Behaviour of Crude Oil Contaminated Clayey Sands

Dr. Dilip Kumar Talukdar

Abstract-- The study has been carried out with two broad objectives – to observe the effect of crude oil contamination on plasticity, unconfined compressive strength, some swelling and chemical properties of soil and to predict the change in the properties in the form of mathematical correlation. Naturally available clayey sands (SC) were used for this study. Laboratory tests were conducted on uncontaminated soil samples and soil samples contaminated at different level of contamination. Mathematical correlation between the soil property and the level of contamination was determined. Change in the properties of crude oil contaminated soil was observed. Liquid limit, plastic limit, plasticity index, free swell index, differential free swell index and pH value increases linearly whereas unconfined compressive strength and electrical conductivity decreases linearly with the increase in the percentage of crude oil contamination. Change in liquid limit, plastic limit, plasticity index, unconfined compressive strength, pH value and electrical conductivity is not statistically significant.

Keywords-- Contamination, free swell index, variance, and correlation, significant.

I. INTRODUCTION

Refined products of crude oil, like petroleum, diesel are major resources for industrial work Exploration, production, storage, refining and transportation etc. are some of the major potential sources for spills or releases of crude oil and its products to the soil. Oil spills also occur at the oil collection centers, where oil is separated from water. These spills or releases may be either accidental or natural. The total number of damaged oil well in the Gulf War in 1991 was 1120 (Khuraibet and Attar, 1995). Out of these, 639 wells were on fire, crude oils were flowing into desert from 42 wells and 439 wells were damaged. The Annual Report (1999) of the National Oil Spill Disaster Contingency Plan has reported major oil spills at the port terminals of Vadinar, Kandla and Haldia amounting to 16,000 m³, 4000 m³ and 5000 m³ respectively (TERI Vision, 2004). Contamination of soil by crude oil in India is a major concern considering the huge network of oil pipelines that transport crude oil to and from various refineries (Bhattacharya 2004).

An accidental release of petroleum products amounting to 240 million gallon (approx) during the gulf war (1991) alone which represents the largest petroleum release event since record began to be kept consistently from 1978 (Singh, Srivastava and John, 2005). Hence, it is observed that, leakage, spills or accident in oil well is unavoidable. The spilled or gushing oil moved down to the ground water under gravity. The soil is partially saturated by the oil on its pathway. After reaching the ground water, the liquid have spread horizontally by migration within the capillary zone (Shroff 1997). This may lead to serious soil contamination. The petroleum hydrocarbons wastes released on the ground ultimately find its way to the soil system changing the properties of pore fluid. Based on experimental and theoretical works done by various geotechnical research workers, such as, Lambe in 1951, Scott (1965), Mitchell (1976) Jakhanwal and Singh (1991), it is confirmed that the geotechnical properties of soil, such as, liquid limit (LL), plastic limit (PL), cohesion, angle of internal friction or shear strength, compressibility etc. depend upon the type of soil, void ratio, degree of saturation, soil structure, stress history and nature of pore fluid.

Change of LL, PL, PI, unconfined compressive strength (UCS), free swell index (FSI), differential free swell index (DFSI), pH value and electrical conductivity (EC) of soil with increase in the level of contamination of crude oil in case CL and CH type of soil was also observed (Talukdar and Saikia, 2010, 2011,2012).

