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An Experimental Comparative Study on Improvement Technology of the Subgrade Filling Expansive Soil

WANG XIN-ZHENG[1] AND ZHANG JIAN[2]

[1]*School of Civil Engineering, Nanyang Normal University, Nanyang 473061, China*

[2]*School of Civil Engineering, Nanyang Normal University, Nanyang 473061, China*

Email: *zhangjian9945016@126.com, wxz791023@126.com*

Abstract: Improvement of the expansive soil is one of the vital issues in the field of subgrade engineering. This paper is based on the test section of Xi'an-Nanjing double track engineering, respectively adopt quick lime and cement as expansive soil improvers, adopts quick lime and cement as expansive soil improvers ,conducts a study on the swell-shrinking property, strength characteristics and strength change law under drying and wetting cycles of NanYang expansive soils. The results show that the lime-improved expansive soil and cement-improved expansive soil can also effectively reduce the swell-shrinking property of expansive soils, which strength can reach the requirement of subgrade filling engineering. The lime-improved expansive soil has better effect in the shearing characteristics, compaction characteristics, permeation characteristics and the ability to lower expansibility than the cement-improved expansive soil. But the cement-improved expansive soil possesses better characteristic of strength reduction after drying and wetting cycles than the lime-improved one. The lime resource is more abundant and the price is cheaper than cement in NanYang city. So the lime-improved expansive soil is one of the most effective and economic method for improvement of the expansive soil.

Keywords: *Expansive Soil; Subgrade Improvement; Shear Characteristics; Expansion; Wetting-drying Cycle*

1. Introduction

As a type of high plastic clay, Expansive soil is composed of a great deal of strong hydrophilic clay minerals, such as montmorillonite and illite, it has much character, such as expansive construction, many cracks, strong expansive and contraction, intensity decadence. Expansive soils are often mistaken as ideal materials for engineering filler because of the high strength and low compressibility under solid state or the state of rigid plastic[1-6]. However, as water content changes, inner soil structure is damaged, which will decrease strength abruptly and increase compressibility. In railway construction, expansive soils will not only affect the schedule of engineering construction, but also cause adverse geological events frequently to the embankment or cutting that contains them, such as severe pavement cracks and side slope subsidence. Thus, during engineering construction, road sections with expansive soils should be avoided as much as possible to reduce unnecessary trouble. However, for areas lack of filler or with wide distribution of expansive soils, improved expansive soils are a need in engineering works. Entailing improvement methods have been researched scientifically in quantity, and many relative theoretical and practical achievements have been obtained. Considering great differences in soil components and expansibility for expansive soils in various areas, instead of referring to design standards in other areas, local improvement methods have to be developed in combination with local engineering conditions and experimental verification. Thus, with the aid of new theories and new methods in modern science and technology, the conduction of specific improvement tests for expansive soils is of great significance to guarantee smooth construction and lasting construction safety.

1.1 Research status of the improvement methods for expansive soils:

The improvement methods for expansive soils have long been concentrated on addition of improvers such as lime and cement or on structural improvement. Many scholars have researched on the improvers. Li Sheng-lin et al[7] studied mainly physical indices of lime-improved expansive soils, including strength, free swelling rate, liquid limit, and plastic index. They also explained the reason why expansive soils gained better properties from the perspective of chemical reaction mechanism. The cement-improved method is similar to the lime-improved, underwent detailed analysis by Huang Bin-ping et al. in Yangtze River Scientific Research Institute [8]. Improvement methods with other improvers (such as NCS, H_24 and other high polymer materials) are currently at the trial stage. Despite the immature technology, But its application is very wide. In light of structural improvement, the reinforcement mechanism of geotechnical materials (such as geotextile and geogrid) was studied by staff in Southeast University and in Tianjin University by similar material simulation test on pits and MTS triaxial test. With tests on the actual stress conditions by sensors, researches in Tongji University are focused on application of geotechnical materials.

