Improvement of high-liquid limit soil in the subgrade of mine roadway

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ABSTRACT. *Considering the unfavourable engineering properties of high-liquid limit soil, this paper determines the optimal proportion of admixtures for a high-liquid limit soil treatment project of a mine roadway. Specifically, the high-liquid limit soil was modified with quicklime, cement, fly ash, and liquid stabilizer plus curing agent, and subjected to swell-shrink test, compaction test, and the California bearing ratio (CBR) test. The test results show that the soil modified by quicklime outperformed other modification alternatives, and satisfied the intensity requirements when the quicklime content is not less than 3%. The high-liquid limit soil, modified by fly ash, saw no intensity improvement, and had intensity similar to that of the plain soil. The modification by cement only partially enhanced the high-liquid limit soil, and the enhancement effect was not impressive. The treatment of CONAID stabilizer (4%) and curing agent (5%) lead to better swell-shrink features, but failed to achieve a major boost to soil intensity. This research shed important new light on the improvement of high-liquid limit soil in engineering projects.*

RÉSUMÉ. *Considérant les propriétés techniques défavorables d'un sol à limite de liquidité élevée, cet article détermine la proportion optimale d'adjuvants dans un projet de traitement du sol à limite de liquidité élevée d'une chaussée minière. Plus précisément, le sol à limite de liquidité élevée a été modifié avec de la chaux vive, du ciment, des cendres volantes et un stabilisant liquide plus durcisseur, et soumis à un test de rétraction de gonflement, un test de compactage et l'essai CBR California Bearing Ratio. Les résultats des tests montrent que le sol modifié par la chaux vive a surperformé les solutions de remplacement proposées et satisfait aux exigences d'intensité lorsque la teneur en chaux vive ne dépasse pas à 3%. Le sol à limite de liquidité élevée, modifié par les cendres volantes, ne présentait aucune amélioration d'intensité et présentait une intensité similaire à celle du sol ordinaire. La modification apportée par le ciment n'a que partiellement amélioré le sol à limite de liquidité élevée, et l'effet d'amélioration n'a pas été impressionnant. Le traitement du stabilisant CONAID (4%) et du durcisseur (5%) a permis d'obtenir de meilleures rapport d'expansion, mais n'a pas réussi à renforcer considérablement l'intensité du sol. Cette recherche a apporté une nouvelle direction d'étude importante sur l'amélioration des sols à limite de liquidité élevée dans les projets d'ingénierie.*

KEYWORDS: *mine road, subgrade, high liquid limit soil, admixture, improvement test.*

MOTS-CLÉS: *chaussée minière, couche de fondationn, sol à limite de liquidité élevée, adjuvant, test d'amélioration.*

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1. Introduction

High liquid limit soil has large moisture content, large deformation, high liquid limit and low intensity, it contains a lot of hydrophilic minerals, and it has the characteristics of poor stability and it's difficult to be compacted. In the engineering construction of mine roads, due to the special features of high liquid limit soil, it often occurs engineering problems such as excessive settlement of subgrade, cracking of road surface, collapse of subgrade slope and landslide. According to industry standards, high liquid limit soil cannot be directly filled as filler and must be treated before filling.

Domestic and foreign scholars have done a lot of research on the treatment methods of high liquid limit soil, and its mechanics and deformation characteristics after treatment., they have treated the high liquid limit soil with various methods such as sand (Xu *et al.*, 2014; Cheng *et al.*, 2012) and gravel (Li, 2010) blending, sand and cement blending, CONAID stabilizer (Song *et al.*, 2004) blending, GURS series curing agent blending, sodium silicate and aluminum sulfate (Zhang *et al.*, 2015) blending, lime (Liang & Ou, 2008; Wan, 2016; Zhao, 2014; Guo, 2014; Zeng *et al.*, 2006) blending, sand and lime (Xu, 2015) blending, lime blending combined with geogrid, gravel pile (Wu *et al.*, 2008) method and plant root reinforcement method, in the expect of improving its physical and mechanical properties. However, these studies focus more on one or two treatment methods, and less on the comparative study of multiple treatment methods, especially there are few systematic researches that combined with actual engineering practices. In order to solve the problem of filling and treatment of large-area high-liquid limit soil in mine road construction, an optimal improvement method for high liquid limit soil in the road section is sought to improve soil intensity and reduce disasters.

