3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 June 2012, Near East University, Nicosia, North Cyprus

Sulfate expansion of lime-stabilized expansive soil

Ece ÇELİK
Eastern Mediterranean University, Department of Civil Engineering, Gazimagusa, T.R.N.C, ece.celik@emu.edu.tr

Zalihe NALBANTOĞLU
Assoc. Prof. Dr, Eastern Mediterranean University, Department of Civil Engineering, Gazimagusa, T.R.N.C

KEYWORDS: Lime, Heave, Expansive soil, Swell

ABSTRACT: Expansive soil is a term applied to any soil that has a potential for shrinking or swelling under changing moisture conditions. These soils can cause more damage to structures, particularly light buildings and pavements, than any other natural hazard. Lime stabilization of expansive soils has been used extensively as an economical method of providing a suitable pavement and fill material. However, it has been reported that the presence of sulfate causes abnormal volume changes in lime-stabilized soil. Lime-treated sulfate-bearing clay soils swelled and disintegrated after a few years when used for road construction. These heave-induced failures have been shown to be related to sulfate reactions that cause the formation of highly expansive crystalline materials namely, ettringite and thaumasite, over time. The aim of this study was to investigate the swelling behavior of natural (control soil), and lime treated expansive soils in the absence and presence of sulfate. Laboratory testing was performed on the soil specimens subjected to different concentration of sulfate solutions. In the study, three different sulfate concentrations: 2000, 5000, and 10000 parts per million (ppm) were used and the swell tests were performed on the specimens. Test results indicated that when there was no sulfate in the environment, lime was very effective in reducing the swell potential of the soil. The swelling of the soil decreased when the soil was treated with 5 percent lime. However, test results indicated that when the lime treated expansive soils were subjected to different concentration of sulfate solutions, instead of a reduction in swell; an increase in the swelling of the soils was obtained. Especially, the swelling of the lime treated soil subjected to 5000 and 10000 ppm sulfate concentration increased significantly.

1 INTRODUCTION

Lime-induced heave of sulfate bearing clay soils is an unusual phenomenon and the use of lime as a chemical stabilizer for sulfate bearing clay soils should be approached with great care (Hunter1988). Literature review reveals that in some cases, lime is not the ideal solution to the volume change problem of sulfate bearing soils (Mitchell, 1986; Hunter, 1988). According to some researchers (Harris 2003, Puppala et al. 2001) if the total soluble sulfates level is below 3,000 parts per million (ppm), by weight of soil, the potential for a harmful reaction is low. But that still needs to be further studied. Sulfate-induced heave problems occur when natural sulfate bearing soils are stabilized with calcium based chemicals such as lime and ordinary Portland cement (Hunter 1988). The engineering properties of lime stabilized soils are affected very significantly by the presence of sulfates. Reports of sulfate-induced heave in subgrade soils received little attention until the mid 1980's. Calcium components of stabilizers are known to react with free alumina and soluble sulfates in soils to form ettringite mineral (Hunter 1988). Field observations indicate that the reactions can be very rapid and occur overnight following a rainfall event, or it may take years for the problem to manifest itself (Harris, 2003). Ettringite, a weak sulfate mineral, will undergo significant heaving when subjected to hydration. This sulfate induced heave is known to severely affect the performance of highways, runways, parking lots, residential and industrial buildings, and the other earth structures build on lime or cement stabilized sulfate rich soils (Hunter 1988; Rollings et al. 1999; Puppala et al. 2001).

In 1976, Las Vegas, Nevada lime treated expansive soil was used for sub-base construction. The completed construction appeared of good quality and initial performance was excellent. However, beginning in the fall of 1977, signs of distress began to appear in the form of surface heaving and cracking. By the spring of 1978 the distress in some areas had become major, with heaves amounting to several inches in some places (Mitchell, 1984). Treated soil and untreated soil were tested to investigate the soil composition and chemistry. Test results indicated that the untreated soil contained significant amounts of soluble sodium sulfate, large amounts of gypsum, calcite and dolomite in it. In the lime treated soils, significant amounts of ettringite, and thaumasite were indicated by X-ray diffraction in both failed and unfailed zones along sections of the street where heaving failures predominated (Mitchell, 1984). In 1985, Hunter reported that, within a period of two years following lime stabilization in Nevada, lime stabilized soils were heaved in excess of 12 in. by adverse chemical reactions between lime and salts in native soils. Heaved areas were found to contain abundant thaumasite, complex of calcium-silicate-hydroxide-sulfate-carbonate-hydrate mineral. Thaumasite formed a solid solution series with ettringite, calcium-aluminum-hydroxide-sulfate-carbonate-hydrate mineral. In the presence of aluminum, ettringite had formed first and replaced by thaumasite at temperature below 15^{o}C (Hunter, 1998).

