Effect of Rate of Crude Oil Contamination on Index Properties and Engineering Properties of Clays and Sands

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Abstract

Background: The recent advancements and industrial growth has adversely affected the environment which has direct or indirect impact on geotechnical properties of soil. One of the most perturbed sources of contamination is crude oil contamination, which basically takes place either due to accidental spillage of crude oil or through the industrial waste. This leads to alternation of index properties, chemical properties as well as engineering properties of soil. Methodology: Many researchers have worked on studying the impact of crude oil contamination on various types of soil. Present research work, focuses on not only evaluating the extent of alternation of the index properties (Specific Gravity, Liquid Limit, Plastic Limit, Shrinkage Limit) as well as engineering properties (Free Swelling Index) for Kaolinite Clay and fine grained sand due to crude oil contamination but also the effect of rate of crude oil contamination viz. 3%, 6% and 9% of crude oil contamination on both the soil types by performing geotechnical tests in accordance with IS Code:2720 part 3-1 (1980), part 5,6 (1985), part 40 (1977) respectively on non-contaminated soil samples as well as crude oil contaminated soil samples. For this purpose, the crude oil contaminated samples were prepared in the laboratory at water content equal to the liquid limit; simulating the in-situ conditions. Findings and Conclusion: The results thus obtained find its application in comparing the effect of crude oil on fine grained and coarse grained soil. The coarse grained soil (sand) due to its inherent structure and high permeability allows the penetration of crude oil at higher rate than that of fine grained soil (clay) which have low permeability and thus are less liable to get affected due to crude oil contamination. Increment in rate of crude oil contamination can be stated for the deterioration of geotechnical properties for both the soil types.

Keywords: Crude Oil-Sand and Clay Interaction, Engineering Properties, Index Properties

1. Introduction

The past few years have witnessed tremendous growth in petroleum sector all over the world. This growing trend has few disadvantages too when it comes to soil properties of variety of soils. In accordance with reference1,2 the accidental spillage of crude oil due to human error or machinery is likely to happen, which is not only an environmental issue but also a geotechnical issue. In this paper, the impact of crude oil spillage on two soil types viz. 1. Clay (with Kaolinite as a basic mineral) and 2. Sand (fine-grained) is studied and evaluated as well as comparative plots are shown to obtain the extent of alternation of geotechnical properties viz. index properties (Specific Gravity, Liquid Limit, Plastic Limit, Shrinkage Limit and Dry density) as well as engineering properties (Free Swelling Index) of this soil due to crude oil contamination which is also a source of hydrocarbon contamination.
Many researchers have worked on evaluating the effect of crude oil contamination on a particular soil-type in accordance with reference 3–7. But this research work not only studies the effect of crude oil contamination on clays and sands, but also its rate of effect viz. at the rate of 3%, 6% and 9% on these soil types. Also, comparative graphs are prepared to evaluate which soil is more susceptible to crude oil contamination and which shows lesser alternation in geotechnical properties of soil. The conclusions drawn can help in carrying out research for finding out remedies for the soil type which is prone to crude oil contamination with respect to other soil type in reference 8,9.

2. Materials and Sampling

For the present research work, crude oil has been procured from one of the major oil refinery of the country and clay with Kaolinite as a basic mineral is obtained from a manufacturing unit at Ahmedabad, Gujarat in natural form. The crude oil contaminated samples has been prepared artificially in the laboratory to replicate in-situ condition in the most possible manner by adding water to clay of amount equal to its liquid limit and adding crude oil in 3% of the total weight of clay sample taken. Similar procedure is applied for sampling of 6% and 9% of clay sample as well as for sand sample as mentioned in reference 10.

3. Methodology

3.1 Index Properties

The index properties viz. Specific Gravity, Liquid Limit, Plastic Limit, Shrinkage Limit of Kaolinite Clay as well as Sand of non-contaminated and crude oil contaminated is determined in accordance with IS Code 2720 part (1-6) for each property.

3.2 Engineering Property

The engineering property viz. free swell index test is determined for Kaolinite Clay in accordance with IS Code 2720 Part-40 to study the effect of crude oil on swelling and shrinking property of soil on both non-contaminated and crude oil contaminated soil sample.

Table 1. Index properties and engineering properties of contaminated and non-contaminated fine grained sand

<table>
<thead>
<tr>
<th>Index properties</th>
<th>Non-contaminated sand</th>
<th>Crude oil contaminated sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit (IS 2720-5)</td>
<td>21.5</td>
<td>20.25</td>
</tr>
<tr>
<td>Specific gravity (IS 2720-3)</td>
<td>2.59</td>
<td>2.19</td>
</tr>
</tbody>
</table>

Table 1 shows the index properties viz. liquid limit and specific gravity of sand contaminated with crude oil and in non-contaminated condition. It can be inferred from the above table that liquid limit and specific gravity, both decreases with increasing the percentage of crude oil contamination.

