CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors:Tichun Wang, Hongyang Zhang, Lei Tian

ISBN978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651027

Experimental Study On Chemical Consolidation Of Expansive Soil Subgrade

Xinzheng Wang*[a], Jian Zhang[a], Ping He[b]

[a]Acadedemy of Civil Engineering and Architechure, Nanyang Normal University, Nanyang 473061,China
[b]Acadedemy of Art and Design, Nanyang Normal University, Nanyang 473061,China
wxz791023@126.com

Much attention on the use of expansive soils has been paid because of the special engineering characteristics and morphology and the damage effects as well. Many methods have been used to reduce the damage effects caused in the application of expansive soils during recent years. One of the effective methods is the chemical consolidation due to high cost-performance ratio. Testing specimens are subjected to physical properties, compaction, free swell index and swell potential, swelling pressure, and unconfined compressive strength tests in laboratory. The paper contrasts and analyses the relationship between the optimum water content, the maximum dry unit weight, the unconfined compressive strength and CBR with different ratio of added lime after expansive soils have been improved. The experiment confirms the optimal ratio of added lime and the result of the experiment is significant to similar projects.

1. Introduction

Expansive soil is composed of a great deal of strong hydrophilic clay minerals, such as montmorillonite and illite, it has much character, such as expansive construction, many cracks, strong expansive and contraction, intensity decadence(Liao,1984). Engineering damages happen frequently for highway construction in expansive soil areas, such as pavement crack, subsidence, bump, side slope collapse, and embankment instability. According to regulations on subgrade filler in expansive soil areas in the Specifications for Design of Highway Subgrade, expansive soils are forbidden to be used as subgrade filler in principle, especially for high-strength expansive soils. If medium-strength expansive soils or weak expansive soils have to be used because of limited conditions, it is necessary to test the used soil to find corresponding treatment measures in case those bad consequences emerge after construction(Kong, 2004; Hui, 2005; Yang, 2011).

The common improvement method for expansive soils is chemical modification. Some materials, such as lime, cement, fly ash, chloride, asphalt, synthetic of curing agent and synthetic resin etc are blended with expansive soils for a series of physicochemical reaction, aiming to reduce swelling potential of expansive soils, enhance soil strength and water stability, and improve the mechanical properties as well. Considering the improvement effect and economic cost of the improved agent, lime-improved expansive soils are verified to be more economical and effective method to improve the treatment of expansive soil. The paper undertook experimental research on the subgrade filler of expansive soils in LuoYang-NanYang Highway construction. The results will serve as reference and guidance for future highway engineering and other construction work in expansive soil areas(Yang, 2007; Bian, 2016; Wang, 2014; Lu, 2009).

2. Improvement mechanism of lime improved expansive soil

As an inorganic cementing material, lime can harden in either air or water. The property of lime is determined by the contents of CaO and MgO. The higher the contents, the greater the activity, and the stronger the cementing capacity is as well. Both the physical reaction and the chemical reaction were happened during the process of lime treatment, the two kinds of reactions makes the soil properties change radically(Li,1992; Huang, 2009; Li, 2005; Lian, 2011).

(1)Lime nitration. Quick lime is decomposed and transformed into $Ca(OH)_2$ and heat is released at the same time. The reaction results are: one is Cao nitrification process reduces the expansive soil moisture content;

second is the formation of $Ca(OH)_2$ volume increased nearly doubled. Both the results help agglomerate and strengthen expansive soils. The relative equation is:

$$CaO + H_2O \rightarrow Ca(OH)_2 \tag{1}$$

(2)Cation exchange. Under the influence of soil water, quick lime is decomposed rapidly and transformed into $Ca(OH)_2$ and a little $Mg(OH)_2$, following the further dissociation of Ca^{2+} and Mg^{2+}. Ca^{2+} and $Mg^{2+}$are exchanged with Na^+, K^+ and H^+ on the surface of soil particles, entailing thinned diffusion layer of the double-layer soil colloid. Also, the infiltrated swelling volume is lowered, the bonding force between soil particles is enhanced, and the soil mass strength is improved as well. Therefore, the subsequent fast agglomerations of soil particles help improve preliminary soil mass strength. This reaction can be expressed in the following formula:

$$Na^+ - Al_2[Si_4 0_{10}](OH)_2 \cdot nH_2O + Ca^{2+} \rightarrow Ca^{2+} - Al_2[Si_4 0_{10}](OH)_2 \cdot nH_2O + Na^+ \tag{2}$$

