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A Preliminary Experimental Study of Mitigating Coastal Erosion by Microbially Induced Carbonate Precipitation (MICP) Using Laboratory Microcosm

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Abstract. The preliminary experimental results of erosion tests conducted on untreated and Microbially Induced Calcite Precipitation (MICP) treated sandy slopes using a laboratory microcosm, simulating tidal cycles are presented in this paper. The slopes were made with sand blended with various proportions of marine clay. The extent of erosion has been assessed, based on the reduction in height of the soil slope model after subjecting to tidal cycles using laboratory microcosm. The majority of studies on the efficiency of MICP, according to the literature, have been done on sand slopes alone; sand combined with marine clay, both treated and untreated with MICP, has received less attention. It has been shown that the collapse of sand slopes is worsened by the presence of marine clay which is a common occurrence in field. It was observed that for the untreated 35° soil slopes, for normal coastal sand the reduction in slope height was 2.5%, and that of the treated soil slope was 1.25%. The untreated soil with 20% sand and 80% clay soil slopes, the reduction in slope height was 28%, and that of the treated soil slope was 9.3%. It is observed from the study that, there is significant improvement in erosion reduction in the soil slopes on MICP treatment.

Keywords: MICP, marine clay, sand, slope stabilization, tidal cycles

1 Introduction

In many estuaries, erosion of foreshore slopes due to tidal currents is a serious problem. Another potential effect of foreshore erosion is the loss of intertidal habitat through "coastal encroachment" or a gradual reduction in the geographic extent of intertidal areas. The crucial involvement of microorganisms in providing environmentally friendly options for stabilizing problematic soil slopes remains largely underexplored. Most of the stabilization techniques used are often expensive or would affect plant growth. Hence a potential treatment method which would improve soil behaviour using microorganisms would be beneficial considering the cost savings and the environmental synchronization in comparison to other chemical stabilization methods. With increasing urbanization, the demand for shoreline erosion control also increases. The aim of this study is to evaluate how soil parameters change when an indigenous bacteria named Bacillus Megaterium is used to induce calcite precipitation in the soil under ideal environmental conditions. Calcite precipitation from indigenous bacteria is a key technique for making soil biomodification more economically viable[1]. It is understood from literature that these microorganisms would induce calcite precipitation through urea hydrolysis which predominates in most of the reactive environments. The aim of the study is to identify and illustrate a technique for stabilizing the slopes of the foreshore in order to avoid erosion of the foreshore with a minimum of consequences. And also, to compare the erosion and failure mechanism on the slopes of untreated and MICP-treated sandy foreshore by simulating tidal cycles with laboratory microcosms. The presence of natural sources of calcium in a marine environment can improve the efficiency of the technology.

2 Materials

2.1 Soil

2.1.1 Sand

Sand was collected from Azheekal Beach in Alappuzha, Kerala. It was then air dried and oven dried in the laboratory for 24hours.Soil was sieved using 4.75mm sieve. Particle size analysis curve of the soil is given in Fig. 1. The soil is classified as poorly graded sand as per IS: 1498 – 1970. The particle size distribution curve of coastal sand used is shown in fig. 1.

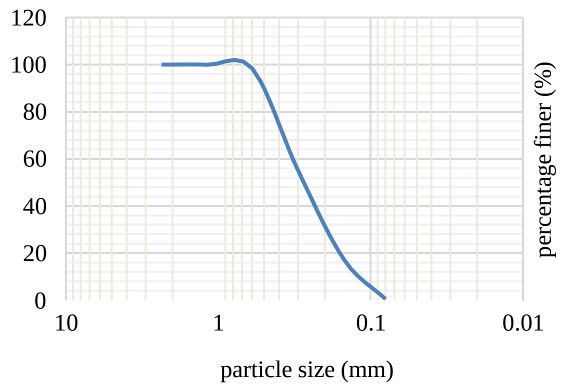

Fig. 1. Particle Size Analysis Curve of coastal sand

2.1.2 Marine Clay

On drying, many clays demonstrate an irreversible change in their mechanical and phys- ical characteristics. Several regions where this behaviour has been observed include Central America, Japan, India, Indonesia, New Guinea, New Zealand, Kenya, and Java.Kuttanad clay and Cochin Marine Clay are examples of this type of clay found in India[3]. It can sometimes be quick clay that is known to be involved in landslides. The co- chin marine clay was collected from Deshabhimanipadi, Ernakulam. The particle size distribution curve of marine clay is given in fig 2. The Cochin marine clay studied constituted about 39% of clay and 61% of silt.

