The effect of microorganisms on shear strength of soils

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ABSTRACT

Basically, in terms of engineering, all soils that construction of structures on it is not safe, is also affected by weather conditions, say the problematic soils. Soils problematic in several types, including swelling, water absorption, collapse, loose, etc. can be found. Due to low shear strength of problematic soils, the use of this type of soil in civil engineering projects would be problematic. So to use this soil must be stabilized using various methods to be done on this type of soil In this study, for environmental stabilization of soil, calcite sedimentation microbial methods were used. The solution of dissolved nutrients Sporosarsina Pasteurii and urea and calcium chloride is used as a material cemantonation percolation injection. Curing at intervals of 7 days, 14 days and 28 days and direct shear tests were performed before and after stabilizing at the time of the consolidation were carried out.
Data shows fixation with micro-injection method, by creating precipitated calcium carbonate increases the shear strength parameters.

Keywords: Soil problematic- Shear strength- Biological fixation- Microorganisms

1 INTRODUCTION

Population and consequently civil projects have increased significantly in different countries during recent years. Therefore soil improvement is continuously in need due to the increase of civil infrastructure. According to the research in 2008, every year more than 40,000 soil improvement projects worth of more than 6 billion US dollars take place around the earth (DeJong et al., 2010). Available methods of soil improvement are often based on utilizing outside material (cement, chemical grout, geo-synthetics, strips and etc.) or mechanical energy (dynamic compaction, compaction piles, vibroflotation and etc.).

One of the most common soil improvement methods is injection of cement and chemical grout into the soil, but according to the reports all chemical grouts are poisonous and dangerous except Sodium Silicate (U.S. Army Corps of Engineers, Engineering Manual NO. EM 1110-1-3500, 1995; Karol, 2003). Some of the acrylamides (a substance used in chemical grouts) are neurotoxic material and have side effects for the neural tissues. The acrylamide poisoning has been reported when acrylamides have been used carelessly. Therefore, this product must be used with caution. In several countries there are restrictions for their use or its consumption is banned (Karol, 2003). Another problem for injection on in-situ ground improvement projects, especially when cement is used, is the depth of grout penetration. Since the injected material is filtered by soil particle, the penetration depth is low and this method is only effective to a radius of 1 to 2 meters depending on the injection pressure and the amount of injected material. Microbiologically induced calcium carbonate precipitation method is one of the newest methods of ground improvement, in which calcium carbonate crystal was formed between soil particle using bacteria in order to improve soil properties. This procedure can stabilize the soil or other small particles (porous material) without disturbing the initial structure. In this method, penetration reduction and the cost of implementation are low. Moreover, it is environmentally compatible and a wide range of material and micro-organisms can be used in this method without harmful environmental consequences (Kahani et al., 2013).

2 MATERIALS AND METHODS

2.1 Bacterial suspension and cementation solution for MICP

Microorganism used in this study was a family of Bacillus called Sporosarcina pasteurii. Sporosarcina pasteurii has high urease activity. So, the bacteria can be decomposed into carbon dioxide (CO2) and ammonium (NH4). Ammonium and calcium chloride (CaCl2) form calcium carbonate precipitation which can improve of soil.

The isolated strain was cultivated under a sterile aerobic batch condition in a yeast extract–based medium (20 g/L yeast extract, 0.17 mol/L ammonium). After 24 h incubation at 28 °C, the culture was harvested and stored at 4 °C prior to use. The optical density (OD600) of the harvested bacterial suspension varied between 1.5 to 2.0, and the urease activity was approximately 10 U/ml (1 U = 1 µmol urea hydrolyzed per minute). The CaCO3 precipitation rate, depending on the amount of urease activity introduced, can affect the size of the crystals and in turn the bonding force of the CaCO3 crystal bridges and corresponding strength of the treated soil (Ismail et al. 2002a). In this study, the average CaCO3 precipitation rate was about 10 g/L (solution)/h. The cementation solution consisted of 1 mol/L urea and 1 mol/L CaCl2.

2.2 Characteristics of the used soil

Considering the abovementioned range for bacteria's activities and movement in soil, it is necessary to get proper grained sand for bacteria.The characteristics and diagrams of the given sand are shown in table 1.