(3)Carbonation. The generated $Ca(OH)_2$ and $Mg(OH)_2$ in the soil can further react to CO_2 to form rough solid $CaCO_3$ and $MgCO_3$ solid particles, with high strength and water stability. Soil cementation by $CaCO_3$ reinforces the soil mass to form lime-stabilized soil; the strength of the lime soil is gradually strengthened. Relative reaction can be expressed as:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \tag{3}$$

(4)Gelling reaction. After the cation exchange, lime reacts to SiO_2 and Al_2O_3 in the soil mass to form complicated composite including calcium metasilicate and calcium aluminate. In this process, strong cementation happens. The content of clayey minerals with water-swelling property is reduced, resulting in an appreciable improvement of post-stage strength and durability of the limestone soil(Wang, 2009; Wang, 2014).

3. Test materials and methods

3.1 Test materials

The expansive soil for test use was extracted from a worksite in LuoYang-NanYang Highway. The middle expansive soil presented the colour of mostly brown-yellow and slight brown-red, grey-green and grey-white. The smooth and hard fracture surface with dense structure was formed due to lack of water, and underwent tests for its mineral components as follows: montmorillonite19.3%, illite 38.5%, chlorite7.7%, quartz12 %, kaolin 6.2%, hydromica5.5 %, feldspar5.8 %, and calcite 5 %. The quick lime for the test was extracted from NanYang city (the content of CaO and MgO in the lime is higher than 70%).

3.2 Test methods

Chapter 2 The laboratory test was undertaken according to the Test Methods of Soils for Highway Engineering (JTJ051—2004). The lime-doped rate, namely the ratio between the quality of quick lime and that of the dry soil, is an important factor that influences the improvement effect. During the laboratory test, certain quality of quick lime was weighed pro rata for decomposition and subsequent blending with dry soil. An analytical test was undertaken for the mixture's physical property, including mineral component, liquid limit, plastic limit, and particle size. There were also respective tests for the samples without lime and for the lime-compaction samples on the shrink–swell capacity in different ages and the mechanical properties, such as swelling force, free swelling ratio and loaded swelling ratio, compaction test, shrinkage test, CBR test, and unconfined compressive strength test. Five lime-doped rates were adopted in the test, namely 2%, 4%, 6%, 8% and 10%. Through the above tests, various indices were obtained before and after the expansive soil are improved at different lime-doped rates. Corresponding test data was analyzed, aiming at the optimum improvement effect.

Table 1: Comparison results of particle size before and after improving expansive soils

particle size /mm	lime ratio /%					
	0	2	4	6	8	10
＞0.25	0	6.3	11.2	17.4	17.2	18.7
0.25~0.075	2.1	12.3	15.7	18.3	18.9	18.2
0.075~0.005	35.5	65.2	61.9	56.5	56.6	45.6
＜0.005	62.4	16.2	11.2	7.8	7.3	10.7

4. Test results and analysis

4.1 Particle grading

Table 1 shows the comparison results of particle size before and after improving expansive soils, and the change degree of particle grading of the improved expansive soils can be seen from the table. The improvement changes particle grading greatly, and the overall trend is: the fine particle content (especially the content of clay particle) drops significantly from 62.4% to 7.3%~16.2%; the fly ash particle content increases from 35.5% to 45.6%~65.2%; the coarsening sand particle gains its content prominently. The more the lime is incorporated, the higher the coarsening degree.

4.2 Compaction characteristics

In order to control the quality of subgrade filler, we must master the compaction characteristics of the filler. The necessary and sufficient condition for control on the quality of subgrade filler is to obtain the maximum dry density and optimal water content of the filler in advance through compaction tests. Figure 1 shows the relationship curves of the compaction characteristics and the ratio of added lime. As can be seen, after the lime is incorporated, with the increase of the lime rate, the optimal water rate increases from 17.5% to 19.2%, while the maximum dry density decreases from 1.78g.cm^{-3} to 1.656 g.cm^{-3}.

