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Effect of Selected Petroleum Products on the Geotechnical Properties of Lateritic Soil

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Abstract

Petroleum contamination causes significant environmental impacts and presents substantial hazards to human health. This study was carried out to identify the effect of selected petroleum products such as petrol, diesel oil and engine oil on the geotechnical properties of lateritic soil in Ede Town (Federal Polytechnic Ede North Campus). Soil samples were collected from both the natural soil (non-oil spillage soil) and contaminated area where there were oil spillage and addition of petrol, diesel oil and engine oil in varying percentages of 5%, 10%, 15% and 20% respectively. The results showed an increase in grain size distribution on both soil samples with a reduction in optimum moisture content, maximum dry density and Atterberg limit (liquid and plastic limit) respectively. The test results showed an increase in maximum dry density with increasing oil contamination of diesel oil to 20% with reduced optimum moisture content. It was found that the maximum dry density for lateritic soil decreased as petrol content increased up to 20%. However, the reduction in the California bearing ratio due to selected petroleum products (petrol, diesel oil and engine oil) contamination, shows that the presence of these petroleum products has remarkable effect on the geotechnical properties of lateritic soil. The effect of petrol on the geotechnical properties of soil seems to be very low of 0.70grams/ml compared to that of diesel oil of about 0.832grams/ml and engine oil of about 0.875grams/ml respectively due to little time it tends to dry off. The lateritic soil is classified as an A-2-6 soil by AASHTO system and are adjudged suitable for sub grade, good fill and sub-base and base materials. But when being contaminated, the strength of the soil reduces and makes it unsuitable for road foundation design and other construction works. Therefore, lateritic soil contaminated with these petroleum products requires stabilization or an improvement technique such as the use of prefabricated vertical drains.

Keywords: Lateritic soil, Petroleum products, Contamination, Compaction, California bearing ratio (CBR)
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1. Introduction

As the world demand for oil products is increasing, the possibility of leakage of oil would also increases. This leakage associated with many problems to both environment and soil properties. When oil is released, it resides in the soil system, in the pore space of the soil, thereby modifying the behavior of the soil (Walia, et al 2013). Ijimdiya (2010) reported that due to oil exploration, oil was released to the environment in the Niger Delta of Nigeria, exposing the area to environmental degradation. Despite the good oil tanker maintenance culture, oil leaked from storage tanks and polluted the soil in the United States of America which our country Nigeria is not left out. Soil sample is porous enough for oil to infiltrate especially within a time frame.

Soil contamination is caused by presence of man-made chemicals or other alteration in the natural soil environment. The contamination typically arises from the rupture of underground storage tanks, application of chemicals, and percolation of contaminated surface water to subsurface strata, oil and fuel dumping, leaching of wastes from landfills or direct discharge of industrial waste to the soil (Alhassan & Fagge, 2013). The most chemicals involved in soil contamination are petroleum hydrocarbons, solvents, pesticides, lead and other metal. The occurrence of this phenomenon is correlated with the degree of industrialization and intensity of chemical usage.

During the past decade, bioremediation of petroleum contaminated soil has been a hot issue in environmental research, and many bioremediation strategies have been developed and improved to clean up soils polluted with petroleum and its derivatives (Al-Naseem & Al-Duwaisan, 2011). Construction of buildings and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Lateritic soil is one of the major soil used in engineering construction work both in highways and foundation.

