Experiment and mechanism study on microbial improvement of dredger fill

Xiaoduo Ou[1, 2, 3,*], Xin Pan[1, 2], Kaiwen Hou[1, 2], Xiantai Yin[4]

1. *College of Civil Engineering and Architecture, Guangxi University, Nanning 530004, China*
2. *Key Laboratory of Disaster Prevention and Structural Safety of Ministry of Education, Guangxi University, Nanning 530004, China*
3. *Guangxi Metal Tailings Safety Prevention and Control Engineering Technology Research Center, Nanning 530004, China*
4. *Nanning Wangting Project Mangement Co.,Ltd, Nanning 530000, China*

ouxiaoduo@163.com

ABSTRACT. *Considering the soil improvement effect of micro-organic metabolites, Aspergillus niger, Agrobacterium radiobacter and Bacillus licheniformis were selected for experiments on the microbial improvement of hydraulic fill soil. Specifically, different microbial strains and culture media were added to hydraulic fill soil, and subjected to triaxial shear tests. Then, the specific surface area (SSA), chemical composition and mineral composition of the microorganism-modified soil were measured and analysed. The results show that, the soil samples mixed with all microbial strains, except Aspergillus niger, underwent the reduction of the peak deviator stress, the increase of cohensive force and the decrease of the internal friction angle. The soil samples had similar mineral composition. After the introduction of microbial strains and culture media, the valent cation content and the friction between soil grains of all samples both dropped, leading to a decline in the internal friction angle. The SSA of soil grains added with Agrobacterium radiobacter increased by 49%, while that of soil grains added with Bacillus licheniformis grew by 45%. This is because the strains altered the connection state between soil grains and the soil structure, which enlarged the soil particles and enhanced the cohesive force. The research findings reveal the good effect of microbial technology in the improvement of hydraulic fill soil, and lays a soild basis for the application of the microbial improvement technology.*

RÉSUMÉ. *ÉConsidérant l'effet d'amélioration des sols des métabolites micro-organiques, Aspergillus niger, Agrobacterium radiobacter et Bacillus licheniformis ont été sélectionnés pour des expérimentations sur l'amélioration microbienne des sols en remblayage hydraulique.Plus précisément, différentes souches microbiennes et différents milieux de culture ont été ajoutés au sol de remblayage hydraulique et soumis à des tests de cisaillement triaxial. Ensuite, la surface spécifique (SSA), la composition chimique et la composition minérale du sol modifié par un microorganisme ont été mesurées et analysées.Les résultats montrent que les échantillons de sol mélangés avec toutes les souches microbiennes, à*

l'exception d'Aspergillus niger, ont subi la réduction de la contrainte de déviation maximale, l'augmentation de la force de cohésion et la diminution de l'angle de frottement interne.Les échantillons de sol avaient une composition minérale similaire. Après l'introduction de souches microbiennes et de milieux de culture, la teneur en cations de valence et le frottement entre les grains de sol de tous les échantillons ont tous deux diminué, entraînant une diminution de l'angle de frottement interne.La SSA des grains du sol ajoutés à Agrobacterium radiobacter a augmenté de 49%, tandis que celle des grains du sol ajoutés à Bacillus licheniformis a augmenté de 45%.Cela est dû au fait que les contraintes ont modifié l'état de connexion entre les grains de sol et la structure du sol, ce qui a élargi les particules de sol et renforcé la force de cohésion.Les résultats de la recherche révèlent le bon effet de la technologie microbienne sur l'amélioration du sol de remblayage hydraulique et constituent une base solide pour l'application de la technologie d'amélioration microbienne.

KEYWORDS: *microbial improvement, hydraulic fill, triaxial shear test, osmotic coefficient.*

MOTS-CLÉS: *Amélioration microbienne, remblayage hydraulique, test de cisaillement triaxial, coefficient osmotique.*

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1. Introduction

As a man-made engineering geological body in coastal areas, the dredger fill features high compressibility, low strength and large pore ratio and so on (Yang *et al.*, 2012). The traditional way of processing not only takes a lot of time, but also has no significant effect. The soil is rich in a variety of microbes: bacteria, actinomycetes and fungi. The metabolite having cementation effect precipitated by microorganisms can improve the soil, so that microbial technology is gradually introduced into soil improvement.

Many scholars had done a lot of research on microbial improvement of soil technology. DeJong *et al.*, (2010; 2011; 2013) carried out a series of experimental studies on the engineering properties of microbe reinforced geo materials. Dick *et al.*, (2006) and Hammes *et al.*, (2003) separated 12 urease-producing bacteria such as Bacillus spheroides and Bacillus lentus from soil and calcareous sludge to treat industrial wastewater. They were injected into limestone and form calcium carbonate layer on the surface to repair deteriorated limestone. Chu *et al.*, (2011; 2012) mixed the bacteria separated from iron ore and urea solution to improve the strength and liquefaction resistance of sandy soil, and reduce soil permeability. Other scholars have also done a lot of research work on improving the engineering properties of soil by microorganisms (Chiungwen *et al.*, 2011; Van Paassen *et al.*, 2010). The results show that the use of microbial technology to improve soil has a good effect. What's more, the dredger fill is rich in many kinds of microbes. If the microbial improvement technology can be applied to deal with the dredger fill works, it will be very meaningful.

However, up till now, there are few reports on the effect of microorganisms on the improvement of the dredger fill on the artificial road area. Therefore, three kinds of microbes were selected in this paper. The influence of microorganisms on the

dredger fill soil is discussed through three axis test and seepage test, and the mechanism of improvement is also explored.

Firstly, three strains of Aspergillus Niger, Agrobacterium radioides and Bacillus licheniformis were selected. Then, soil samples of different microorganisms were tested and analyzed. Finally, the improvement mechanism of microorganisms was discussed.

