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Laboratory Tests on the Improvement of Characteristics of Silt Using Iron Bacteria

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Iron bacteria exist widespreadly in nature, which can be screened to oxidize ferrous iron into hydroxyl complex and produce gelatinous slime with high reactivity and adsorbability. In this paper, microbial technology is introduced for improving silt. The metabolic outcomes and precipitation of iron bacteria can plug mineral lattice crystal and glue the soil granule, simultaneously reduce soil permeability and strength their shear resistance. The engineering characteristics of silt before and after modification are compared by permeability test and CU tri-axial compression test. And the modification mechanism of silt by bio-grouting has been investigated from the perspective of mesoscopic.

Key words: Silt, Iron bacteria, Permeability coefficiency, Unconfined compressive strength, Microstructure.

Soil is a good carrier of microbes, it usually contains all kinds of microorganisms like bacteria, actinomyces and fungus. Recently, researches on how microbe affect the characteristics of soil have received wide attention[1~10]. Due to the small size of bacterial cells and the low viscosity, bacteria have much better permeating ability than cement and thus are more ideal than cement in terms of construction process. Through applying microbial technology, the mechanical characteristics of the soil are modified to satisfy the engineering demand. Mainly, there are two mechanisms that are suitable for modifying the soil. One is bio-clogging which means filling the crystal lattice of the mineral with inorganic compounds from enzymatic reactions. Thus the void between soil particles are clogged to reduce the permeability and increase the strength of soil. The other is biocementation which uses the gelatinous slime generated by metabolism to promote the cementation of soil particles. Day J. *et al* (2003)[7] have done some study on filling calcium carbonate crystal produced by microbial metabolism in polyurethane materials, which can improve its compressive strength and elastic modulus. Through processing incoherent sand with carbonate -mineralization bacteria, De Jong *et al*(2006)[11] found carbonate sedimentation by microbial products can greatly improve shear resistance of the sandy soil. Xu zhaoyang *et al*(2009)[12~13] modified the silt by using pasteur bacillus and polysaccharide gum bacteria products, and found bio-grouting can penetrate into the porous soil by gravity and improve mechanical properties of the silt. J.Chu *et al* (2011)[14] have isolated iron bacteria from sewage treatment plant to oxidizing the ferrous ions into ferric complexes. The resulting iron hydroxide sediment is of great adsorbability which can bind the incoherent sand particles together. Rong Hui *et al*(2012)[15] cemented the particles with product of mineralized microbe metabolism and managed to produce microbial filling sand column of preferable mechanical properties.

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Silt layer, which is characterized by its great permeability, low compressive strength and the liquefaction potential under dynamic load, spread widely in middle and lower reaches of yangtze river. Soil treatment is generally expensive and sometimes brings the negative effects to eco-environment, which shows the significance of research and applications on improving the soil with microbial technology. In this paper, a suitable iron bacteria is screened to improving the silt. The effects of bio-grouting to engineering characteristics of silt are assessed by permeability test and CU tri-axial compression test. And the modification mechanism of silt has been investigated from the perspective of mesoscopic.

MATERIALS AND METHODS

Iron strains were evaluated in terms of mycelial growth, sediment production, and mycelial polysaccharide content. Firstly, the iron-based strains were separated from soil, then inoculated individually into liquid medium after purifying. During 3 or 4 days stationary culture, the strain oxidized the ferrous ions into ferric ions with enzymes and a few iron hydroxides sediment can be observed in this stage. After static culture for 15 days, as shown in Fig.1(a), with nutrient greatly consumed, large amount of hyphae is observed suspending in the nutrient solutions. Also, the nutrient solutions turn murky as the metabolism product accumulates. After cultured for another 5 days, with the suspended sediment increasing and settling gradually, the liquid became clear, as shown in Fig.1(b), and the precipitate contains a large number of sticky brown slime. This is due to the great activity and adsorption of the iron hydroxide precipitation obtained from the oxidation. The suspended mycelia were adsorbed and these polysaccharide bio-films have certain viscosity, then form the slime. As shown in Fig.2 (a) for red brown slime by filtering. Fig.2 (b) shows the red brown fine iron hydroxide precipitation after leaving the slime to air dry.

