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Engineering Properties of Rocks and Soil in Bali and Environs Taraba State, North-eastern Nigeria

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ABSTRACT

A study was carried out to determine the Engineering properties of soil and rocks in Bali and Environs. Various geotechnical tests were conducted including particle size distribution, trial pitting, Atterberg Limit, specific gravity, compaction tests and California Bearing Ratio tests to determine the engineering behaviour of the soils. Results from the particle analysis show a range of soil classes including clays, sands and lateritic clays. The clays are suspected to be swelling types as evident by fractures in current structures around the area. As most of the soil materials are tested for their potential bearing capacity, the lateritic soils show the highest strength and are considered the better materials for siting structures in the area. Similarly, the granite and ortho-gneisses are good materials for engineering constructions ranging from dimension stones to aggregates. Although laboratory testing of rocks was not conducted, results were deduced majorly from field observations as these units show very limited fissures on outcrop surfaces and contained abundant meta-stable minerals such as quartz, feldspars and biotite mica. This study demonstrates that most of the soils around the area will be great for supporting engineering structures including roads and buildings except for a few places underlain by swelling clays.

Keywords: Rock strength, meta-stable, soil properties, engineering behavior, engineering characterisation

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1. INTRODUCTION

The geotechnical characterisation of an area is immensely important for the construction industry. It encompasses the geology of an area, soil properties, stability of slopes and behaviour of materials when subjected to moisture conditions and load. These determine the engineering design and the type of materials to be used for construction. Two important parameters are the strength of the soil and the nature and properties of the underlying rocks.

The term "soil" has different meanings, depending upon the field in which it is considered. To a geologist, it is the material in the relatively thin zone of the Earth's surface within which roots occur, and which are formed as the products of past surface processes. The rest of the crust is grouped under the term "rock". To a pedologist, it is the substance existing on the surface, which supports plant life. To an engineer, it is a material that can be built on such as foundations of buildings, bridges, basements, culverts, tunnels, embankments, roads, dams and retaining walls. This describes the fundamental importance of soil to our society. In 2015, the United Nations set up sustainable development goals where Industry Innovation and Infrastructure formed one of the most important sustainable goals (Lal, 2019). Soil Mechanics is a discipline of Civil Engineering involving the study of soil, its behaviour and application as an engineering material. Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether or not they contain a mixture of organic constituents. Soil consists of a multiphase aggregation of solid particles, water, and air. This fundamental composition gives rise to unique engineering properties, and the description of its mechanical behaviour requires some of the most classic principles of engineering mechanics. Engineers are concerned with soil's mechanical properties: permeability, stiffness, and strength. These depend primarily on the nature of the soil grains, the current stress, the water content and unit weight (Balasubramanian, 2017). To put things into perspective, this study focuses on the characterisation of rocks in Bali area and the physical and geotechnical properties of the overburden (soil). It seeks to provide useful information on the nature and suitability of engineering materials in the area with the view to guiding locals and stakeholders on the suitability of different materials for various types of construction works.

1.2 Study Area

The study area is geo-politically located in Bali Local Government Area (LGA) and part of Gashaka LGA of Taraba State. It lies between Latitudes 7° 45‘ to 8° 00‘N and Longitudes 10° 45‘to 11° 00‘E with a total of 86 km^2 . It encompasses Bali town, GidanIshaku in the south, Osuah in the west, Sarkin Dutse in the North and Gidan Fulani in the northeast. The area geologically falls within the North-eastern basement Complex and part of the Mambilla Highland.