Greater vertical settlement and change in water permeability is there in case of sand contaminated with crude oil (University of Maine,2004). The permeability of Kuwaiti sand decreased and compressibility increased with increase in oil content (Sanad, Eid and Ismae 1995). (Srivastava, Singh and Tiwari, 1997) observed the increase in coefficient of compressibility and coefficient of permeability of typical alluvial (CL-ML) soil due to contamination by industrial waste. Failure of three industrial buildings is due to large settlements of soil caused by accidental spillage and substantial reduction of SPT blow counts were observed due to contamination (Yaji Ramakrishnegowda and Thomas, 1997).
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Although many researchers are working on the aspect of
effect of soil contamination; the problem is mostly local
due to the varied types of soil at different localities of a
region. Different types of soil respond differently with
contaminants and the sensitivity of soil to the contaminants
depends not only on the local environment but the response
also influenced by mineral structure such as particle size,
bonding characteristics between particles, ion exchange
capacity etc. (Singh, Srivastava and John, 2005). Obviously,
there is a great possibility of variation of the consolidation
properties of soil, due to change of pore fluid or
contamination of soil. The change in properties can be
represented in the form of tables and graphs with respect to
the percentage of contamination. The variations shown by
tables and graphs do not provide quantitative information
regarding prediction, judgment or decision making. A
mathematical description of the sets of variables is the best
way of scientific explanation, because in a graphical
presentation, there is always an element of biasness or
misleading presentation. It is observed that statistical
regression technique is used in many Engineering
applications.

There are several oil fields and oil refineries in different
parts of Assam. Accidental fire on oil wells or intentional
burning of natural gas etc. is a regular feature in this region.
Therefore, change in soil properties of this region due to
crude oil contamination is an important geotechnical
problem to be investigated.

This paper deals with the experimental evaluation of
LL, PL, UCS, FSI, DFSI, pH value and electrical
conductivity (EC) of artificially contaminated clayey sands
(SC) collected from different parts of Assam. Different
levels of contamination of crude oil have been chosen for
this purpose. Mathematical relationship between the above
properties with the level of contamination is determined by
statistical analysis of the observed data.

II. MATERIALS

The materials used in this study are soil samples and
crude oil.

Soil

Disturbed soil samples were collected from different
sites of Assam. Grain size and Atterberg limit of all
uncontaminated soil samples were determined. The soils
are then classified as per IS (IS: 1498-1970). Out of total
thirty numbers of samples, seven clay-sand (SC) soil
sample have been taken for this study.

Lime and Crude Oil

The crude oil used for this purpose was procured from
Lakua oil fields, Assam. The API gravity was calculated by
using the relation between the specific gravity and API of
crude oil. The pH value and electrical conductivity of crude
oil were determined by taking 1:1 soil and distilled water
mixture and by using Systronics digital pH meter - 335 and
digital conductivity meter-306 respectively and the
properties are shown in Table 1.

<table>
<thead>
<tr>
<th>Location</th>
<th>API gravity</th>
<th>pH value</th>
<th>EC ms/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakua oil field, Assam</td>
<td>30.77</td>
<td>5.49</td>
<td>0.8689</td>
</tr>
</tbody>
</table>

III. LEVEL OF CONTAMINATION

Level of contamination was defined as the percentage
weight of crude oil with respect to dry weight of soil. The
maximum percentage of crude oil present in disturbed and
undisturbed contaminated soil samples is within 10%
(Shroff, 1997). Based on this consideration, soils were
contaminated at 3%, 6% and 9% level of contamination in
the present investigation.

IV. PREPARATION OF CRUDE OIL CONTAMINATED SOIL

Each type of disturbed soil sample is air dried, ground
and foreign matter present, if any, is removed. The air dried
soil is then sieved through 4.75 mm IS sieve and mixed at
optimum moisture content (OMC) and stored for 24 hours
in air tight polythene bags so that no loss of water takes
place due to evaporation. Optimum moisture content was
chosen because at OMC crude oil absorption of soil will be
uniform. The soil samples so prepared are then mixed
thoroughly with crude oil at 3%, 6% and 9% by weight of
the soil and allowed to cure for ten days before testing.

V. DETERMINATION OF GEOTECHNICAL PROPERTIES OF
SOIL

The main aim of the test programme is to determine the
effect of different percentages of crude oil contamination
on plasticity, unconfined compressive strength, swelling
and some chemical properties of soil. Densities and
moisture contents of soil samples for unconfined
compression test were maintained at maximum dry density
and optimum moisture content.
LL, PL, PI, UCS, FSI and DFSI of selected soil samples before and after contamination were determined according to methods described by the relevant Indian Standard Codes of practice. The pH value and electrical conductivity were determined by taking 1:1 soil and distilled water mixture with the help of Systronics digital pH meter - 335 and digital electrical conductivity meter – 306 respectively. The values of soil property at different level of contamination are tabulated in Table 2.

