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STUDY OF BIO-GROUT TREATED SLOPE MODELS UNDER SIMULATED RAINFALL

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ABSTRACT: Previous data reported that soil erosion in Malaysia was directly related to rainfall trends. This phenomenon could affect the overhead transmission towers which are at risk of collapsing due to slope failure. For soil stabilization, chemical grouting such as cement, lime and acrylamides were generally applied to enhance the physical properties of the soil. However, some of the chemical additives used in the grouting suspension may be toxic and hazardous to both humans and the environment. Thus, it is important to look for alternative grouting substances that are safe and sustainable. Recently, a new soil improvement technique based on carbonate precipitation by microbial activities from vegetable waste has been developed as bio-grout. This study was aimed to investigate the effectiveness of bio-grout from the vegetable waste in reducing soil loss due to rainfall impact. Soil samples were collected from an eroded slope nearby a transmission line in Perak and molded into 45˚ slope models in a custom-made box. A simple rainfall simulation was performed on the untreated and treated soil samples mixed with bio-grout for 30 days. The results showed that the soil loss of treated samples has been significantly reduced from 34.6 g to 13.5 g. Scanning electron microscopy showed aggregated particles occupying the empty spaces of the treated soils. Evidence of bio-mediated microbial activity was indicated by the presence of microorganisms in the bio-grout liquid. The bio-grout from vegetable waste proved to be an effective and eco-friendly new grouting material for soil erosion control.

Keywords: Soil erosion, Bio-grout, Vegetable waste, Slope models, Simulated rainfall

1. INTRODUCTION

Soil erosion is a global issue that imposes an environmental problem financially and economically. Several factors causing soil erosion include unstable climate changes, deforestation, bad farming practices, extreme wind and excessive rainfall. The impact of soil loss on agricultural land leads to the reduction of soil fertility that needs to be replenished in order to maintain productivity [1]. Soil erosion will also physically affect the stability of constructed roads and buildings. In tropical countries which experience monsoon rain, intense and heavy rainfall was the leading factor that causes soil erosion besides moisture content in the soil, steepness of slope and land covering [2].

Soil erosion due to rainfall impact generally begins with the detachment of soil aggregates at the surface of the soil layer followed by transportation of loose soil to the lower ground. The surface runoff will be deposited in drainage systems or other ground surfaces that can obstruct or damage other properties. Slope failures can be triggered by heavy rainfall during or instantly after periods of the prolonged rainy season [3]. Large-scale slope failures usually originate from soil erosion. As the water accumulates, minerals that are binding the soil particles begin to dissolve. Water seepage due to excessive rainfall infiltration will replenish the soil moisture deficiency and rises in groundwater level may reduce the matrix suction in the soil, resulting in a reduction in the soil shear strength and effective stress [4].

In Malaysia, soil erosion that occurs on the slope frequently disturbs the stability of electric transmission towers due to unpredictable soil behavior and harsh climate. The high amounts of rainfall at 2500 mm on the average will accelerate the process of soil erosion and affect the conditions of the surrounding soils [5]. One study mentioned the frequent occurrence of soil erosion incidences due to rainfall based on accumulated rainfall data in the northern and southern part of Malaysia [6]. Global warming phenomenon due to the increase of greenhouse gases also influences the frequency of extreme rainfall events that cause intense and prolonged rainfall.

Soil erosion along the slope area can directly affect the stability of the towers. Controlling soil erosion along transmission lines has always been a great concern to the civil engineers. It is a big task to maintain thousands of 132kV, 275kV and few 500kV lattice towers or monopole towers as these towers actively transfer high voltage of power supply across elevated areas and forest from one city to another. Hence, the grounds and foundation around the perimeter of the towers need to be stabilized to support the towers. In view of this, erosion control is very important to preserve the slope or land adjacent to the tower structure.

There are several measures to prevent soil erosion such as vegetation planting, application of mulch or exotic grass and reforestation [7]. Plants can help stabilize the soil by holding the soil through the extensive root systems. In geotechnical engineering applications, soil-cement mixtures and chemical-based materials are commonly utilized for erosion control and slope stability. However, these methods can be costly and require high energy consumption. Moreover, the use of chemicals or polymers as soil-stabilizer additives can produce negative side effects on human health and the environment eventually [8].

