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Longterm Impact Of Engine Oil Contamination On Soil Properties Of Loose Sand

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Abstract
Oil infiltration from industrial infrastructure such as conduits, shafts, and subsurface loading chambers represents a significant environmental concern, particularly regarding soil contamination. This study investigates the temporal effects of oil contamination on the geotechnical properties of sand, including shear strength parameters, volumetric behaviour, permeability, and particle arrangement. Laboratory experiments were conducted using sand samples with varying oil content percentages to evaluate these alterations systematically. Results demonstrated an initial decrease in shear strength and permeability immediately following oil contamination. However, long-term monitoring revealed a significant increase in these parameters during ageing. Similar patterns of engine oil content effects were observed in the loose sand configuration, with the magnitude of the impact being notably more pronounced. These findings provide crucial insights into the long-term behaviour of oil-contaminated sandy soils and have important implications for geotechnical engineering practices in areas affected by oil spillage.

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I. Introduction

The geotechnical properties of soil contaminated with lubricants can be altered from its original characteristics. These properties include shear strength, changes in volume, permeability, and the redistribution of soil particles. The extent of these property changes from the virgin state of the soil primarily depends on the chemical composition of the contaminant and the physical properties of the soil. To protect structures built on polluted soil, it is crucial to thoroughly investigate the variations in the behaviour of the contaminated soil.

The literature on the geotechnical characterization of soil contaminated by oil spills has been carefully reviewed. From the review, it is evident that oil spills from pipelines and gas stations are the primary sources of soil contamination. The resistance of the soil decreases as the level of lubricant increases, while the stiffness index rises with higher oil content. However, after one month of exposure to the atmosphere, the resistance began to increase with age, and the stiffness index decreased with prolonged exposure(1997). The peak friction decreased by 23% to 27% when the oil content increased from 0% to 1.3%. The reduction in the angle of internal friction was less pronounced for a oil content of 1.3%. Based on model tests, it was concluded that the reduction in soil resistance angle with increased oil content also led to a decrease in ultimate bearing capacity. When oil content increased from 0% to around 1.3%, the load-bearing capacity was reduced by approximately 75%. For oil content greater than 1.3%, the reduction in ultimate bearing capacity (q_u) was not significant(1999). Direct shear tests showed that the ultimate friction angle for dry sand was about 29°.

The magnitude of the ultimate friction angle (ϕ_{ult}) for oil contaminated sand ranged from 26° to 24°. Model tests concluded that both the angle of internal friction and the ultimate bearing capacity decreased with an increase in the proportion of oil contamination. As the specific gravity of the soil increased, the ultimate bearing capacity decreased(2001). When clay content was up to 20%, it did not slow the rate of transport but rather increased the frequency and range of movement. This could be attributed to the stronger suction forces in clayey soil compared to silty soil. Additionally, colder climates reduced the proportion and effectiveness of the lubricant due to the higher viscosity of the oil in cooler conditions(2005).

Increases in lubricant content and internal friction within the oil content tend to decrease the hydraulic conductivity of the soil. Additionally, it has been reported that the total shear failure angle decreases as the oil content content rises. The magnitude of this decrease in the shear failure angle becomes more significant with an increase in the internal friction of the oil content(2008). The moisture content increased with higher kerosene content, reaching up to 75% for a kerosene content of 7.5%. The dry specific gravity of clayey soil decreased as kerosene content increased. The overall dry density of the oil contaminated soil decreased by up to 6% when the kerosene content ranged from 0% to 7.5%(2008). Oil Contaminated cohesive soil showed significant effects on the material strength properties but minimal interaction with the material's composition. A decrease in moisture content, particle dispersion in the fluid, as well as changes in consolidation and shear resistance, were observed as the contamination level increased in cohesive soils(2010).

The impact of engine oil content on various geotechnical properties has been investigated through a series of experimental tests, as detailed in studies(2010 to 2018). Recent research shows that hydraulic conductivity is reduced by up to 10% due to oil contamination, which also affects the moisture content of lubricated soil(2019). The shear failure and permeability characteristics of oil contaminated sand in its loose state were evaluated in the study. The literature also suggests that aging plays a role in altering the geotechnical properties of oil-contaminated sand. However, very few studies have focused on the aging effects on these characteristics. Therefore, this study primarily aims to examine the influence of aging on the geotechnical properties of lubricated sand. To achieve this, a series of experiments were conducted on lubricated sand with varying oil percentages and exposed to atmospheric conditions over different periods.