2. Selection of microbial strains and the properties of soil samples

2.1. Selection of microbial strains

Microorganisms mainly use the cementation, filling, adsorption and ionic action between the the bacteria and their metabolites (extracellular polysaccharide and water soluble organic matter (an acid protease)) and the surrounding environment to improve the microstructure characteristics of soil, so as to reduce the pore space between soil particles and enhance the structural strength of soil (Kitamura & Konno, 2002; Marinari *et al.*, 2000; Namkoong *et al.*, 2002), and so on. Through comparative analysis, the strains used in this experiment were mainly determined from the following two points: one is bacillus, which is of the rod shape and can promote the production of calcium carbonate, such as carbonate mineralization bacteria; two is the fungi whose metabolites are polysaccharide (mainly extracellular polysaccharide), such as marine pseudomonas, polysaccharide viscose bacteria. In the end, three strains of Aspergillus niger, Agrobacterium radiobacter and Bacillus licheniformis were tested to investigate their effect on the strength of the dredger fill. The strains used in the experiment are derived from the domestic microbial species preservation center.

2.2 Soil samples

The experimental soil samples were derived from the dredger fill in Guangxi Qinzhou Free Trade Port Area. The particle composition of the dredger fill obtained through test is shown in Tab. 1. The related physical and mechanical properties under 90% compactness (osmosis coefficient, compression coefficient and C, φ value) are shown in Tab. 2.

Table 1. Particle size distribution of hydraulic fill

Particle size/mm	>2.00	2.00~0.50	0.50~0.25	0.25~0.075	0.075~0.05	0.05~0.005	0.005~0.001
Percentage /%	2.53	7.96	2.16	57.08	11.96	15.37	2.94

Table 2. Physical and mechanical properties of silt filling

Water content w /%	Relative density Gs	Density ρ/(g/cm 3)	Maximum void ratio	Minimum void ratio	Permeability coefficient k/(10-5 cm /s)	Compression coefficient av /MPa-1	c /kPa	φ /(°)
25.5	2.68	1.98	1.16	0.42	8.09	0.055	19.6	35.7

3. Test preparation and method

3.1. Preparation of soil sample

Three strains of Aspergillus niger, Agrobacterium radiobacter and Bacillus licheniformis are activated, and then cultured in the medium to 2×108cell·ml-1 (cell·ml-1 indicates the number of cells in each milliliter liquid). As shown in Tab. 3, each 200g soil is mixed with 5ml and 10ml nutrient solution with high concentration of bacteria, and the solution is well mixed with the soil. Sea water is added to the mixture to increase the moisture content in the soil sample to 12%. The mixture is placed in a closed environment at the room temperature and are incubated for 7 days, 14 days, 21 days, 28 days and 35 days respectively. In order to explore whether the acidic protease produced by Aspergillus niger or Bacillus licheniformis can induce the formation of calcium carbonate, Ca^{2+} ions are added to the abovementioned two bacterial strains respectively. The contrast test A is aimed at the soil sample without adding any substance, and the contrast test B is aimed at the soil sample only adding 2mol / L^{-1} $CaCl_2$ and Na_2CO_3 solution only.

Table 3. Soil component configuration table

Strains	Dose/mL
Aspergillus niger	5, 10, 10+
Agrobacterium radiobacter	5, 10
Bacillus licheniformis	5, 10, 10+

Note: "10 mL+" indicates that in addition to adding high concentration culture medium containing bacteria, every 200g dredger fill contains 20 mL 2 mol/L $CaCl_2$ solution and 20 mL 2 mol/L Na_2CO_3 solution.

According to the engineering practice, the relative compaction of the soil sample is 90%, the corresponding dry density is 1.78g·cm^{-3}, and the three-axis test produces cylindrical specimen with a height of 80mm and a diameter of 38mm using the static pressure method. 4 identical samples are prepared for parallel tests in each group.

According to the pre-determined dry density, actual moisture content and ring cutter volume, the amount of wet soil required for penetrating soil samples is calculated, and the soil is divided into two layers using the sampler to achieve the required density. The difference of density of the soil samples in each group is less than $0.01g \cdot cm^{-3}$, and the difference of water content is less than 1%.

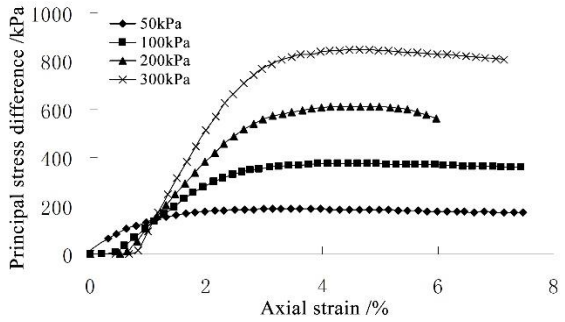
3.2. Test method

The three-axis shear test: The three-axis shear test is carried out under the confining pressure of 50kPa, 100kPa, 200kPa and 300kPa respectively, using the saturated-unsaturated stress path three axis instrument produced by the British GDS Ltd. The control standard of the total deformation of the sample is 15%. When the deviator stress curve of the sample is on the peak, the test can be terminated, and the loading rate is all set as $0.4\ mm \cdot min^{-1}$. During the test, the axial deformation data are automatically obtained through the data acquisition system, and the experimental data are recorded once every 10 seconds.

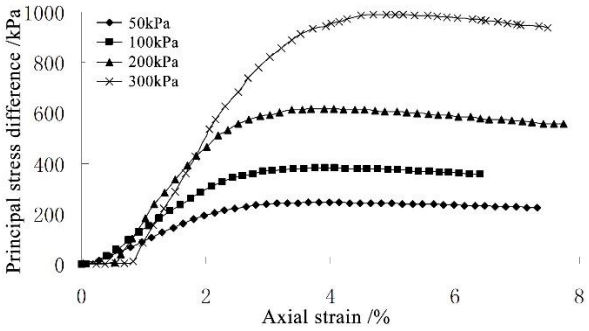
The penetrant test: The ring knives equipped with samples are loaded into the permeable vessel, and then the vessel is sealed without leakage. The sample is saturated with the head of the variable head device. Injection of pure water into the pipe can increase the height of the head to 1m. After the water level is stable, the water inlet pipe clamp is opened to make the water pass through the sample. When the outlet is overflowed, the starting time and the initial height of the water head are recorded. The change of water head and time is recorded according to the scheduled time interval, and the test is repeated 3 times. The test is finished when the permeability coefficient difference is within the allowable range.

