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Evaluation of the Ability to Control Biological Precipitation to Improve Sandy Soils

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Abstract

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. In this paper, the ability to manage time and location when calcium carbonate sediments are biologically formed was investigated in sandy soil. The electrical conductivity method, unconfined compressive strength test and X-ray diffraction examinations were sequentially used to determine urease bacterial activity, measure the amount of the increased strength of treated soil and determine crystal type. The results showed good ability of this method to control time and location of biological precipitating. Furthermore, unconfined compressive strength of Caspian Sea coast sandy soil was increased up to 400 kPa. The ability to manage time and location of biological precipitating indicates this method can be potentially used in different application such as mitigation of liquefaction, soil erosion control, immobilizing of pollutions in soil and other soil improvement projects.

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Keywords: Soil improvement; biological precipitation; urease activity; calcium carbonate sediment; precipitation control.

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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).

Many studies have been carried out up to now on the capability of this method in different applications. MICP has been used to improve sandy soil properties (DeJong et al., 2006; Whiffin et al., 2007; Van Paassen, 2011; Kahani et al., 2013), removal and immobilization of soil pollution (Warren et al., 2001; Fujita et al., 2004; Fujita et al., 2010; Li et al., 2011), crack repair in concrete (Ramachandran et al., 2001; Abo-El-Enein et al., 2012; Abo-El-Enein et al., 2013), increasing brick strength by reducing water absorption (Sarda et al., 2009), distribution and fixation of bacterial activity in soil (Harkes et al., 2010) optimization of carbonate precipitation (Okwadha and Li, 2010). Moreover, many other researches are being carried out in the fields of Microbiology, Chemistry and Geotechnical engineering. Recently, some field trials of this method have been reported in Netherlands and in the US in order to gravel stabilization and heavy metals immobilization (co-precipitation) respectively (DeJong et al., 2013). According to the () results unconfined compressive strength of biological treated soil was increased up to 55 MPa (Yang and Cheng, 2013). Which indicates the ability of this method in soil improvement projects.

After considering different methods of biological precipitation in this study, the possibility of managing the biological precipitation for different functions was investigated.

2. Biochemical catabolic reactions

2.1. A review of biological precipitation methods

Biological soil improvement is often based on sediments containing calcium, magnesium, iron, manganese and aluminum sediments which precipitate between soil particles as carbonates, silicates, phosphates, sulfides and iron hydroxides (Ivanov and Chu, 2008). This paper was focused on microbial induced carbonate precipitation (MICP). One of the most attractive attribute of biological soil improvement method is the ability to use different microbial processes. Therefore different microorganisms and catabolic reactions can be used in order to form carbonate. Table 1 shows several chemical reactions, which can be produced carbonate sediments using bacteria.

As shown in Table 1, reaction material, mediated-bacteria and resulting governor conditions were different in each reaction. The choice of chemical reaction was made regarding different criteria such as reaction condition, reaction rate, material availability, sediment durability, etc. In situ biological carbonate precipitation by hydrolysis of urea was chosen for this study.