International Journal of GEOMATE, April, 2017, Vol. 12, Issue 32, pp. 161-165
Geotec., Const. Mat. &Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.32.76370

EVALUATION OF TIME RATE OF SWELLING PRESSURE DEVELOPMENT DUE TO THE PRESENCE OF SULFATE IN CLAYEY SOILS STABILIZED WITH LIME

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ABSTRACT: The purpose of this study was evaluation of magnitude and time rate of swelling pressure due to the presence of gypsum in clayey soils stabilized with lime. 3,5 and 10 % of lime by dry weight and 0, 5 and 10 % of gypsum (calcium sulphate) were added to a bentonite. Then uncured and cured as compacted samples of mixtures were tested one dimensionally for constant volume swelling pressure measurement. The results showed that only samples treated with 3 and 5% lime without curing and with 7 days of curing showed initial increase in the magnitude of swelling pressure due to the presence of gypsum as compared with untreated bentonite or with bentonite treated with lime only. In fact samples with higher content of lime and gypsum which cured for 7 days or more actually showed lower swelling pressure compared with untreated samples.

Keywords: Lime, Gypsum, Swelling pressure, time rate, ettringite

1. INTRODUCTION

Soil stabilization with lime or cement is a well-established soil treatment technique and has been widely used to improve the load bearing capacity of soft and weak soils in civil engineering construction, such as foundations and pavements. Although the subject of lime-treated soil has been researched for many decades , it is still being done in recent years (e.g.Wang etal. 2012; Tran etal. 2014, Pakbaz and Farzi 2015; Dang etal., 2016 ; Hassanlouradetal. 2017). However, the use of calcium-based lime or cement for treatment of soils rich in sulfate-bearing minerals often causes more expansion. This expansion is due to the formation and subsequent hydration of minerals ettringite and / or thaumasite. The Ca2+ in the calcium-based stabilizers participates with alumina released from clay minerals during pozzolanic reactions and with sulfate, in the presence of water,according tothe following reaction to form minerals ettringite and/or thaumastie (Mitchell, 1986; Mitchell and Dermatas, 1992; Petry, 1994; Dermatas, 1995; Puppalaetal. 2005; Little and Nair., 2009).

$$6Ca^{2+} + 2Al(OH)_4^- + 4OH^- + 3(SO_4)^{2-} + 26H_2O \Rightarrow Ca_6[Al(OH)_6]_2 *(SO_4)_3.26H_2O$$

The Al $(OH)^-_4$ species in the above reaction is the result of combination of hydroxide ions $(OH)^-$ released upon the hydration of lime with alumina disassociated from a clay mineral at a basic environment (PH>12) created by addition of lime (Puppalaetal. 2005).

There are many factors that contribute to ettringite formation beside sulfate content of the soil. The amount of expansion due to formation and hydration of ettringite may vary with lime content, soil type, clay content and mineralogy, environmental conditions namely temperature and humidity conditions, availability of water, void ratio and void size of the soil, rigidity of the cementitious matrix, , timing of ettringite formation, and rate of crystal growth (Dermatas, 1995; Puppalaetal. 2005; Little etal. 2010).
Dermatas (1995) and Puppala etal. (2005) based on the laboratory swelling tests on treated soil samples with lime showed that the increase in lime content at higher sulfate levels (> 0.25 %) exhibited more swelling. At higher lime content, larger amounts of calcium and reactive alumina ions were released and combined with sulfate have led to increased amounts of ettringite formation and heaving of soils tested.
Due to a very high surface area, clay – sized particles in soils are highly reactive and dissolve at high pH conditions providing the alumina needed for ettringite formation. Hence, the extend of ettringite formation in a given time period can vary among soils based on available clay content and type of clay mineral present. The soil with higher clay content may carry a greater risk of ettringite formation at a given sulfate content (Little etal. 2010). Puppalaetal. (2005) reported vertical swell strains varying from 20 to 40 % for lime treated kaolinte clay and 2 to 10 % for lime treated silty clay when sulfates varied from 0 to 1 % (0 to 10000 ppm or 10000 mg/kg). Availability of alumina is a strong function of the amount and type of clay minerals present in the soil. Kaolinte