VI. LIQUID LIMIT BEHAVIOUR

It is observed from Table 2 that liquid limit increases with the increase in percentage of crude oil contamination. The increase in liquid limit of soil can not be due to increase in charge concentration and decrease in diffused double layer since increased electrolyte concentration can only lead to decrease in liquid limit due to depression of diffused double layer (Sridharan et al., 1986). The increase in liquid limit may be due to formation of new swelling type of compounds in presence of crude oil which are different from reaction products of CH soil and Crude oil. Kostecki (1995) reported that crude oil also contains a number of heavy metals such as nickel, vanadium, zinc, lead and copper in low per million ranges. These metals when come in contact with soil minerals may form new compounds. Mitchell (1976) also mentioned that organic particles may be strongly adsorbed on mineral surfaces of soils and this adsorption modifies both the properties of the minerals and the organic material itself.

Plastic Limit Behaviour

The plastic limit of soil is observed to increase slightly with the increase in crude oil contamination because of increased diffused double layer thickness.

The test results supports observations made by Mitchell (1976) where it was mentioned that plastic limit of soil increases when organic matter is added to it.

Plasticity Index

Slight decrease of plasticity index is observed with the increase in the level of crude oil contamination as the rate of increase in liquid limit is more than the rate of increase in plastic limit. The decrease in plasticity index of CH type of soil with the increase in the level of crude oil contamination supports the observations made by Arora (1992), where it is mentioned that soils having higher organic content have low plasticity index.

Unconfined Compressive Strength

The unconfined compressive strength decreases with the increase in crude oil contamination. Chandra et al. (1984) reported that unconfined compressive strength decreases when salt content is increased from 1 to 4%. Rajasekaran et al. (1995) mentioned that the presence of monovalent cations in the soil pore water system weaken the soil. When crude oil is mixed with soils there may be exchange of divalent ions of soil particles by monovalent hydrogen ions of crude oil which may lead to weaken the soil. These trends are in conformity with the findings of Yaji et al. (1997) in case of shedi soil.

Swelling Behaviour

It is observed that FSI and DFSI increase with the increase in the level of crude oil contamination. This may be due to the formation of swelling type of compounds as mentioned earlier.
The dielectric constant of the soil system changes when crude oil is mixed with it. This change may cause the change in the electrical conductivity of crude oil contaminated soils. Yaji et al. (1997) also observed such type of trend in case of shedi soil (soil of high compressibility) as the percentage of crude oil increased.

### VII. STATISTICS FOR ANALYSIS OF SOIL PROPERTIES

The properties of crude oil contaminated soil are essentially random variables as they depend on the extent of contamination and type of soil. Hence, values of soil properties from table 2 are used for determination of statistical correlation with the percentage of crude oil.
For this purpose, analysis of variance has been performed and insignificant relationships between the soil properties and the percentage of crude oil are discarded. The correlation ratio between the soil property and the percentage of crude oil contamination are also determined to get the equation of line of regression.

The level of significance for this study is considered as 5%. The mathematical relationship between the soil property and percentage of crude oil contamination (x) that is obtained are shown in equation (1) through equation (2). The graphical representations of these equations are shown in fig. 1 through fig.2.

\[ FSI = 19.97 + 2.488 \times \]  \hspace{1cm} (1)

\[ DFSI = 12.836 + 1.022 \times \]  \hspace{1cm} (2)

VIII. CONCLUSIONS

- LL, PL, PI, FSI, DFSI and pH value increases in presence of crude oil as contaminant. But the increase is statistically insignificant for LL, PL and PI.
- UCS and EC decreases with increase in the level of contamination of crude oil, but decreases are not significant.
- Mathematical correlation shows that FSI and DFSI increase linearly with the increase in percentage of contamination.
REFERENCES


