Reducing the Expansion of Clays

through Lime Stabilization and Overloading

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ABSTRACT: Expansive clay soils are present in many regions of Mexico and throughout the world. They pose a major problem for the construction industry due to the volumetric changes associated to humidity variations that cause fissures in pipes, foundations, and structures. Although there are different solutions to this problem, most of them do not approach the contribution of structure overloads in reducing soil expansion. In such circumstances the aim of this research is to study the reduction of volumetric changes in expansive soils generated by the action of natural clays stabilized with lime as well as the effect of utilizing overloads transferred by the structure, and the simultaneous application of both solutions to the problem, which consequently will also reduce the stabilization cost. After completing the project it was concluded that the overload that reduces significantly the expansion (approximately 1.5%) of this particular soil (clay of high compressibility) without lime stabilization is of 8 Ton/m2. On the other hand, 6% lime (regardless of overloads) in relation to dry weight also reduces the expansion. When applying both solutions simultaneously (overload and lime stabilization) it was found that the overload actually contributes to reducing the soil expansion with the resulting combinations of 2 Ton/m2 with 4% lime in relation to dry weight, and 4 Ton/m2 with 2% lime in relation to dry weight.

Keywords: lime, clay, overload, stabilization, expansion, expansive soils.

INTRODUCTION

Expansive soils pose many problems when building on them. This, because when the water content increases, the soil swells, and when it shrinks the ground collapses in both cases causing fissures in the constructions.

Lime treatment is one of the many options for improving existing expansive soils. However, it is usually determined and applied in dosages that do not take into account the factor of construction overloads of the structure to be placed on them. Lime stabilization is a very common method used to reduce the expansion potential of so-called expansive soils.

This research seeks, therefore, to reduce the specified percentage of lime added to the soil while simultaneously applying gradually increasing overloads in order to find – as far as possible – the optimal combination of both to reduce the expansion.

The city of Querétaro, in the state of Querétaro, Mexico, is predominantly built on clay soil with a significant presence of montmorillonite, around 40% (Zepeda, 1989). The region's climate is semiarid, which causes the soil to be subject to significant moisture changes—dehydration in times of drought and hydration in the rainy season. As other regions of Mexico, the Bajio, which is located in the central part of the country, offers similar conditions (Zepeda, 2004).

Part of the problem of the deficient performance of foundations built on expansive soils lies in ignoring the nature of the soil, its behavior, and the influence of environment and human actions (Bowels, 1988).

In the United States of America clay soils are responsible for most of the structural damages to buildings. Krohn and Slosson estimated in 1980 the cost of these negative effects in about 7,000 million dollars per year. There is not an assessment of the cost of the annual damage caused by expansive soils in Mexico, and there are no clear criteria for the analysis and design of foundations on different types of soils (Zepeda, 2004). The changes in humidity give rise to the expansion and contraction of expansive soils. These may be induced by variations in the climate, the temperature, the vegetation present, the topography, the type of buildings, the foundations, the current infrastructure in the area, or simply due to leaks in water pipes and drainage. If humidity remains constant, there will be no volume changes in the soil (Trejo, 2003).

The amount and variation of rainfall and evotranspiration strongly influence the availability and depth of humidity. A large seasonal rise occurs in semiarid climates with short and very pronounced periods of humidity (Nelson, 1992).

It was only after the First International Congress of Soil Mechanics held at Harvard, Mass., in 1936 that technical literature mentioned the problem of expansive soils. The expansive nature of soils increases their sodium content within the active layer (thickness of the land subjected to humidity changes), and it is higher on low pressures (De Justo *et al.*, 2002). Unsaturated soils have dominated the attention of scientists and researchers due to the damages and economic impact caused by expansive clays (Fredlund and Rahardo, 1993).

The decrease in the structural stability of the soil results from the crushing of the pores saturated with air. Its recovery starts in the summer and ends in the winter when the soil is damp. This recovery originates from the expansion when the smaller aggregates produced by the crushing of dry soil are linked back to larger structural units (Al-Rawas, A.A., Goosen, M.F.A., 2006).

There are several techniques, such as physiochemical stabilization, mechanical stabilization and preventive practices that are recommended to mitigate the effects of expansive soils (Hudyma, N. and Burcin, B., 2006). Among the physical-chemical techniques used is the stabilization of soil by using a lime treatment.