Table.1. Specifications of used soils

Soil type	ω_{optm}	$\gamma_{d\ max}$	G_s
Silty sand (15% silt)	0.0942	1.868	2.665
Silty sand (30% silt)	0.1126	1.977	2.657
Silty sand (45% silt)	0.1098	1.93	2.637

2.3 Selection of nanoparticles

Some of nanoparticles like copper, silver, zinc and titanium have a strong antibacterial property. In this study, an attempt was made to use a type of nanoparticle which have a weak antibacterial property or a neutral reaction toward bacteria. In this way, soil improvement will be done more properly. Also, after considering different nanoparticles, eventually nanosilica was chosen and was injected to the samples with the limited amount along with the bacteria (0.2%). Nanosilica's properties used in this study are shown in table 2.

Table. 1 physical characteristics of nanosilica

Purity	>99%
Particle size (nm)	1113
Color	White
Density (gr/cm^3)	2.4
Specific area (m^2/gr)	200

3 RESULTS

According to Table 3, which shows the increase in shear strength of soil in all three samples, in all three soil samples, the effect of this type of fixation in lower Vertical stress is higher than the effect of this type of stabilization in upper Vertical stress.

Table.3. Shear strength changes in vertical stresses (50, 100 and 200) kPa

vertical stress	Shear stress increase rate(%)		
	Sample with 15% Silt	Sample with 30% Silt	Sample with 45% Silt
50 kPa	22	81	31
100 kPa	26	49	18
200 kPa	24	41	18

3.1 INTERPRETATION OF TEST RESULTS

In order to investigate the effect of biological stabilization on the internal friction angle and soil adhesion, the values of these two parameters in soil samples were 15%, 30% and 45%, respectively, in tables 4, 5 and 6, based on the duration of treatment.

Table.4. Adhesion and internal friction angle for samples containing 15% Silt

Curing duration (day)	0	7	14	28
Adhesion (kPas)	23.92	24.5	33.5	18.74
Internal friction angle (degree)	35.64	37.86	38.75	41.7

Table.5. Adhesion and internal friction angle for samples containing 30% Silt

Curing duration (day)	0	7	14	28
Adhesion (kPas)	25.63	35.86	48.36	60.4
Internal friction angle (degree)	35.86	40.88	43.19	38.35

Table.6. Adhesion and internal friction angle for samples containing 45% Silt

Curing duration (day)	0	7	14	28
Adhesion (kPas)	27.77	31.05	37.99	33.87
Internal friction angle (degree)	31.22	34.67	35.84	36.95

According to Table 4 and 5, the main effect on the internal friction angle and adhesion in the 15% silt sample after the 14th day is observed, which is the maximum effect on the 30% silt sample for the internal friction angle parameter in the 28-day sample and for the adhesion parameter in the specimen The 14-day period is evident and, for example, 45% of the maximum silt effect is observed in the 14-day sample.

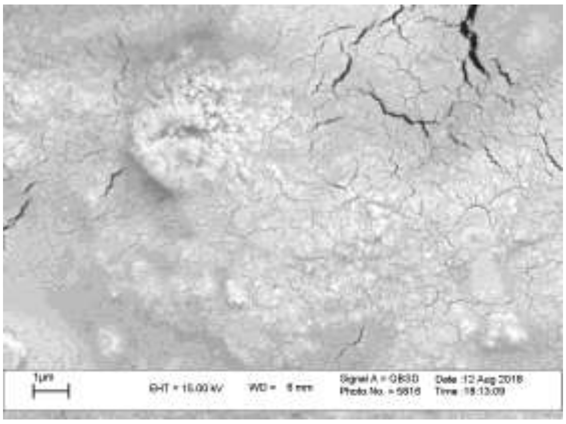
Also according to Table 6, the greatest effect on the shear strength parameters is observed in the 30% sample, which can be considered as an optimal condition among the samples. Also, the effect of this type of fixation on adhesion increase is far greater than the increase in the internal friction angle, which shows the maximum effect of this type of fixation on adhesion.