II. Materials And Methods

Material Propoerty

Initially, grain size analysis and specific gravity tests were conducted to classify the soil. The soil classification and a summary of various tests performed in the study to investigate the geotechnical properties of oil-contaminated sand are discussed in the following section. The sandy soil used in the experiments was collected from Kumbakonam, Tamil Nadu. Once collected, the sand sample was appropriately classified and stored for experimentation. The sand was then dried by exposure to unheated air at room temperature and used for detailed experimental analysis.

The collected sand sample was properly labeled and stored in the research laboratory. Determining the relative density of sand is essential for geotechnical controls. Thus, knowing the specific gravity of a given soil helps us understand the minerals present in it. The specific gravity test was performed according to IS: 2720 (Part 3/Sec 1)-1985, using the specific gravity bottle method. The relative density of the sandy sample at an ambient temperature of 29°C was found to be 2.63. After applying the temperature correction, the specific gravity of the sand sample at a standard temperature of 27°C was determined to be 2.62.

Grain size distribution analysis was conducted according to IS: 2720 (Part 4) – 1985. The sand sample was dry sieved through Indian Standard sieves with aperture sizes of 4.75 mm, 2.36 mm, 1.18 mm, 710 μm, 425 μm, 212 μm, 125 μm, and 75 μm. A mechanical sieve shaker was used to agitate the sandy soil sample. The summary of the grain size distribution and the relative density of the sandy soil sample is presented in Table 1.

Table 1: Summary of Various Laboratory Tests Conducted on the Sand Sample

S.No.	Properties	Sample
1	Specific Gravity	2.62
2	Proportion of Coarse Sand	1.12%
3	Proportion of Medium Sand	95.03%
4	Percentage of Fine Sand	3.85%
5	Clay and Silt	Traces
6	Coefficient of Uniformity, C_u	2.72
7	Coefficient of Curvature, C_c	1.85
8	Soil Classification as per IS	Poorly graded Sand (SP)

The overall density of sand is typically used to assess the level of compaction in a given soil mass. Engineering properties such as friction strength, compaction, and permeability are primarily influenced by the degree of compaction. The relative densities of sand in loose, medium, and dense states are 1.44, 1.68, and 1.92 g/cc, respectively.

Engineering Properties

The basic properties of the sand have been evaluated based on specific gravity and grain size distribution tests. Now, the engineering properties of lubricated sands are assessed using shear failure and permeability tests to determine the geotechnical characteristics of the sand. Studying the geotechnical properties of soil provides the geotechnical engineer with a better understanding of soil behaviour and how to address changes in its characteristics. This knowledge can also assist structural engineers in their design process, as it may influence the soil-structure interaction in foundation design.

Sample Preparation

After characterizing the particle size and determining the relative density, a soil sample was dried in a kiln. The soil was then mixed with used engine oil in varying proportions of 0%, 2%, 4%, 6%, 8%, 10%, and 12%

by weight. The blended samples were placed in an open container for a period to allow potential reactions between the soil and the used engine oil. In total, 14 blended samples were prepared—seven samples for direct shear tests and seven samples for permeability tests. These mixed soil samples were subsequently used for both the direct shear and permeability tests.

III. Results And Discussion

The direct shear test was conducted to investigate the shear strength characteristics of lubricated sand. A series of shear failure tests were performed on sand contaminated with varying levels of oil content, based on the dry weight of the sand. The results obtained from these tests for the contaminated loose sand are discussed as follows.

Shear Strength On Loose Sand

To examine the effect of lubricant on sandy soil in its loose state, a series of shear failure tests were conducted on dry sand with a unit weight of 14.4 kN/m³, incorporating varying oil percentages of 2%, 4%, 6%, 8%, 10%, and 12% by dry mass of the sand, similar to the tests performed on dense sand. The required volume of the shear box was calculated for the sand samples with the unit weight of 14.4 kN/m³. Direct shear tests were then performed on all sandy samples under different normal stress values, including 50 kPa, 100 kPa, and 150 kPa.

Immediate Effect

The virgin sand was mixed with used engine oil in varying percentages ranging from 2% to 12% by dry weight of the sand and allowed to react over time. Subsequently, direct shear tests were conducted on the sand in its loose state. The immediate results of shear failure for the lubricated sand are presented in Figures 1, 2, and 3.

