World Applied Sciences Journal 19 (11): 1607-1612, 2012
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2012.19.11.1858

Investigation on the Effect of Curing Time on Uni-Axial Strength of Clayey Soils Strengthened by Saturated Lime Solution

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Abstract: This paper describes some of the main results of an investigation on the effect of passing saturated lime solution with different curing time on the clayey soil. Six series of laboratory tests had been set up, on lean clay samples, to investigate simultaneously the effect of volume of solution and curing time. The samples were classified based on average volume of passing. Three categories were considered, 19Vv, 28Vv and 40Vv. The volume of the saturated solution was fixed and all of the samples were held in a chamber with desired condition of temperature and humidity for different curing period, followed by a mechanical and chemical test. The findings released from the tests indicated that the length of curing period and volume of saturated lime solution at which curing took place had an important influence on the amount of strength developed. An exponential evolution was found for the uni-axial strength as a consequence of the curing time. Especially after 28 days. Calcium ion consumption after 28 days and also exponential evolution for uni-axial strength demonstrated the threshold value of curing period of 28 days for treatment of soil by saturated lime solution.

Key words: Saturated lime solution · Volume of the passing solution · Curing time · Uni-axial strength · Calcium ion consumption

INTRODUCTION

Landslide stabilization has a considerable role in soil conservation and developing new and cost effective methods is of most importance for unstable slopes which are located in rangelands. There are many techniques for stabilizing unstable slopes, among them lime treatment is a quick, simple and cost-effective operation that can be incorporated into any unstable slopes. Sedimentary impacts from landslides and the importance of controlling sediment production processes have been highlighted by various authors, [1-4]. Soil stabilization is a method introduced many years ago for improving engineering properties of the soils, [5]. Some scientific techniques of soil treatment have been introduced, [6,7,]. Stabilization of soils using additive materials such as lime, cement, Sarooj, natural fiber, have been practiced, [8-16]. Although lime stabilizes the soil rapidly after the treatment, the mechanical properties and strength of soil change over a long period of time, [17, 18,] and curing period and amount of additives needs to be researched.

The influences of lime treatment on mechanical properties of clays with laboratory and in-situ tests have been presented and concluded that the resistance is increased leading to added lime, but this approach is time and cost consummating [19]. Recently a new method has been developed by which lime is injected into soil in the form of saturated solution. As it penetrates into the soil due to the gravity, it improves soil strength through pozzolanic reaction. No appreciable improvement found in the optimum moisture content and maximum dry density for the soil treated with lime solution but strength of soil increases with increase in the concentration of lime, [20]. Moreover, it is known from the studies of Rajani [21], that the curing time influences the physical properties of soil stabilized by lime and considerably increases the shear strength of cohesive soils stabilized by lime. Limited studies have been conducted to investigate the suitability

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of using lime in the form of saturated solution in slope stability. Optimum concentration of lime solution and lime dosage were investigated and reported, [22] and mechanism of slope stability using additive was studied, [23-25]. However, there are very few data available in the literature on the soil improvement by saturated lime solution. This study intend to assess the effect of curing time and volum of passing solution on uniaxial strength of clayey soils stabilized by saturated lime solution in order to be applied in unstable slope stability and sediment control.

MATERIALS AND METHODS

The soils used in this study were obtained from an active land slide in Talegan catchment, which is located in the west of Tehran, the capital city of Iran.

Previous landslide study carried out in the study area, indicated the landslide prone area and the presence of unstable slopes.

Saturated Lime Solution: The lime used for preparing the saturated lime solution was a commercially available lime typically used for construction purposes. The definition of a saturated solution is one that contains as much solute (lime) as the solvent (water) will dissolve while in contact with excess solute. The simple method for preparing the saturated lime solution is to thoroughly stir 5 grams of hydrated lime into one liter of water, allowing the excess to settle; the excess in the bottom will ensure that the solution remains saturated.

Methods: Laboratory tests consisting of compaction and uniaxial strength were conducted on the specimens with a controlled humidity and temperature. Each specimen was compacted at optimum moisture content and maximum dry density and after preparation of specimens, 15 soil samples in five sets were placed in saturated lime solution for 48 hours, then they were kept in the controlled chambers for periods of 3, 7, 28, 42 and 60 days and then mechanical properties were tested. One set for 48 hours was only treated with water for comparison purpose.