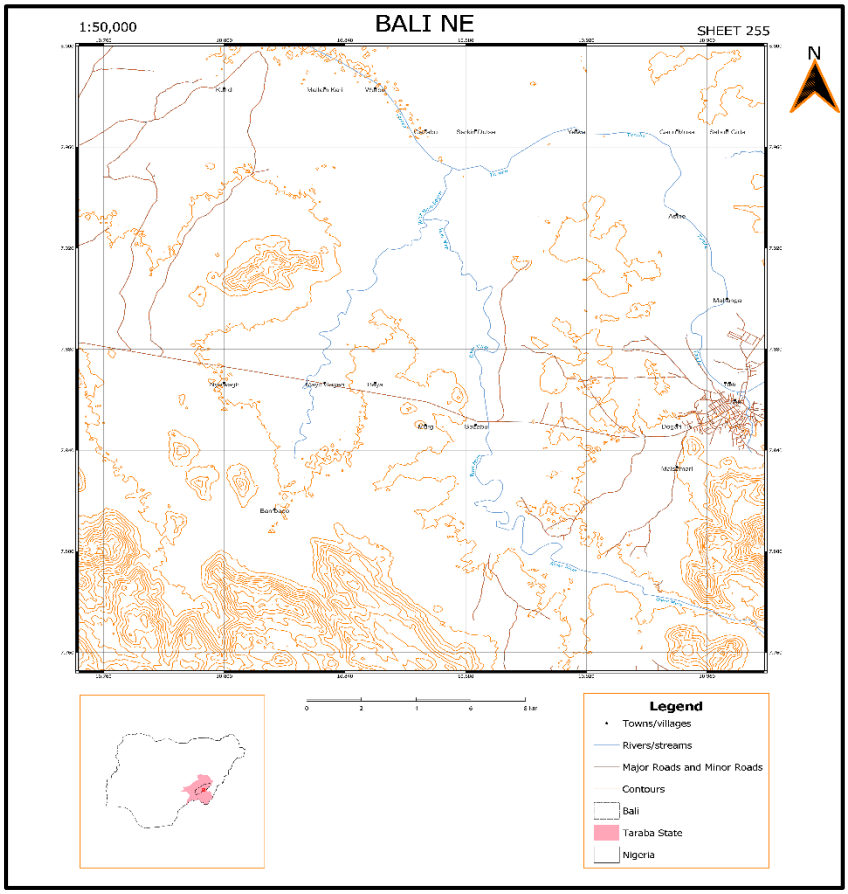

Figure 1. Location map of the study area showing Bali and environs

1.2 Morphology of the study area

The study area is generally flat with gently undulating landscapes in most of the study area except the north-western part occupied by high hills of the Mambilla and the southeastern part of the map, just south of Bali town where high mountains also occur.

2. METHODOLOGY

This research was conducted using a range of methods to determine the geological and geotechnical characteristics of rocks and soils in the study area. It includes Remote Sensing, lithological mapping, soil mapping, trial pitting and laboratory analyses of rocks and soils.

2.1 Remote Sensing

This involved the acquisition of remotely-sensed data from the United States Geological Survey (USGS) platform. LandSat 8 images consisting of 9 spectral bands were downloaded and clipped to represent only the area of interest. The 7-6-2 band combination was used to identify spectral changes due to geology while the 1-3-4 combination was used to delineate different soil types. Generally, this gave only a generic idea on the properties of rock and soil types, and more work had to be done on ground to determine the true geological and soil properties within the area.

2.2 Soil mapping

The soil around the area was mapped especially where physical changes in colour or rock types were observed. This was done in order to evaluate their physical properties since some of the soil properties such as clay types may be associated with the type of rock in the area. Soil samples were therefore systematically taken across rock boundaries using the hand

auger. While sampling, the top 2cm consisting of plant rootlets and peaty materials were scraped off and the lower 3cm to 30cm were taken. A total of 50 soil samples were taken across the area.

2.3 Trial pits

A total of 15 trial pits were hand dug using local tools called diggers. This was due to unavailability of excavators in the area. The pits were dug to a maximum of 1.5m (1500mm) as this was sufficient for most construction works in the area. The soil profile and depth to overburden was evaluated in order to identify engineering behaviour of the overburden materials.

2.4 Laboratory Analyses

Different laboratory analyses were conducted on both the soil and rock samples. The analysis of rock samples includes only the petrographic analysis, while for the soils the tests included Atterberg Limit, specific density, soil compaction, particle size distribution analysis (PSD) and California Bearing Ratio (CBR).

2.4.1 Atterberg Limit Test

The Atterberg test was conducted at the Geotechnical Laboratory, Department of Civil Engineering, Federal Polytechnic Bali using the BS 1377-2:1990 equivalent. This is a classification test to determine the moisture content at which fine-grained clay and silt soils transition between the different phases. The liquid limit, plastic limit and plasticity index of 16 samples was carried out where flow curves were also plotted. The procedure for each test is widely documented in the literature such as (Bell, 2002).

2.4.2 Specific density test

The specific gravity of different soils taken from 15 trial pits and 4 surface samples were determined using the standard bench method. The procedure involved taking measurements of jar, soil, water and their combinations. Test for each sample was performed in quadruple and averaged to get the mean specific gravity of the soil particles. This test was useful to gaining more understanding of the bearing capacity of the soil.

2.4.3 Particle size distribution analysis

The PSD analysis determines the fraction of sand, silt and clay in a given sample. The wet sieve analysis method was preferred due to the homogeneity of the soil samples and follows BS 812 method which is the standard procedure adopted at the geotechnical laboratory, Department of Civil Engineering, Federal Polytechnic Bali. This includes calculating the percentage weight retained and the total passing through 12 sets of sieves with mesh ranging from 2.36 mm to 75 microns (B's 7 to 200). Test was performed on 19 soil samples which were representative of the different soil types in the study area.

2.4.4 California Bearing Ratio (CBR) Test

A CBR analysis tests the pressure required to penetrate a soil sample with a plunger of the standard area and measuring this. The measurement is divided by the pressure needed to achieve an equal penetration on a standard, high quality crushed rock material. This means, hard surfaces would have higher CBR value. The CBR test was conducted on 4 selected trial pit samples at the geotechnical laboratory of the Department of Civil Engineering, Federal Polytechnic Bali. A number of sub-tests including speedy testing, penetration rate, standard dry compaction was conducted according to the British Standard Procedure, BS 1377-4 as summarised in the Table 1.