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1.2 Prevailing key problems in research on expansive soil improvement:

Prevailing key problems in research and manufacture of improved expansive soil scan be summarized in the following aspects:

(1)Despite the large number of improvement methods for expansive soil filler, each of them is limited by certain application conditions. It is a need to further verify application of the above methods to find optimized method systems for improvement technologies as normative instructions for engineering practice [9].

(2)CBR value remains to be used as the assessment index for quality assessment on improved expansive soils. CBR test requires the compaction to be done on the condition of optimal water content, after which the tested soils are immersed in water for as long as four days. However, in real situations, few stretches of expansive soils are immersed in water for such long time. Thus, it is reconsideration for CBR value as the assessment index.

(3)Despite the large number of improvement methods for expansive soil filler, there is only a little comparison of their improvement effects. The paper conducted laboratory tests to compare the effect of lime-improved expansive soil and that of cement-improved expansive soil. The results provide references for proper choice of improvement materials in engineering practice [10-13].

2. Engineering background:

The total length of Zhengzhou section for the 2nd-phase Xi'an-Nanjing double track engineering is 315.32km. It passes through nine counties and districts in Shan Xi, HeNan and Hu Bei province from west to east. The primary special soil types along the rail line are expansive soils and soft soils. Expansive soils are distributed mainly in Nan Yang Basin. The physical indexes of expansive soil in Nan Yang are as follows: the natural water content is in between 15.8% and 31.4%, with the average value of 22.8%; clay particle content is in between 37.5% and 54.3%, with the average value of 43.1%; liquid limit is in between 40.6% and 54.1%; free swelling rate is in between 38.5% and 51%, with the average value of 47.5%; cation exchange amount is in between 7 and 20%, with the average value of 13.3%; the content of montmorillonite is in between 171.83mmol/kg and 364.85mmol/kg, with the average value of 223.3mmol/kg. According to geotechnical trial materials, the expansibility of NanYang soils is medium. Trial soils are extracted from WangCun village, NanYang city. Physical properties of the soils are shown in Table 1:

Table 1: *Basic physical properties of soil samples*

Natural Density (g/cm3)	Natural Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasti-city Index	Maximum Dry Density (g/cm3)	Free swelling Ratio (%)	Optimum Water Content (%)
1.96	23.4	49.3	25.7	28.7	1.78	47	17.5

The laboratory test researched on the swell-shrinking property, strength characteristics and strength decreased characteristics under drying and wetting cycles of plain soils and improved expansive soils (lime, cement). By comprehensively analyzing test data, it aimed to determine the optimal improvement scheme as a basis for improvement schemes of pavement expansive soil filler [14-15].

Tests for this research contained physical property test, compaction test, permeation test, consolidation test, consolidated quick shear test, and test for drying and wetting cycles. Slaked lime was used for the tests. The total content ratio of CaO and MgO exceeded 70%. The tests used ordinary Portland cement with the final setting time of 6.5h and the strength grade of 32.5.

3. Laboratory CBR Test:

3.1 Compaction test:

After lime was incorporated into expansive soils, the entailing actions of ion exchange, carbonation, cementation and crystallization enhanced stability of expansive soils. Figure 1 shows the relationship curves of the compaction characteristics and the ratio of added lime. As can be seen, after the lime is incorporated, with the increase of the lime rate, the optimal water rate increases from 17.5% to 19.2%, which is because physiochemical reactions between lime and expansive soils require certain amount of water. The maximum dry density decreases from $1.78g.cm^{-3}$ to $1.656\ g.cm^{-3}$, which is because the relative density of lime particle is smaller than that of expansive soil particle.

After cement was incorporated into expansive soils, the expansibility of tested soils was improved effectively due to the entailing actions of ion exchange, aggregation, hardening reaction and carbonation reaction. Figure 2 shows the relationship curves between the compaction characteristics and t the ratio of added cement as can be seen, as the cement incorporation amount changes, the change of the optimal water content and maximum dry density of the samples is small and disordered. Therefore, it is not qualified to serve as basis for optimal cement fitting ratio in engineering practice.

