Improvement of soft peaty clays with different configurations of geosynthetic electrodes

L'amélioration d'argiles douces avec différentes configurations d'électrodes géo-synthétiques

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ABSTRACT

Laboratory investigations had been conducted at University of Moratuwa over last six years to study the possibility of the use of Electro-osmotic consolidation process to improve the soft peaty clays. The use of perforated stainless steel electrodes did not produced desired results due to corrosion of the electrodes. The use of the electrodes made of non corroding geosynthetics made it possible to apply the electro-osmosis process to peaty clays with polarity reversals and with increasing voltage gradients. This paper presents results of such a series of tests where different electrode configurations were tried out. Considerable improvement in strength and stiffness were achieved in peats of water content around 300%. When the water content was much higher around 600%, the process was not so effective. The power consumptions for the process was well within the economically viable limits.

RÉSUMÉ

Des investigations en laboratoire ont été dirigées à l'Université de Moratuwa pendant ces six dernières années pour étudier la possibilité de l'usage du processus de consolidation électro-osmotique pour améliorer les argiles douces. L'usage d'électrodes perforées en acier inoxydable n'a pas produit les résultats désirés en raison de la corrosion des électrodes. L'usage des électrodes faites avec des géo-synthétiques non corrosifs a rendu possible l'application du processus d'électro-osmose sur les argiles grâce aux renversements de polarité et aux accroissements de niveau de tension. Ce papier présente des résultats d'une série de tests au cours desquelles différentes configurations d'électrode ont été essayées. Une amélioration considérable dans la force et la raideur a été atteinte sur des tourbes au contenu d'eau de 300% environ. Quand le contenu d'eau était beaucoup plus élevé autour de 600%, le processus n'était pas aussi efficace. La consommation d'énergie pour le processus restait bien dans les limites économiquement viables.

Keywords : Peaty clay, electro-osmosis, improvement, electro kinetic geosynthetics

1 BACKGROUND

Thick layers of extremely soft peaty clays of water like consistency encountered at surface levels, is a major challenge faced by Sri Lankan geotechnical engineers involved in infrastructure development projects. Although preloading with or without vertical drains had been used successfully with peaty clay layers of some modest stiffness, the technique has failed in extremely soft material.

In such instances only feasible approach had been the removal and filling back with granular materials. Although this procedure had been adopted at several occasions, the major environmental problems associated with the process demands the development of alternate approaches, where the material could be improved insitu. Under this background attention was paid to the electro-osmosis consolidation process.

Pioneering research done at University of Moratuwa at the laboratory level has indicated that the engineering properties of Sri Lankan peaty clays could be significantly improved by electro osmotic consolidation.(Kulathilaka et al 2004) Initially, studies were done imposing the electro osmotic consolidation under one dimensional conditions and significant improvements were achieved in strength and stiffness characteristics of Peaty Clay. Subsequently, a field application of the process was simulated with perforated metal electrodes. Although there were some improvements, those were much lower than the anticipated levels due to the corrosion of metal electrodes. (Kulathilaka and Sagarika 2006). In the research reported in this paper non corrosive electro kinetic geosynthetics (EKG) were used.

2 MECHANISM OF ELECTRO OSMOSIS

When an electric field is applied across a fine grained soil mass, cations are attracted to the cathode and anions are attracted to the anode. As the ions migrate they carry their hydration water with them. In a clay water electrolyte system there are more cations than anions to neutralise the negatively charged clay particles. As such, there is a net flow of water towards the cathode. In addition to these movements, electrolysis of water takes place at the surface of electrodes, producing hydrogen ions at the anode and hydroxyl ions at the Cathode. Also, oxygen gas is produced at the anode and hydrogen gas is produced at the cathode. (Mitchell (1993)). As a result, the pH value decreases at the anode and increases at the cathode. The release of oxygen causes rapid oxidation of metallic anodes.

