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Electrochemical Remediation of Oil Contaminated Soil

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***Abstract*— The effects of oil contamination on the geotechnical properties of clayey soil and the effectiveness of electrochemical method as a remediation technique for oil contaminated clayey soil are investigated in this study. Diesel engine oil is mixed with locally obtained clayey soils and the changes in the engineering and index properties of soil are determined. It is proposed to design and fabricate an electrochemical cell, 30cm square, made of acrylic sheets. The electrodes are be fabricated using an inert material such as graphite and a DC power supply is used to provide the necessary potential across the electrodes. The contaminated soil was treated under the current generated by a constant potential. The changes in soil properties such as pH, oil content, Atterberg limits and shear strength with the addition of oil are extensively investigated.**

Keywords*— *Soil, Diesel engine oil, Graphite electrodes , D C supply , Acrylic box

I INTRODUCTION

Oil contamination poses a severe threat to the environment and is considered as a hazardous pollutant to soil. Numerous studies over the past have proven that, contamination with oil products causes significant changes in the geotechnical and physical properties of soil, which make them unsuitable for construction purposes. The major chances of oil pollution occur in terrestrial and marine environments, during exploration, transportation and processing of oil. Some of the geotechnical problems associated with construction over oil contaminated sites include excessive settlement of tanks and breakage of pipelines. Several methods have been used for treatment of oil-contaminated soils. One among them is electrochemical remediation, based on using electrochemical and electrokinetic processes that occur in soil under the electric current generated by a constant potential. The basic principle of electrochemical treatment method involve applying a low direct current or a low potential gradient to electrodes inserted in soils where the permeability is low.

II MATERIALS USED FOR THE STUDY

A. *Soil*

The soil used for experimental work has been collected from Nadakkavu, Calicut area. The samples (fig 2.1) were obtained from the depth of 20 m below the existing ground elevation. Wet soil sample (fig 2.2) was immersed in water for 2 weeks to check for the presence of oil.

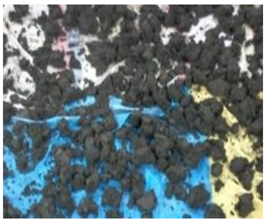


Fig. 2.1 Air dried Soil samples

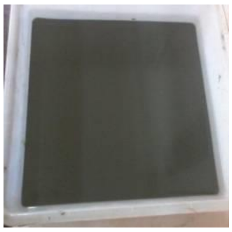


Fig. 2.2 Wet soil kept in water

Geotechnical Properties of Soil was shown in table 2.1. The clay is classified as CH according to the Indian Standard Soil classification.

Table 2.1: Geotechnical Properties of Soil

Properties	Value		
Hydrometer Analysis	D_{10}	D_{30}	D_{60}
	0.002	0.1	0.3
Uniformity Co efficient	150		
Co efficient of Curvature	16.67		
Liquid limit (%)	35.5		
Plastic limit (%)	16.32		
Shrinkage limit (%)	14.5		
Plasticity index (%)	19.18		
Specific gravity	2.46		
Optimum moisture content (OMC (%))	16.8		
Maximum dry density (g/cc)	1.76		
Unconfined compressive strength (kPa)	37.8		
Free swell index (%)	nil		

B. *Oil*

To contaminate the soil artificially, the Mak Auto XL 15W-40 diesel engine oil (Bharath Petroleum, Diesel Oil) was used.

III TESTING METHODOLOGY

The experimental study commenced with the tests on basic properties of soil and oil. Further, the effects of oil addition on the geotechnical properties of soil was investigated by conducting various laboratory tests on soil-oil mix. The entire experimental investigation was divided into three phases. Phase I consisted of characterizing the materials used for the study, viz. soil and oil. Phase II dealt with determining the effect of oil contamination on the geotechnical properties of soil-oil mix. Phase III comprised of electrokinetic remediation on oil contaminated soil and determination of the response of oil, moisture content and pH of soil-oil mix.

IV TEST SET UP CONSTRUCTION OF AN ELECTROCHEMICAL CELL

In order to determine the effect of electrochemical remediation on oil-contaminated soil, a three dimensional box structure was fabricated using acrylic sheets, as shown in Fig.4.1 This cubical reactor was 25 cm long, 25 cm wide and 30 cm deep. A pair of inert graphite, electrodes served as anode and cathode The box was fabricated using 1 cm thick flexbond adhesive. The corners were glued using, providing 30V/ 2A. The electrodes (Fig.4.2) were rectangular in shape having a length of 10 cm length and a cross-section of 3 cm x 1 cm.

