THE TREATMENT OF COLLAPSIBLE LOESS EMBANKMENT IN LANZHOU AREA

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Abstract: *With the development of economics, the city of Lanzhou, which locates in the loess area in china, need to construct many municipal roads. Some of embankments are relatively high. This research studies a typical project in Lanzhou, and compares three different treatment approach, such as treatment of roadbed using gravel and lime, treatment of roadbed using lime, and treatment of embankment using lime. The indoor test, numerical simulation and field test are employed in this research. After 5% lime added in the loess, the performance of high embankment is acquired. The proposed treatment method for different heights of embankment is recommended, and now is promoted in collapsible loess area in Lanzhou. Through field observation in 1a after the traffic opening, the law of settlement is verified. The conclusion is helpful to improve the treatment technology and proposed to the revision the specification of collapsible loess in china.*

Key word: *Loess treatment, lime treatment, high embankments, FEM*

I. INTRODUCTION

The improved soil is popularized in highway and railway engineering projects in recent years [8, 18]. During the construction of roadworks in Lanzhou, high embankment is usually encountered in these projects. Loess has the characteristics of high porosity ratio, poor water stability and easily collapse. It cannot directly be used as construction material on site and must be improved to be a high stranded road construction material.

There are some ways to treat loess, such as cement, fly ash and lime etc. [1, 4, 6, 7, 14, 16, 19, 21]. Researcher discussed about the cement treatment methods [9, 11], Some scholars even add some fiber to enhance the property of loess and discuss its structural properties [10, 22]. Several studies focused on the slope stability of lime [12, 13]. Sungjin Lim compared the Engineering properties of water/wastewater-treatment sludge modified by hydrated lime, fly ash and loess in laborary [1]. In 1991, Ali tried to find a way of using rice husk ash to enhance lime treatment of soil, and evaluated the effectiveness of using RHA as a pozzolan to enhance the lime treatment of the soil [4]. Ian Jefferson test the engineer property of collapsible loess soils using cement materials [6]. GUO Nai-zhen did some research of test and simulation on dynamic compaction in high roadbed (2007) [26]. Li ping made some contribution Experiment of CBR value of loess subgrade improved with quick lime and its application [5]. All the researches which has been down just discussed the mechanism of measures, all what they have done haven't compared the treatment methods using gravel and lime with different height of embankments and some investigators did not commit a relatively long field observation. This project chooses three different experimental section in three different roads in the new district of Lanzhou, and the period of observation is every 14 days. The parameters are tested in the laboratory precisely, and those parameters is helpful in the procession of numerical simulation. The factor of safety (FOS) and settlement of embankments works as important assessments methods. After comparison has been accomplished, the suitable suggestion of treatment is proposed and promoted to the whole area of Lanzhou.

II. INDOOR TESTING

The characteristics of collapsible loess soil is very complex, and testing in laboratory is essential to acquire the parameters needed in the numerical simulation [15]. By the oven drying method, the moisture content of soil specimen is tested. the absolute error is less than 0.01% and it satisfies the road specification in china. The relative density is about 2.68 g/cm^3. The liquid limit and plastic limit of loess is 12.5 and 29.8 respectively. The plasticity index is about 17.3 [25].

Fitting the dots of geo-technical compaction data with multi-nominal interpolation method, the multi-nominal of water content was obtained. The maximum dry density and optimum water content were obtained by calculation and comparison of each dot. The compaction test get a chart as follows, optimum water rate is about 13.1%, and the maximum dry density is 1.802g/cm^3 [5].

The Engineers on site did a series test, and the result of best rate of lime weighs to soil is 5% [2]. The compaction curves show that after adding lime, the optimum moisture content has increased, while the maximum dry density shows reduction. After treatment, the optimum moisture content was 13.9%, increased 5.79% than treated before. After treatment, the maximum dry density of loess is 1.754g / cm^3, decreased 2.77% than before treatment. From the compaction curve, it shows that the range of optimum moisture content becomes larger than untreated loess. This will be beneficial to site construction [23, 24].

