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Study on Improvement Technology for Subgrade Filling of Silty Loess in Inner Mongolia

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Abstract. This study focused on the issue of deficient quality of large distributed salty loess between Ranching to Wuhan Expressway in Inner Mongolia, with a total distance of 60.2km. The empirical study adopted five indices to examine the quality of salty loess, including critical water content, particle composition, maximum dry density and optimum water content, California Bearing Ratio (CBR), and resilient modulus respectively. The test results proved that the indices such as CBR and resilient modulus of the loess with silt content up to 80% can meet the needs of the standard through the improvement of inorganic binder. This new approach can expand the usability of salty loess. Additionally, this study proposed some suggestions about how to use improved salty loess in roadbed via the method of layered construction with the aim of ensuring quality of constructions.

1. Introduction

Salty loess refers to loess with plastic index between 6 and 17[1]. The loess is widely distributed in Inner Mongolia. Because its silt content can be as high as 80%, which is far beyond the range of 45% ~ 65% of the normal loess content [2], it is difficult to be compacted in construction. Because of its low strength and poor engineering properties, it usually needs to be improved. According to 9 samples of salty loess distributed in the 60.2 km section of Ranching to Wuhan Expressway in Inner Mongolia, five indices of critical water content, particle composition, maximum dry density and optimum water content, CBR, and resilient modulus were tested and studied. By adding 5% lime, the indices such as CBR and modulus of resilience meet the needs of the standard, thus the salty loess are used. And the purpose of saving resources and reducing the cost of the project has been realized.

2. Raw salty loess test

Because the soil in 9 fields along the expressway is fine grained soil, according to Specifications for Design of Highway Subgrade [3], the main technical indices of fine grained soil as subgrade fillers are critical water content, particle composition, maximum dry density and optimum water content, Brand modulus of resilience. Corresponding to these indices, five tests were carried out in accordance with Test Methods of Soils for Highway Engineering [4]: critical water content test, particle analysis test, heavy compaction test, CBR test and resilient modulus test. All test results are as follows:

(1) Critical water content test and particle analysis test

Table 1. Critical water content test

Test number	Sampling spot	Liquid limit (%)	Plastic limit (%)	Plasticity index
LJ1	K3+100	30.0	16.5	13.5
LJ2	K11+490	29.3	19.0	10.3
LJ3	K20+300	28.4	18.2	10.2
LJ4	K24+800	30.2	20.7	9.5
LJ5	K30+400	30.4	21.9	8.5
LJ6	K35+400	29.9	20.1	9.8
LJ7	K44+580	28.9	18.7	10.2
LJ8	K56+820	28.2	21.3	6.9
LJ9	K59+030	27.7	22.2	5.5

Table 2. Particle analysis test

Test number	Sampling spot	Percent of total mass(%) for each of the following particle sizes(mm)					
		5~2	2~0.5	0.5~0.25	0.25~0.075	0.075~0.002	<0.002
LJ1	K3+100	0	0.7	0.4	38.3	55.9	4.7
LJ2	K11+490	0	0.10	0	9.7	80.3	9.9
LJ3	K20+300	0	0	0	7.0	80.4	12.6
LJ4	K24+800	0	0	0	30.4	61.9	7.7
LJ5	K30+400	0	0.2	0.1	37.9	54.3	7.5
LJ6	K35+400	0	0	0	9.2	80.4	10.4
LJ7	K44+580	0	0	0	15.6	74.3	10.1
LJ8	K56+820	0	0	0	3.4	84.6	12.0
LJ9	K59+030	0	0	0	39.4	55.1	5.4

The test results of the critical water content in Table 1 show that the plasticity indices of 9 samples are between 6 and 17, and belong to typical salty loess. From the analysis of grain composition in Table 2, it can be seen that the silt content of 9 samples is over 50%, of which 4 samples contain more than 80%silt particles, and the content of silt particles is extremely high, which is difficult to be compacted in subgrade engineering.

(2) Heavy compaction test

The optimum water content is the main index to control the compaction of subgrade fillers, and the maximum dry density is the benchmark to evaluate the compaction degree and the control index of specimen molding in laboratory. The maximum dry density and optimum water content are obtained by heavy compaction test, and the results of heavy compaction test for 9 samples are shown in Table 3.