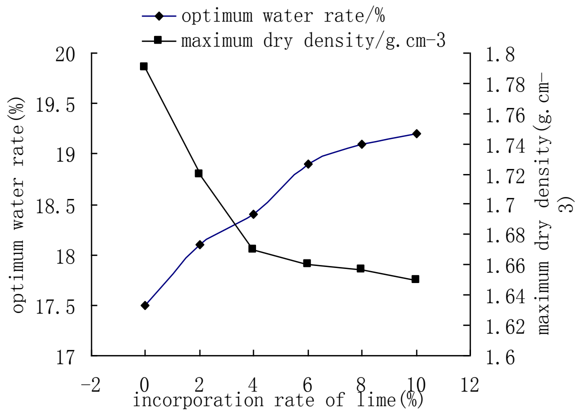

Figure 1:*The relationship curves of the compaction characteristics and the ratio of added lime*

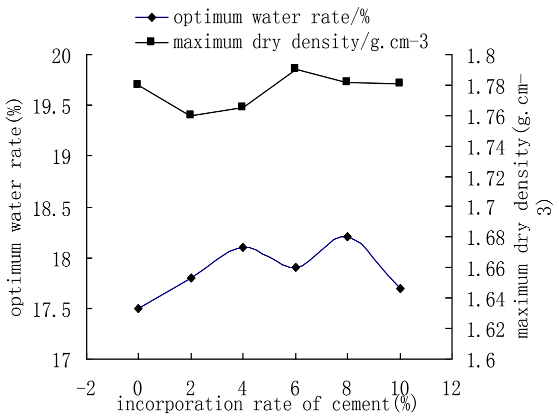

Figure 2: *The relationship curves of the compaction characteristics and the ratio of added cement*

3.2 CBR test after lime incorporation

As CBR test goes, the soil sample is sifted by a 5mm sieve. For the water ratio, the optimal water ratio obtained in the compaction test is used. Add to the soil samples 2%, 4%, 6%, 8%, and 10% lime and cement respectively. Stuffy material 12-24h. 4 days later, the sample is taken out for permeation tests. Test data is shown in Table 2.

As can be seen, CBR value for plain soils was low, but the value jumped after cement or lime was incorporated in the soil. This shows that cement and lime can both improve engineering characteristics of expansive soils effectively. Table 2 shows that the CBR value increases as the lime rate increases, but it is not a nonstop trend. The CBR value at 8% lime rate is bigger than that at 10%, thus the improvement effect of lime is not in positive proportion to lime amount. Surely the above data merely reflect the bearing ratios within four days of lime incorporation, and the bigger optimal water content for samples with 8% lime rate facilitates reactions between lime and soil particles. In terms of cement-improved samples, the CBR values gradually increase as cement rates increase. However, the increase becomes slower over and above 6% cement rate, and the improvement effect is unapparent as well.

Table 2: *CBR test results*

Lime ratio/%		CBR Value on 95% degree of compaction (%)	CBR Value on 98% degree of compaction (%)
lime	2	42.4	55.2
	4	70.8	90.5
	6	127.4	139.2
	8	141.5	172.8
	10	134.2	168.4
cement	2	37.1	39.4
	4	67.7	78.2
	6	121.3	133.2
	8	135.4	141.6
	10	136.7	143.2

4 Research on shearing characteristics of the filler:

4.1 Test scheme:

To understand the influence of natural water contents and water cement ratios on properties of improved expansive soils, the paper conducted consolidated quick shear test on improved expansive soils. First, samples with different water contents and different lime rate were prepared by heavy compaction. Next, expansion test and the consolidated quick shear test were done with the aim of figuring out relationships between different factors. The water contents of the samples were controlled at 12%, 14%, 16% and 18% respectively.

4.2 Shearing test characteristics and analysis:

Indices for the shearing test on plain soils are shown in Figure 3 and Figure 4. As can be seen, the strength of the original soil is higher than that of the tested one. The reason is that the original soil structure sequence tends to be stable under long-time geological process, and there is certain cementation among original soil particles; while the cementation among tested soil particles is damaged to a certain degree, which in turn lowers soil strength, leading to decrease of friction angle and cohesive force. Water content change influences soil strength mainly by changing cohesive force. The increase of water content decreases friction angle, but in amplitude far smaller than that of cohesive force reduction.