4. Analysis of test results

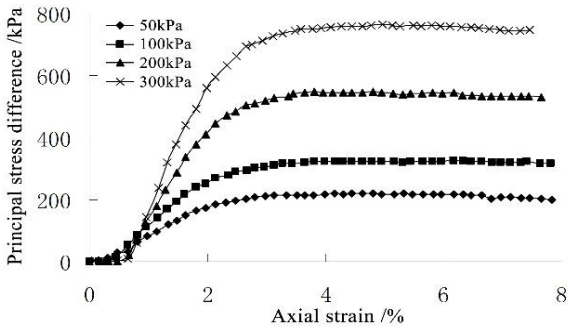
4.1. Analysis of the three-Axis test results



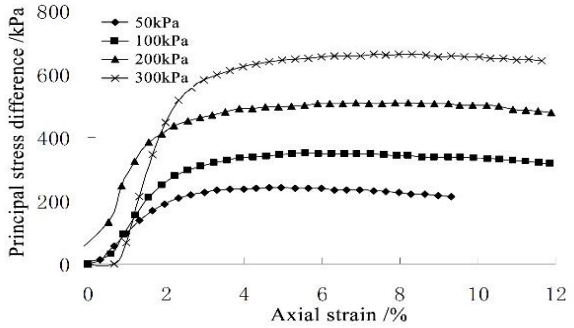
(a) Stress-strain curve of the soil samples mixing 5ml of Aspergillus Niger



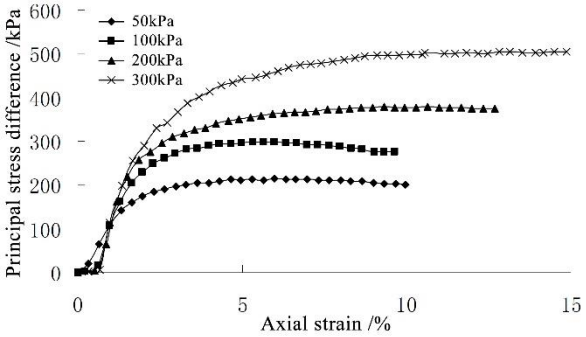
(b) Stress-strain curve of the soil samples mixing 10ml of Aspergillus Niger



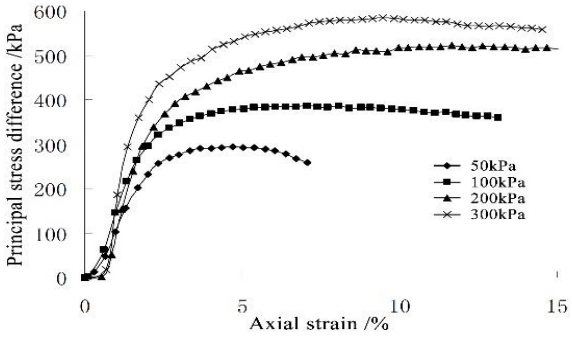
(c) Stress-strain curve of the soil samples mixing 10ml of Aspergillus Niger and ion



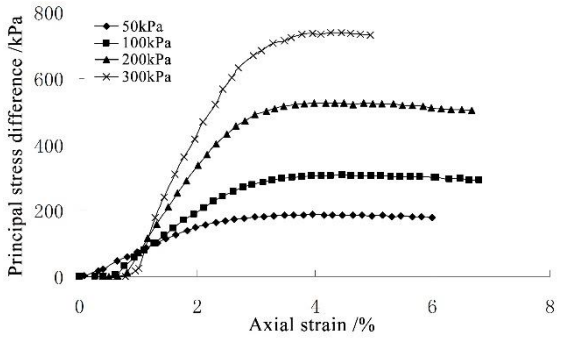
(d) Stress-strain curve of the soil samples mixing 5ml of Agrobacterium radiobacter



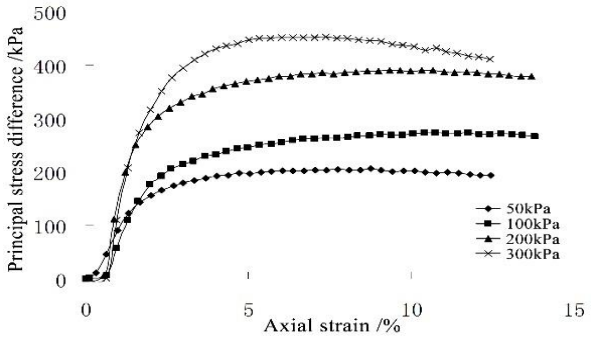
(e) Stress-strain curve of the soil samples mixing 10ml of Agrobacterium radiobacter



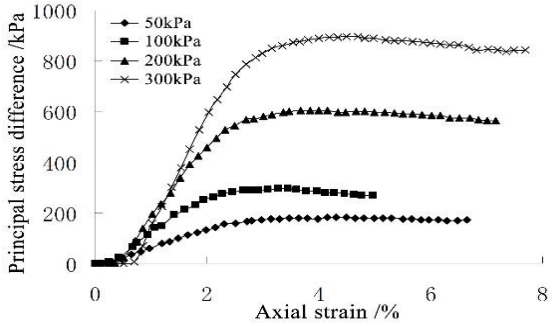
(f) Stress-strain curve of the soil samples mixing 5ml of Bacillus licheniformis



