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Research Article

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Sand Biogrouting through the Deposition of Calcium Carbonate by Ureolytic Bacteria

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Abstract Egyptian irrigation and drainage system consists of the River Nile, its branches, canals and drains. It is very important to keep them working in good condition to assure efficient water management and distribution process. Water channel embankments made of silicate sandy soils, carbonate sandy soils, and sandy silt soils are exposed to slope stability problems. These problems are considered one of the common canal embankments problems in Egypt. Soil improvement is one of the most economic engineering solutions to overcome soil problems. This research studies improving of sandy soils using the biogrouting technique. This bacterially which is used to produce deposition of carbonates has been utilized in the world as biogrouting technique. This process involves the hydrolysis of urea by bacteria containing the enzyme urease in the presence of dissolved calcium ions, resulting in precipitation of calcium carbonate crystals. This paper summarizes the stabilization of sandy soil by using different biogrouting techniques.The results show that an increase of bacteria increases the strength of sandy soil. Decreasing the casting time of the mixtures and increasing the time of the aeration giving higher compressive strength.

Keywords Biogrouting; bacterially induced carbonate; compressive strength

1. Introduction

Water channel embankments made of sandy soil are exposed to slope stability problems. These problems are considered one of the common canal embankments problems in the Valley of Nile River and its branches. Soil improvement is one of the most economic engineering solutions to overcome soil problems, [1].

Soil improvement in its broadest sense is the alteration of any property of a soil to improve its engineering performance. This may be either a temporary process to permit the construction of a facility or may be a permanent process to improve the stability of constructed facility. The result of an application of a technique may increase strength, reduce compressibility, reduce permeability, or improve ground water conditions. The various techniques of soil improvement include, surface compaction, drainage methods, vibration methods, pre-compression and consolidation, grouting and injection, chemical stabilization, soil reinforcement and other methods

Soil improvement is a general term of any physical, chemical, biological, or combined method of changing the natural soil to meet an engineering purpose [2]. It is required if the soil available for construction is not suitable for the intended purpose. Improvement could be accomplished using solid waste material to strength the road surface, increasing the bearing capacity, compaction, pre-consolidation, drainage, and embankments construction, is the main goal of the improvement.

Traditional stabilization of a soil mass is required, surficial techniques are insufficient and in situ strengthening techniques like chemical grouting are used. However, chemical grouting techniques are very expensive and require many injection wells for treating large volumes, due to high viscosity or fast hardening rate of the injected fluids. In addition, these methods significantly reduce the permeability of the strengthened soil, which hinders groundwater flow and limits long distance injection, making large scale treatment unfeasible. Biological techniques (bio grouting) are promising and provide an alternative solution [3].

Currently, new ground improvement techniques are being developed based on bio grouting. Bio grouting is a new soil improvement method based on microbiologically induced precipitation of calcium carbonate crystal [4-5]. The cohesion of sand particles by bio grouting is a very useful technique in geotechnical engineering to prevent erosion and produce increased slope stability [6].

This research summarizes the stabilized of sandy soil by using two ways of mixing sand with bacteria as homogenous mixture and other method by mixing sand with bacteria as layered methods.

2. Materials and methods

2.1. Soil

From figure 1 the natural soil used in this research was a poorly graded uniform sand according to USCS classification system with a mean diameter D50= 0.28 mm, effective diameter D10= 0.16 mm, uniformity coefficient Cu=1.87, coefficient of curvature Cc= 0.88. The Index& Engineering properties of the tested sand were determined following ASTM D 422 – 63, (2002) [7].

