Experimental Study on Road Properties of High Liquid Limit Soil in Yunfu Highway

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Abstract: There are a large number of high liquid limit soil distributed in southern China. As one of the special soils commonly seen in highway construction, high liquid limit soil cannot be used in subgrade filling directly due to its special engineering properties. With the idea of saving engineering investment and protecting environment, high liquid limit soil must be improved to be qualified subgrade filling material. First, detailed laboratory tests are carried out to reveal the special properties of high liquid limit soil. Then, based on the characters of high liquid limit soil, the improving tests of liquid plastic limit, unconfined compressive strength, CBR and compaction are completed by adding different percentages of quicklime and white lime to the high liquid limit soil to study the change in the physical and mechanical properties and strength. The results show that, after being improved by lime, the high liquid limit soil can be used as subgrade filling of expressway as its liquid limit, plastic index being reduced, the strength increased and the value of CBR increased remarkably, and modified effectiveness of quicklime is better than that of white lime. Through comparison and analysis of the test results, it is found that high liquid limit soil with 5% quicklime can be used as subgrade filling material for highway since it is not only economical but also qualified to meet the requirement of improvement and strength.

Keywords: Engineering properties, high liquid limit soil, lime, road properties, soil improvement.

1. INTRODUCTION

High liquid limit soil is a common soil to be met in subgrade filling, and whether it can be used as subgrade filling material has always been a controversial problem to road workers [1]. For present studies on high liquid limit soil, foreign researches mainly focus on the effect of stability and deformation after engineering. For example, Allam *et al.* [2] draw the conclusion after experiments that the change of water content directly influences the character of soil; A.S. AL-Homoud [3] points out that under the effect of wetting-drying cycles, the strength and expansibility of high liquid limit soil will manifest fatigue effect, and the main reason is that under the effect of wetting-drying cycles, the soil changes in structure and after several wetting-drying cycles the soil strengthens in stability. Meanwhile, other researcher [4, 5] have also got the similar conclusion through many experiments, and they explain the external performance of soil through the intrinsic properties. Domestic researches are mainly about the improving treatment, filling technology and basic properties of high liquid limit soil. Wu Lijian [6] reveals the special road properties of high liquid limit soil through specific indoor experiments; Li Binqin [7] studies the engineering geological properties of high liquid limit soil, and then raises a relatively economic and sound improvement scheme. Cao Yihai [8] carries out the practice to use lime-treated high liquid limit soil as subgrade filling material. Through experiments on treating high liquid limit soil with different quicklime ratios, he fixes the best lime ratio and explores the engineering properties of lime-treated high liquid limit soil and ways to use EDTA titration method to test lime content in compressed lime soil; Zeng Jing, *et al.* [9] present the special road properties of high liquid limit soil and red clay of Zhucheng Highway through indoor experiments, and adopt lime improvement tests to study the change laws of the physical and mechanical properties of lime-treated high liquid limit soil; Zhang Guobin [10] carries out detailed indoor stabilizer modifying experiments and obtains different modifying results.

As high liquid limit soil varies in formation and has strong localization, it has a variety of species and complicated mechanical properties. In the project of Yunfu-Wuzhou section in Guangzhou-Wuzhou Highway, the routine lines in hills and mountains, and distributes along a lot of high liquid limit soil. Meanwhile, digging and filling earthwork is huge. If we choose other alternative soil for filling, it must cost greatly. Therefore, it would be of important theoretical significance and remarkable practical value for this research to take indoor experiments on the engineering properties of and lime-treatment effect on the high liquid limit soil from Yunfu-Wuzhou section, and study the change laws of the physical and mechanical properties and strength to make it qualified filling material.

2. ENGINEERING PROPERTIES OF HIGH LIQUID LIMIT SOIL

A series of pertinent indoor and outdoor experiments are carried out to know the classification engineering properties of high liquid limit soil in the region, and provide theoretical references for engineering quality evaluation and improvement scheme selection.

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2.1. Sample Collection

Samples are collected based on the following two criteria: ①representativeness of road section. The road section must be typical high liquid limit soil road, namely, it must be of typical significance for knowing the present situation and following treatment of high liquid limit soil; ②representativeness of usage. It must be typical to be used as subgrade filling material.

2.2. Experiment on Basic Physical Properties of High Liquid Limit Soil

Take experiment according to the requirement in *Geotechnical Engineering Test Method and Criterion* [11], the results of the basic physical properties of high liquid limit soil can be seen in Table **1**.