Table 1. Standard force-penetration Relationship for 100% CBR

Penetration (mm)	**Force (KN)**
2.0	11.5
2.5	13.2
4.0	17.6
5.0	20.0
6.0	22.2
8.0	26.3

3 RESULTS AND DISCUSSION

3.1 Engineering properties of the soil

The engineering properties of the soil was determined using a number of analyses. These include particle size distribution analysis, specific density, Atterberg Tests, Compaction test and California Bearing Ratio Test. This enabled the identification of the engineering behaviour of the soil in the study area.

3.1.2 Soil classes

The soils in the area are generally described based on their colour and texture. In terms of colour, they appear reddish brown, gray or pale red. Texturally, four soil types were identified based on their positions in the USGS textural Ternary diagram. They include sandy loam, clayey SAND, sandy CLAY and silty CLAY with varied proportions of sand, silt and clay. Results of PSD for the 19 selected samples are summarised in Table 3.3. It can be observed from the result that the lighter fractions (silt +clay) in the sandy loam are between 1.6% -4.54%, 7.36% to 9.18% for the clayey sand, 13.86%-24.44% for the sandy clay and 25.04% for the silty clay. This is significant when considering siting engineering structures on these soils based on their ability to retain or easily drain moisture. While the sandy loam is easily drained, the sandy clay and silty clay would have greater water retention and could flow and lead to structural failure at higher moisture content.

3.1.3 Trial pits

The trial pits were excavated to a maximum depth of 1.5m as shown in Table 2. The soil profile was determined and samples evaluated for strength and bearing capacity. In most of the trial pits, only 2 soil profiles were identified, that is the top soil and the intensely weathered rock. Other pits however have up to 3 soil layers, including partially weathered rocks.

Table 2. A summary of the classification of soil profiles and soil descriptions within the trial pits

Pit no.	Location	Depth (cm)	No. of profiles	Description
TP1	N7 51'34" E10 57'10"	150	3	***Profile A:*** 15 cm thick of stiff grayish CLAY ***Profile B:*** 20cm thick of brownish silty CLAY ***Profile C:*** 115cm thick of reddish brown sandy silty CLAY
TP2	N7 52'44" E10 58'55"	120	3	***Profile A:*** 40 cm thick of lateritic CLAY ***Profile B:*** 26cm thick of reddish silty CLAY ***Profile C:*** 84 cm thick of reddish brown sandy silty CLAY
TP3	N7 50'51" E10 58'07"	140	2	***Profile A:*** 40 cm thick of very stiff CLAY ***Profile B:*** 280cm thick of dark grey CLAY and partially weathered rock
TP4	N7 51'19" E10 58'74"	140	2	***Profile A:*** 22 cm thick of gravelly SAND ***Profile B:*** 118cm thick of partially weathered rock with large pebbles
TP5	N7 52'54" E10 58'88"	135	2	***Profile A:*** 90cm thick of very friable silty SAND ***Profile B:*** 45cm thick of silty SAND with intercalated mottled clay
TP6	N7 52'41" E10 58'14"	115	2	***Profile A:*** 60 cm thick of pebbly lateritic CLAY with intermittent white clay layers ***Profile B:*** 55cm thick of reddish gravelly sandy Clay
TP7	N7 51'07" E10 58'03"	150	2	***Profile A:*** 120 cm thick of very stiff greyish CLAY with intermittent white clay layers ***Profile B:*** 30 cm thick of mottled CLAY with some pebbles
TP8	N7 51'13" E10 56'55"	135	2	***Profile A:*** 125 cm thick of lateritic CLAY ***Profile B:*** 10cm thick deeply weathered Rock
TP9	N7 51'36" E10 57'40"	120	3	***Profile A:*** 38 cm thick of dark greyish CLAY ***Profile B:*** 55cm thick of reddish

				gravelly sandy Clay ***Profile C:*** 27 cm thick of pebbly lateritic SAND
TP10		150	3	***Profile A:*** 40 cm thick of lateritic CLAY ***Profile B:*** 26cm thick of reddish silty CLAY ***Profile C:*** 84 cm thick of reddish brown sandy silty CLAY
TP11		150	3	***Profile A:*** 90cm thick of very friable silty SAND ***Profile B:*** 45cm thick of silty SAND with intercalated mottled clay ***Profile C:*** 30 cm thick of mottled CLAY with some pebbles
TP12		125	2	
TP13		150	3	***Profile A:*** 40 cm thick of dark greyish CLAY ***Profile B:*** 55cm thick of reddish gravelly sandy Clay ***Profile C:*** 55 cm thick of pebbly lateritic SAND

3.1.4 Particle Size Distribution

The particle size distribution (PSD) result of 19 randomly selected samples is summarised in Table 3. These samples were taken around Unguwan Nepa, Mession, Chamba, Daniya, Tiv area of Bali and around Mai goge where there are prevalent cracks on a good number of buildings in the area. Samples 10 and 14 taken around N7 50'51" E10 58'07" and $N7°52'54''$ E10°58'88" have the highest amount of fine-grained materials (clay and silt) in them (> 20 %). Samples 9,11, 15 and 19 also have moderate amounts of fine mixtures ≥ 10 %.

