Performance Evaluation of Coir as an Electrokinetic Geotextile

Mumtaz.M, M.S.Girish, K.Balan
Department of Civil Engineering,
College of Engineering Trivandrum
Thiruvananthapuram, India.

***Abstract*—Electro-kinetic geosynthetics offer technical benefits over conventional electrodes in that they can be formed as strips and blankets, light and easy to install and is not susceptible to corrosion, continuing to provide conventional functions of filtration, drainage, separation and reinforcement . This paper describes laboratory tests on EKG materials which are used as conductive geosynthetic reinforcement used to consolidate and reinforce weak cohesive soil. The electroosmosis design was then undertaken, based upon the water content - unconfined compressive strength curve for the fill material obtained from laboratory testing. Using this curve the difference between the as-placed water content and the water content corresponding to required undrained shear strength was calculated, giving the volume of water that needed to be removed from each lift of clay fill. Using this volume of water the electroosmosis calculations were undertaken. Results of the reinforced soil tests showed that EKG reinforcement can be used to increase the undrained shear strength of cohesive fill very effectively.**

Keywords-EKG, coir ,embankment ,settlement

I. INTRODUCTION

The geosynthetic reinforcement within an embankment constructed on very soft soils can substantially improve stability and allow construction to considerable heights. Reinforced embankment is a composite system involving three components: foundation, embankment fill and reinforcement. The performance of reinforced embankment will depend on the interaction between these components and to a large extent, this interaction will arise from strain compatibility requirements at the interface between the various components [5].

Basal reinforcement is the incorporation of geogrids or geotextiles at the base of embankments constructed over soft, compressible ground. It is often used in conjunction with prefabricated vertical drains or band drains or other forms of ground improvement. Woven geotextiles are usually preferred for basal reinforcement [19]. For construction over weak soils, basal reinforcement provides short term stability of the embankment, while horizontal and vertical drains enable the excess pore water pressure to dissipate and the compressible soil to consolidate and settle [8,20].

Traditional geosynthetics are used in civil engineering to carry out a range of functions including drainage, reinforcement, filtration, separation, containment etc. All of these functions are limited by the rate at which water is able to flow through the materials with which the geosynthetics are being used to improve. Most geosynthetics play a passive role by providing tensile resistance, but only after an initial strain has occurred the drains will provide a passage for water but do not cause the water to flow towards the drain [3]. New applications for geo-synthetics have been identified if they can provide an active role, chemical or physical change in which they are installed as well as providing the established functions. This can be achieved by combining the electro-kinetic phenomena of electro-osmosis, electrophoresis and associated electro-kinetic functions with traditional functions to form electro-kinetic geo-synthetics (EKG). The electro-kinetic processes that are activated when ground is treated with EKG materials include electro osmotic flow from the anode areas towards the cathode, pore pressure reduction spreading out from anodes, cementation around the anodes and precipitation around the cathodes [2].

The analysis of published data from case records of electroosmotic consolidation of clays indicates that the power losses at the soil electrode contact constitute a major problem for the field application [7] . The results of the test done on 700 m^3 of clay for 48 days of treatment confirm that soft clay deposits can be successfully treated by electroosmotic consolidation, at a competitive cost compared with other alternatives [9]. Results of electroosmotic consolidation on hydraulic fill silt of test area 1400m^2 for 15 days of testing process and analysis showed that the maximum shear strength of silt increased 3 times and the maximum moisture content decreased by 20%[10].Various types of electrodes, like copper, H-shaped steel pile were used to increase the shear strength of sensitive Leda clay and marine clay respectively[15,16].The studies on the improvement of electroosmosis efficiency of marine clay using steel bar as an electrode reveals that electrophoresis using a high voltage (1500 V/m) did not appear to affect the ground improvement and electroosmosis using a low voltage (3–6.6 V/m) also did not appear to increase the ground improvement[17]

The lack of conventional cohesionless fill material and its cost has lead to the use of cohesive soils in major reinforced soil structures. This includes a drainage layer along the side of the reinforcement [1]. The potential benefits identified for EKG in reinforced soil are they dramatically reduce pore pressure in cohesive fill in excess of that which can be achieved using permeable reinforcement alone, inducing additional consolidation and associated increase in shear strength to that obtained by the self-weight of the fill material above; and dissipating positive pore pressure at the soil/reinforcement interface to a greater degree than with impermeable reinforcement, thereby increasing reinforcement/soil bond along its entire length[4]. Electro-kinetic stabilisation is essentially a combination of the process of electroosmosis and chemical grouting. The four types of EKG commonly used for various purposes are Type 1: a needle-punched geosynthetic material containing a copper Wire stringer, Type 2: a needle punched geosynthetic material incorporating stainless steel fibres, Type 3: a composite polypropylene and carbon fibre nonwoven sheet, Type 4: geocomposite strip reinforcement with a copper wire stringer [3].