In recent years, the use of microbial carbonate precipitation induced by ureolytic bacteria through the metabolic pathways has become popular in many applications such as soil reinforcement, wastewater treatment, bio-remediation, and construction materials [9]. In soil stabilization, the mechanical properties of soil can be improved through a bio-mediated technique based on microbial activity and urea hydrolysis. This new technology has an advantage over conventional methods in term of cost and safety. Many laboratory studies have reported that the shear strength and the compressibility behavior of sandy soil can be improved using this technique [10].

The genus *Bacillus* is most commonly used for microbial carbonate precipitation for their ability to produce urease enzyme. Ureolytic bacteria such as *Bacillus pasteruii* and *Bacillus Subtilis* play an important role in calcium carbonate precipitation and these bacteria are widely found in the soil environment. In natural environments, these bacteria will break down urea to produce ammonia and carbonic acid and this reaction increases the pH of the surroundings to become alkaline. Subsequently, calcium ions in the surroundings will react with carbonic acid and hydroxide ions to produce calcium carbonate precipitation on the bacterial cell wall. As a result, the calcium carbonate crystals will fill the empty spaces within the soil particles and bind them together, thus changing the physical properties of soil and improving its strength through a process known as bio-cementation or bio-clogging [11-12].

Bio-grouting is a new grouting technique in geotechnical engineering practice using microbial technology in contrast with cement and chemical grouting to reinforce the ground. The concept of bio-grouting is based on the ability of urease producing micro-organisms to precipitate calcium carbonate in the presence of urea and calcium additives. The formed calcite minerals will act as cementing agents that bind the soil particles together [13]. A bio-grouting method using bacteria can be applied on the ground where any structures already exist because of its liquefied form that can penetrate through narrow spaces and disperse into soil properly by gravity or injection without compromising the surrounding area.

In previous work by the same research group, it was demonstrated that the strength and stiffness of sandy soil were enhanced following treatment with bio-grout from vegetable waste. The engineering properties, permeability, and shear strength have improved significantly due to the bio-clogging process activated by the indigenous bacteria in the liquid [14-15]. In continuation of our work on the effectiveness of bio-grout from vegetable waste, the objective of this laboratory study was to analyze the quantity of soil loss from bio-grout treated slope models under simulated rainfall condition and to investigate the evidence of bio-clogging process by microbial activity.

2. EXPERIMENTAL

2.1 Soil sampling

The soil samples were specifically collected from a disturbed slope nearby a transmission tower in Segari, Perak and transported to the Geotechnical Laboratory of Universiti Tenaga Nasional for laboratory analysis. The soil was classified as silty SAND according to its physical properties (British Standard 1377: Part 2: 1990). Figure 1 and 2 showed the occurrence of landslide right beneath the transmission tower and a closer look showed that gully erosion has developed due to the collected runoff water. This phenomenon will carry larger volumes of water that can become a small stream. Subsequently, more erosion will occur when soil along the pathway is washed away. If the gully becomes larger, it will be more costly to remediate the soil.

Fig.1 Soil erosion near transmission tower

Fig.2 Development of gully nearby transmission tower

2.2 Preparation of Bio-grout

Bio-grout was produced following previously published method by the same research group [15]. Briefly, vegetables such as cabbage, long bean, and spinach were kept in a tightly closed container for one month to undergo a fermentation process. Then, the liquid from the vegetable waste was filtered and kept in sealed containers at room temperature (Figure 3). The pH value of the bio-grout liquid ranged from 7-8 showing that the bio-grout fluid was alkaline. Mass analysis of the bio-grout showed that it contains considerable amounts of calcium ions. Thus, this provides a favorable condition for the precipitation of calcium carbonate ($CaCO_3$).

