Lime treatment of an expansive soil for swelling potential reduction

L'effet du traitement à la chaux sur la réduction du potentiel de gonflement

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ABSTRACT: The effect of lime treatment on the reduction of swelling potential of an expansive soil was studied using the new geotechnical centrifuge developed by The University of Texas at Austin. The expansive soil Eagle Ford clay was treated with different percentages of lime. The compaction density was varied between 94% and 100% of the maximum dry density, and the compaction moisture was varied between dry of optimum, optimum and wet of optimum moisture content. The results demonstrated that higher potential swelling was observed in specimens prepared with densities near to the maximum than the specimens with lower density compaction. The strong influence of the compaction moisture on swelling showed the same trend observed in untreated soils. High potential swelling was produced in specimens compacted at dry of optimum moisture whereas specimens compacted at optimum or wet of optimum moisture content showed lower swelling potential. The lime percentage required to avoid the swelling depend on the moisture condition and the effective stress. Samples compacted with wet of optimum moisture content required only 2% of lime to prevent the swelling, whereas samples compacted at dry of optimum moisture content needed 4% of lime to avoid expansion.

RÉSUMÉ : L'effet du traitement à la chaux sur la réduction du potentiel de gonflement d'un sol expansif a été étudiée en utilisant la nouvelle centrifugeuse géotechnique développé par l'Université du Texas à Austin. Le sol expansive argile Eagle Ford a été traitée avec des pourcentages différents de la chaux. La densité de compaction varie entre 94% et 100% de la densité sèche maximale, et la teneur en eau varie entre la teneur en eau plus sec que l' eau optimale , la teneur en eau optimale et plus humide que la teneur optimal. Les résultats ont montré que le gonflement potentiel plus élevé a été observé dans les échantillons préparés avec des densités proche du maximum que les échantillons avec un compactage plus faible densité. La forte influence de la teneur en eau lors de la compaction sur le gonflement a montré la même tendance observée dans les sols non traités. Haut gonflement potentiel a été produit dans des échantillons compactés à la teneur en eau plus sec que l' eau optimale alors que les échantillons compactés à la teneur en eau optimale et plus humide que la teneur optimal montré plus faible potentiel de gonflement. Le pourcentage de chaux nécessaire pour éviter le gonflement dépendent de la teneur en eau et de la contrainte effective.Les échantillons compactés avec la teneur en eau optimale requise seulement 2% de chaux pour empêcher le gonflement , alors que les échantillons compactés à la teneur en eau plus sec que l' eau optimale nécessaire 4 % de chaux pour éviter expansion.

KEYWORDS: Expansive soil, centrifuge, lime treatment, swelling.

1 INTRODUCTION

Expansive soils typically involve high plastic clays found around the world, which undergo considerable volumetric changes, in terms of swelling or shrinkage, due to changes in moisture content. The volumetric changes undergone by expansive soils have been responsible for significant damages on transportation infrastructure, shallow foundations and lightweight constructions.

The centrifuge test for evaluating swelling behavior of expansive soils is a new technique developed at the University of Texas at Austin. This technique allows the testing of multiple specimens simultaneously in very short time. The rotation within the centrifuge imposes a gravitational field across the specimen, accelerating the water flow through the specimen and facilitating full water permeation and, consequently, entering into the microporous structure of the soil. Because of this, the centrifuge also allows measurement in an expedited way by an in-flight data acquisition system (Zornberg et al., 2009). So far, a number of studies have confirmed the capability of this centrifuge test to measure accurately and quickly the expansion of natural soils (Plaisted, 2009; Kuhn, 2010; Walker, 2012; Armstrong, 2014; Das, 2014; Snyder, 2015). However, no studies have been performed using this centrifuge technology to analyze the swelling reduction in expansive soils by stabilization treatments.

Among the techniques used to stabilize expansive soils in order to mitigate its swelling behavior, lime addition has been the most common technique due to the low cost of lime and its availability. However, there are no studies reporting the improvement of lime treatment efficiency due to variables controlled during preparation of lime-soil mixtures (i.e. moisture condition and density condition). Thus, the main purposes of this research are to investigate the modification of swelling behavior due to lime treatment, and to measure the efficiency of lime treatment on swelling reduction due to variations of specimen preparation conditions. The modification of swelling behavior due to variations in lime-soil mixtures preparation is studied by analyzing the swelling vs. time curves obtained centrifuge tests carried out in the expansive soil Eagle Ford clay.

