Current Experimental Methodologies in Soil Strength Improvement using Microorganisms

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Abstract: The safety standards and building codes requires the acceptable value for the properties of soil to be used for design and construction and it covers a significant portion of the overall project cost. The usual methods in improving the properties of soil are through mechanical and chemical soil stabilization but they have adverse effects in its surroundings or their costs are high, thus, there are proposals to use microorganisms in soil stabilization. Microorganism named Sporosarcina Pasteurii was used in the study, the said microorganism was introduced in the soil specimen together with dissolved calcium source. Sporosarcina Pasteurii precipitates calcium carbonate and binds the soil particles together and results in an increase in strength. Various experimental methodologies were used in soil strength using microorganism but it needs improvement and development. Recommendations were given to improve the current practice.

Key Words: biomineralization, calcium carbonate, soil stabilization, methodology

1. INTRODUCTION

The high rapid development of infrastructures in metro cities of useful land forced the engineers to improve the properties of soil and they used different methods to improve the mechanical properties of different type of soil [1], furthermore, the safety standards and building codes requires the acceptable value for the properties of soil to be used for design and construction [2], thus, soil stabilization is used. As mentioned, soil stabilization have been used to improve the strength properties of the soil. Soil stabilization are usually categorized into two: mechanical stabilization and chemical stabilization; mechanical stabilization is achieved through physical process by altering the physical nature of native soil particles by either induced vibration, compaction or by incorporating other physical properties such as barriers and nailing, while chemical stabilization is achieved through chemical reactions between stabilizer and soil minerals [3, 4]. These traditional ground improvement methods have several limitations because their action is limited to the proximity of the mixing equipment and these methods are expensive, require heavy machinery, disturbing urban infrastructure and involve chemicals with significant environmental impact [5]. There are proposals to use microorganisms, nutrients, and biological processes naturally present in subsurface soils to improve the engineering properties of soil [1] and using microorganisms has shown greater potential in geotechnical engineering applications in terms of performance and environmental sustainability [6].

The technique utilizes soil microbial processes is technically referred to as Microbially Induce Calcite Precipitate (MICP), it is a biomineralization process which aims to precipitate calcium carbonate into the soil matrix. The calcium carbonate produced binds the soil particles together [7]. Microbially induced calcite precipitation (MICP) was achieved using the microorganisms. The microbes were introduced to the soil specimens in a liquid growth medium amended with urea and a dissolved calcium source [8]. The current laboratory experimental practice in using microorganism for increasing soil strength needs improvement, thus, in this study, the objective is to review the current experimental methodology in soil strength improvement that uses microorganisms.

2. CURRENT EXPERIMENTAL METHODOLOGY

2.1 Index Test and Soil

Rigorous laboratory tests such as Specific Gravity Test [9], Atterberg Limit Tests [9], emax test and emin tests [9] and Particle Size Analysis [9] are mandated in the commencement of the different experiments that involve soils. The type of soil will determine what type of microorganisms are capable of moving freely between its grain particles. Figure 1 shows which microorganism can effectively move between different kinds of soil.

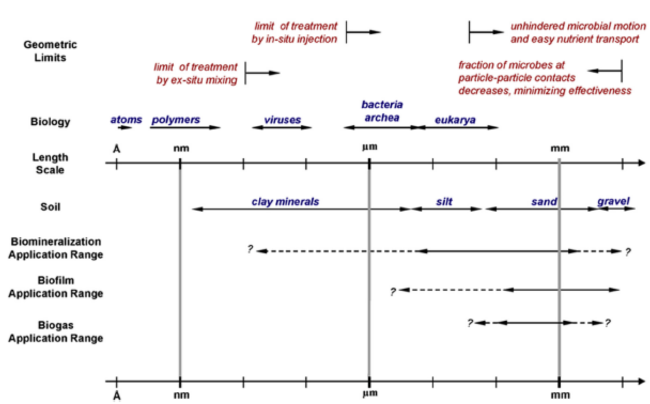

Fig. 1 Application Range of Microorganisms [8]

2.2 Selection of Microorganisms

The selection of the microorganism for biomineralization is an important step because these organisms are able to secrete one or more metabolic products (CO_3^{2-}) that react with ions (Ca^{2+}) in the environment resulting in the subsequent precipitation of minerals [10]. Many considerations shall be considered in determining the microorganisms to be used such as the geometry of the microorganism, urease activity, amount of calcium carbonate precipitation, indigeneity, and pathogenicity. Many studies have used various organisms in their study [6, 10] but Sporosarcina Pasteurii has been commonly used since it has stable urease activity, established research on calcium carbonate precipitation, non-pathogenic (shown on Table 1) and it is pervasive in natural soil deposits.

Table 1. Pathogenecy of Microoganisms

Microorganisms	High Activity	Not pathogenic or genetically modified
Sporosarcina pasteurii	Yes	Yes
Proteus vulgaris	-	Moderately
Proteus mirabilis	-	No
Helicobacter pylori	Yes	No
Ureplasmas (Mocllicutes)	Yes	No

2.3 Culture and Introduction of Microorganism in Soil Medium

Bacterial solution, nutrient solution and calcium chloride solution are needed for the biomineralization process. There are many considerations in the methodology of biomineralization such as cycle and composition of bacterial and nutrient injection [11], method of introduction to soil medium [12], and number of curing days [1].

