Abatement of Clay Expansion via CaOH stabilization and overloading

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ABSTRACT
Expansive clays are soils found naturally in many regions of Mexico and several other countries. However, they represent a major problem in the construction industry due to the volumetric change because of humidity variations. This, in turn, produces many fissures in piping, foundations, and buildings placed on top of them. Although there are several solutions to this problem, most of them lack of the contribution of overloads transmitted by the structure in the diminishing of soils expansion. Because of the above, the aim of this research was to study the decrease of volume change in expansive soils due to overloads in natural clays and stabilized with CaOH. The overloading will improve soil behavior due to the loads transmitted by the structures and savings in the stabilizing material. This, in turn, the stabilization cost will be reduced with the application of overloads, resulting significant savings when both techniques are used to solve the original problem.

RESUMEN
Las arcillas expansivas son suelos que se encuentran de manera natural en muchas regiones de México y otros países, lo que ocasiona problemas en la industria de la construcción por sus variaciones volumétricas cuando varía el contenido de agua, ocasionando fisuramientos en tuberías, cimentaciones y edificios ubicados sobre estas arcillas. Aunque se han planteado varias soluciones al problema, la mayoría de ellas no consideran la contribución de la sobrecarga transmitida por las estructuras, disminuyendo la expansión del suelo. Por esta razón el propósito de esta investigación fue estudiar la reducción del cambio volumétrico en suelos expansivos por la sobrecarga, tanto en arcillas naturales como estabilizadas con CaOH. La sobrecarga proveniente de las cargas transmitidas por las estructuras mejora el comportamiento del suelo y permite economías en el material de estabilización. A su vez los costos del tratamiento de estabilización disminuyen con la aplicación de la sobrecarga, resultando ahorros significativos cuando se emplean ambas técnicas para resolver el problema original.

1 INTRODUCTION AND BACKGROUND.

1.1 Introduction

Expansive soils cause many problems when anything is built on top of them. Indeed, when there is an increase in water content, soil swells and when it is decreased, terrain contracts causing fissures in the constructions in both cases.

From the several alternatives for improving existing expansive soils, the CaOH treatment is a common method used to reduce the soil expansion of the so-called expansive. However, this method is applied with dosages ignoring the load existence due to the construction being placed.

Thus, the aim of this research was to obtain the optimal combination of CaOH and loading. The latter was gradually increased until expansion was abated.

1.2 Background

Querétaro City (Qro, México) was settled on clay soils where montmorilonite has a significant presence, about 40% (Zepeda, 1989). This Mexican region is within a semidesertic climate. This implies that the soil is subjected to significant changes of humidity. Indeed dehydration in the dry season and hydration in the rainy season. Bajio's region, located in Central Mexico, as well as many other places of this country have similar conditions (Zepeda, 2004 and Trejo, 2003).

Part of the problem of the bad behavior of the foundations built on expansive soils is the lack of knowledge about soil nature, its behavior, the influence of the environment, and the human actions as well (Bowles, 1988).

In the USA, expansive clays are the cause of many damages to the structures. Krohn and Slosson (1980, estimated that the cost of this was seven thousand millions US dollars per year. In Mexico there is no cost evaluation of the damages and frequently there is not a clear criteria for the analysis and design of foundation on these soils (Zepeda, 2004).

The amount and variation of precipitation and evapotranspiration strongly influence the availability and depth of humidity. Big stationary risings happen in semi-arid climates whose periods of humidity are short and steeper (Nelson, 1992).

The expansive soil problem rises in the technical literature in the First International Congress of Soil Mechanics held at Massachusets on 1936. The expansive character of soils increases with sodium content, with the depth of the active layer (terrain thickness subjected to humidity changes), and it is greater for low pressures (De Justo et al., 2002). The more studied non-saturated soils have been expansive clays, due to the damage and economic losses (Fredlund and Rahardjo, 1993).

