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Dredged Soil Improvement by Electro Osmosis

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***Abstract**: Water content and Strength of Dredged Soil (DS) obtained from Aliyar reservoir were measured after dewatering using Electro Osmosis (EO). The operational conditions adopted include electrode material (Cu, Fe, Al), voltage (6V, 12V, 24V) and duration (24 hours, 48 hours and 72 hours). 27 combinations of experiments were piloted to explore the influence of operational conditions on water content and strength in shear. Maximum reduction in water content was obtained in Fe electrode with 24V and 72 hours of duration for which the water content falls to 27.22% from 87% and the corresponding shear strength is 27.30 kPa. Further, the loss of electrode materials during EO process was also measured.*

***Keywords** : Electro osmosis, shear strength, water content, dredged soil.*

I. INTRODUCTION

Dredged Soils (DS) are the sediments accumulated in water front structures like reservoir, harbour over a period of time which are highly different from mineral, chemical and particle composition of other natural soil deposits[1]. For efficient operation of water front structures, dredging is necessary. After dredging DS are disposed of as open landfills conventionally which could result in contaminated lands[2]. Dredged soils can be used as sustainable material for reclamation and restoration projects economically in the nearby areas of bodies of water which might save utilisation of naturally available materials. David J. Yozzo used DS for an environmental friendly reclamation project at New York–New Jersey Harbour[3]. Recent researches show that DS can be used as base materials for pavement[1] and raw materials for bricks[4]. Despite various positive aspects of DS the application of DS is controlled by its excessive water content which is very difficult to remove as most of the DS are highly impermeable[5]. This can be overcome by electro osmotic dewatering technique.

II. ELECTRO OSMOTIC DEWATERING

A. Background

In Electro-Osmosis (EO), the water held in the interlinking voids of soils is removed by applying Direct Current (DC) through anodes and cathodes embedded in the soil mass. The negative charges on clay surfaces adsorb water and forms diffused double layer[6]. When a DC is passed through the saturated soil mass the cations and water present in double layer are migrated towards cathode. By making cathode as perforated, water shall be drained off either by gravity or by applying vacuum[7]. EO method of dewatering is very effective in removing water from highly impermeable soils which in turn increases the shear strength of soils[8].

B. Performance of EO process

Efficiency of EO process is highly reliant on type of soil, pH, temperature, initial moisture content, electrode material, configuration of electrodes, voltage gradient, and duration of EO process[9]. For soils containing high amount of organic matter such as muck, cumulose and peat EO proved to be more effective[10]. In case of clayey soils and swelling soils, after EO process water content was significantly reduced and improvement in shear strength was also found[11]. Zhijia Xue applied EO for dewatering of marine sludge and moisture content was reduced to 40% from an initial moisture content of 71.6% [12]. Xiaowei Tanga[13] showed successful application of EO for marine soils. Soils with pH > 7 produced minimum corrosion and soils pH < 5 corroded the electrodes at a higher rate[14]. Mitchel reported that reduction in duration of EO at elevated temperatures due to the increase in permeability of pore water[14]. Kaniraj et al[10] electrically consolidated the soils with high initial water content in the range of 220%-250%. Soils with higher water content have more electrical conductivity and so the more efficient EO. Fe, Cu, Al, titanium and graphite are widely adopted electrode materials[15]. Graphite consumes more power compared with other electrode materials while titanium electrodes are costly. Metallic electrodes are highly liable to corrosion which results in loss of materials of electrode and high power consumptions. Electro kinetic geosynthetics and electric vertical drains are adopted to minimize the corrosion effect[16]. Instead of nonstop supply of DC, an intermittent DC can reduce the susceptibility to corrosion without compromising efficiency. By reversing the polarity, corrosion of electrodes is reduced which in turn reduce the loss of contact between electrodes and soil[17]. Although numerous electrode configurations are adopted by various researchers hexagonal pattern and two cathodes – one anode are found to be more effective[18].

C. Scope

It is essential to identify the strength of dewatered DS in shear for design of various field applications. However limited scholars have investigated shear strength of EO soils as a function of water content. This paper intended to provide shear strength of EO dewatered DS with different electrode material, voltage and duration.

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III. MATERIALS

A. Soil

DS was collected from Aliyar reservoir, Tamilnadu, India at 0.5 m beneath the existing ground level and 500 m away from the upstream side of the dam. Bulk samplers were used for sampling. DS was present in the form of slurry and field moisture content was measured with rapid moisture metre. The properties of DS are enumerated in table 1 which were measured after removal of water followed by pulverization. Sieve analysis shows that 71 % of particles are below 2µ and conventional dewatering is highly difficult.