3 DEVELOPMENT OF ELECTRO KINETIC GEOSYNTHETICS (EKG)

Band drains with Electrokinetic geosynthetics(EKG) developed through number of years of pioneering research at the University of Newcastle UK in collaboration with the Netlon Ltd were used in this study. The geosynthetic material used in the band drain was made conductive by the addition of carbon black powder to the conventional polymers. EKG band drain consists of an electrically conductive geonet core surrounded by a thermally bonded non woven filter fabric. (Figure 1).

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Monofilament wires were located at the centre of alternate ribs to act as current distribution stringers. (Figure 1). The wires were of much higher electrical conductivity than the conductive polymer and this arrangement provides a more efficient distribution of current through the length of the EKG. If the stringers were not included then the electrical current would have taken the path of least resistance, passing majority of the current to the soil at the point of initial contact. This would have caused highly localised current densities with possible adverse implications. (Nettleton et al (1998)).

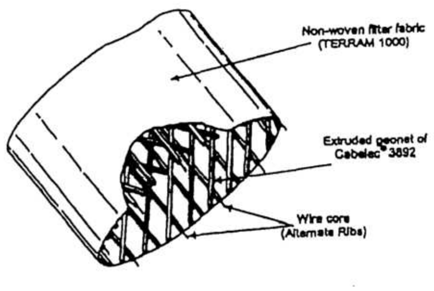

Figure 1. EKG Electrodes

4 ELECTRO OSMOTIC CONSOLIDATION OF PEATY CLAYS WITH ELECTRO KINETIC GEOSYNTHETICS

4.1 Tests 1 with Setup 1

The initial tests of Electro osmotic consolidation of peaty clay were conducted in a Perspex box of dimensions 500mmX200mmX150mm with two EKG electrodes (Figure 2). Test was done with polarity reversals, and increasing the voltage gradient by 50% with each polarity reversal. Voltage gradient was increased from 37.5 V/m to 120 V/m. The decision to change the polarity and increase the voltage was taken when the rate of water flow decreased under the current voltage gradient. The test was conducted for 12 days and the electricity consumption was 5.70 kWhr/m^3.

The improvement of shear strength was assessed by the laboratory vane shear tests and the improvement of stiffness characteristics were assessed by the results of the consolidation test done on undisturbed samples obtained from the electrically treated mass of peaty clay. Figure 2 shows the locations of the undisturbed samples.

The improvement of shear strength is summarized in Table 1. The initial shear strength (C_u) was 1.8 kN/m^2 and initial moisture content was around 300%. The e vs log σ plots of the electrically treated and untreated peaty clay are compared in Figure 3. It could be seen that the electro-osmotic process has improved the stiffness and induced a pre consolidation effect. Owing to the uniform treatment provided with regular polarity reversals, improvements achieved in the two samples were quite similar.

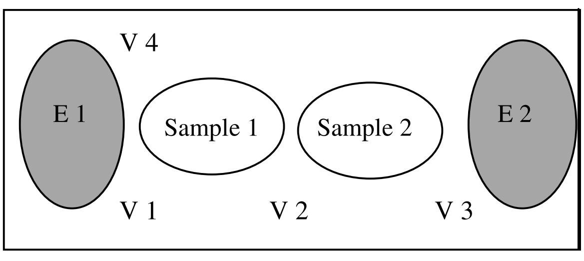

Figure 2. Locations of vane shear tests and consolidation samples of treated mass of peaty clay

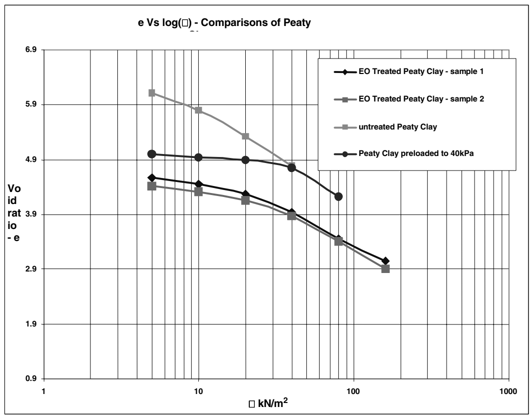

Figure 3. Comparison of compressibility – Test 1

Location	Undrained Shear Strength kN/m^2	Moisture content %
V 1	25.14	214.45
V2	9.43	233.19
V 2 - Deep	10.69	233.35
V 3	6.91	235.94
V 4	5.03	211.76