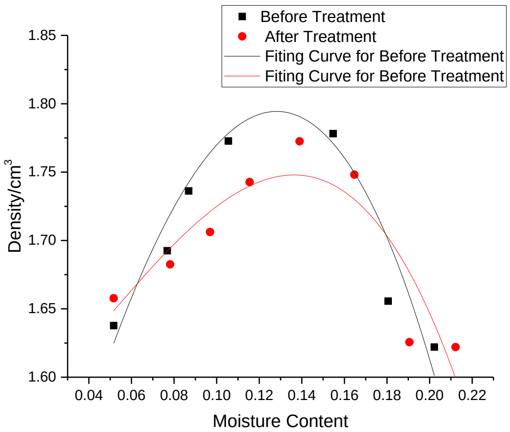
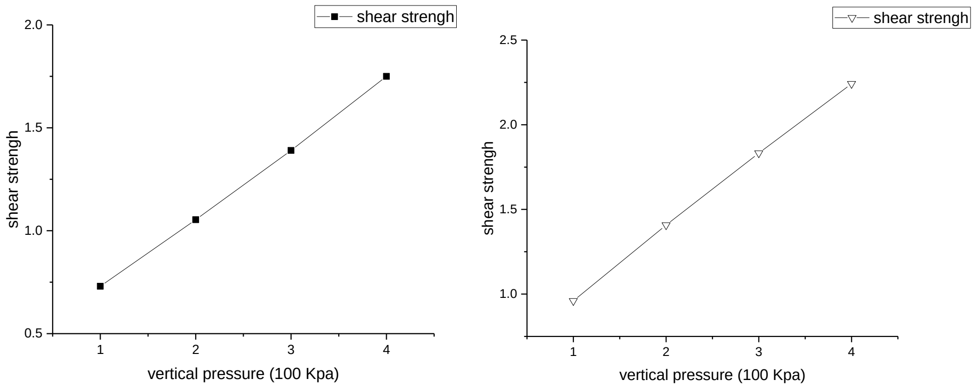


Figure 1. *Compaction Curve of Loses*

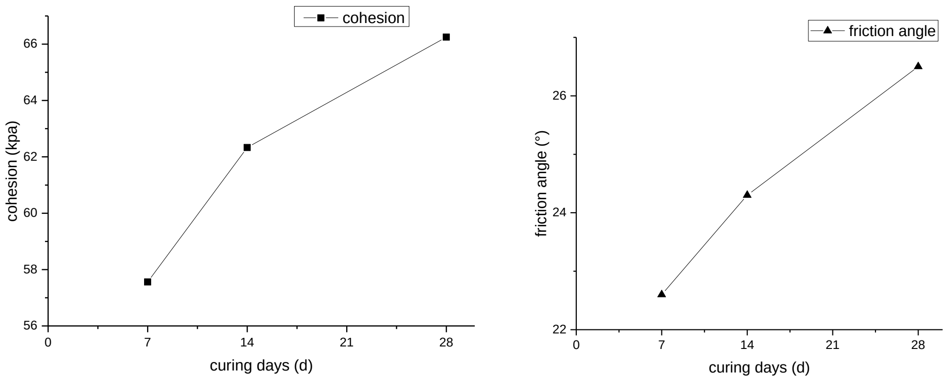
As Fig 1 shown, after the measured compaction factor of 96% has achieved, the cohesion of disturbed soil is about 40.67kPa and the internal friction angle is17.9 ° by direct shearing tests.



a) Loess Shear strength before treatment *b) Loess Shear strength after treatment*

Figure 2. *Direct shear test of Loess soil*

Experimental results also show that after adding lime the effect of age has a greater impact on shear strength and the friction angle [20]. Both cohesion and friction angle show nonlinear growth, and the growth rate tends to slowing. The initial test is about 7days curing. After 14 days curing, cohesion has improved 8.28% than that of 7 days. Similarly, the cohesion after 28 days curing raised 15.07% comparing to 7 days. After 14 days curing friction angle was raised 7.52% than 7 days. After 28 days curing friction angle of the treated loess improved 17.25% than 7 days curing.



a）Cohesion changes by days *b) Friction angle changes by days*

Figure 3. *Direct shear test with age*

For loess, self-weight collapsible coefficient is a very important parameter to discriminate its properties. Self-weigh collapsible tests showed that adding lime is helpful to reduce the self-weight collapsible coefficient, to a certain extent, weakened its collapsibility. Normally, applying 200kpa pressure by steps is a good approach to assess loess collapsibility. If the result of collapsibility coefficient greater than 0.015, it could be distinguished as collapsible loess in projects. As can be seen from figure 3, after adding lime the collapsibility coefficient of loess has been greatly reduced by 67.5%.