The decreasing soil structural stability is due to the collapse of pores saturated with air. The recuperation of such structural stability starts in summer and ends up in winter, when the soil is humidified. Such recuperation is due from the expansion, when the smaller aggregates created by the collapse of dry soil are looped again in larger structural units (Al-Rawas, and Goosen, 2006).

There exist several techniques, such as the physicochemical stabilization, mechanical stabilization, and preventive practices, recommended to mitigate the effects of expansive soils (Hudyma, and Burcin, 2006). Among the physicochemical techniques, one used very often is soil stabilization by CaOH application.

Soil-CaOH reaction has been reported as non reversible in time (López-Lara et al, 1996, 2005). Moreover, this reaction is developed in two stages. The first one happens quickly and immediately after mixing CaOH and clay. The clay minerals produce a physicochemical reaction that transform the soil in a rough and less plastic material. The second one is very slow and takes a long time due to the puzolanic reaction that form cementing agents that increase strength and durability (Di Maio et al, 2002).

The curing time for the CaOH acting on the expansive material has been reported of one day (Lopez-Lara et al., 2005). The stabilization process will be satisfactory when the required qualities are improved and it must comply with the material being compatible with the soil, permanent, easy handling, economic, and safe (Purus, 2000).

Commonly, most of materials suffer an increment of optimum humidity and a reduction of their dry specific weight. Significant increments in strength and Young's modulus are show on these materials when treated with CaOH. The curing period and the temperature have an important influence on the strength (Bell, 1996). A cationic interchange induced by the CaOH is produced after adding it. As a result, grains flocculation and porosity increase is produced (Schanz, 2007).

2 EXPERIMENTAL DEVELOPMENT

2.1 Materials being used

The soil used for this research corresponds to an expansive clay classified as high compressibility (HC), according to the Soil Classification Unified System (SCUS). The CaOH used was a commercial hydrated CaOH. Soil was extracted from Jurica, Queretaro, Mexico.

2.2 Methodology

- Identification of the studied natural soil and modified with CaOH. At this stage, the material index properties were determined, *i.e*, Atterberg's Limits (Liquid and Plastic limits, and Plastic Index) and specific weights of relative solids.
- Determination of the ideal compaction of a natural soil and stabilized with CaOH. The test used was the Proctor Standard. With this, the maximum-dry specific weight (density recommended in field) and the optimum humidity were determined.
- Determination of the amount of CaOH that abated the soil expansion without considering the load. This was done via expansion tests in the consolidometer to natural soil and stabilized with CaOH.
- Determination of the overload for abating natural soil expansion. This was done via expansion tests in the consolidometer to unstabilized expansive soil with different loads, starting from 2 ton/m^2 and increments of 2 ton/m^2 until finding the one that opposed expansion.

Determination of the ideal combinations of overload and amount of CaOH for abating soil expansion. This stage was performed via expansion test in the consolidometer. Tests were carried out to the CaOH-stabilized soil with different CaOH dosages, and applying to each different loads, starting from 2 ton/m^2 and increasing them.

3 RESULTS

3.1 Identification of the natural soil and that modified with CaOH

The natural soil and stabilized with CaOH measured index-properties (Atterberg limits and specific weight of relative to solids) are shown in Table 1. The maximum dosage of CaOH was determined when the index properties did not diminish. Natural soil identification and the one modified with CaOH, according to the Unified System for Soil Classification, was carried out together with the Plasticity Card. The Natural soil Specific weight relative to solids is 2.6.

Table 1. Index properties of natural soil and soil-CaOH

Material	Liquid Limit, %	Plastic Limit, %	Plastic Index, %
Natural soil	72	32	40
Natural soil +2%CaOH	59	33	26
Natural soil +4%CaOH	53	35	18
Natural soil +6%CaOH	49	36	13

The soil used was a high compressibility clay. The expansive natural soil classification was modified while keeping the Plasticity Card. This was done by adding CaOH (2, 4, and 6%). In this fashion, with a 6% of CaOH, the material ends up in the classification as a low compressibility clay.