Fig.4.1 Acrylic box (25cmx25cmx15cm)

Fig 4.2 A pair of graphite electrodes

Fig 4.3 Experimental setup of an electrochemical cell

V RESULTS AND DISCUSSIONS

A. Soil pH

The pH of soils was determined by following a conventional procedure given in literature. Soil was air dried and sieved, in order to separate large particles. About 5g of the sieved soil was taken and mixed with distilled water and stirred in a magnetic shaker. Then, the mixture was allowed to stand for 30 minutes and was sieved through Whatmann No.1 filter paper. A digital pH meter was inserted into filtrate and the pH of the soil was measured.

B. Moisture content

Water content of contaminated soil was determined by simple oven drying method. The flash point of the oil used was 232ºC, hence it does not vaporize at the oven temperature of 105-110^{0}C.

C. Oil content

The oil content of the contaminated soil was measured by mixing air dry soil with n-hexane. Oil can be separated from n-hexane by shaking in a mechanical shaker for about 30 minutes. After this, the mixture of soil, oil and hexane was filtered into a beaker of known weight through a Whatmann No.1 filter paper. The oil content of the filtrate was determined after allowing the mixture to heat to escape hexane and remaining amount of oil can be measured.

D. Effect of oil contamination on Atterberg limits

In order to investigate the effect of oil contamination on the Atterberg limits of soil, liquid limit, and plastic limit of oil-contaminated soil were determined with addition of 2%, 4% 6% and 8% oil, by weight of dry soil. Test results indicate that addition of oil has a significant effect on Atterberg limits. The consistency limits were determined at 7 and 28 days curing. The results indicate that oil contamination reduces the Atterberg limits of soil-oil mix.

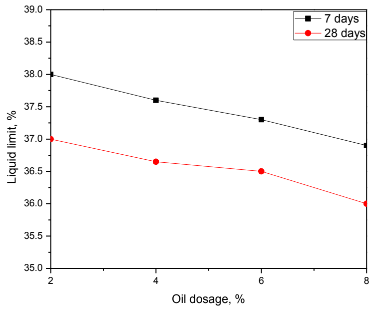


Fig 5.4.1 Liquid Limit vs. oil dosage with ageing effect

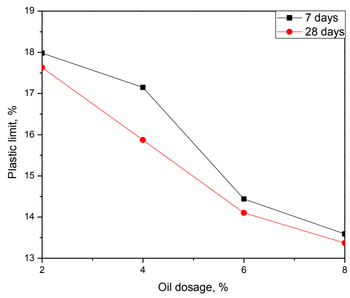
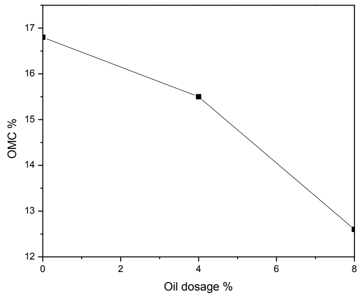


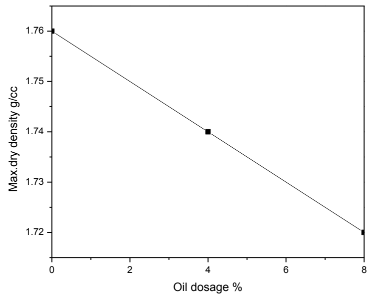
Fig 5.4.2 Plastic Limit vs. oil dosage with ageing effect

E. Effect of oil contamination on compaction characteristics

An increase in oil dosage resulted in a decrease in the optimum moisture content and an increase in the maximum dry density. The role played by oil is similar to that of water. Addition of oil acts imparts a lubricating effect to the soil particles as a result of which they come closer, occupying a denser packing. This results in the soil particles achieving a higher density, even at lower water contents.



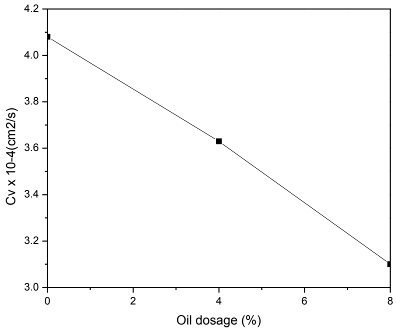
Fig,5.5.1 Oil dosage vs. OMC



Fig,5.5.2 Oil content vs. Max.dry density

F. Consolidation characteristics

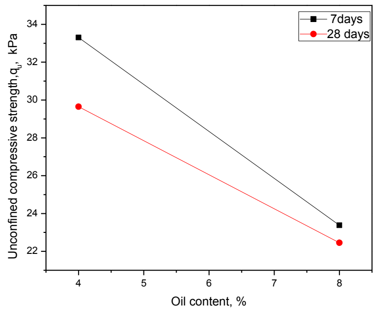
Soil was mixed with varying contents of oil in a conventional odometer. It was observed that addition of oil decreased the coefficient of consolidation and increased the compressibility. This could be attributed to the lubricating effect of oil which reduces the interparticle friction between the soil particles.