Based on the swelling potential (Sp) values obtained for untreated and lime-treated Eagle Ford clay specimens prepared at different conditions, the parameter designated as Swelling Potential Reduction Ratio (SPR) was introduced to estimate the efficiency of lime treatment on swelling mitigation. The SPR compares the swelling potential of untreated Eagle Ford clay and the swelling potential of lime-treated Eagle Ford clay subjected at different parametric variations.

2 EXPERIMENTAL PROGRAM

The natural expansive soil selected for this study was a highly clayey soil named Eagle Ford predominant in Texas, United States. Hydrated high-calcium lime with 94% of Ca(OH)2, henceforward called "hydrated lime" was used in this study contains. Lime-soil mixtures were prepared with dosage rates based on the dry weight of soil to be treated.

The centrifuge test for evaluating swelling behavior of expansive soils is a new technique developed at the University of Texas at Austin. The centrifuge allows testing up to six soil specimens simultaneously, which facilitates the repeatability of results among identical specimens in order to obtain results that are more reliable. The rotation of the specimen within the centrifuge imposes a gravitational gradient across it by accelerating the water flow. Thus, the centrifuge testing can take short time to permeate the water into the specimen and to enter into the microporous structure of the soil.

The centrifuge set-up is composed by a Damon IEC CRU-5000 centrifuge with a Model 259 rotor, a Data Acquisition System (DAS), six centrifuge cups and a control board. Figure 1 shows an internal view of the centrifuge. The DAS includes a battery supply, an accelerometer, an analog to digital converter and a Linear Position Sensors (LPS). The LPS is used for monitoring the vertical deformations of the soil specimens. The DAS is able to transmit wirelessly the sensors data to a computer, which records voltage values over time from LPS and accelerometer.

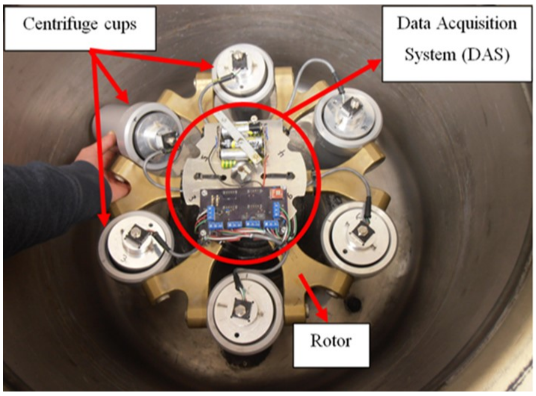


Figure 1. Damon IEC CRU-5000 centrifuge (internal view)

In order to conduct the centrifuge test, the specimen was compacted to 1cm height and 5cm diameter into the metal ring. After specimen compaction, each ring was placed into a permeameter cup, which allows water infiltration from both sides, i.e., the top and base side of the specimen.

3 TEST RESULTS AND ANALYSIS

The swelling was defined as the ratio of the increase in height to the original specimen height, expressed as a percentage. In order to analyze the efficiency of lime percentage on the reduction of swelling potential, a new parameter, called Swelling Potential Reduction Ratio (SPR), was introduced. SPR measures the reduction on swelling potential produced by hydrated lime additions, at different specimen preparation conditions, regarding to swelling potential in natural soil. SPR is defined by Eq. 1.

$$SPR = 1 - \frac{Sp_{(n\%HL)}}{Sp_{(0\%HL)}} \qquad (1)$$

where $Sp_{(0\%HL)}$ is the swelling potential in untreated Eagle Ford clay and $Sp_{(n\%HL)}$ is the swelling potential at particular hydrate lime percentage (n% HL). SPR value ranges from zero to one. SPR will be zero for untreated Eagle Ford clay because there is no reduction of swelling potential, since there is no lime addition. SPR will be one when the addition of lime produces 100% of reduction of swelling potential compared with swelling potential in untreated Eagle Ford clay. Therefore, the higher SPR is, the lime treatment can be considered more efficient.