3.2 Determination of the ideal compaction of natural soil and CaOH stabilized

The Proctor Standard test was used for determining the maximum volumetric dry weight (γ_d) of 1295 kg/m^{3}corresponding to an optimum humidity (ω_{opt}) of 33.2 %. Such density and humidity were reproduced for the next expansion experiments, since they represent the optimum condition of material distribution.

Compaction Proctor Standard curves of natural soil and stabilized with CaOH (2, 4, and 6 %) are shown in Fig. 1. From that figure, it can be seen that an increase in CaOH produces, in turn, an increase in humidity while the specific weight decreases.

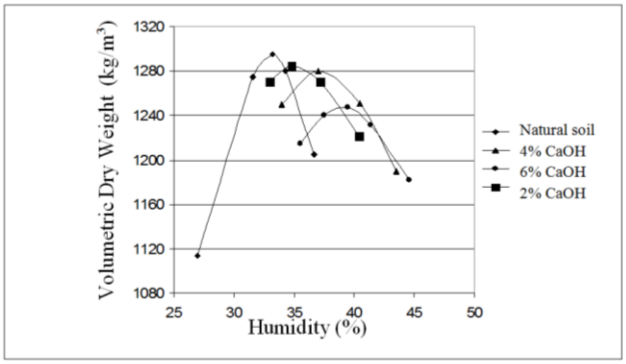

Figure 1. Compaction Proctor Standard of natural soil and with different CaOH contents

3.3 Determination of the amount of CaOH that abates soil expansion, without considering overloading

Another method for defining the amount of CaOH necessary for stabilizing an expansive soil is via consolidometer expansion tests. Therefore, in this section by comparison it was verified that a 6 % of CaOH produced the results obtained with the modified soil Index Properties. Although the expansion test specifies the placing of a load of 1 KPa, such load was applied to this test, but it was not considered as part of this research because it is part of the procedure, and besides it was very little.

In Fig. 2, results of expansion tests carried out to the natural soil and CaOH modified. From that figure, it can be seen that the behavior of each group of samples are similar at all times. The average expansions of natural soil and CaOH treated with 2, 4, and 6 % are shown in Table 2. From that Table, it can be observed that 6 % of CaOH, without overloading, was enough for stabilizing it.

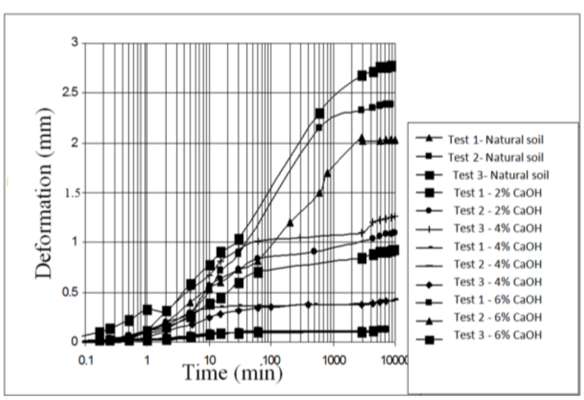

Figure 2. Expansion tests in unaltered samples of natural soil and stabilized with 2, 4 and 6 % of CaOH

Table 2. Expansion of natural soil and mixed with CaOH

Soil	Average Expansion (%)
Natural soil	10.58
Natural soil + 2%CaOH	5.47
Natural soil + 4%CaOH	2.74
Natural soil + 6%CaOH	0.058

3.4 Determination of the overload for abating the expansion of unstabilized natural soil

Expansion tests were carried out with unstabilized expansive natural soil in the consolidometer. Different loads starting from 2 ton/m^2 and increments of 2 ton/m^{2}until reaching swelling were tested. Results from these experiments are shown in Table 3 and Figure 3. At 8 ton/m^2 the expansion was abated considerably (1.5 %). From these results, it is very likely that at 10 ton/m^2 the expansion values be decreased to less than 1%.