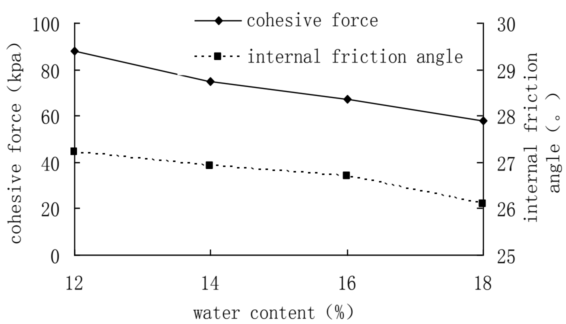

Figure 3: *The relationship between water content and strength of original plain soil*

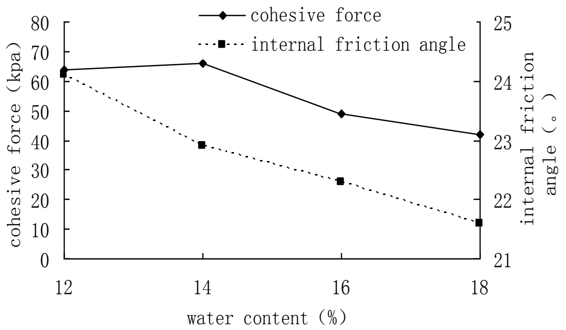

Figure 4: *The relationship between water content and strength of compacted plain soil*

Cement and lime are added separately to the expansive soils in the proportion of 2%, 4%, 6%, 8% and 10%, respectively. After 7 days' maintenance, both the strength rises significantly. The cohesive force and friction angle of the two types of improved soils gradually increase. The larger the incorporation rate is, the more obvious the amplitude is. These phenomena show that the properties of lime-improved expansive soils and cement-improved expansive soils have changed in the process. The test results are shown in Table 3 and Table 4. As there is less CaO and more MgO in the cement than in the lime, the strength growth and reaction rate of cement-improved expansive soils are slower than those of lime-improved expansive soils.

As seen from Table 3 and Table 4, there are consistent influence trends of water content on strengths of lime-improved expansive soils and cement-improved expansive soils. Other things being equal, as the water content increases, strength growth of improved soils accelerates correspondingly, which is because certain water is required for reactions between lime/cement and soil, and high water content is thus conducive to such reactions. From the tests, a 2~4% height of water content than the optimal one for compacted soils facilitates strength growth. During practical construction, 6% height will cause the soil to be in soft plastic condition that is hard to be compacted well. Also, the soil will deform greatly and crack due to water loss after engineering rolling, bringing damage to side slopes or uneven precipitation to the embankment. Therefore, on the premise that the strength can be guaranteed for lime-improved expansive soils and cement-improved expansive soils, the water content should be under 6% height than the optimal one for compacted soils, which is easy to realize in real engineering work.

Table 3: *Strength of lime-improved expansive soils (7d maintenance)*

water content / lime rate	12%		14%		16%		18%	
	c	φ	c	φ	c	φ	c	φ
2%	118	31.4	122	33.2	138	34.6	142	34.8
4%	123	33.3	132	37.5	148	36.3	160	37.2
6%	138	34.9	142	37.8	152	38.2	167	36.8
8%	141	35.6	149	37.2	152	39.0	171	37.2
10%	142	36.1	148	38.1	155	39.7	177	39.9

Table 4: *Strength of cement-improved expansive soils (7d maintenance)*

water content / cement rate	12%		14%		16%		18%	
	c	φ	c	φ	c	φ	c	φ
2%	91	28.4	95	29.3	109	30.2	111	31.2
4%	102	31.2	105	33.2	115	35.6	127	34.0
6%	108	32.1	112	34.9	127	35.5	142	36.3
8%	111	35.2	121	36.8	152	40.2	160	37.8
10%	122	35.7	131	36.8	157	40.2	163	37.8