This paper evaluates the effectiveness of coir geotextile as basal reinforcement with and without electrokinetic process for embankments constructed in soft clay. The effectiveness is measured by comparing the deformation obtained in two different models and also with the UCC and Atterberg's limit before and after the test.

II ELECTROOSMOTIC DESIGN

The water content required to achieve this strength was derived from the water content - unconfined compressive strength curve for the fill material obtained from laboratory testing. Fig. 1, shows the relation between unconfined compressive strength and water content. The relation is not linear. Hence a greater increase in strength occurs for smaller reduction in water content at lower water content. The difference between the as-placed water content and the water content corresponding to the required strength was used to calculate the volume of water that needed to be removed from each lift of clay fill during construction. The treatment time required to remove this volume of water was then determined based on a linear voltage gradient and fixed soil parameters using Eq (1)

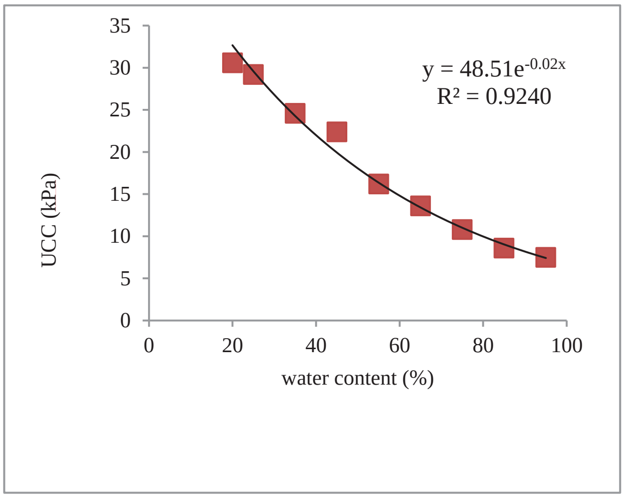

Fig. 1. Relation between UCC and water content

$$\frac{Q}{t} = k_e \frac{V}{L} A \qquad (1)$$

where Q is the quantity of water in cm^3 transported through an area A(cm^2)under an applied voltage gradient V/L (volts/cm) in time t(seconds) in a soil with an electroosmotic permeability of k_e (cm/s per V/cm)[6].

TEST SET UP

Laboratory scale models of two different sizes were constructed using 12 mm thick waterproof plywood. The dimensions of two models are 20cm X 15cm X 15cm and 100cm X 100cm X 60cm as shown in Fig.2 and Fig. 3.

The model tank was provided with a mouthpiece, a 1 cm diameter small PVC pipe provided at a small distance from the bottom of cathode using an acrylic sheet as a separator for allowing free flow of water during the process and the water is collected in a graduated cylinder. Wattman No. 42 filter paper was placed over this partition to restrict the flow of any soil particles. Conductive geotextile was placed

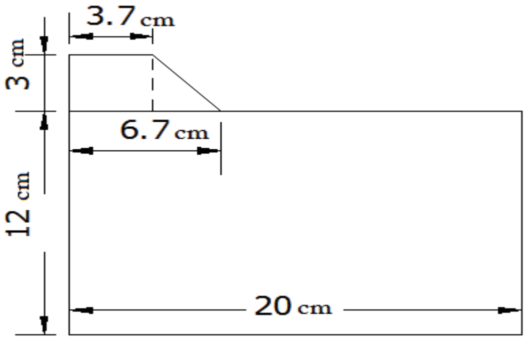

Fig. 2 .Dimensions of Model 1

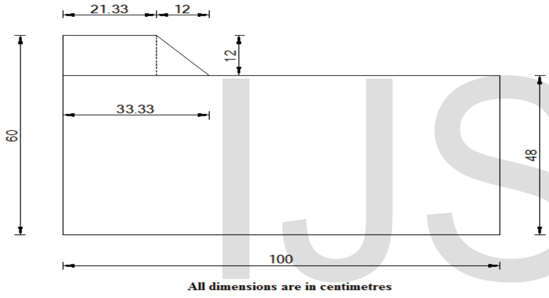

Fig. 3 . Dimensions of Model 2

on acrylic sheet to act as cathode with the carbon electrode being placed at a distance from the cathode to act as anode.

III MATERIALS

A . Kuttanad clay

Kuttanad clays are dark brown coloured medium sensitive alluvial deposits, spread over the Kuttanad region in the state of Kerala in India [11]. The dominant mineral constituents in this clay are montmorillonite and illite [12]. These clays are characterized by high compressibility, low shear strength and high percentage of organic matter [14]. A substantial change in the plasticity characteristics on drying is one of the distinct aspects of these clays [13].Total area of 1100 km^2 lies 0.6-2.2 m below mean sea level [12].The properties of soil sample collected are shown in Table .I.