Analyses of soil samples in the area suggest that different soil types would behave differently under different engineering conditions. Results of PSD analysis describe the simple relationship of possible grain to grain compaction and load bearing capacity. While most of the soils have reasonable amounts of sand fractions, samples 10 and 19 contained high amount of clay which can pose significant challenge during construction works. It is no coincidence that there is evidence of structural failures such as cracks and damps around the areas where samples 10 and 19 were taken (Unguwan Mission and Unguwan Tiv in Bali). Although no geochemical analysis was undertaken to determine the clay types in these areas, the pattern of cracks in the area may suggest a significant amount of swelling clays in them.

Table 3. A summary of PSD results showing sand percentages of sand and clay & silt in the soil samples

S/N	LOCATIONS	% SAND	% CLAY AND SILT
1	N7 51’36” E10 57’40”	96.68	3.32
2	*N*°7°51’04", E10'58’42"	95.46	4.54
3	*N*7°51′ 30″ E10°48'51"	92.14	7.86
4	*N*7°51′34", E10°57'10"	96.68	3.32
5	*N*7°51′34", E10 57'10	97.38	2.62
6	*N*7°52′ 44″, E10°58'55"	97.30	2.70
7	*N*7°51′ 7″, E10°58'3"	98.32	1.68
8	N7 51’34” E10 57’40”	98.40	1.60
9	N7 52’34” E10 58’36”	88.92	11.08
10	N7 50’51” E10 58’07”	75.56	24.44
11	*N*7°51’ 13″, E10°56'55"	86.14	13.86
12	*N*7°51′34″, E10°57'10"	98.04	1.96
13	*N*7°51′19″, E10°58'74"	90.95	9.02
14	*N*7°52′54″, E10°58'88"	74.96	25.04
15	*N*7°52′41″, E10°58'14"	87.06	12.94
16	*N*7°51′19″, E10°58'74"	92,70	7.30
17	*N*7°51′22″ *E*10 58′39"	95.66	4.34
18	*N*7°51′04″, E10°58'42"	92.14	7.86
19	*N*7°52′16″, E10°57'06"	90.82	9.18

3.1.5 Atterberg Limit Analyses

The liquid limit (LL), plastic limit (PL) and plasticity index (PI) of 16 samples was determined. However, inconsistent results point to experimental errors and results of four representative samples are presented in Table 4. The samples having the highest amount of clay fractions in the PSD results were considered most important. Results show LL of 34.00 %, PL of 21.75% and PI of 12.25% for sample 14 compared to LL; 20.00%, PL;11.11% and PI; 8.89 % in Sample 12 with lower amount of clay. The higher PI value in Sample 14 describes its greater plasticity relative to most of the other soils. Samples also taken outside

of Bali especially around Mayo Gageri show higher PI values which indicate their engineering behaviour subject to load. Flow curves are shown on Figures 2 to5.

Table 4. Summary of the Atterberg tests results for 4 soil samples showing various grades of plasticity.

Sample no.	**LL (%)**	**PL (%)**	**PI (%)**	**Plasticity description**
Sample 10	44.00	26.49	17.51	Highly plastic
Sample 14	34.00	21.75	12.25	Medium plastic
Sample 15	20.00	11.11	8.89	Medium plastic
Sample 3	21.00	16.78	4.22	Less plastic

