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Modeling and Optimization of the Compressibility Properties of Waste Engine Oil Contaminated Fine-Grained Soil

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Abstract

This research study investigated the effect of waste engine oil contamination on fine-grained soil. The study entailed the stimulation of various predetermined amounts of used engine oil with fine-grained soil collected from Eke Obinagu, Emene, Enugu state. Firstly the physical properties of the soil sample was determined and classified by the American Association of State Highway and Transportation Officials (AASHTO) classification system as A-2-6 soil. Soil samples were contaminated with 0%, 2%, 4%, 6% and 8% oil by mass of soil with waste engine oil collected from a mechanic workshop. Consolidation test was performed on the samples to determine the void ratio, coefficient of consolidation (Cv), coefficient of volume compressibility (Mv), coefficient of compressibility (Av), and compression index(Cc). The results of the test showed the soil to decrease in void ratio from 0.68 of 0% oil content (natural soil) to 0.63 of 2% oil content, 0.560 at 4% oil and increased in void ratio at 6% oil to 0.599 and 0.6048 at 8% oil content. The coefficient of consolidation (Cv) decreased with increase in oil content at 2%, 4%, 6% oil and increased at 8% oil. The coefficient of volume compression increased at 2% oil, but decreased at 4%, 6% and 8% oil content. The coefficient of compression (Av) similarly, increased at 2% oil, but decreased at 4%, 6% and 8% oil content. The compression index increased with addition of oil at 2%, but decreased at 4%, 6% oil, with a slight increase at 8% oil. Mathematical models were developed from statistical regression analysis for correlation of the compressibility parameters of soil. The model was tested for adequacy using the control data against the results from the model equation. The models were optimized using a QBASIC program.

Keywords: Waste engine oil; Oil contaminated soil; fine-grained soil; consolidation test; void ration; coefficient of consolidation; coefficient of volume compressibility; coefficient of compressibility; compression index; statistical regression analysis.

1.0 INTRODUCTION

The effect of the continuous contamination of soil by oil owing to the daily activities of man has become a growing threat to human and terrestrial habitats all over the world. Nigeria as a member of oil producing and exploration countries of the world export oil in millions of metric tons daily. Oil spillage into the soil during exploration and refining in regions like the Niger Delta has become a major catastrophic degradation of the soil in this region, as a result of this contamination; major rivers in these regions are polluted for aquatic life and use of this river for home and domestic purposes.The affected soils cannot also be used for farming as the micro organisms that aid the growth of crops are all destroyed. Also the fast rise in industrialization and machineries generate disturbing amounts of waste oil, solid and gaseous wastes products which are disposed indiscriminately. Most industries located across the country do not have a policies or procedures for waste oil collection, managing, reuse or recycle. The contamination of the soil alters the geotechnical properties of such soil for construction purposes. Waste oil is any synthetic or petroleum based organic compound which is a residue from a running machinery, equipment or vehicles. The engines of such machineries leave impurities such as metal scraps, dirt and chemicals mixed in the oil and hence require change. This waste oil from the machineries is insoluble and contains toxic chemicals which are slow to degrade. If not properly disposed, waste hydraulic fluids, lubrication oil and gear oils from vehicles and machinery contaminate the soil hence result in soil failure. Indiscriminate location of mechanic workshops all over the country accounts for major oil spillages and water contamination. Also affecting the soil properties are agricultural practices such as the use of fertilizers and herbicides for farming.

Most advanced countries have in place series of policies or regulations, incentive programs and voluntary aids put in place for the treatment and disposal of hazardous wastes. Clean-up processes of this contamination may involve physical, chemical and biological methods. A conventional method used to combat the increasing soil contamination is by physical containment or movement of affected soil, incineration and washing of the soil. Chemical treatments using dispersants and surfactants can be applied although the method is hugely limited by cost. A well-known and acceptable method is an engineered process that uses microorganisms to clean-up contaminants called bioremediation. This process of bioremediation is efficient and adequate to clean up soil contamination use microorganisms like fungi and bacteria to degrade petroleum products in the soil to inorganic products. Bioremediation is also very economical compared to other methods.