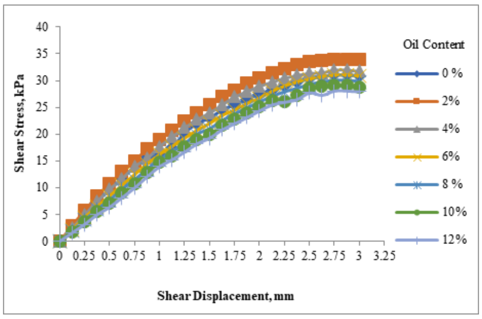

Figure 1: Immediate Response Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 50 kPa Normal Stress

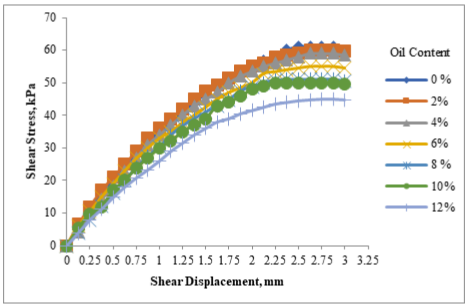

Figure 2: Immediate Response Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 100 kPa Normal Stress

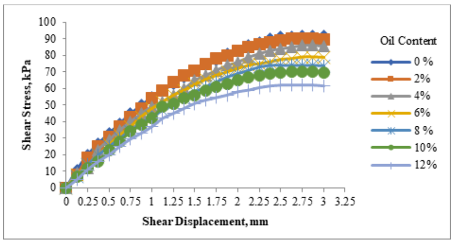

Figure 3: Immediate Response Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 150 kPa Normal Stress

Figure 4 demonstrates the variation in ultimate shear stress with respect to the fluctuating percentages of oil content and varying normal stresses in the loose state. The figure shows that the effect of the oil mixture on the ultimate shear failure is not significant at low normal stress levels. However, a more noticeable decrease in peak stress is observed at higher normal stress levels. The reduction in shear failure is more pronounced in the loose state compared to the dense state of sand.

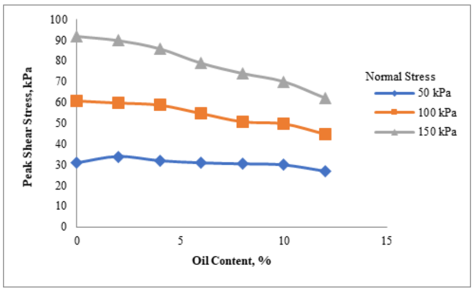

Figure 4: Variation of Ultimate Shear Stress with Respect to Varying % of Oil Content

Figure 5 illustrates the effect of oil content on the internal friction angle of loose sand immediately after mixing with oil at varying percentages. From the figure, it is evident that the internal friction angle of oil contaminted sand decreases as the oil mix increases. The curve indicates that the reduction in internal friction angle is linear with the increase in oil content. However, a slight reduction in the friction angle was observed for sand contaminated with 1% oil at a lower normal stress of 50 kPa(2015).

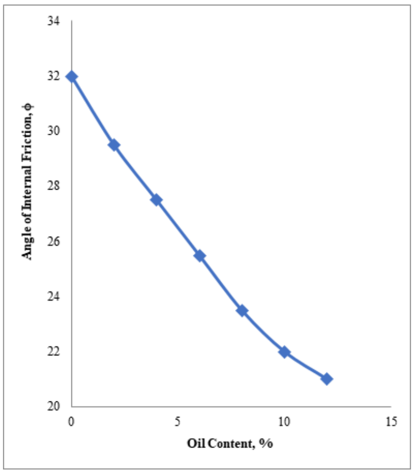

Figure 5: Effect of Oil Content on the Variation of Angle of Internal Friction

10 Days Effect

The well-mixed soil with varying proportions of oil was kept outside for atmospheric exposure. Similar to the dense state, a series of direct shear tests were conducted on the loose state of sand. To examine the aging effects on shear failure in loose sand, the tests were performed after a 10-day period of atmospheric exposure. The results of the 10-day aging effect on the shear failure of lubricated sand, under different normal stresses, are presented in Figures 6, 7, and 8, respectively.

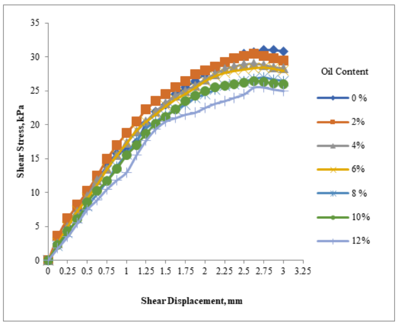

Figure 6: 10 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 50 kPa Normal Stress

