Analysis of Mechanical Properties of Loess with Lime Incorporation Ratio

Tiehai Wu [1], Zhaofeng Jia [1], Baogui Rong [1, 2], Laishuan Zhao [1, 2]

[1] China Railway No.3 Bureau Group Investment Co., Ltd. Taiyuan, Shanxi,030006, China
[2] Tianshui Sanyangchuan Tunnel Traffic Engineering Co., Ltd. Tianshui, Gansu,741030, China

Abstract: Taking loess as the research object, the effect of lime content on mechanical properties of loess was studied. Firstly, the basic physical parameters of loess were obtained by laboratory physical index test and improved by lime. Secondly, the mechanical parameters of lime-modified loess were obtained by heavy compaction test and liquid-plastic limit test under different incorporation ratios (3%, 5%, 7%, 9%). Finally, the shear strength parameters and compressive strength of improved soil samples were obtained by unconsolidated and undrained triaxial shear test and unconfined compressive strength test respectively. The results showed that the liquid limit, plastic limit and plastic index of the loess improved by adding lime increased compared with the original soil sample, indicating that the binding force between soil particles was improved and the plasticity was enhanced. The variation range of dry density and water content had no obvious relationship with the dosage of lime. At the same time, the compressibility of soil is reduced and the collapsibility of soil is eliminated. With the increase of age, the strength of lime-modified soil also increases. Through unconsolidated and undrained triaxial shear tests and unconfined compressive strength tests, the strength of the loess improved by adding lime is significantly improved, and the strength of soil-cement increases with the increase of the dosage, and the water stability is obviously improved.

Keywords: Loess; Lime incorporation ratio; Mechanical properties.

1. Introduction

Loess refers to the yellow silt deposits transported by wind during the Quaternary Geological Age. There is a certain regularity in geographical distribution, mainly distributed in Shaanxi, Henan, Gansu and other regions. In soil classification, loess is often classified as "special soil", which is mainly attributed to two aspects. On the one hand, loess not only has strong hydrophilicity, adheres to the particle skeleton, but also has swelling and shrinking properties. Due to water swelling, the soil structure is softened, and the bonding capacity between particles is weakened, which improves the compressibility and strength of the soil. reduce. On the other hand, loess in its natural state has the characteristics of large void ratio and low density. When it encounters water, it will collapse rapidly, drop in strength, and increase in deformation[1].

Loess is widely distributed in China, especially in collapsible areas. Once it meets rain weather, a large amount of water penetrates into the soil, making the pore water pressure in the soil rise continuously, while the strength of the soil decreases continuously, which is easy to induce landslides, road subgrade collapse, uneven settlement of the foundation and other engineering accidents. Therefore, a large number of scholars have carried out research on the mechanical properties of loess. Du Jingfang[2] studied the variation rules of compression characteristics, shear strength and permeability of loess under dry-wet cycle through direct shear test. The experimental results show that the shear strength and its parameters decrease with the increase of the number of drying and wetting cycles and moisture content, and increase with the increase of moisture content. Wei Yao et al.[3] analyzed the influence of freezing temperature on mechanical properties of freezing-thawing loess by testing its unconfined compressive strength, shear strength and compressibility under different freezing temperatures. The test results show that the unconfined compressive strength of loess with different moisture content decreases after freezing-thawing at different freezing temperatures, and the cohesion of soil with different moisture content decreases with the decrease of freezing temperature. Fei Xiaoou et al.[4] conducted experimental studies on mechanical properties such as pore pressure dissipation and different water content in order to study the failure mechanism of loess foundation in the dump of open-pit coal mine under large area loading. The results show that the shear strength of loess decreases greatly with the increase of water content, and the change of water content and cohesion is log-linear. The dissipation degree of pore water pressure decreases with the increase of confining pressure, and the dissipation coefficient increases with the increase of water content, and presents the embrittlement failure phenomenon at low confining pressure. Shoubang Sun et al.[5] compared the vertical and horizontal shear strength differences of intact Q_4 loess samples through triaxial and direct shear tests. The results show that the shear strength of surrounding rock of Q_4 loess has obvious anisotropy. The internal friction angles of loess are basically the same in different directions. The vertical strength is generally greater than the horizontal strength. Leng Yanqiu et al.[6] studied the variation rules of structural strength, deformation modulus and strength parameters of intact loess under different moisture content through measuring instrument test and triaxial shear test. It is found that the yield stress, initial deformation modulus and cohesion of structure are sensitive to the water content. With the increase of initial water content, the yield stress, initial deformation modulus and cohesion of structure decrease by power function or exponential function. Kui Liu et al.[7] studied the effects of dry density and water content on mechanical properties of loess through shear strength and compressibility tests, and the results showed that: the lower the water content, the greater the impact of dry density change on cohesion. With the same dry density, the internal friction Angle of compacted loess decreases with the increase of water content. Xiangtian Xu et al.[8] studied the influence of water content on strength, stiffness and damage characteristics of frozen loess through triaxial compression and cyclic loading and unloading tests. The test results show that moisture content of frozen soil is an important factor affecting damage parameters during deformation. The effects of confining pressure on mechanical and damage properties of frozen loess are sensitive, indicating that the effects of water content and confining pressure are coupled. Taking loess as the research object, Shi Chang 'an[9] studied the influence of freezing-thawing cycle on mechanical properties of loess through triaxial test. The results show that the strength of soil decreases with the increase of the number of freezing-thawing cycles, and the influence on the strength decreases with the increase of the number of freezing-thawing cycles. When the water content is constant, the cohesion of loess decreases and the internal friction Angle decreases with the increase of freezing-thawing cycles.