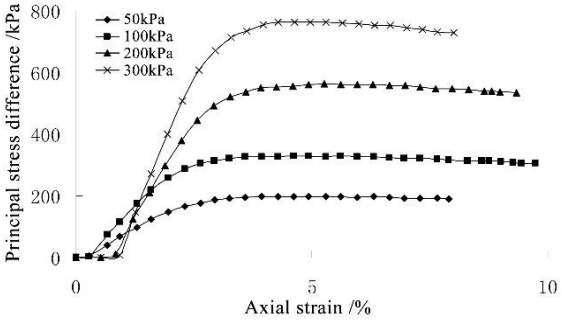
(g) Stress-strain curve of the soil samples mixing 10ml of Bacillus licheniformis



(h) Stress-strain curve of the soil samples mixing 10ml of Bacillus licheniformis+ ion



(i) Stress-strain curve of contrast test A



(j) Stress-strain curve of contrast test B

Figure 1. Relation curve of strain and principal stress difference of soil samples

After he strains are cultured for 7 days, 14 days, 21 days, 28 days and 35 days, the test results of each group are similar. The experimental data of the 35-day

cultivation is analyzed as an example, and the stress-strain relationship curve is shown in Fig. 1.

From the analysis of Fig. 1, it can be concluded that the stress strain curves of the specimens added with different strains under four confining pressures can be divided into three stages: approximately linear elastic deformation stage, elastic-plastic deformation stage and softening failure stage. From the beginning of the test to the time when the axial strain of the specimen reaching about 1%, the principal stress difference caused by the axial strain of each group of specimen is not very different with the increase of confining pressure, which may be due to the full contact between the specimen and the instrument at this stage. When the test is carried out to the initial approximate linear elastic deformation stage, the confining pressure becomes the leading factor of the variation of the principal stress difference. The difference of the principal stress caused by the axial strain of the specimen increases with the growth of the confining pressure, and the peak value of the principal stress difference increases with the rise of the confining pressure.

Under the same confining pressure, the peak value of the principal stress difference of each group remains unchanged with the increase of time. Under different confining pressure, the peak value of the principal stress difference of each sample increases. Under the confining pressure of 50kPa, the difference of the main stress between the samples of each group is small. With the increase of the confining pressure, the peak value of the principal stress difference of the soil sample adding Agrobacterium radiobacter, Bacillus licheniformis and that of the soil sample of contrast test B are lower than that of the contrast test A.

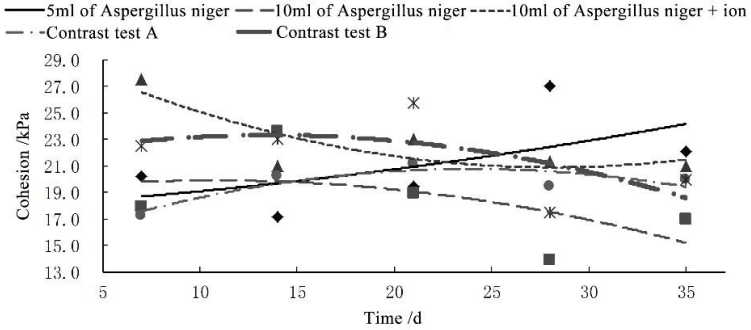
The effect of Aspergillus Niger on the shear strength index of the soil sample is shown in Fig. 2, and it is known from Fig. 2:

1) In the contrast test A, the cohesive force of the untreated soil sample increases first and then decreases, and the internal friction angle remains unchanged. In the contrast test B, the cohesive force of the soil sample only adding ion is decreasing, and the internal friction angle is increasing. The cohesive strength of the soil sample in contrast test B gradually decreased to the level which is close to that of contrast test A, while the internal friction angle of the soil sample in contrast test B is always less than that of the contrast test A.

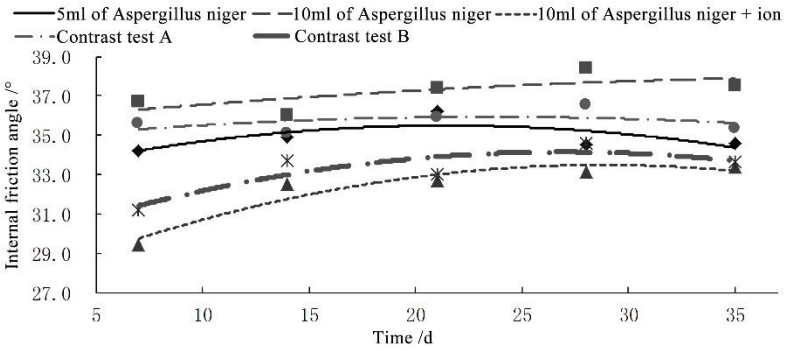
2) The cohesive force of the soil samples mixed with 5ml of Aspergillus Niger presents an increasing tendency. In addition, it gradually becomes greater than the cohesive force of the soil samples in contrast test A and contrast test B as time goes on. The internal friction angle increases first and then decreases, and it is less than the internal friction angle of the soil sample in contrast test A, and is greater than the internal friction angle of the soil sample in contrast test B.

3) The cohesive force of the soil samples mixed with 10ml of Aspergillus Niger presented a declining tendency. It is less than the cohesive force of the soil sample mixed with 5ml of Aspergillus Niger and all contrast test soil samples. The internal friction angle presents an increasing tendency, and the value is the largest in the soil samples with Aspergillus Niger and all contrast tests.

4) The cohesive force of the soil samples mixed with 10ml of Aspergillus Niger + ion is declining. It is greater than the cohesive force of the soil samples mixed with 10ml of Aspergillus Niger and all contrast test soil samples as the time goes on. The internal friction angle is increasing, but its value is the smallest in the samples with Aspergillus Niger and in the samples of all contrast tests.