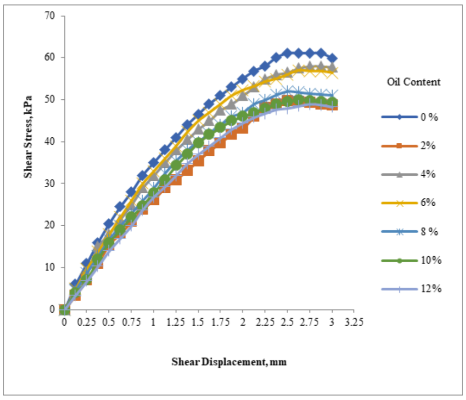

Figure 7: 10 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 100 kPa Normal Stress

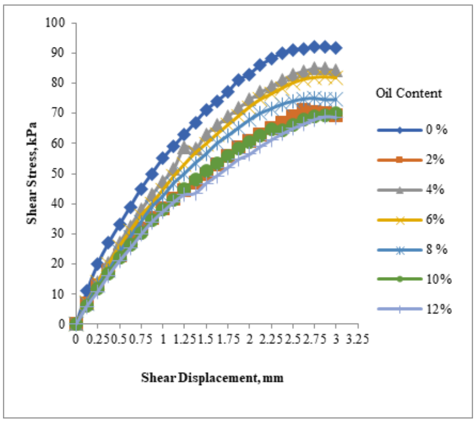

Figure 8: 10 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 150 kPa Normal Stress

Figure 9 illustrates the difference in ultimate shear stresses of loose sand in relation to varying percentages of oil content and normal stresses after ten days of atmospheric exposure. The figure shows that the effect of the oil mixes on shear failure is not significant at low normal stress levels. However, a more pronounced decrease in peak stress is observed at higher normal stresses. It is also observed that the reduction in shear failure is greater in the loose state compared to the dense state of sand.

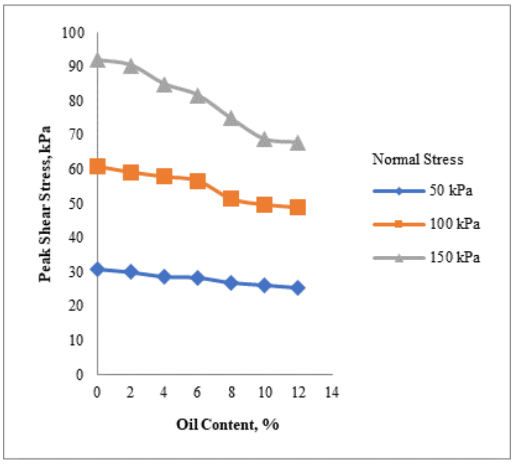

Figure 9: Variation of Peak Shear Stress with Respect To Varying % of Oil Content

Figure 10 illustrates the aging effect of the oil mix on the shear failure angle with varying oil content after ten days of atmospheric exposure in the loose state. It can be observed from the figure that the shear failure angle of lubricated sand decreases as the lubricant mix increases. The curve indicates that the reduction in shear failure angle becomes less significant beyond 10% oil content.

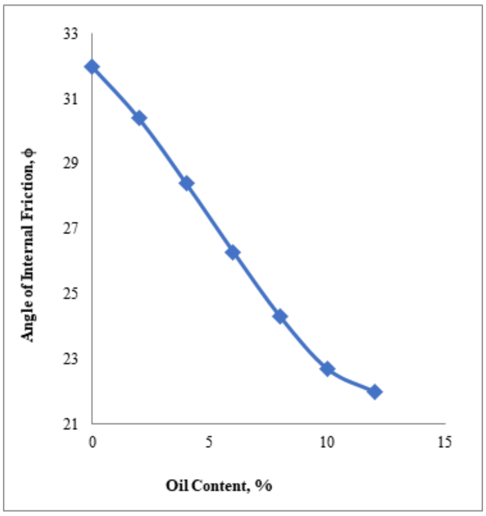

Figure 10: Effect of Oil Content on the Variation of Angle of Internal Friction

15 Days Effect

The well-mixed soil with varying proportions was kept outside for atmospheric exposure. Similar to the dense state, a series of direct shear tests were performed on the loose state of sand. To examine the aging effect on shear failure in loose sand, the tests were conducted after a 15-day period of atmospheric exposure. The results of the 15-day aging effect on the shear failure of lubricated specimens, under different normal stresses, are presented in Figures 11, 12, and 13, respectively.