Table- I: Characteristics of DS

Properties	Values
Field Water content	87 %
Liquid limit	61 %
Plastic limit	33 %
Plastic index	28 %
Colour	Pale Brown
pH	7.9
Field density	1.21 g/cc
Soil Classification	CH

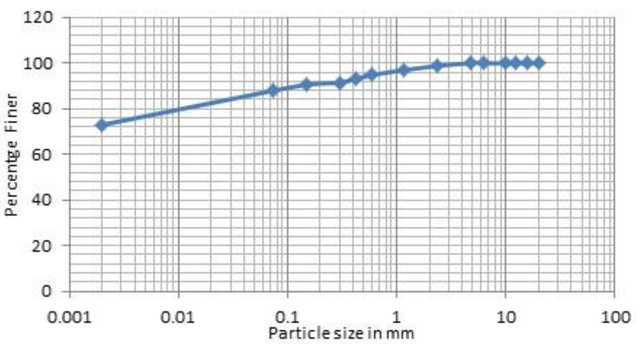

Fig. 1. Gradations

B. Electrodes

Based on literature survey, Fe, Cu and Al electrodes were chosen as their performance are better and are conventionally available. The anode was solid rod and the cathodes were hollow pipes containing 3mm diameter holes. The electrodes has diameter of 12 mm and 300 mm in length. One anode and two cathode configuration was used for EO process.

C. Electro-Osmotic Tank

EO tank of 700 mm in length, 300 mm wide and 350 mm depth was developed using 8mm thick plexiglass. Two notches at the lowest part of the tank were made to facilitate drainage of water being removed by EO process. Two perforated cathodes were fixed exactly over the bottom holes. Anode was placed at the centre of the tank and cathodes were fixed at an offset of 50 mm from tank wall. The electrodes were located along the longitudinal centroid line of the tank. Regulated Power Supply (RPS) device was used to power the electrodes. RPS is capable of delivering 0-5A and 0-50V. Copper wires were used to connect the electrodes with RPS.

IV. EXPERIMENTAL PROCEDURE

DS was first dried, powdered and required quantity of water was supplied in three segment. DS and water were mixed thoroughly to get uniform mixture. A minimal layer of vaseline was applied on all the walls of EO tank. Electrodes were setup in the position after weighing them. The prepared DS was then filled for a height of 15 cm inside the tank in three layers. Each lift was compacted in so that unit weight was 16.2 kN/m^3 as measured in the field. The electrodes were connected with RPS. To eliminate evaporation of water and temperature effect on EO thermo coal sheets was used as cover over the EO tank. Testing temperature was maintained at 27^{o}C. The settlement was measured by 18 numbers of scales fixed outside the tank. The RPS was to deliver required voltage and applied on electrodes for the required duration as given in table 2. The drained water was collected from the measuring flask. At the end of duration of EO process, the electrodes were weighed, the loss of metal indicates the percentage of corrosion. Vane shear tests were executed at the beginning and end of EO process. Further, moisture content was also determined. The procedure was repeated on freshly prepared DS for other configurations.

Table- II: Test Schemes

Test No.	Voltage	Duration	Electrode Material
1.	6	24	Cu
2.	6	48	Cu
3.	6	72	Cu
4.	12	24	Cu
5.	12	48	Cu
6.	12	72	Cu
7.	24	24	Cu
8.	24	48	Cu
9.	24	72	Cu
10.	6	24	Fe
11.	6	48	Fe
12.	6	72	Fe
13.	12	24	Fe
14.	12	48	Fe
15.	12	72	Fe
16.	24	24	Fe
17.	24	48	Fe
18.	24	72	Fe
19.	6	24	Al
20.	6	48	Al
21.	6	72	Al
22.	12	24	Al
23.	12	48	Al
24.	12	72	Al
25.	24	24	Al
26.	24	48	Al
27.	24	72	Al

V. RESULT ANALYSIS

A. Effect of EO on water content

Water content near cathode, in-between positive electrode and negative electrode and near anode was measured and it is illustrated in fig 2-4. For a fixed voltage, with the intensification in duration, the water content is decreasing. While raising the voltage also, the water content is decreased[13]. The moisture content of DS before subjected to EO was 87%. After completion of EO process of 72 hours with 24V, the water content near cathode is 35.3%, 27.22%, 55.68% for Cu, Fe, Al electrodes respectively. This proves that Fe electrode perform better than other electrodes.

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However the water content varies as a function of distance from cathode. For 24V and 48 hours of duration using Fe electrode, the water content near cathode is 29.28%, in-between electrode is 32.43% and near anode is 33.93%. This is due to fact that during the EO processes the water molecules drags soil particle along with its movement and hence the seepage of water is reduced during the EO process.