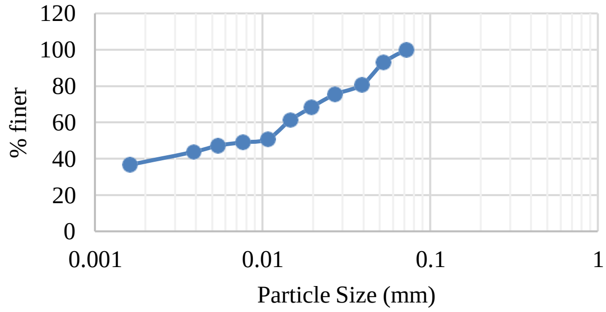

Fig. 2. Particle size analysis curve of cochin marine clay

2.1.3 Soil Samples prepared for testing

The coastal sand was blended with various percentages of marine clay (0%, 20%, 60% and 80%), and is designated as shown in table 1. It is carried out to investigate the effectiveness of MICP in a clayey-sand setting. It has been shown that the collapse of sand slopes is worsened by the presence of marine clay.

Table 1. List of soil samples

Samples	Designation
Sand (100%) +Marine Clay (0%)	S100M0
Sand (80%) +Marine Clay (20%)	S80M20
Sand (60%) +Marine Clay (40%)	S60M40
Sand (40%) +Marine Clay (60%)	S40M60
Sand (20%) +Marine Clay (80%)	S20M80

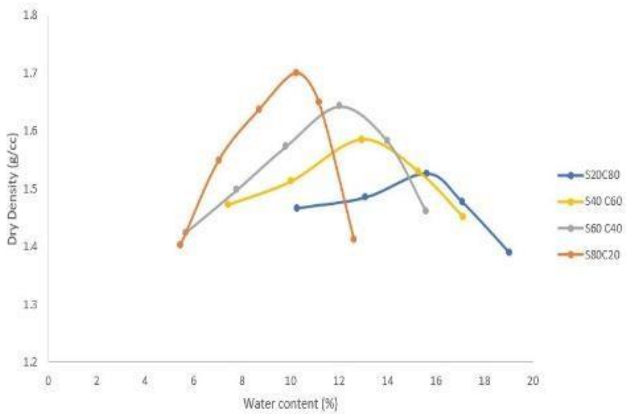

Fig. 3. Compaction curves of coastal sand blended with various percentages of marine clay samples

2.2 Bacteria Culturing

The current study utilized the urease-active strain MTCC 6544 (Bacillus Megaterium), which was procured from microbial type culture collection and gene bank (MTCC) Chandigarh in freeze dried condition. The growth medium was prepared with the following components, Beef extract (0.25g/L), Yeast Extract (0.5g/L) Peptone (1.25g/L), Sodium chloride (1.25g/L) dissolved in distilled water. The solution was then autoclaved and cooled to room temperature. The growth medium was then mixed with the bacterial cells, and the mixture was incubated at 37˚C in a humid environment. A spectrophotometer was used to determine the optical density (OD 600) of the cultivated bacterial solution by measuring the absorbance spectrum using radiation with a wavelength of 600 nm. When the culture's OD 600 value was higher than 0.6, it was used for treatment [6].

2.3 Cementation Solution

The cementation solution was made by mixing 500 ml of water with 294 g of calcium chloride dihydrate ($CaCl_2\,2H_2O$) and 120g of urea [$CO(NH_2)_2$] in a mixing cylinder and 20 times inverting up and down to make 1litre of 2 M cementation solution [5].