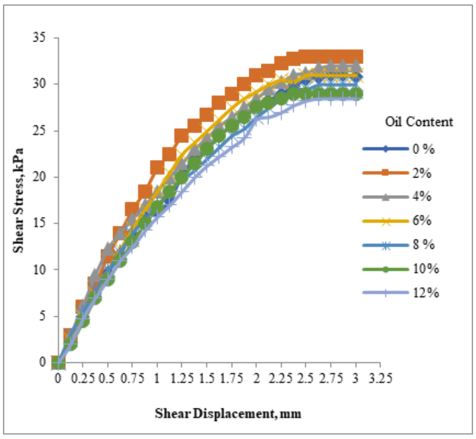

Figure 11: 15 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 50 kPa Normal Stress

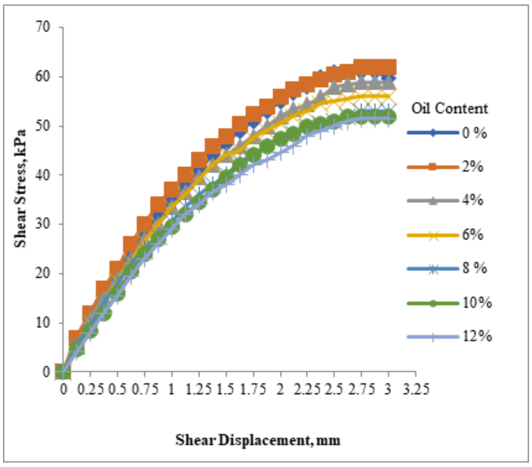

Figure 12: 15 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 100 kPa Normal Stress

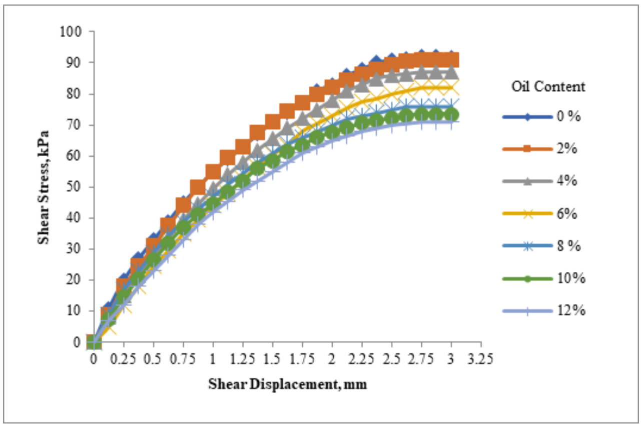

Figure 13: 15 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 150 kPa Normal Stress

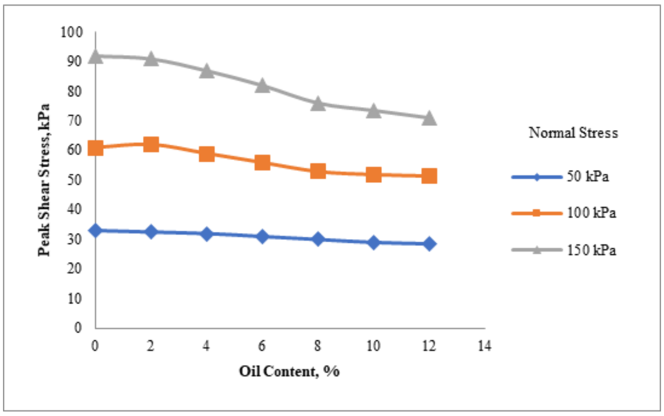

Figure 14: Variation of Peak Shear Stress with Respect to Varying % of Oil Content

Figure 14 illustrates the variation in peak shear failure of loose sand with respect to varying percentages of oil mix and different normal stresses after 15 days of atmospheric exposure.

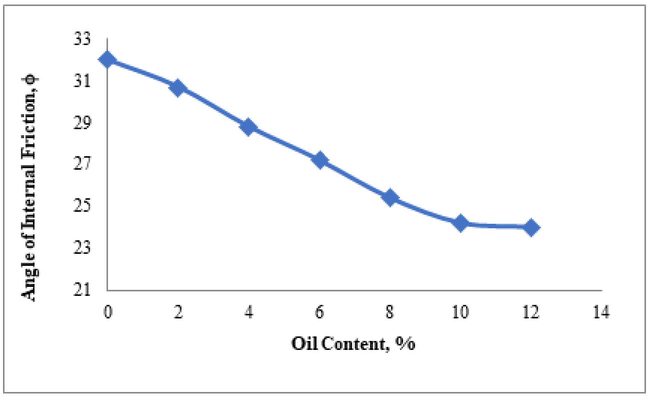

Figure 15: Effect of Oil Content on the Variation of Angle of Internal Friction

Figure 15 shows the aging effect of oil mix on the angle of shear failure with varying oil content after 15 days of atmospheric exposure in the loose state. From the trend of the curve, it is observed that the reduction in the shear failure angle becomes less significant beyond 10% oil content.

