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A REVIEW OF EFFECT OF BACTERIAL CALCITE PRECIPITATION ON GROUND IMPROVEMENT

RAVI RAVAL[1], DR. TEJASKUMAR THAKER[2]

1. M. Tech Student (Infrastructure Engineering And Management), Department Of Civil Engineering, Pandit Deendayal Petroleum University, Gandhinagar
2. Assistant Professor, Dept Of Civil Engg., Pandit Deendayal Petroleum University, Gandhinagar

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Abstract: The concept of using biological process for ground improvement also known as biologically induced ground improvement has shown greater influence as ground improvement technique and also environmental friendly technique. In the past few years bacterial calcite precipitation technique has become more popular as environmental friendly process and shown great research exposure for sandy as well as in organic soils. This paper presents the review of different factors and conditions responsible for ground improvement.Biological soil improvement is a novel improvement technique in which chemical and biological processes leads to an improvement of physical and mechanical soil properties. Since this method is environmentally compatible and applicable to various soil types using different materials, it has turned into an efficient soil improvement method in numerous ground treatment projects. Microbiologically induced calcite precipitation (MICP) is one of the most well-known biological soil improvements method in which after the injecting bacterial suspension, reaction solution (cementation solution) into soil particles, calcium carbonate sediment is formed, and thereby soil properties are improved. Improvements in the engineering properties of soil such as strength/stiffness and permeability as evaluated in some studies were explored. Potential applications of the process in geotechnical engineering and the challenges of field application of the process were identified.

Keywords: Soil stability, biological process, bacterial calcite precipitation, MICP

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Corresponding Author: RAVI RAVAL

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INTRODUCTION

In design and construction of any structure, the role of soil is very crucial. Since the soil is in direct contact with the structure, it acts as a medium of load transfer and hence for any analysis of forces acting on structure, one has to consider the aspect of stress distribution through soil, as stability of structure itself depends on soil properties. Geotechnical study of site is crucial at feasibility stage, taking place before the design begins (a critical design input) in order to understand the characteristics of subsoil upon which the structure will stand.

In order to improve the ground conditions, the geotechnical properties of soil are improved by ordinary improvement techniques, such as deep mixing with cement or lime or fly ash, vertical drains, sand columns, and dry jet mixing. In recent years study of microbes in ground improvement is becoming very popular. The use of bacterial carbonate precipitation for stabilization purpose is presented as a new, ecofriendly and cost effective technique compare to other stabilization methods. Many studies in the literature have reported that the microbial-induced calcite precipitation technique is very effective in increasing the shear strength and in decreasing the permeability of sandy and gravelly soil (Van Paassen et al., 2010b; Van Wijngaarden et al., 2010; Van der Star et al., 2011). Scaled-up studies were also performed on sandy soil and successful results were obtained (Van Paassen et al., 2010b)[1].

In this method calcium carbonate crystal was formed between soil particle using bacteria in order to improve soil properties. This procedure can stabilize the soil or other porous material which contains small particles without disturbing the initial structure. This method can be useful to improve sandy soil properties, organic soils, crack repair in concrete, improving the strength of bricks by reducing the water absorption and to increase the unconfined compressive strength of soils.

Many years of studies have suggested the relevance of use of microbes in improvement of the ground conditions but less work has been done for exploring the importance of microbes and effectiveness of it in the stabilization. Meanwhile, it is expected that use of bacterial calcite can be useful for improving the engineering properties of soils. Hence, it can also be an alternative solution for ground improvement.

REVIEW OF LITERATURE

Bacterial calcium carbonate precipitation or cementation has been applied to a variety of civil engineering applications, such as to repair cracks in rock and concrete, to improve the bearing capacity, to reduce permeability, to increase dilative tendencies, and to increase the strain stiffness in sand (Gollapudi et al., 1995). Gollapudietal.(1995) used microbial mineral plugging to reduce the porosity of rock fractures. A series of column tests was conducted in order to evaluate the effectiveness of the proposed microbial technique.[2]

Dejong et al. (2006) demonstrated that microbial cemented specimens exhibited increases in the strength of sandy soil. Their results showed that the behaviour of the bacterially cemented specimens was similar to that of gypsum-cemented soil. [3]