clay has a large amount of alumina which is released into solution at a high rate in a high pH environment. Montmorillonite clay on the other hand, has only half amount of alumina as present in kaolinite, and at high pH conditions, it is released into solution at a rate that is five times slower than for kaolinite (Dermatas (1995). At the same void ratio kaolinte clay is much permeable than montmorilonite clay (Terzaghi etal.,1993) and therefore, it is expected that chemical reactions leading to ettringite formation occurs faster in kaolinte soil than in montmorillonite soil due to the fact that water containing sulfate seeps faster in the former. Thus, it is expected that the time rate of expansion due to ettringite formation is affected by clay mineralogy.

One of the important factors affecting the formation of ettringite crystals in treated soils in the presence of sulfate is environmental factors such as the availability of high moisture and moderate to high temperature (Dermatas, 1995; Puppala etal. 2006). However, according to Dermatas, (1995) some researchers that support the topochemical mechanism (at soil water content) of ettringite formation, an uptake of water from the environment is not required for the expansion to occur. In fact, mellowing the soil before compaction have been suggested by some researchers to be used to overcome the problem of ettringite expansion in the field (Petry and Little, 1992; Dermatas, 1995; Little etal, 2010). Many researchers, however, believe that the formation of ettringite crystals ocuurs by through-solution reactions (Dermatas, 1995). Puppalaetal. (2006) showed that curing of treated soil specimen using soaked based curing as compared with samples cured under humidity room based curing provided lower stiffness property. They concluded that the method of curing with continuous moisture access resulted in continuous ettringite formation at high sulfate content, which in turn reduced stiffness properties when hydrated. It seems that both topochemical (at soil moisture content) and through-solution (availability of high moisture uptake) reactions are responsible for formation of ettringite crystals in treated soil in the presence of sulfate, however the latter worsens the dilemma of expansion due to continuous ettringite crystals formation.

At both low and high lime content and low sulfate content pozzolanic reaction in strengthening the soil structure can lead to decrease of expansion and dominating ettringite formation reactions(Puppalaetal. 2005).

The reverse effect of presence of sulfates in lime-treated expansive clay on the magnitude and time rate of swelling pressure has not been studied before. The aim of this work was to investigate the effect of a wide range of gypsum-lime content and curing periods on the magnitude and time rate of swelling pressure of a bentonite.

2. MATERIALS AND SAMPLE PREPARATION

2.1. Bentonite

The bentonite that was used in experiments of this study were obtained from Doreen Kashan(Iran) factory. The color of this Bentonite is a bright white and the result of Atterberg limits tests are shown in Table 1.

Table 1 Index properties for bentonite

Sample	Liquid limit(%)	Plastic limit(%)	Plasticity index(%)
Bentonite	163	53	110

2.2 Lime

The lime that was used in this study is industrial hydrated lime, chemical composition of which is shown in Table 2. Treated samples were prepared at 3,5,and 10 % lime content. Lime contents above 3 % have proved to be enough to bring the pH of the soil – water system above 12.4 for alumina release from clay particles during pozzolanic reactions (Mitchell, 1981).

Table 2. Chemical composition of Lime (weight %)

Ca(OH)2	93.27
MgO	0.81
L.O.I	5.92

2.3. Gypsum (Calcium sulfate)

The sulfate minerals are present at low concentrations in surface soils and rocks. Gypsum is a major source of sulfate that causes sulfate-induced heave in lime treated soils. Chemical composition of gypsum that was used in this study is shown in Table 3. Lime treated samples were prepared at 0, 5, and 10% gypsum content in terms of dry weight of soil. These gypsum contents are much higher than threshold value (>0.3 %) above which is considered to pose problem due to ettringite formation in lime-satbilized soils (Chrysochoouetal. 2012).