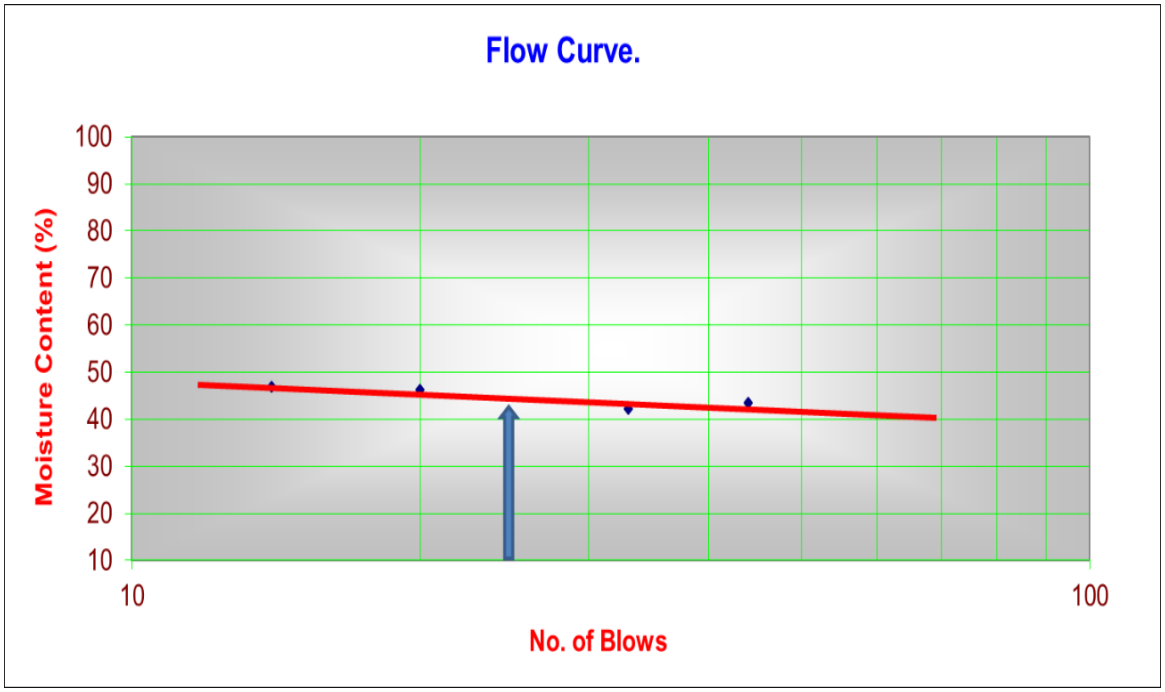

Figure 2. Flow curve for sample 10 which is a highly plastic soil

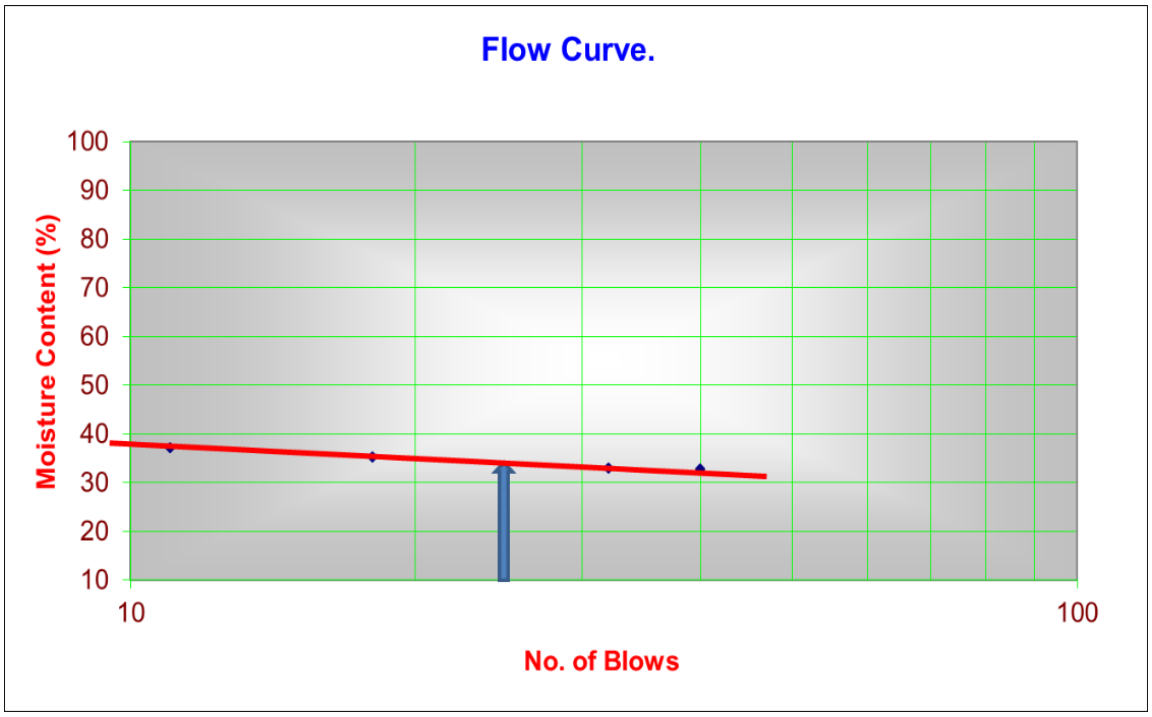

Figure 3. Flow curve for Sample 14; a medium plastic soil

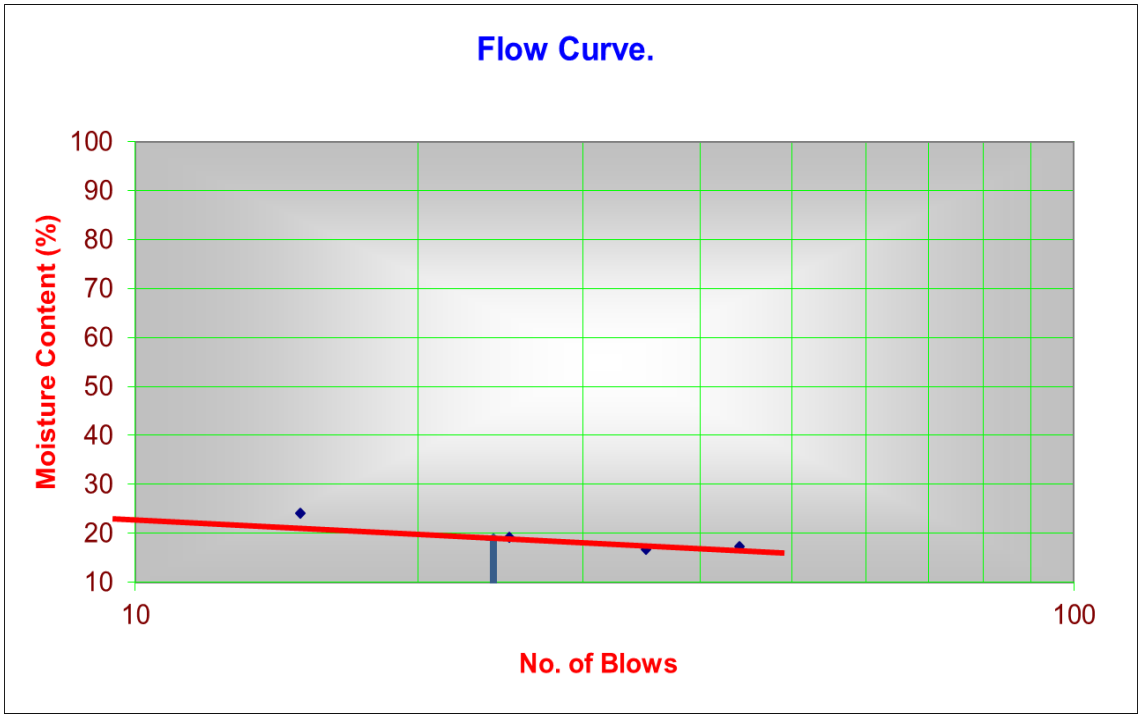

Figure 4. Flow curve for sample 15, a medium plastic material

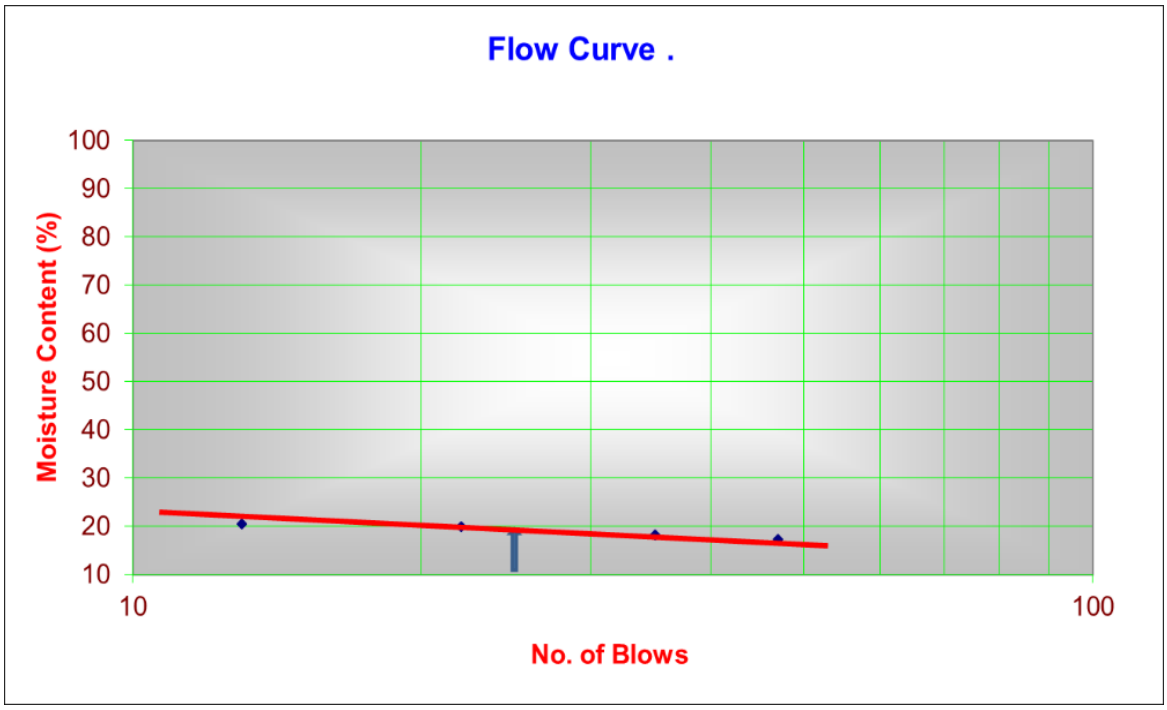

Figure 5. A flow curve for sample 13, a less plastic material

3.1.6 Compaction Analyses

Laboratory compaction test was conducted on 5 trial pit samples in order to determine the optimal moisture content and the dry density values of the soil. The results are summarised in Table 5. Samples from TP1 and TP8 showed the highest MDD values while TP4 has the lowest as shown in Figures 6 to 9. The OMC value range of 8 % to 15 % is typical of

granular to silty and non-plastic clays which corroborates the PSD results. Furthermore, these results fall within the range given by Abrahamson et al. (1995) for a similar kind of materials. Generally, the soils show good compaction within 95% confidence interval. This implies that for most of the soils taken in the trial pits, they show good compaction under load and are therefore considered as fair to good engineering materials although in-situ tests need to be carried out to validate these results.