Table 3. Heavy compaction test

Test number	Sampling spot	Maximum dry density (g/cm3)	Optimum water content (%)
LJ1	K3+100	1.95	12.2
LJ2	K11+490	1.81	12.2
LJ3	K20+300	1.83	11.1
LJ4	K24+800	1.89	10.0
LJ5	K30+400	1.71	12.2
LJ6	K35+400	1.83	12.8
LJ7	K44+580	1.85	12.8
LJ8	K56+820	1.73	13.5
LJ9	K59+030	1.65	14.0

Because the salty loess is intended to be used as roadbed filler for expressway, the following tests of mechanical strength index are based on the specimens with compaction degree of 96%, which were formed against the benchmark of the maximum dry density of table 3.

(3) CBR test and resilient modulus test

The CBR is an index to evaluate the bearing capacity of compacted soil, in fact, it is a kind of shear strength of the soil. Because the CBR test condition stipulate that the specimen must be saturated with water for 4 days before testing [4], it is also used as an index to evaluate the water stability. The materials whose CBR do not meet the requirements should not be used as subgrade fillers. The requirements for CBR are shown in Table 4 according to Specifications for Design of Highway Subgrade. The resilient modulus indicates the ability of soil to resist vertical deformation during elastic deformation, and it is the embodiment of compressive strength. The resilient modulus is the main index of pavement thickness design, and in Specifications for Design of Highway Asphalt Pavement [5], it is required that the subgrade should be designed in a dry or medium wet state, the resilient modulus of roadbed should be more than 30 MP, and under the condition of heavy load traffic or extra-heavy load traffic, it should be more than 40 MP.

Table 4. Minimum requirements for CBR and compaction degree of roadbed filler

Position		Depth below the surface of the roadbed (m)	CBR (%)			Compaction degree (%)		
			Expressway, Class-1 highway	Class-2 highway	Class-3 highway , Class-4 highway	Expressway, Class-1 highway	Class-2 highway	Class-3 highway , Class-4 highway
Upper roadbed		0~0.3	8	6	5	≥96	≥95	≥94
Lower roadbed	Light,medium or heavy load traffic	0.3~0.8	5	4	3	≥96	≥95	≥94
	Extra-heavy load traffic	0.3~1.2	5	4	—	≥96	≥95	—

The test results of CBR and resilient modulus of the soils in 9 fields are shown in Table 5.

Table 5. CBR and resilient modulus

Test number	Sampling spot	dry density (g/cm3)	Water content (%)	Water absorption (%)	Swelling rate (%)	CBR (%)	Resilient modulus (MP)
LJ-1	K3+100	1.88	12.2	3.5	0.37	2.7	40
LJ-2	K11+490	1.74	12.2	7.3	0.64	4.6	31
LJ-3	K20+300	1.76	11.1	8.0	0.77	3.8	28
LJ-4	K24+800	1.81	10.0	6.8	0.29	5.6	33
LJ-5	K30+400	1.64	12.2	8.1	0.57	4.8	32
LJ-6	K35+400	1.75	12.8	7.7	0.37	4.7	32
LJ-7	K44+580	1.78	12.8	6.9	0.64	2.4	31
LJ-8	K56+820	1.66	13.5	7.8	0.18	5.5	31
LJ-9	K59+030	1.58	14.0	8.5	0.12	6.0	40

According to the results of Table 5, CBR of the soils in 9 fields cannot meet the requirement for upper roadbed of expressway (8%), and only LJ-4/ LJ-8 and LJ-9's CBR can reach the minimum value (5%) for lower roadbed of expressway. LJ-1 and LJ-9 are the only ones whose resilient modulus has just reached 40 MP. In order to use these soils as roadbed fillers, improvement should be carried out.

3. Improvement scheme test

For the improvement of fine grained soil with poor engineering properties, physical and chemical methods can be considered [6-8]. The former is mainly to add coarse grained soil such as gravel and crushed stone to fine grained soil, and the latter is improved with inorganic binders such as lime and cement. According to engineering experiences, the most commonly used and economic improvement method is lime treatment.

The effect of lime treatment is mainly affected by lime grade and ash dosage. Generally speaking, lime containing more than 55% effective calcium oxide and magnesium oxide can be used, and this standard is the requirement of Class-Ⅲ calcareous hydrated lime. In principle, under the same improvement effect requirement, the content of lime with high grade can be reduced. However, due to the homogeneity of mixing process, if the lime content is too small, even if the grade is increased, the effect of the improvement of the low grade lime under the high content cannot be achieved, especially in the field mixing construction. The following test uses the Class-Ⅲ calcareous hydrated lime with 5% content, which refers to the addition of 5% lime to 100% soil to form lime-soil. The main technical indices of lime -soil are maximum dry density and optimum water content, CBR and resilient modulus, and the test items include heavy compaction test, CBR test and resilient modulus test.