3 Methodology

3.1 Beach Slope Samples

The beach slope samples were prepared in accordance with Salifu et al. (2016) [4] using a profile model of dimensions 20cm × 20cm × 20cm (Fig. 4). The walls of the model were made of transparent acrylic Plexi glass, to evaluate the eroded slope profile during the tidal trials. One side of the container is fitted with a valve at the outer end and a screen for distributing the water flow inside. Water was supplied and drained via a 4 mm internal diameter pipe through a dual inlet-outlet valve. The height of the above water tank was 1.3 metres above the bottom of the erosion box. (Fig. 5).

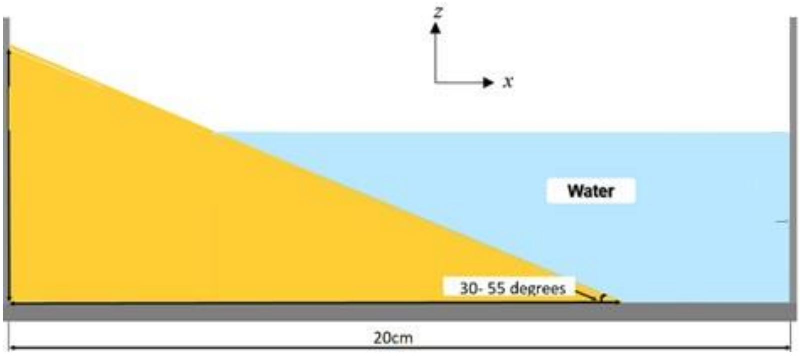

Fig 4. Schematic diagram for coastal erosion set up

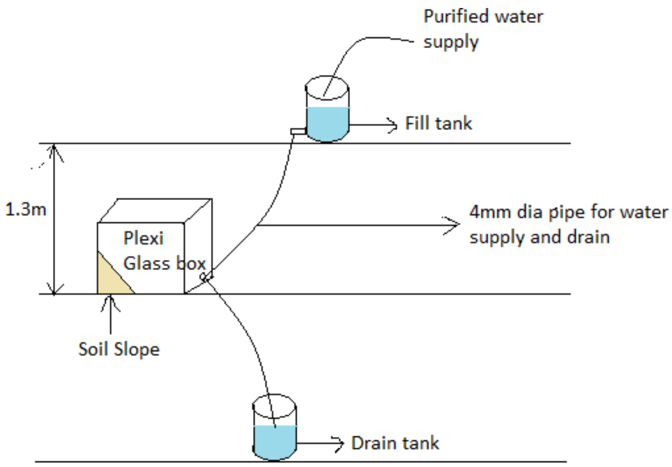

Fig 5. Schematic Arrangement of the entire coastal erosion testing set up

3.2 Method of treatment adopted

Fig. 6. Gravity Flow method for MICP treatment

By using a combination of mixing and gravity flow, bacterial solution with active bacteria and cementation solution of urea and $CaCl_2$ were delivered into soil. Fig. 6. The selection of the treatment strategy also supports the findings that 83% of the $CaCO_3$ that precipitated in bio-cemented samples utilising the premixing procedure was uni- formly distributed throughout the treated soil putting to rest the homogeneity concern [2].

3.3 Method for Erosion Tests

The investigation included two main workplans to meet the experimental objectives, as follows 1) Tidal cycle simulation with and without cementation treatments to determine the baseline erosion mechanisms with a 35° and 53° sand slope. 2) Tidal cycle simulation on 35° sand slope blended with various percentage of marine clay untreated and treated with MICP. The progressive sediment erosion trends were observed and studied per tidal cycle.

3.3.1 Tidal cycle simulation with and without cementation treatments on 35° and 53° sand slope.

Microcosm simulations were established and evaluated slope failures at two different slopes (35˚ and 53°) (table 2). The prepared sand was formed into slopes by hand compaction at a dry density of 1.48g/cm^3 in the mould. The samples were then tested by subjecting to tidal cycles at 2 hours interval (total 3 cycles), and the amount of sand eroded from each sample was assessed from the change in slope dimensions and was recorded. If the slope failed during the experiment, the test was ceased.

