

BIO-CEMENTATION OF COASTAL SEDIMENT FEATURES AND ROCK REVETMENTS TO REDUCE EROSION AND FLOOD RISK

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INTRODUCTION

Bio-cementation is a process by which microbes within the sediment produce bonds between individual particles through biochemical reactions that can occur naturally under the right conditions or can be induced artificially by supplying microbes and needed nutrition. Bio-cementation effectively increases the erosion resistance of the sediment material. A specific bio-cementation process called microbially induced calcium carbonate precipitation (MICP) is explored via field and laboratory tests to quantify its effect on sediment erodibility and slope stability. MICP, is an environmentally friendly process that utilizes the natural environment to facilitate calcium carbonate formation. The process binds sand grains together through calcite formation at particle-particle contacts (e.g., Montoya, 2012). Fig. 1 provides a schematic of the intended coastal features and locations of interest here, where the MICP application may add value. Two types of coastal protective features are investigated for MICP treatment: (1) beach and dune systems and (2) rock revetments.

Coastal beach and dune systems undergo rapid morphological changes during storm impact. Elevated water levels and increased wave energy cause erosion of the berm and dune leading to increased flood risk for landward areas, especially if dune breaches occur. The longer a beach and dune system can withstand erosion and delay breaching during a storm, the lower the risk of flooding becomes. Rock revetments are coastal structures protecting land slopes facing bodies of water, rivers, or navigation channels from erosion by flowing water, waves, and vessel wakes. Two ways to increase the stability of a rock revetment under wave loading are increasing the weight

of individual rocks or decreasing the slope. Larger rocks are more expensive and harder to handle whereas decreased slopes require a larger structure footprint which is often prohibitive.

The objective is to explore and quantify the utility of the MICP process in increasing beach and dune sediment resistance to erosion and to offer a method to strengthen rock slopes without using traditional concrete. The work is intended to produce quantitative data to help utilize MICP in coastal risk reduction infrastructure design as a nature-based option.

MICP PRELIMINARY LAB AND FIELD TESTING

This bio-cementation process can be completed with different types of naturally occurring microbes present in sediments, such as *Sporosarcina pasteurii*. The MICP process has been applied to various soil strengthening problems. For example, in earthquake prone areas, bio-cementation introduced by injection has been used to combat liquefaction issues in susceptible soils. Rock fractures have been "healed" via MICP grout (Minto et al, 2016). Temporary airfields have been created by spraying MICP inducing solutions on untreated surface sediments. Some limited coastal applications have also been tested where dunes have been strengthened via injection and surficial spraying of MICP solutions in laboratory and field settings (e.g., Shanahan and Montoya, 2016; Do et al., 2019). Our initial laboratory and field tests were conducted with the objective of optimizing the parameters needed to achieve MICP formation in coastal sands. They included sets of sediment column strength tests varying MICP mixture application method, environmental conditions, mixture composition and amount, as well as