(1) Heavy compaction test

The maximum dry density and optimum water content of lime-soil obtained by heavy compaction test are shown in Table 6.

Table 6. Heavy compaction test of lime-soil

Test number	Sampling spot	Maximum dry density (g/cm3)	Optimum water content (%)
LJ1	K3+100	1.83	14.2
LJ2	K11+490	1.80	12.5
LJ3	K20+300	1.81	13.0
LJ4	K24+800	1.84	12.4
LJ5	K30+400	1.74	13.9
LJ6	K35+400	1.83	11.8
LJ7	K44+580	1.84	12.0
LJ8	K56+820	1.78	14.0
LJ9	K59+030	1.74	14.8

Comparing the results in Table 6 with the experimental results in Table 3, it can be seen that the optimum water content of lime-soil increases in varying degrees, and the maximum dry density of most samples decreases. It shows that the amount of water needed during lime-soil compaction is increased.

(2) CBR test and resilient modulus test

The test condition of CBR is as follows: the formed specimen is in the curing room for 3 days, then saturated with water for 4 days before testing. The test condition of reliant modulus is that the formed specimen is in the curing room for 3 days, and then directly test it. The test results are shown in Table 7.

Table 7. CBR and resilient modulus of lime-soil

Test number	Sampling spot	dry density (g/cm3)	Water content (%)	Water absorption (%)	Swelling rate (%)	CBR (%)	Resilient modulus (MP)
LJ-1	K3+100	1.76	14.2	3.5	0	52	134
LJ-2	K11+490	1.73	12.5	4.6	0	70	91
LJ-3	K20+300	1.74	13.0	3.7	0	71	78
LJ-4	K24+800	1.77	12.4	4.2	0	49	106
LJ-5	K30+400	1.67	13.9	4.5	0	72	63
LJ-6	K35+400	1.76	11.8	5.3	0	75	108
LJ-7	K44+580	1.77	12.0	3.9	0	73	69
LJ-8	K56+820	1.71	14.0	3.0	0	47	55
LJ-9	K59+030	1.67	14.8	3.3	0	60	61

By comparing the results of table 7 with the results of table 5, it can be seen that:

1) The water absorption of lime-soil is decreased, which is about 0.6 times as much as that of raw salty loess, and the swelling amount disappears to 0. This reflects the improvement of the water stability.

2) CBR has been significantly increased, with an average of about 15 times of that of the raw salty loess, which not only reflects the improvement of the shear strength, but also reflects the improvement of the water stability on the other hand.

3) The resilient modulus is greatly improved, which is about 2.6 times of raw salty loess, which reflects the improvement of resistance to deformation.

4. Conclusions and recommendations

(1) The salty loess with poor engineering property is improved obviously by adding 5% lime, which can completely meet the requirement for upper roadbed filler of expressway. But in the actual engineering, almost all the lime-soil construction uses field mixing, and the uniformity of mixing is always the factor that affects the effect of lime improvement. Considering the influence of this unfavorable factor, it is necessary to appropriately increase the amount of lime, and generally adopt 6%~8%. The test section should be set up on the field, and the lime content in lime-soil after mixing and rolling is measured and then the appropriate lime content is determined.

(2) The thickness of the upper roadbed is 30 cm and the thickness of the lower roadbed is 50 ~ 90 cm, and the strength requirements (CBR) of the upper and lower roadbeds are 8% and 5% respectively. This regulation is considered to be suitable for bearing the traffic load transmitted by pavement, but it makes it difficult for lime-soil to be compacted layer by layer. The loose spreading thickness of lime-soil is generally controlled at 30 cm. The thickness of lime-soil compacted by roller with excitation force of 55 t or more should not exceed 20cm. Therefore, the thickness of 30cm upper roadbed is too thick to be compacted in 1 layer, and it is too thin in 2 layers, which is not economical. The compaction of the lower roadbed with 50(90) cm thickness also has the problems of too thick compaction in 2(4) layers and too thin compaction in 3(5) layers. Considering this situation, the roadbed with 80(120)cm thickness can be divided into two parts: the top 40cm adopts the lime amount of the upper roadbed and can be compacted in 2 layers,the following 40(80)cm uses the lime amount of the lower roadbed and can be compacted in 2(4) layers . The layered construction method is especially important for the treatment of loess with high silt content by adding lime, which is convenient for construction and ensures the safety of the project.

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