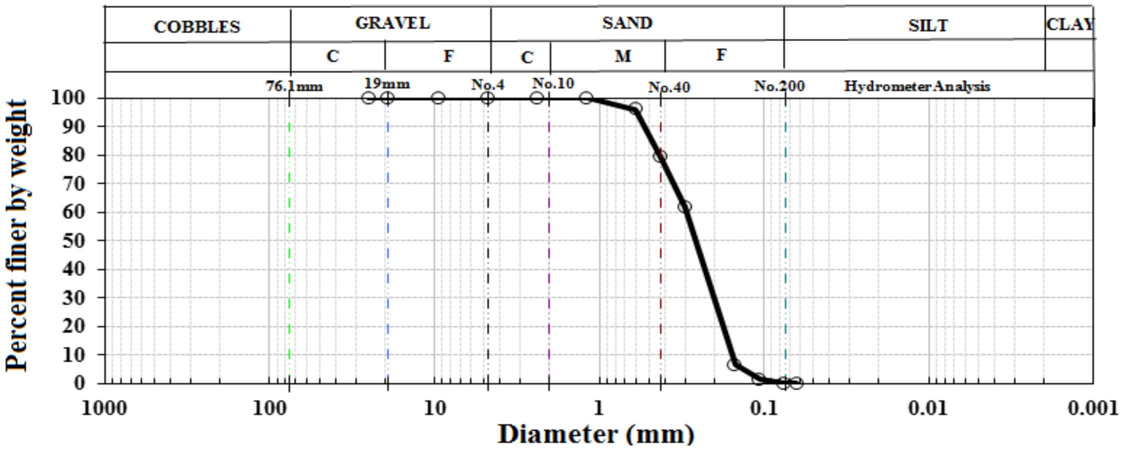

Figure 1: Grain size distribution curve of the natural tested siliceous sand

2.2. Bacteria and growth conditions

The bacterium utilized in this study is *Sporosarcina pasteurii* (DSM 33), which obtained from Deutsche Sammlung van Mikroorganismen und Zellkalturen, Germany by National Research Center, Egypt. Cultures were grown in media consists of 20g/L yeast extract and10g/L ammonium chloride for approximately 24h at 30 ^{0}C under aerobic condition at 200 rpm. The bacterial cells were then precipitated by centrifugation at 4000 cycle /min for 10 min.

Ureolytic bacteria, especially *Sporosarcina pasteurii* (formerly *Bacillus pasteurii*), has generated a lot of interest and are able to convert urea into ammonium and carbonate. The produced carbonate precipitates with calcium (Eqs. (1) and (2)) [5, 8].

2.3. Cementation solution

$$CO(NH_2)_2 + 2H_2O \xrightarrow{\text{urease}} 2NH_4^{+} + CO_3^{-2} \qquad (1)$$

$$CO_3^{-2} + Ca^{+2} \xrightarrow{\text{urease}} CaCO_3 \qquad (2)$$

The cementation solution consisted of urea (1M) and calcium chloride (1M).

2.4. Treatment

The improvement of engineering soil properties may vary widely between different biogrouting treatment methods. In all samples we used a piece of cotton which is putted at the bottom of the tube to prevent sand from flowing out, and the sand was placed to the tube and genteelly vibrated.

2.5. Optical density (OD_{600})

Optical density is used as an indication of biomass concentration, where Bacteria are incubated until samples obtained an optical density value of 0.5 and 2.3. Optical density was measured using a spectrophotometer at a wavelength of 600 nm (UV-VIS Spectrophotometer, T60U, United Kingdom).

Table 1: Summary of the column treatments

Samples code	Treatment	Soil volume (g)	Bacterial suspension	Cementation solution	Optical Density
			mL	mL	(OD)
S1	Mixing	60	32	230	0.5
S2	Mixing	550	110	1100	2.3
S3	Layered	500	100	1000	2.3

The procedure that applied in sand column mixtures is described as following:

Bacterial suspension of samples S1 and S2 are used with optical density values of 0.5 and 2.3 respectively, were mixed with the cementation solution as 1 bacterial suspension to 10 cementation solutions, and then the mixture was left until the beginning of the precipitation formation, afterwards, the precipitate was added to the soil and stirred to ensure homogeneity, Finally, sand was casted in the tube and the residual solution was added to the sample.