The increase in voltage increases the voltage gradient across the soil mass which in turn accelerates the dewatering process. For Cu electrode with 72 hours duration, the water content near cathode is 62.9%, 49.1% and 35.3% for 6V, 12V and 24V respectively. The higher voltage may cause high cost due to increased power consumption.

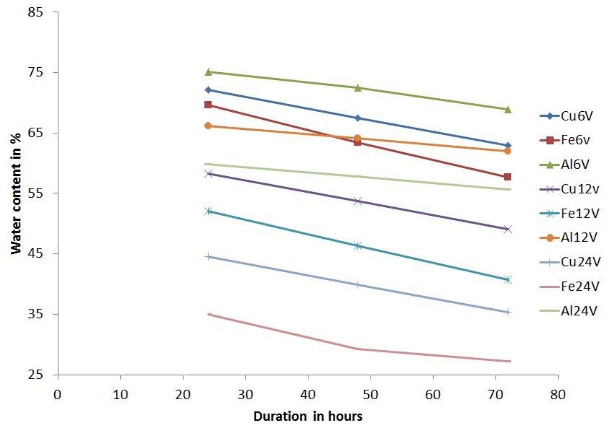

Fig. 2. Water content near cathode

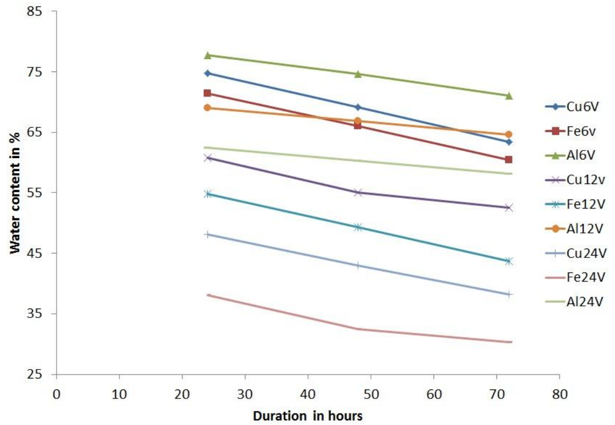

Fig. 3. Water content in-between electrodes

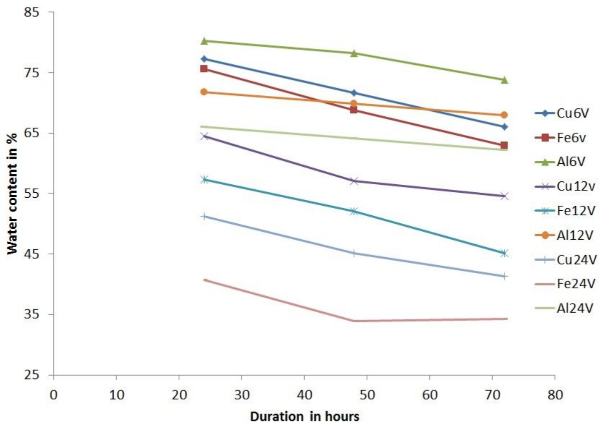

Fig. 4. Water content near anode

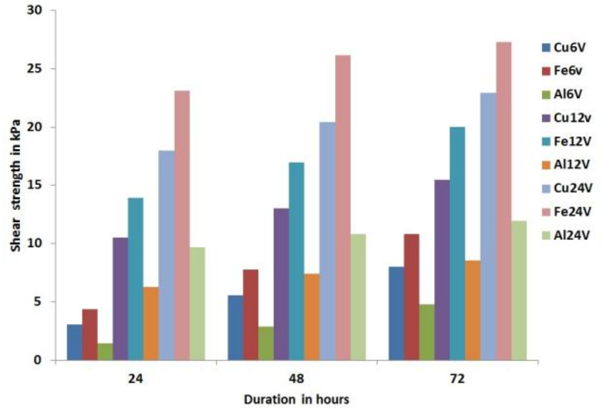

Fig. 5. Shear strength near cathode

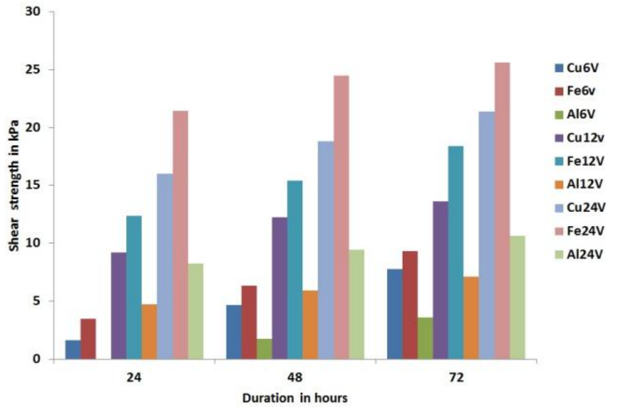

Fig. 6. Shear strength in-between electrodes

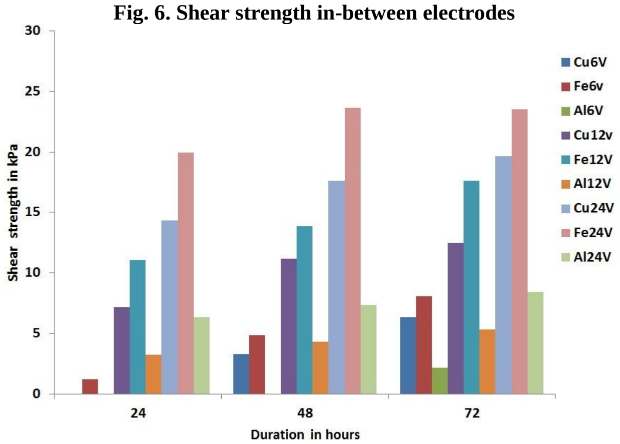

Fig. 7. Shear strength near anode

B. Effect of EO on shear strength

Shear strength of DS is dependent on its moisture content. When there is a loss in moisture content the strength of DS in shear is increased[13]. Shear strength of DS before subjected to EO was almost zero and it is in flowable state. After completion of EO process of 72 hours with 24V, the shear strength near cathode is 22.93 kPa, 27.30 kPa and 11.94 kPa for Cu, Fe, Al electrodes respectively. This demonstrates that Fe electrode perform relatively better than other electrodes in increasing shear strength also.

Strength of soil in shear falls with increase in distance from cathode. For 24V and 48 hours of duration using Fe electrode, the water content near cathode is 26.18kPa, in-between electrode is 24.48kPa and near anode is 23.67 kPa.

This happens as the water content away from cathode is high compared to the water content at cathode.

