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BIOGROUTING STABILIZATION ON MARINE SANDY CLAY SOIL

T. Harianto [1], S. Hamzah [1], S. H. Nur [1], M. A. Abdurrahman [1], R.U. Latief [1], I. Fadliah [2] and A. Walenna [2]

ABSTRACT: Bio-grouting technology is a technology that simulates the process of diagenesis which shows the transformation of sand into sand stone (calcarinite/sandcone), calcite (CaCo3) which is formed from bio-grouting process. They will function to bind the grains of sand which is causing the cementation process and transformation of sand into stone. This research aims to determine the optimum composition of the bacillus subtilis bacteria solution for soil stabilization and evaluate the mechanical characteristic of the soil that is stabilized with variations bacillus subtilis bacteria solution and cementation solution, combined with variety of curing time. The soil testing for sandy clay soil employed standard from SNI and ASTM. Method of experimental development testing was performed in an experimental model with test the design of each size 7.2cm x 3.6cm, 6cm x 6,6cm, and 2cm x 6,4cm with grouting method. The kinds of examinations conducted to analyze the result are test of unconfined compressive strength, permeability, and direct shear. The volume of bacillus subtilis bacteria which are injected into the soil are 2cc to 32cc with curing time 3, 7, 14, 21, and 28 days. The results of unconfined compressive strength test on laboratory scale shows that testing without injection of bacteria is at 0.13 kg/cm2, for the sample injected with bacteria is at 0.35 kg/cm2. Permeability experiments without bacteria has coefficient value of 2.49.10-4cm/sec and the sample with the injection of bacteria has coefficient value of 4.91.10-6cm/sec. Direct shear experiments without bacteria injected has angle of internal friction 4.46 º and for the results with the injection of bacteria is 35.07º. It can be concluded that the addition of bacteria for stabilization of sandy clay soil with bio-grouting method manages to increase the soil's bearing capacity. This has proven with increasing strength of the soil and decrease of permeability in the soil.

Keywords: Bio-grouting, bacillus subtilis, unconfined compressive strength, permeability, direct shear test.

INTRODUCTION

Soil is the most important part in any works related with the construction of foundation and structure of building. However, it is common to witness the damages on layer of road pavement which is caused by settlement of subgrade layer of soil, especially after it receives load from construction above it. Structural failure can be induced by ground settlement particularly those which is really susceptible to settlement such as clay soil. Ideal and stable of subgrade layer is a prerequisite to enable the construction to carry the load above it. Several improvement methods toward soil which has swelling-shrinkage characteristic have been widely done such as soil stabilization. Some examples for it are stabilization which employs grouting method using not-environmentally compatible substances such as suspense (cement, clay-cement, pozzolan, bentonite, etc) or emulsion (asphalt, etc) (Karol, 2003). Hence, it is highly suggested to find alternatives for grouting method which is environmentally friendly, one of the alternatives is the utilization of microorganism (classified as bacteria) which can produce calsit and can transform grain of sand into sand stone. This method is called "bio-grouting".

Clay is defined as particle composition which has size less than 0.002 mm (Das, 1995). According to Hardiyatmo (2010), characteristics of clay soil are its fine grain has size less than 0.002 mm, low permeability, high increase of water capillary, cohesive, high degree of swelling-shrinkage and slow process of consolidation.

Several researches had been done in past, such as Microbially Induced Cementation to Control Sand Response to Undrained Shear (Dejong, 2006). This research used microorganism named Bacillus pasteurii. Utilized as material for soil improvement, another research is Biogrout ground improvement by microbial induced carbonate precipitation (Van Passen, 2009). In this research, bio-grouting process utilized bacteria named Sporosarcina pasteurii, species of bacteria which contains high amount of urease enzyme. The other researches, In situ Soil Cementation with Ureolytic Bacteria by Surfa Percolation (Cheng, L. 2012), provide brand new application which is Deposition of Solid

[1] Lecturer of Civil Engineeering Department, Hasanuddin University, Jl. Perintis Kemerdekaan km. 10, Makassar, 90245, INDONESIA
[2] Student of Civil Engineeering Department, Hasanuddin University, Jl. Perintis Kemerdekaan km. 10, Makassar, 90245, INDONESIA

Calcium Carbonhydrate (MICP) as consolidation technique for saturated soil using isolated surface method. For this research, Modelling Biogrout: a new ground improvement method based on microbial induced carbonate precipitation (Wijngaarden, 2009), new model is formulated to illustrate the process of bio-grouting. Electro-Biogrouting and Its challenges (Keykha, 2011), this research introduces bio-grouting as new method for $CaCO_3$ deposition on sandy soil by activity of microbes in order to increase the strength with Pasteurii Bacillus. Lastly, Bacterial carbonate precipitation for biogrouting (Lisdianti, 2011), this research tried to seek alternative material which can be used to increase the strength of soil by utilizing microorganism.