The soil-lime reaction besides being reported as nonreversible in time (López-Lara *et al.*, 1996, López-Lara *et al.*, 2005), takes place in two stages: the first phase occurs rapidly and immediately after adding lime to the soil, causing a physical-chemical reaction generated between the lime and the clay minerals, and which transforms the soil in a rougher and less plastic material; the second appears in the long term and more slowly due to a pozzolanic reaction that forms cementing agents, which increase the soil's strength and durability (Di Maio, C., Hueckel, T., Loret, B., 2002). The curing time for the lime to act on the expansive material may be recommended for one day (López-Lara *et al.*, 2005). The stabilization process is qualified as satisfactory when the required qualities and following conditions are met: compatibility with the material (soil), to be permanent, easily manageable and enforceable, economical and safe (Purus, H. R. 2000).

All materials experience an increase in their optimum moisture content and a specific decrease in their volumetric dry weight. Significant increases and strength and Young's modulus appear in these materials when treated with lime. The time and temperature for curing to occur greatly influences the amount of resistance developed (Bell, 1996). The lime induces a cation exchange that takes place immediately after being added to the soil, resulting in the flocculation of grains and an increased porosity (Schanz, T., 2007).

EXPERIMENTAL

Materials

The soil used is clay of high compressibility (CH) according to the Unified Soil Classification (USCS); and the lime, commercial hydrated lime. The soil was collected from the Jurica home-development, Queretaro, Mexico.

Methodology

- Identification of the natural soil type of the study and modified with lime. This stage is developed by determining the index of the material properties: Atterberg Limits (Liquid Limit, Plastic Limit and Plastic Index) and the specific gravity of solids.
- Determination of the ideal compaction of the natural soil stabilized with lime. The used assay is the Standard Proctor that determines the maximum dry unit weight (the density recommended in the field) and the optimum humidity.
- Determination of the percentage of lime that reduced the soil expansion, regardless of overloads. This is done by conducting a consolidometer expansion test in the natural soil stabilized with lime.
- Determination of the overload that reduces the expansion of the natural soil not treated with lime. This is done by conducting a consolidometer expansion test in the natural soil with different loads, starting from 2 Ton/m^2 and increasing it by two until finding the load that counteracts the expansion.
- Determination of the ideal combination of overloads and the percentage of lime required to reducing the soil expansion. This is done by means of a consolidometer. The assays were performed using different lime dosages, applying to each of them, simultaneously, different loads starting from 2 Ton/m^2 and increasing them.

RESULTS AND DISCUSSION

Table 1 shows the meassures of the index properties (Atterberg Limits and specific gravity of solid) of the natural soil stabilized with lime. The maximum dosage of lime is determined, once the index properties have stopped decreasing. The identification of the natural soil stabilized with lime according to the Unified Soil Classification is performed in conjunction with the Plasticity Chart.

Table 1. Index Properties of Natural Soil and Lime Soil

	Liquid Limit (%)	Plastic Limit (%)	Plastic Limit (%)	Ss*
Natural soil	72	32	40	2.60
Nat. soil + 2% lime	59	33	26	
Nat. soil + 4% lime	53	35	18	
Nat. soil + 6% lime	49	36	13	

* Specific gravity of solids.

The soil used is clay of high compressibility (CH). The classification of the natural expansive soil is modified in the Plastic Chart when adding the lime (2, 4 and 6%). Therefore, with 6% lime the material is finally classified as clay of low compressibility (CL).

The application of the Standard Proctor Test determines that the natural soil has a maximum volumetric dry weight (γd) of 1,295 kg/m^3 that corresponds to an optimum humidity (w_{opt}) of 33.2%; such density and humidity should be reproduced for performing the following expansion tests as they represent the optimum bearing capacity and consolidation of the material.

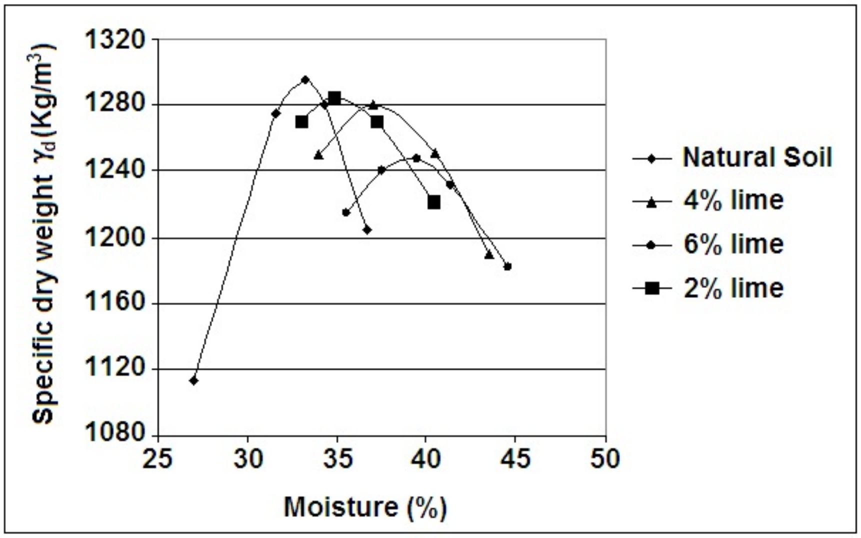

Figure 1 shows the Proctor Standard compaction curves for the natural soil stabilized with lime at 2.4 and 6%. It is noted that when increasing the lime, the humidity increases and the specific dry weight decreases.