Table 2. Index properties and engineering properties of contaminated and non-contaminated Kaolinite Clay

<table>
<thead>
<tr>
<th>Index properties</th>
<th>Non-contaminated clay</th>
<th>Crude oil contaminated clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit (IS 2720-5)</td>
<td>51</td>
<td>48.8</td>
</tr>
<tr>
<td>Plastic limit (IS 2720-5)</td>
<td>25.5</td>
<td>26.05</td>
</tr>
<tr>
<td>Shrinkage limit (IS 2720-6)</td>
<td>25.2</td>
<td>26</td>
</tr>
<tr>
<td>Specific gravity (IS 2720-3)</td>
<td>2.66</td>
<td>2.28</td>
</tr>
<tr>
<td>Engineering properties</td>
<td>Non-contaminated clay</td>
<td>Hydrocarbon contaminated clay</td>
</tr>
<tr>
<td>Free swell index (IS 2720-40)</td>
<td>35.71</td>
<td>56.52</td>
</tr>
</tbody>
</table>

Table 2 shows the index properties and engineering property of Kaolinite Clay contaminated with crude oil and in non-contaminated condition. It can be inferred from the above table that the liquid limit and specific gravity goes on decreasing with increasing the percentage of crude oil in the given soil sample whereas plastic limit, shrinkage limit and free swell index goes on decreasing as the rate of crude oil contamination increases.

4. Results and Discussions

Based on the test results for various index and engineering
properties of Kaolinite Clay and sand, comparative plots are shown to compare the results and analyze to draw valid conclusions based on the extensive testing of the two soil type.

4.1 Specific gravity vs. % Contamination
The Specific Gravity decreases by 15.44%, 29.73% and 40.54% for 3%, 6% and 9% of crude oil contamination for sands 14.3%, 32.71% and 50.1% for 3%, 6% and 9% of crude oil contamination for Kaolinite Clay respectively (Figure 4.1).

4.2 Liquid Limit vs. % contamination
The liquid limit of Kaolinite Clay and that of fine grained sand decreases as the percentage of contamination increases by 4.31%, 9.41% and 16.08% for 3%, 6% and 9% of crude oil contamination in clay and 5.81%, 20.0% and 22.33% for 3%, 6% and 9% of crude oil contamination in sand (Figure 4.2).

4.3 Plastic Limit vs % Contamination
The plastic limit of Kaolinite Clay increases by 4%, 4.2% and 5.5% for 3%, 6% and 9% of crude oil contamination respectively (Figure 4.3).

4.4 Shrinkage Limit vs, % Contamination
The shrinkage limit increases by 2.7%, 3.8% and 5.2% for 3%, 6% and 9% of crude oil contaminated kaolinite clay respectively with respect to non-contaminated clay sample (Figure 4.4).

4.5 Free Swell Index vs. % Contamination

Figure 4.3 Plastic limit vs. % of contamination.

Figure 4.4 Shrinkage limit vs. percentage of contamination.

Figure 4.5 Free swell index vs. percentage of contamination.
Free swell index of contaminated clay increases by 58.27%, 78.21% and 128.6% for 3%, 6% and 9% of crude oil contamination respectively (Figure 4.5).

5. Conclusion and Future Work

The above study reveals that there is a major influence of crude oil contamination on engineering behavior of clays and sands. This leads us advance assessment of influence of both percentage contamination and periodic contamination on strength characteristics of such 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 and sands so as to analyze the suitability of such contaminated zone for construction of civil engineering structure in future. From the comparative plots, it can be concluded that, percentage variation for each property (Specific Gravity, Liquid Limit) shown by fine grained sand for each percentage of contamination is higher than that in clays. Hence, it can be inferred that properties of sands are more susceptible to deteriorate due to crude oil subjection than that in clays. The reason can be stated for physico-chemical interaction of crude oil with sand and clay. Due to lower permeability of clay, the penetration of crude oil through them is not remarkable. Also, clay form double diffused layer around it which does not allow penetration of oil through it as oil tends to float around its surfaced i.e. adsorption occurs. Whereas in sand, due to its higher permeability, crude oil can easily penetrate through it and hence the index property tends to deteriorate due to interaction of hydrocarbons present in crude oil and sand grained particles.

There exists a linear relationship between percentage of crude oil contamination and all index and engineering properties for both sand and Kaolinite Clay. Coefficient of regression for specific gravity test is, \( R^2 = 0.9939 \) for sand and 0.9972 for clay. Similarly, \( R^2 \) value for liquid limit of sand is 0.9334 and for clay is 0.9901. It can thus be interpreted that as the percentage of crude oil contamination increases, specific gravity and liquid limit goes on decreasing for both clays and sands. \( R^2 \) value for plastic limit is however lesser being 0.8254. For shrinkage limit and FSI, \( R^2 = 0.9568 \) and 0.9703 respectively.

The main purpose of this research work is to evaluate whether crude oil contaminated clays and sands provide any suitability for construction of roads, pavements, buildings, Dams etc. in future or not and also that which soil type is more susceptible to such contaminants. Through the comparative graphs and linear regression analysis, it can thus be concluded that sands are more prone to such contamination and thus less reliable than clays for any future civil engineering projects. Clays on the other hand may remain intact and thus serve for the construction purpose.

6. Acknowledgements

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7. References