2.4 Microscopic Characterization, Elemental Composition, and Strength Tests

The scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) were used to evaluate the microfabric of soil, the bonding of the soil particles and its chemical composition, local studies have used these methods to support their experimental results [13, 14].

Strength tests are usually done using triaxial test [8, 12], direct shear testing [1], unconfined compressive tests [15], and rebound hammer tests [15].

2.5 Calcium Carbonate Concentration Determination

The calcium carbonate concentration may be determined using a U-tube manometer [12], or the traditional back titration technique [16]. The availability of equipment and the chemicals used will determine which methodology may be used in determining the calcium carbonate concentration of a specimen.

2.5 Models

Various models are used to represent the strength of soil which is biomineralized, it may be constitutive [1, 17], probabilistic [18], and numerical [19]. These said models are usually used to represent the stress strain behavior of the biomineralized soil, other factors such as the concentration of calcium carbonate may be considered.

3. DISCUSSIONS & RECOMMENDATIONS

The soil type is a big factor in determining which organism may be used, the dimension of the grains and its void will enable to microorganism to move freely. Microorganisms which are relatively small compared with the voids of the soil grains may have a hard time to bond the soil particles because it will require a more calcium carbonate precipitation to bond two soil particles. Relatively large microorganism will have a hard time to move in between particles, and sometimes results to clogging of voids. A seamless arrangement is the Sporosarcina Pasteurii and sand, the void dimension of sand will enable the dimension of sporosarcina pasteurii to move freely in its spaces.

As mentioned, sporosarcina Pasteurii has been commonly used since it has stable urease activity, established research on calcium carbonate precipitation, non-pathogenic and it is pervasive in natural soil deposits. Sporosarcina Pasteurii is currently cultured and made commercially available to be used in research.

Researches in determining how many cycles must be used in bacterial and nutrient injection are already established, also, in the recent researches cited that longer curing time results to a higher strength yield, shown on Figure 2. The method of introduction is variable, it may be through injection method [12] or through puddle method [15]. To enable researchers to simulate the natural movement of fluid to soil medium, the puddle method is usually resorted.

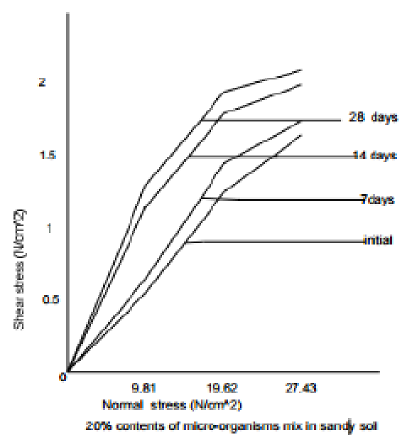

Fig 2 . Increase in Shear Strength depending on Curing Days [1]

The interpretation of the microfabric of the biomineralized soil and its elemental composition is already established, the interpretation will depend on the researcher. The effect of biomineralization is shown on Figure 3.

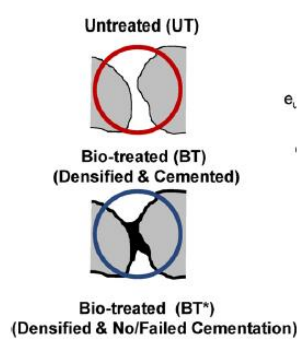

Fig 3. Impact of calcite precipitation [8]

It can be noticed that most of the mentioned strength tests are only small-scale, and are analytically processed to be used in a large scale. A large-scale test is recommended, such as a large-scale direct shear test [20] may be used to consider the extent of calcium carbonate precipitation in the soil specimen, shown on Figure 4.

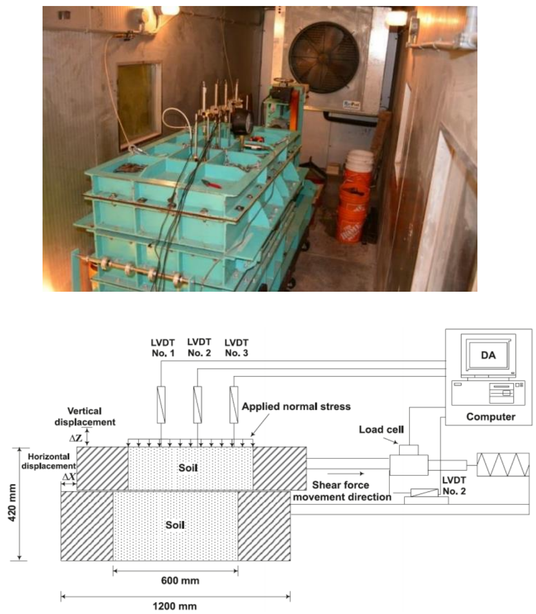

Figure 4. Photo and Schematic Diagram of the Large-Scale Direct Shear Apparatus [20]

Current methodologies [1, 6, 8, 10, 11, 12, 15] assume that calcium carbonate precipitation are uniform horizontally since most of them utilized pipes in their experiments. Since, it is recommended that the specimen may be in large-scale [20] the extent of calcium carbonate may be determined in a lateral direction.

A simple regression and equality line may be provided in order to determine the correlation between the strength and the calcium carbonate concentration. A graphical model is needed in this field of study.

The current laboratory experimental practice in using microorganism for increasing soil strength needs improvement and with this review, recommendations were given to expand the field of study.

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