Correlation between index properties and electrical resistivity of hydrocarbon contaminated periodic marine clays

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Abstract. Hydrocarbon contamination is a measure issue of concern as it adversely affects the soil inherent properties viz. index properties and strength properties. The main objective of this research work is to determine Electrical resistivity to study and correlate with soil index properties and engineering properties contaminated with hydrocarbon at the rate of 3\%, 6\% and 9\% for the period of 15, 30, 45 and 60 days and compare it with the results obtained for non-contaminated marine clay. Electrical resistivity of virgin marine clay (bentonite which is expansive in nature) and hydrocarbon contaminated clay for each percent of contamination is obtained in the laboratory for each period and its co-relation with index properties and engineering properties is proposed. CEC, EDAX tests were performed to evaluate the effect of ions of montmorillonite clays and their penetrability into hydrocarbon-clay matrix. The correlations at the end of each period for each percentage of contamination thus enabled to integrate index properties of non-contaminated and hydrocarbon contaminated marine clays with Electrical resistivity.

1. Introduction

The past few years have witnessed tremendous growth in petroleum sector all over the world. This has led to hydrocarbon contamination of soil situated in the vicinity of the petroleum spillage areas which is a serious problem for the environment as it adversely affects the soil inherent properties viz. index properties and strength properties. Hydrocarbons contaminated clay resulting in large amounts from the treatment of crude-oil and oil Refineries represent a great geo-environmental pollution threat. Hydrocarbon soil contamination is very common in marine clays. Petrochemicals, hydrocarbons (oil spills), are extensively liberated onto the surrounding soil and get penetrated into the deep ground soil further affecting its physico-chemical properties. With this process of large-scale exploitation of coastal and offshore oil, coastal soils have encountered oil pollution. And this legacy of industrialization which has resulted in a prevalence of hydrocarbons
contamination of surrounding soils, necessitates the evaluation and analysis of the hazardous effects of these contaminants on soils as well. Electrical resistivity is one of the perturbed properties in the presence of hydrocarbons in the soil. Some authors have correlated Electrical resistivity with varied soil parameters: 1. Moisture content 2. Specific gravity 3. Atterberg's limit 4. C and ϕ (G. Kibria and M. S. Hossain (2012), Mohd Hazreek Bin Zainal Abidin et.al (2013) and Z Abu-Hassanein et.al (1996). In the present research work, efforts have been made to obtain a correlation between Electrical resistivity of non-contaminated and periodic (15, 30, 45 and 60 days) hydrocarbon contaminated marine clays at the rate of 3%, 6% and 9% with index properties of non-contaminated and hydrocarbon contaminated bentonite clays so as to evaluate whether electrical resistivity can be used as a tool to study the geotechnical properties of areas subjected to hydrocarbon contamination.

2. Material and experimental setup

2.1 Soil resistivity box

Soil resistivity is obtained in laboratory by fabricating soil resistivity box (10 cm × 5cm × 5cm) in accordance with ASTM G187. For laboratory test an individual soil sample is compacted in the resistivity box in a predetermined unit weight and moisture content. LCR meter, D.C voltage and current source, can be utilized for the resistivity measurements. To obtain the correlations, soil resistivity tests are conducted using different geotechnical considerations. Using Ohm's law,

Electrical resistance, $R = \frac{\Delta V}{I}$

Electrical resistivity, $\rho = \frac{AR}{L} = \frac{\Delta V}{IL}$

Thus electrical resistivity of the soil sample can be obtained using the above equation.

![Fig 2.1 Typical Two-Electrode Soil Box (Empty and Full)](image)

2.2 Clay sample and hydrocarbon sample

Source of the Bentonite clay was identified and procured commercially from Baroda, Gujarat. The disturbed soil samples were put in plastic bags, and then transported to the soil laboratory. The natural soil was classified visually and experimentally as clay of high plasticity (CH) according to unified classification soil system (IS classification). For the present study the hydrocarbon contaminated soil was procured from one of the major petroleum unit. The sample was in saturated form mixed with various hydrocarbons.
3. LABORATORY TESTING

3.1 GC-MS (Gas chromatography & Spectroscopy)
To identify the type of hydrocarbon, GC-MS test was performed at Department of Chemistry, Gujarat University and the hydrocarbon was identified as Dodecane (C₁₂H₂₆).