This research used bio-grouting process to mix bacteria and sandy clay soil. In order to analyze it, test of unconfined compressive strength, permeability, and direct shear are conducted. The aim of employing bio-grouting process in this research is to increase the bearing capacity of soil, and also introducing this process as safe and environmentally friendly method. This research aims to determine the optimum composition of the bacillus subtilis bacteria solution for soil stabilization and evaluate the mechanical characteristic of the soil that stabilized with variations bacillus subtilis bacteria solution and cementation solution, combined with variety of curing time

METHOD AND MATERIAL

Location and Research Design

This research was conducted at Soil Mechanic Laboratory, Department of Civil Engineering, University of Hasanuddin and Biotechnology Research Center, Lembaga Ilmu Pengetahuan Indonesia (LIPI). This was laboratory experiment-based research which covered sandy clay testing grouted by Bacilius subtilis bacteria solution and cementation solution. The observation included test of index and mechanical properties of clay soil. Clay soil used in this experiment was taken from soil which was located at Kelurahan Tamalanrea, Kecamatan Tamalanrea, Makassar City. The examination of index and mechanical properties of clay soil used standard imposed by SNI and ASTM. Research design used in this research is experimental method in laboratory with laboratory physical scale.

Population and Micro Sampling

This research was started by collecting data of soil characteristics and conducting test to obtain data of soil microstructure using Scanning Electron Mikcroscope (SEM) and X-Ray Diffrection (XRD) for sandy clay soil. Afterwards, it was followed by creating cementation solution and Bacillus subtilis solution. Ultimately, bio-grouting process was commenced.

Initial step of the testing is breeding culture of bacteria Bacillus subtilis in the B4 medium which is comprised by urea 20g, nutrient brouth 3g, $NaHCO_3$ 2.12g, $CaCl_2$.2H2O 4.14g, NH_4CL 10g, and dH_2O. Then it is mixed with 1 liter of water in erlenmever flask. After that, it is stored into Autoclave with temperature of 121º for 15 minutes under 1 ATM pressure. Afterwards, the medium is chilled, process of bacteria inoculation is conducted by mixing bacteria isolate into B4 medium and all of experiment should be conducted inside the laminar Airflow in order to ensure its sterility. Thereafter, bacteria are breed for 3 days under room temperature. Further step is the creation of cementation solution which is created by the amalgamation of urea and CaCl2 which are used by bacteria to produce calcite. Third procedure is the process of mixing bacteria solution and cementation solution with soil by grouting with 4 variations of injection and curing time of 3, 7, 14, 21 and 28 days.

Method of Obtaining Data

Data collection is conducted by executing test of index and mechanical properties of soil which is used in this research, these tests cover water content, specific gravity, sieve analysis, hydrometer, and Atterberg limit. Besides that, other kinds of examination such as compaction, unconfined compression test, permeability test, and direct shear strength test are also conducted. Those collected data are used as parameter to analyze the strength of improved soil

RESULTS

Index and Mechanical Properties of Soil

On the examination of water content, it is obtained that the water content of soil is 43.40%. Based on the test of specific gravity, it indicated the value of 2.70. On the sieve analysis and hydrometer test, it showed that more than 57.5% of soil particles passed sieve no. 200 and it indicated that it has dominant fine grain particles. Based on AASHTO, this soil is categorized into type A-7-5, clay soil with plasticity index less than 11. Observation towards soil classification which has grain size less than 0.075 is not straightly based upon its gradation, thus its classification is determined based on Atterberg limit. According to the graph on the relationship between number of knock and water content, the value of Liquid Limit is 45.97%, Plastic Limit is 31.54%, and Plasticity Index is 16.47%. The result of unit weight test indicates the value of 1.66 gr/cm3. The outcomes of proctor standard test are the

value of Optimum Moisture Content, 36%, and Maximum Dry Density, γdmaks = 1,328 gram/cm3. Full result is available at Table 1.