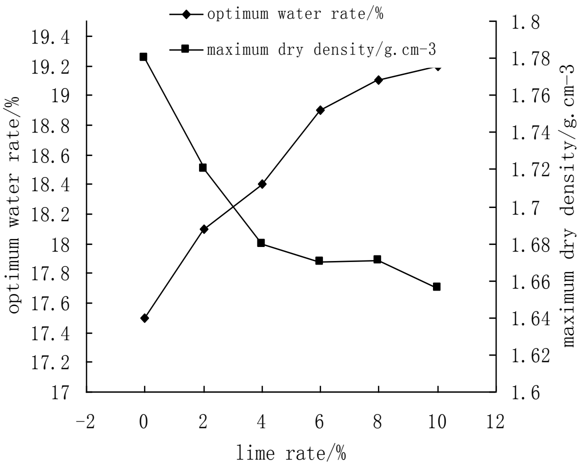

Figure 1: The relationship curves of the compaction characteristics and the ratio of added lime

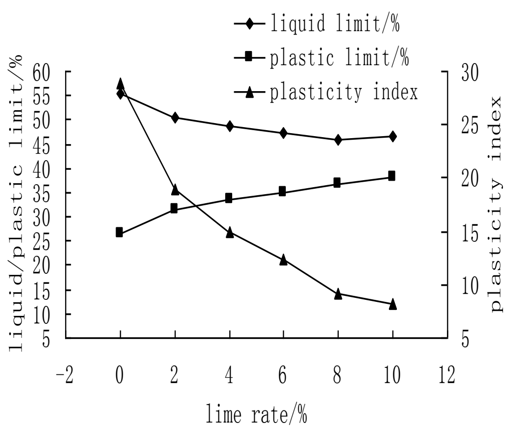

Figure 2: The relationship curves for the liquid limit test and the plastic limit test

4.3 Change of liquid limit and plastic limit

Figure 2 shows the relationship curves for the liquid limit test and the plastic limit test. As can be seen, the plasticity index of the lime soil decreases from 28.8 to 8.2 as the ratio of added lime increases. The reason is that the plastic limit increases as the ratio of added lime increases. The shrink–swell capacity for the lime-doped expansive soils is realized primarily by reducing soil plasticity. When a certain amount of lime is added to the expansive soils, the plasticity index drops significantly, the hydrophilic weakens significantly, and the soil structure changes as well. Thus, the shrink–swell capacity weakens.

Table 2: The results for expansion and shrinkage test

lime ratio /%	instar/d	expansion test		shrinkage test		
		non-pressure expansive rate /%	50KPa expansive rate /%	expansive force /Kpa	shrinking limit /%	shrinking ratio /%
0		36	9.3	284	16.2	3.1
6	7	0.5	0	9.6	5.2	1.9
6	28	0.2	0	0.7	4.3	1.07

4.4 Change of swelling shrinkage of expansive soil after added lime

In order to research on the influence of lime mixture on the shrink–swell capacity, the paper undertook expansion test and shrinkage test for the expansive soil with no lime and with 6% lime, respectively. The results are shown in Table 2. As can be seen, when there is no lime added, the non-pressure expansive rate is 36%, the expansive rate under 50kPa is 9.3%, the expansive force is 284kPa, and the shrinkage ratio is 3.1%. The above ratios all drop significantly after 6% lime is incorporated. Therefore, addition of lime to the expansive soil can significantly reduce its expansibility, and can effectively lower shrinking deformation after construction.

Table 2 also shows that all the tested indices for the soil with 6% lime after 28 days conservation are smaller than that after 7 days conservation. This means that with the conservation instar increases, the effect for lime in reducing expansibility and lowering shrinking deformation increases. Thus, attention should be paid to instar conservation during construction so as to reach optimal construction effects.

4.5 The CBR test before and after lime is incorporated

Figure 3 shows the relationship curve between the CBR value of the improvement soil and different ratio of added lime. As can be seen, the CBR value is low when there is no lime; as the ratio of added lime increases, the CBR value increases prominently until to the peak where the lime rate is 8% and begins to drop again.

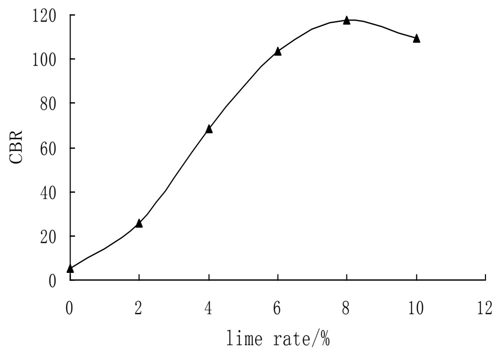

Figure 3: The relationship curve between the CBR value of the improvement soil and different ratio of added lime

