Geochemical and Engineering Properties of Selected Lateritic Deposits in Akure Metropolis as Highway Subgrade Foundation Material

ABSTRACT

Laterite occurrences at three locations in Akure metropolis, Ondo State, southwestern Nigeria were characterized geochemically and geotechnically in order to evaluate their potentials as subgrade and subbase/base civil engineering foundation material. The geochemical analysis employed X-ray fluorescence and Atomic Absorption Spectrophotometer (AAS) to determine the major and minor oxide geochemistry while particle size analysis, Atterberg limit test, compaction test, specific gravity, triaxial compression test and California bearing ratio were determined following the British Standard (BS-1337). Abundances of major elements show that SiO_2 (50.44 - 58.82%), Fe_2O_3 (18.34 – 24.41%), Al_2O_3 (16.30 – 53.82%) constitute over 95% of the bulk chemical compositions. Other constituents include Na_2O, k_2O and $Ti0_2$. Although notable disparities exist in the SiO_2 and Fe_2O_3 contents of the samples, as the LC2 samples are more siliceous and ferrous than others. The silica: sesquioxide ratio (S_e) of the samples are generally less than 1.33 indicating true laterite. Geotechnically, the in-situ derived LC 2 samples have distinctive characteristics in terms of compaction, consistencies, and CBR as they satisfied the Federal Ministry of Works and Housing recommended liquid limits of 50% maximum, plastic limits of 30%, plasticity index of 20% for subbase and base materials; while LC 1 and LC 3 are characterized by values higher than FMWH specification This also corroborates AASHTO classification which rates samples in LC 1 and 3 as fair to poor (i.e. A-7), and LC 2 as excellent to good subgrade (A-2-4/A-2-4).Thus LC 2 samples are suitable for subbase and base foundation materials, while LC 1 and LC 3 for them to be suitable as foundation material would require stabilization, to improve their density and compaction characteristics using conventional lime, cement, and asphaltic stabilization.

Keywords: geotechnical characteristics, laterite, shear strength, sesquioxide, geochemical characteristics,

1. INTRODUCTION

Of the important groups of the tropical and subtropical soils of the world, lateritic soils occupy a unique place, in regard to both their extensive occurrence and peculiar properties. Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and/or decomposition of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions, with red, reddish brown, or dark brown color, with or without nodules or concreting and generally (but not exclusively) found below hardened ferruginous crust or hard pan [1]. Lateritic soils are formed in hot, wet tropical regions with an annual rainfall between 750 mm to 3000 mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. Laterite formation factors include climate (precipitations, leaching, capillary rise, and temperature) to topography (drainage), vegetation, parent rock (iron rich rocks) and time.

Of all these primary factors, climate is considered the most important [2]. Laterites are rich in iron oxides, aluminum oxides and low silicates but may contain appreciable amounts of kaolinite and due to the presence of iron oxides. Accordingly, laterites may be classified as ferruginous (iron oxide dominating; brown colour); aluminiferous (aluminium hydroxide dominating; grey colour); manganiferous (manganese dioxide present – dark colour). In texture, they could be hard, compact and massive.

It is believed that bauxite (aluminium hydroxide) and laterite (hydrous aluminium-iron oxide) are closely related in their origin. A free circulating and highly alkaline environment will cause quick removal of dissolved clay ions from the decomposing rock leaving behind bauxite (rich in iron ions), whereas an acidic environment and interrupted drainage will favour accumulation of clay ions along with some iron ions so that the resulting rock is a double hydroxide of iron as well as aluminium [3].

Laterite is amongst the most important natural resources (soil) in Nigeria and widely used as fill materials for various construction works (especially the ferruginous varieties) in most tropical countries whereas clay-rich varieties approaching bauxite find use in chemical industry [4]. However when they are continuously intensely weathered under conditions of high temperatures and humidity with well-defined alternating wet and dry seasons could result in poor engineering properties such as high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content [5,6,7].

Many geoscientists have researched exclusively on laterites in different areas of Nigeria [1,], [8-16] and the outcome of their studies have appreciably benefited the government at all levels and private sectors. Therefore in order to sustain these culture there must be continuous research into geotechnical and geochemical properties of soils (laterites) and determine their applications in civil engineering foundation and constructional work. On the basis of this, the thick lateritic deposits in three major locations were studied so as determine their engineering significance as regard construction activities (Plate 1).

2. DESCRIPTION OF THE STUDY AREA

The study area (Akure metropolis) is located in central part of Ondo State, southwestern Nigeria. It lies within Latitudes 07° 09' and 07° 19'N and Longitudes 05°07' and 05° 17'E (Northings 790820 – 809277 mN and Eastings 733726 – 752139 mE, UTM Minna Zone 31) (Fig. 1). It covers an area extent of about 340 km². The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs [17]. Topographic elevations vary between 260 and 470 m above sea level. The metropolis is drained by several streams and rivers.

The geological mapping and other related studies of the area around Akure Metropolis have been carried out by several workers amongst whom are [18-22]. The relative age of the rocks ranges from Late Precambrian to Early Paleozoic [21]. The area around the Akure Metropolis is underlain by four of the six petrological units of the Basement Complex of Southwestern Nigeria identified by [23]. These are the Migmatite-Gneiss Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and unmetamorphosed dolerite dykes (Fig. 2). The sampling locations i.e. LC 1, LC 2, and LC.3 are underlain by Charnockite, Migmatite Gneiss, and Biotite Granite respectively. The basement rocks exhibit varieties of structures such as foliation, schistosity, folds, faults, joints and fractures. Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. Numerous small and long fractures, joints and fissure zones which generally trend north south are common. These structural trends fall within the principal basement complex fracture direction identified by [19, 17].