3.1 *Evaluation of compaction moisture condition effect on swelling behavior*

Although several researchers have been demonstrated that the swelling potential in expansive soils can be reduced with compaction at high moisture contents (Walker, 2012; Armstrong, 2014; Snyder, 2015), there are no studies about the effect of moisture condition on the swelling potential of lime-treated soils. In order to examine the combined effect of lime addition with compaction moisture condition variations on swelling behavior, the specimens with different percentages of hydrated lime were compacted at three different moisture conditions, designated as dry of optimum (DOP), optimum (OPT) and wet of optimum (WOP). The DOP condition was established equivalent to 21% of moisture content, the OPT condition was equivalent to 24% of moisture content and the WOP condition was equivalent to 27% of moisture content. The dry density was kept constant at 1.51 g/cm3.

The swelling vs. log-time curves obtained by centrifuge test of untreated and lime-treated Eagle Ford clay (with 0.5% HL), and prepared at different compaction moisture condition are depicted in Figure 2.

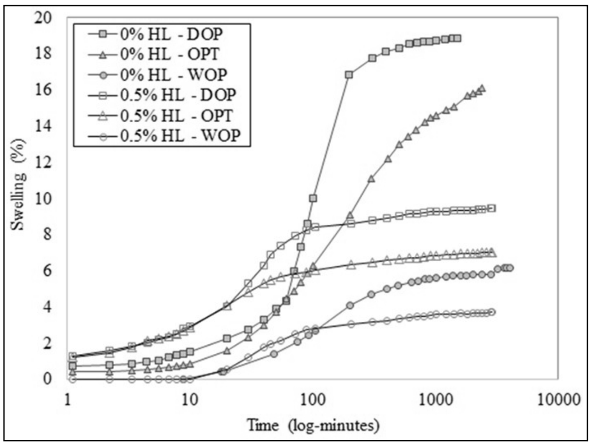
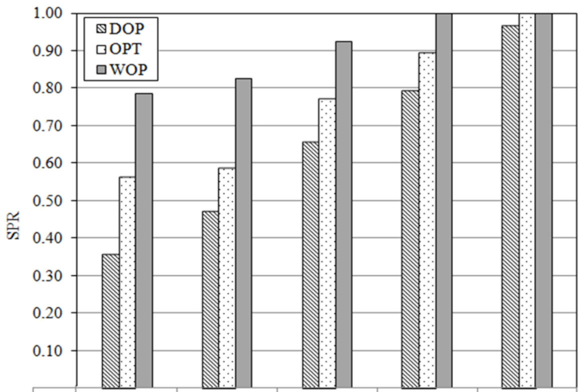


Figure 2. Semi-log plot of centrifuge test results from specimens with 0% and 0.5% of hydrated lime compacted at different moisture conditions.

The effect of compaction moisture condition on swelling potential for different hydrated lime percentages suggests that the increase in moisture content is able to substitute somehow the lime addition in order to reduce the swelling potential. In order to estimate the swelling potential reduction ratio (SPR), defined by Eq. 1, the baseline swelling potential was established as the swelling potential obtained using the centrifuge test for untreated Eagle Ford clay at OPT moisture condition, i.e., swelling potential = 13.1%. The SPR at different compaction moisture conditions and hydrated lime percentages is illustrated in Figure 3. Based on the patterns exposed in this figure, the WOP condition produced the highest SPR values for all percentages of hydrated lime applied. Furthermore, it can be noticed that while the hydrated lime percentage is increased, the difference between the SPR at the three compaction moisture conditions DOP, OPT and WOP seems to be reduced.



HL (%)	0.5	1	2	3	4
DOP	0.36	0.47	0.66	0.79	0.97
OPT	0.56	0.59	0.77	0.89	1.00
WOP	0.79	0.82	0.92	1.00	1.00

Figure 3. Swelling potential reduction ratio (SPR) at different compaction moisture conditions.

