Soft soil strengthening by calcium cation permeation

Renforcement du sol mou par l'infiltration du cation de calcium

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ABSTRACT

Different methods are used for increasing shear strength of soft soils; among them are additive materials such as slag, fly ash, lime and cement. This paper presents a new method for evolution of shear strength in soft soils. In this method the calcium ion is prepared by dissolving hydrated lime in the water. Once saturated lime solution (SLS) is permeated in the soil, two phenomenons, cation exchange and pozolanic reaction, take place and result in soil strengthening. To study this method, a physical model was design and built in SCWMRI and 1600 liter SLS was permeated through a high plastic clay, then direct shear and Atterburg limit tests were carried out on treated samples. The results showed that the shear resistance of soil increase about 200% while the settlement and plasticity index decreases 58% and 14% respectively.

RÉSUMÉ

Il existe différentes méthodes pour renforcement du sol mou parmi eux c'est les matériaux additifs comme métal scorie, cendres volantes, chaux et ciment. Cet article présente une nouvelle méthode pour l'évolution de la résistance au cisaillement des sols mous. Dan cette méthode, les cations de calcium sont préparés par la dissolution des chaux dan l'eau. Lors que la solution saturée de la chaux (SSC) s'infiltre dans le sol deux phénomènes, l'échange cationique et réaction pozolanique, se placent et entraine le renforcement du sol. A fin de l'étude de cette méthode, un model physique a était conçu et fabriqué à SCWMRI et un volume de 1600 litre du SSC a était infiltré à travers une argile de plasticité élevée, puis les essais cisaillement direct et limites d'Atterburg ont étaient réalisés sur les échantillons traités. Les résultats montrent que la résistance au cisaillement du sol monte autour de 200% tandis que le tassement et l'indice de plasticité diminuent 58% et 14% respectivement.

Key words: soft soil, calcium cation, soil improvement, shear resistance, plasticity index

1 INTRODUCTION

Many projects encounter soft soils which should be treated due to their low shear resistance or large potential of subsidence. Stabilizing of these soils which may be faced with in natural sliding slopes, estuaries, shores or low lands significantly increases the project cost. Some current techniques for treating these soils are such as: reinforced pile and nailing for stabilizing natural slopes (Mellit, 1992) and piling, lime column (Broms and Boman, 1967) and lime piles (Ingles and Metcalf 1972) for increasing bearing capacity in lowland soft soils.

Some researchers have attempted to improve the shear resistance of soil by adding some additive materials such as fly ash, slag, cement and lime to the soil. This method is essentially based on pozolanic reaction between soil particles and additive materials. The presence of these materials, in general, causes a decrease in the plasticity index and thus the workability and performance of soil, and in the other side, an increase in the shear resistance and the bearing capacity (Indraratna, 1996).

The other method of soft soil improvement is to change the ionic condition of soil. Paassen and Gareau (2004) explained that the pore fluid salinity affects the shear strength and compressibility of clays. Results of their study on a normally consolidated and high plasticity marine clayey soil from the Caspian Sea showed that an increase in the pore fluid salinity causes a decrease of the moisture content while the remolded shear strength corresponds to the measured moisture content. Dexter and Chant (1991) investigated on the improvement of mechanical properties of soil by means of ionic treating. They reported that the tensile strength increased with increasing exchangeable sodium and decreased with increasing exchangeable calcium. Shear strength of moist soil, increased with increasing exchangeable calcium, potassium and sodium. The influence of exchangeable magnesium was variable in that it tended to increase the tensile strength of the soils when dry, whereas it tended to decrease the shear strength of one of the sets of soils in the moist state. They concluded that the exchangeable cations which give rise to greater repulsion between, and dispersion of, clay particles in water also give rise to greater strength in the dried soil. It is proposed that this is because greater particle repulsion in the soil water during drying enables particle rearrangements to take place more readily and these results in denser packing arrangements and increased strength.

Zhao et al (200) investigated on landslides possibly affected by acid rain induced changes in soil strength. They studied remolded samples taken from slip surfaces at two landslides in the region of the Three Gorges, China, and subjected them to acid water bath and found that the largest changes occur in the internal friction angle, which drops over one-third, concomitant with alteration of the originally smectitic soil with a substantial illite component into completely smectite dominated soil, while changes in cohesion are much less significant.

Asavadorndeja and Glawe (2005) injected calcium ions by electrokinetic mehod into soils to replace monovalent ions. The calcium ions and hydroxide ions react with the dissolved silicates and aluminates in the clay to form cementing agents,

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calcium silicates and/or aluminum hydrates. They coupled this technique with a depolarization technique and found an increase in strength of up to 170% immediately after treatment and up to 570% after a 7-day curing.