Table 3. Chemical composition of gypsum (weight %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
0.7	0.26	0.11	38.55	0.26	55.68	4.44

Soil, lime and gypsum were mixed dry and then required water (2 % dry of optimum water content according to standard compaction procedure) was added before samples were compacted according to ASTM D698 standard compaction procedure. After compaction, each sample was wrapped in plastic bags and kept in a humid environment for curing. Selected samples of each group were tested immediately without any curing. Testing specimens were then cut from as compacted uncured or cured samples into brass rings 50 to 75 mm in diameter and 25 mm in height. The specimens were then placed into odometer and transferred into a consolidation front loading apparatus for measurement of constant volume swelling pressure according to ASTM D4546. Inthis method, first a small surcharge pressure of about 5 kPa was applied to the specimens. Specimens were then immediately exposed to the water. Further swelling of specimens was prevented each time by application of additional surcharge of about 5 kPa until the tendency for swelling of specimens was seized.

3. RESULTS AND DISCUSSION

Compaction tests on the samples were performed according to standard Proctor test. Table 4 shows the results of standard compaction test. In this table B, L and G represent bentonite, lime and gypsum (Calcium sulfate) respectively.

Test results in Table 4 indicated that when lime with lower specific gravity than base soil, were added to the soil, the maximum dry unit weight of the soil decreased and optimum water content increased.

3.1 Magnitude of Swelling Pressure

Figures 1-3 show the time rate of swelling pressure development for all untreated, treated, uncured and cured samples. Final values of magnitude of swelling pressure measured after 24 hours of inundation are shown beside each graph. As indicated, they were decreased by20 to 54 % , 50 to 89 % and 72-94 % for uncured samples and samples cured for 7and 28 days respectively, as compared to the final value of 213 kPafor the untreated bentonite sample. The most decreased values belonged to the sample with 10 % L-5%G after 28 days of curing. The higher content of lime and longer period of curing have made this sample stronger due to pozzolanic reactions that have occurred during curing period. It is however noted that the magnitudes of swelling pressure for uncured treated samples measured during about the first 100 minutes after inundation were observed to be higher than the value for untreated sample (Fig. 1) or sample treated with only 3 % lime with no gypsum (Figs. 1-2). In Fig. 1 uncured sample treated with 3 % lime and 10 % gypsum and after that uncured sample treated with 3 % lime and 5 % gypsum showed swelling pressure higherthan other samples, including samples with no gypsum, during the first 100 minutes of tests. Final values for these samples at the end of the test were about 26-49 % higher than the value for the samples with no gypsum. However, these similar samples after 7 days of curing showed a final swelling pressure about 25 % lower than the sample with 3 % lime with no gypsum (Fig. 2). As shown in Fig. 2 sample with 3 % lime 10 % gypsum tested after 7 days of curing, at about initial 10 minutes of test, showed higher swelling pressure than sample with no gypsum. The reason for measurement of higher swelling pressures for samples with gypsum as compared to untreated sample and samples with no gypsum is due to the formation of ettringite crystals that occurs apparently faster than expansive pressure due to tendency for double layer development. The measurement of lower swelling pressure for samples with gypsum as compared to untreated sample as well as samples with no gypsum after initial 100 minutes may be due to both higher tendency for double layer development in untreated sample and the resistance developed within these samples due to pozzolanic reaction. The lower swelling pressure that was measured for cured samples with lime and gypsum as compared to samples treated with lime only (Figs. 2 and 3) is also due to the strengthening effect of pozzolanicreactions that have occurred within samples during curing period.

Table 4. Result of compaction tests

Sample	ω_{opt} (%)	$\gamma_{d(max)}$ (gr/cm^3)
B	25	1.21
B + 3% L	28	1.12
B + 3% L + 5% G	32	1.05
B + 3% L + 10% G	33	1.16
B + 5% L + 5% G	31	1.1
B + 10% L + 5% G	32	1.1

4. CONCLUSION

One dimensional constant volume swelling pressure measurement of bentonite soil untreated and treated with lime were examined in the presence of gypsum to investigate the effect of this presence on the magnitude and time –rate of swelling pressure development. According to this study the final magnitude of swelling pressure 24 hrs after inundation decreased by 20 to 94 % as compared to that for untreated samples. The most decreased values belonged to samples with higher lime – gypsum content and longer curing period. The least decreased values belonged to uncured samples with lower lime and higher gypsum content. On the other hand, the presence of gypsum caused initially generation of higher magnitudes of swelling pressure than untreated bentonite and bentonite treated with 3 % of lime. Measurement of swelling pressure of uncured samples can be good indicator for ettringite formation but for samples with curing period more than 7 days this test cannot be relied upon to show this matter.