From Table **1**, it can be seen that the degree of saturation of high liquid limit soil is high enough to reach more than 80%; dry density is low with big pores, which indicates the soil belongs to high- or middle-compressible soil; compression coefficient is more than 0.5 MPa-1, which indicates it belongs to high compressible soil; the permeability coefficient of "kv" is low, which indicates that the high liquid limit soil is almost imperviable.

2.3. Experiment on Engineering Properties of High Liquid Limit Soil

To find the engineering properties of high liquid limit soil, the following tests are conducted:

2.3.1. Liquid and Plastic Limit Tests

The liquid and plastic limit of liquid and plastic limit is tested according to the requirement defined in *Geotechnical Engineering Test Method and Criterion* [11], and the results are shown in Table **2**.

According to the state of clay [12], if the tested sample soil is in soft plastic condition, high liquid limit soil from 1m below the ground has been in soft plastic condition. According to the present professional standard [13], it cannot be used directly as subgrade filling material. From the calculation result of consistency, it is shown that the disparity of high liquid limit soil in research area is not good, and the soil should be sunned to disperse.

2.3.2. Unconfined Compressive Strength Tests

Unconfined compressive strength of undisturbed soil is tested when the degree of compaction is 93%, and the result is shown in Table **3**. It is found that the value of unconfined compressive strength is low, with the minimum value as being 0.051MPa and the maximum value, 0.131 Mpa, which is not safe for subgrade stability.

2.3.3. Compaction Tests and CBR Tests

Compaction test and CBR test are two basic tests to evaluate filling material road properties. Compacting to improve the quality of subgrade soil and ground is one of the important and economic ways to ensure the period of road service. After full compaction, the subgrade soil and ground can maintain better strength, better anti-deformation capacity and good stability; Compaction test can get the best water content ω_{opt} and maximum dry density ρ_{dmax} to fix the standard degree of compaction. California Bearing Ratio (CBR) is an index to represent subgrade soil, pellets and strength of stabilized soil, and it works as one of the important criteria to decide whether the material can be used as subgrade filling material.

Compaction tests and CBR tests are both carried out according to the requirements of *Geotechnical Engineering Test Method and Criterion* [11], and CBR tests are done under the condition of 93% degree of compaction. The tests results can be seen in Table **4**. It has been observed that the

Table 1. Basic physical properties of high liquid limit soil.

Water content $w(\%)$	Natural density $\rho(g/cm^3)$	Dry density $\rho_d(g/cm^3)$	Specific gravity of soil G_s	Porosity ratio e	Degree of saturation $S_r(\%)$	Compression coefficient $a_v(MPa^{-1})$	Compression modulus $E_s(MPa)$	Permeability coefficient $k_v(cm/s)$
32.48	1.74	1.32	2.73	1.07	82.50	0.54	3.29	1.90×10^{-7}

Table 2. Results of tests on water content limit of high liquid limit soil.

Natural water content ω(%)	Plasticity limit				Consistency
	Liquid limit ωL(%)	Plastic limit ωP(%)	Plasticity index IP	Liquidity index IL	
32.48	62.65	31.75	31.00	0.88	0.97

Table 3. Results of tests on unconfined compressive strength of high liquid limit soil.

degree of compaction	Unconfined compressive strength MPa			
	sample1	sample2	sample3	Sample4
93%	0.056	0.088	0.131	0.051

Table 4. Results of tests on compaction and CBR of high liquid limit soil.

Number	Natural water content ω(%)	Best water content ω_{opt}(%)	Dry density ρ_d(g/cm^3)	Maximum dry density ρ_{dmax}(g/cm^3)	Degree of compaction (%)	$CBR_{2.5}$ (%)	$CBR_{5.0}$ (%)
1	33.6	19.8	1.32	1.70	77.6	1.0	2.0
2	33.1	17.2	1.30	1.64	79.3	2.1	3.0
3	32.2	17.1	1.31	1.75	74.9	1.9	3.1
4	31.0	19.0	1.33	1.70	78.2	1.7	2.6

Table 5. Results of free expansive soil tests on high liquid limit soil.