Combined with engineering practices, this paper determines the physical and mechanical parameters of the soil through on-site sampling and indoor basic soil properties tests, and then it uses four kinds of admixtures of liquid stabilizer, lime, cement and fly ash for the improvement tests, so as to determine the optimal improvement method and reveal the change law of the physical and mechanical properties of the soil with different admixtures.

2. Test materials and test plans

2.1. Test materials

In the process of constructing a section of a mine road, in order to obtain a good high liquid limit soil improvement effect so as to choose better improvement method that is suitable for the high liquid limit soil improvement of the road section, the test uses soil that is taken at two pile positions respectively. The mileage pile number and the depth of the soil samples are shown in Table 1. The soil samples are tested for physical and mechanical properties and subjected to compaction test. The test results are shown in Table 2, Table 3 and Table 4.

Table 1. Sampling

Mileage Peg Numbering	Soil Depth /m	Sample Numbering	Soil Specimen
k1+650 Left 50m	1.5	1#	Grayish white clay
K2+220 Left 20m	3.0	5#	Grayish yellow clay

Table 2. Test results of physical and mechanical properties of undisturbed soil samples (1)

Sample Numbering	Natural Moisture Content ω/%	Unit Weight $\gamma/(kN\cdot m^{-3})$	Specific Gravity Gs		Liquid Limit ωL/%
1#	21	19.27	2.77		56.4
5#	24.3	18.92	2.76		57
Sample Numbering	Plastic Limit ωP/%	Plasticity Index /%	Particle size /mm		Soil classification
1#			<0.005	<0.002	
5#	24.1	32.3	60	45	CH

Table 3. Test results of physical and mechanical properties of undisturbed soil samples (2)

Sample Numbering	Unit Dry Gravity $\gamma d/(kN\cdot m^{-3})$	Void Ratio e	Saturation Sr/%	Free Swelling Rate δef/%
1#	15.92	0.737	79	45
5#	15.23	0.814	82.4	65
Sample Numbering	Compression Coefficient α1-2/Mpa-1	Constrained Modulus Es/Mpa	Cohesive Force c/kPa	Internal Friction Angle φ/(°)
1#	0.136	12.4	186.1	32
5#	0.137	12.2	131.1	28.8

Table 4. Soil sample compaction test and CBR test results

Sample Numbering	Compaction Test	
	Optimum moisture Content ω_{op}/%	Maximum dry density $\rho_{dmax}/(g\cdot cm^{-3})$
1#	18.5	1.79
5#	17.7	1.75

Sample Numbering	CBR Test						
	Strike number /(Strike/ layer)	Water content /%	dry density /($g \cdot cm^{-3}$)	swelling rate /%	Water absorption /g	CBR2.5 /Mpa	CBR5.0 /kPa
1#	98	19.9	1.73	5.2	165	2.56	2.68
5#	98	15.6	1.7	10.4	492	1.26	1.42

According to Table 2, Table 3 and Table 4 of soil physical and mechanical test results, the average liquid limit of 1# soil sample is 56.4%, and the plasticity index is 32.3%. According to the current *Code for Design of Highway Subgrade* (JTG D30—2015) and the provisions of the *Highway Geotechnical Test Specifications* (JTG E40-2007), it’s a kind of high liquid limit clay, the CBR value is only 2.68% at the maximum dry density and the CBR swell increment is 5.2%, which cannot meet the requirement of minimum intensity of the subgrade filler, so it cannot be used directly as subgrade filler.

The average liquid limit of 5# soil sample is 57%, and the plasticity index is 32.7%. According to the current *Code for Design of Highway Subgrade* (JTG D30—2015) and the provisions of the *Highway Geotechnical Test Specifications* (JTG E40-2007), it’s a kind of high liquid limit clay, the CBR value is only 1.42% at the maximum dry density and the CBR swell increment is 10.7%, which cannot meet the requirement of minimum intensity of the subgrade filler, so it cannot be used directly as subgrade filler.