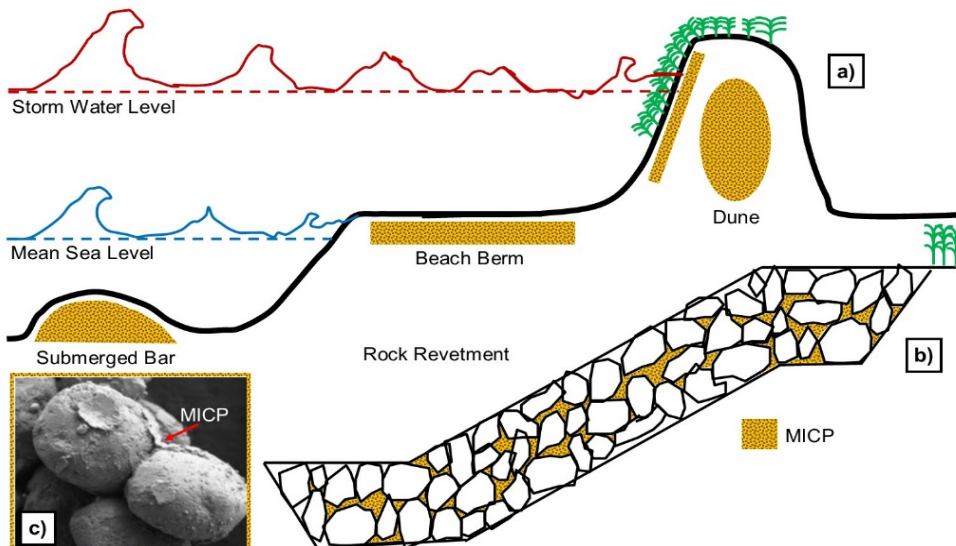


Figure 1 - Potential application of MICP enhanced sediment. Panel a) Schematic of beach and dune locations for MICP treatment. Panel b) Schematic of MICP treated sediment filling void spaces of a rock revetment. Panel c) Microscopic image (70x zoom) of MICP between two sand grains (Courtesy of Nafisi et al., 2018).

curing time. Additional field tests using enclosed pods on a beach in Galveston, Texas, were conducted to fine-tune optimal mixture parameters and to collect Torvane shear and normal stress penetrometer data. Results showed that the MICP process was most effective in increasing sediment strength when a 2-component approach was taken with a bacterial mixture (S1) and cementation mixture (S2) under aerobic conditions around a pH level of 9. It was concluded that the most effective components of these mixtures are as follows: exponential phase culture of *S. pasteurii* in S1 and 1.5M CaCl₂ + 1M urea + 18 g/L fructose + 0.5M sodium bicarbonate in S2. After applying S1 using surficial pump sprayers distributed over several days, MICP formation was allowed to happen over two weeks before testing was conducted.

ROCK SLOPE EXPERIMENTS AND RESULTS

To quantify the effect of MICP treatment on rock slope stability, three different setups were investigated in the lab: (i) rocks only, (ii) sand and rocks, and (iii) sand and rocks with MICP. For each setup, a two-layer thick rock slope was placed on a plywood ramp covering about one square meter. A toe sill provided the lower boundary of the slope to simulate typical toe protection in a prototype scenario and side panels provided lateral boundaries. Rough semi-angular basalt rocks with nominal diameter $D_{n50} = 0.05$ m and sand with a median diameter $D_{50} = 0.14$ mm were used. After several preliminary tests to optimize the method and collect initial data, the final test series were completed in triplets for each setup using similar material. Rocks were placed by hand on the slope at zero Degree angle with the horizontal. The angle was subsequently increased incrementally while recording any rock movement or dislocation up to complete failure of the majority of rocks making up the revetment ($N \approx 200$). Setup (ii) was done in a similar fashion but after rock placement, sand was filled into the voids of the rock matrix allowing only for the surface of the top rock layer to be visible. Setup (iii) included the same setup process as setup (ii), but now MICP treatment was applied ahead of a two-week curing process as explained in the section above. At the end of the curing period, the slopes were raised incrementally until complete failure occurred. Fig. 2 shows photos before and after an MICP rock slope failure.

The results showed a significant increase in the angle required to induce complete failure of the MICP rock and sand slope (iii) compared to the setups with just rocks (i) or rocks with sand-filled void spaces (ii). Setups (i) and (ii) started showing individual rock movement and dislocation at around 50 Degrees incline with complete failure occurring at angles between 60 and 70 Degrees. Setup (iii) complete failure only occurred as the angle was raised past 90 Degrees. A thin layer (~2 mm) of MICP had formed across the entire test surface including sand-sand and sand-rock contacts. This layer was very effective in retaining slope integrity up to vertical inclination and also featured much increased resistance to shear and normal stress applied to the sand surface. The MICP treatment thus seems to provide a nature-based option to strengthen rock revetments, reduce rock size requirements, or allow for steeper slopes to reduce the overall structure footprint.



Figure 2 - Rock revetment slope test with MICP enhanced sediment before (left) and after failure (right).

OUTLOOK

More rock revetment experiments including MICP treatment are currently in planning to expand the findings across other configurations. In addition, experiments in the 15-m mobile-bed wave flume facility on the Texas A&M University Galveston Campus are underway exploring the erodibility of MICP enhanced sediment features under wave attack including beach-berm and submerged bar features as well as rock revetments (Fig. 1). Available results from these ongoing tests will be presented at the conference in addition to the rock revetment findings.

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