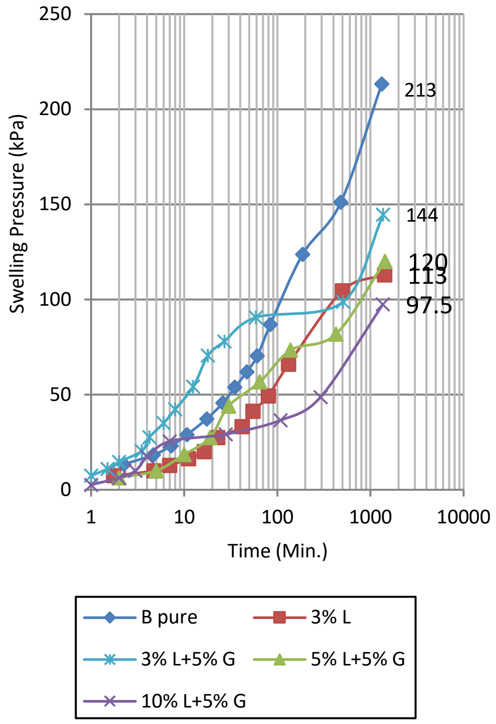

Figure 1. Compare the time rate of swelling pressure development of samples without curing.

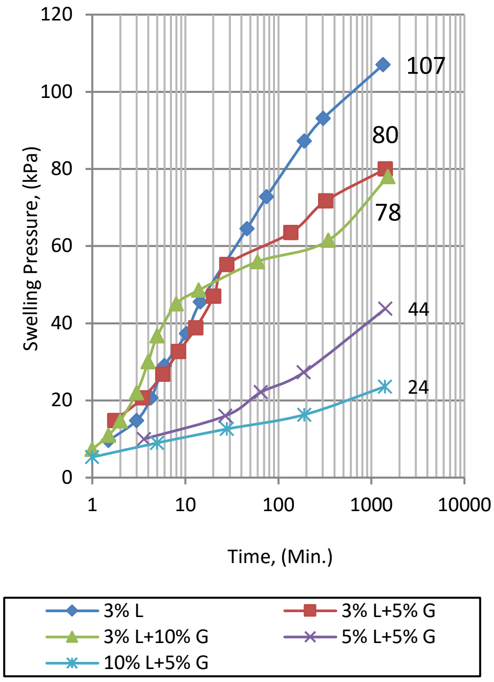

Figure 2. Compare the time rate of swelling pressure development of samples with7-days of curing

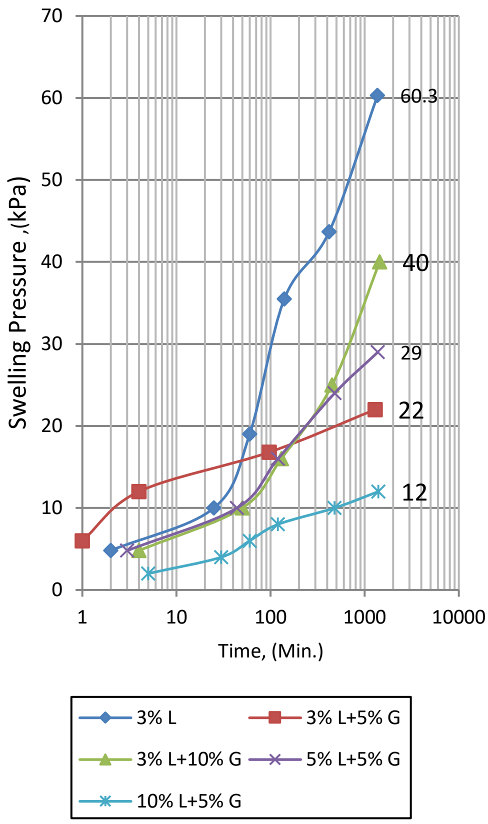

Figure 3. Compare the time rate of swelling pressure Development of samples with28-days of curing.

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