(a) Trend diagram of cohesive force change



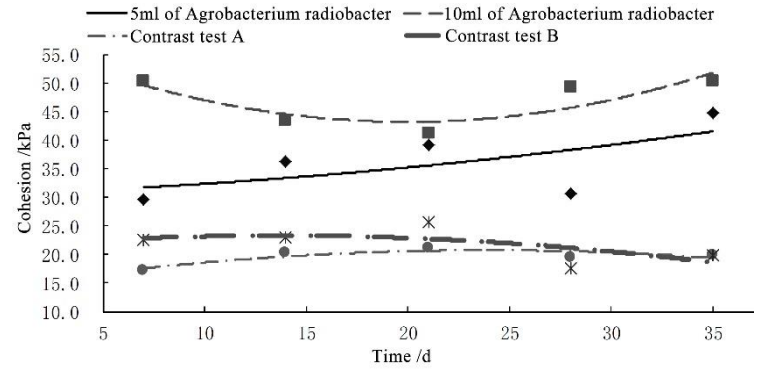
(b) Trend diagram of internal friction angle change

Figure 2. Relation curve between time and cohesion or angle of soil samples with Aspergillus niger

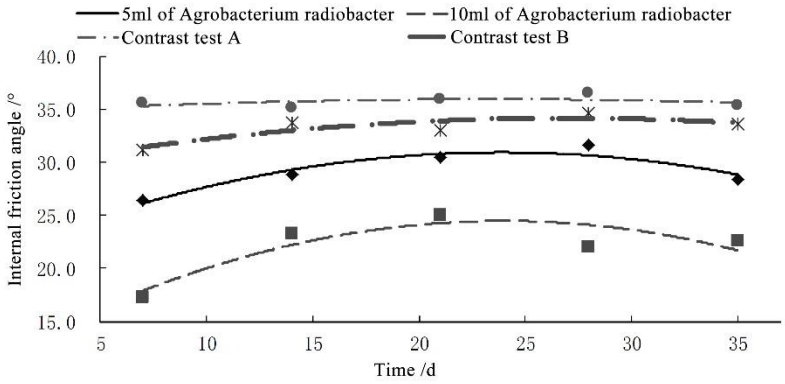
The effect of Agrobacterium radiobacter on the shear strength index of the soil sample is shown in Fig. 3, and it is known from Fig. 3 that:

1) The cohesive force of the soil samples mixed with 5ml of Agrobacterium radiobacter presents an increasing tendency, and is larger than that of all contrast test soil samples. The internal friction angle increases first and then decreases, and is less than that of all contrast test soil samples.

2) The cohesive force of the soil samples mixed with 10ml of Agrobacterium radiobacter is decreases first and then increases. The value is the greatest in the soil samples mixed with Agrobacterium radiobacter and all contrast tests. The internal friction angle increases first and then decreases, and its value is the smallest in the soil samples mixed with Agrobacterium radiobacter and all contrast test soil samples.



(a)Trend diagram of cohesive force change



(b)Trend diagram of internal friction angle change

Figure 3. Relation curve between time and cohesion or angle of soil samples with Agrobacterium radiobacter

3) It is known from the above that the addition of Agrobacterium radiobacter has a significant influence on the shear strength index of soil samples. The cohesive force of the soil increases with the rise of the amount of addition, and the internal friction angle decreases with the increase of the amount of addition.

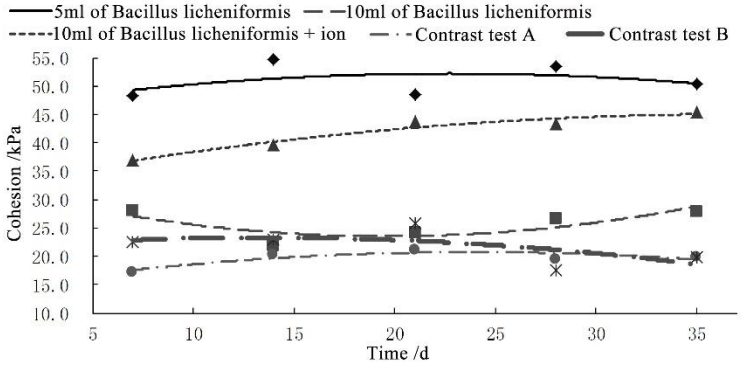
The effect of Bacillus licheniformis on the shear strength index of the soil sample is shown in Fig. 4, and it is known from Fig. 4 that:

1) The cohesive force of the soil samples mixed with 5ml of Bacillus licheniformis basically remains unchanged. The value is the greatest in the soil samples mixed with Bacillus licheniformis and the soil samples in all contrast tests. The internal friction angle decreases first and then increases, and is less than that of the soil sample in all contrast tests.

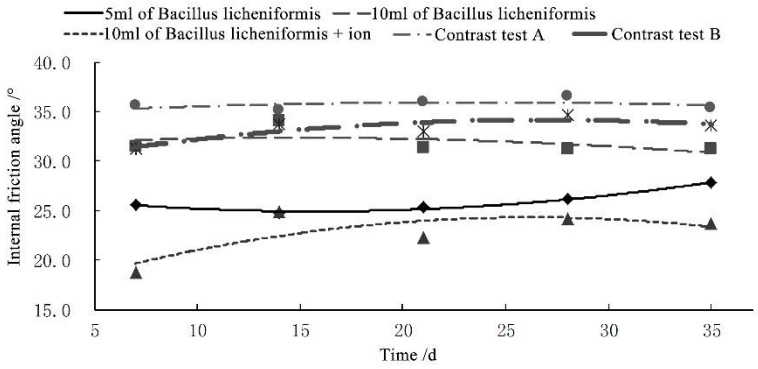
2) The cohesive force of the soil samples mixed with 10ml of Bacillus licheniformis decreases first and then increases. That value of the soil sample with Bacillus licheniformis is the smallest, but it is larger than that of the soil sample in all contrast tests. The internal friction angle is basically unchanged, and its value is the largest in the soil samples mixed with Bacillus licheniformis, but it is less than that of all contrast test soil samples.