Table 5. A summary of compaction test of 5 soil samples to determine their optimum moisture content (OMC) and maximum dry density (MDD)

TP no.	**Soil type**	**OMC (%)**	**MDD (Mg/m^3)**
TP1	Composite (sand and clay)	8.8	1.98
TP4	Composite (loam and clay)	14.3	1.76
TP8	Composite (loam and clay)	10.8	1.94
TP11	Composite (loam and clay)	8	1.89
TP13	Composite (silty sand)	8.2	1.92

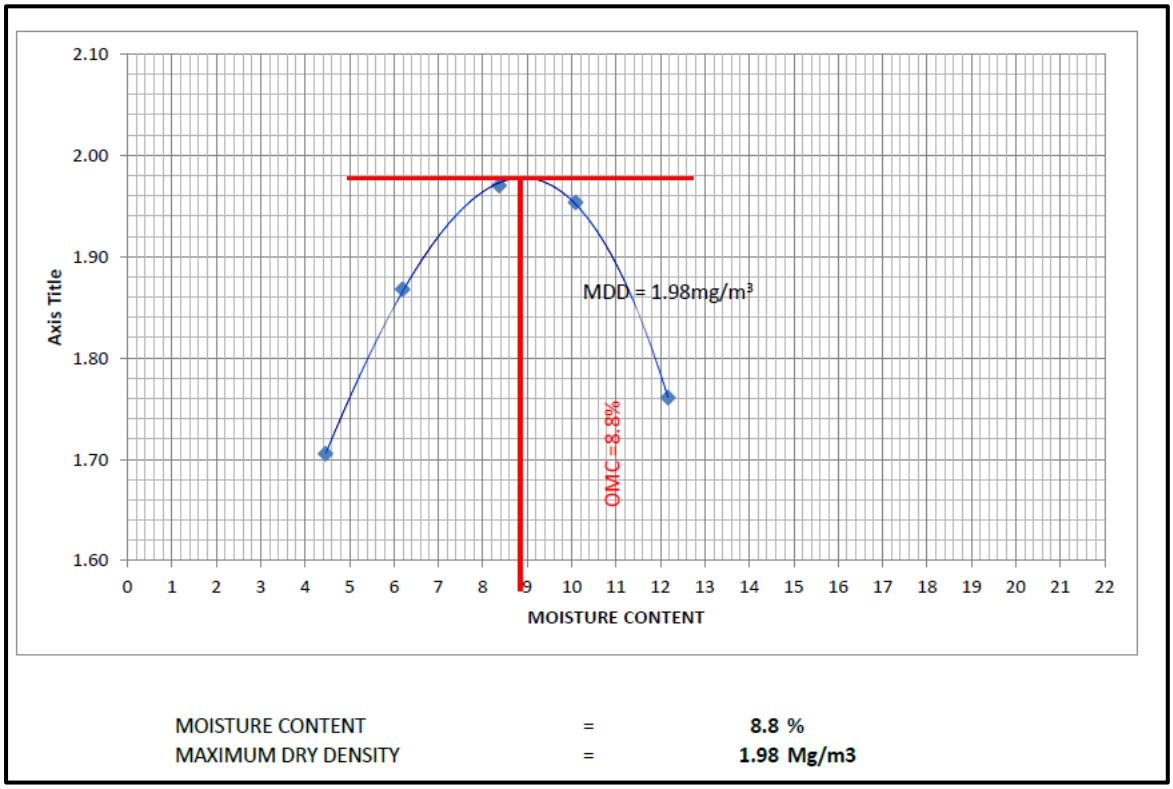

Figure 6. Proctor curve for samples from TP1 showing the optimum moisture content (8.8%) and maximum dry density (1.98 Mg/m^3)