Table 1. *The collapsible coefficient of disturbed loess*

Load/kpa	Sample 1	Sample 2	Sample 3	Average
12.5	0.0012	0.0007	0.0009	0.0009
25	0.0052	0.0062	0.0075	0.0063
50	0.0083	0.0094	0.0085	0.0087
100	0.011	0.012	0.011	0.011
200	0.015	0.016	0.018	0.0163

Table 2. *The collapsible coefficient of treated loess*

Load/kpa	Sample 1	Sample 2	Sample 3	average
100	0.004	0.002	0.003	0.003
200	0.005	0.007	0.005	0.006

California Bearing Ratio (CBR) has been commonly accepted and used as an indication of resistance and stability of subgrade all over the world. The chemical reaction occurred between lime and loess after the addition of lime [7]. CBR value shows a rapid growth, reaching 3 times than the original. Adding lime improves the bearing capacity and deformation resistance of the embankment effectively, and may be helpful to increase the safety and long-term service behavior.

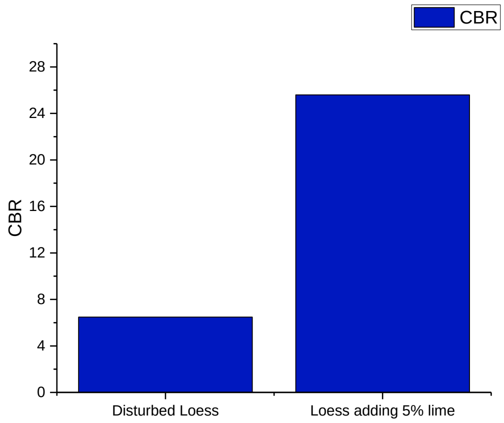


Figure 4. *CBR test results*

III. NUMERICAL SIMULATION

Based on the results of indoor test, comparison has been made between before treatment and after treatment. Due to many conditions, an optimized solution could be found to guide construction by comparison different treatment ways [3].

3.1. Slope stability analysis and elasto-plastic analysis

In the model, four working conditions are considered. The first one is that full section is untreated, and the second one is that full section is treated by 5% lime. The third one is that only roadbed section is treated, and the fourth one is that upper roadbed is treated with gravel while the lower part is treated with lime.

A model for the typical working conditions was established. Suppose an embankment have different heights under different situations, and compares those treatment methods. The section of K18+770 was chosen to analysis the stability of embankment. Then a recommendation could be made to help the Engineers on site.

Table 3. *Material Parameters in FEM*

Parameters	E/MPa	Density/kg.m3	poisson ' s ratio	c/kPa	φ/°
Before Treatment	35.2	1985	0.3	40.67	17.9
After Treatment	45.4	1900	0.3	57.56	22.6

After initial calculation finished, reset displacement to be zero and construction of embankment by stages. Displacement contour of embankment under its own weight can be acquired from the calculations.