5 Analysis on expansibility:

Compared to unimproved soils, swelling and deformation of lime-improved expansive soils and cement-improved expansive soils are effectively inhibited. The relationships between swelling amount and water content for lime-improved expansive soils and cement-improved expansive soils are shown in Figure 5 and Figure 6. The overall trend for them is that the swelling amount decreases gradually as the water content of the prepared samples increases. As the water content increases from 12% to 18%, the swelling amount of improved expansive soils with 2% lime ratio from 4% to 2.6%, and the swelling amount of improved expansive soils with 6% cement turns from positive to negative. On the case that the mixing amounts are the same with each other, the swelling amount of lime-improved expansive soils are higher than that of cement-improved expansive soils, and the swelling trend as water contents change of lime-improved expansive soils is similar to that of cement-improved expansive soils. From the perspective of swelling amount, the higher the water content of soils, the smaller the swelling amount. From the perspective of experimental data and existing engineering data, the optimal water content for local pavement filler should be around 16%.

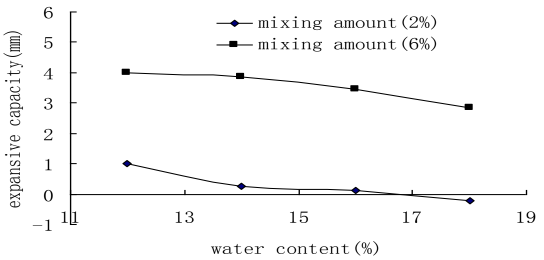

Figure 5: *The relationship between swelling amount and water content for lime-improved expansive soils*

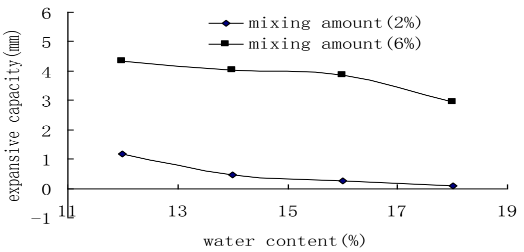

Figure 6: *The relationship between swelling amount and water content for cement-improved expansive soils*

The results show that when mixing amount of cement or lime is small, the higher water content exerts great significant on expansion; and when mixing amount of cement or lime is large, the higher water content exerts small significant on expansion. The water content at 16% marks the turning point of effects between water contents and mixing amounts. For soil samples with 2% lime or cement, when the water content is larger than 16%, the influence of water contents on swelling amounts is significant. For soil samples with 6% lime or cement, when the water content is larger than 16%, the influence of water contents on swelling amounts is insignificant. Thus, under the same condition, the more lime or cement is added to expansive soils, the faster chemical reactions will be[15]. During construction, when soil strength needs to grow faster, it is considerable to increase the mixing amount of lime or cement.

6 Tests on drying and wetting cycles of improved expansive soils:

In natural states, the improved expansive soils are in an environment of drying and wetting cycles. Internal water contents change constantly during drying and wetting cycles, when the soil mass swells and shrinks repeatedly and soil strength changes as well. Therefore, it is a necessary for us to undertake tests on drying and wetting cycles of improved expansive soils, aiming at comparing the influence of drying and wetting cycles on the strength of improved expansive soils. We chose the soil sample to be with 8% lime and cement respectively, 16% water content, with 28 days' maintenance. The change scope of water contents for drying and wetting cycles was from 10% to 30%. After 5 times of drying and wetting cycles, soil strength was measured by the triaxial shearing test with no consolidation and no water discharge, and the results for soil strength under different drying and wetting cycles were obtained.