Also, the increment of compaction moisture content, e.g. from OPT to WOP condition, might reduce the amount of hydrated lime needed to avoid swelling behavior. For instance, in Figure 3, it is observed a slightly higher SPR value for the specimen treated with 1% HL and compacted at WOP than the SPR value obtained from the specimen treated with 2% HL and compacted at OPT condition. Therefore, an increase of 3% in compaction moisture content (i.e. from OPT = 24% to WOP = 27%) might result in almost the same swelling reduction produced by an additional of 1% of hydrated lime into the mixture. Since the lime addition also reduces the clay plasticity, problems related with workability are not be expected with increasing compaction moisture content, as could be expected in the case of natural expansive soils compacted at high moisture contents.

Conversely, the DOP condition exhibited an adverse effect on swelling reduction. As can be observed in Figure 3, the SPR value obtained in the specimen treated with 3% HL and compacted at DOP condition was similar to the one obtained with 2% HL and compacted at OPT condition. Since the DOP moisture condition may result in higher swelling potential, regardless the hydrated lime percentage, the lime-treated soil moisture should be checked before compaction in construction processes in order to ensure that this soil had not lost too much water.

3.2 *Evaluation of compaction dry density effect on swelling behavior*

In order to quantify the combined effect of lime addition with compaction dry density variations on swelling behavior, the specimens were compacted at 94% and 100% of relative compaction (RC). According to the results of standard Proctor compaction test carried out in untreated Eagle Ford clay, the maximum dry density was 1.51g/cm^3. Thus, the specimens with RC = 100% were compacted as close as possible to this dry density, whereas specimens with RC = 94% were compacted with dry density equivalent to 1.42g/cm^3. In this set of experiments, the specimens were spun at 5g's into the centrifuge. The moisture content was kept constant and close to the OPT condition of 24%.

The swelling vs. log-time curves obtained by centrifuge testing of untreated and lime-treated Eagle Ford clay specimens (with 0,5% HL) that were compacted at RC = 100% and RC = 94% are shown in Figure 4. By observing these figures, the general trend noticed is a higher swelling in specimens compacted at RC = 100% than specimens compacted at RC = 94%. Some authors (Likos & Lu, 2006) have demonstrated that denser specimens swelled more than initially loose specimens, indicating that loosely compacted specimens exhibit more inefficient translation from particle-scale swelling to bulk-scale swelling because the interlayer volume changes occurring on the particle scale are internally adsorbed by the larger scale pores. Conversely, densely compacted specimens exhibit more efficient translation from particle-scale swelling to bulk-scale swelling because the interlayer volume changes are less well accommodated by the internal pores. Therefore, in the present study, it was observed that expansive soils treated with lime also present swelling mechanisms dependent on compaction density, where specimens compacted with higher density have more efficiency in swelling translation from particle-scale swelling to bulk-scale swelling.

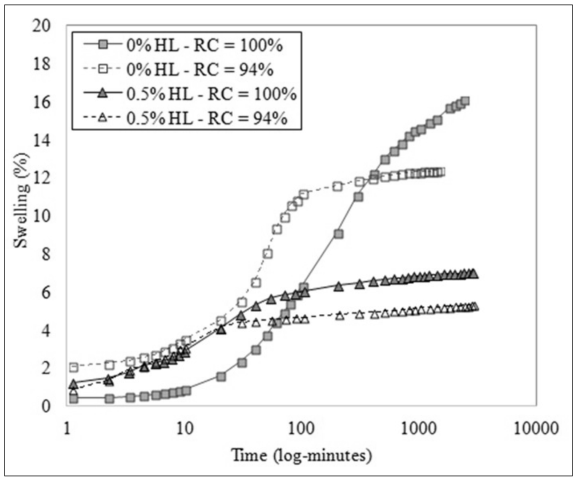
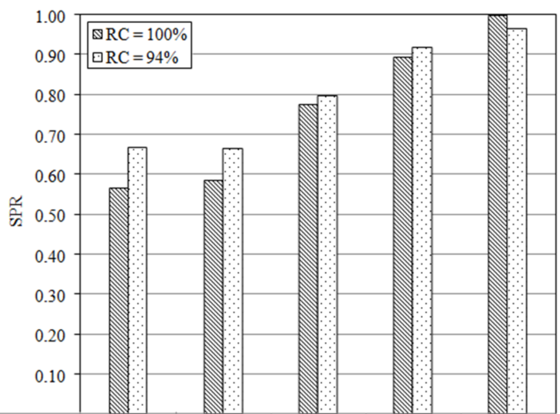


Figure 4. Semi-log plot of centrifuge test results of specimens with 0% and 0.5% of hydrated lime and compacted at 94% and 100% relative compaction (RC).