3) The cohesive force of the soil samples mixed with 10ml of Bacillus licheniformis + ion is increasing. However, it is less than that of the soil sample mixed with 5ml of Bacillus licheniformis, and is greater than that of all contrast test soil samples and that of the soil sample mixed with 10ml of Bacillus licheniformis. The internal friction angle increases first and then decreases, and its value is the smallest in the soil samples mixed with Bacillus licheniformis and all contrast test soil samples.

4) It is known that the addition of Bacillus licheniformis has a significant effect on the shear strength index of soil samples. After the strain was added, the cohesive force of the soil samples increases and the internal friction angle decreases.



(a)Trend diagram of cohesive force change



(b)Trend diagram of internal friction angle change

Figure 4. Relation curve between time and cohesion or angle of soil samples with Bacillus licheniformis

4.2. Analysis of the penetration test results

The test data of the variable water head permeability test of each sample is shown in Tab. 4, and the following conclusions can be obtained:

1) Compared with the permeability coefficient of the soil samples in contrast test A, the permeability coefficient of the soil samples added with strains, strains and ions and ions all reduced somewhat.

2) The permeability coefficient of soil samples mixed with Aspergillus niger is at the same order of magnitude as that of the soil sample in the contrast test A. Among them, the permeability coefficient of the soil samples mixed with 5ml of Aspergillus niger reduced sharply, and the permeability coefficient of the soil samples mixed with 10ml of Aspergillus niger and of the soil samples mixed with 10 ml of Aspergillus niger + ions decreased less dramatically compared with that of the soil sample in contrast test A.

3) The permeability coefficient of the soil samples added with Agrobacterium radiobacter decreased significantly, and the permeability coefficient of the soil samples added with 10ml of Agrobacterium radiobacter decreased by an order of magnitude compared with the permeability coefficient of the soil samples in contrast test A.

4) The permeability coefficient of the soil samples mixed with Bacillus licheniformis also greatly reduced. The permeability coefficient of soil samples mixed with 5ml of Bacillus licheniformis, 10ml of Bacillus licheniformis + ions decreases by an order of magnitude compared with the decrease of the permeability coefficient of the soil samples in the contrast test A. The decrease of the permeability coefficient of soil samples mixed with 10ml of Bacillus licheniformis

is slight, and remains at the same order of magnitude as that of the soil samples in contrast test A.

Table 4. The variable head permeability test data

Name of soil sample	Sectional area of piezometer a (cm^2)	Time consuming t_2-t_1 (s)	Beginning water head h_1(cm)	Ending waterhead h_2 (cm)	Permeability coefficient k ($\times10^{-5}$cm·s^{-1})	Average permeating coefficients k ($\times10^{-5}$cm·s^{-1})
5ml of Aspergillus niger	0.757	180	90.0	81.7	5.42	5.03
		180	81.7	74.7	5.03	
		180	74.7	68.7	4.64	
10ml of Aspergillus niger	0.757	180	90.0	78.2	7.87	7.70
		180	78.2	68.2	7.61	
		180	68.2	59.5	7.61	
10ml of Aspergillus niger + ion	0.757	180	90.0	78.0	8.00	7.89
		180	78.0	67.7	7.93	
		180	67.7	59.0	7.74	
5ml of Agrobacterium radiobacter	0.717	300	90.0	84.2	2.13	1.98
		300	84.2	79.2	1.98	
		300	79.2	74.6	1.83	
10ml of Agrobacterium radiobacter	0.726	600	91.2	90.3	0.16	0.13
		600	90.3	89.7	0.11	
		600	89.7	89.0	0.13	
5ml of Bacillus lichenifor mis	0.726	600	90.0	88.2	0.33	0.31
		600	88.2	86.6	0.30	
		600	86.6	85.0	0.30	
10ml of Bacillus lichenifor mis	0.757	180	90.0	81.3	5.68	5.59
		180	81.3	73.6	5.55	
		180	73.6	66.6	5.55	
10ml of Bacillus lichenifor mis + ion	0.757	600	90.0	87.5	0.47	0.46
		600	87.5	85.2	0.45	
		600	85.2	82.9	0.46	
Contrast test	0.757	180	90.0	77.5	8.39	8.09

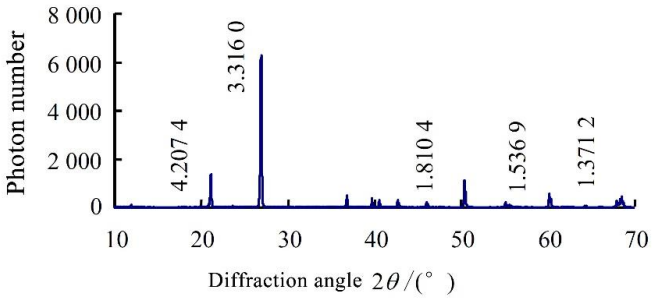
A		180	77.5	67.0	8.13	
		180	67.0	58.3	7.74	
		180	90.0	84.2	3.74	
Contrast test B	0.757	180	84.2	78.8	3.74	3.70
		180	78.4	73.9	3.61	

5. Study on the mechanism of microbial improvement

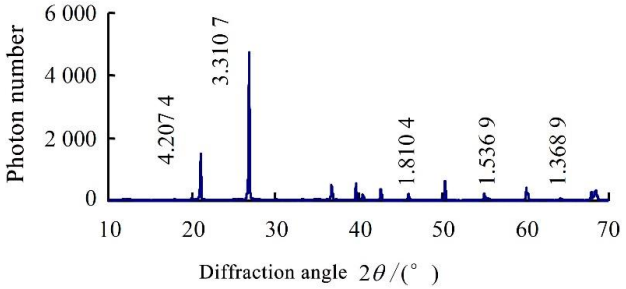
According to the results of the three-axis test, 3 groups of soil samples with the optimal improvement results are selected, including the soil sample mixed with 10 ml of Agrobacterium radiobacter, the soil sample mixed with 5ml of Bacillus lichenif ormis, and the soil sample of contrast test A. The mineral composition, chemical composition and specific surface area of the soil samples are determined.

