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COMPARISON OF TWO CHEMICAL AGENTS' PERFORMANCE IN THE STABILIZATION OF A CLAY SOIL

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— Abstract—

During the execution of engineering works, it is common that the soil that one wishes to use does not meet the quality criteria that the corresponding regulations require to guarantee the structural stability of the structures. For those cases in which the value of the soil plasticity index exceeds the maximum allowed, the chemical stabilization has shown the best results. In this research, a comparative analysis of the performance of calcium oxide (CaO) or lime, and sodium chloride (NaCl) or salt, as stabilizing agents. These chemical agents were added in different proportions to the soil under study. The variations of the liquid limit, plastic limit, and the plasticity index were monitored. The results showed, contrary to what is traditionally expected, that for the case of the soil under study the best stabilizing agent is sodium chloride, because not only is it more effective in reducing the plasticity index, but also is cheaper than the lime.

Keywords

calcium oxide; clay; plasticity index; sodium chloride.

The soil is the most superficial layer of the earth's crust, which has its origin in the decomposition of rocks due to the action of weathering agents. The mechanisms of attack on rocks can be classified into two groups: mechanical and chemical. Starting from numerous minerals (mainly silicates) found in igneous and metamorphic rocks, the agents of chemical decomposition reach a final product: clay (Juárez and Rico, 2005). The hydro-mechanical behavior of these soils is decisively influenced by their structure and their mineralogical constitution. Clays are soils whose particle size is less than 0.002 mm and consist of hydrous aluminum silicates, sometimes presenting magnesium, iron or other metals silicates, also hydrated. The structure of these minerals is generally crystalline and their atoms are arranged in a laminar form, there being two types of such sheets: silicic and aluminum (Braja, 2001). The surface of each clay particle has a negative electric charge. The intensity of this load is a function of the structure and composition of the clay. Thus, each particle attracts positive ions from water [Juárez and Rico, 2005]. This characteristic of clay soils gives rise to a very important property: plasticity. This property causes some soils to change their consistency depending on their moisture content, that is, when the clay soils are dry they show great resistance and very little deformability, but when wet they lose much of that resistance, they become very compressible soils. The parameter that allows to quantify plasticity in soils is the plasticity index (PI), which is defined as the difference between the liquid limit (water content in percentage for which a soil goes from a plastic to a liquid state) and the plasticity limit (water content in percentage for which a soil passes from a semi-solid state to plastic). In general, it is considered that when the IP is greater than 18% there is volumetric instability in clays.

From a civil engineer's point of view, all the above makes the clays a complicated material to work that regularly does not meet the minimum requirements that building standards require to be used in construction projects (roads, foundations, earth dams, etc.). However, the abundance of clay soils and the need to use them as construction material has led to the development in recent years of techniques that contribute to improving the engineering properties of these soils. Soil stabilization procedures have as main objectives to increase the resistance and decrease the volumetric variation before changes in its moisture content. The methods to stabilize soils are classified into two categories: mechanical stabilization and chemical stabilization. Chemical stabilization consists of altering the properties of the soil using a certain additive, which, mixed with the soil, produces a change in the superficial molecular properties of the soil's grains. For its part, mechanical stabilization is the alteration of soil properties by changing its granulometry, either by mixing it with other soils or by compaction (De Solminihac and Thenoux, SF).

The improvement of the behavior of clay soils is essentially achieved by decreasing the value of the plasticity index (IP), the smaller this value the better its performance from the point of view of the construction engineer. To achieve the above, chemical stabilization is the one that has shown the best results (Nuñez, 2011, Kalkan, 2011). In this type of stabilization, the improvement of soil properties depends mainly on the chemical reactions between the stabilizing agent and the soil minerals, that is, the choice of a type of chemical agent depends essentially on the type of soil.