In sample S3 layering method was used, layering method depends on dividing the soil, cementation solution, and bacterial suspension to the same volume and casted as layered. A layer of sand (100 g) followed by bacterial suspension then the cementation solution. This process was repeated to accomplish 5 layers. The solution falling from the sample was added to the same sample several times.

3. Experimental tests

The influence of the treatment on the properties of the soil was evaluated in terms of mechanical tests, which are performed according to the methodologies proposed by Egyptian code for soil mechanics and foundations design and execution (ECP) and the American Society for Testing and Materials (ASTM) test methods. Analyzing the mechanical behavior of soils is very important in defining the influence of bio grouting in soil stabilization against erosion. Mechanical properties of soil were expressed in terms of stability in water, unconfined compressive strength, Point load tests, and slake durability.

3.1. Stability in water

All the samples were flooded in tap water at room temperature for about 24 hours.

3.2. Unconfined compressive strength test

The unconfined compressive tests were performed according to ECP (2001a) [9]. Using a universal testing machine in a room temperature of around 25 ^{o}C. Test specimens of 5.0 cm diameter and 8.0 cm length were placed on the lower fixed plate of the testing machine. Load was then applied with a uniform rate of 2 mm/min on the testing sample until failure occurs. The maximum failure load was recorded and hence the compressive strength was calculated.

3.3. Point load test

Point load test (PLT) is used to determine rock strength indexes in geotechnical practice. Plate load test is performed by applying a concentrated load until failure occurs by splitting the specimen. The apparatus used for this test consists of a rigid frame, two point load platens, hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points. The pressure gauge should be of the type in which the failure pressure can be recorded**.** The point load tests were performed according to ECP (2001b) [10].

3.4. Slake durability test

The slake durability index test is mainly designed to estimate qualitatively the durability of weak rocks through application of a standard cycles of wetting and drying. The main purpose of this test is to evaluate the weathering resistance of shales, mudstones, siltstones and other clay-bearing rocks [11-12]. The slake durability index tests were performed according to ECP (2001c) [13].

4. Results and Discussion

4.1. Stability in water

The results of the stability in water test clearly illustrated the improvement of the structural stability of the soils when partially or totally immersion with a tap water. Little or no breakdown was observed for the treated soils after immersion in water. Figure (2) show that the sample S1 before and afterimmersionin water for about 24 hours. The loss of weight of Sample S1is 25%, loss of weight of sample S2 is 0.0 %, and the loss of weight of sample S3 is 60%. The results showed that the bio grouting reduced the potential of erodibility of the treated soils.

Figure 2: S1 before and after immersion with water

Figure 3: S2 before and after immersion with water

Figure 4: S3 before and after immersion with water

4.2. Unconfined compressive strength

The sand cementation increase is induced by calcite deposition (biogrouting) which can be effectively through the treatment by mixing method and layered method as shown in Fig. 5. Previous experiment showed that the maximum compressive strength is 27kg/cm^{2}using the mixing methods, while it is about 9.43 kg/cm^2 when soil treated by using the layering method. In mixing method, the amount of bacteria in the sample 1(etch 21mL bacterial suspension for 40g sand) is higher than that in sample 2(etch 8mL bacterial suspension for 40g sand), but the sample 2 has more cementation than sample1. It could be attributed that the decrease of the optical density of bacterial cells leads to decrease of the compressive strength. These results are compatible with those finding by Adel Gawad (2013), who found that the compressive strength values increase with increasing optical density of bacterial cells. This is due to that with increasing of bacterial cells, more enzymes produced by bacteria which hydrolyzed urea to ammonia and carbon dioxide to react with Ca^{2+} and producing calcium carbonate this is responsible for binding sand grains together and, therefore, the compressive strength increases. Also, the casting time was about 12 days and 45 days in sample 2 and sample 1 respectively. It is noticed that decreasing the casting time and increasing the aeration time lead to increases the cohesion between deposited calcite and soil granules.