3. METHODOLOGY

Nine (9) lateritic soil samples were collected from the aforementioned sites within Akure metropolis in ratio 3:3:3 respectively. The samples were collected on the basis of colour and grain size variation. The samples were packed into air-tight polythene bag and the bags were labeled accordingly to avoid mix-up or any kind of contamination required for chemical and geotechnical analyses.

The soil samples were sun-dried separately and carefully, without mixed up or contamination for about a week and they were later pulverized. All the samples were selected for the analyses in accordance with British Standard as outlined in BS 1377 [24] and labeled as: S1 – S9 respectively. The samples were subjected to grain size analysis test, Atterberg limits test, specific gravity test, compaction test, natural moisture content determination, California bearing capacity determination, shear Strength determination using equation 1.

$$s = c + \sigma \tan \emptyset \quad (1)$$

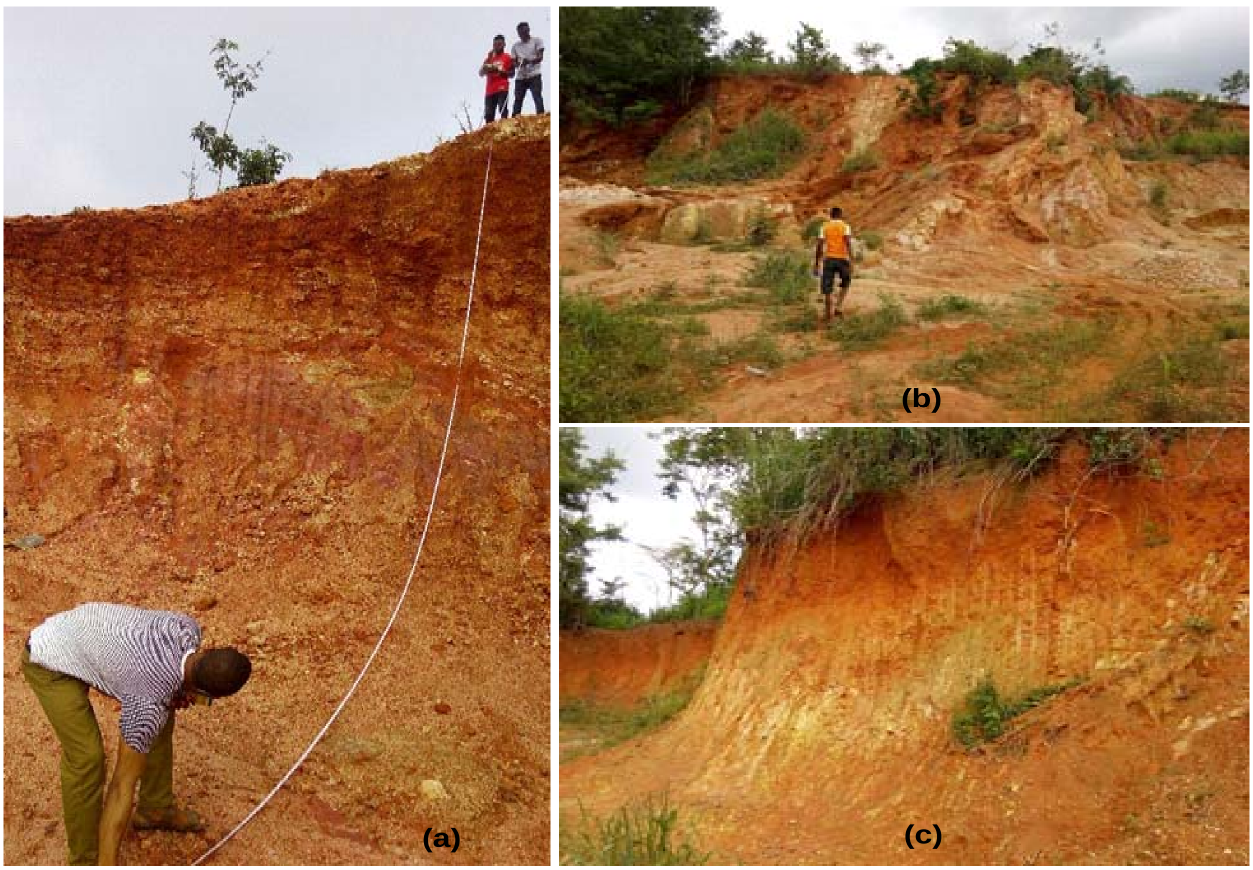


Plate 1: The studied lateritic deposits in Akure Metropolis: (a) Along Fiwasaye Road; (b) Oda Road; and (c) Shagari Village Area

where, s= shear strength
c = cohesion;
σ = total normal pressure on the failure plane;
$\emptyset$ = angle of shearing

The chemical analysis was also carried out on the samples to determine the mineral oxides that were present in each sample. The sample were initially sieved using 2 mm sieve and 2 g of the sieved sample was taken, after which they were put into digesting tube and digested using and *HCl*, then with $HClO_4$ and H_2O_2 . The samples were heated to dryness and make up with distilled water in a 100 ml volumetric flask. The resultant solution was analyzed using X-ray fluorescence and Atomic Absorption Spectrophotometer (AAS). The silicon oxide and Aluminium oxide were analyzed with nitrous oxide while Iron-oxide with oxyacetylene. P_2O_5 and TiO_2 were determined by a colorimetric method. The steps were repeated for the remaining samples, and the samples were subsequently allowed to stand for at least I hour in the solutions while they were frequently stirred. The extent to which a residual soil has been laterized may be measured by the ratio of silica (SiO_2) remaining in the soil (except for discrete pebbles of free quartz that may remain) to the amount of Fe_2O_3 and Al_2O_3 that has accumulated. The silica: sesquioxide ratio (S_e) (Table 1) has served as a basis for classification of residual soils. Ratios less than 1.33 have sometimes been considered indicative of true laterites, those between 1.33 and 200 of lateritic soils, and those greater than 2.00 of non-lateritic tropically weathered soils [25].