For many years, chemical products have been tested to stabilize clay soils, in the majority of cases satisfactory results were obtained. However, the cost and availability of these products have meant that only some of them are used (Little, 1999). Among the chemical agents that have been used successfully are sodium chloride (NaCl) (Garnica *et al*., 2002, Roldan, 2010, Abood *et al*., 2007), and calcium oxide (CaO) (Olinid1 and Olinid2, 2016- Jawad *et al*., 2014). This article compares the performance of these two chemical agents as clay soil stabilizers of the Chontalpa Unit of the Universidad Juárez Autónoma de Tabasco (UJAT), located in the municipality of Cunduacán, Tabasco, Mexico. The results allowed to identify the better of the two stabilizing agents for the soil of this zone and to define their optimum amount of use.

METHODOLOGY

The area from which the study material was extracted is located behind the Applied Science and Technology Research Center of Tabasco (CICTAT) in the Chontalpa Unit of the Universidad Autónoma de Tabasco (UJAT), in the municipality of Cunduacán, state of Tabasco, Mexico (image 1). In this unit the Academic Divisions of Basic Sciences (DACB), Computing and Systems (DAIS) and Engineering and Architecture (DAIA) can be found. The original basic characteristics of the soil used are shown in table 1. The material under study was extracted to a depth of 1.5 m by the OPM method (open pit).

Image 1. Origin of the under study soil. Chontalpa Unit of the UJAT

Table 1
Basic characteristics and material classification

Liquid limit (LL)	69.2 %	**Relative specific weight of solids**	2.62
Plastic limit (PL)	49.06 %	**USCS classification***	CH (high plasticity clay)
Plasticity index (PI) = LL - LP	20.14 %	**Sand quantity**	2.41 %

* Unified Soil Classification System

As seen in table 1, the soil is a clay of high plasticity with 2.41% sand. Due to the high value of the plasticity index (PI ≥ 18) this soil is resistant during the dry season, but it is susceptible to large deformations when wet.

The criterion of improvement of the terrain that was followed in this investigation was the decrease of the PI, because the smaller this value is, the better the behavior of the soil from the point of view of the construction engineer.

The chemical agents that were used to reduce the plasticity of the soil were sodium chloride or common salt (fine grain) and calcium oxide (lime). These agents were chosen because of their high availability and low cost in this area.

The manner in which the chemical agents were applied to the soil is described next. First, the soil was dried in the sun for 24 hours, then sieved by the number 40 mesh (4.25 mm opening). Next, the soil was divided into two groups, A and B (image 2). Each group was composed of six pairs of samples of 300 g of soil each. These samples were placed individually in aluminum cups of 1 liter capacity. Each group was added with a single stabilizing agent (image 2). The agent was added to each pair of samples as a percentage of its dry weight (300 g). The percentages used of the chemical agents in this investigation were 2%, 4%, 6%, 8%, 10% and 16% (image 2). That is, two soil samples were added with 2% of a stabilizing agent, two samples with 4% of the same chemical agent and so on. Two samples with the same percentage of chemical agent were added to have a redundant reading and to ensure that the results obtained were correct. Image 2 schematizes the process described above. It was decided to work with the aforementioned percentages of stabilizing agent (2%, 4%, 6%, 8%, 10% and 16%) because the consulted bibliography suggests that the optimal amount of said agents is generally between 5% and 8% (Roldán, 2010; Jawad *et al.*, 2014).

Once the stabilizing agent was added to the dry soil, it was mixed with the help of a low speed mixer for 30 minutes in order to homogenize the mixture. Said mixture was allowed to stand for 48 hours in a chamber at a constant temperature of 25°C outside of direct contact with the sun's rays and humidity. After this curing period, the liquid limit (LL), plastic limit (PL) and the plasticity index (PI) of all the samples added with both stabilizing agents were determined following the procedure marked by the NMX-C- 416-ONNCCE-2003 standard chapter 6.