B. Coir Geotextile

Coir geotextile are permeable fabrics, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain. Coir is a 100% organic fibre, from the coconut husk. It is naturally resistant to rot and moisture and it needs no chemical treatment. It is hard and strong and it can be spun and woven into matting. They have the right strength and durability to protect the slopes from erosion, while allowing vegetation to flourish. The greater the geo-textile density, the steeper the embankments it can be utilized on. Geo-textiles can improve soil strength at a lower cost than conventional soil nailing. Coir geo-textiles last approximately 3 to 5 years depending on the fabric weight. Reinforcement with natural fibre in composites has recently gained attention due to low cost, easy availability, low density, acceptable specific properties, ease of separation, enhanced energy recovery, CO_2 neutrality, biodegradability and recyclable in nature [21]. The properties of woven geotextiles are shown in Table .II.

TABLE I. PROPERTIES OF SOIL SAMPLE

Properties	**Values**
Specific gravity	2.64
Void ratio	0.63
Liquid limit %	88
Plastic limit %	44
Shrinkage limit%	31
Plastic index	38
Percentage of clay	71
OMC	38
Maximum dry density gm/cc	1.34
Unconfined compressive strength kPa	2.3
Compression index	0.7233

TABLE II. PROPERTIES OF WOVEN GEOTEXTILE

Density (gm/m2)	**Thickness(mm)**	**Tensile stress (kN/m)**	**Failure strain (%)**
681	7.16	5.2	24.6

IV METHODOLOGY

Using the soil parameters obtained from the laboratory testing, a relationship was established relating the unconfined compressive strength of the clay to the water content .The clay was placed in a very fluid state with unconfined compressive strength of 1.5 kPa with water content 88%. From fig.1, the required strength of 50kPa is associated with a water content of 15%. For a 73% reduction in water content the volume of water needed to be removed for model 1 was 4500cm^3 and for model 2 was 90000 cm^3.The value of k_e for clayey soil is assumed to be 5X10^{-5} cm/s per V/cm, and V/L is established by dividing the applied voltage by the distance between the anode and cathode assuming point electrodes, then a preliminary treatment time of 15 hours for model 1 and 3.4 days for model 2 is provided for each 30 mm lift of clay. The change in volume associated with the removal of this volume of water would cause a surface settlement of approximately 30–75 mm over the whole surface area.

By varying the electrode spacing and the voltage gradient, the theoretical treatment time could be altered. Embankment was constructed with the cohesive soil over the soft Kuttanad clay with and without coir geo-textile as basal reinforcement and also with and without electrokinetic process.

A 10 mm diameter and 300 mm long carbon electrode was used as the anode. The conductive geotextile used was woven with steel filaments in warp direction only. The steel filament made the geotextile conductive. The electrodes were then connected using standard flexible copper wire to an AC-DC convertor unit. A voltage of 15V was applied to the soil. After the test water content and unconfined compressive strength were noted. Tests were repeated two times. Loading was done using sand bags. Vertical and lateral deformations were noted using dial gauges. After treatment time soil samples were collected from the area near cathode and anode to measure the pH . Tests were also done for four different voltages .Before and after treatment Atterberg limits and unconfined compressive strength of the soil were found out.

V. RESULTS

Fig.4, shows the vertical deformation under different surcharge pressure in both the models for reinforced, unreinforced and EKG condition. They are represented as M1 or M2 reinforced, M1 or M2 unreinforced and M1 or M2 EKG. For Unreinforced case, using model 1 with embankment height 3cm percentage of settlement is 63.33% and for model 2 with embankment height 12cm, percentage of settlement is 36.67%. For reinforced case using model 1, percentage of settlement is 58.3% and for model 2, it is 23%. For EKG reinforced case using model 1, percentage of settlement is 44% and for model 2, it is 16.3%.The effect of reinforcement and EKG on consolidation settlement with respect to unreinforced embankment having different height of embankment is shown in Table III. From table III, it can be concluded that EKG is more effective as surcharge is higher and at constant voltage. The Fig.5.shows the lateral deformation of the two models and the variation was not very significant. The variation of UCC and water content of the soil sample after the EKG treatment for the two models are shown in Table IV. In model 1, the strength shows an increase of almost 2.8 times after EKG treatment. In model 2, the strength shows an increase of almost 4.7 times after EKG treatment. The variation of properties of soil sample with four different voltages is shown in Table. V. From Table V, it can be observed that as the voltage increases liquid limit decreases and plastic limit increases. Owing to this the plasticity index decreases. This trend is more predominant for voltage upto 45V. For higher voltages the effect is found to be nominal. In the case of UCC, it is found to increase with increase in voltage. The limiting value of 45V for Atterberg's limit has no influence in UCC value, as it increases with increase in voltage.