Table 3. Soil expansion under loads of 2, 4, 6 and 8 Ton/m^2

Soil	Average Expansion (%)
Natural soil	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

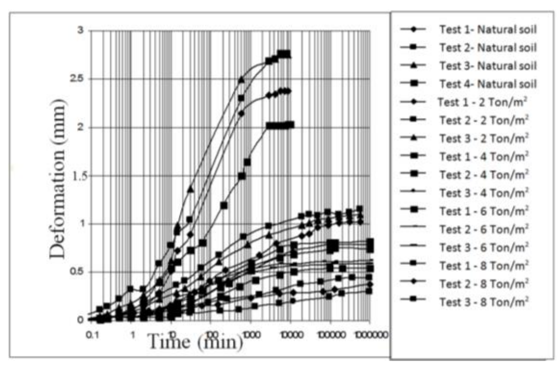

Figure 3. Expasion Tests of non-stabilized natural soil with loads of 2, 4, 6 and 8 Ton/m^2

3.5 Overload and amount of CaOH determination for abatement of soil expansion

This stage was carried out by expansion test of CaOH-stabilized soil (2, 4 and 6 %, with respect to its dry weight) in the consolidometer. This was done by applying to each dosage several loads starting from 2 ton/m^{2}with increments of 2 ton/m^2, until finding the maximum load to compensate soil expansion.

Once the study was perform it was determined that a load of 6 ton/$m^2$was good enough in the different combinations. Because of the above, this stage consisted of nine load combinations and CaOH applied to the soil, namely, 2, 4 and 6 ton/m^2 with 2, 4 and 6% of CaOH (respect to its dry weight) in each load. First, 2 % of CaOH was added to the material and loads of 2, 4 and 6 Ton/m^2. Values of the resultant expansion are shown in Table 4. From those results, it can be considered that a load of 4 Ton/$m^2$with 2% of CaOH abate the soil expansion.

Table 4. Resultant expansion of a natural soil with 2% of CaOH and loads of 2, 4 and 6 Ton/m^2

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

Then, test were conducted with natural soil with 4 % of CaOH and 2, 4 and 6 Ton/m^2.Values of the resultant soil expansion are shown in Table 5. From that Table, it can be considered that a load of 2 ton/m^2 with 4% of CaOH abate soil expansion.

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

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

Finally, tests with natural soils with 6 % of CaOH and loads of 2, 4 and 6 Ton/m^2 were made. The resulting expansion values are shown in Table 6. From that Table, it can be seen that, practically, residual expansion is present with these combinations of load and CaOH.

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

Soil	Average Expansion (%)
6%CaOH + 2 Ton/m^2	0.46
6%CaOH + 4 Ton/m^2	0.16
6%CaOH + 6 Ton/m^2	0.08

4 CONCLUSIONS

For this expansive soil in particular (high compressibility clay), the CaOH content, without loading, reduces soil expansion in 6 %. Moreover, the overload that diminishes soil expansion in a considerable fashion (1.5 %), without CaOH, is of 8 ton/m^2; however, it is very likely than an overload of 10 ton/m^2 reduces expansion to values less than 1 %.

By applying both alternatives, namely, overload and CaOH stabilization, it was shown that loading contribute effectively in the abating of soil expansion. Indeed, the recommended combinations were 2 ton/m^2 con 4% of CaOH and 4 ton/m^2 with 2% of CaOH as well. Therefore, the above, in turn, translates in economic savings because diminishes the CaOH being used, due to the best use of overloading. Besides, the use of both alternatives can be recommended.

Additionally, it was found that by increasing the CaOH in the soil, the optimum humidity conditions and the maximum specific weight of natural soil are modified. Thus, the greater the CaOH content (in the studied range of 2, 4 and 6 %) the lesser the specific weight. Moreover, the humidity increases

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