30 Days Effect

The well-mixed soil with varying proportions was kept outside for atmospheric exposure. As done for the dense state, a series of shear failure tests were conducted on the loose state of sand. To examine the aging effect on shear strength in loose sand, the tests were performed after a 30-day period of atmospheric exposure. The results of the 30-day aging effect on the shear strength of the lubricated sand, under different normal stresses, are presented in Figures 16, 17, and 18, respectively.

Figure 16: 30 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 50 kPa Normal Stress

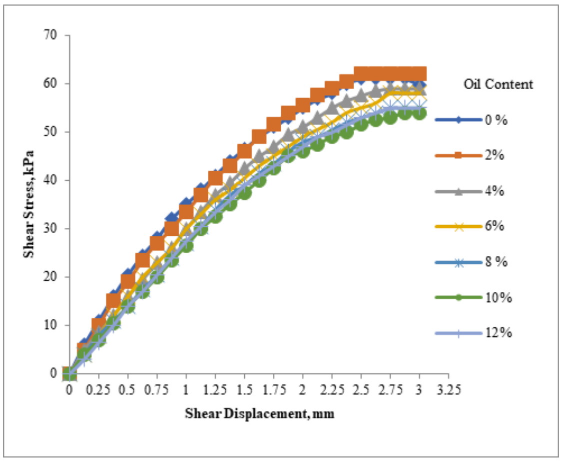

Figure 17: 30 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 100 kPa Normal Stress

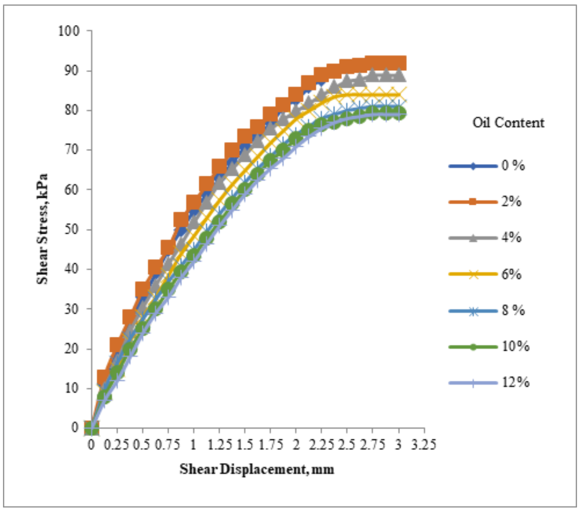

Figure 18: 30 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Contaminated Loose Sand at 150 kPa Normal Stress

Figure 19 shows the variation in shear failure of the loose state of sand with respect to varying percentages of oil content and different normal stresses for the contaminated sand after 30 days of atmospheric exposure.

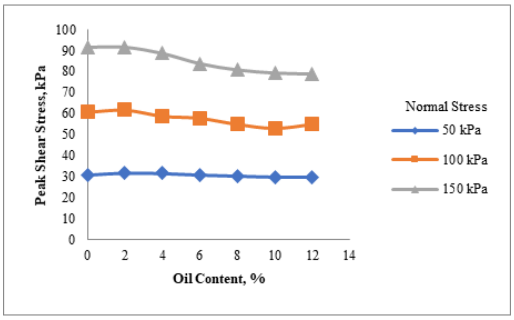

Figure 19: Variation of Peak Shear Stress with Respect to Varying % of Oil Content

Figure 20 shows the aging effect of oil content on the angle of shear failure with varying oil content after 30 days of atmospheric exposure in the loose state. From the trend of the curve, it is observed that the reduction in the shear failure angle becomes less significant beyond 10% oil content.

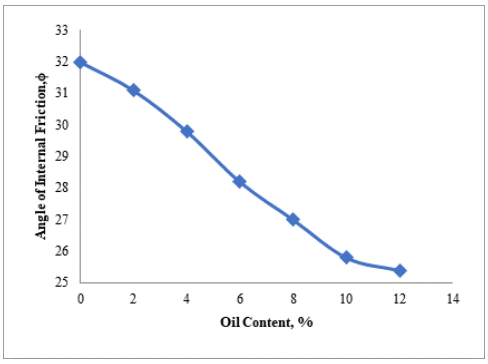

Figure 20: Effect of Oil Content on the Variation of Angle of Internal Friction

45 Days Effect

The well-mixed soil with varying proportions was kept outside for atmospheric exposure. As done for the dense state, a series of shear failure tests were conducted on the loose state of the specimen. To examine the aging effect on shear capacity in loose sand, the tests were performed after a 45-day period of atmospheric exposure. The results of the 45-day aging effect on the shear resistance of the lubricated sand, under different normal stresses, are presented in Figures 21, 22, and 23, respectively.

