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Model test study on soft clay slope reinforced with electro-kinetic geosynthetics

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ABSTRACT: Electro-kinetic geosynthetics (EKG) presented in this paper was made from a kind of electrically conductive plastic, whose resistivity was 0.064Ω · m. A model test was carried out to study the feasibility of applying this kind of EKG to improve the stability of soft clay slope. Test results showed that EKG acted well as both electrodes and drains of electro-osmotic consolidation. Under the D.C. voltage of 40 V, The initial electric current was 194 mA. It decreased gradually following negative exponential function. Developing process of suction and settlement showed that electro-osmotic consolidated zone expanded from anode to cathode gradually. Maximal suction recorded near the anode was 80 kPa. Isolines of settlement and water content showed that the consolidation of the soil was inhomogeneous. Soil around EKG anode near the wire holder of electrode positive had the strongest effect of consolidation; while soil around EKG cathode far away from the wire holder of electrode negative had the weakest effect of consolidation. Comparison of the *e*~log *p* curve, water content, dry density, and c, ϕ of the soil before and after electro-osmotic consolidation showed that the stability of the slope was greatly enhanced after the treatment with EKG. Study shows that EKG made from electrically conductive plastic has great potentialities of commercial application in geotechnical engineering. It is worth to do further researches on this kind of EKG.

1 INTRODUCTION

Electro-kinetic geosynthetics (EKG) is a kind of electrically conductive geosynthetics, which can incorporate the electro-kinetic phenomena into traditional functions of geosynthetics (Nettleton et al. 1998; Zou et al. 2002). Generally speaking, there are two ways to make geosynthetics electrically conductive: one is combining the traditional geosynthetics with some conductive elements, such as copper wires, carbon fibres etc; the other is directly using the conductive synthetic as the raw materials of geosynthetics. Most existing researches on EKG adopted the first way (Hamir et al. 2001). As composite conductor, this kind of EKG does not have homogeneous electrical conductibility. And if metal materials (such as aluminum, iron, copper) are used as the conductive elements, the problem of electro-chemical corrosion would still exist (Zhuang & Wang 2004). Carbon fibres do not have the problem of electro-chemical corrosion, but it is too expensive to use as conductive elements of EKG.

Under the background of great breakthrough achieved in the field of electric conductive plastic, EKG samples presented in this paper adopted the second way. They were made from some electrically conductive plastics with a resistivity of 0.064 Ω · m. EKG made from electrically conductive plastic has the following advantages (Zhuang 2005): (1) It can provide homogeneous electrical conductivity; (2) It does not have the problem of electro-chemical corrosion; (3) It will not introduce new metal ions into the soil when used in the electro-cleaning of contaminated soil; (4) the price of electrically conductive plastic is acceptable (about 15,000 RMB per ton).

EKG has wide prospect of application. It can be used in the fields of reinforcement, consolidation, environment remediation etc. Researches presented in this paper focus mainly on its function of electro-osmotic consolidation. A model test was carried out to study the feasibility of applying EKG samples mentioned above to improve the stability of soft clay slope. Test results showed that EKG acted well as both electrodes and drains of electro-osmotic consolidation.

2 MODEL PREPARATION

2.1 *Soil preparation*

Soil used in the test was taken from Wuhan Branch of Academy of Sciences of China. Its liquid limit was 44.17; plastic limit was 19.25; plasticity index was 24.92. Some water was added to increase the water content of the natural soil. Then the soil was mixed homogeneously. The water content tested after 24 hours storage time was 37.53%.

2.2 *Electrodes preparation*

Three rows of EKG were used as anode and cathode respectively. Every row of EKG was made up of 18 strips of electrically conductive plastics, which were stitched on a 10 cm wide non-woven geotextile (see Figure 1). The average diameter of electrically conductive plastics was 1.5 mm, and the resistivity was 0.064Ω · m. Length of anode was 34 cm. Length of cathode was 75 cm. Wires were connected to the electrically conductive plastics through the connection rods of terminal array at the edges of every strip. These wires and connection rods were used to insure the good connection of electrically conductive plastics with electrical source.

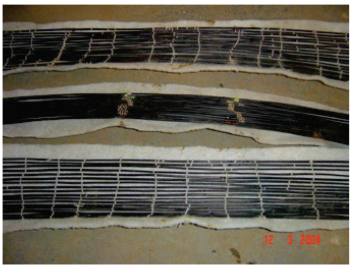

Figure 1. Photo of EKG electrodes.