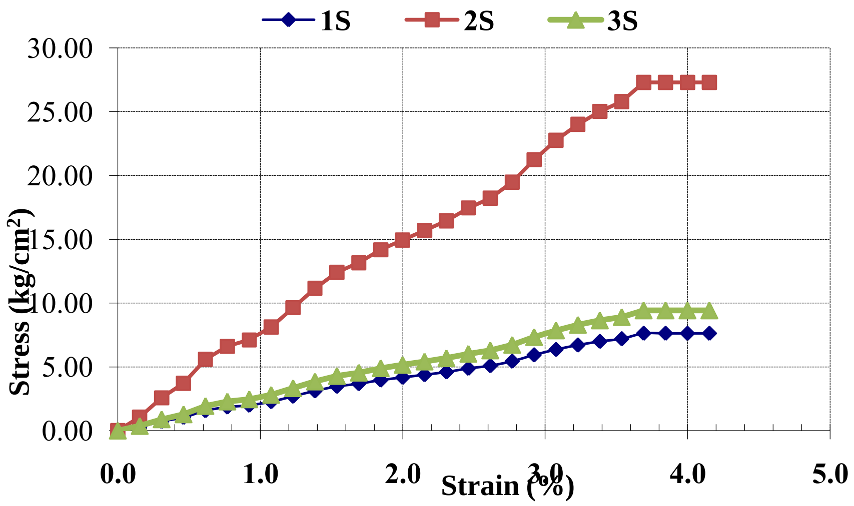

Figure 5: Unconfined compressive strength for samples S1, S2 and S3

Sample1 that prepared by using mixing method and consists of 21mL bacterial suspension for 40g sand, and sample 3 that prepared by using layering method and consists of 8mL bacterial suspension for 40g sand, are exposed to the same air aeration time which is about 45 days, we found that the compressive strength of sample 3 is higher than sample 1 (9.42 kg/cm^2 and 7.63 kg/cm^2 respectively) which means that the layer method is effective than the mixing method when the casting time of both of them are the same.More researches with these types of materials are needed.

4.3. Point load test

Through our results of the three tested samples we found that the maximum compressive strength of the group comes from sample 2 as 12.43Kg/cm^2, also the minimum compressive strength of the group comes from sample 1 as 4.23Kg/cm^2.The results can be putted in descending order as following: sample 2 (12.43Kg/cm^2) followed by sample 3 (5.12Kg/cm^2) then sample 1(4.23Kg/cm^2).

Table 2: Unconfined compressive strength, point load index, and slake durability values of treated sand samples

Sample	Unconfined compressive strength (Kg/cm^2)	Point load index (Kg/cm^2)	Slake durability (%)
S1	7.43	4.23	40
S2	27.5	12.43	55
S3	9.42	5.12	45

4.4. Slake durability index (SDI)

The results of SDI are shown in Table (2). The maximum value of the SDI was obtained from sample 2 and equal to 55%, also the minimum value was obtained from sample 1 and equal to 40 %. This can conclude that sample 2 is more durable than samples 1 and 3. It appears that all tested samples are sensitive to water.

5. Conclusions

The objective of the current research was to investigate the possibility of improving the mechanical properties of sand by treatment with bacterially induced carbonate precipitation. A series of tests of unconfined compressive strength, point load, slake durability and stability in water was performed on the treated sand specimens. Based on the results presented in this research, the following conclusions can be drawn.

1. The bio grouting substantially increases the unconfined compressive strength of the treated sand. The compressive strength values ranges between 7.63 Kg/cm^2 to 27.5 Kg/cm^2.

2. Decreasing the casting time of the mixtures and increasing the time of the aeration giving higher compressive strength.
3. The results suggest that the biogrouting of sand is a sustainable and eco-friendly practice in the hot environment and it will be very attractive to develop geotechnical systems.

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