$$S_e = {SiO_2}/{Al_2O_3 + Fe_2O_3} \quad (2)$$

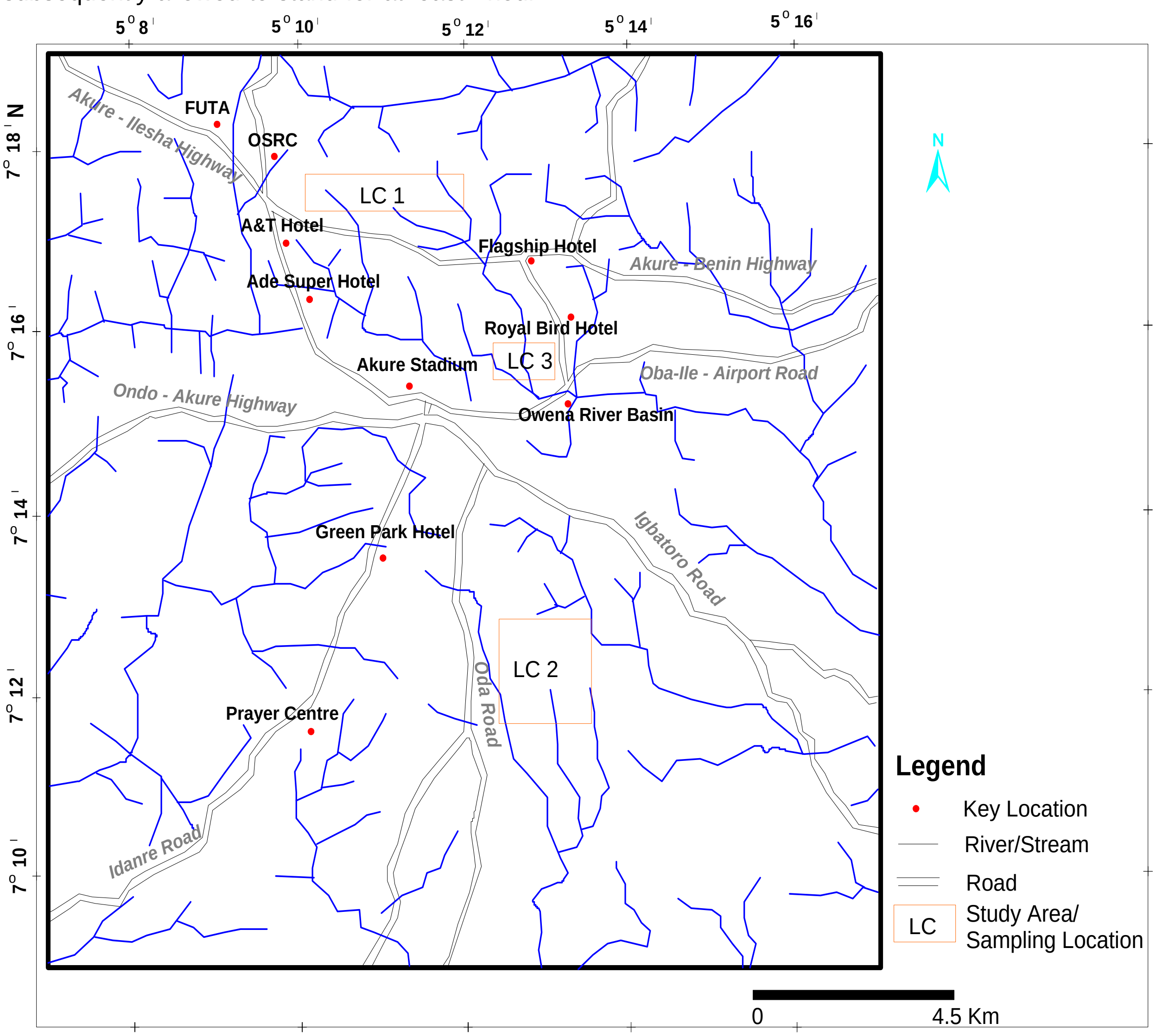


Figure 1: Map of Akure Metropolis showing the Drainages and Sampling locations

4. RESULTS AND DISCUSSION

Tables 2 and 3 present the results of chemical analysis showing the different oxide forms of the major elements contained in the soil samples, and silica: sesquioxide ratio (S_e) respectively. The samples are well dominated (in ascending order) by Al_2O_3 , Fe_2O_3, and SiO_2 with a little over 95 % of the materials being characterized by three elements oxide. The remaining less than 5% of the composition is ascribed to Na_2O, k_2O and TiO_2. The % SiO_2 in LC1, LC 2 and LC3 varied between 50.44 – 51.30, 49.60 – 52.40, and 51.20 – 58.82 respectively. The % Fe_2O_3 concentrations also varied between 24.35 - 24.41, 23.61 – 23.75, 18.34 – 22.80, while Al_2O_3 ranges from 16.30 to 17.30%, 49.60 to 52.40% and 51.20 to 53.82% respectively. Location 3 (LC3) shows higher degree SiO_2 and Al_2O_3 since the source rock (Granite Gneiss/Biotite granite) is rich in aluminosilicates minerals; while samples taken from Location 1 (LC1) are richer in Fe_2O_3 reflecting the higher degree of oxidation of iron-rich clay minerals, since charnockite which dominates LC1 are rich in mafic minerals. Sesquioxide ratio (S_e) of the soil shows that all the soil sampled soil are true laterite except S8 and S9 which correspond to samples taken from LC 3 and are derivatives of biotite-granite rock. The reason why their S_e values are higher might be due to incomplete laterization process resulting to immaturity.