Table 1. Undrained shear strength and moisture contents of treated Peaty clay

4.2 Test 2 – Test with Setup 2

The second an third of tests were conducted in a much larger box of dimensions 600mmX 600mmX500mm, made of 5 mm thick transparent Perspex sheets. Peaty clay obtained from the Southern Transport Development project was remoulded after removal of pieces of wood and other debris.

Electrodes were arranged, to the pattern depicted in Figure 4, and remoulded peaty clay was poured into the box. The initial water content of the peat mass was 305 %. The peaty clay was allowed to consolidate under its self weight. During this process water discharged into each electrode. The water collected inside electrodes was pumped out at regular time intervals. The pH value of the water discharged was around 4.5. Once, the rate of discharge reduced to an insignificant value, the self weight consolidation was assumed to have been completed and the electrical treatment was commenced.

As indicated in Figure 4, the central electrode was made the cathode and the four electrodes at the corners were made anodes. With this arrangement water was discharging only towards the central electrode. The test was conducted without any polarity reversal. Voltage probes were inserted to monitor the voltage gradient across the sample and voltage losses at the electrodes. (Figure 5).

Once, the voltage gradient was applied, the pH value of the water discharged increased gradually as presented in Figure 6. This is due to the release of hydroxyl ions at the cathode. Since no polarity reversal was done during the test, the pH value increased steadily.

The test was started with a voltage gradient of 120 V/m (Voltage Difference of 22V). The water collected at the cathode was pumped out at regular time intervals and the rate of discharged was computed. When the rate of discharge diminished, the voltage gradient was increased to 300 V/m (voltage difference of 55V). With that the rate of water discharge increased again and decreased after some time. The test was terminated once the rate of discharged decreased to an

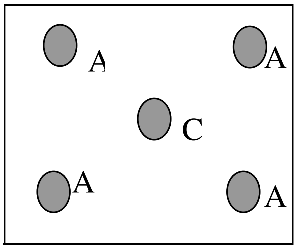

Figure 4. Electrode Configuration

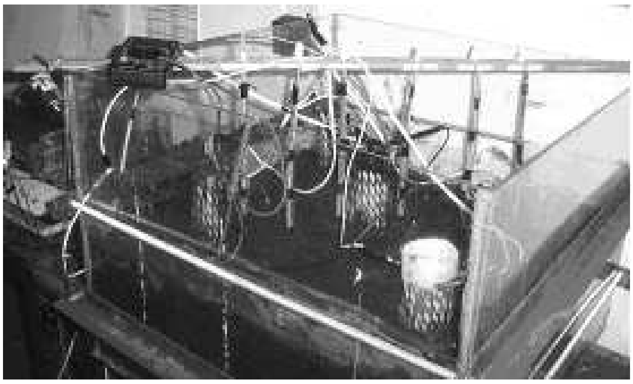

Figure 5. Electro Oosmotic arrangement with voltage probes

insignificant value again. This indicates that the process has come to equilibrium. Although it could have been reactivated by increasing the voltage gradient, it was not attempted due to the difficulties in providing greater voltage gradients.

When the electro osmotic consolidation was progressing, cracks started to develop. Most of them appear near the anode. Since the propagation of crack would hamper the process, they were closed with the help of a spatula as soon as noticed.

The average placement moisture content of the peaty clay was 303.23%. The final moisture contents of the samples obtained after the completion of the test varied between 135% and 219%. The higher values corresponded with samples close to cathode.