RESULTS AND DISCUSSION

It is generally accepted that the penetration of lime solution in clayey based soils readily lead to the pozzolanic reaction that may cause increasing geotechnical characteristics. Some aspects of the influence of the presence of lime on soil stabilization have been studied by [26,27] and demonstrated that the shear strength of stabilized cohesive soils with lime and natural pozzolan is higher when curing period is extended and an appreciable improvement of the cohesion and internal friction angle with curing period is reported.

Table 1: Physical properties of the soils

Values	Characteristics	
8.22	PH	
2.51	EC	(µS/cm)
12.81	Ca^{++}	meq/lit
13.09	Lime	(%)
8.5	$HCO3^{-}$-meq/lit	
15		Cl-meq/lit
5.39	$SO4^{-}$-	meq/lit
8	Mg^{++}	meq/lit
15.87	Na^{+}	meq/lit
0.22	K^{+}	meq/lit

Table 2: Chemical Properties of the soils

Values	Basic characteristics	
2.63	Specific gravity	
65	Passing200µm sieve	(%)
21.64	Liquid limit	(%)
18.92	Plastic Limit	(%)
2.72	Plasticity index	(%)
CL-ML	Classification(USCS)	
10.9	Optimum water content	(%)
1.88	Maximum dry density gr/cm^3	

The physical and chemical characteristics of the soils are presented in Table 1 and 2.

Characteristics of the specimen at the end of compaction and after treating by lime solution are presented in Tables 3 and 4 and the results of uniaxial strength test are presented in Table 5. Considering that in the initial preparation processes, according to the porosity of the sample, different volumes of solution had passed. For more accurate analysis and to investigate simultaneously effect of volume of solution and curing time, the samples were classified based on average volume of passing. Three categories were considered, 19Vv, 28Vv and 40Vv. For better comparison of the effect of saturated lime solution on soil strength, the Relative Strength was plotted versus curing periods in different volume categories. Results were presented in Figs. 5-7.

Table 3: properties of the soils at the end of compaction

Specific gravity gr/cm^3	dry density gr/cm^3	Void ratio	porosity	water content%	Saturation %	sample
1.62	1.49	0.79	0.44	8.73	29.09	1
1.62	1.49	0.61	0.38	8.72	37.34	2
1.62	1.49	0.60	0.37	8.70	38.24	3
1.62	1.49	0.67	0.40	8.72	34.00	4
1.63	1.49	0.75	0.43	8.73	30.53	5
1.62	1.49	0.75	0.43	8.72	30.63	6
1.62	1.49	0.69	0.41	8.70	32.97	7
1.62	1.49	0.71	0.42	8.71	32.17	8
1.62	1.49	0.72	0.42	8.72	31.69	9
1.62	1.49	0.71	0.42	8.70	32.15	10
1.62	1.49	0.79	0.44	8.73	28.94	11
1.62	1.49	0.77	0.43	8.72	29.86	12
1.62	1.49	0.74	0.43	8.70	30.76	13
1.61	1.49	0.73	0.42	8.71	31.34	14
1.62	1.49	0.76	0.43	8.73	30.21	15

Table 4: properties of the soils at the end of treating and before uniaxial testing

dry density gr/cm$^{3)}$	Void ratio	Porosity(n)	Water content (%)	saturation %	Volume passed V_v	Calcium ion consumption meq/lit	sample
1.47	0.79	0.44	27	89	18	46	1
1.63	0.61	0.38	18	76	31	41	2
1.65	0.60	0.37	17	77	21	46	3
1.57	0.67	0.40	21	83	15	41	4
1.50	0.75	0.43	26	91	16	43	5
1.50	0.75	0.43	27	94	8	40	6
1.55	0.69	0.41	26	98	21	48	7
1.54	0.71	0.42	26	95	16	49	8
1.53	0.72	0.42	27	98	41	45	9
1.54	0.71	0.42	26	96	27	45	10
1.47	0.79	0.44	29	98	40	29	11
1.49	0.77	0.43	28	96	41	29	12
1.51	0.74	0.43	27	96	28	37	13
1.52	0.73	0.42	28	100	38	30	14
1.49	0.76	0.43	27	94	16	31	15