The increased in voltage produces high shear strength DS as higher voltage removes more water. For Cu electrode with 72 hours duration, the shear strength near cathode is 8.034kPa, 15.486 kPa and 22.94 kPa for 6V, 12V and 24V respectively.

C. Effect of EO on corrosion

Corrosion of electrodes is measured in terms of % loss in mass. The weight of electrode material is decreased with the increase in applied voltage and duration of EO process. The worst condition for the evaluation is taken as 24V and 72 hours duration under which the % loss in materials is 38.9%, 33.4%, 44.2% for Cu, Fe and Al respectively. Lower value of Fe indicates that its corrosion resistance.

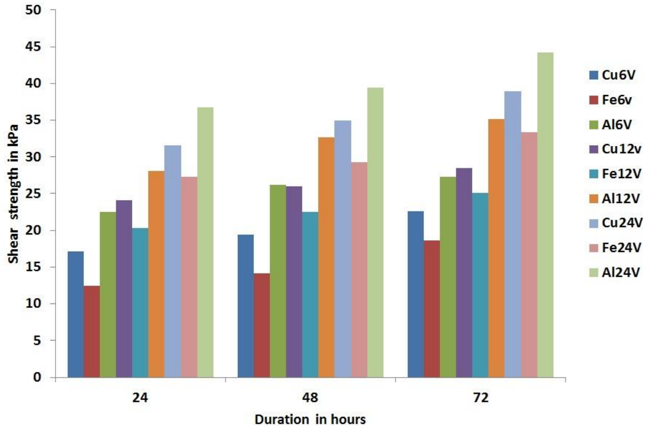

Fig. 8. Corrosion

VI. CONCLUSION

In this paper, EO was conducted on DS from Aliyar reservoir considering the effects of electrode materials, voltage and time of EO. The strength of DS in shear and moisture content were examined and are summarized as follows:

- EO dewatering is very effective for dredged soils. For longer duration the water content is well lowered.
- Water content of DS near cathode is lower than DS in any other places and adjoining the anode water content is relatively high.
- Maximum reduction in water content was obtained in Fe electrode with 24V and 72 hours of duration for which the water content falls to 27.22% from 87%.
- Strength of DS in shear is a function of water content and it increases with the drop in water content.
- Maximum achieved shear strength is 27.30 kPa under 24V, and 72 hours duration using Fe electrodes.
- The loss of materials in Cu electrode after 72 hours of EO process is 38.9%, Fe electrode is 33.4% and Al electrode is 44.2%. Fe electrode is more effective in dewatering, shear improvement and material loss during EO than Cu and Al electrodes.

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