Fig,5.6.1 C_v Vs. oil dosage

G. Unconfined compressive strength

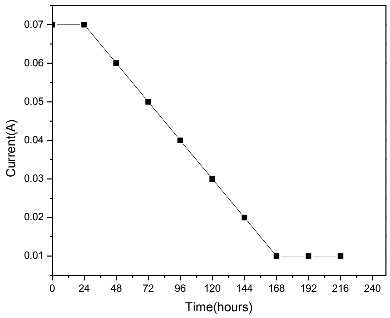
The soil samples were mixed with 4,8 and 12% of oil and moulded into cylindrical samples of 38mm diameter and 76mm height. The samples with varying oil contents were wrapped in air-tight plastic covering and cured for 7 and 28 days and tested in the Unconfined compression testing apparatus. It was observed that addition of oil significantly reduced the unconfined compressive strength of the oil contaminated samples. The reason for this could be attributed to the lubricating effect imparted by oil, resulting in a decreased interparticle cohesion between the soil grains, resulting in the failure of soil over a shorter period of time .



Fig,5.7.1 UCC vs. Oil dosage with ageing effect

H. Variation of current with time

The electric current passing through the contaminated soil and the electrodes in the reactor was checked periodically. It was observed that current started to decrease a few days after the tests commenced (Ferrarese et al. 2010). Only during the initial stages of treatment, the electro-osmotic flux becomes significant.



Fig,5.8.1 Variation of current with time

I. Soil pH

The initial pH of soil was found to be 7.1. Towards the end of tests, it was observed that pH at the anode decreased and that at cathode increased. This could be attributed to the hydrolysis of water

At cathode: $4H_2O+4e^- \rightarrow 2H_2(g)+4OH^-$ ………………(1)

At anode: $2H_2O \rightarrow O_2(g)+4H^+ +4e^-$ ……………………(2)

Properties such as soil pH, oil content and moisture content were measured along three mutually perpendicular directions. The line joining the center of two electrodes is considered as the x-direction. The y-direction was considered perpendicular to this line. Depth wise, the z-direction was considered.

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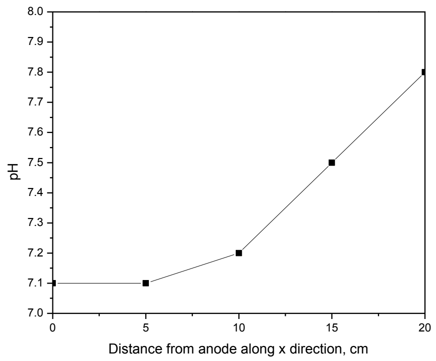

Fig 5.9.1Variation in soil pH along the x-direction after treatment

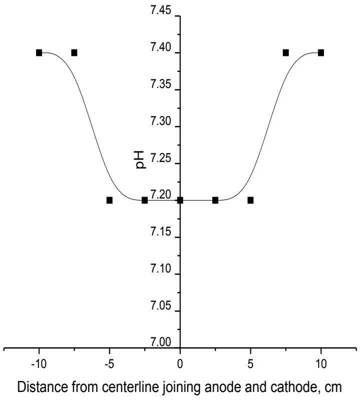

Fig 5.9.2 Variation in soil pH along the y- direction after electrochemical treatment

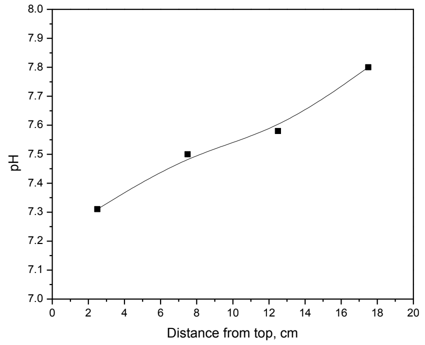

Fig 5.9.3 Variation in soil pH along the z-direction after electrochemical treatment

J Soil moisture content

During the commencement of the tests, the soil moisture content was determined to be 16.8%. The final moisture content, towards the end of tests was obtained as 9.8% near the anode and 17.2% near the cathode. Along the x-direction, the moisture content increased towards the cathode. However, along the y-direction, the variation in moisture content is only marginal. Along the depth, the soil moisture content increases.

