Development of Microbially Induced Calcium Carbonate Precipitation Technology in Soil Improvement

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Abstract—**Bacteria plays an important role in the mineralization process in nature. It participates, induces or controls the formation of inorganic mineral deposit. This paper presents an overview of soil reinforcement techniques based on MICP. In this paper with the discussion of research results and status in both domestic and international areas, the role of microorganism in calcite precipitation and the modification mechanism is systematically summarized. Comparison and selection of several MICP methods are made. And it also offers the great application prospect of the introduction of microbe debris flow prevention and control which are urgently needed to be solved and described .**

Keywords: MICP; Microorganism; Conditioned Sands; Geological disasters.

A strong competitiveness on the cross in dealing with some cutting-edge discipline has been shown since the 21st century. Employing the properties of microorganisms which can grow in the porous media migration to do breeding soil modification is not only a new theoretical breakthrough and innovation, but also brings profound influence on ecological environment and sustainable development. Therefore, it has become a kind of new governing measures to do geological disaster prevention by the use of biological geotechnical technology such as microbial induced calcium carbonate precipitation [1].

I. Introduction of Microbial induced calcium carbonate precipitation technology

1.1 Theoretical base for microbially induced calcium carbonate precipitation

Microbial induced calcium carbonate precipitation, generally speaking, refers to that in the process of metabolism microbes produces urease. And then the decomposition of urea enzyme will produce ammoniumion and carbonate ions. When calcium source is sufficient, calcium source and carbonate ions react to form calcium carbonate precipitation. It is a novel and environment-friendly biological technology.

Microbial urease, the urea in the hydrolysis environment, ammonia and carbon dioxide, will be converted into ammonium ions and bicarbonate ions in the alkaline solution environment. If there is enough calcium ions, calcium carbonate precipitation will response to bicarbonate ions in alkaline environment. At the same time, microbe is usually negatively charged and can readily absorbs positively charged organisms such as calcium cation to make micro-organisms the crystallization core of calcium carbonate crystallization process that will make it easier for calcium carbonate crystallization process to take place. Then the crystal is easier to grow.

$$CO(NH_2)_2 + 3H_2O \xrightarrow{\text{Urease Bacteria}} 2NH_4^+ + HCO_3^- + OH^-$$

$$Ca^{2+} - cell + 2HCO_3^- + 2OH^- \xrightarrow{\text{Nucleation}} cell - CaCO_3 + 2H_2O$$

The activities of microbial life can improve the concentration of bicarbonate around and create the alkaline environment to create supersaturated conditions for precipitation of inorganic mineral precipitation. So calcium carbonate cementation appearance of fluff ball can have cemented filling effect with increasing the cohesive force and the friction between particles embedded squeeze effect and improving the soil compaction degree, thus can greatly improve the engineering properties of soil.

1.2 Introduction of several methods about MICP

Theoretically as long as the microbial metabolic process could make environmental pH value increase and lead to the reach oversaturated solution concentration of the calcium carbonate, the inducement of calcium carbonate will be provided. Here following some available ways:

(1) urea hydrolysis;
(2) sulfate reduction;
(3) denitrification;
(4) fatty acid fermentation.

II. APPLICATION OF MICP IN BIOLOGICAL GEOTECHNICAL ENGINEERING

Biologically geotechnical engineering is to use microorganisms and biological technology to process rock and soil mass. Inoculating the pathogenic microorganism inherent in the nature and the medium rock mass to the processed rock, microbe will induce mineralization deposition to effectively improve the projected performance in geotechnical engineering. Besides, it can be used in the biological soil reinforcement technology (soil enzymes and microorganisms, insects, discharge, etc.), slope ecological restoration (soil microbe, plant roots), and bank slope protection technology, etc.

2.1 Development of MICP technology in western countries

Fischer[2] and others found that the pap of Bacillus coli(Bacillus Pasteurii) precipitation has the cementation of sandy soil in the precipitation of calcium carbonate; Ferris and others in the university of Toronto used pap spore eight fold aureus to precipitate calcium carbonate as a kind of mineral block and cementing agent to reduce the permeability of sandstone oil field and to control the flow of crude oil for improving the efficiency of oil exploration, which has played a very good economic benefit; Bang and others in South Dakota School of Mines and Technology adopted the bacteria produce calcium carbonate as a porous surface materials and to repair the surface of the gel material. At the same time they studied the effect of pH, concentration of nickel ion, calcium ion concentration and fixed urease on the activity of urease;