In recent years, loess is the foundation of the industrial development in northwest China, as well as the source and basic conditions of building materials for highway transportation, water conservancy facilities and civil and industrial construction. In order to improve the strength of loess and meet the characteristics of compressibility, permeability and durability, the improved method is often used to meet the needs of practical engineering[10]. Therefore, a large number of scholars have carried out research on soil improvement. Yang Mei et al.[11], through the performance test of improving loess with lime, showed that adding lime into loess can effectively improve the properties and structure of loess, reduce the permeability and compressibility of loess, control the occurrence of its collapsibility, partially or completely eliminate the collapsibility, and thus improve the strength of loess. Tao Fujin[12] studied the physical properties, strength characteristics, water stability and strength variation rule of lime-improved loess under dry-wet cycles through laboratory tests and field tests. The results show that the control range of water content of lime-improved loess becomes wider with the increase of ash content. The shear strength of lime-modified soil increases with the increase of compaction coefficient. The compressibility decreases with the increase of compaction coefficient, mixing ratio and age. The cohesion of lime-improved soil increases with the increase of wetting and drying cycles, and its strength also increases significantly. Zhou Jianji et al.[13] took loess as the research object and analyzed the influence of different incorporation ratios of lime on improved loess performance through consolidation test. The experimental results show that with the increase of lime incorporation ratio, the compression coefficient of improved loess decreases first and then increases, and the permeability coefficient decreases first and then increases. The addition of lime can effectively improve the properties of loess, and the maximum improvement can be achieved when the lime incorporation ratio is 7%, so the best lime incorporation ratio is 7%. Wang Bo[14] studied the physical properties, stress-strain relationship and compression characteristics of lime-improved loess through indoor geotechnical tests and theoretical analysis. The results show that the maximum dry density of lime-improved soil decreases and the optimal water content increases with the increase of lime mixing ratio. The stress-strain curve of lime-modified loess has obvious stress peak point, and the lime-modified loess shows obvious brittle failure. Mr.li[15] through the red bed mudstone and lime improved soil compaction test, then consider the optimal moisture content and saturation moisture content without confining pressure, CBR and direct shear mechanics test, the results show that with the increase of the ratio of lime, improvement of red mudstone layer of optimum moisture content increases gradually, while the maximum dry density decreases. Wang Lixia et al.[16] explored the optimal incorporation ratio of lime-improved silty sand in the seasonally frozen zone under the condition of high temperature curing, based on the conventional triaxial unconsolidated and undrained (UU) shear test of lime-improved silty sand in the seasonally frozen zone with different freeze-thaw cycles. The results show that compared with plain soil, the cohesion, internal friction Angle and shear strength of lime-improved silty sand are significantly increased, and the increase is the largest when the lime incorporation ratio is 6%. Compared with lime improved silt, the cohesion, internal friction Angle and shear strength of fly ash/lime improved silt are improved to a certain extent, and the improvement is most obvious when the ratio of fly ash/lime improved silt is 4：1. Wang Lifeng et al.[17] discussed the yield characteristics of lime-improved soil through triaxial test, and established the elastic-plastic constitutive model of lime-improved soil. The results show that the improved lime soil with 10% cement ratio has higher shear strength. Liang Zhichao et al.[18] used unsaturated consolidation apparatus to conduct compression tests on lime improved loess, and studied soil-water characteristics, compression characteristics, humidification deformation and collapsibility deformation characteristics of lime improved loess with different lime content and dry density. The results show that the lime content has little effect on the soil-water characteristic curve of unsaturated loess, but the dry density has a great effect on the soil-water characteristic curve of lime-modified loess. Both the compression index and yield stress increase with the increase of suction. Under the same vertical pressure, the greater the initial suction, the greater the coefficient of collapsibility. Xu Zhijian[19] studied the strength and physical-mechanical variation of soft soil with different lime incorporation ratio, compaction degree and curing age. The results show that the improved soft soil with lime incorporation ratio of 6% has good road performance and can meet the requirements of design and economic benefit. Wei Jie[20] studied the settlement characteristics of lime-improved loess as subgrade material through tests on parameters such as unconfined compressive strength, springback modulus and compression consolidation. The results show that when the lime incorporation ratio is 6%, the workability and economy of lime soil are the best, and the compaction degree, bending modulus and rebound modulus of the roadbed meet the design requirements, which can effectively reduce the roadbed settlement.