3.2 Index properties
The index properties of non-contaminated bentonite clay (with montmorillonite as basic mineral) and periodic (15, 30, 45 and 60 days) hydrocarbon contaminated clay was obtained in accordance with IS code for each percentage of contamination i.e., 3%, 6% and 9%.

| Parameters          | Symbol | B<sub>NC</sub> | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  |
|---------------------|--------|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Liquid limit        | LL     | 335            | 290 | 300 | 325 | 338 | 250 | 285 | 310 | 275 | 292 | 312 | 327 |
| Plastic limit       | PL     | 113            | 120 | 118 | 115 | 113 | 128 | 125 | 123 | 120 | 122 | 117 | 115 |
| Shrinkage limit     | SL     | 57             | 17  | 19  | 21  | 22  | 38  | 41  | 45  | 47  | 21  | 22  | 25  | 29  |
| Specific gravity    | G      | 2.05           | 2.4 | 2.7 | 2.8 | 2.9 | 2.1 | 2.3 | 2.4 | 2.5 | 2.2 | 2.4 | 2.6 | 2.7 |
| Free swell index    | FSI    | 60.25          | 54  | 51  | 49  | 48  | 52  | 49  | 45  | 44  | 50  | 47  | 42  | 41  |

Table 1: Index properties of contaminated and non-contaminated bentonite clay

3.3 Electrical Resistivity
The electrical resistivity is obtained in accordance with ASTM G187 and the values are obtained for non-contaminated and hydrocarbon contaminated marine clay at the rate of 3%, 6% and 9% using constant DC source having voltage of 35V (provides most desirable and comparable results) for the purpose of setting correlations and evaluation of various geotechnical properties.

| Parameters          | Symbol | B<sub>NC</sub> | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  | 3%  | 6%  | 9%  |
|---------------------|--------|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Electrical resistivity | ρ     | 2.7            | 3.75| 3.45| 3.27| 3.12| 4.28| 3.83| 3.52| 3.31| 4.03| 3.58| 3.31| 3.21| 3.75| 3.45| 3.27| 3.12| 4.28| 3.83| 3.52| 3.31| 4.03| 3.58| 3.31| 3.21|

Table 2: Electrical resistivity of contaminated and non-contaminated bentonite clay
4. RESULTS AND DISCUSSION

4.1 Electrical resistivity v/s period of contamination and rate of hydrocarbon contamination
The Electrical resistivity increases for hydrocarbon contaminated bentonite clay by 28%, 40%, and 33% for 3%, 6% and 9% of hydrocarbon contamination respectively (Fig 4.1) at the period of 15 days of contamination. As the period of contamination increases to 60 days, Electrical resistivity decreases by 17%, 23% and 20% for 3%, 6% and 9%. Hydrocarbons are non-polar in nature floats over the water layer around the clay particles and hence they do not participate in ion exchange mechanism. Current is flow of charges and since hydrocarbon is hindering with the flow of charges, therefore results in increased resistivity.

4.2 Comparison between Electrical resistivity and liquid limit
Electrical resistivity decreases with increase in liquid limit (fig. 4.2) and LL increases as the period of hydrocarbon contamination increases by 14.2%, 19%, and 16% for 3%, 6% and 9% respectively. LL of non-contaminated clay is higher than hydrocarbon contaminated clay. Electrical resistivity decreases as the liquid limit increases as higher liquid limit states for higher cation exchange capacity and greater the cation exchange capacity, lower is the resistivity.

4.3 Comparison between Electrical resistivity and Plastic limit
Electrical resistivity increases with increase in plastic limit (fig. 4.3) and PL decreases as
the period of contamination increases. PL of non-contamination clay is lower than that of hydrocarbon contaminated bentonite clay. Presence of hydrocarbon leads to increase in plastic limit. The interaction between bentonite clay and hydrocarbon which has C-H layer over it prevents the fast shrinkage of clay, causing increase in plastic limit.