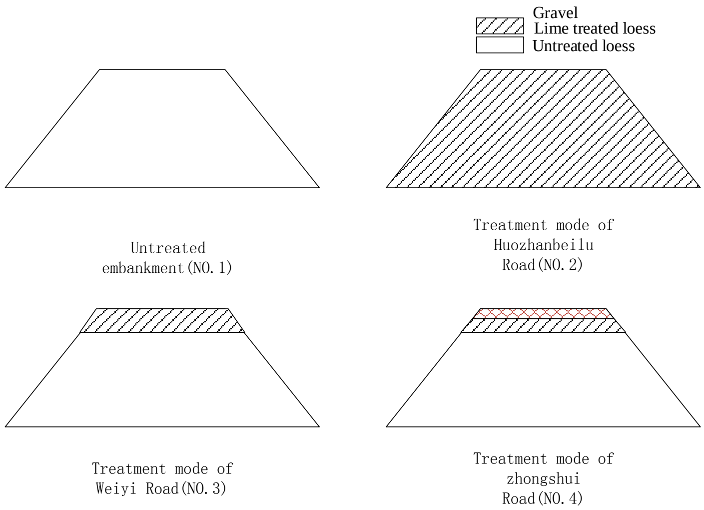


Figure 5. *The treatment ways*

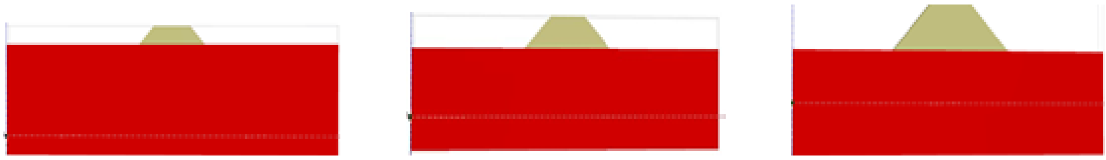
The section of embankments are filled by different construction materials and method. It might influence the performance of subgrade. Comparing with the untreated loess embankment, the deformation of huozhanbeilu road,weiyi road and zhongshui road is reduced respectively by 16.35%, 12.64% and 8.18%. With respect to factor of safety (FOS), the FOS of huozhanbeilu road,weiyi road and zhongshui road is decreased respectively by 7.65% and 5.04%,while the FOS of zhongshui road is similar to that of untreated one. Calculation result demonstrates that adding lime to the loess is very helpful to improve and enhance the plastic deformation and FOS of embankment. The full section treatment method, which huozhanbeilu road was applied, shows this method is the best among those methods.

Table 4. *Settlement and FOS calculation result*

Situation	Before treatment	Huozhanbeilu Way of treatment	WeiyiluWay of treatment	Zhongshui Way of treatment
Settlement/m	0.0269	0.0225	0.02350	0.02494
FOS	2.125	2.925	2.232	2.176

3.2 Influence of filling height

Considering that many roads are going to build and the height of those roads might be different. under embankment heights of 5m, 10m, 15m respectively.



(a) H =5m (b) H =10m (c) H =15m

Figure 6. *FEM Model of calculation*

Similarly, embankment of different heights need to be compared regarding the FOS and maximum displacement contour. Choosing the height of 5m, 10m, 15m embankment as examples. As mentioned before, the treatment conditions were in four ways: NO.1-without any Treatment; NO.2 lime improved loess of the whole section; NO.3- only top 80cm (road bed portion) treating with lime; NO.4- only treating road bed, top 30mm with gravel and lower 50 cm with lime.

According to calculation results, the following conclusion could be acquired: for embankment height more than 10m, the NO.1 method is recommended; in terms of embankment less than 10m but more than 5m, if the FOS is satisfied, NO.2 method is recommended. For embankment less than 5m, more attention should be paid to the quality of filling materials and compaction than other factors.

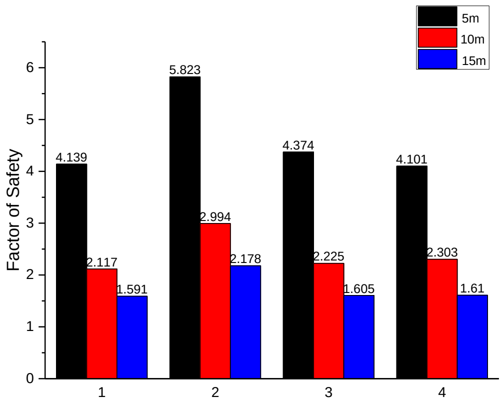


Figure 7. *Slope Stabilization*

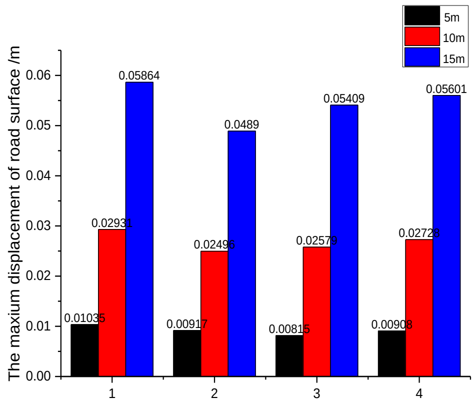


Figure 8*. The maximum displacement of road surface (unit/m)*

IV. FIELD OBSERVATIONS

The loess is widely distributed in Lanzhou area. It forms collapse deformation easily, resulting in the occurrence of uneven settlement of foundation and affecting the stability of the roadbed and bridge foundation. By monitoring the settlement of embankment, several targets could be made.