Lateritic soil is a pedogenic and highly weathered natural materials formed by concentration of hydrated oxide of iron and aluminum, further oxidized to form an insoluble precipitate of the particles Lateritic soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content (Alhassan&Fagge, 2013). In the course of using lateritic soil in construction works it has been discovered that the behaviour of laterite in area exposed to the contamination with petroleum product has effect on its usage. These and some other challenges needs urgent attention and should be addressed appropriately. Researchers have studied the effects of contamination soils with various petroleum petroleum products and crude oil on the engineering properties of the soil. Akinwumi et al. (2014) investigated effects of contamination of a lateritic clay soil with both crude oil and waste engine oil on the plasticity, strength and permeability of the soil . Their results showed that the LL,PL and PI of the soil increased as crude oil and waste engine oil increased while S.G, OMC, MDD, CBR and permeability of the soil decreased as crude oil and waste engine oil increased. Al-Adili et al. (2017) investigated crude oil pollution effect on stiffness characteristics of sandy and Gypseous soil. It was observed that the OMC, MDD, S.G, Liquidity decreased when the crude oil content increased for both soils. Also, the consolidation, compression and swelling indices were increased when the soil is soaked in oil. Karkush and Al-Taher (2017) studied the impacts of industrial waste water contamination on the geotechnical properties of clayey soil. Their results showed that the contaminant causes an increase of Atterberg□s limits, MDD, Compression index and the coefficient of vertical consolidation while the contaminant also causes a decrease in S.G, OMC, coefficient of permeability, swelling index and cohesion between soil particles. Oyediran and Enya (2020) investigated the variation based on the effects of curing time and environmental exposures on the geotechnical characteristics of some crude oil contaminated soils. The contaminated soils were cured under an unexposed and exposed conditions for 21, 63 and 189 days. Results indicated that for unexposed soils, the LL, PL increased for all the curing ages as crude oil concentration increased up to 4% while PI increased for all ages. The UCS and MDD increased upon the addition of crude oil up to 4%, thereafter decreased with increase in crude oil concentration and for the exposed soil, LL, PL and PI increased upon addition of crude oil up till 4% and later decreased above 4% for the curing duration of 21 days while for 63 and 189 days, LL and PL decreased as PI increased. Onyelowe (2015) studied the geotechnical properties of pure crude oil contaminated lateritic soil and assess its suitability in construction of civil engineering structures. In his research, it showed that compression index of the soil decreases with increase in crude oil contamination and the Atterberg limit examination indicated that the crude oil contamination affected both the bonding between the soil particles and the fluidity of the entire mixture. Ayininuola (2013) carried out laboratory studies to determine the effect of crude oil contamination of a lateritic soil on its shear strength. However, despite studies undertaken by several researches, not much has been done on lateritic soil contaminated with petrol and diesel oil, it has only been limited to that of crude oil and engine oil. Therefore, this research works gives a laboratory test programme designed to determine the effects of selected petroleum products such as petrol, diesel oil and engine oil on the geotechnical properties and major parameters of lateritic soil in Ede Town (Federal Polytechnic Ede North Campus). The parameters are Sieve Analysis, California Bearing Ratio (CBR) and Compaction Test. British Standard Institute procedures and ASTM Standards were adopted in the tests.

2 Methodology

2.1 Preparation Of Materials

The materials used for the research work are laterite and petroleum products such as petrol, diesel oil, and engine oil. The lateritic soil sample was collected from Federal Polytechnic Ede North Campus. The procedure involves spreading of the soil samples in trays, air dried and subsequently pulverized to break up the lumped soil aggregates. Different petroleum products bought from the market were added at different percentage of 0%, 5%, 10%, 15%, and 20% respectively .Hydrometer test was conducted on the sample to ascertain the credibility of the laterite before applying the petroleum products.

Mixing proportion was specified by volume. The mixing involves thorough mixing of any of the petrol, diesel oil, and engine oil with laterite. The mixing was done manually and thoroughly so as to avoid segregation.

2.2 Testing

2.2.1 Sieve analysis

A sample of the soil was dried for about three hours and pulverized by means of wooden mortal and rubber pestle. Suitable quantity of soil samples was taken and sieved through the BS 4.75 mm sieve. The soil retained on the 4.75 mm sieve was subjected to coarse analysis which consists of the soil through the net of sieves diameter of 40mm, 10mm, and 5mm respectively. The soil passing through the 4.75mm sieve was subjected to fine sieve analysis which involves sieving the soil through a net of sieves with varying sieve sizes of 1.18mm, 2.00mm, 3.35mm, 600mm, 425mm, 300mm, 150mm, and 63mm respectively. Each set of sieves was shaken continuously on mechanical sieve shaker as shown in Plate 3.1 to ensure the passage of particles through them. The particle retained on each sieve was weighed, expressed in gram and the percentage weight of the sample calculated.