The foresaid methods require their proper equipments and impose significant costs to projects. Furthermore, in cases such as sliding slopes in rangelands or forests where the land is not worthy and there is not any valuable or important property, for stabilizing these landslides by these techniques, authorities face usually limitations and difficulties to provide considerable budget. In this paper it's tried to examine a less costly method for soil improvement.

2 MATERIAL AND METHOD

The new method is based on ionic treatment of soil while additive material method is also taken into account. As many researchers have mentioned, adding lime to the soil may result in the following four reactions: hydration, cementation, ion exchange and carbonation. The first reaction drives the calcium ion from the lime to the media and provides the required cations for the second and the third reactions.

In the proposed method the hydration process takes place directly by dissolving lime in the water then permeating the dissolved lime containing calcium cation into the soil by the gravity.

$$Ca(OH)_2 \longrightarrow Ca^{++} + 2OH^- \qquad (1)$$

The clear and colorless solution doesn't contain any solid particle; its permeability is very close to normal water and is able to penetrate the soil down to any depth. Based on the solubility of lime in water, 0.139% at room temperature, required quantity of powder of hydrated lime passing sieve No. 200 was dissolved in the water, then left for a while to precipitate the extra amount of lime. By this way 1600 liter of "saturated lime solution" (SLS) was prepared.

A high plastic soil originating from highly weathered gypsum marl located in the Alborz chain, Iran, was used for this study. The plastic limit and plasticity index of the soil were measured as 30.3% and 25.1% respectively. The double hydrometery test was conducted to ensure the absence of any sign of dispersivity.

A physical model was set up as shown in Fig. 1. The model consists of two parts separated by a perforated galvanized plate. The smaller part, designated as "reservoir", was filled with SLS (saturated lime solution). The larger part to be filled with soil and is equipped with nine drains located at three levels on the downstream end of the model. The soil was placed in the model and compacted homogenously to a unit mass of 1300 kg/m^3.

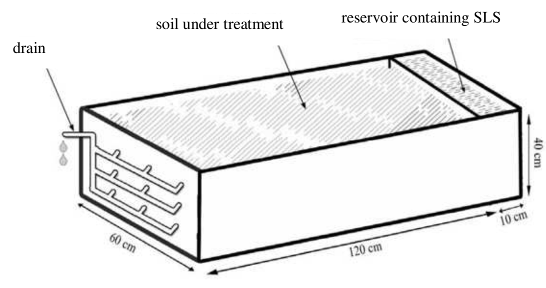

Figure 1. Schematic view of Set up of the tests

The bed of the model was prepared such that its upstream end was 12 cm higher than the downstream one to apply a hydraulic gradient of 0.1 to the model. To assure the soil mass be penetrated entirely by SLS, the end of drains was fitted at the level of soil top surface. By this way, under a gravitational gradient of 0.1, a permanent one dimensional flow of SLS was developed throughout the soil mass, intruding calcium cations into the soil and drained via the downstream drains. In order to prevent any evaporation from the top surface of the soil which results in the accumulation of dissolved materials at the soil top surface and the creation of a two dimensional flow, the model was covered entirely by a wrap and the level of SLS in the reservoir was kept 2 cm lower than the soil top surface.

The test was running for sixty days while a continuous flow of calcium cations was established through the soil block. During this time, twenty seven undisturbed samples were taken in three equal time steps. In each time, nine samples were taken at three distances of 30, 60 and 90 cm from the reservoir, and their places were immediately filled with the same kind of soil. Sampling was carried out using an aluminum core cutter of 6 cm depth and 8 cm diameter at three depths of 12, 22 and 32 cm. The three samples were used for a direct shear test under three normal stresses of 136, 272 and 408 kPa. The specimens were subjected to the allocated normal stress for 5 hours, followed by a shear stress at a rate of 0.08 mm/min. until arriving a displacement of 10%. In order to examine the affects of SLS flow on the physical properties of soil, Atterburg tests were carried out on the treated soil samples. All tests were carried out on untreated soil samples too.

3 RESULTS AND DISCUSSION

The results of tests are presented in Table (1). The "settlement" represents the settlement of specimens after 30 seconds being subjected to the vertical stress. A general comparison between treated specimens and untreated one reveal the effect of SLS on the shear resistance parameters. A significant increase in the cohesion and the internal friction angle are observed while a considerable decrease in the settlement has been recorded. The cohesion has risen from 16.5 kPa to 65 kPa and the internal friction angle has developed from 5.1 to16.4 degree. In the other side the compressibility of soil has decreased such that the measured settlement diminished from 2.97 to 1.69 mm.