Fig.3 Bio-grout that has been filtered

2.2 Slope Models and Rainfall Simulation

There are several designs of rainfall simulators mentioned in the literature for the assessment of soil erosion [16-17]. Laboratory-scale rainfall simulators have been widely used since it is an effective tool for assessing soil erosion that includes control parameters such as drop impact velocity and rainfall intensity. In this study, the soil samples were molded into a 45˚ slope models inside custom-made boxes consisted of untreated (control) and treated the soil with bio-grout. A simplified version of rainfall simulator using a plastic container with holes to deliver the water was performed on the slope models in the duration of 5 minutes, every 10 days up to 30 days. The source of simulated rainfall was located 0.8 m above the slope surface models (see Figure 4). The soil loss from the detachment of soil particles due to the rainfall impact was collected and weighted. Measuring soil loss is significant to erosion control as one of the important parameters. The parameters of rainfall characteristics such as intensity and velocity were not taken into account due to some limitations.

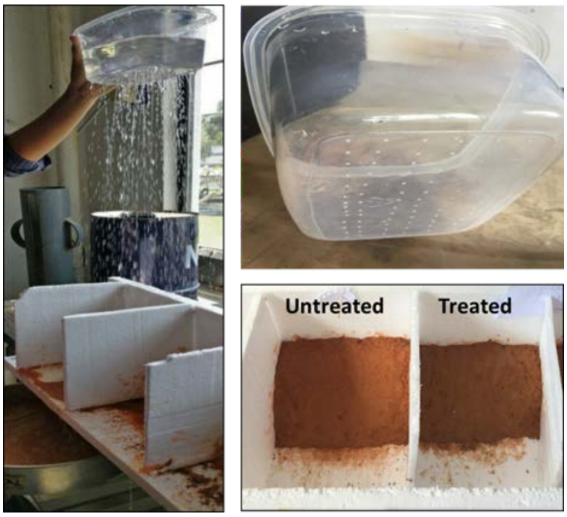

Fig. 4 Rainfall simulation using soil slope models of untreated and treated samples

2.3 Detection of bacterial colonies

There are many microorganisms that are able to precipitate minerals through several biochemical processes. Most previous laboratory studies involving microbial carbonate precipitation (MCP) utilized cultivated bacterial culture and nutrient medium which can be costly if applied in larger scale experiments. Hence, the bio-grout from vegetable waste would be a suitable medium for the growth of bacteria. For this purpose, nutrient agar and serial dilution method were used to detect the presence of microorganisms in the bio-grout liquid. A metal loop was used to streak the sample on agar-based nutrient medium in a petri dish and incubated at 30ºC for 48 hours. Another control was incubated at 4ºC. If bacteria are present, bacterial colonies will be observed on the agar.

Preliminary screening of the bio-grout fluid for microbial pathogens showed that pathogenic bacteria such as *Escherichia coli*, *Salmonella sp*, *Staphylococcus aureus*, *Clostridium perfringen* and *Pseudomonas aeruginosa* were only detected in smaller amounts (< 1 cfu/mL). This shows that the bio-grout fluid is safe for environmental application. If pathogenic bacteria are present in larger quantities, the bio-grout liquid from vegetable waste will not be suitable for in situ treatment as these bacteria can pollute the underneath groundwater and cause adverse effects. The bio-grout fluid was prepared according to hygiene practices to avoid cross-contamination.

3. RESULTS AND DISCUSSION

3.1 Soil Loss Analysis

The ability of the treated soil sample to endure rainfall impact specifically on the surface of the slope was analyzed from the rainfall simulation test. A graph that depicted soil loss against curing time was constructed to show the effectiveness of soil treated with bio-grout in resisting rainfall impact in comparison to untreated sample (control) (See Figure 5). The results showed that the soil loss in the bio-grout treated sample has significantly reduced throughout the curing period. On zero day of curing time, 34.6 g of soil loss was collected due to the surface runoff by the simulated rain. After 10 days, the mass of soil loss recorded was greatly reduced to 13.5 g and continued to decrease until 30 days.

Observation after 30 days showed that the treated soil samples had been cemented thoroughly especially on the soil surface area (Figure 6). The soil was more firm and compact. Development of bio-cementation was clearly observed, characterized by white precipitations due to the formation of calcium carbonate crystals. This process was known as biomineralization that improves the engineering properties of soils, such as permeability, stiffness and shear strength [18]. On the contrary, more soil loss was observed from the untreated soil sample during the rainfall simulation. At the end of 30 days, the soil loss from the untreated sample has increased from 36.7 g to 45.8 g.