Another method of defining the percentage of lime required to stabilize expansive soils is to apply the expansion test using a consolidometer. Therefore, this was the method used in this stage of the testing, comparing the results previously obtained with the properties index of lime-treated soil. The percentage shown was 6%. The expansion test specifies the placement of a load of 1 kPa (0.01 Kg/cm^2); this load was thus applied to perform the test, but it is not considered as part of the research as it is an element of the procedure, besides being very small.

Figure 2 shows the results of the expansion tests performed in the natural soil modified with lime. Thus, we can see that each group's behavior is very similar at all times. Table 2 contains the average expansion ranks of the natural soil modified with lime at 2, 4 and 6% in relation to its dry weight. It is noted that 6% of lime, regardless of overloads, is enough to stabilize this particular soil.

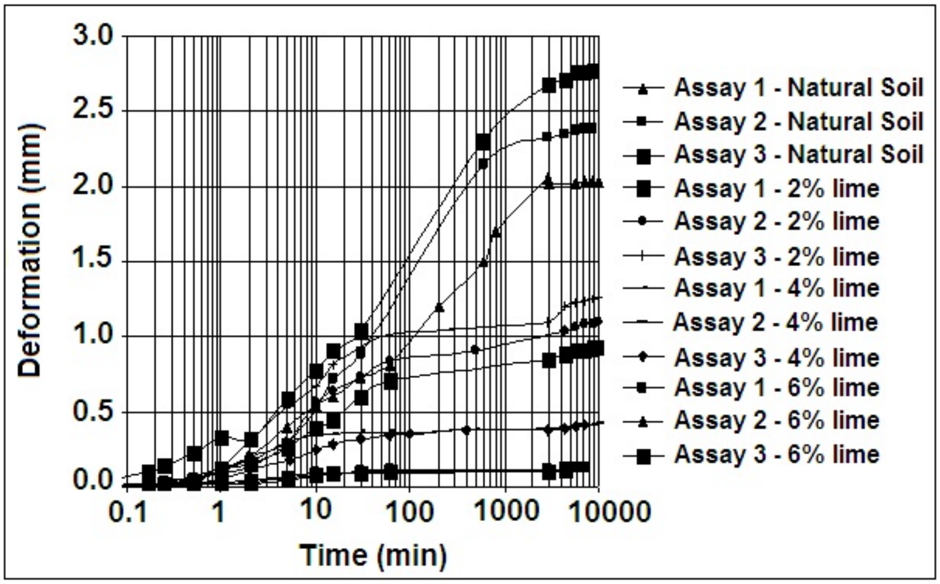

Figure 2. Expansion assays on unaltered samples of natural soil stabilized with 2, 4 and 6% lime.

Table 2. Expansion of the natural soil mixed with lime.

Soil	Average expansion (%)
Natural	10.58
Natural soil + 2% lime	5.47
Natural soil + 4% lime	2.74
Natural soil + 6% lime	0.058

The evaluation of this stage was done by conducting consolidometer expansion tests in the natural expansive soil without modifying it with lime, and with different loads that started from 2 Ton/m2 and were increased by two in order to find the load that countered the swelling. Table 3 and Figure 3 show the results of the expansion test done to the natural loaded soil. The loads required in this stage of the study were 2, 4, 6 and 8, because 8 Ton/m^2 reduced the expansion considerably (1.5%). As shown in the results, it is likely that 10 Ton/m^2 will reduce the expansion to values of less than 1%.

Table 3. Expansion of the soil under loads of 2, 4, 6 and 8 Ton/m^2.