Consolidation tests were conducted on undisturbed samples obtained from the peat mass after the completion of the electrical treatment. The e vs log σ graphs obtained from a sample of treated clay is compared in Figure 7 with that obtained from a sample of untreated peaty clay (a sample at the placement water content).

There were significant voltage losses at the electrodes as indicated by the reading taken through voltage probes. The voltage transferred to the sample was around 40% at the start and reduced to 20% towards the end. The voltage loss at the cathode was constant at around 30%, but at the anode it increased from around 30% to 50% as test progressed.

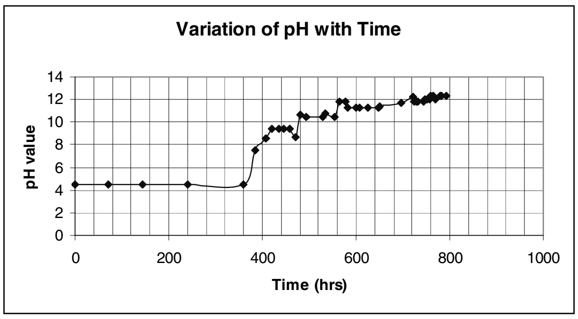

Figure 6. Variation of pH value – Test 2

The compression index (C_c) has reduced from 2.857 to 0.164 and the compression ratio ($C_c/(1+e_o)$) has reduced from 0.485 to 0.049. The coefficient of secondary consolidation (C_α) has also reduced by more than an order of magnitude from 0.1 to less than 0.01 over the tested stress range.

The undrained shear strength (c_u) was obtained by the unconsolidated undrained triaxial tests conducted on the undisturbed samples extruded from the treated peaty clay mass at various locations. The c_u values of the improved peat were in the range 19 kN/m^2 to 38 kN/m^2. The higher values corresponded to locations closer to the anode.

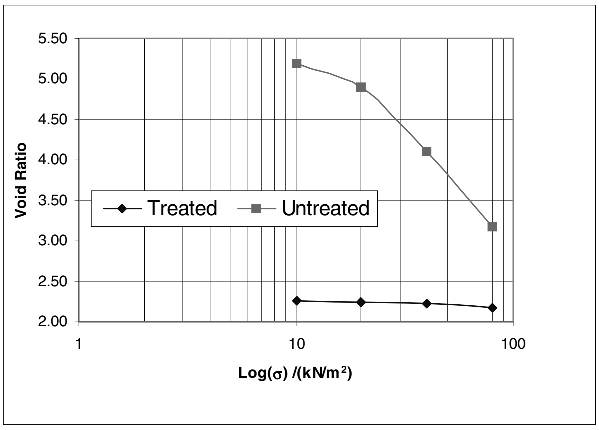

Figure 7. Comparison of compressibility – Test 2

4.3 Test 3. with polarity reversal in setup 2

This test was conducted in the same apparatus, with peaty clay remoulded in the same manner, but with a different electrode configuration (Figure 8). The initial placement water content was much higher at 600% and electrical treatment commenced after the completion of the self weight consolidation.

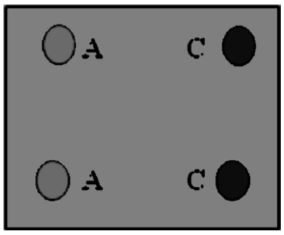

Figure 8. Electrode connection – Test 2

In contrast to the previous test, this was done with polarity reversals when the process has appeared to reach equilibrium under the applied voltage gradient. With each polarity reversal the voltage gradient was increased by 100%. Voltages differences of 7.5 V, 15 V, 30 V and 60 V corresponding to voltage gradients changing from 60 V/m to 480 V/m were used.

The pH value of the water discharge was measured regularly and presented in Figure 9. With a given polarity, the pH value of the water discharged increased gradually, from the initial natural value of 4.1 to values of the order of 10.0. With the polarity reversal, the water starts to discharge from the former anode where hydrogen ions had been discharging. Thus the pH value of the water discharged is low initially. As time progresses, with hydroxyl ions releasing at this new cathode, the pH value keeps on increasing. This behavior confirms the progression of the electro – osmotic consolidation process.