2.3 *Fill of slope model*

Size of the slope model was as following: length of the top side was 43 cm; length of the bottom side was 83 cm; width of the model was 30 cm; the slope angle was 45°. Total height of the slope was 46 cm. Therein, electro-osmosis treated layer between anode and cathode was 30 cm height; layer above anode was 6 cm; and layer under cathode was 10 cm. (see Figure 2) Total weight of the wet soil filled in the model was 160.9 kg. The model of slope was filled and compacted at each 5 cm. The dry density was controlled to be 1.35 g/cm^3. By testing the soil sampled from the slope model before electro-osmotic treatment, we got the initial hydraulic permeability $k_h = 7.60 \times 10^{-8}$ cm/s; the initial cohesion $c = 5.10$ kPa; the initial friction angle $\phi = 2.04°$.

The boundary conditions of the slope were as following: the top surface and the inclined surface of the slope were exposed to the air directly; other

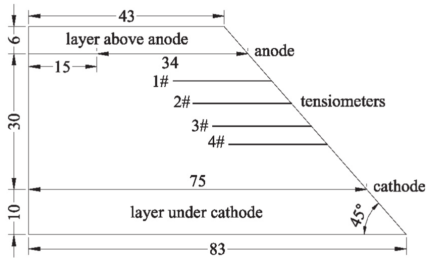

Figure 2. Sketch of the slope model (unit: cm).

surfaces of the slope were laid with waterproof geosynthetics; the bottom surface of the layer above anode was also laid with waterproof geosynthetics to model the waterproof boundary on anode; the top surface of the layer under cathode was laid with non-woven geotextiles to model the permeable boundary on cathode.

2.4 *Configuration of tensiometers*

Four tensiometers were used to measure the suction in the soil during the process of electro-osmotic consolidation. They were all preset in the soil along the middle line of the inclined surface of the slope. The configuration of the tensiometers was showed in Figures 2 and 3.

Figure 3. Photo of EKG, tensiometer and dial gauge.

2.5 *Configuration of displacement tracing points*

The settlement of top surface of the slope was measured by dial gauge; and the displacement of the soil in the slope was traced via displacement tracing method with microscope. Figure 4 was the photo of slope model and corresponding displacement tracing system.

3 PROCESS OF EXPERIMENT

D.C. voltage of 40 V was adopted in this experiment. Whole process of testing lasted for 396.4 hours, which include three stages of electrifying, intermission, and

Figure 4. Photo of slope model and corresponding displacement tracing system.

re-electrifying. During the first and third stages, which lasted for 334.77 and 37.3 hours respectively, the variation of electric-current, suction, and displacement was observed. During the intermittent time, which was 24.33 hours, the decreasing process of suction was observed. Data of the second and third stages reflected the effect of intermittent electrifying technique on electro-osmosis.

The water content, dry density, *c*, ϕ, permeability, and *e*~log p curve of the soil after electro-osmosis were tested and compared with those of the soil before electro-osmosis to evaluate the effect of electro-osmotic treatment with EKG.

4 TESTED RESULTS AND ANALYSES

4.1 *Electric current*

Curve fitting showed that the variation of electric current before and after intermittent time followed the negative exponential functions of $I - 60 = 126.28e^{-0.0036t}$ (correlation: $R^2 = 0.9615$) and $I - 77 = 36.307e^{-0.0659(t-359.1)}$ (correlation: $R^2 = 0.9905$) respectively. Figure 5 showed that the technique of intermittent electrifying could increase the electric current, but the increased current would decrease to a lower value than the terminal current before intermission with a higher decreasing rate. This phenomenon, which was named as "impaction and fall", was related to the readjusting of water content and suction in the soil during the intermittent time.

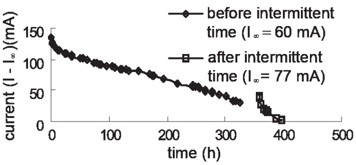

Figure 5. Decreasing process of electric current.

4.2 *Suction*

Figure 6 showed that suction developed from anode to cathode gradually. Suction of the soil near the anode increased faster than that of the soil near the cathode. The nearer to the anode, the higher suction we got. Maximal suction recorded near the anode was 80 kPa. The suction of 3# tensiometer decreased suddenly after 153.0833 hours' electro-osmosis due to the damage of 3# tensiometer under the inhomogeneous settlement caused by electro-osmotic consolidation. The decreasing and re-increasing section of the suction~time curve of 4# tensiometer corresponded to the intermission and re-electrifying stages of the test.

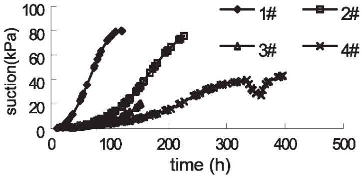

Figure 6. Suction~time curve.

