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Laboratory assessment of shear strength parameters in sandy soil by lime permeation method and sensitivity analysis from Doi Chang case study

Évaluation en laboratoire des paramètres de résistance au cisaillement dans un sol sablonneux par la méthode de perméation à la chaux et analyse de sensibilité à partir de l'étude de cas de Doi Chang

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ABSTRACT: In nature, slopy terrain or loosely compacted soil can have high permeability which can cause rise in groundwater table and may create stability problems. To minimize this phenomenon, hydrated lime slurry permeation can be used. Hydrated lime has been in use for many years. But using lime slurry to treat low shear strength soil can be a solution for slope stability. The purpose of this research is to increase the sand's shear strength by hydrated lime permeation under the influence of constant head. The test samples were obtained by passing through sieve #40 and retained on #200. After 66 days of lime permeation, permeability decreased by 94% and cohesion increased up to 77%. Also, to identify the mineral compounds and analyze the structure of crystalline materials, X-ray Diffraction Method (XRD) was used which showed formation of calcium cations along with the sand silica. The Sensitivity Analysis from Doi Chang mass movement case study (a village in Thailand having active mass movement currently) showed that the increase in cohesion help in the increase in factor of safety by 11.2% even though groundwater level was higher.

RÉSUMÉ: Dans la nature, un terrain en pente ou un sol peu compact peut avoir une perméabilité élevée, ce qui peut entraîner une montée de la nappe phréatique et créer des problèmes de stabilité. Pour minimiser ce phénomène, on peut utiliser la perméation à la boue de chaux hydratée. La chaux hydratée est utilisée depuis de nombreuses années, mais l'utilisation de boue de chaux pour traiter un sol de faible résistance au cisaillement peut être une solution pour la stabilité des pentes. Le but de cette recherche est d'augmenter la résistance au cisaillement du sable par perméation à la chaux hydratée sous l'influence d'une tête constante. Les échantillons de test ont été obtenus en passant à travers un tamis #40 et retenus sur le tamis #200. Après 66 jours de perméation à la chaux, la perméabilité a diminué de 94 % et la cohésion a augmenté jusqu'à 77 %. De plus, pour identifier les composés minéraux et analyser la structure des matériaux cristallins, la méthode de diffraction des rayons X (XRD) a été utilisée, montrant la formation de cations de calcium avec la silice du sable. L'analyse de sensibilité de l'étude de cas du glissement de terrain de Doi Chang (un village en Thaïlande connaissant actuellement des mouvements de masse actifs) a montré que l'augmentation de la cohésion contribue à augmenter le coefficient de sécurité de 11,2 %, même si le niveau de la nappe phréatique était plus élevé.

Keywords: Permeability; lime permeation; cohesion; XRD; sensitivity analysis.

1 INTRODUCTION

Lime treatment by permeation in porous soil is a challenge to let lime particles or soluble cations into the soil. However, pore size of the soil must be larger than the inherent lime particles. When lime is added to a fine-grained soil and intimately mixed, several reactions initiate. Cation exchange and agglomeration-flocculation reactions take place rapidly and produce immediate changes in soil plasticity, workability, and swell properties. A soil-lime pozzolanic reaction may commence depending on the characteristics of the soil being stabilized. The pozzolanic reaction results in the formation of various types of hydrated calcium silicate and calcium aluminate cementing agents or both. The cementing agents increase strength and durability. Pozzolanic reactions are time dependent, and strength development is gradual but continuous for a long period of time (several years in some instances) (Thompson & Robnett, 1976).