5.1. Mineral composition

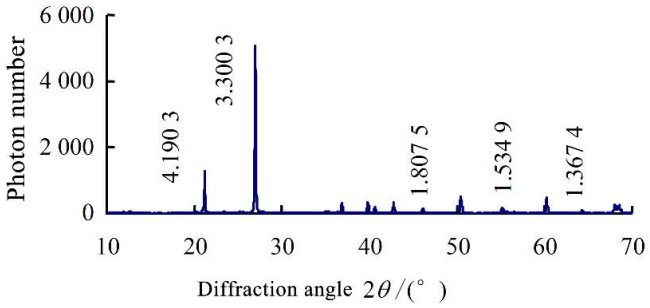
3 groups of prepared soil samples are tested by X ray diffraction, and the diffraction results are shown in Fig. 5.



(a) Contrast test A



(b) Agrobacterium radiobacter



(c) Bacillus licheniformis

Figure 5. X-rays diffraction patterns of three of group soil samples

From Fig. 5, it can be seen that the X ray diffraction characteristic spectrum data of the 2 kinds of soil samples mixed with Agrobacterium radiobacter and Bacillus licheniformis respectively are basically the same with the X ray diffraction data of the soil sample in contrast test A, and there is no obvious change. The main mineral components are quartz and a very small amount of impurities, and the incorporation of microbial strains and its culture medium has no effect on the mineral composition of the dredger fill in a short period of time.

5.2. Chemical composition

The composition and content of cations in the liquid phase of the soil body mixed with different microbial strains and their culture media are tested by Optima 5300DV, produced by America-based Perkin Elmer. The results are shown in Tab. 5.

Table 5. The cation content of soil

Name of soil sample	Cation content /(mg/L)				
	Al3+	Fe3+	Ca2+	Mg2+	K+
10ml of Agrobacterium radiobacter	0.091	0.285	74.16	84.24	37.86
5ml of Bacillus licheniformis	0.022	0.079	79.81	77.94	30.05
Contrast test A	0.128	1.369	68.78	93.94	36.09

From table 4, it can be seen that compared with the contrast test A, the content of cationic of the soil sample mixed with bacilli has greatly reduced, and the reduction of high valence cation in the soil liquid phase will reduce the shear strength of soil. However, after the microbial strains and their culture medium are added, the

metabolites of the strains and the strains can produce cohesive action on soil particles and change the connection state between soil particles. Therefore, the macro effect shows the increase of cohesive force. The main reason for the decrease of the internal friction angle may be that the friction between the soil samples can be reduced after the incorporation of microbial strains and culture medium.

The decrease of permeability coefficient not only results from that the addition of microbial strains and their culture medium changed the porosity characters of the particles in the soil samples, but also is related to the change of cationic components in the soil liquid phase. The decrease of high valence cations will increase the thickness of the diffusion layer of soil and reduce its permeability. Therefore, the decrease of Al3+, Fe3+ and Mg2+ content in soil liquid phase can help to reduce the permeability of soil, and the increase of Ca2+ content and the decrease of K+ content is helpful to increase the permeability of soil. While the sum of the valence reduction of the three ions of Al3+, Fe3+ and Mg2+ is obviously higher than the algebraic sum of the Ca2+ valence increment and the K+ valence decrement. Therefore, the macroscopic effect shows the decrease of the permeability coefficient.

5.3. Specific surface area of soil particles

The specific surface area of the soil particles is one of the main factors that affect the cohesive force of the soil body, and the cohesive force of the soil body increases with the increase of the specific surface area of the soil. In this paper, the specific surface area of the soil samples mixed with different microbial strains and culture medium was measured with the intelligent specific surface tester (SSA-3600) produced by Beijing Biaode Electronic Co. Ltd. and the results are shown in Tab. 6.

Table 6. Specific surface areas of soil particles /(m^2/g)

10ml of Agrobacterium radiobacter	5ml of Bacillus licheniformis	Contrast test A
2.432	2.360	1.627

It can be seen from Table 5 that the specific surface area of the soil particles in the soil samples mixed with Agrobacterium radiobacter and Bacillus licheniformis increased to 1.49 times and 1.45 times respectively, compared with that of the contrast test A. It is due to the cementation, filling and ion effect of the strains and their metabolites after the microbial strains and their culture solution are added to the soil body. It changes the connection state between the soil particles and leads to the increase of soil particles or the change of soil structure makes the specific surface area increase. In chemical composition analysis, it is found that the high valence cations of soil decreased, indicating that the high-valence cations generate new structures in the physical and chemical reactions in soil. This process will lead to the increase of the soil particles or the changes in the structure of the soil, and also explains the reason for the increase of the specific surface area. At the same time, the cohesive force of soil increases with the increase of the specific surface area of

the soil, and the permeability coefficient decreases with the increase of the specific surface area, which also verifies that the cohesive force of soil samples mixed with 10ml of Agrobacterium radiobacter and 5ml of Bacillus licheniformis increases significantly compared with the contrast test A, and the permeability coefficient decreases significantly.

6. Conclusion

This section should clearly state the main conclusions of the research and give a comprehensible explanation of their importance and relevance.

In this paper, the change of shear strength index of the soil body with 3 different strains is studied. Based on mineral composition analysis, chemical composition analysis and soil particle specific surface area measurement, the mechanism of dredger fill biological improvement is studied on the soil samples mixed with 10ml of Agrobacterium radiobacter, 5ml of Bacillus licheniformis and soil samples in the contrast test A. The conclusions are as follows:

(1) After adding the strains, the stress-strain relationship curves of each group of soil samples are similar. The difference between the principal stress and the main stress peak caused by the axial strain increased with the growth of the confining pressure. Under the same confining pressure, the peak value of the principal stress difference of each group remains basically unchanged with the increase of time. Under different confining pressure, the peak value of the principal stress difference of each sample increases. With the increase of the confining pressure, the peak value of the principal stress difference of samples mixed with Agrobacterium radiobacter and Bacillus licheniformis and of the samples in contrast test B decreases somewhat compared with that of test A.