To investigate the effect of iron-based bio-grouting on properties of silt, permeability test and unconfined compressive strength test were carried on remolded sample and iron-based bio-grouting sample. The silt was sampled in Yangzhou along the Yangtze River. The main property indexes are presented below in Table 1 and Table 2. This kind of silt has low ductility and high compressibility characteristics.

The remolded soil samples were 61.8mm in diameter and 40 mm high according to Specification of Soil Test. The saturation samples by means of vacuum were numbered as No. I(plain soil) and No. II(bio-grouted soil). The bio-grouted samples were made by mixing sediment in three equal lots from the 1500ml solution. Analysis shows every 500ml solution produces 3~4g iron hydroxides sediment. The variable-head permeability test was performed using TST-55 Permeability Tester. The summarized permeability test result is illustrated in Table 3.

As shown in Table 3, the permeability coefficient of No. I sample is 28.4×10^{-5}cm/s while coefficient of No. II sample (the bio-grouted sample) is 5.9×10^{-6}cm/s. Permeability coefficient reduced by approximately 95% after bio-grouting, which indicating that iron-based bio-grouting can effectively lower the permeability of the silt.

Unconfined compressive strength is considered as a criterion for evaluating modification performance. To investigate the effect of iron-based bio-grouting on shear strength of silt, Unconfined compressive strength tests were carried on bio-grouted and plain samples. With same compaction times and moisture content, three cylinder sample groups were taken. One was plain soil sample and the other two samples were bio-grouted with equal concentrations in three or six times respectively. Every grout uses sediment from the 500ml solution. Figure 3 shows the experiment results for unconfined compressive strength test. Figure 4 is the corresponding failure modes of the three sample groups.

As is shown in figure 3, after bio-grout, the unconfined compressive strength of the grouted samples improved to different degrees. The compressive strength of the sample goes up to 19.26kpa and 22.88kpa respectively after three and six bio-grout. Conclusions can be drawn that iron-based bio-grout can increase the unconfined compressive strength of silt and the degree of strength improvement is largely irrelevant to grouting quantity.

As is shown in figure 4, On plain soil sample, the first crack appeared at a 45-degree angle in the middle part of the plain soil sample. With the load increasing, the crack developed obliquely upward and downward in two directions and ultimately went through the sample. For the sample bio-grouted for three times, more and bigger slanting cracks appeared during the shearing process. For the soil sample bio-grouted for six times, no obvious cracks can be observed around the middle area but its two ends bulged out with cracks, which is accorded to features of ductile failure.

The light micrograph of plain soil and bio-grouted soil are shown in Fig.5 which magnified 100 times under OLYMPUS-BX51M metallurgical microscope. A comparison of the two pictures shows that the silt particles are bound together after it is treated by bio-grouting. It can been seen that there are many large pores in the samples without grouting. On the contrary, intergranular porosity is filled with fine-grained material and colloid material produced by the microbial process, which lead to the compactness of soil increase. This may explain partially why bio-grouting can increase the shear strength and reduce the permeability of soil.

Iron slime is mainly composed of the polysaccharide gel and $Fe(OH)_3$ particles. There are the following mechanisms that contribute to soil improvement by iron bio-grouting.

The ferric hydroxide colloid in slime is not only $Fe(OH)_3$, but a macromolecular complex which forming salt bridges between soil particles and the hydroxyl or ionized iron ions colloids mediated by microorganisms. Specific process is as shown in Fig. 6.

The slime can bind fine silt particles together with certain structure, so the integrity of soil and shearing strength are increased.

The macromolecular complex is of high reactivity and adsorbability. It can adsorb metal cations and mycelium polysaccharide to form insoluble organic or in organic film in the soil particle surface, which preventing water through the soil particles, so that the lower the permeability of the soil. At the same time, the augment of the contact surface between soil particles leads to the shearing strength increase.