Table 1. Results of direct shear tests

duration of SLS flow (day)	Distance to reservoir (cm)	Average settlement of three specimens (mm)	φ (degree)	C (kPa)
Untreated	-	2.97	5.1	16.5
20	60	2.68	5.4	48
20	90	2.78	6.5	34.5
40	30	2.19	11.4	53.0
40	60	2.44	9.2	42.5
40	90	2.67	8.1	30.0
60	30	1.69	16.4	65.0
60	60	2.31	14.1	56.0
60	90	2.65	12.4	45.0

In order to investigate effective parameters, the results of tests were classified based on two parameters: distance to the reservoir and duration of SLS flow. Figures (2) and (3) show the evolution of the internal friction angle and the cohesion due to the above factors. As revealed, the closer the samples to the reservoir, the greater φ and C are. In other words, the internal friction angle and the cohesion in samples taken from upper stream of soil block were developed more than those of downstream. This means that soil particles located in the upstream portion of the model have more chance to interact with calcium cations intruding the soil block by SLS. For example, the value of φ at a distance of 30 cm to the reservoir is 30% more than that at 90 cm. Moreover, in most of the cases, the evolution of cohesion and internal friction angle with respect to the distance to reservoir is very close to a linear function.

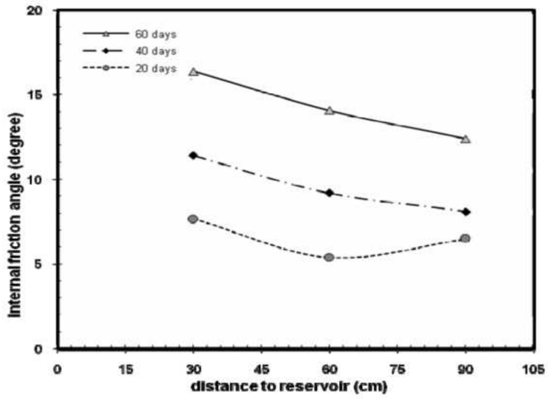

Figure 2. The influence of distance to the reservoir on the internal friction angle

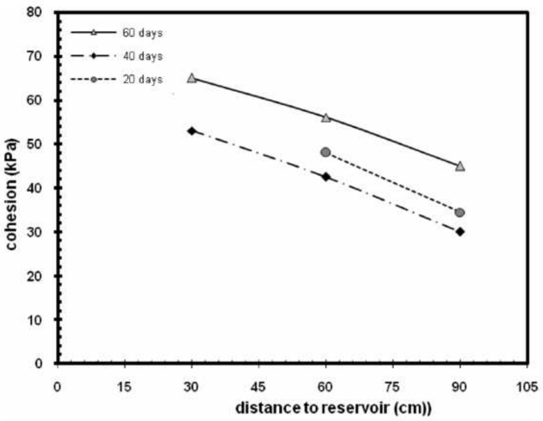

Figure 3. The influence of distance to the reservoir on the cohesion

In these figures it's also revealed that, with time, as more cation enter into the soil block, the chance of coming into reaction with soil particles increases, particularly for those located in the downer stream portion of the model. For example, at a distance of 90 cm from the reservoir, the value of φ increases to 6.5, 8.1 and 12.4 degree at twenty, forty and sixty elapsed days respectively; similarly the value of C increases to 34.5, 30 and 45 kPa after the same duration. The same trend is observed for specimens taken sixty and thirty centimeters far from the reservoir.

The influence of distance to reservoir on the settlement of samples is shown in Fig. (4). The settlement of three series of sample taken after 20, 40 and sixty days are against the applied stress is drawn separately. Each series includes three specimens taken at different distances of 30, 60 and 90 cm from the reservoir. As revealed, at equal distance to the reservoir, the longer the duration of SLS, the less the settlement is. Moreover, samples closer to the reservoir detect a less settlement comparing to those located further to the reservoir. For instance, in the sixty days specimens subjected to 136 kPa, the minimum settlement was 1.46 mm and observed at the distance of 30 cm of the reservoir, and the settlement of specimens of distances of 60 and 90 was 1.98 and 2.12 mm; while the settlement of untreated soil was 2.95 mm somewhat about two times of the minimum.