By summarizing the research results of the above scholars, it is not difficult to find that the use of lime to improve the loess water stability, improve its strength, reduce its permeability, avoid the occurrence of engineering accidents, at the same time, has important theoretical and practical significance in engineering. In this paper, the influence of lime incorporation ratio on mechanical properties of loess was studied by compaction test, liquid-plastic limit test, consolidation test, collapsibility test, triaxial test and unconfined compressive strength test.

2. Physical Property

Loess is non-saline soil, and its physical parameters are shown in Table 1 through indoor parameter test. Grade ii calcareous quicklime is used for lime, and quicklime is used for self-digestion of hydrated lime. The physical and mechanical indexes are shown in Table 2.

Table 1 Physical parameters of loess

Liquid limit/%	Plastic limit/%	Plasticity index	Maximum dry density/(g/cm^3)	Optimum water content/%
29.2	19.8	9.4	1.880	14.3

Table 2 Physical and mechanical indexes of lime

Available calcium and magnesium oxide content	Water content	0.17mm Sieve allowance of square hole sieve	0.125mm Sieve allowance of square hole sieve
$\geq 60\%$	$\leq 4\%$	$\leq 1\%$	$\leq 20\%$

3. Mechanical Analysis

The methods of loess improvement mainly focus on physical improvement and chemical improvement. Physical improvement is to join the coarse particle in loess and the use of dynamic compaction, the compaction pile method such as physical soil compaction method to change the internal grain size distribution, particle arrangement and contact, increase the contact area between particles and reduce the pore volume, make the internal structure of soil tend to be more compact, thus achieve permeability, such as improving strength improvement purpose. Chemical modification is to improve the stability and strength of loess by adding a certain modifier to the loess, using the effect of modifier and water and the chemical reaction with soluble salt in the loess, to produce cementing material to fill the pores, change the soil particle composition and spatial structure, so as to improve the stability and strength of loess engineering properties. The commonly used improvers are mainly cement, lime, fly ash and other materials[21-24] to reduce the permeability of loess and improve the strength of loess.

Lime is a kind of gaseous inorganic cementitious material with calcium oxide as the main component. It is made of limestone, dolomite, chalk, shell and other products with high calcium carbonate content, calcined at 900~1100℃. Therefore, lime as a modifier, not only low cost, economic and environmental protection, and significant improvement effect, is widely used in construction engineering, water conservancy engineering and traffic engineering and other special construction engineering field. Since this paper studies the influence of lime incorporation ratio on mechanical properties of loess, the following tests will be carried out to analyze it[25] :

(1) Heavy compaction test and liquid plastic limit test were carried out by adding lime to the loess at the rate of 3%, 5%, 7% and 9% respectively.

(2) Improved soil specimens with corresponding density were prepared by pressing 95% compacting method and kept in a constant temperature and humidity curing box (chamber) with a temperature of 20±2℃ and humidity >90%. After keeping in good health, their compression coefficient, compression modulus and collapsibility coefficient were measured.

(3) Modified soil specimens with the corresponding density were prepared by pressing 95% compacty by hydrostatic method. The specimens were kept in a constant temperature and humidity curing box (chamber) with a temperature of 20±2℃ and humidity >90%, and their unconsolidated and undrained triaxial shear strength was measured after 28 days of curing.