An effective clean-up process starts with an understanding of the extent of the change in the geotechnical properties of affected soil. Oil contamination of soil can alter its bearing capacity, compression or settlement and compaction characteristics of soil. This has necessitated the research study for an effective understanding of the effect of changes particular to soil type and type of contaminant. The contamination of soil by petroleum hydrocarbons has resulted into a major problem in oil producing regions. Nigeria is not left out in the growing concern as oil spillage is through our daily activities is on the rise. The challenge of researchers does not only encompass remediation but also data collection. Remediation of contaminated soil can be achieved after understanding the rate of contamination of the soil. Hence, before remediation can be carried out, a proper test on the soil need to be carried out to understand the deviation of the soil original properties. Most construction works being carried out on soil which has been exposed to oil contamination will require an investigation of the change in the consolidation or settle of the soil. This research work bridges the gap by providing data for consolidation properties of affected fine grain soil.

Hosseini *et al* (2016) performed extensive laboratory tests on remoulded clayey samples mixed with gasoil to evaluate their geotechnical properties. The Response Surface Methodology (RSM) was used to analyse the data and find behavioural equations. According to test results and RSM outputs, a decrease in Atterberg limits, and increase in maximum dry density happen by increasing contamination. Also their shear strength parameters (c and f) both exhibit a turning change point at 8% gasoil content, while their variations trends are quite in opposite directions.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used for this research study are fine-grained soil and waste engine oil.

2.1.1 Sample collection

The soil sample was collected from Eke-Obinagu in Emene, Enugu East, Enugu state. The soil was collected 0.5 meters below the ground surface as a disturbed sample. Waste engine oil was collected from a Mobile vehicle servicing station along Enugu Abakaliki express way, Enugu state.

2.1.2 Sample preparation

Soil sample was air-dried for 48hours, pulverized and sieved using sieve size 4.75mm. Five portions of oil samples measuring 5kg each was weighed out and each were thoroughly mixed with waste engine oil at a proportion of 0%, 2%, 4%, 6% and 8%. The mixture was stored for 72hours for saturation.

2.2 Method

Geotechnical tests were carried out on the natural soil following theUnified AASHTO soil classification systemto determine the natural properties of the soil. Consolidation tests were conducted on the contaminated samples by oedometer test to determine the coefficient of volume compressibility (Mv), coefficient of compressibility (Av), and compression index(Cc) of various oil contamination percentages. Mathematical models were developed using statistical regression method for determining the compressibility of various oil percentage contaminations. A QBASIC program was also developed for the optimization of the model equations.

3.0 RESULTS AND DISCUSSION

Table 1 below shows the results of preliminary geotechnical tests and the classification of the soil. The results of the tests on the natural soil was used to classify the soil as A-2-6 using the Unified AASHTO soil classification system.

Table 1. Physical Properties and Classification of Natural Soil

acteristics	**lts**
ntage passing B.S. No. 200	
al Moisture Content	
ific Gravity (GS)	
d Limit (LL), %	
c Limit (PL) %	
icity Index (PI), %	
HTO Classification	5

The result of the consolidation test is shown below in table 2 for all samples of soil varying in oil percentage contamination. These results were used to determine the void ratios, coefficient of consolidation, coefficient of volume compressibility, coefficient of compressibility and compression index of various oil contamination samples.