A comparison between series "a", "b" and "c" shows that the influence of SLS in specimens of 60 days is much more than those of 40 days and this one is more than that of 20 days; this can be mainly attributed to the volume of permeated SLS and thus the quantity of calcium ion intruded. For instance, under a given normal stress of 408 kPa the Min. settlement is 1.96 mm and belongs to the distance of 30 cm from the reservoir, the Max. is 3.34 mm and belongs to the distance of 90 cm, and the settlement of the untreated specimen was 3.45 mm.

It should be noted that, the difference between series "a", "b" and "c" is not merely due to the volume of circulated SLS and thus the quantity of infiltrated calcium cation, but also in some degree, it can be affected by the time passing after the interaction has been developed between cation and soil particles; i.e. curing.

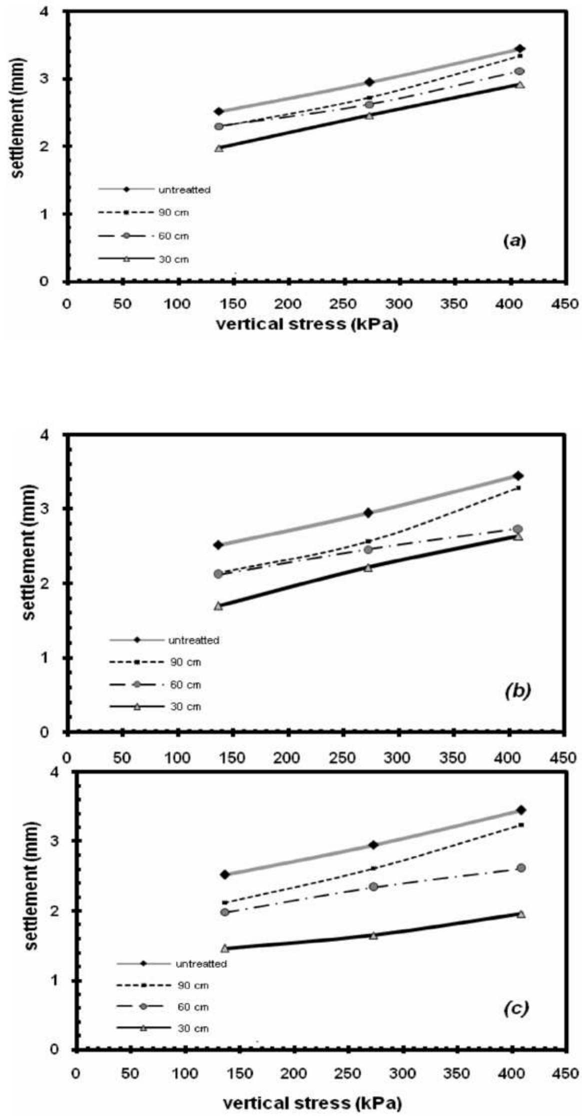

Figure 4. The influence of distance to the reservoir and the duration of SLS flow on the settlement: a) 20 days specimens; b) 40 days specimens; c) 60 days specimens

Table (2) presents the results of Atterberg limit tests carried out on three 60 days samples and the untreated soil. As shown, circulation of SLS has caused a slight decrease in liquid limit and a little increase in plastic limit, which results in 14% decrease in plasticity index. This quantity may seem to be low, but it should be noted that the quantity of intruded calcium to the soil is very low and just 0.5%.

Table 2. Results of Atterberg limits on treated and untreated samples

sample	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
untreated	56.7	34.2	22.5
60 days	54.9	35.6	19.3

4 CONCLUSION

The results of tests reveal that dissolving lime in the water and intruding saturated lime solution (SLS) containing calcium cations to soil by means of gravity gradient is an effective, high efficiency and low cost technique for strengthening and stabilizing massive soft soils. The influence of this technique on the mechanical properties of soil is a function of two parameters: distance to the SLS reservoir, duration of permeation of SLS. Samples closer to the reservoir, due to receiving more calcium cations, develop a better shear resistance and rigidity than those located further.

Duration of permeation of SLS is an effective parameter on the evolution of mechanical properties of soil since more calcium cation is provided to soil particles. Furthermore, the time elapsed after pozoloni reaction does affect the developed shear resistance. However, to be able to quantify this parameter, more research needs to be done in further studies.

Results of tests show that for the material used in this study, permeation of 1600 liter SLS and intruding 0.5% calcium ion into the soil results in an increase of 294% in cohesion and 222% in internal friction angle, and a decrease of 58% in the settlement of specimens.

Since the calcium is added to the soil in form of ion, and this ion is exchangeable, a small quantity of this calcium plays a high efficiency roll, in such a way that just half percent of calcium decreases 14% the plasticity index of soil.

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