(4) 39.1×80 mm specimens were prepared by pressing 95% compactness method, kept in a constant temperature and humidity curing box (chamber) with a temperature of 20 ±2℃ and humidity >90%, and their water-soaked and unconfined compressive strength without water-soaked for 7 days were measured (water-soaked means that the specimens were taken out one day before they reached age. The specimen was immersed in water at a temperature of 20 ±2℃ for 24h).

3.1 Beating Experiment

Beating experiment is a basic method to study the compactability of fine grained soil in laboratory. The dry density and moisture content of the soil samples were measured by heavy-duty compactor. By changing the moisture content and repeating the test, the compaction curve is obtained and the maximum dry density and optimal water content of soil samples are obtained, among which the maximum dry density and optimal water content are the necessary conditions for controlling the quality of subgrade filling. The results of compaction test are summarized in Table 3.

Table 3 Results of compaction test and liquid plastic limit test

Soil sample	Liquid limit/ %	Plastic limit/ %	Plasticity index	Maximum dry density/ (g/cm^3)	Optimum water content/ %	Dry density /(g/cm^3)	Dry unit weight / (kN/m^3)
3% lime soil	36.6	22.9	13.7	1.760	15.6	1.672	16.386
5% lime soil	36.1	22.5	13.6	1.772	15.9	1.683	16.497
7% lime soil	36.0	23.5	12.5	1.740	15.8	1.653	16.199
9% lime soil	36.1	23.8	12.3	1.753	15.8	1.665	16.320

3.2 Liquid Limit-Plastic Limit Joint Test

Liquid limit is the limit water content of soil sample when it transitions from plastic state to flowing state. Plastic limit is the limit water content of soil sample from plastic state to semi-solid state. Liquid and plastic limits are important physical characteristics of clay and reflect the degree of interaction between soil particles and water. In engineering practice, the exact value of liquid-plastic limit index directly affects the determination of soil name and bearing capacity of corresponding soil foundation, and indirectly reflects the engineering properties of soil samples. The liquid limit, plastic limit and plastic index of the modified filler were obtained through the liquid plastic limit test. The results of liquid plastic limit test are summarized in Table 3, in which the dry density is 95% of the maximum dry density.

It can be seen from Table 3 that the maximum dry density and optimal water content do not change significantly after the addition of lime with different incorporation ratios in loess, and the maximum dry density and water content are found at 5% lime incorporation ratio. The liquid limit and plastic limit of the improved soil decreased with the increase of lime incorporation ratio, and both increased compared with the original soil sample, indicating that the adhesion between soil particles was improved and the plasticity was enhanced after the addition of lime. The plasticity of the improved loess with 3% lime incorporation ratio was the strongest.

3.3 Consolidation Test, Loess Collapsibility Test

Consolidation test refers to the compression test to determine the saturated clay sample under the condition of confining pressure. Compressibility of soil is mainly caused by the reduction of pore volume. Therefore, the relationship between pressure and sample deformation or pore ratio is measured through consolidation test, so as to calculate the compression coefficient and compression modulus of soil sample. The test results are shown in Table 4.

Loess collapsibility is the process of loess compression and collapsibility deformation under certain pressure and water immersion. The collapsibility coefficient of loess can be obtained through loess collapsibility test, and the results are shown in Table 4.

Table 4 Results of consolidation test and loess collapsibility test

Soil sample	Degree of compaction /%	Curing age：1d			Curing age：7d		
		Compression coefficient /MPa-1	Compression modulus /MPa	Collapsible coefficient	Compression coefficient /MPa^{-1}	Compression modulus /MPa	Collapsible coefficient
Original soil sample		0.18	10.6	0.026			
Compaction of soil samples	95	0.10	15.0	0.000	0.09	16.2	0.000
3% lime soil	95	0.08	20.3	0.000	0.08	20.1	0.000
5% lime soil	95	0.08	20.0	0.000	0.08	20.3	0.000
7% lime soil	95	0.08	20.6	0.000	0.06	27.0	0.000
9% lime soil	95	0.08	23.1	0.000	0.07	22.9	0.000

As can be seen from Table 4, compared with the original soil sample, the compression coefficient of the improved soil sample decreases and the compression modulus increases, indicating that its compressibility decreases. Meanwhile, the collapsibility of the improved soil sample is eliminated, and the relationship between the change range and the incorporation ratio is not obvious. With the increase of health age, the compression coefficient decreases and the compression modulus increases with the same incorporation ratio of lime-improved soil, indicating that the strength of lime-improved soil increases slightly.