Table 2. Details of Soil Slopes prepared

Slope angle	Slope dimension (cm) and ratio	Mass of soil (g)	Volume of soil (cm^3)	Dry Density (g/cm^3)
35˚	4.8/6.9 (1:1.44)	1960	1324.8	1.48
53˚	8/6 (1:0.75)	710	480	1.48

The amount of sand that was eroded from each sample was calculated based on the change in slope dimensions and recorded. These treated soil slope samples were then tested against each tide cycle for a 2 hour interval (a total of 3 tidal cycles).
The input rate of the uprush flow of water was 10^{-5} m^3/s. The water level was raised to the point that it completely saturated the slope, drowning its crest by 0.08 m. As soon as the uprush reached the top of the slope, the valve was released to release water from the container at a rate of 1.3 x 10^{-5} m^3/s, allowing the tide to begin to descend. Due to the slope head's ability to accelerate backwash relative to uprush, backwash velocity was somewhat higher than uprush velocity. The height and base of the soil slope in the container were measured using the graduated scale that was attached to it, and the change in slope was observed after the tidal cycle.

3.3.2. Modelling of tide cycles on marine clay blended sandy soil samples (on untreated and treated soils).

Slope samples of sand blended with various percentages of marine clay (0%, 20%, 40%, 60% and 80%, as designated in table 1) was prepared at a slope angle of 35˚ and was subjected to tidal cycles. In order to create slopes, the autoclaved sand was moulded to a relative density of 0.75 for the sand slopes and 95% of the maximum dry density of respective samples for the marine clay blended sand slopes. After MICP treatment, Tidal simulations was performed to evaluate the effect of treatment on slope failure as described earlier.

4 Results and Discussions

4.1 Shear Strength

Unconsolidated Undrained triaxial tests were conducted on both untreated and treated sand and marine clay blended sand as per IS2720 (Part 11): 1993. The test results (table 3) have shown that there is greater increase in the shear strength for normal sand as compared to the marine clay blended sand.

Table 3. Cohesion and angle of friction values obtained from triaxial tests

Samples	c (kN/m^2)		Φ˚	
	Untreated	Treated	Untreated	Treated
S100 M0	0.7672	1.2056	36.167°	35.065°
S80 M20	0.9367	1.28	33.901°	33.457°
S60 M40	1.2233	1.6113	31.757°	30.989°
S40 M60	1.8033	2.31	25.74°	25.46°
S20 M80	2.446	2.77	19.959°	19.90°

It can be seen that the greatest improvement of cohesion is for the S100M0 sample, which is about 57% and the lowest for the S20M80 sample, about 13% on the MICP treatment. Angle of friction is observed to have no significant effect on the samples studied with MICP treatment.

4.2 Erosion Tests

4.2.1 Erosion tests on 35° and 53° sand slope with and without cementation treatments

Figures 7 and 8 show the responses or evolution of the soil slope for the two different inclinations (35˚ and 53°), (untreated and treated) after subjecting to repeated tidal cycles. Visual evidence (figs. 4 and 5) show that the first simulated tidal cycle caused an abrupt failure of the untreated slope in both cases (35˚ and 53°); the slopes then changed gradually as gradual sediment erosion occurred.

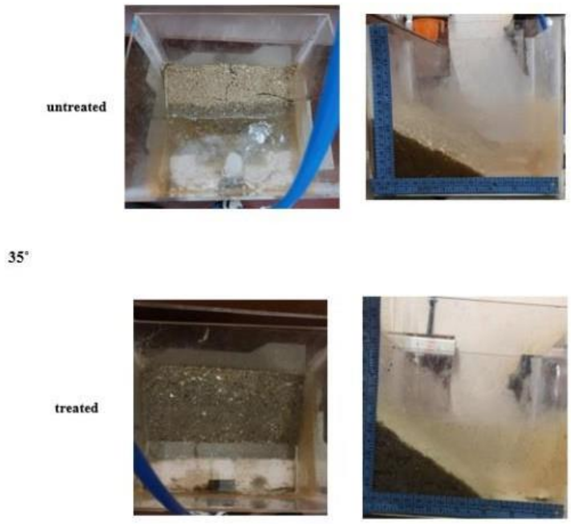

Fig. 7. Slope failure and erosion (35° untreated and MICP-treated slope after tidal events.)