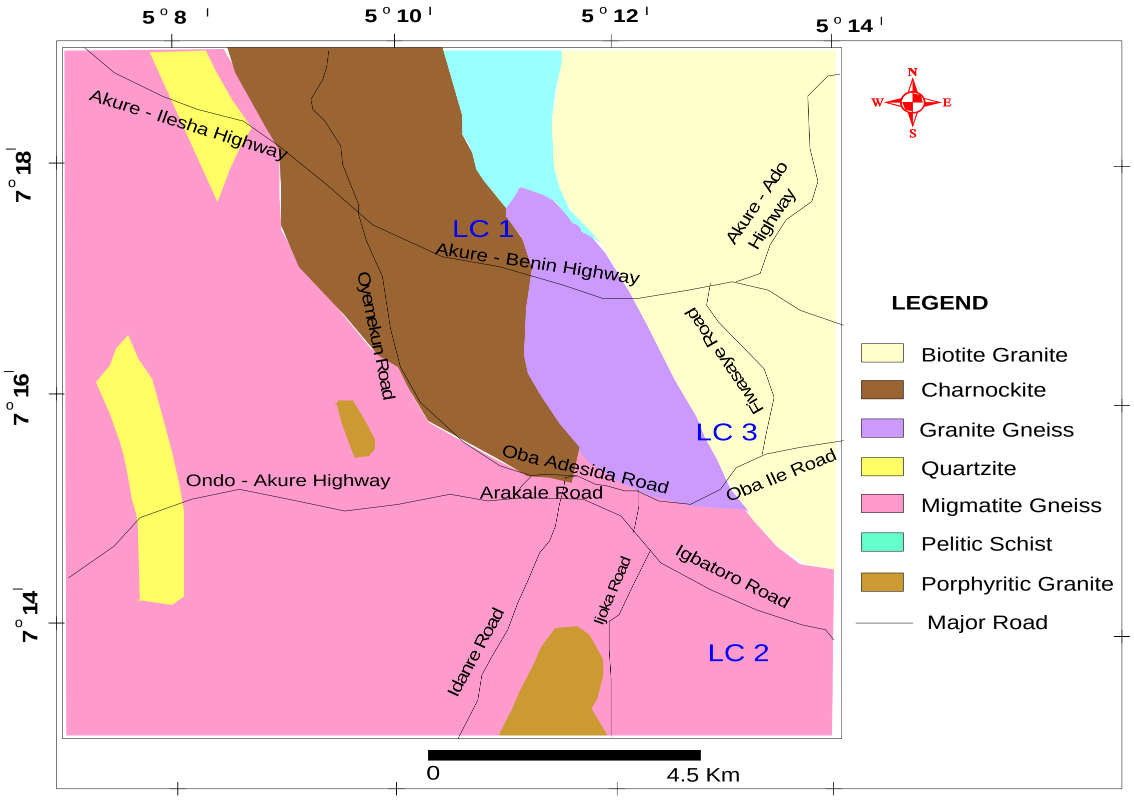


Figure 2: Geology Map of Akure Area (Modified after [20])

Plate 2: Surface exposures of the Rock units in the Sampling Sites (a) Biotite granite (LC3) (b) Migmatite gneiss (LC2) (c) Charnockite (LC1)

Geotechnical characteristics of soils are often associated with their mineralogical composition, especially with clay mineralogy. The results of the geotechnical tests are presented in Tables 4 and 5. The moisture content of the samples varies from 5.5% to 23.2%, this range of values show that the soil have low – moderate moisture content in their natural states. However samples taken from LC2 are characterized by very low values. The result of the grain size analysis (Table 4) and grading curves (Fig. 3) show the percentage of material passing through No.200 BS sieve ranges between 15.30% and 74.10%. All the soil samples generally contain % fines higher than 35% except samples taken from LC 2 which are less than 35%. The results show that samples from LC1 and LC 3 are more sandy (lateritic sand) while LC 2 are more clayey/silty.

Table 1: Classification of Soil Types based on Silica-Alumina Ratio

Soil Type	Sesquioxide
Laterite soil	1.33 or Less
Lateritic soil	1.33 – 2.00
Non-Lateritic	2.00 and Over

Table 2: Result of the Chemical analysis of the lateritic soil samples

	Oxide Percent (%)								
Location	**LC1**			**LC2**			**LC3**		
Element	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
MgO	0.32	0.32	0.45	0.41	0.62	0.54	0.41	0.40	0.35

Al_2O_3	16.30	17.30	16.70	17.22	17.20	18.34	15.90	18.42	17.40
$Si0_2$	51.00	50.44	51.30	49.60	52.40	51.66	51.20	53.82	53.40
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na_2O	1.23	1.23	1.08	1.26	1.17	1.14	1.13	1.22	1.32
k_2O	2.67	2.67	2.51	2.46	2.17	1.85	2.67	2.67	1.54
CaO	0.10	0.10	0.10	0.43	0.32	0.43	0.10	0.43	0.21
$Ti0_2$	1.14	1.14	0.95	0.84	0.76	0.76	1.72	1.72	1.12
V_2O_5	0.67	0.67	0.04	0.04	0.03	0.03	0.67	0.67	0.56
Cr_2O_3	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03
MnO	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03
Co_3O_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	23.41	23.41	24.35	25.30	23.75	23.61	22.80	18.34	20.10
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CuO	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02
ZnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As_2O_3	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.03
PbO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$W0_3$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BeO	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00
Ag_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rb_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ZrO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nb_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MoO_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CdO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SnO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sb_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: Silica: Sesquioxide Ratio (S_e) of the Sampled Soil