3.4 Unconsolidated and undrained triaxial shear test

The unconsolidated and undrained shear test, also known as the fast shear test, does not allow the sample to drain during the process of applying confining pressure and increasing axial pressure until the specimen is broken. The shear strength parameters, namely c and φ, can be obtained through the test. The index parameters of soil shear strength are an important index to determine the bearing capacity of soil. Therefore, it is of great significance to accurately measure the index parameters of soil shear strength for engineering design and construction. The results of unconsolidated and undrained triaxial shear test are summarized in Table 5.

Table 5 Results of unconsolidated and undrained triaxial shear test

Soil sample	Degree of compaction/%	Curing age/d	Internal friction angle/(°)	Cohesion/(kPa)
Original soil sample			31.2	21
Compaction of soil samples	95	28	35.6	34
3% lime soil	95	28	36.5	84
5% lime soil	95	28	36.9	222
7% lime soil	95	28	39.7	125
9% lime soil	95	28	45.0	121

As can be seen from Table 5, the improved soil specimen prepared by pressing 95% compaction was kept in a curing box (chamber) with a temperature of 20±2℃ and humidity >90% for 28 days. The internal friction Angle increased with the increase of cement incorporation ratio, and the cohesion showed a trend of first increasing and then decreasing. Among them, the cohesion was the largest at 5% lime incorporation ratio.

3.5 Unconfined Compressive Strenght Test

Table 6 Unconfined compressive strength test results

Soil sample	Degree of compaction/%	Curing age/d	Unconfined compressive strength during immersion/kPa	Unconfined compressive strength without flooding/kPa	Strength degradation /%
Original soil sample			0	100	100
Compaction of soil samples	95	7	0	387	100
3% lime soil	95	7	337	605	44
5% lime soil	95	7	426	782	46
7% lime soil	95	7	416	843	51
9% lime soil	95	7	378	855	56

The unconfined compressive strength test is a special case of the triaxial test, that is, the soil sample is subjected to the pressure test under the condition of no lateral limitation, so as to obtain the ultimate strength of resisting axial pressure, that is, the unconfined compressive strength. The unconfined compressive strength test results are summarized in Table 6.
From table 6 unconfined compressive strength test results can be seen that the degree of compaction (95%) cases, lime improved soil under the condition of standard curing and dry-wet circulation and saturated 7 d of unconfined compressive strength increase significantly with the increase of the cement mortar, the water stability are improved obviously, flooding after 24 h the unconfined compressive strength attenuation 44% ~ 56%, Except that the strength attenuation rate of modified soil mixed with 9% lime is slightly higher, the other attenuation rates are relatively small. Among them, the improved soil sample with 3% cement incorporation ratio has the lowest strength attenuation, indicating that water stability is the strongest.

4. Conclusion

In this paper, loess is taken as the research object. Firstly, the basic physical parameters of loess are obtained through laboratory physical parameter test. Secondly, the loess was modified by adding different doses of lime (3%, 5%, 7%, 9%). The mechanical parameters of the loess were measured by compaction test, liquid-plastic limit test, consolidation test, collapsibility test, triaxial test and unconfined compressive strength test. Finally, the influence of lime incorporation ratio on mechanical properties of loess is studied through data analysis. The results show that:
(1) Compared with the original soil sample, the liquid limit, plastic limit and plastic index of the loess improved by adding lime increased, indicating that the binding force between soil particles was improved and the plasticity was enhanced. The variation range of dry density and water content had no obvious relationship with the incorporation ratio.
(2) After adding lime to the loess, the compressibility of the soil is reduced and the collapsibility of soil is eliminated; With the increase of age, the strength of lime-modified soil also increases.
(3) Unconsolidated and undrained triaxial shear tests show that the strength of loess improved by adding lime;
(4) The unconfined compressive strength test shows that the water stability of loess improved by adding lime is obviously improved.
In conclusion, after adding a certain proportion of lime into the loess, the properties of the soil are greatly improved, which can improve the strength and water stability of the soil, reduce the compressibility of the soil and eliminate the soil collapsibility.