Chou et al. (2011) conducted a laboratory study to evaluate the effect of growing, dead, and resting cells on the geomechanical properties of microbially cemented sand. They performed direct shear and California Bearing Ratio (CBR) tests on sand specimens and found that the bacterial cells effectively improved the geomechanical properties of the sand. An analysis of the sand from CBR specimens treated with growing cells demonstrated that the microbial processes contributed to the clogging of the porous medium. [4]

Martinezetal.(2013) worked on optimizing MICP treatment by varying the procedural parameters, including the flow rates, the flow direction, and the formulations of the biological and chemical amendments. They monitored the physical, chemical, and biological properties essential to the performance of MICP, including shear wave velocity, permeability, calcium carbonate content, aqueous calcium, aqueous ammonium, aqueous urea, and bacterial density. Their experiments showed that the shear wave velocity of treated soil increased from 140m/s to an average of 600m/s. [5]

Whiffin et al. (2007) examined the effect of microbial carbonate precipitation on the permeability and shear strength of sandy soil. In their study, a 5-meter sand column was used to simulate field conditions. The results from tri axial tests conducted on specimens from the treated sand column showed that the soil porosity, strength, and stiffness were all significantly affected by the calcium carbonate content. [6]

Al Qabany and Soga (2013) conducted unconfined compressive strength and permeability tests on sand samples treated with 0.1, 0.25, 0.5, and1M urea calcium chloride solutions. The MICP treatment increased the strength of the treated samples. The magnitude of this increase depended on the concentration used in the treatment; the use of a low urea calcium chloride solution resulted in stronger samples. The use of a high urea calcium chloride concentration solution resulted in a rapid drop in permeability at the early stage of the calcite precipitation, whereas the use of a low chemical concentration solution was found to result in a more gradual and uniform decrease in permeability. [7]

It was revealed that microorganisms influence the formation of fine-grained soils and change the behaviour of coarse-grained soils such as strength and hydraulic conductivity. They also facilitate chemical reactions within a soil mass, promote weathering and change the chemical and mechanical properties of specimens after sampling. Hence, the effects of these microorganisms on mechanical properties of soils are still not fully discovered in geotechnical engineering field (Mitchell and Santamarina, 2005). [8]

Bio-mediated method of soil improvement generally refers to the biochemical reaction that takes place within a soil mass to produce calcite precipitate to modify some engineering properties of the soil (DeJong et al., 2010). Meanwhile, utilizing the interdisciplinary knowledge of civil engineering, chemistry and microbiology to alter the soil engineering properties in the subsurface has emerged recently (Whiffin et al., 2007; Ivanov and Chu, 2008; Mitchell and Santamarina, 2005; DeJong et al., 2010).

The technique utilizes soil microbial processes, which is technically referred to as microbially induced calcite precipitation (MICP), to precipitate calcium carbonate into the soil matrix. The calcium carbonate produced binds the soil particles together (thereby cementing and clogging the soils), and hence improves the strength and reduces the hydraulic conductivity of the soils. MICP can be a practicable alternative for improving soil-supporting both new and existing structures and has been used in many civil engineering applications such as liquefiable sand deposits, slope stabilization, and subgrade reinforcement (DeJong et al., 2006; Cheng et al., 2013).

Bioclogging can be defined as the reduction of hydraulic conductivity of soils or porous rocks by pore-filling materials generated by microbial processes. The carbonate precipitate generated microbially is responsible for clogging the soil pore spaces, thereby restricting flowofwater and decreasing the permeability of the soil. Whiffin et al. (2007) reported a reduction in permeability from 22% to 75% of the initial permeability of the treated soil. Yasuhara et al. (2012) [9] similarly revealed a decrease in permeability of 60% to 70% of a soil sample when an extract of urease enzyme was used directly to calcite precipitations induced. Meanwhile, Soon et al. (2014) [10] presented a decrease in hydraulic conductivity of 90% in residual soil after a species of bacillus, Bacillus megaterium, was used to trigger calcite precipitation in the soil.

Yasuhara et al. (2012) reported potentials of using urease enzyme from other sources different from bacteria to catalyze the hydrolysis of urea in the presence of calcium chloride to precipitate calcium carbonate for the improvement of engineering properties of sand samples. Findings from this study indicated that unconfined compressive strength of the treated samples increases considerably, with the initial hydraulic conductivity of the treated samples being decreased by 60% to 70%. Hence, since the urease enzyme can be obtained directly from some plants such as sword beans, exploring into this alternative would be of immense contributions particularly in field applications of this technique. This is because that handling of bacteria in terms of cultivation and storage needs some technical expertise, and microbial metabolism which is a key factor in MICP may not be straightforward enough to be controlled. Therefore, it may be impossible to constrain the extinction and/or the generation of living bacteria in natural environments.