Sample No.	Sesquioxide Ratio	Soil Classification
S1	1.28	True laterite
S2	1.24	True laterite
S3	1.25	True laterite
S4	1.17	True laterite
S5	1.28	True laterite
S6	1.23	True laterite
S7	1.32	True laterite
S8	1.46	Lateritic soil
S9	1.42	Lateritic soil

According to Federal Ministry of Works and Housing [26] specification, samples from LC 2 can be deduced as suitable for subgrade, subbase, and base materials as the percentage by weight finer than No.200 BS test sieve is less than 35%. The liquid limits value ranges between 28.0 to 59.7% while the plastic limits range between 18.1 and 26.4%. Plasticity index ranges between 9.9 to 35.6%. Federal Ministry of Works and Housing [26] for road works recommend liquid limits of 50% maximum, plastic limits of 30%, plasticity index of 20% for subbase and base materials. Samples from LC 2 fall within this specification, thus making them suitable for subbase and base materials, while LC 1 and LC 3 are characterized by values higher than FMWH specification, hence stabilization is required for them to be suitable as foundation material. This observation is also in line with AASHTO classification [27] in Fig. 4 which rates samples in LC 1 and 3 as fair to poor (i.e. A-7), and LC 2 as excellent to good subgrade (A-2-4/A-2-4). The shrinkage limits of the soil is between 5.5% - 9.6% with an average less than 8%. This implies that all sampled soils will exhibit low shrinkage potential, hence suitable for subgrade/fill and subbase material.

The specific gravity of the soil depends on the amount of sand and also depends on their mineral constituents and mode of formation of the soil. According to specification, a good lateritic material should have specific gravity ranging from 2.50 to 2.75.The specific gravity of the tested samples lies between 2.66 and 2.72 indicating a lateritic material. These values are suitable in accordance with [28] which states that the standard range of values of specific gravity of soils lies between 2.60 and 2.80. Lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil [24].

The maximum dry density for the soil samples varied between 1290Kg/m³ and 1967Kg/m³ while that of optimum moisture content ranged between 14.2% and 33.7% (Fig. 5). All the studied samples have MDD at lower OMC. However samples from LC 2 exhibit higher MDD (greater than 1800Kg/m³) and lower OMC (less than 20%) than other locations probably due high content of iron oxide found in the samples (Table 2). This also corroborates with the studies conducted by [11, 15, 29, 30] in southwestern Nigeria. Generally, these values show that, the soils respond gradually to compaction. The importance of compaction is to improve the desirable load bearing properties of soil as a foundation material. Therefore LC2 samples are geotechnically better as subgrade/fill material than soils from LC 1 and LC3 on the basis of OMC and MDD.

The results of the triaxial compression test is presented in Table 4 and typical curves are shown in Fig. 5. The shear strength of the soil varies between 214Kpa and 444Kpa with LC 1 showing more competence than other locations as they are characterized by values greater than 300Kpa. Therefore soil showing higher shear strength would be less susceptible to rupture or failure along any plane inside it. But all the soil are above 200Kpa targeted specification/ standard.

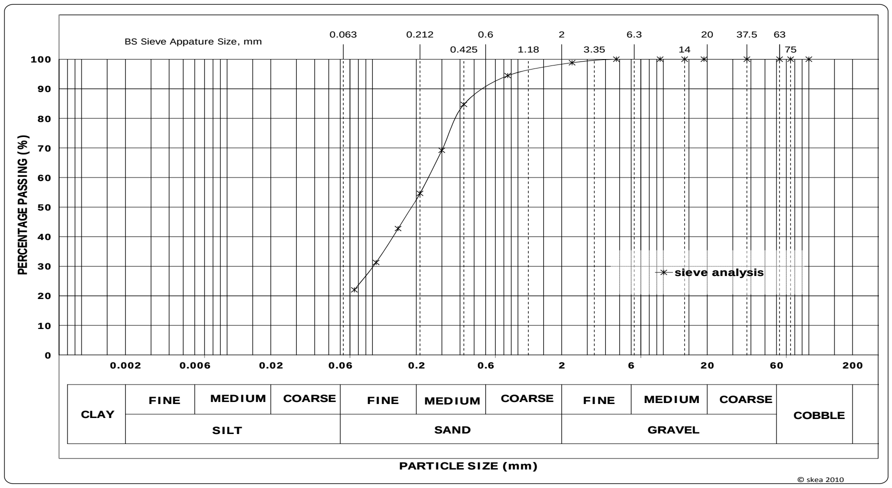
The results of the California bearing ratio and typical curves of the studied soil samples are presented in Table 4 and Fig. 6. The unsoaked California bearing ratio (CBR) value for the lateritic soil samples range from 46% to 70%. The standard specification of CBR recommended by the Federal Ministry of Works and Housing (FMWH) [26] is 10% minimum for subgrade, 30% minimum for subbase materials, and 80% for base soils. Thus all the sampled soils satisfy the condition of subgrade and subbase materials.

Table 4: Results of the Grain size Analysis, Consistency limits, Natural Moisture Content and Compaction