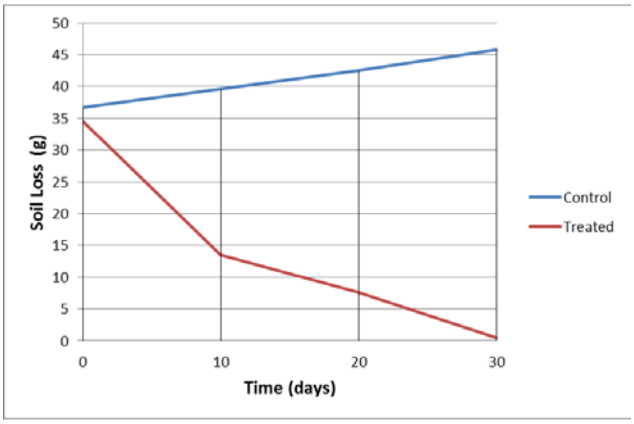

Fig. 5 Mass of soil loss during curing period

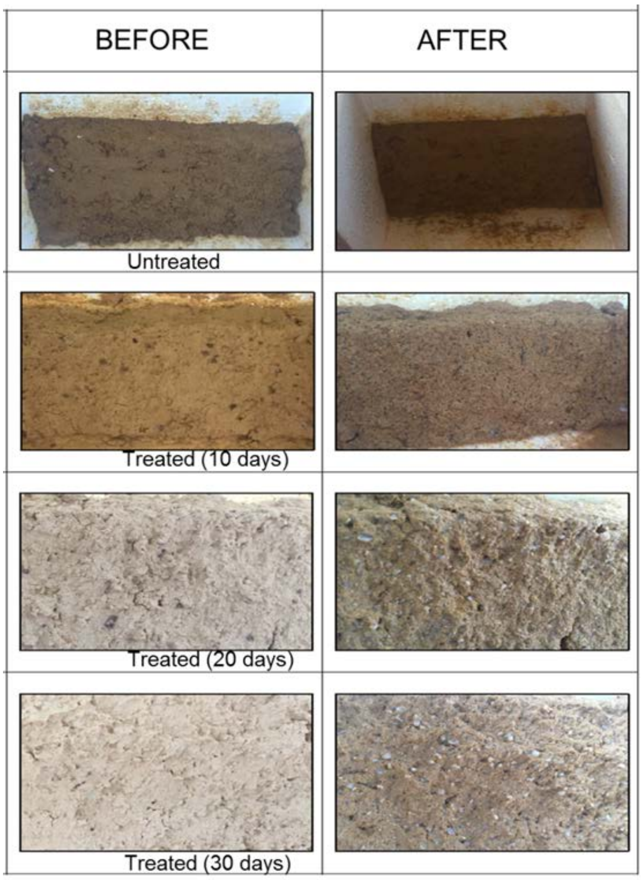

Fig. 6 Slope surface before and after rain simulation

3.2 SEM Analysis

The visualization of the bio-clogging or bio-cementation formation was carried out using Scanning Electron Microscope (SEM). The viewing was at 100 µm that show the particle contact. Figure 7 illustrated SEM microscope images of untreated (control) and treated the soil with bio–grout. Aggregation of soil particles was observed in the treated sample and the soil was more compact and firmer. In the control sample (untreated), voids were observed between the soil particles. This result was in agreement with the results of the previous study that showed the formation of calcite minerals on the surface of soil particles due to bio-calcification induced by microbes. [19].