Table 5: The results of uniaxial compressive strength test

maximum Strength(kpa)	Increased strength %	Curing time(days)	Volume passed V_v	sample
120	380	60	18	1
197	687	60	31	2
128	411	60	21	3
64	155	42	15	4
61	143	42	16	5
51	104	42	8	6
132	426	28	21	7
69	176	28	16	8
202	707	28	41	9
104	316	7	27	10
89	257	7	40	11
101	304	7	41	12
77	206	3	28	13
77	207	3	38	14
57	127	3	16	15

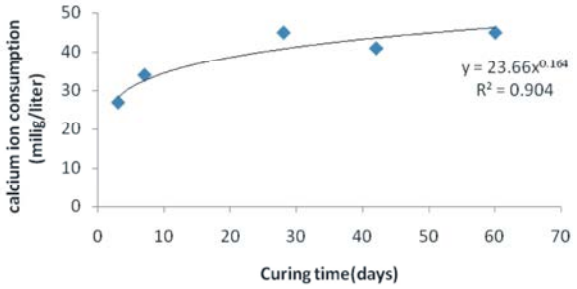

Fig. 1: Calcium ion consumption versus curing time

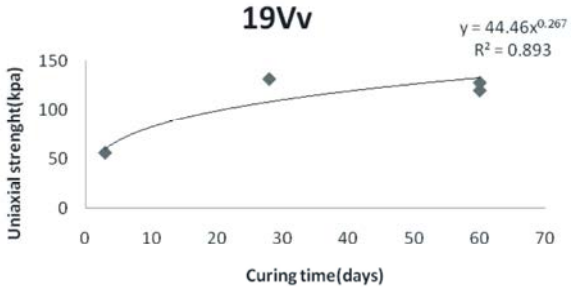

Fig. 2: Uniaxial strength versus curing time for 19Vv

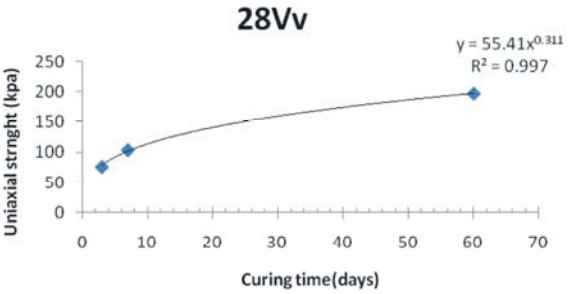

Fig. 3: Uniaxial strength versus curing time for 28Vv

Figure 1 illustrates the evolution of lime consumption with curing time. The Initial consumption of lime can be used as an indication of the minimum quantity of lime that must be added to the soil in order to achieve a significant change in soil properties in short time. In this study determination of this minimum percentage of lime is based on measurement of calcium ion concentration in soils before and after solution affect. Average calcium consumption for short term treatment (3 days) was found to be 27 milligram per liter, for 7 days it was 34 milligram per liter, for 28 days curing period it reached 45 milligrams per liter, for 42 days was found to be 41 milligrams per liter and for 60 days curing period also 45 milligrams per liter were found. This demonstrates that there is no important effect of lime addition after 28 days and it also demonstrates the minimum lime consumption for short term soil improvement. The calcium consumption values suffer from low decrease during the 42days curing time that can be attributed to mineralogical effect of the soils.