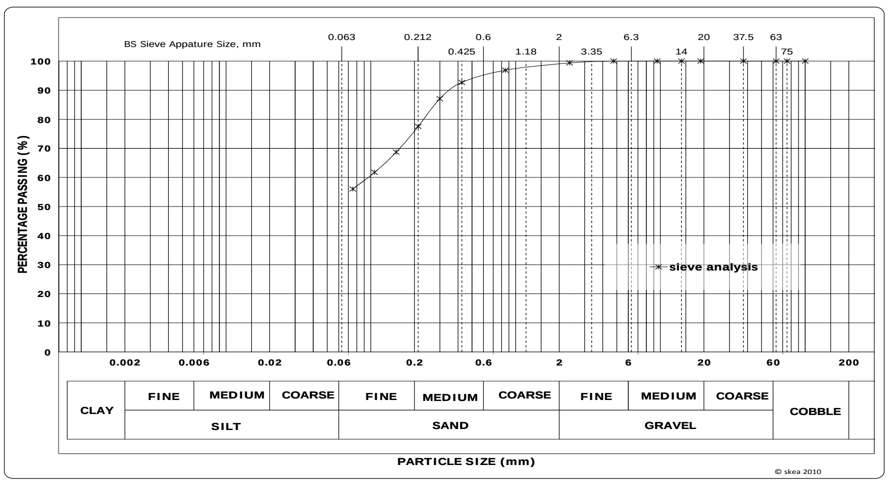
Sample Location	SAMPLE NO.	N.M.C (%)	% Fines	% Sand	% Gravel	S.G	L.L (%)	P.L. (%)	P.I (%)	L.S (%)	OMC (%)	MDD (Kg/m³)
Oda Area	S 1	21.4	56.0	43.3	0.6	2.684	47.1	20.0	27.1	9.1	28.3	1476
	S 2	23.2	68.3	31.7	-	2.677	53.8	24.5	29.3	7.7	32.7	1325
	S 3	22.2	74.1	25.9	-	2.715	59.7	24.1	35.6	6.8	33.7	1290
Shagari Village	S 4	8.3	22.0	76.8	1.2	2.655	32.4	18.9	13.5	6.0	16.2	1897
	S 5	6.4	20.5	78.0	1.6	2.660	34.0	18.9	15.1	6.5	15.3	1928
	S 6	5.5	15.3	83.5	1.2	2.657	28.0	18.1	9.9	5.5	14.2	1967
Fiwasaye Area	S 7	14.6	60.3	38.8	1.0	2.675	47.1	24.1	23.0	9.1	32.4	1336
	S 8	14.9	62.5	37.5	-	2.680	44.2	25.1	19.1	9.1	33.4	1301
	S 9	14.8	35.3	64.7	-	2.665	43.4	26.4	17	9.6	16.2	1897

Table 5: Results of the Shear strength and California Bearing Capacity (CBR)

Sample Location	SAMPLE NO.	Shear Strength (Kpa)	CBR (%)
Oda Area	LC 1	405	51
	LC 2	396	49
	LC 3	444	46
Shagari Village	LC 4	194	68
	LC 5	186	72
	LC 6	187	70
Fiwasaye Area	LC 7	214	41
	LC 8	216	48
	LC 9	353	69



(a)



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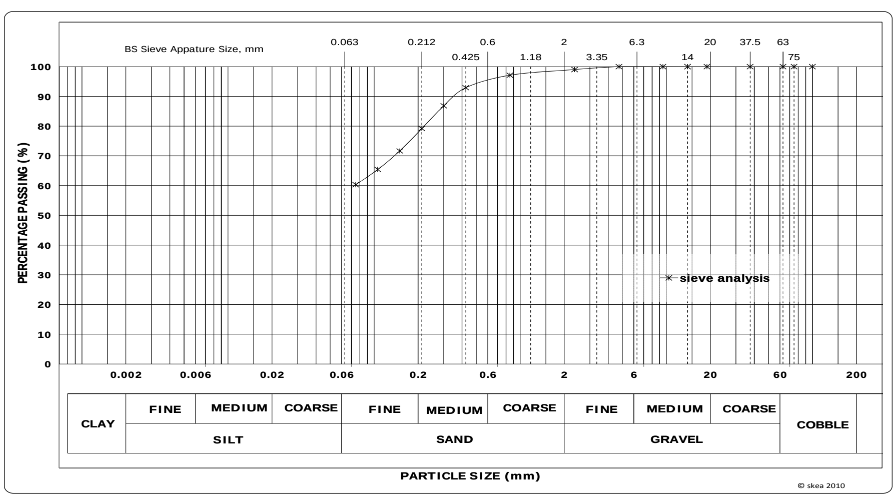
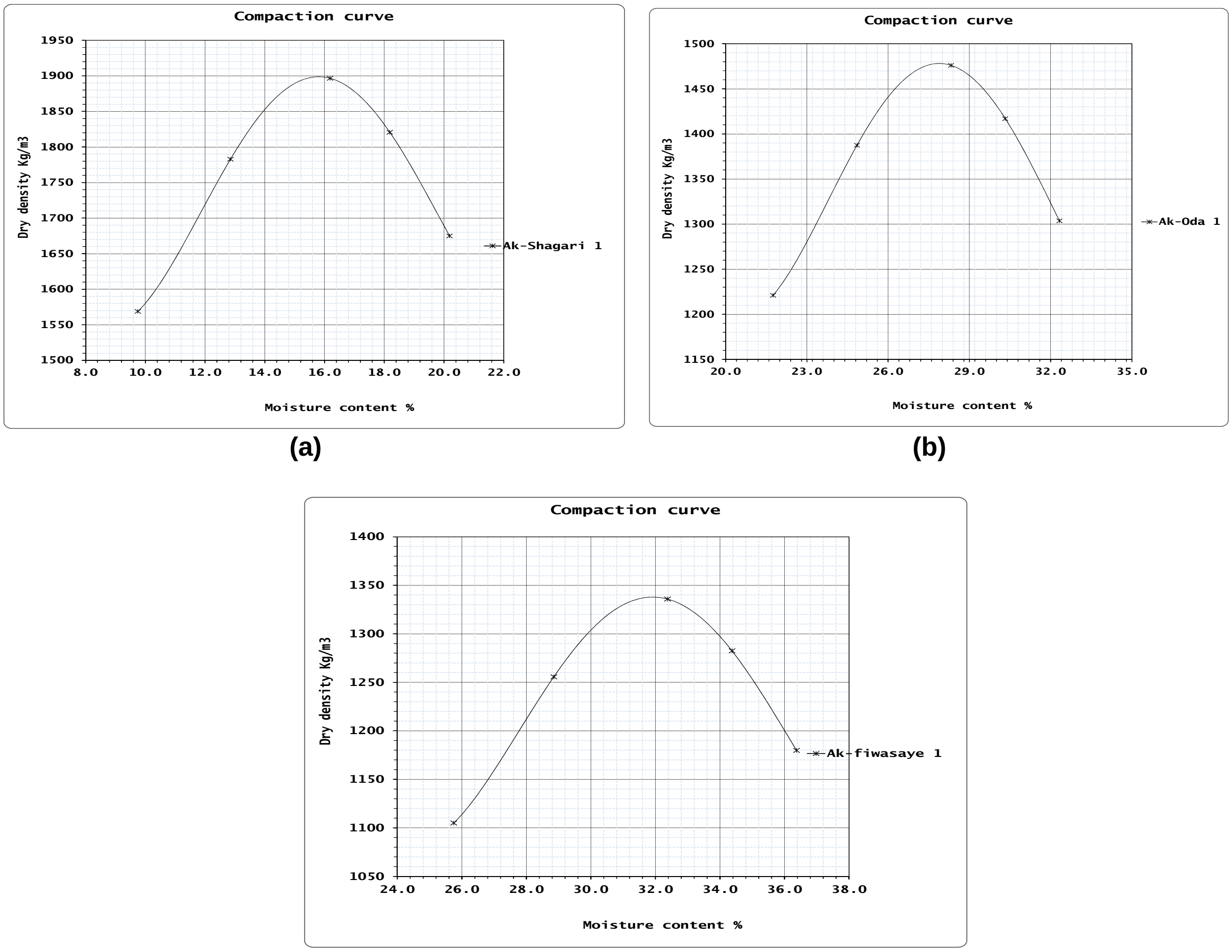