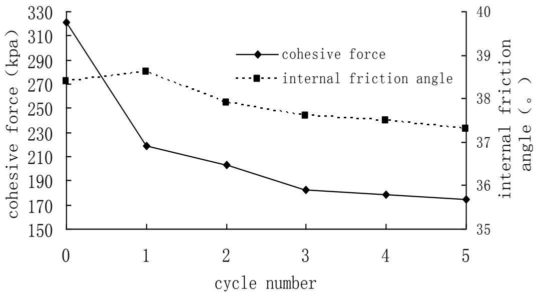

Figure 7: *The relationship between lime soil strength parameters and cycle numbers*

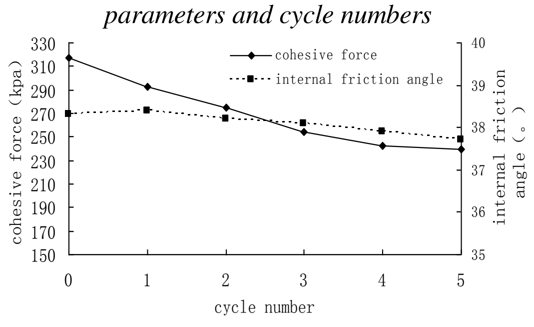

Figure 8: *The relationship between cement soil strength parameters and cycle numbers*

As can be seen, after 28 days' maintenance, the strength value of improved expansive soils increase significantly in comparison with the value at Seventh days. With the increase of cycle numbers, the friction angle first increases and then decreases. After one drying and wetting cycle, the friction angle in either lime-improved expansive soils or cement-improved expansive soils increases by different amplitude. The main reason is that the damaged soil structure during the cycle entails decrease of cementation between soil particles, so clay particles are combined into greater aggregation mass. At the second cycle, friction angles begin to decrease, whose reason is that soil fracture starts to emerge after two cycles, and the interaction force between soil particles is weakened; also, great changes happen to soil water distribution, soil duct distribution and soil particle sequence. Overall, the decreasing amplitude of friction angles for lime-improved expansive soils is greater than that for cement-improved expansive soils.

The increasing cycle numbers lead to decreasing cohesive force of sample soils. During the cycles, cohesive force for the lime-improved expansive soils decreases greatly after one cycle and slightly after 2 cycles, while cohesive force for the cement-improved expansive soils also decreases as cycle numbers increase, but with smaller amplitude. At the 4th or 5th cycle, a new balance state form for the soil and the change of cohesive force tends to be stable.

As seen from the tests, on the whole, the resistivity against strength attenuation that is brought by drying and wetting cycles for the cement-improved expansive soils is stronger than that for the lime-improved expansive soils. However, engineering cost will soar if cement is used for expansive soil improvement.

7. Conclusions

If railway construction is done in expansive soil areas, improvement shall be done of expansive soils. The paper undertook deep and systematic research on property improvement technologies of expansive soils as railway pavement filler, and obtained the following achievements:

(1)The laboratory tests show that the strength of improved expansive soil(lime or cement) can reach the requirement of subgrade filling engineering. The lime-improved expansive soil has higher strength than the cement-improved expansive soil. The lime is more abundant and at a lower cost than cement in NanYang city. Thus, from the perspective of economy and applicability, the lime-improved expansive soil is one of the most effective and economic methods for improvement of expansive soils.

(2)The water content for improved expansive soil filler is allowed to be 2~4% higher than the optimal water content, but too high water content should be avoided. Determination of lime amount is supposed to refer to practical conditions. Specifically, the lime amount should be higher if the soil strength is demanded to grow rapidly, and be lower if construction time is enough. If the main aim is to improve soil strength, it can be achieved alternatively by increasing lime amounts, improving water content, or prolonging reaction time. For real construction, it is supposed to find the optimal point among the three alternatives according to practical situations.

(3)The expansibility of improved expansive soils is limited to a certain degree. Notwithstanding, drying and wetting cycles will also cause strength attenuation for soils under cyclic loading. Under the condition of drying and wetting cycles, the expansive amount will gradually decrease as cycle numbers increase. After three or four cycles, the internal friction angle and cohesive force of the soil tend to remain stable, but the swell-shrink rate keeps accelerating. According to analysis of experimental data, the resistivity against strength attenuation that is brought by drying and wetting cycles for the cement-improved expansive soils is stronger than that for the lime-improved expansive soils.

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