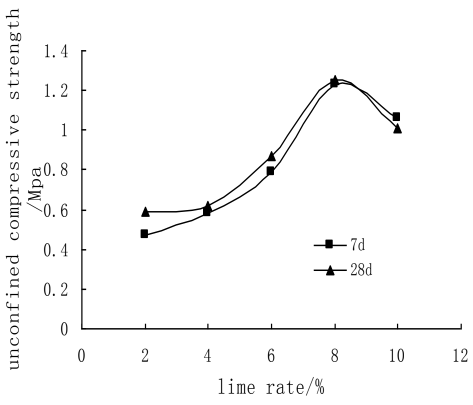

Figure 4: The relationship curves between unconfined compressive strength and different ratio of added lime at the instar of 7d and 28d

4.6 Unconfined compressive strength test

It is simple, feasible and easy to operate to determine the optimal ratio of added lime by the unconfined compressive strength test. Figure 4 shows the relationship curves between unconfined compressive strength and different ratio of added lime at the instar of 7d and 28d. The optimal lime-doped rates at 7d and 28d are found to be the lime-doped rates at curve peaks.

As can be seen, when the ratio of added lime increases, the unconfined compressive strength for the lime-doped saturated soil first increases and then decreases. This is because Ca^{2+}in the lime replaces lower-valence cation in the expansive soil (Na^{+} in the surface of clay particles, for example). The remaining Ca^{2+}may be absorbed, which causes the total quality of ion to increase. When lime is incorporated into the soil, soil structure changes due to flocculation of clay particles. Therefore, as clay content is decreased due to the increase of lime rate, the shrink–swell degree drops correspondingly and the lime soil strength is increased. However, the excessive lime that is left after the compaction process blocks combination of soil particles, thus leading to the decrease of lime soil strength.

5. Conclusion

To add lime to expansive soils is to lower soil expansibility and to improve soil strength. As ratio of added lime increases, various indices decreases in varying degrees, including clay particle content, maximum dry density, plasticity index, swelling rate. This proves the feasibility of the method of lime-improved expansive soils. However, the improvement effect of expansive soils may decrease in turn when lime rate increases too much. For example, in the CBR test and the unconfined compressive strength test, with the increase of lime rate, both the CBR value and the unconfined compressive strength first increases and then decreases. So, there is optimal ratio of added lime in the improvement of expansive soils (Wang, 2005)..

The improvement of expansive soils can result in reduction of large amount of disused soil in construction areas, of occupied area of land, and of the increasing engineering cost due to borrow fill. In areas with large distribution of expansive soils, local materials can be used for laboratory fitting test according to the free swelling rate and the swelling potential. After the improvement effect of mechanical properties is determined for different fitting rates, the optimal fitting rate will be chosen to meet the engineering demand. On the premise that strength and other design requirements are guaranteed, the lime amount should be reduced properly, aiming at shortening construction periods, lowering construction cost, and reducing engineering damages as well(Zhou,2012)..

Acknowledgments

The authors are grateful to the anonymous referees for their valuable remarks and helpful suggestions, which have significantly improved the paper. This research is supported by the national natural science foundation of China (Grant No: 41402267); Natural Science Basic Research projects of the Education Department of Henan Province (Grant No: 15B560008).the Youth Projects of NanYang Normal University (Grant No: QN2010008, QN2014018)

Reference

Bian J.M., 2016, Water Stability of Lime-treated Expansive Soil[J], Journal of Yangtze River Scientific Research Institute.33(1), 77-81(in Chinese)

Ene E., Okagbue C., 2009, Some basic geotechnical properties of expansive soil modified using pyroclastic dust. Engineering Geology, 107(1): 61-65.

Huang B., Nie Q., Xu Y.Y., Luo J, 2009, Experimental Research on Cement-modification of Expansive Soil, Journal of Yangtze River Scientific Research Institute, 26(11), 27-30(in Chinese)

Hui H.Q., Lei S.Y, 2005, Summarizing on the swelling mechanism of expansive soil and the method of restraining the swelling of expansive soil[J]. Journal of Highway and Transportation Research and Development, 22(9), 90–102. (in Chinese)

JTGD30-2004 Design code of highway subgrade[S].Beijing: China Communications Press, 2005. (in Chinese)

Kong L.W., Guo A.G., Zhao Y.W., Chen S.X, 2004, Water stability of JingMen expansive soils and their mechanical effect[J]. Chinese Journal of Geotechnical Engineering, 26(6), 727–732 (in Chinese)

Lian J.F., Yang Y.H, 2011, Experimental Study on Improvement of Expansive Soil Fillings for Railway Subgrades[J],Railway Standard Design, (11), 20-23 (in Chinese)

Liao S.W, 1984, Expansive soil and Railway engineer(in Chinese),Beijing: China Railway Press(in Chinese)