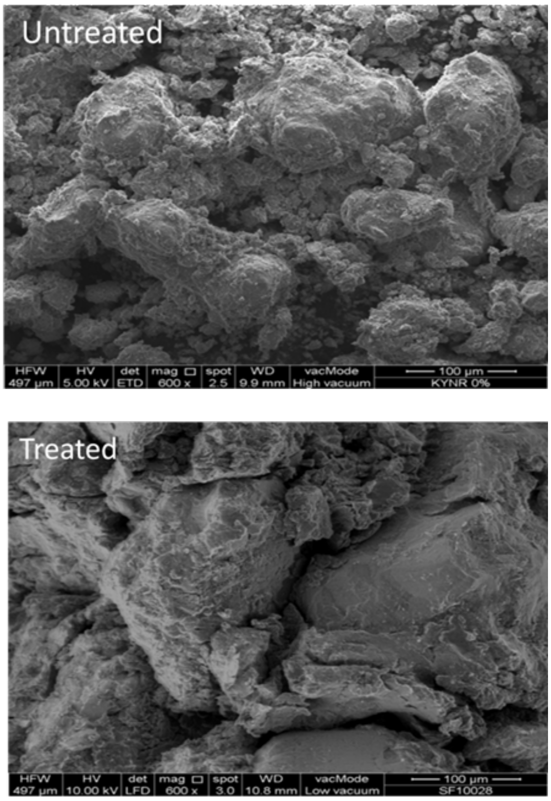

Fig. 7 SEM images showing the bio-clogging soil (600 X)

3.3 Microbiological analysis

Bacterial growth in the form of colonies was observed on nutrient agar plates at 30^{o}C (Figure 8). This verified the presence of indigenous bacteria in the bio-grout liquid. No bacterial growth was detected at 4^o C which is not an optimum temperature for bacterial activity. The pH of the culture medium increased from a pH value of 7 to 8. These results indicate that the bio-grout fluid may contain microbial ureolytic agents that are capable of inducing calcium carbonate precipitation. However, due to financial constraint and some limitation, the identification of the bacterial strains could not be carried out at the time of the experiment. Further microbiological analysis and bacterial isolation will be carried out in future studies.

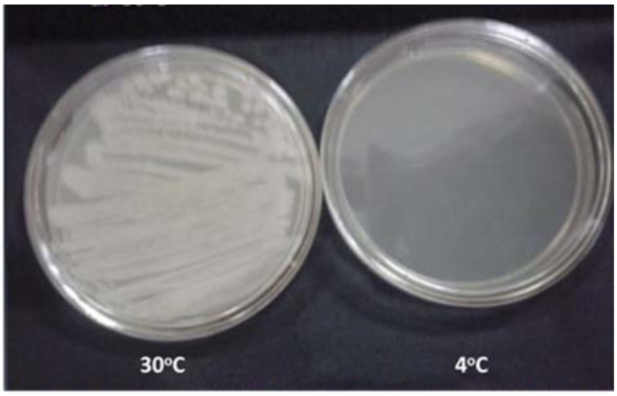

Fig. 6 Growth of bacterial colonies on nutrient agar

4. CONCLUSION

The impact of raindrops can loosen up the soil and create runoff which causes deformation of foundation or slope failure. Cementation of soil structure by using biological mechanism or microbial technology is considered as a new natural approach to improving the engineering properties of the soil. The objective of this experiment was to analyze the effectiveness of soil treated with bio-grout produced from vegetable waste against soil loss with respect to erosion control by using rainfall simulation. It was observed that the soil loss from bio-grout treated slope models has significantly reduced from 34.6 g to 13.5 g compared to that of untreated sample.

This study has demonstrated that the bio-grout method using vegetable waste provides an ideal soil stabilization solution to control soil erosion. The problems of soil erosions by heavy rainfall can be reduced and controlled by this method. Bio-grout based on vegetable waste has the potential to replace cement and chemicals as soil stabilizer due to the presence of indigenous bacteria as well as mineral contents without having to add active stabilizers such as calcium chloride to precipitate calcium carbonate.

Bio-grout from vegetable waste can be used as an alternative growth medium for indigenous ureolytic bacteria. This method is economical and reduces the cost of using nutrient medium and bacterial cultures. Vegetable waste can be recycled for this purpose. This study has the potential to meet the needs for an innovative cost-effective soil treatment that can support new and existing infrastructure. However, further experiments to identify the bacteria in the bio-grout liquid and their metabolic pathways that induce calcium carbonate precipitation need to be carried out in future studies.

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