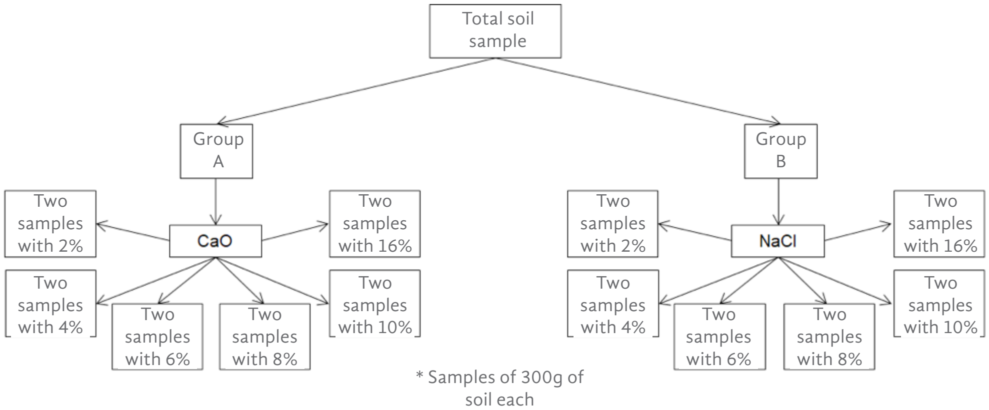

Image 2. Samples with different CaO and NaCl proportions

RESULTS

To analyze the performance of the chemical agents, the original plasticity characteristics of the material were taken as control (table 1). Only these properties were monitored (liquid limit, plastic limit and plasticity index) because the stabilization of the soil seeks to reduce the characteristics of plasticity of the material, since it is well known that by decreasing these, the characteristics of strength and volumetric stability ground improve.

Next, the results of the determination of the liquid limit (image 3), plastic limit (image 4) and the plasticity index (image 5) are presented in all the samples added with the stabilizing agents.