2.2. High liquid limit soil improvement test plan

(1) Objective of the improvement test

Respectively use liquid stabilizer + curing agent, lime, cement and fly ash as modifiers to perform improvement tests on the special soils that do not meet the requirements of subgrade filler intensity of *Code for Design of Highway Subgrade* (JTG D30—2015) in the road section, and then analyze the improvement effect and adaptability of different special soils modified by various admixtures in the road section through the tests.

(2) Test standards for improvement test

According to the requirement of *Code for Design of Highway Subgrade* (JTG D30—2015), for the optimal admixture blending ratio of the improvement treatment of the swelling soil, it is preferred that the total swell-shrink ratio after admixture blending does not exceed 0.7%. The total swell-shrink ratio can be used as a control index for the expansion and contraction of the soil. The CBR value is the current intensity design index of the standard subgrade filler, and according to the research, there is a certain corresponding relationship between the total swell-shrink ratio and the CBR swell increment. The CBR test is used as an intensity test index for the improvement of soil, and the CBR swell increment can also be used as one of the control indicators for the swell-shrink characteristics.

(3) Improvement materials

The improvement test materials adopt lime, P·O 42.5 cement, fly ash and liquid stabilizer. The blending of the admixture is determined by the following proportions, and the blending ratio is calculated by the mass ratio to the dry soil. Liquid stabilizing curing agent. The blending amount is 4% of the stabilizer + 5% of the soil curing agent. Grounded fine lime powder. According to engineering experience, the blending amount is 3%, 5%, 7%. P·O 42.5 cement. According to engineering experience, the blending amount is 3%, 5%, 7%. Fly ash. According to engineering experience, the blending amount is 15%, 20%, 30%.

(4) Methods and processes of the improvement test

- According to the heavy compaction test, the optimal moisture content and the maximum dry density of various soil samples are obtained;

- Before blending the admixtures and preparing the soil samples, the air-dried moisture content of the soil samples should be determined. The dry soil weight of each sample should be calculated, and the weight of the improvement material added to each sample should be calculated according to the designed amount.

- For each sample of lime-modified soil, cement-modified soil and fly ash-modified soil with different blending amount, all of their optimal moisture content and maximum dry density need to be re-measured, but according to experience, the optimal moisture content of the modified soil blended with cement is close to that of the plain soil, and the optimal moisture content of the modified soil blended with lime is 1% to 2% larger than that of plain soil; as for the fly ash, there’s a lack of experience, so we need to perform compaction test to determine the optimal moisture content.

- Calculate the amount of water to be added to the modified soil according to the optimal moisture content and the air-dried moisture content of the soil sample. 1) When using CONAID stabilizer + soil curing agent, determine the moisture content of the air-dried soil and calculate the dry soil weight and the required water amount for achieving the optimal moisture content; and then calculate the required amount of the CONAID stabilizer + the weight of the curing agent according to the dry soil weight and the designed blending amount, mix them with water and evenly spray into the soil; treat the soil sample under the condition of optimal moisture content, stand and cover the soil sample tightly for 24h (if the soil sample is too wet, it needs to be dried to the optimal moisture content); 2) When using lime or fly ash to improve the soil, after the lime or the fly ash is mixed with the soil sample, evenly spray the required water amount on the soil mixture, stir and mix well, and then stand and cover the soil sample tightly for 24h. 3) When using cement to improve the soil, first evenly spray the required water amount on the soil sample, stir and mix well, and cover the soil sample tightly for 24h, then add the cement into the prepared soil sample, fully mix well, and then the test should be completed within 1h.

- Preparation of soil samples. 1) CBR test. The wet soil sample with the optimal moisture content is subjected to the standard heavy compaction test (divide the sample into 3 layers for the compaction, for each layer, compact 98 times). 2) Swell-shrink test. The air-dried soil is crushed and sieved through a 2 mm sieve, a wet soil sample is prepared according to the optimal moisture content, then place the soil sample into the mold according to the maximum dry density standard, and then prepare the sample in a press machine by the static pressure method. In the test, the height of the pressed soil sample should not be greater than 5cm, and the size of the prepared sample should meet the requirements of the shrinkage test and the swelling rate test at 50 kPa.