2 MATERIALS AND METHODS

The soil investigated in this study was taken in Değirmenlik village in Turkish Republic of Northern Cyprus. Since Degirmenlik soil had a high swell potential and had a low sulfate level of 640 parts per million (ppm), this soil was selected as a control soil in order to study the effect of different sulfate concentration on lime treated soil. For the study, three different sodium sulfate concentrations: 2000, 5000, and 10000 ppm were used. Sodium sulfate (Na_2SO_4) was used to raise the sulfate level in the control soil. Sodium sulfate powder was mixed with the calculated amount of water and different sodium sulfate+water concentrations were prepared. Then the prepared sodium sulfate mixture was added into the soil.

In this research, the natural expansive Değirmenlik soil, that is, the control soil was mixed with 5% lime in order to reduce the swell potential. The physical properties of the natural (control soil) and lime stabilized soils were determined and the test results were given in Table 1. In Table 1,

the physical properties of the control soil and 5% lime stabilized soils can be seen. Test result indicate that although there is an increase in liquid limit and plastic limit values of the soil with 5% lime addition, the overall plasticity index of the soil decreases from 31 to 25. Upon lime addition into the soil the plasticity of the soil decreases, mainly because of an increase in the plastic limit; the liquid limit may increase or decrease, depending on the soil type (Hausmann, 1990).
On these natural and lime stabilized soils, standard Proctor compaction tests were performed and the compaction characteristics: The maximum dry density and optimum moisture content were determined. Throughout the study, all swell tests were performed on the soil samples compacted at optimum moisture content at approximately 25°C room temperature.

Table 1. Physical properties of the control soil and the lime stabilized soil.

Soil properties	Control soil	5% Lime + Control soil
Sand (%)	0	0
Silt (%)	40	52
Clay (%)	60	48
Liquid Limit (%)	56	63
Plastic Limit (%)	25	38
Plasticity Index	31	25
Optimum Moisture Content (OMC) (%)	23	26
Max. Dry Density (ρ_{max}) (gr/cm^3)	1.53	1.56
pH	8.3	12.8

4 RESULTS AND DISCUSSIONS

Figure 1 indicates the swell percent of the control soil, control soil stabilized with 5 % lime and control soil stabilized with 5% lime subjected to 10000 ppm sulfate solution. The figure shows that the swell potential of the control soil was approximately 3 percent. When the soil was mixed and stabilized with 5% lime, the swell percent decreased to around 1 percent. The results indicated that when there was no sulfate in the environment, lime was very effective for reducing the swell potential of the control soil. With 5% lime addition, the swell potential decreased from 3 percent to 1 percent. However, Figure 1 also indicated that when 5% lime stabilized soil was subjected to 10000 ppm sulfate solution, instead of a decrease in the swell, an increase in the swell percent was obtained. That can be explained due to the chemical reaction taking place in soil in the presence of lime-clay-sulfate solution. The addition of lime into the soil raises the pH of the soil above 12. The high pH causes the dissolution of clay minerals and releases aluminum into the environment. The alumina liberated from the clay mineral and sulfate present in the environment react with lime and form a series of calcium-aluminate-sulfate hydrate compounds, leading to the formation of ettringite minerals which are highly expansive and cause the heave.

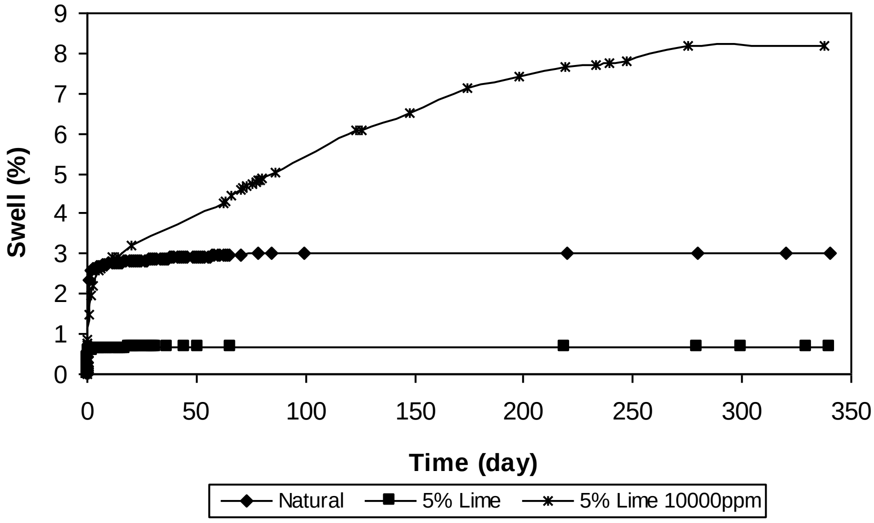

Figure 1. Swell percent of the control soil, 5% lime stabilized soil and 5% lime stabilized soil subjected to 10000 ppm sulfate solution.