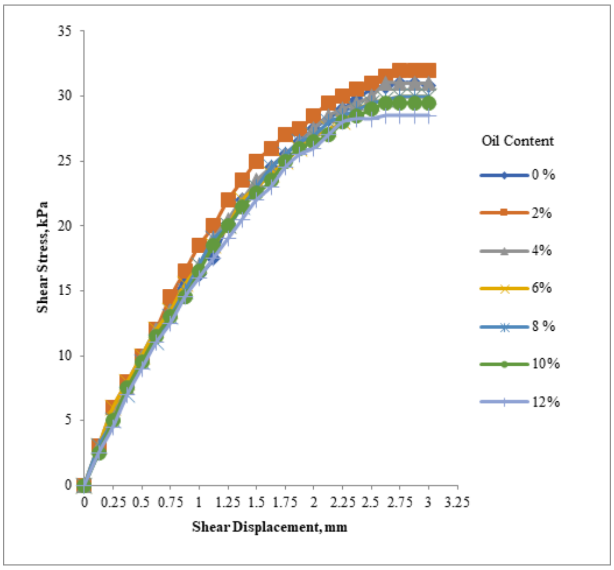

Figure 21: 45 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Lubricated Loose Sand at 50 kPa Normal Stress

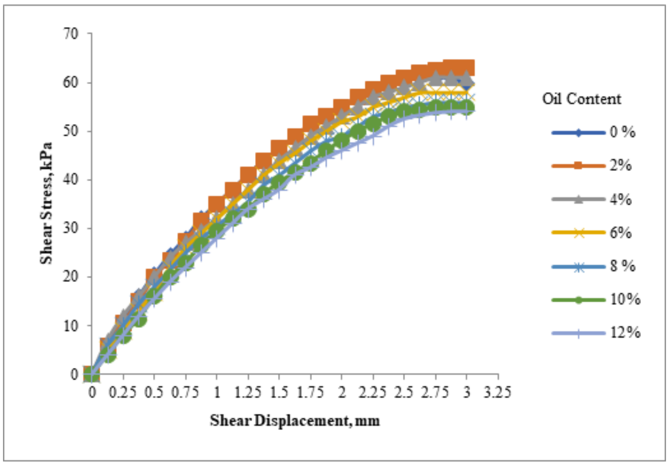

Figure 22: 45 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Lubricated Loose Sand at 100 kPa Normal Stress

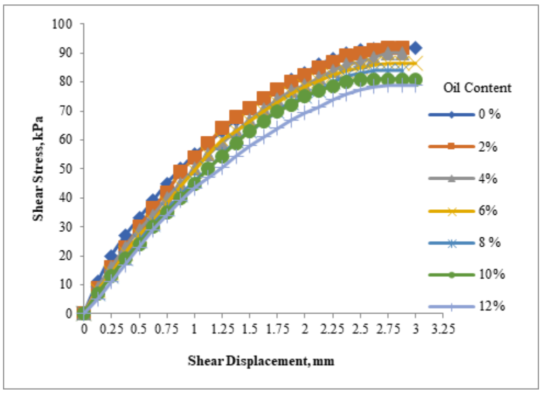

Figure 23: 45 Days Aging Effect Curve of Shear Stress vs. Shear Displacement for Lubricated Loose Sand at 150 kPa Normal Stress

Figure 24 displays the variation in peak shear failure strength of the loose state of sand with respect to varying percentages of oil content and different normal stresses for the lubricated sand after 45 days of atmospheric exposure.

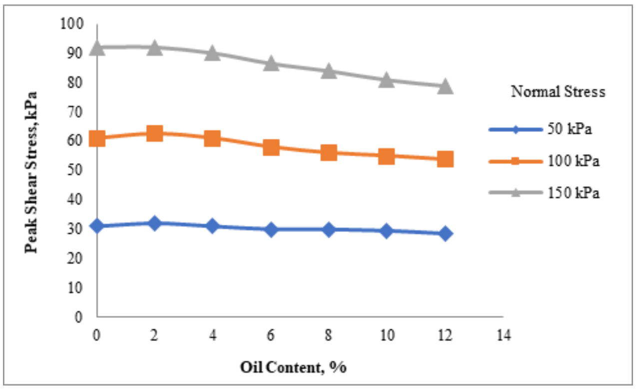

Figure 24: Variation of Peak Shear Stress with Respect to Varying % of Oil Content

Figure 25 shows the aging effect of oil mix on the angle of shear failure with varying oil content after 45 days of atmospheric exposure in the loose state. From the trend of the curve, it is observed that the reduction in the shear failure angle becomes less significant beyond 10% oil content.