Number of undisturbed samples were extruded from the treated soil mass to conduct the consolidation tests and shear strength tests to assess the improvement achieved by the process. Also, the moisture contents were obtained in the samples obtained from number of locations of the peat mass. There were variations, but the moisture content of the treated mass was around 400%. The e vs log σ data obtained form a sample of treated peaty clay is plotted along with that from a sample of untreated peaty clay in Figure 10.

Although there is a reduction of the water content, the compression index has reduced only marginally from 4.313 to 3.150 and the compression ratio has changed from 0.482 to 0.458. The value of the coefficient of secondary consolidation has not changed much and was in the range 0.1 to 0.25.

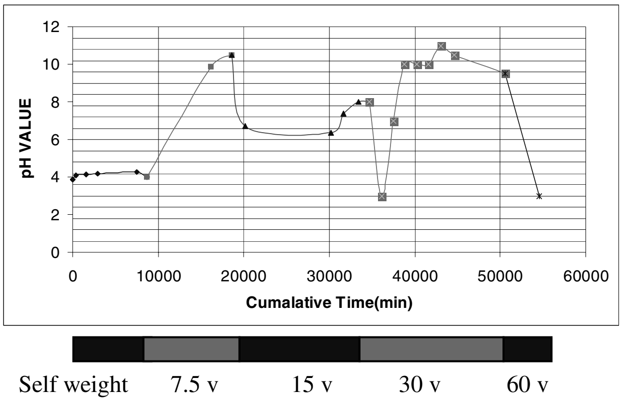

Figure 9. pH Variation with time – Test 3

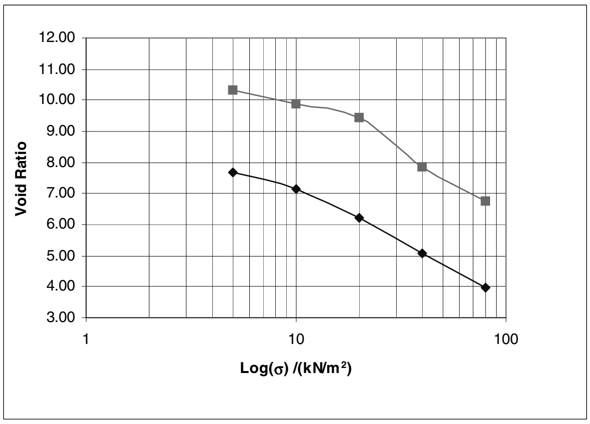

Figure 10. Comparison of Compressibility – Test 3

The results of the unconsolidated undrained traxial tests conducted on treated peaty clay showed that the undrained shear strength C_u has increased to values in the range 10 kN/m^2 to 12 kN/m^2.

5. CONCLUSIONS

Laboratory studies of electro osmotic consolidation of peaty clays EKG electrodes showed that with the application of high voltage gradients the strength and stiffness characteristics of extremely soft peaty clays can be improved significantly. With regular polarity reversals uniform level of improvements could be achieved in a peat mass. Although the process was successful at initial water content of around 300%, at much higher water contents of the order of 600%, improvements achieved were only marginal.

When the electro osmotic process comes to an equilibrium , it could be reactivated by increasing the voltage gradient. However, there are practical limits to the applicable voltage gradients. EKG electrodes are particularly useful in peaty clay as they do not decay due to the oxygen gas released at the anode. Also, high voltage gradients could be maintained for longer durations.

These laboratory findings should be confirmed with field studies. As these soft peaty clay layers are encountered near the surface, the process could be applied with minimum electrical losses. The necessary voltage gradients could be applied with DC generator.

The process need not be continued for a long time in the field. Once the strength of the peaty clay is improved to an adequate level conventional construction processes such as construction of embankments with staged filling can commence. Then the installed EKG electrodes will function as ordinary vertical drains.

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