Table 1. Result of Test of Index and Mechanical Properties

No	Type of Examination Test of Soil Characteristics		Results	
1	Water content (w)		43.4	%
2	Specific Gravity (Gs)		2.7	
3	Sieve Analysis			
	a.	Fine grain	57.5	%
	b.	Coarse grain	42.5	%
5	Atterberg			
	a.	Liquid Limit (LL)	45.97	%
	b.	Plastic Limit (PL)	31.54	%
	c.	Plasticity Index (PI)	14.42	%
	d.	Shrinkage Limit (SL)	16.47	%
6	Unit weight		1.66	gr/cm³
7	Standart Compaction			
	a.	Maximum Dry Density, γd (MDD)	1.328	gr/cm³
	b.	Optimum Moisture Content (OMC)	36	%

Result of Laboratory Model Test using Method of Soil-Bacteria Grouting

Based on model testing which had been conducted, it is obtained that the value of unconfined compressive strength of soil without injection of bacteria is 0.13 kg/cm^2. For curing time of 3 days, the value of unconfined compressive strength is 0.16 kg/cm^2 with the amount of injection is 9cc. For curing time of 7 days, the value of unconfined compressive strength is 0.06 kg/cm^2 with the amount of injection is 9cc. For curing time of 14 days, the value of unconfined compressive strength is 0.16 kg/cm^2 with the amount of injection is 9cc. For curing time of 21 days, the value of unconfined compressive strength is 0.22 kg/cm^2 with the amount of injection is 9cc. For curing time of 28 days, the value of unconfined compressive strength increase up to 0.35 kg/cm^2 with the amount of injection is 9cc as it is shown in Figure 1.

Based on model testing which had been conducted, it is obtained that the value of permeability of soil without injection of bacteria is 2.49.10-4 cm/sec. For curing time of 3 days, the value of permeability is 5.14.10-5 cm/sec with the amount of injection is 32cc. For curing time of 7 days, the value of permeability is 1.49.10-5 cm/sec with the amount of injection is 32cc. For curing time of 14 days, the value of permeability is 1.49.10-5 cm/sec with the amount of injection is 32cc. For curing time of 21 days, the value of permeability is 6.88.10-6 cm/sec with the amount of injection is 32cc. For curing time of 28 days, the value of permeability decrease up to 4.91.10-6 cm/sec with the amount of injection is 32cc as it is shown in Figure 2.

Based on model testing which had been conducted, it is obtained that the degree of direct shear strength of soil without injection of bacteria is 4.46º. For curing time of 14 days, the degree of direct shear strength is 2.23º with the amount of injection is 6cc. For curing time of 28 days, the degree of direct shear strength increase up to 35.07º with the amount of injection is62cc as it is shown in Figure 3.

Result on the analysis of Scanning Electron Microscope (SEM) from the examination of unconfined compressive strength test, permeability and direct shear strength indicate that there are change of soil structure which is caused by the development of bacteria inside the soil. The result of Scanning Electron Microscope (SEM) can be viewed in Figure 4.

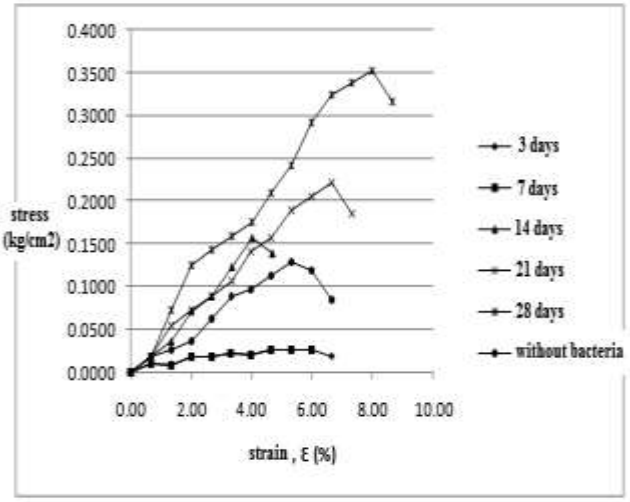

Fig. 1. The graph on the relationship between stress and strain (Unconfined Compression Test).