Table 2. Data result of Consolidation Test

e Elapse	**Oil**	**Oil**	**Oil**	**Oil**	**Oil**
5secs	43	72	95	55	60
0secs	48	85	04	68	73
5secs	58	90	10	73	77
min	64	93	15	76	80
mins	69	00	22	81	85
mins	72	10	28	88	90
mins	74	21	38	95	95

5mins	75	35	43	04	01
0mins	76	50	56	20	10
0mins	77	63	72	32	20
0mins	78	70	80	41	28
0mins	79	83	90	45	35
40mins	80	98	96	52	51

3.1 EFFECT OF OIL CONTAMINATION ON VOID RATIO

Table 3. Data of Void ratio at varying percentage oil contamination

Oil percentage	Void ratio
0% Oil	0.68
2% Oil	0.663
4% Oil	0.560
6% Oil	0.599
8% Oil	0.6048

The above result show a drop in the void ratio of fine-grained soil under a loading pressure of 81.4KN/M^2 at 0% oil contamination from 0.68 to 0.663. The void ratio further dropped to 0.560 with increase in oil contamination to 4%, but increased to 0.599 at 6% of oil contamination and further increase to 0.6048 at 8% Oil. The probable reason for the decrease in void ratio at 2% and further decrease at 4% oil could be that the oil content in the soil increased inter-particle friction due to the lubrication effect provided by the oil leading to reduced void. And the increase in the void ratios from 6% and 8% could also be as a result of higher oil content which hence occupied the voids in-between the soil particles. However the void ratio still maintained a lower value at 8% oil contamination compared to the value of void ratio at 0% oil (uncontaminated soil), at same loading pressure of 81.4KN/M^2.The lowest value of void ratio recorded at 4% oil contamination.

3.2 EFFECT OF OIL CONTAMINATION ON THE COEFFICIENT OF CONSOLIDATION

Table 4 Test Results of Coefficient of Consolidation

Oil percentage	efficient of Consolidation (Cv), m^2/KN
0% Oil	7.8046 x 10^{-7}
2% Oil	4.0472 x 10^{-7}
4% Oil	1.9858 x 10^{-7}
6% Oil	1.807 x 10^{-7}
8% Oil	4.11 x 10^{-7}

The result from consolidation test showed that the coefficient of Consolidation(Cv) of the fine-grained soil decreased from 7.8046 x 10^{-47}m^2/KN at 0% oil (natural soil) to 4.0472 x 10^{-7}m^2/KN at 2%, 1.9858 x 10^{-7} at 4% oil, 1.807 x 10^{-7} at 6% oil but increased to 4.11 x 10^{-7} at 8% oil content.

3.3 EFFECT OF OIL CONTAMINATION ON THE COEFFICIENT OF VOLUME COMPRESSIBILITY

Table 5. Test Results of Coefficient of Volume Compressibility

percentage	Coefficient of Volume ompressibility (Mv), m^2/KN
0% Oil	7.1 x 10^{-4}
2% Oil	7.31 x 10^{-4}
4% Oil	7.27 x 10^{-4}

6% Oil	6.19×10^{-4}
8% Oil	6.15×10^{-4}

The result of consolidation test showed that the coefficient of volume compressibility (Mv) of fine-grained soil had an initial increase from $7.1 \times 10^{-4} m^2/KN$ at 0%oil (natural soil) to $7.31 \times 10^{-4} m^2/KN$at 2% of oil contamination. The value declined at 4% Oil content to $7.27 \times 10^{-4} m^2/KN$. It had further decline to $6.19 \times 10^{-4} m^2/KN$ as the oil content increased to 6% and $6.15 \times 10^{-4} m^2/KN$ at 8%. The decline in the coefficient of volume compressibility (Mv) of fine-grained soil with higher oil content could be as a result of few voids.

3.4 EFFECT OF OIL CONTAMINATION ON THE COEFFICIENT OF COMPRESSIBILITY

Table 6. Test Results of Coefficient of Compressibility

Oil percentage	Coefficient of Compressibility (Av).
0% Oil	1.2285×10^{-3}
2% Oil	1.253×10^{-3}
4% Oil	1.1692×10^{-3}
6% Oil	1.0154×10^{-3}
8% Oil	1.0123×10^{-3}

The above results from consolidation showed a slight increase in the value of the coefficient of compressibility (Av), from 1.2285×10^{-3} for natural fine-grained soil to 1.253×10^{-3} at 2% oil content. The coefficient of compressibility dropped continuously as oil content was increased from 2% to 4% till 8%. The coefficient of compressibility dropped from 1.253×10^{-3} at 2% oil content to 1.0123×10^{-3} of 8% oil content.