Residual soil or colluvium is the heterogeneous mixture of boulder or granular soil and mixtures of both. The colluvium loses the valuable minerals under leaching such as iron, calcium, aluminum under high rainfall and form lateritic soils and andosols downslope. Many past studies have suggested that permeability in case of In situ residual soil is higher than compacted soil in laboratory and use of lime for high plasticity soils is effective except for organic soil (Townsend, 1985). Grouting by lime slurry with fly ash increased the alkalinity in time, having maximum concentration at 59 days. Also, grouting about 59-64%, hydraulic conductivity was found to decrease (Gabr et al., 1995). The hardening and strengthening of the lime mixture with soil depend on carbonation of the lime. This is likely because of the attachment of the calcite crystals to the surface of aggregate particles. The pore size of the soil is directly involved in the carbonation process (Lawrence et al., 2007).

Dissolving lime in water and intruding saturated lime solution (SLS) containing calcium cations into soil by means of gravity gradient resulted in an increase of 294% in cohesion and 222% in internal friction angle and a decrease of 58% in settlement of specimens (Davoudi et al., 2009).

The sequential permeation of $CaCl_2$ and NaOH solutions into compacted expansive soil resulted in the precipitation of lime in the expansive soil and increased pH level which is important for pozzolanic reactions to effectively reduce plasticity index and swell potential. This is an effective method for lime precipitation for stabilizing expansive soils (Thyagaraj et al., 2012; Thyagaraj & Zodinsanga, 2015).

Another study about the remediation of reactivated landslide used a method to introduce lime slurry into the sheared zone. Just after remediation of 10% of the slip surface by 7% lime, it caused increase in factor of safety from 1.1 to 2.89 after 5 weeks of curing (Moridzadeh, 2019).

X-Ray Diffraction (XRD) test is successful in identifying crystalline minerals such as calcite, illite, quartz, kaolinite and chlorite-serpentine mixed layers. It provides a powerful nondestructive technique for characterizing crystalline materials. It provides information on structures, phases preferred crystal orientation (texture), and other structural parameters, such as average grain size, crystallinity, strain and crystal defects (Moretti et al.,2020).

2 SPECIFIC OBJECTIVES OF THE RESEARCH

- To use lime stabilization to monitor the changes in cohesion and frictional properties of soil.
- To observe the relative changes in soil permeability before and after improvement using lime stabilization.
- To study the changes in soil structure using XRD.
- To perform sensitivity analysis in real case scenario with increase in cohesion.

3 METHODOLOGY

A laboratory set up was arranged using custom made constant head apparatus as in Figure 1. The top two containers contain two separate mixtures of 500 g and 4000 g solutions. The two small constant head containers take solutions to the samples separately. T1, T2 and T3 were passed through 500 g solution whereas T4, T5 and T6 were passed through 4000 g solution. An acrylic waterproof tube was made for testing samples. Altogether 6 sample tubes were prepared to test lime permeation. Samples were obtained from construction site and taken only samples passing #40 and retained on #200. A uniform density was maintained by mild compaction using Proctor for 25 blows at 5 cm each interval. Two solutions were prepared having 500 g and 4000 g for the same volume of water in separate containers. 500 g solution was passed through T1, T2 and T3 whereas 4000 g solution was passed through T4, T5 and T6. Continuous monitoring of the outlet permeability was done to measure and analyse the effectiveness of lime permeation. Samples were taken out at different time intervals to observe strength behaviour. Cohesion and friction angle were measured at different time intervals as in Figure 5 and Figure 6. A direct shear test method was used under drained conditions Also, X-Ray diffraction (XRD) test was done for T5 to see calcium ions within the samples. Finally, a sensitivity analysis was done using the laboratory data to evaluate possible changes in factor of safety in slope stability.