The combined effect of relative compaction reduction with lime addition on swelling potential was estimated by the swelling potential reduction ratio (SPR) value, as defined by Eq. 1. The baseline swelling potential was established as the swelling potential obtained from untreated Eagle Ford clay compacted at OPT moisture condition and RC = 100%, i.e., swelling potential = 13.1%. Therefore, the SPR values were calculated using the swelling potential obtained with different hydrated lime percentages and both relative compaction RC = 100% and RC = 94%, and the results are reported in Figure 5.



HL(%)	0.5	1	2	3	4
RC = 100%	0.57	0.59	0.77	0.89	1.00
RC = 94%	0.67	0.67	0.80	0.92	0.97

Figure 5. Relative compaction effect on swelling potential reduction ratio (SPR) for different hydrated lime percentages.

The results suggest that when the hydrated lime percentage was increased, the SPR difference between specimens with RC = 94% and 100% was reduced. Also, it can be observed that SPR for all hydrated lime percentages was greater in specimens compacted at RC = 94% than those compacted at RC = 100%, except for 4% of hydrated lime. Thus, the reduction in dry density (or RC) leads to increase of lime addition efficiency on swelling reduction. However, unlike to what was observed for variations of compaction moisture content, the dry density variation could not offset the effect of a greater percentage of lime.

4 CONCLUSIONS

In this study it was successfully verified the capability of the centrifuge technology to analyze the swelling reduction in expansive soils by stabilization treatments, such as lime treatment. The present results demonstrated that this technology also can facilitate the evaluation of varied solutions for soil expansion.

The swelling behavior of untreated and lime-treated Eagle Ford clay was found to be highly sensitive to variations in compaction moisture condition. It was found that the increment of compaction moisture content, e.g. from OPT to WOP condition, was able to substitute in some quantity the percentage of hydrated lime needed to reduce the swelling potential of Eagle Ford clay. The compaction moisture condition DOP was found to have an adverse effect on lime-treatment efficiency for swelling reduction. This moisture condition resulted in higher swelling potentials than those found in OPT or WOP conditions.

The evaluation of compaction dry density on swelling behavior of untreated and lime-treated Eagle Ford clay showed that the swelling potential slightly decreases with a decrease in relative compaction. This behavior was attributed to the fact that loosely compacted specimens exhibit more inefficient translation from particle-scale swelling to bulk-scale swelling because the interlayer volume changes occurring on the particle scale are internally adsorbed by the larger scale pores. Conversely, densely compacted specimens exhibit more efficient translation from particle-scale swelling to bulk-scale swelling because the interlayer volume changes are less well accommodated by the internal pores.

The lime addition efficiency can be increased with the reduction of compaction dry density. However, unlike to what was observed for variations of compaction moisture content, a reduction in compaction dry density was not able to offset the effect of a greater percentage of hydrated lime for swelling mitigation

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4 REFERENCES

Das, J. T. 2014. Evaluation of the rate of secondary swelling in expansive clays using centrifuge technology. (Master thesis). The University of Texas at Austin.

Kuhn, J. A. 2010. Characterization of the swelling potential of expansive clays using centrifuge technology. (Doctoral dissertation). The University of Texas at Austin..

Likos, W. J. and Waylllace, A. 2010. Porosity evolution of free and confined bentonites during interlayer hydration. Clays and Clay minerals, 58(3), 399-414.

Plaisted, M. D. 2009. Centrifuge testing of expansive clay. (Master thesis). The University of Texas at Austin.

Snyder, L. M. 2015. Determination of potential vertical rise in expansive soils using centrifuge technology. (Master thesis). The University of Texas at Austin.

Walker, T. M. 2012. Quantification Using Centrifuge of Variables Governing the Swelling of Clays. (Master thesis). The University of Texas at Austin.

Zornberg, J. G., Kuhn, J. A., and plaisted, M. D. 2009. Characterization of the Swelling Properties of Highly Plastic Clays Using Centrifuge Technology. Center for Transportation Research (CTR), Report No. FHWA/TX-09/0-6048-1, Austin, Texas.