Fig. 8. Slope failure and erosion (53° untreated and MICP-treated slope after tidal events.)

The slope failure mechanisms were found to be comparable both the slopes tested (35° and 53°) even though they were made up of different masses of soil (1960g and 710g respectively); This shows that erosion mechanisms and slope failures in sandy soils have similar patterns regardless of the type of soil mass producing the slope. The heights of the slope before and after subjecting to tidal cycles and the percentage reduction in slope heights (for 35˚ and 53˚) before and after treatment is shown in fig 9.

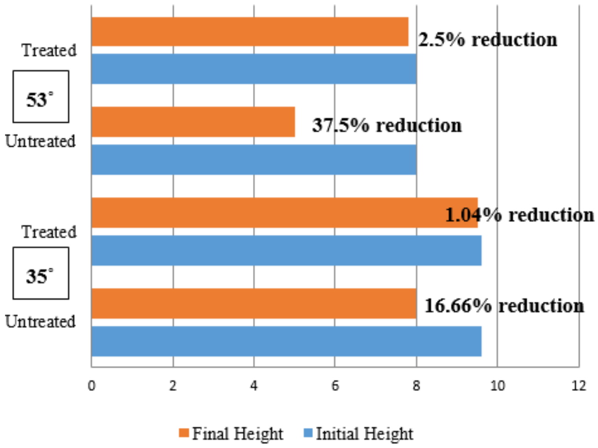

Fig. 9. Comparison of height reduction with and without treatment upon wave action.

4.2.2 Erosion tests on marine clay blended sandy soil samples (on untreated and treated soils).

The water's force as it rises during the early tidal cycles tore apart soil grains and moved them in the direction of the flow. The majority of them dispersed and began to roll down the slope, further agitating other grains. While some grains halted and landed slightly lower than their initial position, others stopped and deposited themselves at the bottom of the slope. As the tide rose during the first tidal cycle, a "new" pseudo-slope formed beneath the saturated region. The entire soil mass above the water disintegrated as soon as the water level rose past the slope's halfway. This was a classic "rotational" type slope failure that immediately reduced slope height and increased slope length [4]. The backwash was less eventful; but some fine particles continued to accumulate in the tide water as it subsided along the slope surface. Figures 10 and 11 demonstrate, for the untreated slope S80M20 and the treated slope S80M20, respectively, how the slope responded or changed after being subjected to tidal cycles.

Fig. 10. Slope S80M20 failure during simulated tidal cycle (untreated)

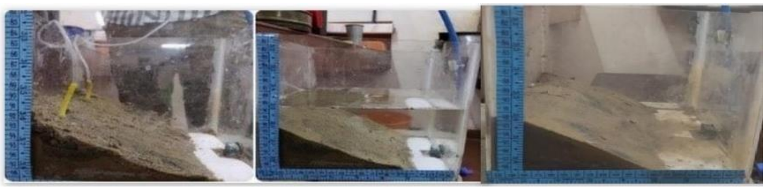

Fig. 11. Slope S80M20 failure during simulated tidal cycle (treated)

Figures 12 and 13 illustrate, respectively, the slope height reduction results of the erosion tests conducted on the samples that were both untreated and treated.