(c)

Figure 3: Typical Grading Curves obtained in (a) LC 1; (b) LC 2; and (c) LC 3



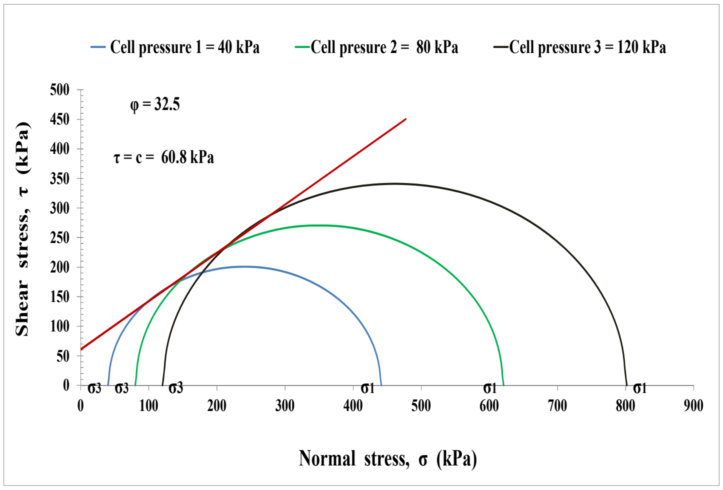
(a) (b) (c)

Figure 4: Compaction Curves of Sampled soils (a) LC 1 (b) LC 2 (c) LC 3

Table 6: AASHTO [27] Soil Classification System

	Granular Materials (35 % or less passing No. 200)							Silt-Clay Materials (More 35 % or less passing No. 200)			
General Classification	A-1			A-2							A-7
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5 A-7-6
Sieve analysis, percentage passing:											
No. 10 (2.00 mm)	50max	....	....	....	....	....	....	....	....	....	....
No. 40 (0.425 mm)	30max	50max	51max	....	....	....	....	....	....	....	....
No. 200 (0.075 mm)	15max	25max	10max	35max	35max	35max	35max	35max	36min	36min	36min
Characteristics of fraction passing No. 40 (0.425 mm)											
Liquid Limit	....	....	....	40max	40min	40max	41min	40max	41min	40max	41min
Plasticity Index	6max		N.P	10max	10max	11min	11min	10max	10max	11min	11min
Usual types of significant Materials	Stone fragments Gravel and Sand		Fine Sand	Silty - Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as subgrade	Excellent to Good							Fair to Poor			

(a)



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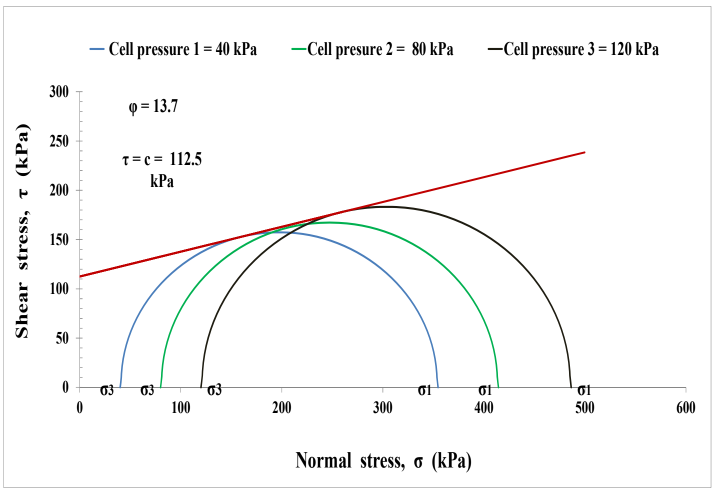