Figure 2 indicates the swell potential of 5% lime stabilized soil subjected to different sulfate concentration. The figure shows that the swell percentage of lime stabilized soil increased with the increase in the sulfate concentration. Unacceptable increasing of swell percentage was obtained for the soil subjected to 5000 to 10000 ppm sulfate solutions. The figure indicated that 2000 ppm sulfate concentration was not very effective in the formation of the secondary minerals, ettringite. However, with 5000 and 10000 ppm sulfate concentration, intolerable increase in the swell percentage was obtained. Test results indicated that a drastic increase in the swell percentage of these soils with 5000 and 10000 ppm sulfate concentration was obtained after a few days. The swell percentage of these soils became an undesirable value. Figure 2 indicated that the formation of the ettringite minerals was very rapid in lime stabilized soil subjected to 10000 ppm sulfate solution. The ettringite formation at this sulfate concentration was more rapid than the other concentrations.

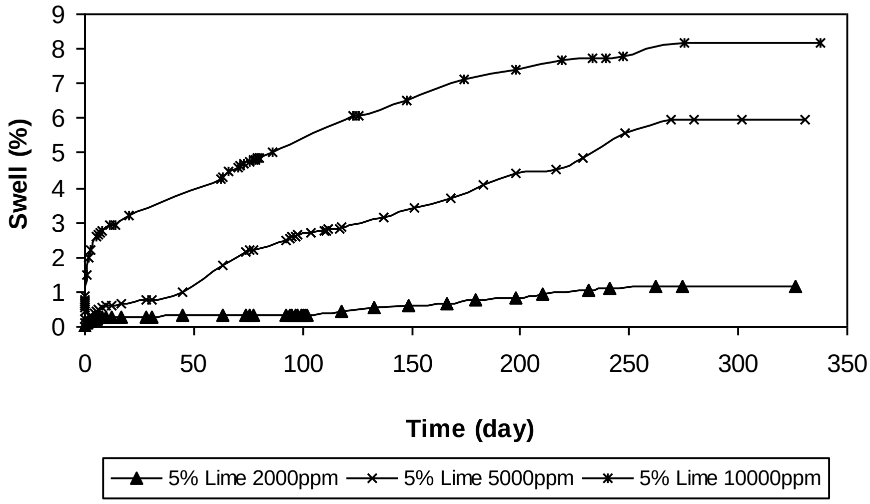

Figure 2. Swell percentage of 5% lime stabilized soil subjected to different concentration of sulfate solutions: 2000, 5000 and 10000 ppm.