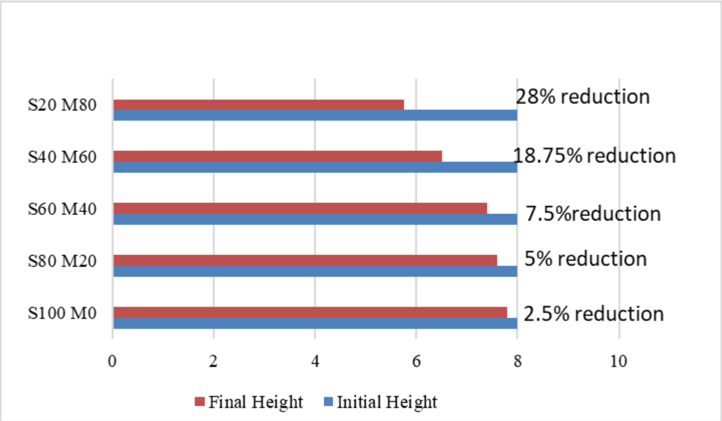

Fig. 12. Height reduction without treatment upon wave action.

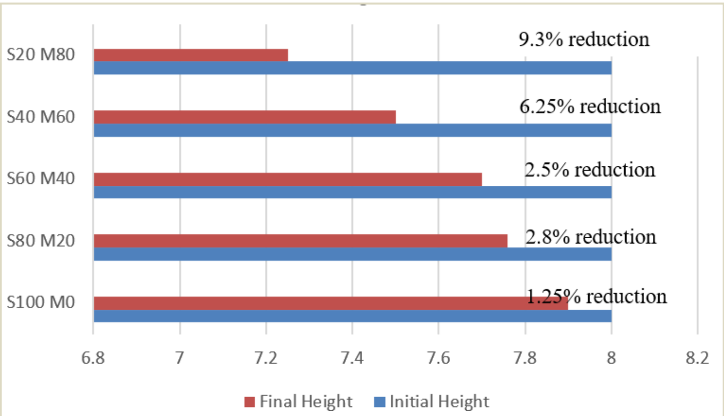

Fig.13. Height reduction with treatment upon wave action.

It was observed that for the untreated 35˚ soil slopes, the reduction in soil slope height was 2.5%, and that of the treated soil slope was 1.25%. For S80 C20 soil slopes the reduction in slope height was observed to be 5% in the untreated condition and 2.8% in treated condition. For S60 C40 soil slopes the reduction in slope height was observed to be 7.5% in the untreated condition and 2.5% in treated condition. Similarly, for S40 C60 soil slopes the reduction in slope height was observed to be 18.75% in the untreated condition and 6.25% in treated condition. When S20 C80 soil slopes the reduction in height was observed to be 28%, which was reduced to 9.3% in MICP treatment

5 Conclusions

- Clearly, the results of the study imply that there is substantial improvement in the shear strength and reduction in erosion for the treated soil slopes After MICP treatment, the largest improvement in cohesion (approximately 57%) was observed for sample S100M0 (pure sand) and the lowest improvement (about 13%) for S20M80. Angle of friction on the samples tested after MICP treatment was not improved much.
- The extent of erosion in untreated and treated slopes of two different slope angles, 35˚ and 53˚ has been assessed, based on the reduction in height of the soil slope model after subjecting to tidal cycles. It was observed that for the untreated 35˚ soil slopes, the reduction in height was 16.6%, and that of the treated soil slope was 1.04%. Similarly, for the untreated 53˚ soil slopes, the reduction in height was 37.5%, and that of the treated soil slope was 2.5%. This shows that there is significant improvement in the reducing the erodibility of soil slopes after MICP treatment when subjected to wave action.
- It has been shown that the collapse of sand slopes is worsened by the presence of marine clay. It is observed that the improvement brought about by MICP treatment is more effective when applied to samples with more percentage of sand, than marine clay. The use of MICP might be able to effectively cement soil grains, reducing the likelihood of slope failure or erosion to a respectable degree.
- Nevertheless, issues with erosion and slope stability are many and arise in a variety of environments. However, one of the greatest challenges in field application will be the penetration of treatment or its non-heterogeneous distribution across soil volumes Future research should effectively address these important factors in order to modify strength and permeability over relatively large volumes of soils.

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