Reference

1. Zhang Xuejiao. Experimental study on permeability and mechanical properties of lime improved loess [D]. Guangdong University of Technology,2020.
2. Du Jingfang. Study on mechanical properties and slope stability of remolded loess under dry-wet cycle [D]. Taiyuan University of Technology,2020.
3. Wei Yao, Yang Genshe, Ye Wanjun. Journal of Yangtze river scientific research institute, 2018,35(08):61-66.
4. Fei Xiaoou, Miao Haibin, Wang Jianguo. Experimental study on mechanical properties of loess under large area loading [J]. Coal mine safety, 2016,47(12).
5. Shoubang Sun,Xiaoping Cao. Study on Physical and Mechanical Properties of Q4 Loess in Lanzhou Rail Transit Area [J]. Recent Patents on Engineering, 2021,15(4).
6. Leng Yanqiu,Peng Jianbing,Wang Shuo,Lu Feng. Development of water sensitivity index of loess from its mechanical properties[J]. Engineering Geology, 2021,280.
7. Kui Liu,Liu Kui,Yuan Kang ze,Wu Kai. Effect of Water Content and Dry Density on Mechanical

Properties of Compaction Loess[J]. IOP Conference Series: Earth and Environmental Science, 2020, 598(1).

8. Xiangtian Xu, Qionglin Li,Ying Lai,Wentai Pang,Ruiping Zhang. Effect of moisture content on mechanical and damage behavior of frozen loess under triaxial condition along with different confining pressures[J]. Cold Regions Science and Technology,2018.
9. Shi Chang'an. Experimental study on the effect of freezing-thawing cycle on mechanical properties of loess [D]. Xijing University,2019.
10. Li Lei. Experimental study on mechanical properties and structure of loess modified by silica powder [D]. Xi 'an University of Technology, 2019.
11. Yang Mei, Liu Yonghong. Experimental study on the performance of loess modified by adding lime [J]. Subgrade Engineering,2007(01).
12. Tao Fujin. Experimental study on lime modified loess filler for passenger dedicated line [J]. Journal of lanzhou jiaotong university,2011,30(06).
13. Zhou Jianji, Liang Jiyun, Zhang Fangyu, Wu Wanjiong, Yan Xude. Experimental Study on Engineering Characteristics of Lime Modified Loess [J]. Railway Construction, 2014(09).
14. WANG Bo. Experimental Study on Lime Improved Soil of Highway Subgrade [J]. West Transportation Science and Technology, 2016(03).
15. Li Junfeng. Experimental study on mechanical properties of red mudstone soil modified by lime under different water content [J]. Urban Roads, Bridges and Flood Control, 2021(04).
16. Wang Lixia, Han Bing, Zhang Yunlong, Wang Jing, Sun Shuang, Zhang Xinyue. Journal of jilin jianzhu university, 2020, 37(01).
17. Wang Lifeng, Xie Xirong, Wang Tian. Mechanical properties and constitutive model of lime-improved soil [J]. Chinese science and technology bulletin, 2019, 35(11).
18. Liang Zhichao, Hu Zaiqiang, Guo Jing, Wang Kai, Feng Zhe, Zheng Haicheng. Journal of hydroelectric engineering, 2020,39(03).
19. Xu Zhijian. Experimental study on the Performance of lime improved silty soft soil Road [J]. Traffic Construction and Management,2019(03).
20. Wei Jie. Experimental study and engineering application of lime improved loess performance [J]. Heilongjiang Transportation Science and Technology, 201, 44(02).
21. Xue Huike. Experimental analysis on the effect of fly ash, lime and cement to improve loess filling [J]. Science and Technology Vision,2016(14).
22. Alireza Tabarsa,Nima Latifi,Christopher L. Meehan, Kalehiwot Nega Manahiloh. Laboratory investigation and field evaluation of loess improvement using nanoclay – A sustainable material for construction[J]. Construction and Building Materials, 2018.
23. Brian G Palmer,Tuncer B Edil,Craig H Benson. Liners for waste containment constructed with class F and C fly ashes[J]. Journal of Hazardous Materials,2000,76(2).
24. Phongthorn Julphunthong. Chemical Stabilization of Loess in Northeast Thailand Using the Mixture of Calcined Marble Dust Waste and Sugarcane Bagasse Ash Waste[J]. Geotechnical Engineering Journal of the SEAGS & AGSSEA,2015,46(1).
25. Ji lei. Performance test of loess improvement soil [J]. Railway survey, 2009, 35(05).