- Maintenance methods and time. Considering the requirements for the construction period and the actual conditions of the test equipment, after the compact test and static pressure molding, the soil samples modified by lime, cement and fly ash are wrapped with two layers of plastic film and put into a sealed box, keeping the moisture content unchanged, the samples stand for 7d and then are subjected to the test. For the soil sample treated with liquid stabilizer + curing agent, after the sample is prepared, it should be placed in the air for 1-2d to be dried by the curing agent. Then the soil sample is wrapped with two layers of plastic film and placed in a sealed box to keep the moisture content unchanged, the soil samples stand still until the 7th day after the compaction test and static pressure molding, and then are subjected to various test.

3. Test results analysis

The 1# and 5# soil samples are respectively subjected to the swell-shrink test, the compaction test, and the CBR test. The results of the 1# soil sample improvement test are shown in Table 5 and 6. It can be seen from the test results before and after the 1# soil sample improvement that, before the improvement, the swell-shrink characteristics index and the intensity index of the modified soil cannot meet the requirements of the standard for the subgrade filling material.

After treatment with CONAID stabilizer + curing agent, the modified soil can meet the intensity requirements of subgrade filler, while the swell-shrink characteristics index decreases. According to the method in the *Regulations of Guangxi Region* (DB45/T396-2007) and the method in the *Code for Design of Highway Subgrade* (JTJ013—95) to calculate the total swell-shrink rate, all of the samples failed to meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%.

After the treatment with cement, the intensity increases greatly. All soil samples modified by various cement content can satisfy the requirement of the intensity of filler in various parts of the subgrade, the swell-shrink characteristics index decreases greatly, but still cannot meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%.

Table 5. Test results of total swell-shrink rate of 1# modified soil sample

	Item	Untreated Soil	CONAID + Curing Agent	Cement			Lime		
			4% + 5%	3%	5%	7%	3%	5%	7%
Guangxi regional regulations DB45/T 396-2007	50kPa Relative swelling rate δ_{xe50}/%	3.88	2.69	1.26	1.05	1.01	0.52	0.46	0.28
	Vertical line shrinkage δ_S/%	3.18	1.3	0.65	0.51	0.76	0.91	1.71	0.91
	total swelling ratio δ_{xs}/%	7.06	3.99	1.91	1.56	1.77	1.43	2.17	1.19
Code for design of Highway Subgrade JTJ013-95	50kPa swelling rate $\delta_{e50}(e_{p50})$/%	3.83	2.6	1.25	1.05	1	0.51	0.46	0.28
	shrinkage coefficient $\lambda_s(c_{sl})$	0.312	0.254	0.132	0.11	0.094	0.157	0.227	0.132
	Optimum water content ω/%	18.5	18.5	19.7	18.8	19.2	18.5	19.4	18.5
	Coefficient of working condition K	0.873	0.873	0.873	0.873	0.873	0.873	0.873	0.873
	Plasticity limit ω_p/%	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
	Shrinkage water content ω_m/%	21	21	21	21	21	21	21	21
	total swelling ratio e_{ps}/%	3.83	2.6	1.25	1.05	1	0.51	0.46	0.28
	Item		Untreated Soil		CONAID + Curing Agent			Fly Ash	

			4% + 5%	15%	20%	30%
Guangxi regional regulations DB45/T 396-2007	50kPa Relative swelling rateδ_{xe50}/%	3.88	0.27	0.15	0.03	
	Vertical line shrinkage δ_S/%	3.18	2.1	1.44	2.25	
	total swelling ratio δ_{xs}/%	7.06	2.37	1.59	2.28	
Code for design of Highway Subgrade JTJ013-95	50kPa swelling rate $\delta_{e50}(e_{p50})$/%	3.83	0.26	0.14	0.03	
	shrinkage coefficient $\lambda_s(c_{sl})$	0.312	0.254	0.258	0.273	
	Optimum water content ω/%	18.5	18.6	18.3	18.5	
	Coefficient of working condition K	0.873	0.873	0.873	0.873	
	Plasticity limit ω_p/%	24.1	24.1	24.1	24.1	
	Shrinkage water content ω_m/%	21	21	21	21	
	total swelling ratio e_{ps}/%	3.83	0.26	0.14	0.03	