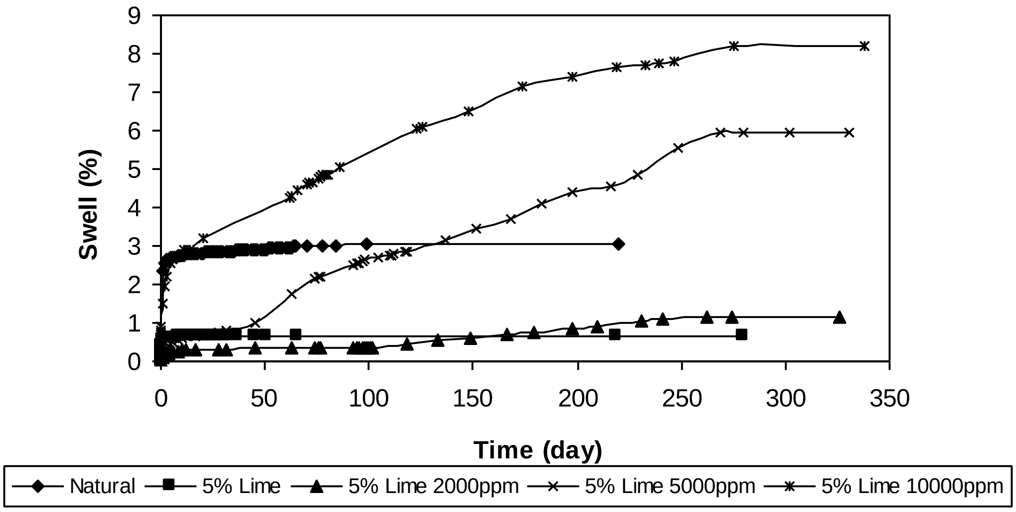

Figure 3. Comparison of the swell values

Figure 3 indicates the comparison of the swell values of the natural, 5% lime stabilized soil and 5% lime stabilized soil subjected to different concentration of sulfate solutions. The figure indicated that when the natural Değirmenlik soil was stabilized with 5% lime, reduction in the swell potential was obtained. Test results indicated that the swell percentage of 5% lime stabilized soil subjected to 2000 ppm sulfate concentration were below the swell percentage of the natural control soil. That shows that in the absence of sulfate, lime is very effective in reducing the swell potential of the natural soil. Test results showed that when only lime was added into the soil, reduction in the swell percentage was obtained. 2000 ppm sulfate concentration did not result in an increase in the swell potential of the 5% lime stabilized soil. This concentration of sulfate solution was not sufficient for the formation of the ettringite minerals. At this sulfate concentration level, the swell potential of the soil was still below the swell percentage of the natural soil. Figure 3 also indicated that the swell percentage of the 5% lime treated soil subjected to 5000 ppm sulfate concentration reached the swell percentage of the control soil approximately after 120 days and at the end of the testing, the swell percentage increased approximately two times the control soil's swell value. From the figure, it can be seen that 10000 ppm sulfate concentration increased the swell percentage of the control soil from 3 percent to approximately 8 percent.

6 CONCLUSIONS

Test results indicated that lime can be a very effective chemical additive in the stabilization of fine grained expansive soils. Such soils can react well with lime, and result in valuable changes in soil plasticity, workability, and swell.

However, the use of lime as a chemical stabilizer for sulfate bearing soils should be approached with great care. In this study, test results indicated that 5% lime addition into the expansive soil with a very low sulfate content (640 ppm) reduced the swell potential of the soil. However, with the same soil, test results indicated that with the increase in the sulfate concentration of the natural soil, an increase in the swell potential of the same soil was obtained. 5% lime stabilized soil with 5000 and 10000 ppm sulfate concentration resulted in a very high swell potential whereas the swell potential of the lime treated soil with 2000 ppm sulfate concentration remained below the swell potential of the natural soil indicating that 2000 ppm sulfate concentration for this soil was inadequate for the formation of the ettringite minerals.

Since the presence of sulfate causes abnormal volume changes in lime-stabilized soils, for each soil to be investigated, the sulfate level that could be detrimental to the performance of the stabilized sulfate rich soil should be well evaluated.

7 REFERENCES

Dermatas, D., 1995. "Ettringite-induced swelling in soils: State-of-the-art". Center for Environmental Engineering, Stevens Institute of Technology, Hoboken, vol. 48, no 10.

Harris, P., Scullion. T., Sebesta. S., and Claros. G., 2003. "Measuring sulfate in subgrade soil". Transportation Research Record. 1873. paper no. 03-3437.

Harris, P., Scullion. T., and Sebesta. S., 2003. "Hydrated lime stabilization of sulfate-bearing vertisols in Texas". Submitted for publication Transportation Research Record.

Hunter, D., 1988. "Lime-induced heave in sulfate-bearing clay soils". Journal of Geotechnical Engineering. Vol. 114, No. 2.

Hausman R. M., 1990. "Engineering principles of ground modification". Mc Graw Hill International Edition.

Mitchell, J. K., 1984. "Practical problem from suprising soil behaviour". Journal of Geotechnical Engineering. Vol. 112, No. 3.

Puppala, J. A., Viyanant, C., Kruzic, P., and Perrin, L., 2002, "Evaluation of a modified soluble sulfate determination method for finegrained cohesive soils". Geotechnical Testing Journal, GTJODJ, Vol. 25, No. 1, pp. 85-94.

Puppala, J. A., Griffin, J. A., Hoyos, L.R., Chomtid, S., 2004 "Studies on sulfate-resistant cement stabilization methods to address sulfate-induced soil heave". Journal of geotechnical and geoenviromental engineering, ASCE, pp. 391-402.

Rollings, R. S., Burkey, P., and Rollings, M. P., 1999. "Sulfate attack on cement-stabilized sand", Journal of Geotechnical and Geoenviromental Engineering, Vol. 125, No. 5.

Sherwood, P. T., "Effect of sulfate on Cement- and Lime-stabilized soils", Road Research Laboratory, Department of Scientific and Industrual Research, United Kingdom.