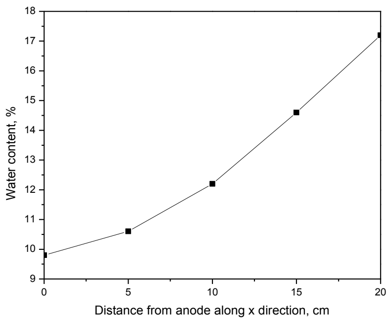

Fig 5.10.1 Soil moisture content along x direction before and after treatment

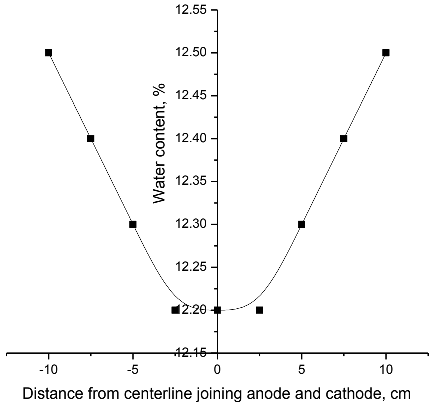

Fig 5.10.2 Soil moisture content along y direction before and after treatment

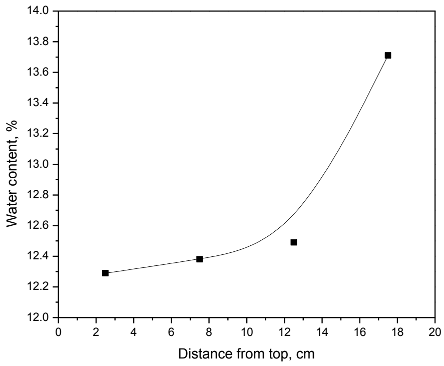

Fig 5.10.3 Soil moisture content along z direction before and after treatment

K. Oil content

The initial oil content of the contaminated soil was 8%. After electrokinetic treatment, the oil content reduced to 7.4% at the anode and 2.8 %at the cathode. Along the x-driection, the oil content gradually increased towards the cathode. However, along the y-direction, a decrease was observed towards the cathode. Along the depth, the soil oil content only marginal.

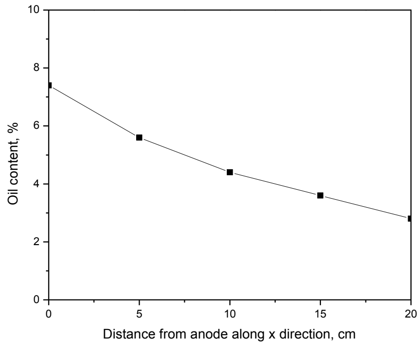

Fig 5.11.1: Oil content along x-direction before and after treatment

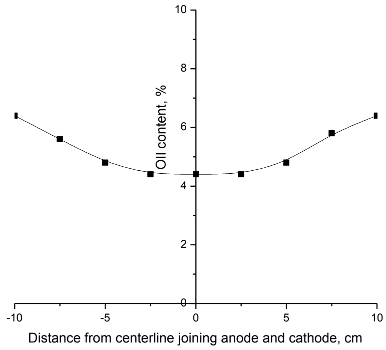

Fig 5.11.2: Oil content along y-direction before and after treatment

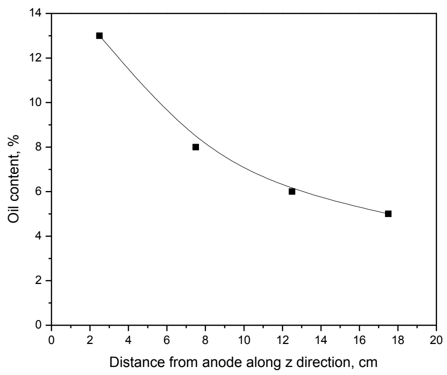

Fig 5.11.3: Oil content along z-direction before and after treatment

VI CONCLUSIONS

In this study, the effects of oil contamination on some geotechnical properties are clearly observed on clayey soils. Based on results obtained from the present investigation, the following conclusions can be made .

- The results indicate that oil contamination reduces the Atterberg limits of soil-oil mix.
- An increase in oil dosage resulted in a decrease in the optimum moisture content and an increase in the maximum dry density
- It was observed that addition of oil significantly reduced the unconfined compressive strength of the oil contaminated samples
- It was observed that addition of oil decreased the coefficient of consolidation and increased the compressibility

From electrochemical treatment following results were obtained

- A good removal of engine oil was achieved from contaminated soil.
- It is observed that about 7.5%oil at cathode and 65%oil at anode was removed within 7 days by using 0.6V/cm specific voltage.
- Higher the specific voltage, higher will be the efficiency of treatment.
- Overall efficiency of the treatment and restoration of properties lying in the range of 65-75%.

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