Table III. Effect of reinforcement and EKG on consolidation settlement

Embankment height (cm)	3	12
Reduction in settlement due to reinforcement with respect to unreinforced case(%)	8	37
Reduction in settlement due to EKG with respect to unreinforced case(%	31	55
Reduction in settlement due to EKG with respect to reinforced case(%)	25	29

Table IV. Variation of UCC and water content after EKG treatment

	UCC before treatment (kPa)	**UCC after treatment**	**Water content before treatment**	**Water content after treatment**
Model 1	1.6	4.32	87.6	67.3
	1.8	5.62	86.2	65.2
Model 2	1.8	6.44	88.6	76.3
	1.4	7.53	87	62.3

TABLE V. Variation of properties of soil sample with different voltage

	Before treatment	After treatment			
	0 V	15V	30V	45V	60V
Liquid limit%	88	76	63	57	56
Plastic limit%	33	36	37	38	38
Plasticity index	55	40	26	19	18
UCC(kPa)	2.2	9.2	12.4	14.4	19.6

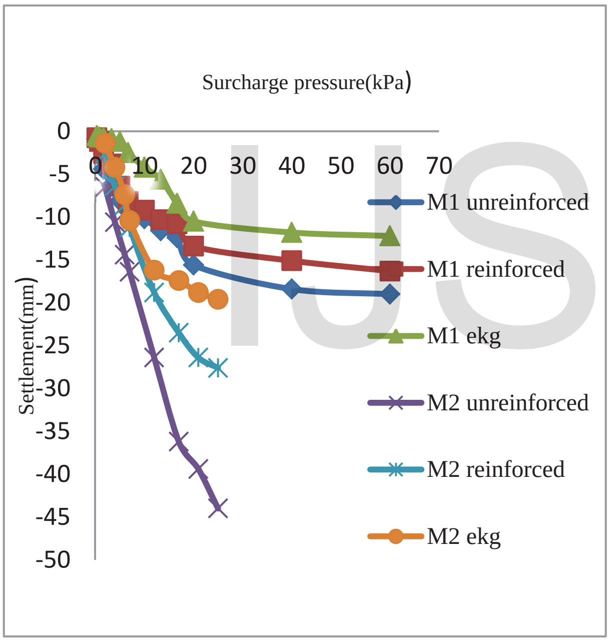

Fig.4.Vertical deformation of two models

The pH values were measured for the soil sample collected from the area near anode and cathode of the two models .The result is shown in Table VI.

TABLE VI. VARIATION OF pH OF SOIL SAMPLE NEAR ANODE AND CATHODE

	Model I	**Model II**
Anode	4.2	5.1
Cathode	8.6	7.8

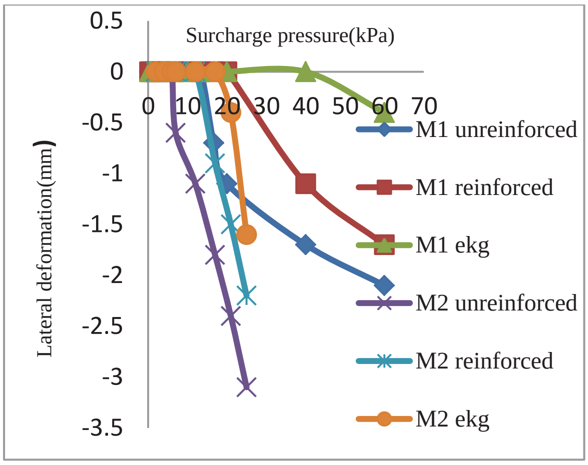

Fig .5. Horizontal deformation of two models

VI. CONCLUSION.

Model tests were conducted to evaluate the effectiveness of coir geotextile as basal reinforcement with and without electrokinetic process for embankments constructed in soft clay. The effectiveness is measured by comparing the deformation obtained in two different models and also with the UCC and Atterberg's limit before and after the test. In model 1, the strength shows an increase of almost 3 times after EKG treatment. In model 2, the strength shows an increase of almost 5 times after EKG treatment. From results it can be concluded that EKG is more effective as surcharge is higher and at constant voltage. The results show low value of pH for soil sample near the anode area and high value near the cathode area. After the EKG treatment with different voltages, the results show that the liquid limits and plasticity indices decrease significantly with increasing applied voltages upto 45V. In the case of UCC, it is found to increase with increase in voltage. The limiting value of 45V for Atterberg's limit has no influence in UCC value, as it increases with increase in voltage.

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