4.1. Site information

For huozhanbeilu road, the selected monitoring stations is K16 + 680 ~ K16 + 750 segments and K19 + 440 ~ K19 + 490 segments. Monitoring observation period is every14 days.

Monitoring points are arranged at Stake for K16 + 688, K16 + 740, K19 + 440, K19 + 480 four sections. Set up five deformation observation post on each cross-section.

For Weiyi road, K4 + 080 ~ K4 + 150 section and K5 + 410 ~ K5 + 470 segments are selected Monitoring points are arranged at Stake for K4 + 100, K4 + 140, K5 + 420, K5 + 460 four sections, set up five deformation observation post on each cross-section. Referring to the drawings. Monitoring observation period is also every14 days.

For zhongshui road, K9 + 710 ~ K9 + 770 segments and K10 + 330 ~ K10 + 390 segments are selected Monitoring points. Monitoring observation period is also every 14 days.

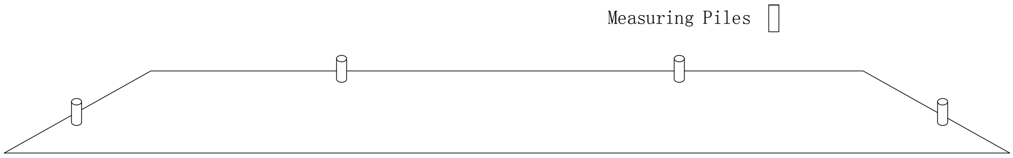


Figure 9. *Schematic diagram of embankments*

a) Measuring piles on site *b)Technicians on site*

Figure 10. *Measuring on site*

4.2. Field test results

4.2.1. Huozhanbeilu Road

The observation starts at 30th March 2015.Both K16+690 and K160+740 segments have four monitoring piles. The figure below shows that the differences among those piles are minor, and the mixium settlement is about 14mm. At K16+690 section the differential settlement is also not very large. This results show that after 8 months, the huozhanbeilu road becomes stable, and the treatment approach shows its priority.

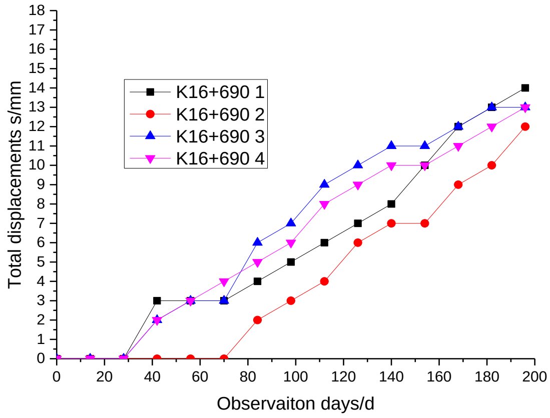


Figure 11*. Field observation of K16+690*

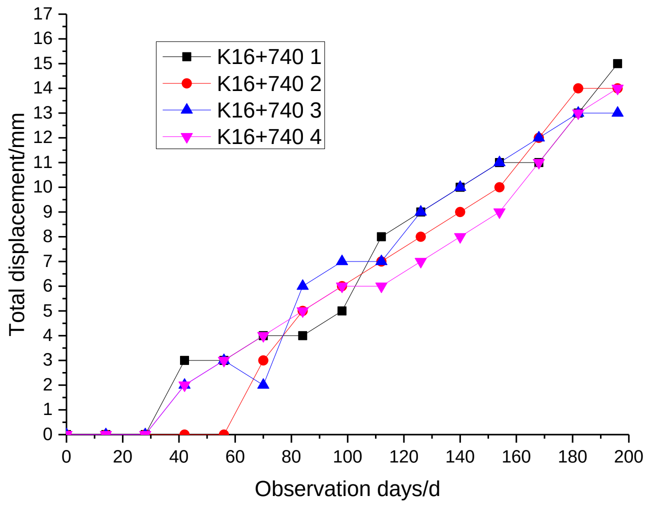


Figure 12. *Field observation of K16+740*

4.2.2. Weiyi Road

The observation starts at 14th March 2015.The treatment only applies at the roadbed part. Compares with huozhanbelu road, the deformation is much larger than that of huozhanbeilu road. The maximum displacement is 36mm, 2 times than that of huozhanbeilu road.