(2) After incorporation of bacilli, the shear strength index of the soil samples has a significant change. After Aspergillus niger is added, there is no obvious change in the cohesive force and the internal friction angle of the soil sample. With the addition of Agrobacterium radiobacter, the cohesion of the soil samples increases with the rise of the strains and culture medium, and the internal friction angle decreases with the increase of the strains and culture medium. After Bacillus licheniformis is added, the cohesive force of the soil samples increases somewhat and the internal friction angle decreases somewhat.

(3) After the strains and ions are added, the permeability coefficient of the soil samples in each group weakens somewhat compared with that of the contrast test A. The permeability coefficient of three groups of soil samples mixed with 10 ml of Agrobacterium radiobacter, 5ml of Bacillus licheniformis and 10ml of Bacillus licheniformis + ions greatly declined, dropping down by an order of magnitude compared with that of the contrast test A.

(4) After different microbial strains and culture medium are added, the high valence cations in the liquid phase of the soil decrease greatly, resulting in the decrease of the permeability coefficient. However, after incorporation of the

microbial strains and its culture medium, the metabolites of the strains and the strains can produce cohesive action on soil particles and change the connection state between soil particles. Therefore, the macro effect is the increase of cohesive force. The main reason for the decrease of the internal friction angle is that the friction between the particles in the soil samples is reduced after the incorporation of microbial strains and culture medium.

(5) After incorporation of bacilli, the specific surface area of the particles in the soil samples increases, because the incorporation of microbial strains and their culture fluid into the soil changes the connection state between the soil particles, resulting in the increase of soil particles or the change of soil structure. At the same time, the cohesive force of soil increases with the growth of the specific surface area of the soil, and the permeability coefficient decreases with the increase of the specific surface area of the soil particles.

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References

Chou C. W., Eric S., Asce A. M., Ahmet H. A. (2011). Biocalcification of sand through ureolysis. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, Vol. 137, No. 12, pp. 1179-1189. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000532

Chu J., Ivanov V., He J., Naeimi M., Li B. (2011). Development of Microbial Geotechnology in Singapore. *Geotechnical Special Publication*, No. 211, pp. 4070-4078.

Chu J., Stabnikov V., Ivanov V. (2012). Microbially induced calcium carbonate precipitation on surface or in the bulk of soil. *Geomicrobiology Journal*, No. 29, pp. 544-549. https://doi.org/10.1080/01490451.2011.592929

DeJong J. T., Mortensenb B. M., Martinez B. C., Nelson D. (2010). Biomediated soil improvement. *Ecological Engineering*, No. 36, pp. 197-210. https://doi.org/10.1016/j.ecoleng.2008.12.029

DeJong J. T., Soga K., Banwart S. A., Whalley W., Ginn T., Nelson D., Mortensen B., Martinez B., Barkouki T. (2011). Soil engineering in vivo: Harnessing natural biogeochemical systems for sustainable, multi-functional engineering solutions. *Journal of the Royal Society, Interface*, No. 8, pp. 1-15. https://doi.org/10.1098/rsif.2010.0270

DeJong J. T., Soga K., Kavazanjian E., Burns S., Van Paassen L. A., Al Qabany A., Aydilek A., Bang S. S., Burbank M. (2013). Biogeo-chemical processes and geotechnical applications: progress, opportunities and challenges. *Geotechnique*, No. 63, pp. 287-301.

Dick J., De Windt W., De Graef B., Saveyn H., Van Der Meeren P., De Belie N., Verstraete W. (2006). Bio-deposition of a calcium carbonate layer on degraded limestone by Bacillus species. *Biodegradation*, Vol. 17, No. 4, pp. 357-367. https://doi.org/10.1007/s10532-005-9006-x

Hammes F., Boon N., De Villiers J., Verstraete W., Siciliano S. (2003). Strain-specific ureolytic microbial calcium carbonate precipitation. *Applied & Environmental*

Microbiology, Vol. 69, No. 8, pp. 4901-4909. https://doi.org/10.1128/AEM.69.8.4901-4909.2003

Kitamura M., Konno H., Yasui A., Masuoka H. (2002). Controlling factors and mechanism of reactive crystallization of calcium carbonte polymorphs from calcium hydroxide suspensions. *Journal of Crystal Growth*, Vol. 236, No. 1-3, pp. 323-332. https://doi.org/10.1016/S0022-0248(01)02082-6

Marinari S., Masciandaro G., Ceccanti B., Grego S. (2000). Influence of organic and mineral fertilizers on soil biological and physical properties. *Bioresesource Technology*, Vol. 72, No. 1, pp. 9-17. https://doi.org/10.1016/s0960-8524(99)00094-2

Namkoong W., Hwang E. Y., Park J. S., Choi J. K. (2002). Bioremediation of diesel-contaminated soil with composting. *Environmental Pollution*, Vol. 119, No. 1, pp. 23-31. https://doi.org/10.1016/S0269-7491(01)00328-1

Van Paassen L. A., Daza C. M., Staal M., Sorokin Dvan der Zon Wvan Loosdrecht M (2010). Potential soil reinforcement by biological denitrification. *Ecological Engineering*, Vol. 36, No. 2, pp. 168-175. https://doi.org/10.1016/j.ecoleng.2009.03.026

Yang P., Tang Y. Q., Wang J. X., Yang Y. (2012). Test on consolidation of dredger fill by cube grid of plastic drain board preinstalled. *Engineering Geology*, Vol. 127, pp. 81-85. https://doi.org/10.1016/j.enggeo.2012.01.004