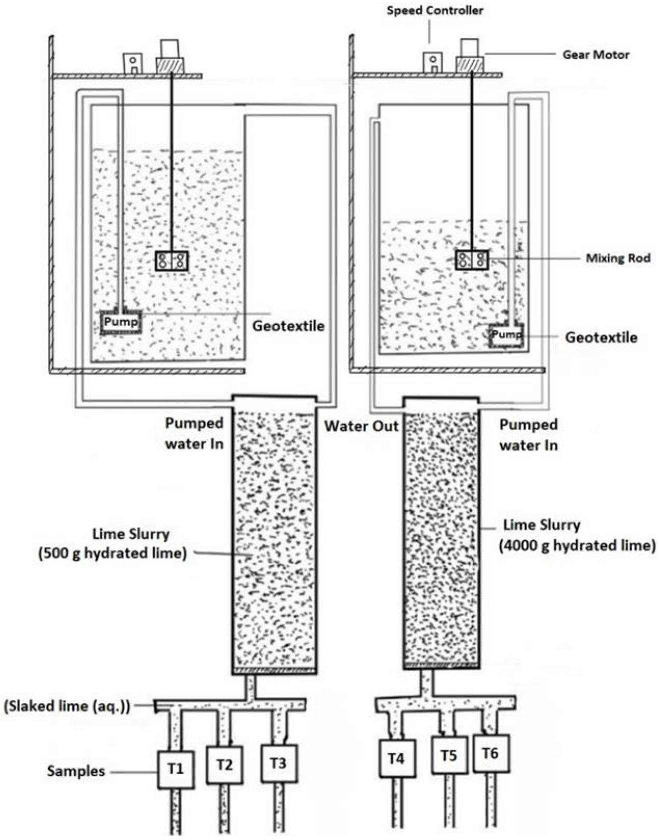

Figure 1. Schematic diagram of laboratory experiment.

4 FLOWCHART

The flowchart shows workflow and varieties of laboratory tests as shown in Figure 2.

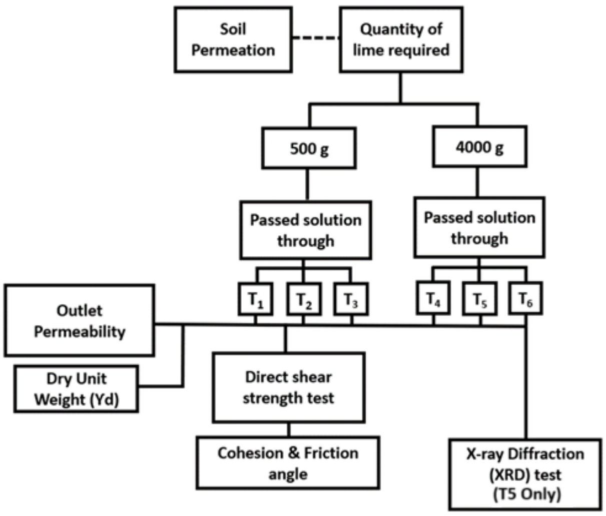

Figure 2. Flowchart of laboratory tests.

5 RESULT AND DISCUSSION

5.1 Unit Weight Variation

Lime water permeation method showed slight gain in the density of the sample i.e. increase in the unit weight of the soil by small percentage from original value. The value from 0.991% to 1.001% was the increased unit weight percentage range from T1 to T6. The result showed increase in unit weight percentage, which was higher in lime solution of 500 g than solution with 4000 g, as in Figure 3 below. 12 days and 66 days had similar results; however, 46 days results were reversed due to uneven flow and irregular permeability during treating.

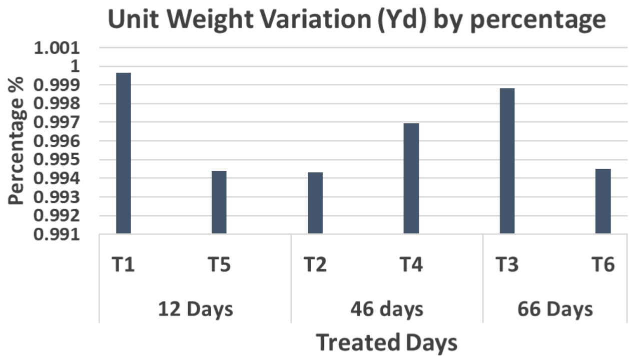

Figure 3. Percentage change in unit weight of the treated soil and its comparison.