DeJong[3] and others in the University of California , Davis, used pap spore eight fold aureus gel to reinforce sand body which is loose and easy to collapse, and used shear wave velocity method for the nondestructive detection of microbial reinforcement. It shows that the microbial reinforcement treatment of the sample has the high initial shear stiffness through a series of isotropic consolidated undrained triaxial compression test. At the same time, the shear strength of the samples increased significantly;

Van Paassen and others in Delft University of Technology, with applying pap spore eight fold aureus in sandy soil foundation reinforcement, did an in-depth research by controlling the speed of grouting, grouting time, the amount of bacteria and gelling fluid which can control factors, such as to improve soil strength, stiffness, and control soil permeability, porosity and other projects. The group had a relatively comprehensive study through 1 m3 and 100 m3 volume of large scale experiment for the large scale sandy soil microbial grouting, making the sandy soil uniaxial compressive strength of up to 12 MPa, and making a certain contribution for microbial grouting engineering scale application;

Soga and others in the University of Cambridge optimized pap spore eight fold aureus microbes grouting conditions by controlling the concentration of reactants, reaction time, and valid parameters such as grouting rate to improve the efficiency of microbial induced calcium carbonate. They used different concentrations of 0.1 1 mol/L gelling fluid grouting on sandy soil microbes and it can improve the strength of sandy soil but with low concentration of gelling fluid it can get higher strength, lower permeability smoother and more uniform.

2.2 Development of the technology in China

Chao-yang Xu and others from Yangzhou University, introduced microbial modification technology into the geotechnical and selected a variety of carbonate mineralization bacteria and polysaccharide glue bacteria, using of carbonate mineralization bacteria ATCC64533, and 5 of the metabolites of polysaccharide glue on engineering properties of silty soils to modify. And they put the modification of soil infiltration and unconfined compressive strength in test for the determination of the change of the soil engineering index. Their research shows that mixed carbonate mineralization bacteria and polysaccharide glue bacteria on the permeability of silt and unconfined compressive strength all have different degrees of influence;

Zhou Fangqin and others in Wuhan Institute of Rock and Soil Mechanics, CAS, discussed the microbial effects induced by environmental factors change on dam base rock soil engineering properties; also they discussed the influence of physical chemistry and biochemistry changes on geotechnical engineering properties due to environmental factors, emphasizing the REDOX caused by organic matter and microbial effect on the cementation of free iron oxide state transformation.

Li Peihao and others in Tongji University also used pap spore eight fold aureus surface of concrete to study stone relics protection. And they expounded the bacteria induced mineralization material phase and growth morphology factors such as the influence of carbonation resistance of concrete. Experiments shows that bacteria induced calcium carbonate mineralization materials can effectively improve the carbonation resistance of concrete and repair reinforcement of stone relics confronting with weathering surface it also has good compatibility, effectiveness and durability. They also made useful attempts with the use of microbial mineralization technology in material surface repairing;

Chun-xia Qian and others from Southeast University studied the area of bacteria micro cracks of concrete repair, ancient building surface protective treatment and other fields of study. At the same time they tested bacteria and discharged the influence of the concentration of calcium carbonate crystal formation. The group also studied microbial induced calcium carbonate, gelling loose sand particles, repaired the surface of the defects and cracks of the cemented material. At the same time they generated microbial sand pillar , testing the samples of the compressive strength , pore structure and microstructure, getting the uniaxial compressive strength nearly 12 MPa microbial sand pillar samples;

Lian Bing and others from Nanjing University used the loess in the separation of huge Bacillus Bacillus megaterium , compared and studied microbe in the induction of calcium carbonate crystallization process, the impact on the formation of crystal morphology, structure, and it is concluded that the bacteria cell metabolism controls surrounding environment inside and outside to gain the mineralization mechanism of the induced calcium carbonate;

Yang Zan and others in Tsinghua University studied the main factors influencing the formation of microbial mortar strength systematically through the sand pillar grouting model experiment. Combined with microbial simplified model, the grouting reinforcement simulation experiment and theory analysis, they found the method of preparation of microbial high strength mortar, and they for the first time made the microbial mortar strength grade of the material, system, comprehensive testing and analysis of mechanical performance to laid a solid foundation experimental theory for microbial grouting technique's application in high quality brick masonry monument reinforcement,

Tan Yefei and others in Nanjing Institute of Water Conservancy Science opened a liquid used in slope reinforcement reinforcement of microbes and their method in the use of the patents. The microbial strengthening fluid includes bacteria and nutrient solution. The described bacteria is bacillus. The nutrient solution includes urea, calcium ions, nutrients and dissolved oxygen, wherein nutrients is starch or glucose. Applicability is wide and the test results show that tto all kinds of gradation of the sand, loam slope he technology can increase their strength by 10% - 50%, and the cost is very low.

