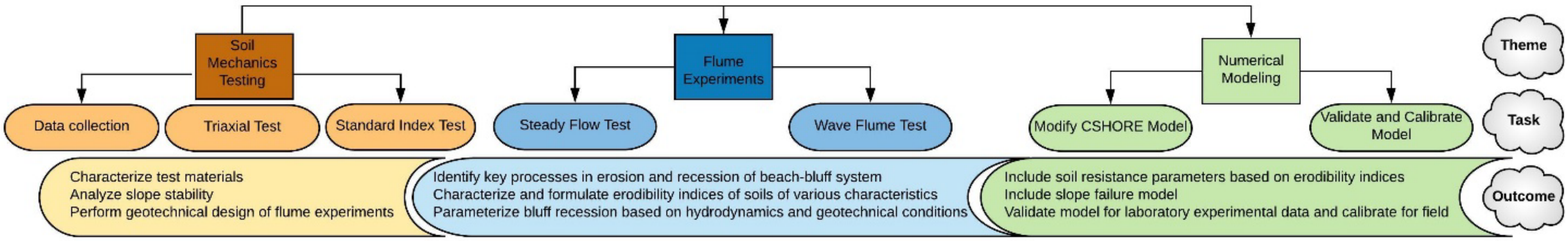
Objective 1: To quantifying morphodynamic and geotechnical processes leading to the failures of bluffs due to extreme events as well as land-based conditions.

Objective 2: To formulate relation between material strength indices and rate of erosion (erodibility indices).

Objective 3: To formulate erosion and recession processes for beach-bluff systems considering the combined effect of wave-induced erosion and slope failure.

Objective 4: To modify an existing process-based model to include erodibility parameter for soils of various geotechnical properties.

Objective 5: To apply and validate the model based on historical recession data for Long Island and Great Lakes bluffs.



Project outline, tasks and outcomes

Task 1: Use data collected from geotechnical testing of soil samples from two bluff shorelines in NY, Long Island (mostly sandy) and Great Lakes bluffs (predominantly till), to quantify the range of soil water content, composition and strength characteristics.

Milestone 1: Detailed quantifications of the range of soil characteristics for the two different bluff sites (e.g., gradation, plasticity, optimum moisture, stiffness, Mohr-Coulomb failure criterion).

Task 2: Use flume experiments including steady state initiation of motion tests to measure soil samples erodibility, and wave flume tests to quantify recession of scaled bluff models.

Milestone 2-1: Shields type graphs representing initiation of erosion for soils of various geotechnical characteristics.

Milestone 2-2: Quantitative information on rates of downcutting, slope failure mechanisms and bluff top recession rates, for the soil samples.

Task 3: Use numerical modeling which involves modifications of the CSHORE numerical model (Kobayashi & Farhadzadeh, 2008; Kobayashi & Zhu, 2019) to include the erodibility of soil mixtures.

Milestone 3: Updated numerical model CSHORE with an improved capability for predicting erosion and recession of beach and bluff systems with varying soil properties.

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Publications

- **Journals**
- Ghazian Arabi, M., Khosravi, M., & Farhadzadeh, A. (2020). Effects of Fine Content and Relative Density on Erosion and Recession of Predominantly Sandy Beach-Bluff System. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, In Press.
- Ghazian Arabi, M., Farhadzadeh, A. (2020). Characterizing Erodibility of Low Fine Content Soil with Varying Properties, *Water Resources Research*, Under Review.
- **Conferences**
- Ghazian Arabi, M., Farhadzadeh, A., Ghazian Arabi, M., & Farhadzadeh, A. (2019). Initiation of erosion of cohesionless and cohesive soil mixtures: Effects of density and fine content on the erosional behavior of soil. *AGUFM*, *2019*, EP13C-2154.
- Ghazian, M., Farhadzadeh, A., and Khosravi, M. (2020). "Erosion and Recession of Beach-Bluff System due to Wave and Surge Actions", *Geo-Congress 2020*, Minneapolis, MN
- Ghazian, M., Farhadzadeh, A. and Khosravi, A. (2018). "Recession of Predominantly Sandy Bluffs", *36th International Conference on Coastal Engineering (ICCE2018)*, Baltimore, MD
- Farhadzadeh, A. and Ghazian Arabi, M. (2020). Linking geomechanical characteristics of soil with erosion of steep shore and recession of bluff, *Submitted to AGUFM, 2020*

Questions?