Soil	Expansion (%)
Natural	10.58
Natural soil + 2 Ton/m^2	5.81
Natural soil + 4 Ton/m^2	4.10
Natural soil + 6 Ton/m^2	3.60
Natural soil + 8 Ton/m^2	1.54

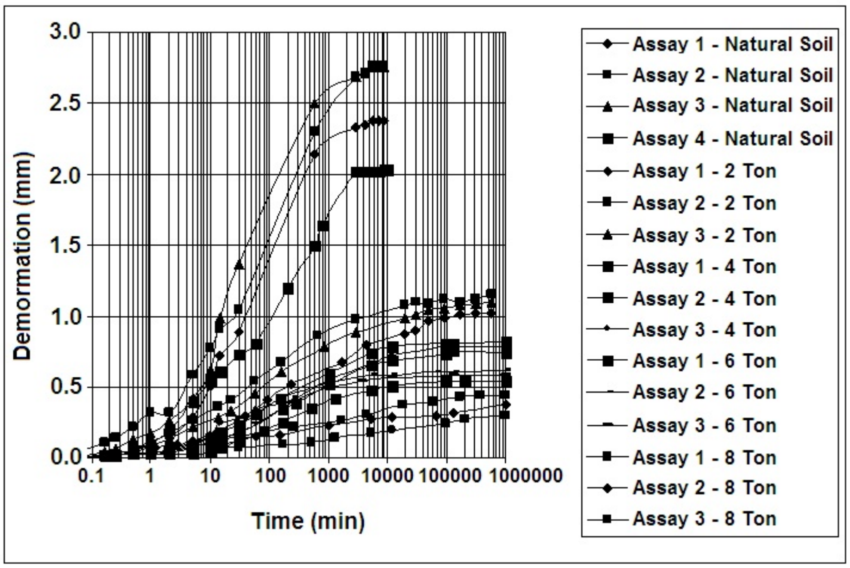

Figure 3. Expansion of the natural soil under loads of 2, 4, 6 and 8 Ton/m^2, without stabilizing it.

This stage is performed by conducting consolidometer expansion tests on the soil stabilized with lime (2, 4 and 6% in relation to its dry weight), applying simultaneously to each dosage different loads starting from 2 Ton/m^2 and incrementing them by two until finding the maximum load that, together with the lime dosage, will counter the expansion.

Once the study was done, it was determined that a load of 6 Ton/m^2 was enough in the different combinations. Therefore, this stage consisted of nine combinations of load and lime percentages applied to the soil: 2, 4 and 6 Ton/m^2 with 2, 4 and 6% lime (in relation to its dry weight) for each load. The percentage of lime was 2% lime, and the loads were 2, 4 and 6 Ton/m^2. Table 4 shows the values of the resulting expansion. From these results, it is possible to conclude that a load of 4 Ton/m^2 with 2% lime reduces the expansion.

Table 4. Resulting expansion in natural soil with 2% lime and loads of 2, 4 and 6 Ton/m^2

Soil	Expansion (%)
2% lime + 2 Ton/m^2	2.71
2% lime + 4 Ton/m^2	0.48
2% lime + 6 Ton/m^2	0.35

Assays were performed then in natural soil with 4% lime and loads of 2, 4 and 6 Ton/m^2. The values of the resulting expansion are shown in Table 5. From this results it is possible to conclude that a load of 2 Ton/m^2 with 4% lime reduce the expansion.

Table 5. Soil expansion with 4% lime and loads of 2, 4 and 6 Ton/m^2

Soil	Expansion (%)
4% lime + 2 Ton/m^2	0.49
4% lime + 4 Ton/m^2	0.11
4% lime + 6 Ton/m^2	0.10

Finally, assays were performed in natural soil with 6% lime and loads of 2, 4 and 6 Ton/m^2. The values of the resulting expansion can be seen in Table 6. In these combinations of load and lime one can see that only occurs a virtual residual expansion.

CONCLUSIONS

- For this particular expansive soil (clay of high compressibility), the lime content, regardless of overloads, reducing the soil expansion is 6% in relation to its dry weight. Also, the overload that reduces the soil expansion significantly (1.5%), without stabilizing it with lime, is of 8 Ton/m^2, although it is likely that 10 Ton/m^2 will reduce the expansion to values less than 1%.
- In the implementation of both solutions (overloads and lime stabilization) it is found that the overload actually contributes to the stabilization of soil expansion when decreasing the dosage of lime determined (6%), resulting combinations of 2 to 4 Ton/m^2 with 4% lime in relation to dry weight, and 4 Ton/m^2 with 2% lime in relation to its dry weight.
- Consequently, this translates into cost savings as it reduces the amount of lime used due to the utilization of the overload under discussion. Besides, there are alternatives to using both solutions.
- Additionally, it was found that by increasing the lime added to the soil; the conditions of optimum humidity and maximum specific weight of the natural soil are also modified. Thus, it is noted that to a higher content of lime (in the range of the studied dosages of 2, 4 and 6%), the specific weight decreases while the humidity increases.

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