2.2.2 Compaction test

The soil sample was air dried and passed through the 19mm sieve with the particle retained being discarded and those passing being collected for the compaction. The empty weight of the mould was taken using a balance readable to 1g and recorded. A 5kg of the soil was weighed and mixed with a measured volume of water for 0% and varying percentages of selected petroleum products. The volume of water used was not fixed but based on the soil texture and for subsequent trials. The soil mixing was done manually using a scoop and trowel and three layers of the soil were introduced into the mould whose base plate have been covered with filter paper to prevent adherence. The quantity of the soil for each layer was such that three of it fills the mould and 25 blows of 2.5kg metal rammer of a height of 300mm was applied to each layer. After compacting the three layers, the collar was removed and excess soil was scrapped with a straight edge. The mould and compacted soil were then weighed to determine the wet bulk density. A sample of the soil was collected for moisture content determination from both the top and bottom of the mould. This procedure was repeated three times where maximum dry density and optimum moisture content was determined for different petroleum products added at different percentage of 0%, 5%, 10%, 15%, and 20% respectively.

2.2.3 California bearing ratio test (CBR)

A soil sample of weight 8kg was prepared in order to have enough sample that will fill the CBR mould. The mould was weighed, less base and collars and then representative samples of water content determination was taken. The soil was compacted according to compaction test standards. The collar was removed and the sample was trimmed smooth and flushed with the mould after being compacted then taken to the CBR machine and recorded.

3. Results

The result of sieve analysis test, compaction test, and California bearing ratio test on lateritic soil sample are presented in Table 3.1 – 3.5 while Table 3.2 presents the summary of moisture content and dry density determination with immediate and 24hrs delay compaction. The corresponding plot of graphs for petrol, diesel and engine oil are presented in Figure 3.1 – 3.3 respectively.

Table 3.1: Result of Sieve Analysis Test on Lateritic Soil

S/N	Sieve Opening (mm)	Weight of empty Sieve(g)	Weight of sample + Sieve (g)	Weight of Sample retained	% retained	Cumulative retained	% passing
1	2	544	785	241	48.30	48.30	51.70
2	1	369	479	110	22.04	70.34	29.66
3	0.85	372	386	14	2.81	73.15	26.85
4	0.60	319	353	34	6.81	79.96	20.04
5	0.425	335	356	21	4.21	84.17	15.83
6	0.300	316	334	18	3.61	87.78	12.22
7	0.212	358	371	13	2.61	90.39	9.61
8	0.150	350	361	11	2.20	92.59	7.41
9	0.075	262	288	26	5.21	97.80	2.20
10	Base	271	282	11	2.20	100.00	0.00
	Total	3496	3995	499	100		

Table 3.2: Summary of Moisture Content and Dry Density Determination with Immediate and 24hrs Delay Compaction

Duration	Percentage %	Maximum Dry Density			Optimum Moisture Content		
		Petrol	Diesel oil	Engine oil	Petrol	Diesel oil	Engine oil
Immediate	0%	23.5	23.5	23.5	13	13	13
	5%	21	19.8	21.0	10.0	11.5	4.1
	10%	19.5	20.2	20.0	11.5	9.4	5.6
	15%	19.0	21.0	19.5	12.2	8.8	6.4
	20%	19.2	21.5	18.0	13.4	8.2	7.3
24hrs delay							
	5%	20.3	19.0	22.0	14.5	12.0	8.2
	10%	20.8	18.0	22.6	13.7	11.3	7.9
	15%	21.5	17.5	23.1	13.2	11.0	6.5
	20%	21.8	17.0	24.0	12.9	10.6	6.0

Table 3.3: Results of California Bearing Ratio Test from 0% to 20% on Petrol

Penetration	Load(KN) for 0%	Load (KN) for 5%	Load (KN) for 10%	Load (KN) for 15%	Load (KN) for 20%
0.00	0.00	0.00	0.00	0.00	0.00
0.50	72.5	20.0	41.0	42.5	44.0
1.00	84.5	44.0	60.5	58.5	55.5
1.50	100.0	67.0	82.5	80.5	72.0
2.00	114.5	139.0	104.5	96.5	86.5
2.50	131.5	161.5	130.0	108.0	103.5
3.00	147.5	180.0	152.0	123.0	116.5
3.50	160.0	195.5	170.0	137.5	129.5
4.00	180.0	212.5	190.0	150.5	144.0
4.50	212.0	227.5	206.5	167.5	159.0
5.00	240.0	244.0	228.5	185.0	173.0
5.50	268.5	256.0	244.0	199.5	183.0
6.00	284.5	270.0	258.0	215.5	194.5
6.50	300.5	280.0	273.0	231.5	205.5
7.00	316.0	297.0	287.0	249.0	222.0
7.50	332.0	307.5	296.0	264.0	236.0
8.00	348.5	320.0	307.0	276.0	253.0