Note: 1) Guangxi regional regulations DB45/T 396-2007: $\delta_{xs}=\delta_{xe50}+\delta_S$; 2) Code for design of Highway Subgrade JTJ013-95: $e_{ps}= e_{p50}+ c_{sl}(\omega-\omega_m)$; $(\omega-\omega_m)<0$, $(\omega-\omega_m) = 0$; $(\omega-\omega_m>8$, $(\omega-\omega_m) = 8\%$; $\omega_m = K\omega_p$, $K = 0.873$ (Nangning region), Based on experience, the ωp value of the improved soil should be the same as that of the original soil.

After the treatment with lime, the intensity of the lime-modified soil increases greatly. All soil samples modified by various lime content can satisfy the requirement of the intensity of filler in various parts of the subgrade, the swell-shrink characteristics index decreases greatly, calculate according to the method in the *Regulations of Guangxi Region* (DB45/T396-2007), the total swell-shrink rate is 1.19% ~ 2.17%, which cannot meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%. Calculate according to the method in the *Code for Design of Highway Subgrade* (JTJ013-1995), the total swell-shrink rate is 0.28% ~ 0.51%; when the lime content is 3%, the total swell-shrink rate is 0.51%, which has met the current specification of total swell-shrink rate is less than 0.7%, at this time, the CBR value of the soil modified by lime is 28.47%, which satisfies the intensity requirements of the fillers in various parts of the subgrade. Therefore, when the amount of lime is not less than 3%, the intensity requirement of the filler of each part can be satisfied.

Table 6. Results of compaction test and CBR test of 1# modified soil sample

Item		Compaction Test		CBR Test						
		Optimum Moisture Content /%	Maximum Dryensity/ $(g·cm^{-3})$	Strike Number /(Strike / layer)	Water Content /%	Dry Density /$(g·cm^{-3})$	Swelling Rate /%	Water Absorption /g	$CBR_{2.5}$/Mpa	$CBR_{5.0}$/kPa
Plain Soil		18.5	1.79	98	19.9	1.73	5.2	165	2.56	2.68
CONAID + Curing Agent	4%+5%	18.5	1.79	98	18.9	1.77	3.17	211	3.2	3.83
Cement	3%	19.7	1.77	98	19.7	1.77	1.81	60	11.04	8.64
	5%	18.8	1.78	98	18.8	1.78	1.27	80	35.34	26.01
	7%	19.2	1.75	98	19.2	1.75	1.59	87	37.55	26.5
Lime	3%	18.5	1.75	98	18.5	1.75	0.33	52	18.41	28.47
	5%	19.4	1.74	98	19.4	1.74	0.83	144	24.3	21.6
	7%	18.5	1.75	98	18.5	1.75	0.07	140	45.28	29.69
Fly Ash	15%	18.6	1.7	98	18.6	1.7	2.36	102	1.4	2.94
	20%	18.3	1.69	98	18.3	1.69	2.6	95	2.58	4.56
	30%	18.5	1.65	98	18.5	1.65	1.04	108	2.5	3.93

Table 7. Test results of total swell-shrink rate of 5# modified soil sample

Item		Untreated Soil	CONAID +Curing Agent	Cement			Lime		
			4%+5%	3%	5%	7%	3%	5%	7%
Guangxi regional regulations DB45/T 396-2007	50kPa Relative swelling rate δ_{xe50}/%	7.38	6.59	2.46	1.21	0	0.69	0.26	0.25
	Vertical line shrinkage δ_S/%	0.75	0.3	1.07	1.11	0.9	1.23	0.15	0.43
	total swelling ratio δ_{xs}/%	8.13	6.89	3.53	2.32	0.9	1.92	0.41	0.68
Code for design of Highway Subgrade JTJ013-95	50kPa swelling rate $\delta_{e50}(e_{p50})$/%	7.30	6.20	2.43	1.20	0	0.68	0.26	0.05
	shrinkage coefficient $\lambda_s(c_{sl})$	0.123	0.162	0.163	0.161	0.125	0.156	0.137	0.151
	Optimum water content ω/%	17.7	17.7	21.4	21.1	21.2	16.7	18	16.7
	Coefficient of working condition K	0.873	0.873	0.873	0.873	0.873	0.873	0.873	0.873
	Plasticity limit ω_p/%	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
	Shrinkage water content ω_m/%	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
	total swelling ratio e_{ps}/%	7.30	6.20	2.43	1.20	0	0.68	0.26	0.05