ZhuangYan and others in Hehai University invented a microbial river embankment reinforcement ecological slope protection technology. The results show that the method of microorganism in soil slope reinforced; at the same time, it can also produce a large number of air bubbles, evenly distributed in the soil, which greatly reduces the probability of soil mass in a saturated state to prevent sand liquefaction and improve the seismic performance of soil. And the effect is obvious.

III. THE APPLICATION PROSPECTS OF MICROORGANISMS IN GEOLOGICAL DISASTER PREVENTION

China now faces the most serious geological disasters and is the country with the largest threatened population across the world with the complicated geological conditions, frequent tectonic activity.Collapse, landslide and debris flow hazard are in wide distribution and concealment having the feature of sudden-happening and destruction which are difficult to prevent against. Especially in recent years by the extreme weather, earthquake, construction factors, the frequent geological hazards will cause serious losses to people's lives and property. Table 1 summarizes different prevention and control of engineering measures and the corresponding faults:

Table 1 Traditional management of disasters and microbial management

Name	Measures	Disadvantages
Traditional project management	Build Obstruct, supporting, platoon guide structures, etc	Cost is relatively high, but the construction and maintenance is difficult
Traditional grouting governance	Pumping chemicals	The impact on the environment and ecology; some even poisonous
Microbial control	Microbial grouting	Governance is slower; technology not mature enough

From the table above, the traditional main geological disaster prevention project will build a slope protection like retaining wall, dam, spur dike, etc.The engineering cost is relatively high, and the construction, maintenance is difficult. Its biggest drawback is that it is only the protection for buildings, railways, and highways, bridges and other engineering in designing and construction. In opposite it seldom considers the impacts on the environment and ecology.

In order to improve the engineering properties of rock and soil mass, many processing methods are adopted, such as chemical grouting and pressure grouting which is until today still widely used. Usually some serous can change the ecological environment in geotechnical engineering, some is even toxic which will cause serious damage to the rock and soil microbial community in the body, and damage the natural ecological balance. And he recent use of microorganisms biological technology can vaccinate the pathogenic microorganism that is inherent in the nature of the rock and soil mass and medium rock mass that is to be processed, then microbial will induce sedimentary mineralization and is effective to improve the engineering properties of rock and soil mass. It is a more traditional and friendly processing method to environmental and is conducive to the ecological balance in the closed in geotechnical engineering which has less investment, low maintenance cost but is environment friendly and owns other potential advantages.

As a new direction of geotechnical engineering microorganisms on geotechnical engineering, though it has its application potential, for now geotechnical engineering has been applied in protective slope unstability , dam seepage control and foundation soil reinforcement areas. But there is no case with the application in disaster governance at home and abroad. Whether Microbes can be large-scale applied in disaster management or nor mainly depends on the following questions:

(1) appropriate screening of microorganisms under different environmental conditions ;

(2) the optimization of microbial activation reaction conditions;

(3) species security;

(4) economic feasibility;

(5) modified soil stability and durability;

IV. CONCLUSION

(1) The technology is relatively mature in foreign country. It improves soil strength mainly through microbial grouting. Experiments prove that the sample shear strength increased significantly;

(2) The technology in China has just started. It is mainly used for protection, dam body seepage slope unstability, concrete crack repair field. And it hasn't seen in the field of related disaster management cases;

(3) the soil loose debris flow source area is mostly clay content at about 11% of sandy soil that based on where the modified method can be used for debris flow prevention and control. At the scene of the large-scale applications, it is appropriate to choose facultative anaerobic type or trace aerobic microorganisms;

(4) Soil modification methods based on MICP have replaced building structures such as the potential of traditional control method, but must still be microbiology chemistry between disciplines such as geotechnical engineering achieve mastery through a comprehensive study. Further promote of this method can be extended to the field of practical engineering and application;

(5) Microorganisms and geotechnical engineering produced under the background of the combination of debris flow prevention and control technology is not only rich in resources, environment friendly and economical advantages, but also improves the ground by the method of a new, sustainable development. It promotes the development of the

emerging field such as biological geotechnical engineering and has a great application prospect.

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