Number of sample soil	1		2		3		4	
Free swelling ratio (%)	13.0	12.0	22.0	22.0	15.0	12.0	21.0	22.0
Average value (%)	12.5		22.0		13.5		21.5	

natural water content of high liquid limit soil in the research region is high, due to which it cannot be used as subgrade filling material directly. Since high liquid limit soil is almost imperviable with good water retention, which makes it difficult to lower the water content to near the best point. Through comparison of dry density and maximum dry density, the maximum degree of compaction is only found to be 79.3%, which cannot meet the regulation requirement.

CBR value is very low, between 2.0% to 3.1%. According to the requirement that CBR value of high-rank subgrade filling material should not be lower than 3%, only two values could reach the standard, which can only meet the requirement for strengthening the filling material in the down-parts and below parts of subgrade. Therefore, how to treat to raise the CBR value is one of the keys of modifying strategy.

2.3.4. Free Swelling Ratio Tests

Under the condition of ignoring the natural structure of soil, free swelling ratio can reflect the expansibility of fine soil, which is the basic index to judge whether the soil is expansive. High liquid limit soil bears the character of water swelling and water loss shrinking, as the soil usually contains minerals with strong hydrophilicity like montmorillonite and illite. Therefore, it is necessity to study the swelling property of high liquid limit soil in the region. According to *Geotechnical Engineering Test Method and Criterion* [11], four free swelling ratio tests are conducted, and the results are shown in Table **5**.

In the four tests results, the maximum free swelling ratio is 22.0%. According to *87 National Regulation* and *Highway Subgrade Design Standard* (JTJ 013-95), when the free swelling ratio ≤ 40%, the soil is not an expansive soil. Therefore the high liquid limit soil in the research region can be regarded as non-expansive soil.

3. INDOOR EXPERIMENT ON LIME-TREATED HIGH LIQUID LIMIT SOIL

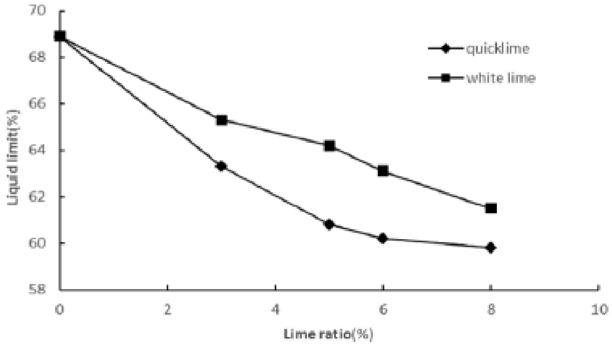
From the above tests and analysis, for its high natural water content, big compressibility and poor permeability, high liquid limit soil can be destructive to the road stability when used as subgrade filling material. To explore the possibility of adopting high liquid limit soil to subgrade soil engineering, 3%, 5%, 6%, 8% of quicklime and white lime ratios are used to treat high liquid limit soil in the experiment.

3.1. Effect of Lime Ratio on Liquid and Plastic Limit of High Liquid Limit Soil

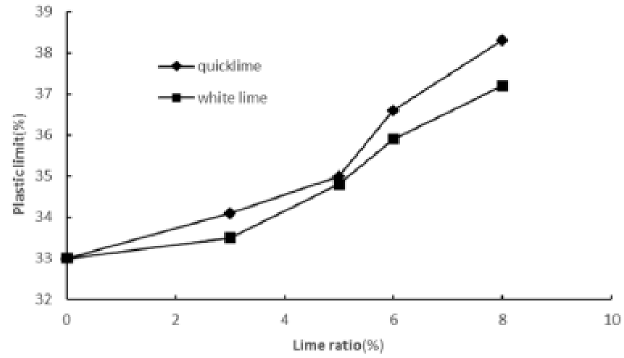
According to *Geotechnical Engineering Test Method and Criterion* [11], a combined determination analysis of liquid and plastic limits is made under different lime ratios of quicklime and white lime.

From Fig. (**1**) it is shown that when quicklime and white lime are added into high liquid limit soil, high liquid limit and high plastic index are obviously improved. With the increasing amount of dozed material, liquid limit declines, plastic limit increases and plastic index declines too. When lime ratio is 5%, liquid limit of quicklime-treated soil is 60.8%, plastic index is 25.3, which reduces 11.5% and 29.5% respectively compared with pure soil. While the liquid limit of white lime-treated soil is 64.2%, plastic index is 29.4, which only reduces 6.8% and 18.1% compared with pure soil.