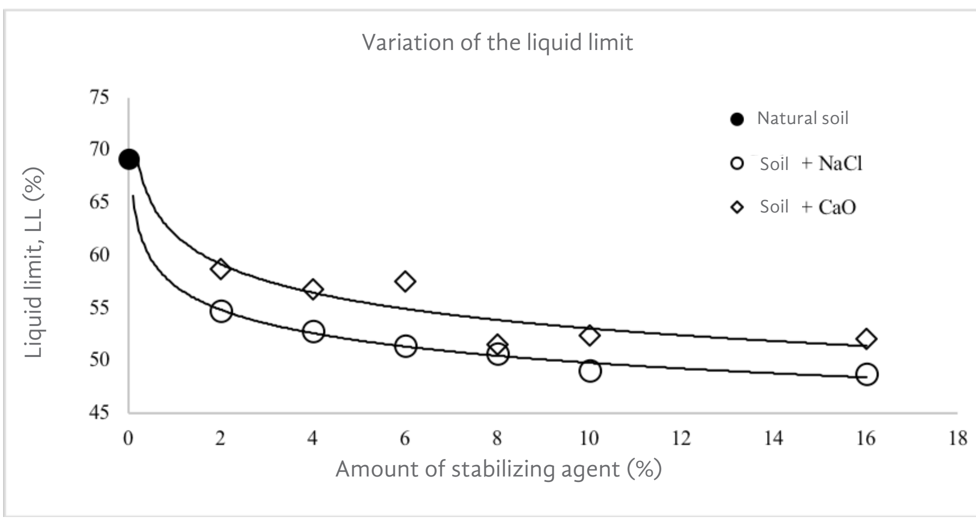

Image 3. Effect of chemical agents in the liquid limit

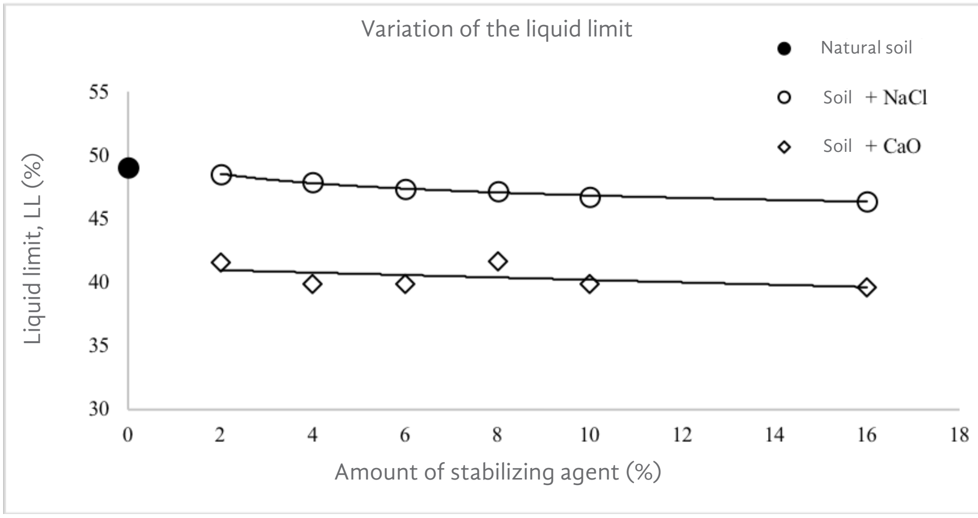

Image 4. Effect of chemical agents in the plastic limit

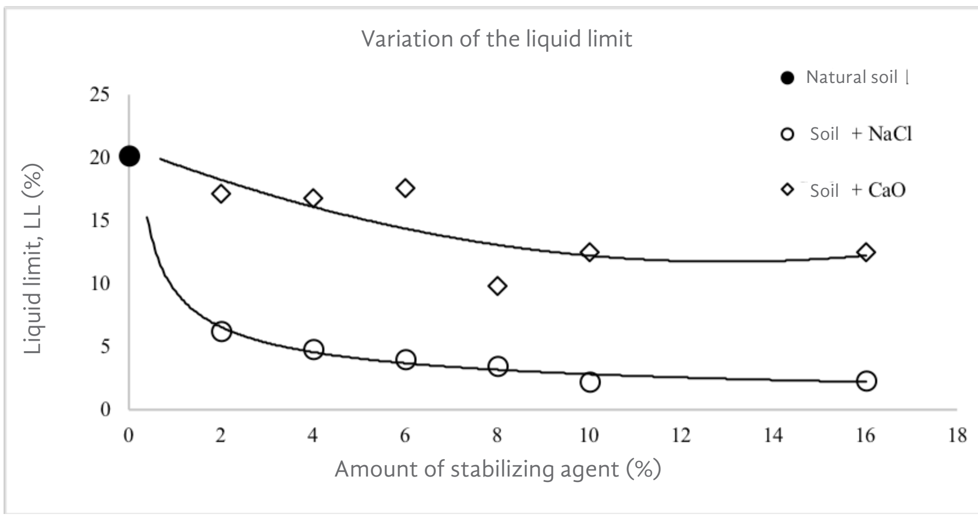

Image 5. Effect of chemical agents in the plastic index

As seen in Image 3, both chemical agents decrease the value of the liquid limit (LL), with sodium chloride (NaCl) consistently being the most effective. It can be seen that each increase in the percentage of NaCl corresponds to a decrease in LL, generating a reduction curve (trend line). It should be noted that for the range of 2% to 6% the curve is going down sharply. From 8% the curve begins to become horizontal and from 10%, it is increasingly flat. This behavior indicates that from 10% of salt the benefits are practically the same as if 10%, 12%, 14% or 16% were added to the soil. That is to say, from 10% it is no longer advisable to add more salt. Therefore, the optimal amount of NaCl to stabilize this soil is around 8%. This implies that, for this type of soil, it is enough to add 8% NaCl to obtain the best cost-benefit results. Adding a larger amount of this agent no longer generates a reduction in the liquid limit that merits the application cost. Similarly, in the case of calcium oxide the optimum amount of stabilization is around 8% (image 3).

Image 4 shows the variation of the plastic limit (LP) due to stabilizing agents in the material under study. As can be seen, NaCl has little effect on the LP of the soil, showing a practically linear trend. A similar behavior is observed in the samples added with CaO, although for this type of stabilizing agent there is a reduction in LP greater than in the case of NaCl.

Regarding the variation of the plasticity index (PI) in the soil samples, both agents proved to be effective in reducing this value (image 5), however, it was NaCl that showed the best results.

Table 2 shows the percentage of reduction of the limits of consistency with respect to the natural characteristics of the soil (table 1). It is important to note that the optimal amount of chemical agent is the same in both cases.