3.5 EFFECT OF OIL CONTAMINATION ON THE COEFFICIENT OF COMPRESSIVE INDEX (Cc)

Table 7 Test Results of Compressive Index

Oil percentage	Compressive Index (Cc).
0% Oil	0.166
2% Oil	0.1694
4% Oil	0.1581
6% Oil	0.1345
8% Oil	0.1369

The above showed that the coefficient of compressive index (Cc) decreased with addition of oil. The coefficient of compressive index decreased from 0.166 of natural soil to 0.1345 of 6% oil content with a slight increase at 8% oil.

3.6 MODELING

The results of this test were used to develop model equations by method of statistical linear regression. The idea being to generate mathematical equations or models for determining the values of compressibility properties of fine-grained soil with varying predetermined quantities or percentages of oil contamination against a quantity of soil. This model will be developed using values of results generated from consolidation test. The generated model will aid in getting compressibility property of fine-grained soil without going back to conduct consolidation test over again with minimal error values. The model is a statistical linear regression technique, which is most widely used statistical technique in modeling relationships between two sets of variables. The linear regression equation can be used to make predictions about data by modeling a relationship between two variables. The equation have the form of $Y = a + bx$.Where x represents oil percentage of soil and Y the compressibility property of soil.

The developed models are

$Y = 0.1713 - 4.665 \times 10^{-3}x$ for compressive index of the soil.

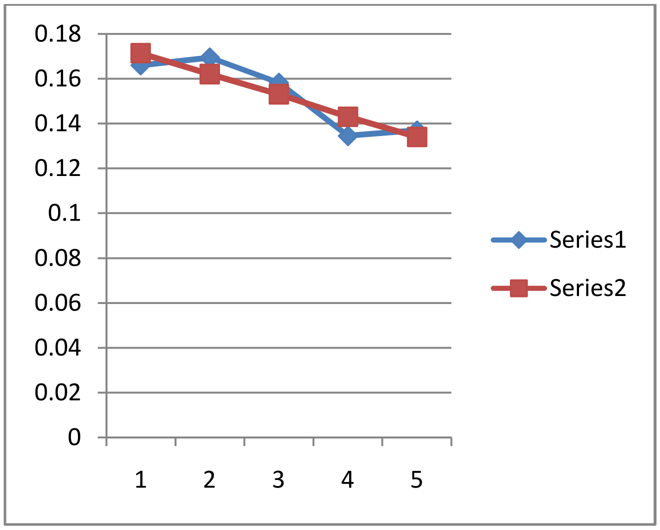


Fig 4.3 Line graph demonstrating the relationship between the experimental and modeled data sets of compressive index.

Y = 1.2696 x 10-3 – 3.349 x 10-5x for coefficient of compressibility (Av)