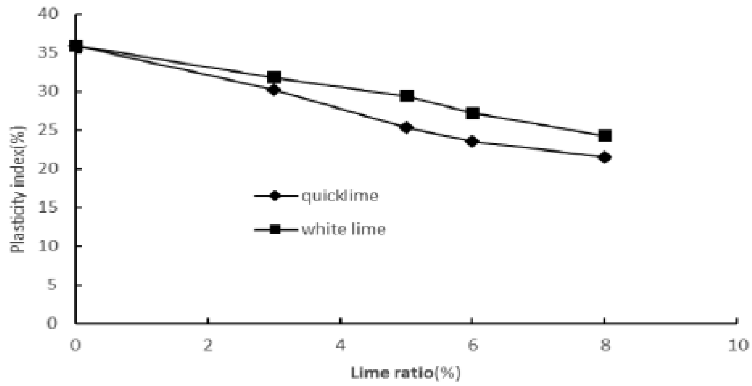
Figs. (**2 & 3**) are curves of relation between limit water content and lime ratio of quicklime-treated soil and white lime-treated soil under different lime ratios. From the comparison of liquid limit curve, the curves of quicklime-treated soil and white lime-treated soil are a straight line decline; from the comparison of plastic limit curve with lime ratio increase, it is found that the increase in amplitude of liquid limit of quicklime-treated soil is large, while the increase in amplitude of white lime-treated soil is smaller. For plastic index curve, with the increasing lime ratio, the plastic index of white lime turns into linear reduce, with a small reduction in amplitude. The reduction in amplitude of plastic index of quicklime-treated soil is large. There is an inflection point in the curve when lime ratio reaches 5%. While lime ratio is above 5%, the plastic index starts decreasing, which indicates that for quicklime, 5% is a key lime ratio.



(a) Liquid limit curve under different lime ratio



(b) Plastic limit curve under different lime ratio



(c) Plastic index curve under different lime ratio

Fig. (1). Curve of limit water content change of improved soil.

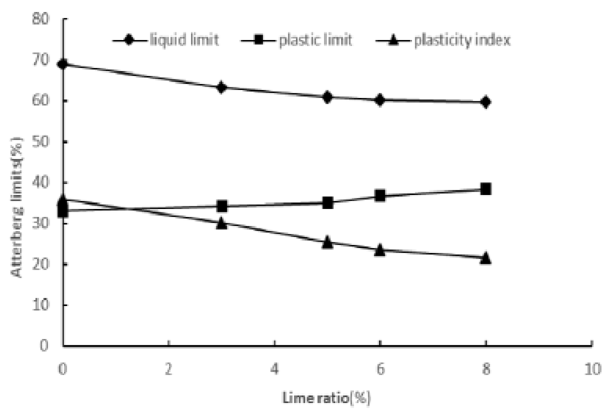


Fig. (2). Relation between limit water content and lime ratio when quicklime is added.

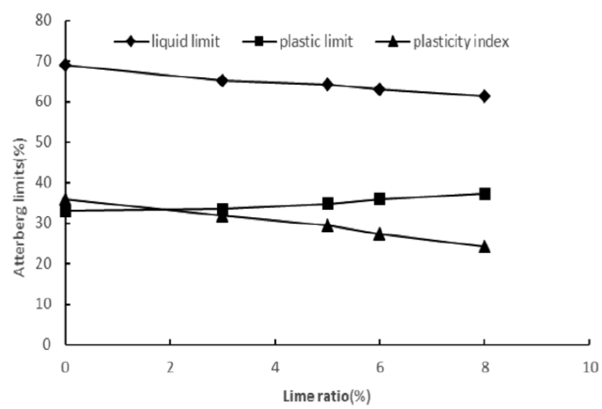


Fig. (3). Relation of limit water content and lime ratio when white lime is added.

3.2. Effect of Lime Ratio on the Strength of High Liquid Limit Soil

According to the best water content fixed in compaction test, samples are made with different lime ratio and curing time. The test result of unconfined compressive strength of different lime-treated soil can be seen in Fig. (**4**).

Fig. (**4**) shows, 7d and 28d unconfined compressive strengths increase with the increasing lime ratio. From the curve of 7d unconfined compressive strength, when lime ratio is low, unconfined compressive strength increases gradually. When lime ratio reaches to 5%, 7d unconfined compressive strength undergoes a sudden increase, but with lime ratio continually increasing, the increase in amplitude of unconfined compressive strength slows down; from 28d unconfined compressive strength, even the lime ratio is small, through long period of curing, high strength still can be obtained. From curves of 7d and 28d unconfined compressive strength, before lime ratio reaches 5%, with the increase of lime ratio, the increase in amplitude of strength is large; while when lime ratio is above 5%, high strength still increases but increase in amplitude slows down.