Fig.2. improved soil samples with 15% silt in 28 days that calcium

The above figure shows a sample Contains 15% before the direct shear test. The specimens were removed from the lubricated mold and then placed in direct shear test. As seen from the figure, calcium carbonate precipitation is observed on parts of the sample (white parts). Because of the low permeability of the silt, a large amount of calcium carbonate precipitation has remained on the sample, which is also evident in the above image.

3.2 Scanning electron microscopy

Scanning electron microscopy (SEM) tests were conducted on soil specimens to explore their microstructure qualitatively.



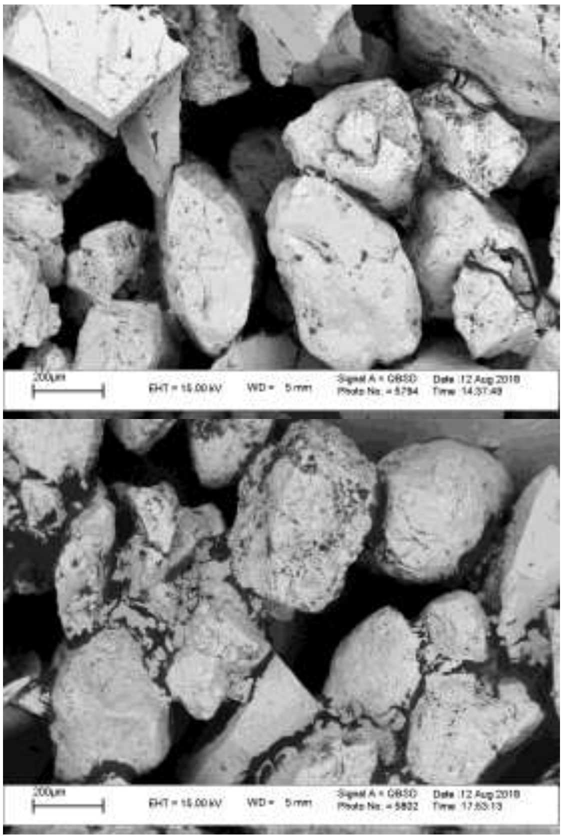


Fig.1. SEM photos of the sample containing 30% S Silt after 28 days curing.

REFERENCES

DeJong, J.T.; Mortensen, B.M.; Martinez, B.C.;Nelson,D.C.:Biomediated soil improvement. Ecol. Eng., 36(2), 197–210(2010).doi:10.1016/j.ecoleng.2008.12.029

U.S. Army Corps of Engineers, Engineering Manual NO. EM 1110-1-3500, 1995. “Engineering and Design Chemical Grouting”,Department of the ArmyU.S. Army Corps of Engineers Washington, DC 20314-1000

Karol, R. H., 2003. Chemical grouting and soil stabilization, revised and expanded (Vol. 12). CRC Press.

Kahani, M., Kalanatary, F., Bazzazzade, R., Mirzaie, B., 2013. Biological Calcium Carbonate precipitation in Sandy Soils and its Effect on Soil Stabilization. Environment Science and Engineering Journal 52: 11-19. (In Persian)

Whiffin, V.S.; van Paassen, L.A.; Harkes, M.P.: Microbial carbonate precipitation as a soil improvement technique.Geomicrobiol. J. **24**, 417–423 (2007). doi:10.1080/01490450701436505.

Hai Lin, S.M.ASCE1; Muhannad T. Suleiman, A.M.ASCE2; Derick G. Brown, M.ASCE3;and Edward Kavazanjian Jr., F.ASCE4J. Geotech. Geoenviron. Eng.,142(2):04015066 (2016). DOI: 10.1061/(ASCE)GT.19435606.0001383.

Leon A. van Paassen.; Ranajit Ghose.; Thomas J. M. van der Linden.; Wouter R. L. van der Star.;Mark C. M. van Loosdrecht.: Quantifying Biomediated Ground Improvement by Ureolysis:LargeScale Biogrout Experiment. J.Geotech.Geoenviron. Eng.,136:17211728(2010).DOI: 10.1061/(ASCE)GT.19435606.0000382.