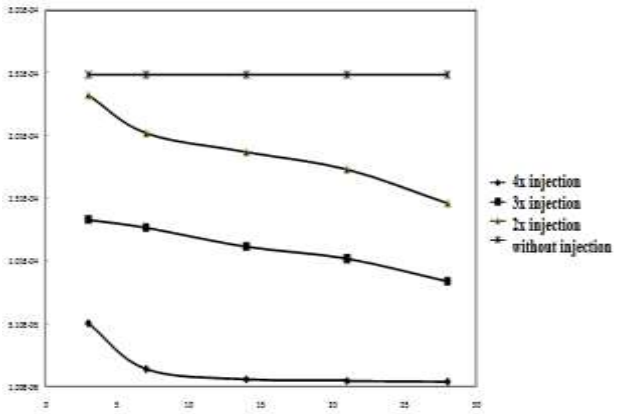

Fig. 2. The graph on the relationship between the value of permeability and curing time with maximum 4 times injection.

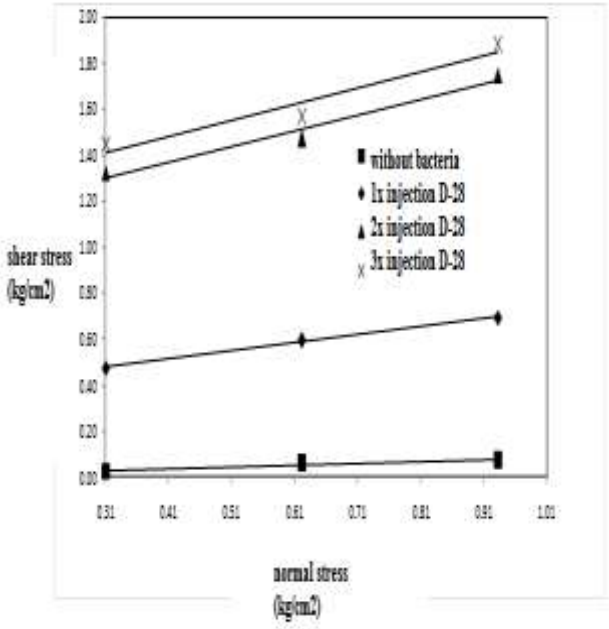

Fig. 3. The graph on the relationship between the value of shear stress and normal stress.

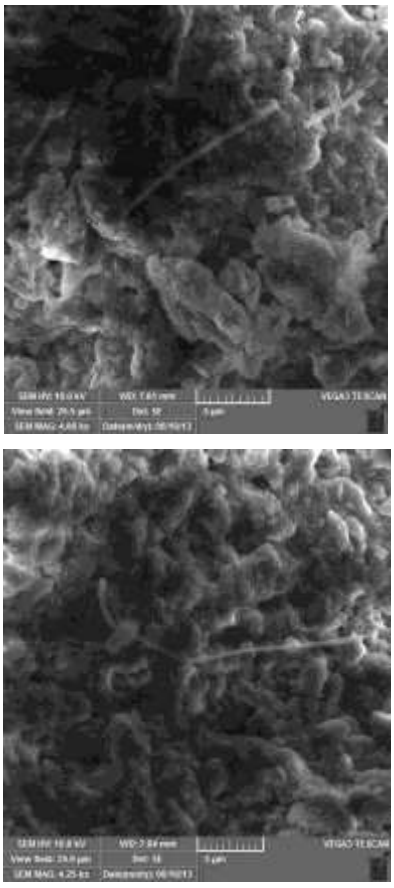

Fig. 4. The result of *Scanning Electron Mikroscope* (SEM), Injection of Bacillus Subtilis which is developing inside the pore of soil.

DISCUSSION

This research shows that based on the result of laboratory test on physical model towards mechanical properties of soil (unconfined compressive strength, permeability and shear strength), it can inferred that the optimum content of Bacillus subtilis solution which injected to the soil is 4 times of injection with curing time of 28 days. For the result of unconfined compressive strength test, it is obtained that there is increase of 60% from the soil without injection of bacteria to soil which is injected with bacteria. Meanwhile, the value of permeability from bacteria stabilized soil indicates the decrease of value of permeability coefficient. For the direct shear strength test, it is casted that the higher the volume of injected bacteria, the higher the value of cohesion.

Based on the obtained data, it can be interpreted that the soil without injection of bacteria experienced the drop, whereas the soil which is injected with bacteria casted the increase of 60% for the value of unconfined compression test. For permeability test, the soil experienced the growth of 80% and for direct shear strength test, the soil gained the rise of 90%. By employing the bacteria injection volume of 9cc, 32 cc, and 6cc with curing time of 28 days, the increase of 80% was gained.