Results indicate that curing time and environment exert great influence on the strength increase of lime-treated soil.

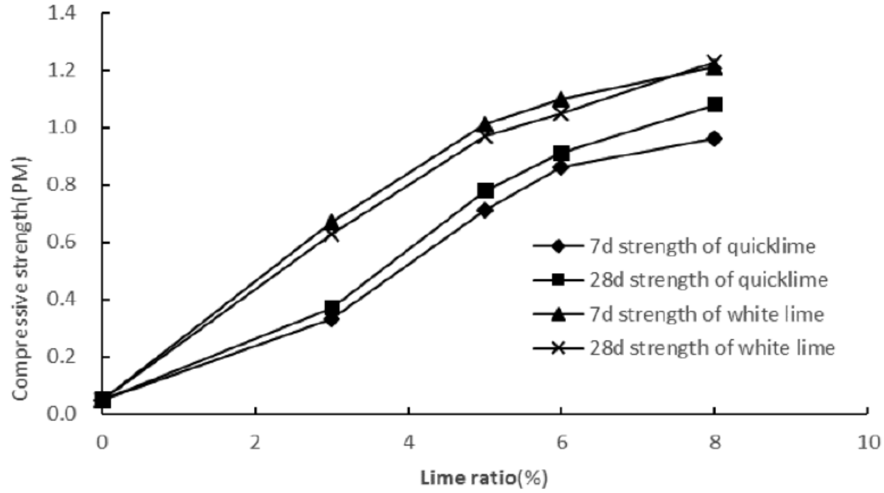


Fig. (4). Relation between unconfined compressive strength and lime ratio.

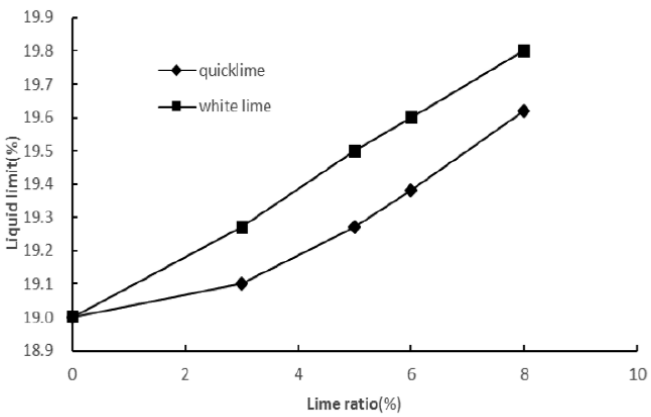


Fig. (5). The best water content under different lime ratios.

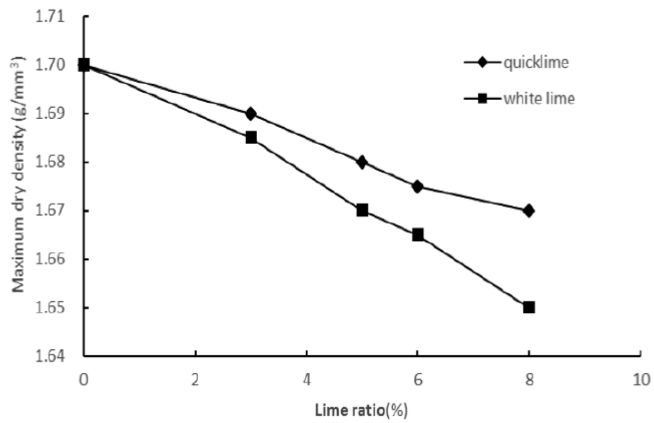


Fig. (6). The maximum dry density under different lime ratios.

When lime is added into soil, soil's water absorption capacity is much increased, resulting in the gradual increase in its strength. As time passes, with the hydration of lime, the strength of lime soil can reach high. From comparison of unconfined compressive strength between quicklime-treated soil and white lime-treated soil, the early strength of white lime-treated soil is found larger than quicklime-treated soil. But after a long period, the strength of quicklime-treated soil increases greatly, and from 28d unconfined compressive strength under the same lime ratio, the strength of quicklime-treated soil is found larger than white lime-treated soil. It indicates that when white lime is added for modification, the soil can get high early strength. But, as far as the total strength is concerned, the effectiveness of quicklime-treated soil is better than white lime-treated soil.