Item		Untreated Soil	CONAID +Curing Agent	Fly Ash		
			4%+5%	15%	20%	30%
Guangxi regional regulations DB45/T 396-2007	50kPa Relative swelling rate δ_{xe50}/%	7.38	3.59	0.98	0.67	
	Vertical line shrinkage δ_S/%	0.75	0.74	0.58	0.68	
	total swelling ratio δ_{xs}/%	8.13	4.33	1.55	1.35	
Code for design of Highway Subgrade JTJ013-95	50kPa swelling rate $\delta_{e50}(e_{p50})$/%	7.30	3.40	0.96	0.66	
	shrinkage coefficient $\lambda_s(c_{sl})$	0.123	0.118	0.083	0.081	
	Optimum water content ω/%	17.7	18.6	18.3	18.5	
	Coefficient of working condition K	0.873	0.873	0.873	0.873	
	Plasticity limit ω_p/%	24.3	24.3	24.3	24.3	
	Shrinkage water content ω_m/%	21.2	21.2	21.2	21.2	
	total swelling ratio e_{ps}/%	7.30	3.40	0.96	0.66	

Note: 1) Guangxi regional regulations DB45/T 396-2007: $\delta_{xs}=\delta_{xe50}+\delta_S$; 2) Code for design of Highway Subgrade JTJ013-95: $e_{ps}=e_{p50}+c_{sl}(\omega-\omega_m)$; $(\omega-\omega_m)<0$, $(\omega-\omega_m)=0$; $(\omega-\omega_m>8$, $(\omega-\omega_m)=8\%$; $\omega_m=K\omega_p$; K=0.873(Nangning region), Based on experience, the ωp value of the improved soil should be the same as that of the original soil.

After the treatment with fly ash, the swell-shrink characteristics index decreases greatly, calculate according to the method in the *Regulations of Guangxi Region* (DB45/T396-2007), the total swell-shrink rate is 1.59% ~ 2.37%, which cannot meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%. Calculate according to the method in the *Code for Design of Highway Subgrade* (JTJ013-1995), the total swell-shrink rate is 0.03% ~ 0.26%, when the fly ash content is 15%, the total swell-shrink rate is 0.26％, which has met the current specification of total swell-shrink rate is less than 0.7%, but at this time the CBR value is 2.94%, which cannot satisfy the intensity requirements of the subgrade filler; when the fly ash content is 20%, the total swell-shrink rate is 0.14%, and the CBR value is 4.56%, which can meet both the requirement of current specification that the total swell-shrink rate is less than 0.7%, and the intensity requirement of the upper and lower subgrade filler.

The improvement test results of the 5# soil sample are shown in Table 7 and 8. It can be seen from the test results before and after the improvement of 5# soil sample that, before the improvement, both the swell-shrink characteristics index and the intensity index of the remolded soil cannot meet the requirement of the subgrade filling material.

Table 8. Results of compaction test and CBR tests of 5# modified soil sample

Item		Compaction Test		CBR Test						
		Optimum Moisture Content /%	Maximum Dry Density/(g·cm^{-3})	Strike Number /(Strike / layer)	Water Content /%	Dry Density /(g·cm^{-3})	Swelling Rate /%	Water Absorption /g	$CBR_{2.5}$ /Mpa	$CBR_{5.0}$ /kPa
Untreated Soil		17.7	1.75	98	15.6	1.7	10.4	492	1.26	1.42
CONAID + Curing Agent	4%+5%	17.7	1.75	98	17.7	1.75	7.55	388	1.55	1.90
Cement	3%	21.4	1.64	98	21.4	1.64	4.13	133	5.89	5.64
	5%	21.1	1.71	98	21.1	1.71	2.53	84	14.72	12.27
	7%	21.2	1.69	98	21.2	1.69	2.26	102	19.14	16.2
Lime	3%	20.7	1.68	98	20.7	1.68	0.63	42	25.77	25.52
	5%	20.4	1.64	98	21.0	1.67	1.10	56	30.92	21.11
	7%	21.0	1.67	98	20.4	1.64	1.46	116	36.07	28.22
Fly Ash	15%	18.6	1.70	98	18.6	1.70	4.62	463	3.53	3.58
	20%	18.3	1.69	98	18.3	1.69	5.62	608	2.28	2.31
	30%	18.5	1.65	98	18.5	1.65	3.35	510	1.62	1.72