RESULTS AND DISCUSSION

In this paper, iron-based bio-grouting was proposed to improve the silt. During the process of iron-based bio-grouting, a series of physical, chemical and biological reactions occur between the metabolites and silt particles. By cementation, adsorption and filling the pores between silt particles, the permeability of silt soil was reduced and the unconfined compressive strength increased, its degree of change related to the grouting quantity.

Microbial technology can play a positive role in improving soil. From the preceding analysis, it can be seen that iron bacteria can apply to different places, such as increasing the bearing capacity of foundation, reducing the liquefaction potential of silt or sandy soil, preventing piping of soil in water conservancy dam foundation, as well as sealing leakage of refuse landfill etc. Further study is required to identify potential application of iron-based bio-cementation and bio-clogging.

Microbial modification technology is a

Table 1. The engineering characteristics of silt

Specific gravity of silt particle Gs	Plastic Limit w_p	Liquid Limit w_L	Plastic Limit index I_p	Maximum dry density g/cm^3	Best moisture content wop%
2.70	21%	30.4%	9.4	1.52	25.6

Table 2. Grain composition of silt

Grain composition (mm)	2~0.5	0.5~0.25	0.25~0.075	0.075~0.005	<0.005
Silt	0%	0.2%	16.6%	76.3%	6.9%

Table 3. Results of Penetration test

Soil sample	elapsed time t(s)	$2.3\frac{a}{A}\frac{L}{t}$	$\lg\frac{h_1}{h_2}$	Permeability coefficient k_{20}(cm/s)	Permeabilities k(cm/s)
I	300	3.47×10^{-4}	0.9206	0.000371	
	300	3.47×10^{-4}	0.9208	0.000371	
	600	1.73×10^{-4}	1.0969	0.000221	
	1200	0.87×10^{-4}	1.699	0.000171	28.4×10^{-5}
II	300	3.47×10^{-4}	0.176	0.0000064	
	600	1.73×10^{-4}	0.206	0.0000074	
	1500	0.69×10^{-4}	0.247	0.0000061	
	3000	0.35×10^{-4}	0.273	0.0000036	5.9×10^{-6}

multidisciplinary complex subject involving a range of basic theories. There are still a lot of problems in the application field. The effect of soil treatment by microbes varies considerably according to soil type. With accumulation of experience in this discipline, future research on application of microbial technologies in geotechnical engineering will be the trend of the future. When more knowledge is accumulated through research findings and technology development, a new branch of geotechnical engineering the microbial geotechnology can be established.

(a) After 3 days (b) After 25 days

Fig. 1. Variation of iron bacteria culture solution

(a) Slime by filtering (b) iron hydroxide precipitation

Fig. 2. Photos of red brown slime

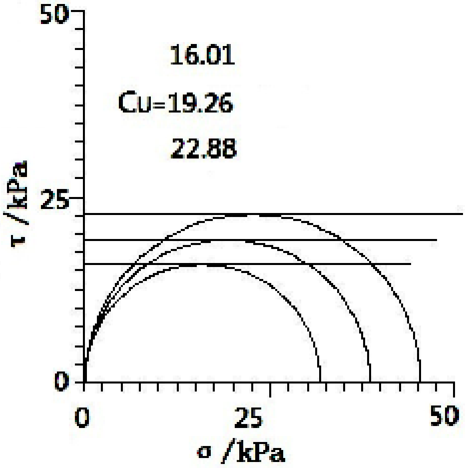

Fig. 3. Unconfined compressive strength envelope

(a) Plain soil (b) Biogrouting soil (three times) (c)Biogrouting soil (six times)

Fig. 4. The damage form of soil sample

(a) Plain soil (100 X) (b) Grouting soil (100 X)