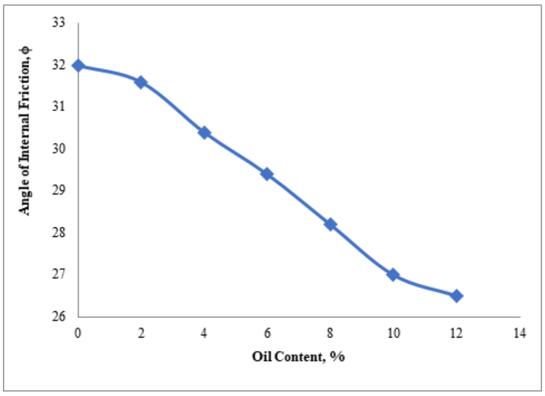

Figure 25: Effect of Oil Content on the Variation of Angle of Internal Friction

Permeability Effect On Loose Sand

The effect of oil content on the permeability of sandy soil in the loose state was investigated by conducting a series of constant head permeability tests on dry sand with a unit weight of 14.4 kN/m³. The sand was mixed with varying percentages of oil, including 2%, 4%, 6%, 8%, 10%, and 12% by dry mass. The required volume of permeability moulds was calculated based on the unit weight of 14.4 kN/m³. Constant head permeability tests were performed for all proportions of contaminated sand, and the discharge was recorded over a constant period of 120 seconds.

Table 2 presents the permeability values of sand contaminated with varying proportions of oil in the loose state. To assess the aging effect of lubricated soil on the permeability values, a series of permeability tests were conducted for different periods of atmospheric exposure, including 10, 15, 30, and 45 days.

Table 2: Summary of Various Laboratory Tests Conducted on the Sand Sample

Oil Content	0 Days	10 Days	15 Days	30 Days	45 Days
0	0.098000	0.098	0.098000	0.098000	0.098000
2	0.079870	0.083692	0.088592	0.093590	0.096922
4	0.060270	0.0671496	0.078684	0.088151	0.093492
6	0.047040	0.0544586	0.070991	0.082516	0.089180
8	0.038710	0.046452	0.064680	0.077420	0.085162
10	0.034594	0.04212824	0.060721	0.074529	0.077910
12	0.030478	0.0373527	0.057232	0.070442	0.073696

The permeability of oil-contaminated sand has increased with an increase in aging. Other researcher also agreed with result showing more viscous liquid contaminants accelerated the rate of water infiltration between particles (2014).

IV. Conclusions

From the results and graphs obtained, it is observed that oil contaminated sand has gained some cohesion values. This cohesion is attributed to the presence of adsorbed viscous oil on the surface of the sand particles. Although the oil contaminted sand shows a reduction in shear strength, as indicated by a decrease in the angle of internal friction, it retains some shear strength due to the cohesion. However, the apparent cohesion decreases with ageing.

The shear strength, as measured by the failure in shear values, decreases with an increase in oil content. A significant reduction in shear strength is observed at higher normal stress levels compared to lower normal stress levels. The angle of internal fricition decreases with increasing oil content, while the apparent cohesion in the oil contaminated sand increases with higher oil content. This trend continues up to 10% oil content, beyond which the shear strength of the sand remains relatively constant.

The ageing effect also significantly influences the geotechnical properties of oil contaminted sand. The reduction in shear strength becomes less pronounced as ageing increases. For permeability, the permeability factor of lubricated sand decreases with increasing oil content, while the permeability increases with ageing(2017).

The maximum reduction in shear strength for loose oil contaminted sand is 34.5% immediately after contamination and 17.2% after 45 days of ageing. The maximum reduction in permeability for loose oil contaminted sand is 67.5% immediately after contamination and 24.8% after 45 days of ageing.

Finally, desgn engineers should take into account the changes in the geotechnical properties of soil when designing structures in areas prone to oil leakages. Despite the negative impact of oil contamination on soil properties, oil contamination sand and its concrete can still be reused for appropriate engineering applications, provided that the alterations in strength, permeability, and cohesion are carefully considered(2016).

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