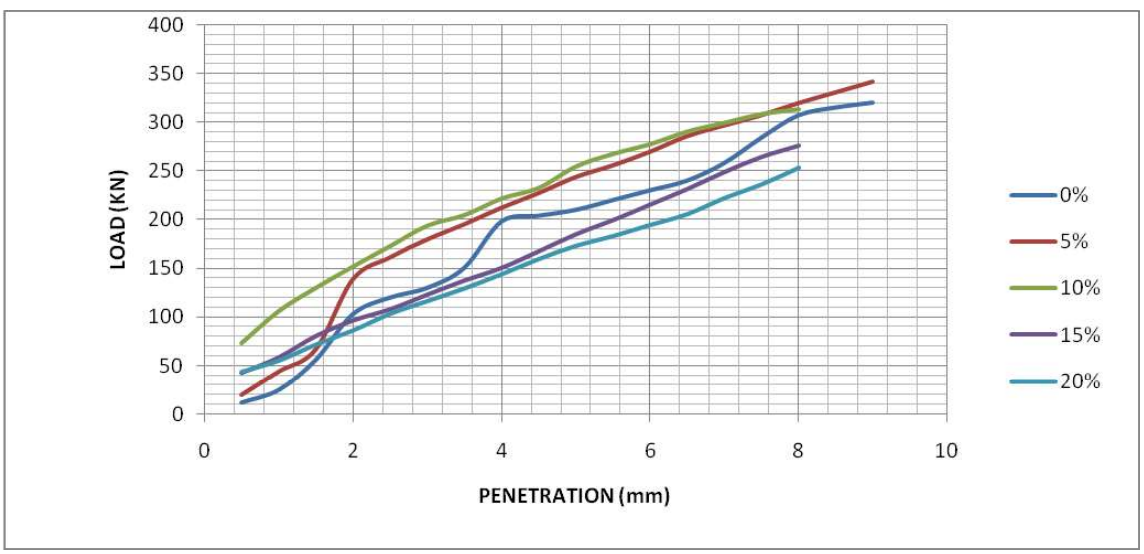

Figure 3.1: Plot of Load Bearing against Penetration for Petrol

Table 3.4: Results of California Bearing Ratio Test from 0% to 20% on Diesel Oil

Penetration	Load (KN) for 0%	Load (KN) for 5%	Load (KN) for 10%	Load (KN) for 15%	Load (KN) for 20%
0.00	0.00	0.00	0.00	0.00	0.00
0.50	72.5	42.5	11.5	13.5	11.5
1.00	84.5	68.0	17.5	19.5	17.0
1.50	100.0	97.0	23.5	24.0	22.5
2.00	114.5	126.0	30.5	31.5	27.5
2.50	131.5	150.0	37.0	36.0	32.5
3.00	147.5	171.5	44.5	42.0	38.0
3.50	160.0	189.0	52.0	47.5	44.0
4.00	180.0	206.0	58.0	54.0	49.0
4.50	212.0	219.0	65.0	61.5	58.5
5.00	240.0	233.0	71.5	68.5	57.5
5.50	268.5	245.0	78.5	74.5	63.0
6.00	284.5	254.0	85.5	80.5	66.5
6.50	300.5	262.0	92.0	86.5	70.5
7.00	316.0	272.5	98.5	91.5	76.5
7.50	332.0	278.5	105.0	95.0	83.0
8.00	348.5	287.0	109.5	98.5	89.5