From the result of experiment, it explains that the longer the curing time and the higher the volume of bacteria injection, the bigger the increase of soil strength. Dejong (2009), compared with loose specimen, the result of research indicates higher value for the initial shear stiffness and elastic capacity. Van Passen (2009), the experiment displays the result that urease which catalyzes the conversion of urea to ammonium and carbonate produces precipitate with calcium as crystal calcium carbonate. This crystal creates bond among the soil particles which increases the strength and the stiffness of soil. Cheng (2012), The result demonstrated that Bacteria could move in column with the length of less than 1 m under the high level isolation by implementing variety of layer of bacteria suspension and fixation solution then followed by incubation. The increase of sand column's strength can reach reasonable level without the formation of crack on the surface. Wijngaarden (2009). The result of research showed that Bio-grout influenced characteristics of soil. The result is deposition of calcium carbonate managed to decrease the value of porosity and permeability. Akiyama (2010), the result of research indicated the use of soil extract from acid soil, the outcome of Calcium Phosphate bio-grouting was the sample which was grouted indicated higher value of compressive strength, compared to those

which were not grouted. Keykha (2011), the outcome of research introduced the procedure to create inducted carbonate rainfall ($CaCO_3$) to improve the soil thus can operate in soft soil such as clay, mud or peat which have no ability on mobilizing microorganism and bacteria. Lisdianti (2011), the result of research indicated that Bacillus subtilis is type of bacteria which can develop under the average temperature in Indonesia and can produce the biggest amount of calcite which is from Papua.

CONCLUSION

Based on the result from experiment and further analysis on it, there are several conclusions that can be made; based on the result of laboratory test on mechanical properties of soil (unconfined compressive strength, permeability and shear strength), it can inferred that the optimum content of Bacillus subtilis solution which injected to the soil is 4 times of injection with curing time of 28 days. For the result of unconfined compressive strength test, it is obtained that there is increase of 60% from the soil without injection of bacteria to soil which is injected with bacteria. Meanwhile, the value of permeability from bacteria stabilized soil indicates the decrease of value of permeability coefficient. For the direct shear strength test, it is casted that the higher the volume of injected bacteria, the higher the value of cohesion.

Basing on the result of testing and its analysis, this research only counts the increase of characteristic of soil before and after the injection of bacteria as the parameter to adjudicate the mechanical capability of Bacillus subtilis as material for soil improvement, the result of this research thus can be used as reference for further research and study. Several advices which can give valuable inputs for this research is there should be further study towards Bacillus subtilis in order to minimize the number of special treatment which need to conducted during the mixing process. Furthermore, mixing Bacillus subtilis with other types of soil should be conducted in order to compare the reaction of this bio-grouting process towards other types of soil in Indonesia.

REFERENCES

Akiyama Masaru. (2010). Microbially Mediated Sand Solidification Using Calcium Phosphate Compounds, Faculty Of Engineering, Hokkaido University, Kata 13, Nishi 8, Kita-Ku, Sapporo, Hokkaido 060-8628, Japan

Cheng, L. (2012). In-Situ Soil Cementation With Ureolytic Bacteria By Surfa Percolation, Ecological Engineering, 42 . Pp. 64-72.

Das, Braja M. (1995). Mekanika Tanah (Prinsip-Prinsip Rekayasa Geoteknis) Jilid I, Erlangga, Jakarta.

Dejong, (2006). Microbially Induced Cementation To Control Sand Response To Undrained Shear. Journal Of Geotechnical Andgeoenvironmental

Hardiyatmo, C. H. (2011). Mekanika Tanah 1, Gadjah Mada University Press, Jakarta.

Karol, R.H. (2003). Chemical Grouting And Soil Stabilization. New York. P558

Keyka A. Hamed. (2011). Electro-Biogrouting Abd Its Challenges, Int. J. Electrochem. Sci., 7 2012 1196 – 1204.

Lisdiyanti P. (2011). Bacterial Carbonate Precipitation For Biogrouting, Prosiding Simposium Nasional Ekohidrologi, Pp 219-232.

Van Paassen, La (2009), Biogrout Ground Improvement By Microbial Induced Carbonate Precipitation. Delft University Of Technology, Pp 202.

Wijngaarden V K.W M. (2009). Modelling Biogrout: A New Ground Improvement Method Based On Microbial Induced Carbonate Precipitation, Issn 1389-6520 Reports Of The Delft Institute Of Applied Mathematics Delft 2009.