3.3. Effect of Lime Ratio on Compaction of High Liquid Limit Soil

The compaction property of treated soil is evaluated by the best water content and the maximum dry density obtained in compaction test. Electric compaction device and heavy-compaction method are applied in the experiment. The experiment results can be seen in Figs. (**5 & 6**).

From Figs. (**5** & **6**), in compaction property, quicklime-treated soil and white lime-treated soil are similar. In the case of best water content, both increase with the increase of lime ratio. The increase in amplitude of both is small and that of the white lime-treated soil is relatively larger. In the case of maximum dry density, both reduce with the increase of the lime ratio, but the reduction in amplitude of white lime-treated soil is larger.

3.4. Effect of Lime Ratio on CBR of High Liquid Limit Soil

According to the results of compaction test, prepare CBR soil sample. Make CBR specimen under different lime ratios with 93% degree of compaction in a CBR specimen maker. Equip percent meter for testing CBR swelling ratio on the specimen, then put them in flume to immerse for 4 days before the test. Test result shows that the value of CBR2.5 is smaller than the value of CBR5.0, which is proved again and again in the repeated tests. According to *Highway Geotechnical Test Regulation*(JTJ 051-93), the value of CBR5.0 can be regarded as the result of CBR test.

Fig. (**7**) reflects the relation between CBR5.0 value of lime-treated soil and lime ratio. The curves show: when lime is added into high liquid limit soil, CBR value increases obviously, and it increases with the increase of lime ratio. But under the same lime ratio, CBR value of quicklime-treated soil is larger than that of white lime-treated soil. When lime ratio is 3%, there is not much difference in CBR value of both soils. When lime ratio is higher than 3%, there is still obvious increase of CBR value of quicklime-treated soil with the increase of lime ratio, while the curve of CBR value of white lime-treated soil becomes flat and does not show much increase. Therefore, under the same lime ratio, CBR value of quicklime-treated soil is obviously larger than that of white lime-treated soil. From CBR test result, when lime ratio is 3%, CBR value of quicklime-treated soil is 10.6%, and that of white lime-treated soil is 9.4%, which both can meet the requirement for highway subgrade filling material.

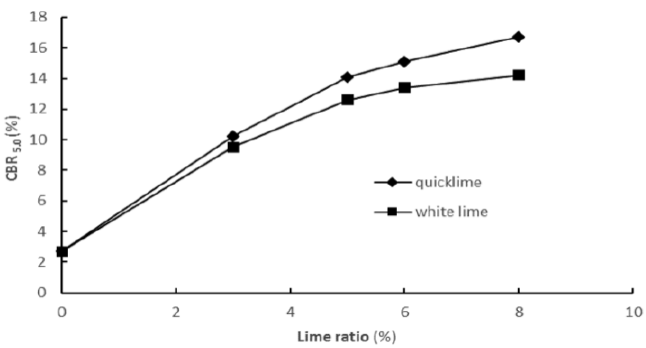


Fig. (7). Relation between CBR5.0 value of lime-treated soil and lime ratio.

CONCLUSION

By taking integrated analysis of the above test results, the following conclusions can be drawn:`

Indoor experiment and analysis indicate that high liquid limit soil has characteristics of high natural water content, big compressibility and poor permeability. The unconfined compressive strength and CBR strength of untreated high liquid limit soil is too low, and the compaction can hardly meet the required standard.

Experiment on adding lime to treat high liquid limit soil indicates, lime-treated high liquid limit soil reduces in plastic limit and plastic index, and increases in plastic limit greatly improves the strength index. Treated soil can easily meet the required compaction standard.

For the plastic index of quicklime-treated soil, the best lime ratio is 5%. When lime ratio reaches 5%, the reduction in amplitude of plastic index of treated soil is large; when the lime ratio is higher than 5%, the decreasing speed of plastic index slows down. 5% of lime ratio is not only economic and reasonable, but also meets the requirement for subgrade improvement and strength.

When lime ratio is 3%, there is not much difference in CBR value of both quicklime-treated soil and white lime-treated soil. When lime ratio is higher than 3%, there is still obvious increase in CBR value of quicklime-treated soil with the increase of lime ratio, while the curve of CBR value of white lime-treated soil becomes flat and does not show much increase.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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