Bio mineralization processes as documented in many studies reported by Lian et al. (2006) are found to be active in almost every environment on Earth, with much of the microbial activity resulting in the carbonate minerals formation near the surface of the Earth. [11] The microbial activity has been considered to play an essential role in the carbonate formations as sediments and soil carbonate deposits. Thus microbes from soils and some aqueous media are predominantly responsible for the inducement of calcium carbonate precipitates in both natural and laboratory settings.

Therefore, recent understanding of the concept of bacterially mediated carbonate precipitation relies on the fact that the carbonate precipitate produced does not have any specific biological functions which may be genetically related to the microorganisms involved in the process. This confirms that microbially induced mineralization to produced carbonate is the most prevailing process (Mann, 2001). However, the existence of different possible mechanisms with respect to the role of the microorganisms in the carbonate precipitation describes the complexity of the biomineralization process and the need to explore more into the process.

Biomineralized calcium carbonate has proved its efficiency in both bioclogging and biocementation of soils and could be used in geotechnical engineering to improve the engineering properties of soil in situ (Ivanov and Chu, 2008). [12] The authors further emphasized that these methods could be used as a replacement of the traditional energy demanding mechanical compaction and chemical grouting methods that are expensive and sometimes harmful to the environment

Many bacterial species have earlier been identified and suspected to be connected with natural carbonate precipitates from different environments. The main function of the bacteria in the precipitation process has consequently been attributed to their capability ofcreating an alkaline environment through the increase in pH value and dissolved inorganic carbon during their physiological activities (Hammes and Verstraete, 2002). [13]

While in the biologically induced mineralization process, extracellular metabolic activities of the microorganisms which depend substantially on the environmental conditions result in the formation of the minerals. Thus, bacterial precipitation of calcium carbonate is generally regarded as the biologically induced process which depends largely on the type of bacteria involved, abiotic factors such as salinity and composition of medium, and other environmental conditions.

Biocementation can be defined as the soil improvement process through the production of particle-binding materials via microbial means. It is mainly used in geotechnical engineering applications for strengthening, plugging and improving soils (Whiffin et al., 2007).[6] Recent studies by Soon et al. (2013) revealed the effectiveness of microbial induced calcite precipitation in improving the shear strength and reducing the permeability of tropical residual soil and sand. The results proved an excellent improvement in shear strength of 96% at 0.5 M concentration of the cementation reagents. However, the strength improvement was retarded at higher concentration of the reagent (i.e. 1 M) due to high salinity that resulted in inhibitory effects on the microbial activities.[10] The findings are in agreement with that higher concentration of cementation reagents usually increases the salinity of the medium thereby retarding the microbial activity due to inhibitory effects, though the activity of some microorganisms is not really affected by the high salinity of the environment (Whiffin, 2004).

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Hence, considerable increase in unconfined compressive strength and limited reduction in permeability of treated samples are the basic qualities that make biocementation treatment attractive. Meanwhile, preservation of permeability allows for multiple treatments, use of low injection pressure and possibility of treating large volume of soil. Therefore, biocementation can be used for in situ treatment underneath without disturbing the existing buildings. Microbial calcite precipitate induced in sands was studied and various microscopy techniques were used to assess how the pore space volume was altered by calcite precipitation. The calcite precipitate was distributed spatially within the pore spaces of the sand, thereby reducing the permeability and increasing the stiffness of the sand samples (DeJong et al., 2010). [3]

According to Mitchell and Santamarina (2005), the most abundant microorganisms in soils are bacteria. In order to withstand adverse environmental conditions, some bacteria make spores. They have a cell diameter ranging from 0.5 mmto 3 mmand shape of nearly round, rod like or spiral. It also revealed that bacteria can survive in an environment of low to high acidity and/or salinity. They can also survive at very low to high temperatures ranging from below freezing to above boiling points and withstand very high pressures. Majority of bacterial cells have a negative surface charge for groundwater pH values between 5 and 7, which is typical for near surface soils; and the negative surface charge decreases with increasing concentration and valence of ions in the pore fluid.Because the bacteria are native to the earth, they may not likely cause any environmental hazard in future.

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