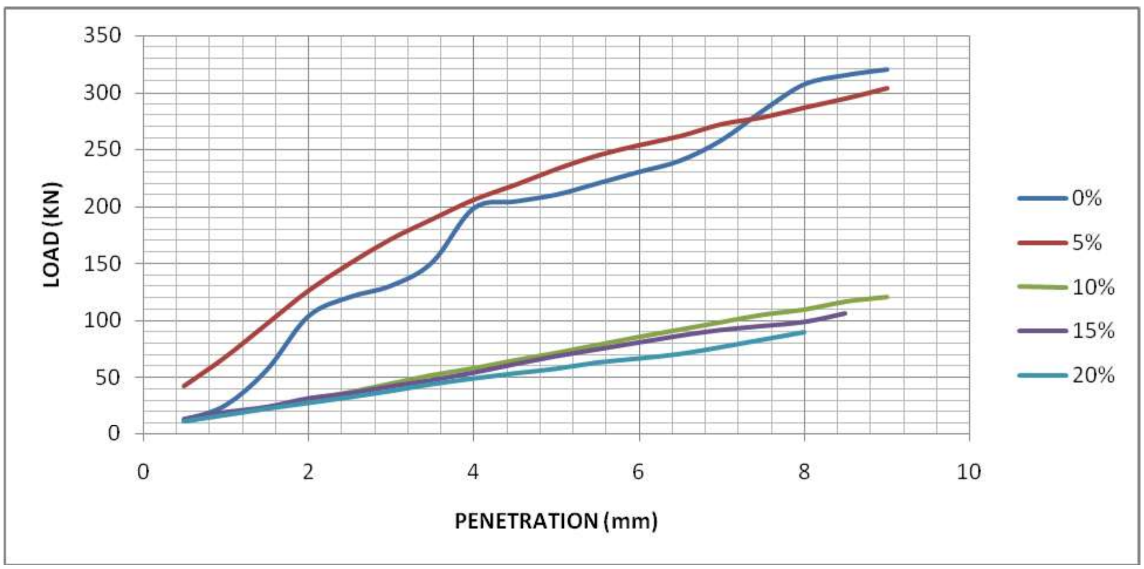

Figure 3.2: Plot of Load Bearing against Penetration for Diesel Oil

Table 3.5: Results of California Bearing Ratio Test from 0% to 20% on Engine Oil

Penetration	Load(KN) for 0%	Load (KN) for 5%	Load (KN) for 10%	Load (KN) for 15%	Load (KN) for 20%
0.00	0.00	0.00	0.00	0.00	0.00
0.50	72.5	25.5	19.0	8.5	6.5
1.00	84.5	51.0	37.5	13.5	11.0
1.50	100.0	72.5	55.0	18.5	15.0
2.00	114.5	91.0	69.5	23.5	19.5
2.50	131.5	106.0	86.0	27.5	23.0
3.00	147.5	123.0	95.5	32.5	28.0
3.50	160.0	136.5	106.5	36.5	31.5
4.00	180.0	151.5	121.5	41.0	36.0
4.50	212.0	162.5	134.0	46.0	39.5
5.00	240.0	176.0	142.5	51.0	43.0
5.50	268.5	192.5	152.5	55.5	46.0
6.00	284.5	204.5	158.0	61.0	49.0
6.50	300.5	213.5	164.5	64.5	54.0
7.00	316.0	218.5	171.0	68.5	66.0
7.50	332.0	229.0	177.5	74.0	58.5
8.00	348.5	235.5	184.0	81.0	61.5