5.2 Permeability

The permeability over the period of 2 months (66 days) showed a significant decrease in both 500 g and 4000 g solutions. In the Figure 4, the coefficient of permeability was seen to be slightly higher in 500 g mixture solution than that of 4000 g of solution because of the concentration of the lime particles. Also, as we could see T4 had minimum permeability from beginning due to apparatus misposition of perforated filter or apparatus failure, because of the insufficient permeation, it did not gain enough strength in strength test results. The ups and downs of values in the graph was due to clogging of lime particles. Frequent cleaning of inlet valves and pipes were done. However, this method could not show how much portion of the soil was impermeable and it requires another level of instrumentation or monitoring. The general graph of permeability for all soil samples in different time is in Figure 4 below.

5.3 Strength Test and Analysis

The samples were tested, and friction angle was found to fluctuate slightly lower than beginning as shown in Figure 5. The reduction in friction angle was uniform, which was not much affected by time whereas cohesion was increased exponentially. The friction angle reduction value ranges between 1-5.5% whereas cohesion was increased 0.4% in 12 days, 30% in 46 days and 77% in 66 days of treatment as in Figure 6.

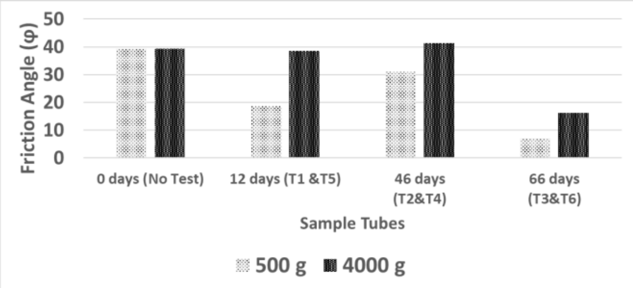

Figure 4. Coefficient of permeability for all samples at two different hydrated lime concentration.

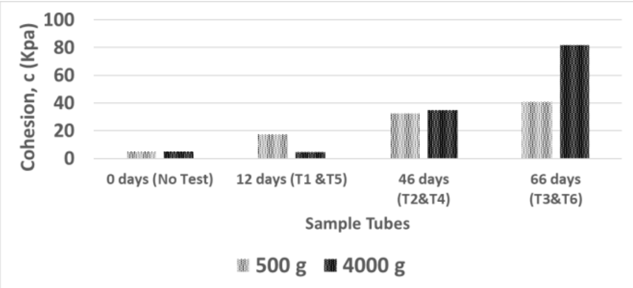

Figure 5. Comparison of friction angle of samples.

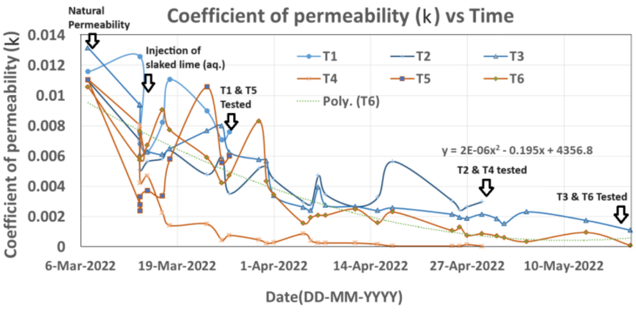

Figure 6. Comparison of Cohesion of samples.

5.4 XRD Test and Analysis

X-Ray Diffraction test was conducted to check the content of lime in compound form or formation of calcium carbonate. A sample tube T5 containing 4000 g solution was tested after 12 days of lime permeation. In a 2D section of the sample tube T5 as in Figure 7, altogether 6 samples were taken out for X-Ray Diffraction test from which Calcite and Quartz crystalline compounds were found. Quartz (SiO_2) is the silica found in sand itself, which had no change unless being mixed by lime particles. Calcite ($CaCO_3$) is the calcium carbonate compound being developed due to lime concentration. The X-ray diffraction was recorded based on reflected light and it is generally called 2θ (2 theta) which gives an angle made between incident and diffracted X-Rays. The result shows higher $CaCO_3$ in the beginning (i.e S51=1.30% and S52=3.46%). However in the middle (i.e S53=0.91%) and last part of the sample got lesser $CaCO_3$ after 12 days of treatment as in Figure 7.