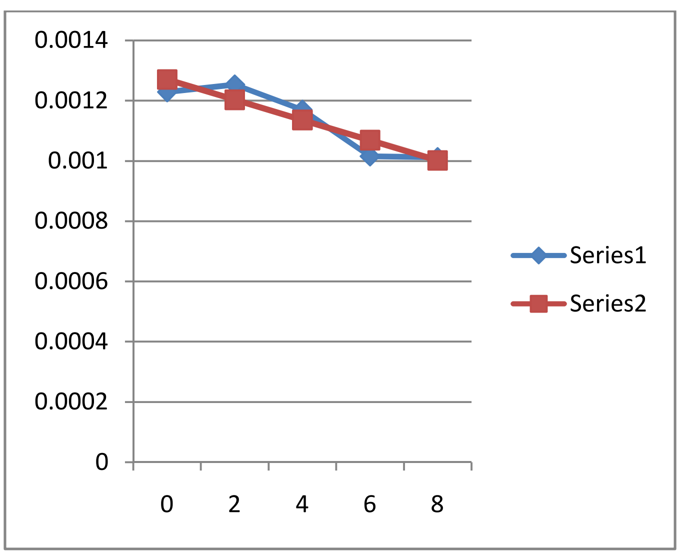
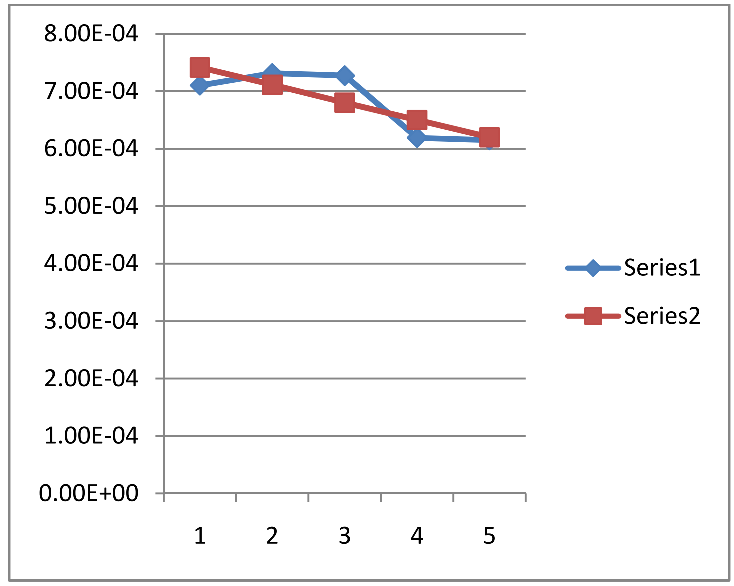


Fig 4.4 Line graph demonstrating the relationship between the experimental and modeled data sets of coefficient of compressibility.

$Y = 7.4082 \times 10^{-4} - 1.5095 \times 10^{-5}x$coefficient of volume compressibility (Mv)



3.7 MODEL OPTIMIZATION

A QBASIC program for the optimization of the model equations for the compressibility properties of fine-grained soil was developed as shown in the algorithm below.

Program Algorithm

Step 1: Declare variables x, y1, y2, y3.

Step 2: Prompt the user to input an oil percentage value.

Step 3: Assign value user to entered to variable x

Step 4: Assign equation for compression index for variable y1 with value of x.

Step 5: Assign equation for coefficient of volume compression for variable y2.

Step 6: Assign equation for coefficient of compression to y3 with value of x.

Step 7: Print value gotten from variable x as entered value of oil percentage.

Step 8: Print value gotten from variable y1 as compression index.

Step 9: Print value gotten from variable y2 as coefficient of volume compression.

Step 10:Print value gotten from variable y3 as coefficient of compression.

Conclusions

An experimental study performed to investigate the variation on the compression index, coefficient of volume compressibility, coefficient of consolidation and coefficient of compressibility gave the following conclusions:

a. The fine grained soil used for the study was classified as A-2-6 soil by the AASHTO classification system.

b. The void ratio of the fine-grained soil decreased at 2% and 4% oil content but increased at 6% and 8% oil.

c. The coefficient of consolidation Cv showed a significant decrease with oil contamination at 2%, 4%, 6% oil content but increased at 8% oil content.

d. The coefficient of compressibility Av showed an increase at 2% oil content, but decreased at 4%, 6% and 8% oil content.

e. The coefficient of volume compressibility showed similar behaviour with the coefficient of compressibility Av, increasing at 2% oil and decreasing at 4%, 6% and 8% oil content.

f. The compression index Cc showed an increase at 2% oil but decreased at 4%, 6% and a slight increase at 8% Oil content.

The above findings from the test result showed that waste engine oil contamination on fine-grained soil have a significant effect on the compression/settlement of soil. The result of this research will be useful in design and civil engineering construction where the soil is of similar classification and is exposed to contamination with waste engine oil.

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