After the 5# soil sample is treated with CONAID stabilizer + curing agent, its swell-shrink characteristics index decreases, calculate the total swell-shrink rate according to the methods in the *Regulations of Guangxi Region* (DB45/T396-2007) and the *Code for Design of Highway Subgrade* (JTJ013-1995), it cannot meet the requirement that the total swell-shrink rate should be less than 0.7%, the intensity index increases slightly, but cannot meet requirements of the subgrade filling material.

After the treatment with cement, the intensity of the soil sample increases greatly, all soil samples modified by various cement content can satisfy the requirement of the intensity of filler in various parts of the subgrade, the swell-shrink characteristics index decreases greatly, calculate according to the method in the *Regulations of*

Guangxi Region (DB45/T396-2007), the total swell-shrink rate is 0.90% ~ 3.53%, which cannot meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%. Judging according to the *Code for Design of Highway Subgrade* (JTJ013-1995), when the cement content is not less than 7%, the total swell-shrink rate is 0.0%, and the CBR value is 19.14%, which can meet both the requirement of current specification that the total swell-shrink rate is less than 0.7%, and the intensity requirement of the upper and lower subgrade filler.

After the treatment with lime, the intensity of the soil sample increases greatly, all soil samples modified by various lime content can satisfy the requirement of the intensity of filler in various parts of the subgrade. The swell-shrink characteristics index decreases greatly, judging according to the *Regulations of Guangxi Region* (DB45/T396-2007), when the lime content is more than 3%, the total swell-shrink rate is 0.41% ~ 0.68%, which can meet the requirement of the current specification that the total swell-shrink rate of the modified soil should be less than 0.7%. Judging according to the *Code for Design of Highway Subgrade* (JTJ013-1995), when the lime content is 3%, the total swell-shrink rate is 0.68％, which has met the requirement of the current specification that the total swell-shrink rate of the modified soil is less than 0.7%, at this time, the CBR value of the soil modified by lime is 25.77%, which satisfies the intensity requirements of the fillers in various parts of the subgrade.

After the treatment with fly ash, the swell-shrink characteristics index decreases, judging according to the *Regulations of Guangxi Region* (DB45/T396-2007), it cannot satisfy the requirement that the total swell-shrink rate is less than 0.7%. Judging according to the *Code for Design of Highway Subgrade*, when the fly ash content is 30%, the total swell-shrink rate is 0.66%, which can satisfy the requirement that the total swell-shrink rate of the modified soil should be less than 0.7%, but when the fly ash content is 30%, the CBR value is 1.72%, which does not meet the intensity requirement of the subgrade filler.

4. Conclusion

(1) Using quicklime for the improvement can achieve better results, when the lime content is not less than 3%, the swell-shrink characteristics and intensity of the modified soil can both reach the requirements of the *Code for Design of Highway Subgrade* (JTJ013-1995). The effect of using fly ash for the treatment is not ideal, although it has a certain improvement effect on the swell-shrink characteristics, the intensity didn’t change much, it’s basically the same as the plain soil. When the cement content is not less than 7%, the swell-shrink characteristics and intensity of the modified soil can meet the requirements of the current specification, but only parts of the road sections can achieve the improvement effect, so the applicability is not wide.

(2) Using CONAID stabilizer 4%+ curing agent (5%) for the treatment can improve the swell-shrink characteristics, since the liquid stabilizer takes a long time

to carry out chemical reaction such as ion exchange, the intensity increase requires a certain time and process; therefore, the intensity increases slowly.

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