Li D.S., Xia X.L., Chen C.C., Zhang J.F., Zou W.L, 2011, Experimental Study on Engineering Characteristics of Expansive Soils Modified with Lime, Cement and Sand[J], South-to-North Water Diversion and Water Science & Technology, 9(4)m 25-28(in Chinese)

Li S.L., Chen H.D, 1992, Quick lime effect on reducing the disaster of the expansive soils-A case study on the expansive soil of Tai An-Lai Wu highway[J],The chinses journal of geological hazard and control, 33(1)m 65-71(in Chinese)

Li Z.X., Hu R.L, Xiong Y.S., Hu X.R., Song J.H, 2005, Experimental study on optimai water content of the modified expansive clay used as the embankment fills[J],Journal of Engineering Geology, 13(1), 113-117(in Chinese)

Lu H.B., Zeng Z.T., Zhao Y.L., Lu H, 2009, Experimental studies of strength of expansive soil in drying and wetting cycle[J], Rock and Soil Mechanics, 30(2), 3797-3802 (in Chinese)

Mirzababaei M., Yasrobi S., Al-Rawas A., 2009, Effect of polymers on swelling potential of expansive soils. Mutaz E., Shanrani M.A., Puppala A.J., et al., 2011, Evaluation of chemical stabilization of a highly expansive clayey soil. Transportation Research Record, 2204(19): 148-157.

Mohd R.T., Omer M.E.T, 2012. Influence of nano-material on the expansive and shrinkage soil behavior. Journal of Nanoparticle Research, 14(10): 1-13. Doi: 10.1007/s11051-012-1190-0

Proceedings of the ICE-Ground Improvement, 162(3): 111-119. Doi: 10.1680/grim.2009.162.3.111

Puppala A.J., Punthutaecha K., Vanapalli S.K., 2006, Soil-Water Characteristic Curves of Stabilized Expansive Soils. Journal of Geotechnical and Geoenvironmental Engineering, 132(6): 736-751.

Rao M.R., Rao A.S., Babu D.R., 2008, Efficacy of lime-stabilised fly ash in expansive soils. Proceeding of ICE-Ground Improvement, 161(1): 23-29.

Seco A., Ramírez F., Miqueleiz L., García B., 2011, Stabilization of expansive soils for use in construction. Applied Clay Science, 51(3): 348-352.

Tetsuya T., Yoshikazu K, 2012. Improved soiling resistance of polypropylene fibers on the addition of synthetic compounds [J]. Textile Research Journal, 82(8): 789-800. Doi: 10.1177/0040517511433148

Umit C., Erol S, 2014. Classification, shear strength, and durability of expansive clayey soil stabilized with lime and perlite. Natural Hazard, 71(3): 1289-1303. Doi: 10.1007/s11069-013-0950-1

Viswanadham B.V.S., Phanikumar B.R., Mukherjee R.V., 2009, Swelling behaviour of a geofiber-reinforced expansive soil. Geotextiles and Geomembranes, 27: 73-76. Doi: 10.1016/j.geotexmem.2008.06.002

Wang M.W., Qin S., Li J., Xu P, 2014, Strength of unsaturated lime-treated expansive clay in HEFEI[J],Chinese Journal of Rock Mechanics and Engineering, 33(Supp.2), 4233-4238(in Chinese)

Wang X.Z, 2009, Experimental Study on Improving Expansive Soil Roadbed with Lime[J],Building Science, 25(11), 70-72 (in Chinese)

Wang X.Z., Zhang J, 2014, Destructive mechanism and preventive measures of expansive soils slope[J],Journal of Nanyang Normal University, 13(2), 49-51 (in Chinese)

Wang B.T., Wu L.J., Xiang W.J, 2005, A study of construction of expressway embankment with modified soies[J]. Rock and Soil Mechanics, 1, 87–90. (in Chinese)

Yang H.P., Zhan W.T., Xiao J., Ni X, 2011, Soil Property Testing of Nanning Expansive Soil as Embankment Filler[J], China Journal of Highway and Transport, 24(1), 1-8(in Chinese)

Yang H.P., Zhao P.C., Zheng J.L, 2007, Suggestion and Verification on Modified CBR Test Method for Expansive Soils Fill[J].Chinese Journal of Geotechnical Engineering, 29(12), 1751-1757. (in Chinese)

Zhou B.C., Kong L.w., Guo A.G, 2012, Stress-strain-strength behaviour and constitutive description of lime-treated expansive soil[J]. Rock and Soil Mechanics, 33(4), 999–1005.(in Chinese)