4.4 Comparison between Electrical resistivity and Shrinkage limit
Electrical resistivity increases with increase in shrinkage limit (fig. 4.4) and SL increases as the period of contamination increases. SL of non-contamination clay is higher than that of hydrocarbon contaminated bentonite clay. Electrical resistivity

4.5 Comparison between Electrical resistivity and specific gravity
Electrical resistivity decreases with increase in specific gravity (fig. 4.5) and specific gravity increases as the period of contamination increases. Specific gravity of non-contamination clay is lower than that of hydrocarbon contaminated bentonite clay. Presence of hydrocarbon leads to increase in specific gravity.

4.6 Comparison between CEC (Cation Exchange capacity) and period of contamination and Electrical resistivity
CEC values for hydrocarbon contaminated clays decreases by 53.8%, 61%, & 56.57% for 3%, 6% and 9% respectively in comparison with non-contaminated clays after 15 days. CEC values decreases by 38%, 30% & 35% for 3%, 6% and 9% respectively after 60 days of contamination. Presence of hydrocarbon thus leads to decrease in CEC values in comparison with non-contaminated clays and as the period of contamination increases, CEC values further increase. Electrical resistivity can thus be correlated with the fact that higher the...
CEC values, lower is the value of Electrical resistivity as the ion exchange mechanism reduces the resistivity values.

4.7 Comparison between Electrical resistivity and free swelling index

Electrical resistivity increases with increase in free swelling index (fig. 4.6) and free swelling index increases as the period of contamination increases. Free swelling index of non-contamination clay is higher than that of hydrocarbon contaminated bentonite clay. Presence of hydrocarbon leads to decrease in swelling capacity of expansive clays. The hydrocarbons used are volatile in nature due to which under the influence of these volatile substances, free swelling index reduces and electrical resistivity increases.

CONCLUSIONS

The above study aimed at correlating index properties of non-contaminated marine clay and hydrocarbon contaminated marine clay with electrical resistivity. The electrical resistivity is found to be directly correlated to liquid limit, plastic limit, shrinkage limit and specific gravity. Also the effects of hydrocarbon contamination on the index properties were evaluated. The hydrocarbon contamination leads to decrease in liquid limit by 2.9%, 13.43%, & 6.8 %, increase in plastic limit by 6%, 11% & 7.3% and decrease in shrinkage limit by 70%, 33% and 63% for 3%, 6% and 9% of hydrocarbon contamination respectively. There is an increase in specific gravity by 28%, 18% and 24% for 3%, 6% and 9% of hydrocarbon contamination respectively. There exists a definite correlating pattern of various index properties and Electrical resistivity. Therefore in can be concluded that the electrical resistivity can be used to correlate various index properties of non-contaminated and hydrocarbon contaminated marine clay being a non-destructive tool which can be economical as well as time saving. The above study reveals that there is a major influence of hydrocarbon contamination on engineering behavior of clays. This leads us advance assessment of influence of both percentage contamination and periodic contamination on strength characteristics of such marine clays. India’s coastal belt is highly influenced by oil and gas spillages and other volatile toxic and non-toxic intrusion of chemicals demands geotechnical engineer to study the engineering behavior of clays by adapting various types of geophysical methods simulating true field conditions. The actual field application of the present study is that the hydrocarbon contaminated soil samples collected through
boreholes through soil samplers at varied depths can be brought to the laboratory and instead of extensive, conventional and destructive soil investigation methods, Electrical resistivity can be used as a tool, values of which can give an idea about soil index and engineering properties. There are numerous types of hydrocarbons, some of which are very complex in nature, whose assessment should be done thoroughly so as to know its long term influence on engineering behavior of clays. Mostly, statistical analysis of such relevant data may not be useful every time unless the soil characterization is done through method like electrical resistivity which replicates soil-water-hydrocarbon interaction. Thus in the present research an attempt is made to know the influence of periodic hydrocarbon contamination particularly on expansive clays using not only conventional analysis but also using physico-chemical analysis (CEC, EDAX) which gives clear insight on various parameters responsible for compressibility and shear strength characteristics which are easy to determine using soil-electrical resistivity inter-relationships developed for various % of contamination.

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