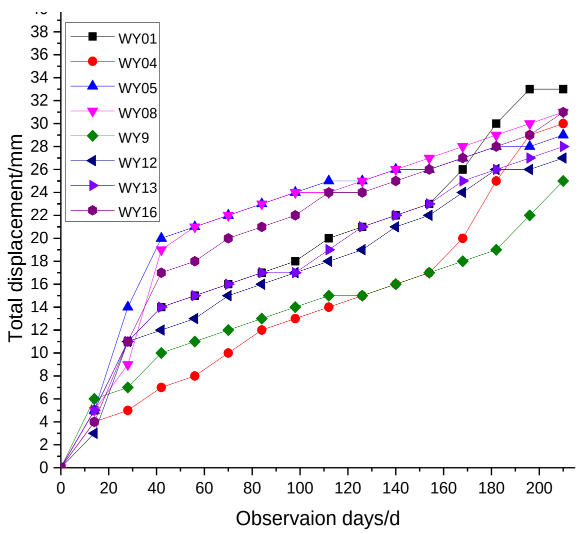


Figure 13. *Field observation of Weiyi road*

4.2.3. Zhongshui Road

The observation starts at 12th April 2015.The treatment only applies at the roadbed part.Compares with huozhanbelu road,the deformation is much larger than that of huozhanbeilu road.The maximum displacement is more than 60mm,but most of the figures is 40mm,and it is a little larger than that of weiyi road.

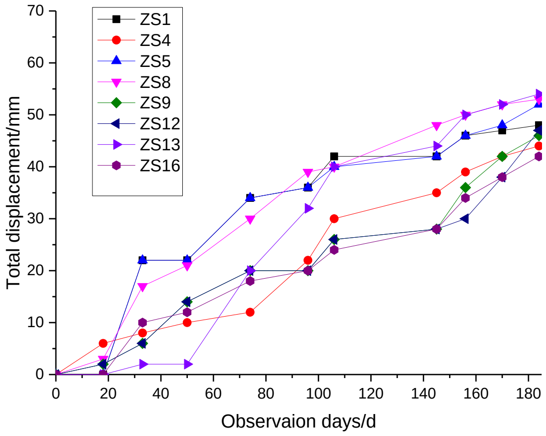


Figure 14. *Field observation of zhongshui road*

V. CONCLUSION

Based on this project, the following conclusion could be acquired.

(1) The compaction curves show that after adding lime, the optimum moisture content has increased, while the maximum dry density shows a little reduction. After treatment, the optimum moisture content was 13.9%, increased 5.79% than treated before. Before treatment, the maximum dry density of loess 1.754g / cm^3, and it decreased 2.77% after treatment. From the compaction curve, it shows that the range of optimum moisture content becomes larger than untreated loess. This will be beneficial to site construction. The compaction properties of loess didn't show much difference between before treatment and after treatment

(2) Both cohesion and friction angle show nonlinear growth, and the growth rate tends to slowing. The initial test is about 7days curing. After 14 days curing, cohesion has improved 8.28% than that of 7 days. Similarly, the cohesion after 28 days curing raised 15.07% comparing to 7 days. After 14 days curing friction angle was raised 7.52% than 7 days. After 28 days curing friction angle of the treated loess improved 17.25% than 7 days curing.

(3) After adding lime, CBR value shows a rapid growth, reaching 3 times than the original. Adding lime improves the bearing capacity and deformation resistance of the embankment effectively, and may be helpful to increase the safety and long-term service behavior.

(4) For embankment height more than 10m, the NO.1 method is recommended; in terms of embankment less than 10m but more than 5m, if the FOS is satisfied, NO.2 method is recommended. For embankment less than 5m, more attention should be paid to the quality of filling materials and compaction than other factors.

(5) Field test also prove that the NO.2 method is better than NO.3 method and NO.4 method. Adding lime is helpful to the performance of road.

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