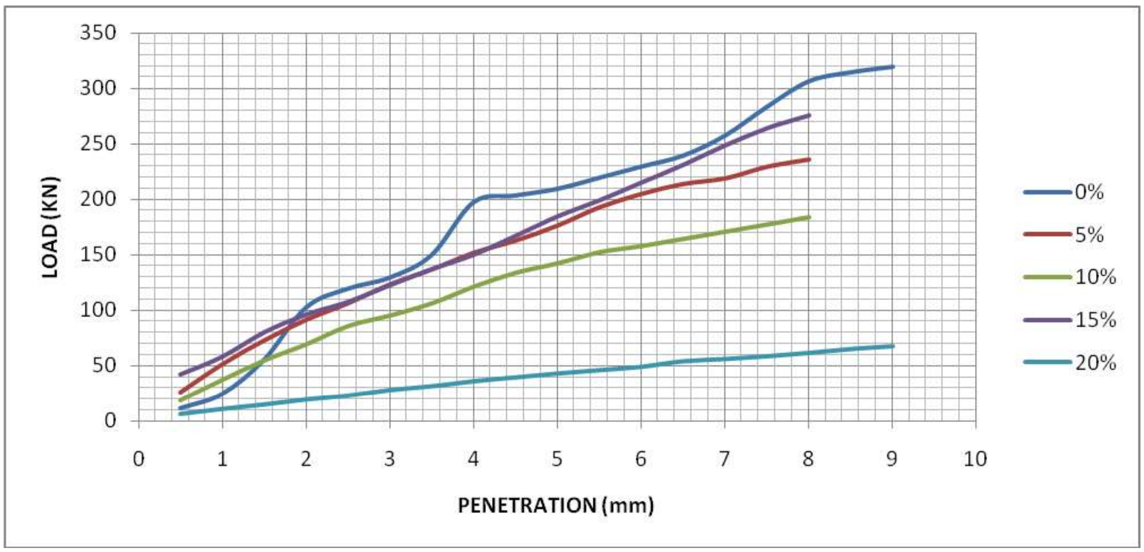

Figure 3.3: Plot of Load Bearing against Penetration for Engine Oil

4. Discussion

The result of all the tests conducted on uncontaminated and contaminated soil samples are shown in tables and graphs. From the results, it was seen that soil properties are modified when they are contaminated with petroleum products. The extent of modification of properties depends upon the type of soil itself and nature of contaminants. The cause of change in properties of laterite contaminated with petroleum products may be due to effect on its Base Exchange Capacity, change in thickness of diffuse double layer and the nature of contaminants. However, the engineering properties of the soil were affected significantly after being contaminated with petrol, diesel oil, and engine oil.

Effect of Petroleum Products on Compaction Test

The summary of Figure 3.1 □ 3.3 showed a decrease in the maximum dry density of the soil. The low maximum dry density may be attributed to the dispersed structure of the soil in the presence of the polar organ of liquid, which consequently lead to reduced maximum dry density. Decrease in maximum dry density of soil with increased petroleum products content may also be due to the low specific gravity value of the petroleum products compared to that of the natural lateritic soil. The research indicates an increase in maximum dry density with increasing oil contamination of diesel oil to 20% with reduced optimum moisture content. It was found that the maximum dry density for lateritic soil decreased as petrol content increased up to 20%. These results were in agreement with findings from Akinwumi et al. (2014)

Effect of Petroleum Products on California Bearing Ratio Test

In comparison of uncontaminated laterite, compacted lateritic soils produce excellent shear strengths and California bearing ratio values. However, the brittleness and tensile cracking of this compacted materials become enhanced on the dry side of the optimum moisture content, or if excessive compaction is imparted. Nevertheless, at a moisture content of 2% wetter than the optimum, the tensile mode of failure is suppressed and the lateritic fill become ideally suited for the construction of high embankments and impervious dam cores. The California bearing ratio of the load penetration tests for 0, 5%, 10%, 15% and 20% of petroleum products shows that as the percentage of the petroleum products increases, the California bearing ratio value decreases. This was a little bit contrary to the findings of Akinwumi et. al (2014), which stated that as the percentage of waste engine oil increases, the soaked and unsoaked CBR values of the contaminated soil increased and that the increases were observed for up to 6% and 8% waste engine oil content. The California bearing ratio test indicates that the laterite starts attaining some cohesion with the addition of petrol, diesel oil and engine oil to it, but the fall in angle of friction is an indication of lower bearing capacity. Since the bearing capacity factors reduced by almost 20% with addition of these petroleum products, the bearing capacity of the contaminated laterite becomes 20% of that of the uncontaminated laterite. The California bearing ratio value of the uncontaminated sample is greater than that of the contaminated sample. As the degree of contamination increases, the California bearing ratio values of petrol slightly decreases compare to that of engine oil and diesel oil. The shear strength of laterite decreases from 0.765kg/cm^3 with 10% contamination with petrol, but with further increase in petrol, the shear strength decreases. It becomes only 0.513kg/cm^{3}with 20% contamination which is approximately 50%of the natural soil.

$$\text{CBR value at 2.5mm} = \frac{\text{load carried by the specimen at 2.5mm penetration}}{\text{Standard load carried for 2.5mm penetration (13.24KN)}} \times 100$$

$$\text{CBR value at 5.0mm} = \frac{\text{load carried by the specimen at 5.0mm penetration}}{\text{Standard load carried for 5.0mm penetration (19.60KN)}} \times 100$$

5. Conclusion

Lateritic soil used for the experiment was plastic in nature when no petroleum product was added. Addition of petroleum products reduced the liquid limit and plastic limit of the soil. Similarly, the maximum dry unit density of the soil was reduced while the optimum moisture content also reduced with increase in proportion of the petroleum products. But when being contaminated reduces the strength of the soil and makes it unsuitable for road foundation design and other construction works. The effect of petrol on the geotechnical properties of soil seems to be very low compared to other petroleum products like engine oil and diesel oil because it has a lower density of 0.70grams/ml compared to that of diesel oil of about 0.832grams/ml and engine oil of about 0.875grams/ml because with little time it tends to dry off.

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