Fig. 5. Soil and grouting soil mesoscopic picture

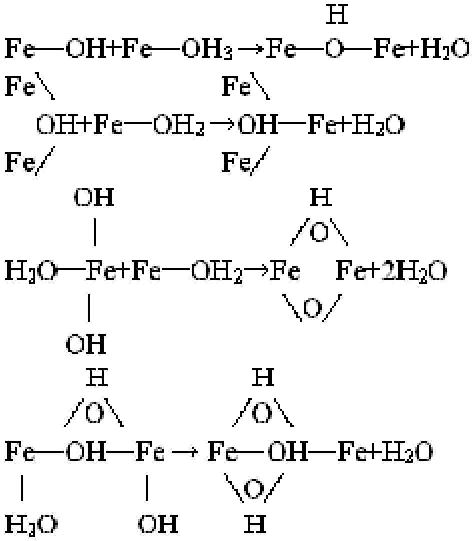

Fig. 6. The process of formation of hydroxyl complexes

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REFERENCES

1. Harkes, Marien P., van Paassen, Leon A., Booster, Jacco L., Whiffin, Victoria S., van Loosdrecht, Mark C.M. Fixation and distribution of bacterial activity in sand to induce carbonate. *Ecological Engineering*., 2010; **36**(2): 112-117.
2. Stocks-Fischer S., Galinat J K., Bang S S. Microbiological precipitation of $CaCO_3$. *Soil Biology and Biochemistry.*, 1999; **31**(11): 1563-1571.
3. Bang S.,Ramakrishnan V. Microbiologically to enhanced crack remediation. *Proceedings of the International Symposium on Industrial Application of Microbial Genomes*., 2001: 3-13.
4. Bang S., Galinat J., Ramakrishnan V. Calcite precipitation induced by polyurethane immobilized Bacillus pasteurii. *Enzyme and Microbial Technology.*, 2001; **28**(4): 404-409.
5. Ramachandran S., Ramakrishnan V., Bang S. Remediation of concrete using microorganisms. *American Concrete Institute Materials Journal.*, 2001; **98**(2): 3-9.
6. Bachmeier, Keri L., Williams, Amy E., Warmington, John R., Bang, Sookie S. Urease activity in microbiologically to induced calcite precipitation. *Journal of Biotechnology.*, 2002; **3**(2): 171-181.
7. Day J., Ramakrishnan V., Bang S. Microbiologically Induced Sealant for Concrete Crack Remediation, *Proceedings of the 16 Engineering Mechanics Conference.*, 2003: 5-20.
8. Vemuri S., Panchalan R Ramakrishnan V. Plastic Shrinkage CrackRemediation Capacity of Bacterial Concretea Smart Biomaterial, Proceedings of the ICFRC International Conference on Fibre Composites. *High Performance Concretes and Smart Materials.*, 2004; 1057-1067.
9. De Jong J.T., Mortensen B.M., Martinez B.C., Nelson, D.C. Bio to mediated soil reinforcement. *Ecological Engineering.*, 2010; **36**(5): 197-210.
10. Van Paassen L., Bio to mediated ground improvement: from laboratory experiment to pilot applications. *Geo to Frontiers.*, 2011; **2**(11): 4099-4108.
11. De Jong J., Fritzges M., Nusslein K. Microbially Induced Cementation to Control Sand Response to Undrained Shear. *Journal of Geotechnical and Geoenvironmental Engineering.*, 2006; **132**(11): 1381-1392.
12. Xu Zhaoyang., Zhang Li., Zhou Jian. Effect of Microorganisms on Some Engineering Properties of Silt. *Journal of Civil Construction and Environmental Engineering.*, 2009; **31**(2): 80-84.
13. Xu Zhaoyang., Zhang Li. The Effect of Microbes on Strength of Silt. *Building Science.*, 2009; **25**(5): 45-48.
14. Ivanov V., Chu J. Applications of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. *Rev Environ Sci Biotechnol.*, 2009; **7**(2): 139-153.
15. Rong Hui., Qian Chunxiang. Characteristics of microbial cement to based materials, *Chinese Science Bulletin*, 2012; **57**(9): 770 -775.