It is observed that both chemical agents reduced the liquid limit by approximately 25% (with respect to their initial value shown in Table 1). Regarding the plastic limit (LP), the samples that experienced the greatest reduction were those added with CaO. The chemical agent that proved to be most effective in reducing the plasticity index was NaCl, since it was able to reduce this parameter by 88.93% with respect to its initial value (table 1).

Table 2
LL, PL and PI soil reduction by effect of the chemical agents

		Reduction percentage*		
Stabilizing agent	**Optimal quantity by dry weight of soil**	**Liquid limit (LL)**	**Plastic limit (PL)**	**Plasticity index (PI**
NaCl	8 %	25.19 %	4.67 %	88.93 %
CaO	8 %	25.58 %	15.02 %	51.29 %

*According to the natural soil sample

DISCUSION

Lime (CaO) is one of the chemical agents that has traditionally been used successfully in the stabilization of soils. Several studies mention the positive effects of the use of this agent (Olinic1 and Olinic2, 2016, Olinic1 and Olinic2, 2014, Aldaood, 2007, Holt and Freer, 1996, Rogers and Glendinning, 1996). However, in these investigations a comparison of the performance of this important agent with other stabilizing agents was not performed. The comparative analysis between different soil stabilizing agents is very important, since the factor of greatest impact on the success of the stabilization is the relationship between the stabilizing agent and the soil minerals, that is, the choice of the type of stabilizing agent will depend of the type of soil. For example, the National Association of Lime Manufacturers (1982) notes that the effectiveness of lime as a stabilizer is considerably reduced in soils with a plasticity index (PI) of less than 10. This organism mentions that in cases in which Soils do not respond to lime, a second pozzolanic additive is required. Fly ash, waste material from coal calcination plants is the pozzolan most commonly used for this purpose.

In this research it was found that for the stabilization of the soil in the study area the best chemical agent performance is table salt. It was found that, if 8% dry weight of the chemical agents is added to the soil, the IP of the samples that were added with salt decreases on average 37% more than those to which lime was added. With regard to the costs in the study area of each stabilizing agent, the kilogram of salt costs on average $7.00 Mexican pesos, while the kilogram of lime is sold at $8.00 Mexican pesos. That is, salt (NaCl) is approximately 12.50% cheaper.

It is important to bear in mind that even with the improvement achieved by these stabilizing agents, the occasion may arise in which the limits established by the current regulations (SCT Standards) are not reached in order to use these stabilized soils in road pavement structures. In these cases, other alternatives must be analyzed.

CONCLUSIONS

The abundance of clay soils in nature creates the need to use them as building materials. The main problem of working with clay soils is their high plasticity because this property causes the soils to change their consistency depending on their moisture content. The plasticity index (PI) is the parameter by which the plasticity in clay soils is quantified. The most efficient way to decrease plasticity is through chemical stabilization. Traditionally this type of stabilization has been carried out with calcium oxide (lime). In this research, the performance of this important chemical agent was compared with the sodium chloride NaCl (table salt) in the stabilization of the clay soil of the Chontalpa unit of the UJAT. To achieve the above, different percentages of these chemical agents were added to different soil portions (image 2), this allowed to monitor the effects of the stabilizing agents on the liquid limit (LL), plastic limit (LP) and the plasticity index (IP). The results showed that, for the soil under study, the optimum amount of each stabilizing agent is 8%, however, table salt (NaCl) is the agent with the best results, since for the same optimum percentage (8% in dry soil weight) reduces the PI by 37% more than lime. Regarding the cost (in the study area) of the aforementioned stabilizing agents, using salt to stabilize the soil is not only more effective but also approximately 12.50% cheaper. Another benefit of using salt in the stabilization of soils is that it presents less volatility than lime, in addition, salt represents a lower health risk for the personnel who apply it. A relevant aspect regarding the application of both agents is that it can be done as a slurry, so that its volatility is practically null.

It is important to point out that the use of salt or another chemical agent as soil stabilizing elements, can cause ecological problems and in cases of contact with reinforced concrete structures or steel can cause corrosion.

Lime is one of the most successful stabilizing agents in the world for its effectiveness and great manageability, however, for the particular case of the soil analyzed in this research, the best stabilizing agent is table salt.

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