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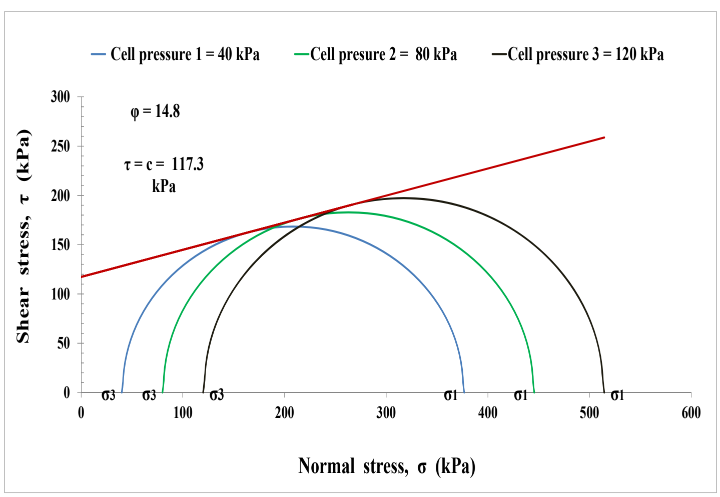

(c)

Figure 5: Triaxial Compression Curves (a) LC 1 (b) LC 2 (c) LC 3

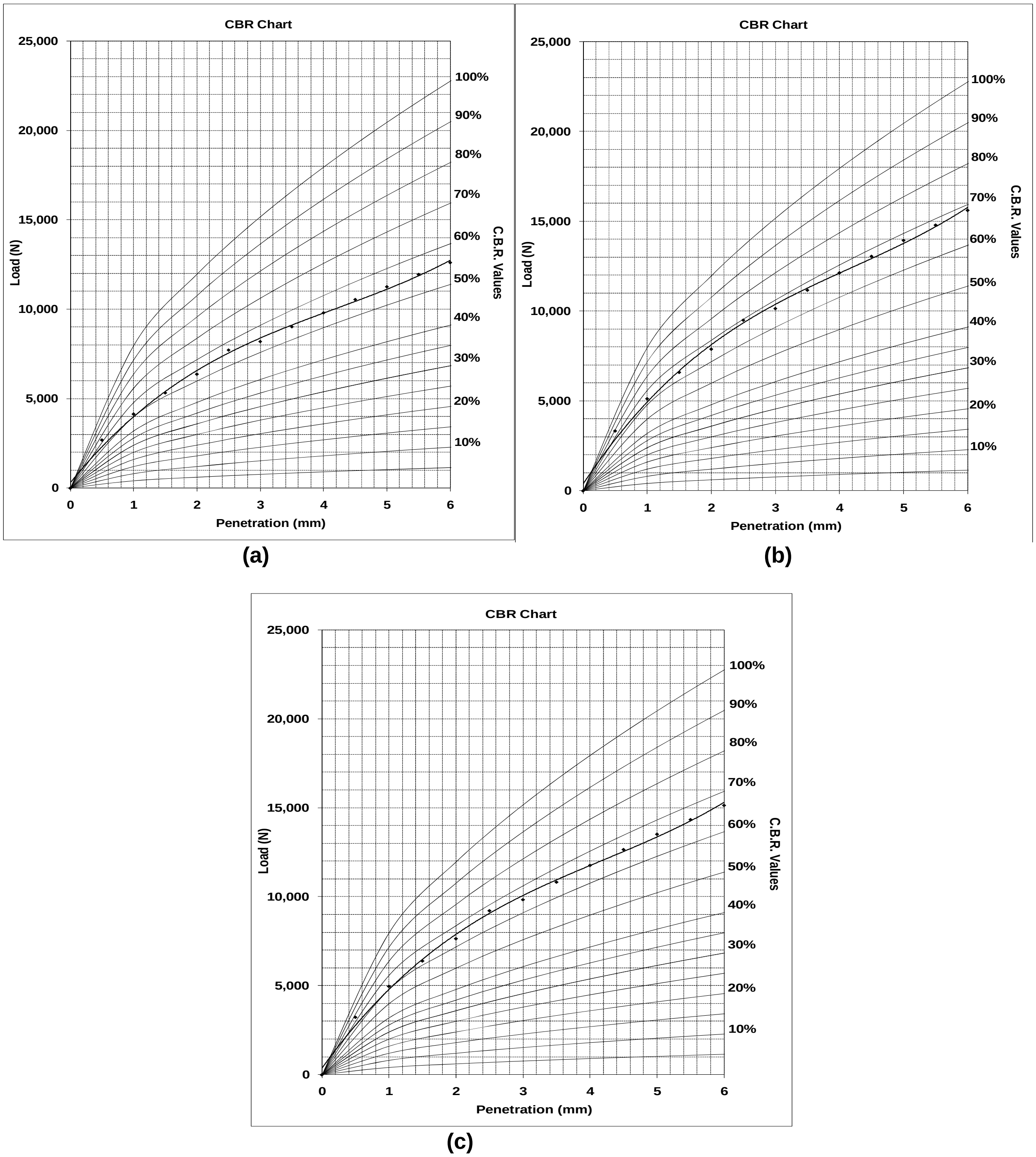

Figure 6: Typical California Bearing Ratio Curves obtained from (a) LC 1 (b) LC 2 (c) LC 3

CONCLUSION

The results of the geochemical investigations showed that the soil vary from true laterite to lateritic soil, with high percentage of Fe_2O_3, and SiO_2 especially samples taken from LC 2. The high content of iron oxide is responsible for cementing action of laterites samples in LC 2 which invariably improve the strength and deformation characteristics. This also corroborates the geotechnical results which satisfied samples from LC 2 as a good subgrade and subbase material for foundation construction as they fall within the Federal Ministry of Works and Housing Specification and AASHTO standard for subgrade, subbase, and base material on the basis of natural moisture content, Atterberg limits, and California bearing Ratio. However samples from LC 1 and LC 3 would require some level of stabilization to improve their density and compaction using conventional lime, cement, and asphaltic stabilization.

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