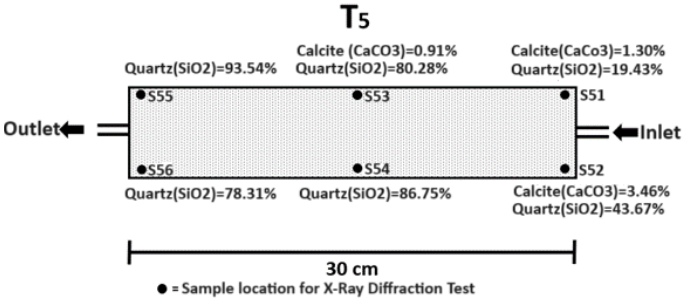

Figure 7. XRD result of T5 sample.

5.5 Sensitivity Analysis

A sensitivity analysis was used to determine the effect of various input parameters on slope stability. The effect of uncertainty or variability in the values of soil parameters could be explored. In this study, cohesion was more dominant parameter than friction angle. From the experiment, it was found that there was no significant change in friction angle values with respect to time; however cohesion was increased over time.

The residual cohesion of soil was found to be 7.84 kPa from a previous study. To check the effect of cohesion parameter in final factor of safety in the Doi Chang case, varying groundwater table and an infinite slope equation was used (Soralump et.al., 2021). In the performed experiment, the cohesion value had increased by 77% over 66 days of lime treatment. Using this cohesion value to simulate safety factor, an 11.2% increment in safety factor was of the unstable slope obtained. This showed that lime treatment would be an effective treatment for unstable slopes with high GWL.

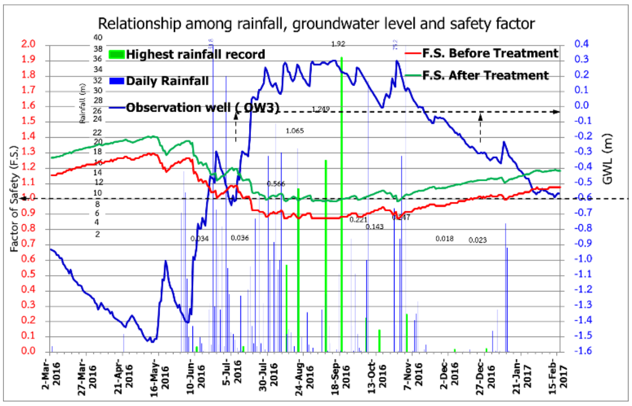

Figure 8. Relationship among rainfall, groundwater, and factor of safety before and after treatment of 66 days of lime permeation.

6 CONCLUSIONS

The lime permeation method is found to be effective for reduction in permeability in fine sand. However, uniform permeation is also a key to strengthen soil within its specimen. It can be greatly expected to have risen in strength where there is higher lime water permeation.

This method also increases cohesion in the cohesionless soil such as sand. However, permeability must be regular and not sudden drop in flow, which might result in the low treatment as in case of T4. Moreover, friction values are not affected much by this method. In case of fiction angle, reduction value ranges between 1-5.5% whereas cohesion was increased 0.4% in 12 days, 30% in 46 days and 77% in 66 days of treatment.

Moreover, presence of Calcium crystals detected by X-Ray Diffraction (XRD) shows successful treatment by lime permeation.

Also, sensitivity analysis for Doi Chang case study shows the cohesion increases by 77% resulting in increase in factor of safety by 11.2% even though high groundwater table is present.

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