4.3 *Settlement*

Isolines of settlement showed that electro-osmotic consolidated zone expanded from anode to cathode gradually (see Figures 7, 8). It was accordant with the suction developing process.

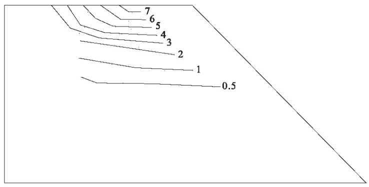

Figure 7. Isolines of settlement after 98.4 hours (unit: mm).

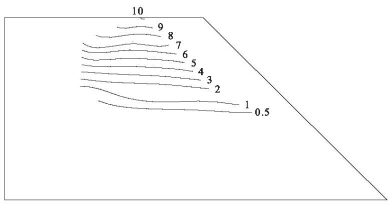

Figure 8. Isolines of settlement after 146.1 hours (unit: mm).

4.4 *Water content*

Isolines of water content after electro-osmosis distinctly reflected the spatial inhomogeneity of the consolidation effect of electro-osmosis. Soil around EKG anode near the wire holder of electrode positive had the strongest effect of consolidation; on the contrary, soil around EKG cathode far away from the wire holder of electrode negative had the weakest effect of consolidation (see Figure 9). This inhomogeneity was due to the electric resistance of EKG electrodes, which was not negligible like metal electrodes.

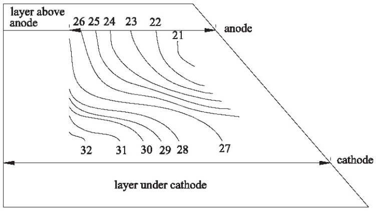

Figure 9. Isolines of water content after electro-osmosis (%).

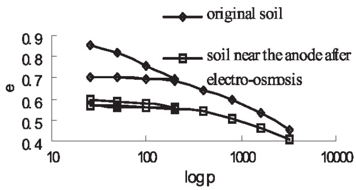

Figure 10. e~log p curves of the soil before and after electro-osmosis.

4.5 *Comparison of e~log p curves before and after electro-osmosis*

Comparison of the e~log p curves before and after electro-osmosis showed that void rate and compressibility of the soil was greatly reduced after electro-osmotic treatment with EKG.

4.6 *Variation of physical properties of the soil*

Soil after electro-osmosis was inhomogeneous. Table 1 showed that from anode to cathode, water content increased, whereas dry density, and c, ϕ of the soil decreased. Soil near the anode was well consolidated while soil near the cathode was almost unconsolidated.

Table 1. Variation of physical properties of the soil.

Distance from anode (cm)	Water content (%)	Dry density (g/cm^3)	c (kPa)	ϕ (degree)
0	21.4	1.69	182.4	27.91
5	23.68	1.67	48.34	20.28
12	24.07	1.64	18	14.70
20	27.76	1.49	1.71	10.68
25	28.89	1.47	5.6	4.80
Original soil	37.53	1.35	5.10	2.03

Permeability of the soil decreased slightly after electro-osmosis, but still remained at the same magnitude with that of the soil before electro-osmosis. Permeability of the soil before and after electro-osmosis was 7.60×10^{-8} cm/s and 2.51×10^{-8} cm/s respectively.

5 CONCLUSIONS

Model test study presented above leads to the following conclusions:

1. EKG acted well as both electrodes and drains of electro-osmotic consolidation.
2. The decreasing process of electric current followed negative exponential function.
3. Phenomenon of electric current's "impaction and fall" was observed when applying the technique of intermittent electrifying. This phenomenon was related to the readjusting of water content and suction in the soil during the intermittent time.
4. Suction developed from anode to cathode gradually. The nearer to the anode, the higher suction we got. Maximal suction recorded near the anode was 80 kPa.
5. Corresponding with the suction developing process, electro-osmotic consolidated zone expanded from anode to cathode gradually.
6. Soil around EKG anode near the wire holder of electrode positive had the strongest effect of consolidation; on the contrary, soil around EKG cathode far away from the wire holder of electrode negative had the weakest effect of consolidation. This spatial inhomogeneity was due to the non-negligible electric resistance of EKG electrodes.
7. Comparison of the e~log p curve, water content, dry density, and c, ϕ of the soil before and after electro-osmotic consolidation showed that the stability of the slope was greatly enhanced after electro-osmotic treatment with EKG.
8. EKG made from electrically conductive plastic has great potentialities of commercial application in geotechnical engineering. It is worth to do further researches on this kind of EKG.

ACKNOWLEDGEMENT

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