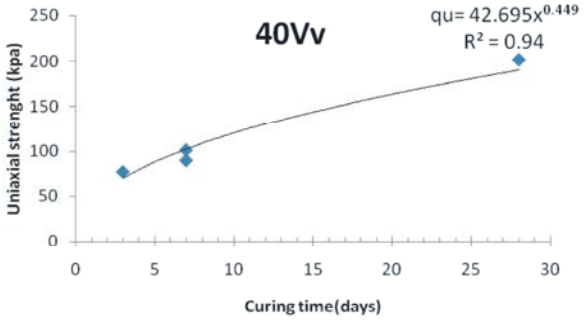

Fig. 4: Uniaxial strength versus curing time for 40 Vv

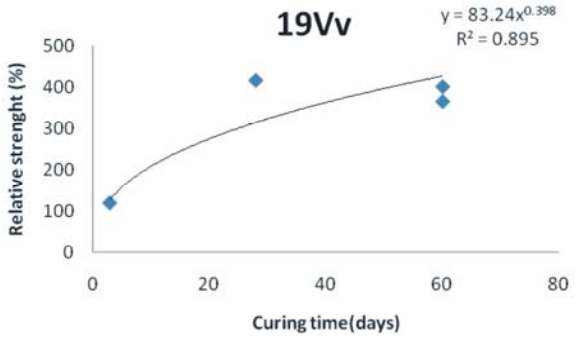

Fig. 5: Relative strength versus curing time for 19Vv

Variation of uniaxial strength with curing time of the soils in different categories are shown in Figs. 2-4, addition of saturated lime solution had a significant effect on strength with the curing period in different volume categories. At each category, as the curing time increases the strength increases exponentially. There is a considerable increase in uniaxial strength at later categories and in categories containing higher average of volume. This behavior was probably due to the pozzolanic reaction effect related to the volume of lime solution over the time. Also, as it can be seen from comparison of Figs. 2-4 for all three categories the uniaxial strength increased with time as volume of saturated lime solution increased. This can be the result of simultaneous effect of solution volume and curing period.

An increase of 9 units in volume passing showed an increase of16% in exponential power coefficient and increasing 12 units showed 35% increase in exponential power coefficient. This also demonstrates high effect of simultaneous effect of time and volume of solution.

For more accurate interpretation of relationship between uniaxial strength and curing period, relative strength is plotted versus curing time. Figures 5-7 indicate the variation of strength over time in different volume categories. As is shown in Fig. 5, maximum strength is achieved in 28 curing period and in the

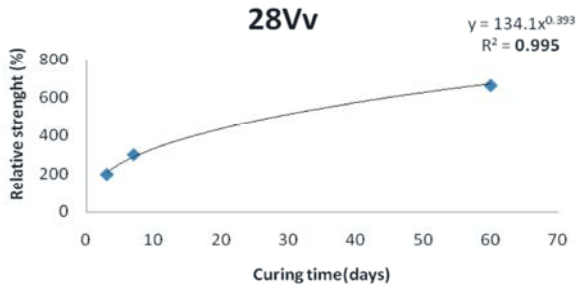

Fig. 6: Relative strength versus curing time for 28Vv

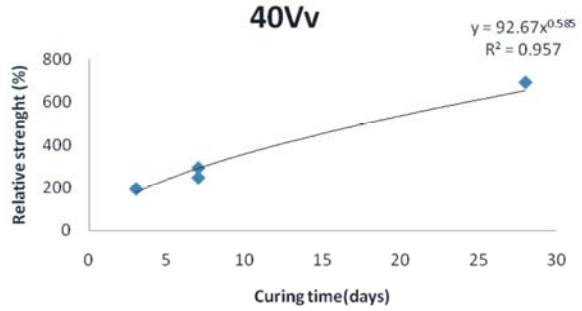

Fig. 7: Relative strength versus curing time for 40Vv

second group, by increasing the volume of the solution passing through the specimens up to 28 v_v, maximum strength was obtained in 60 days. In the third category which is shown in Fig. 7, by increasing the volume of the solution, a maximum strength was obtained at 28 days and after that there was no increasing up to 60 days. On average, among the three categories it has been observed that increasing both volume of the solution and curing time leads to maximum strength and also 28 curing time was found a promising period for soil improvement using saturated lime solution.

Based on mathematical equation between curing time and strength in different volume categories, in 60 days curing period for the categories of 19Vv the maximum relative strength was found equivalent to 406% and for 28Vv amount of 740 % and for 40Vv maximum amount of 980% were found. The high value of relative strength for 40 Vv categories demonstrates simultaneous effect of time and volume of solution on improving soil properties.

CONCLUSION

- Uniaxial strength increased exponentially with time as volume of saturated lime solution increased. This can be attributed to the simultaneous effect of volume solution and curing period.
- Highest relative strength achieved was 980% for soil treated by saturated lime solution and curing time of 60 days.
- About 27 milligram per liter calcium ion was sufficient for the short term reaction referred to as the initial lime consumption for soil improvement.
- The trend of calcium ion consumption after 28 days and the exponential evolution of uniaxial strength demonstrated the threshold value of curing period of 28 days and saturated lime solution treated soil.

ACKNOWLEDGMENT

The Research was supported by Soil Conservation and Watershed Management Research Institute of Islamic Republic of Iran (SCWMRI), this support is gratefully acknowledged.

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