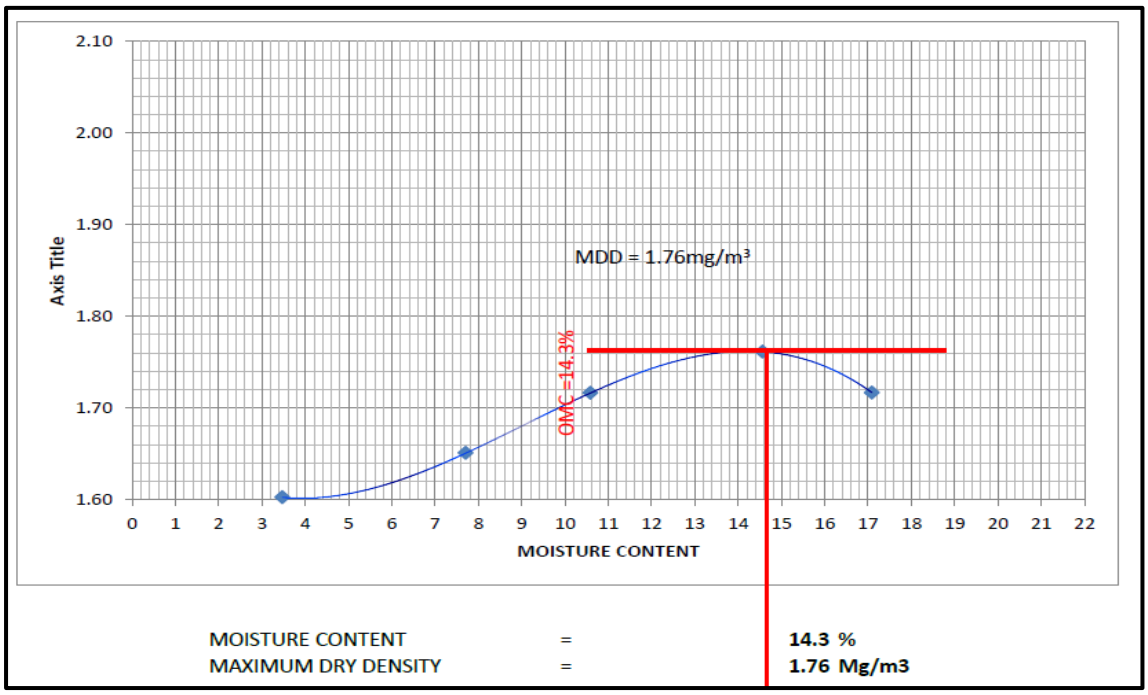

Figure 7. Proctor curve for samples from TP4 showing the optimum moisture content (14.3%) and maximum dry density (1.76 Mg/m3)

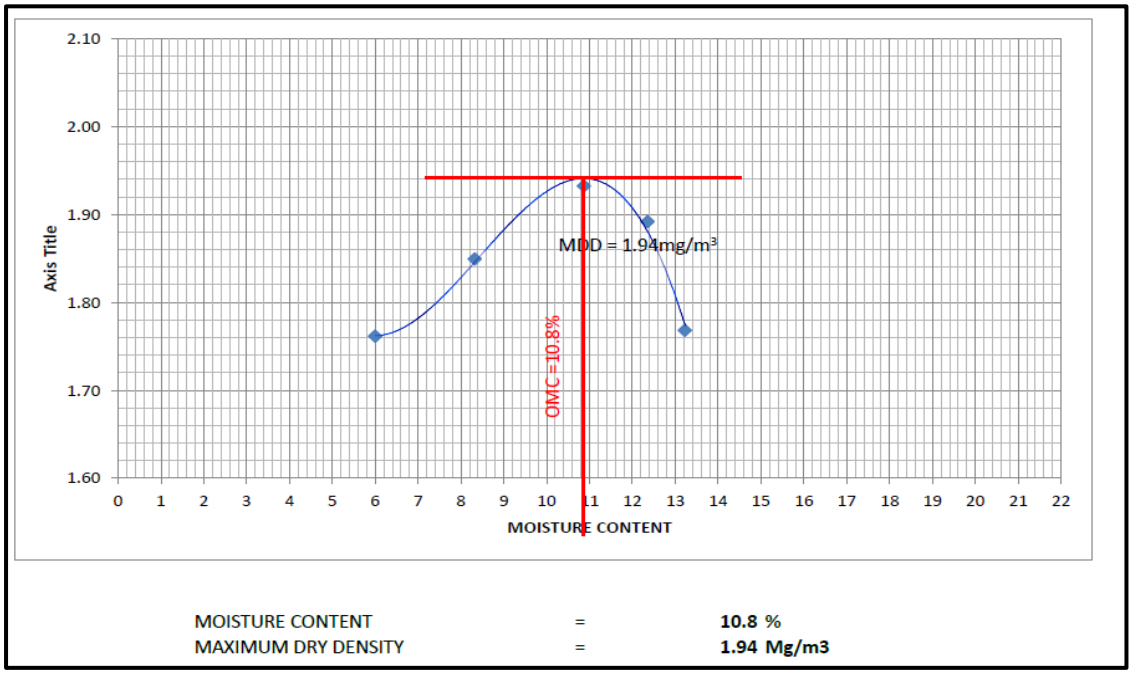

Figure 8. Proctor curve for samples from TP11 showing the optimum moisture content (10.8%) and maximum dry density (1.94 Mg/m3)

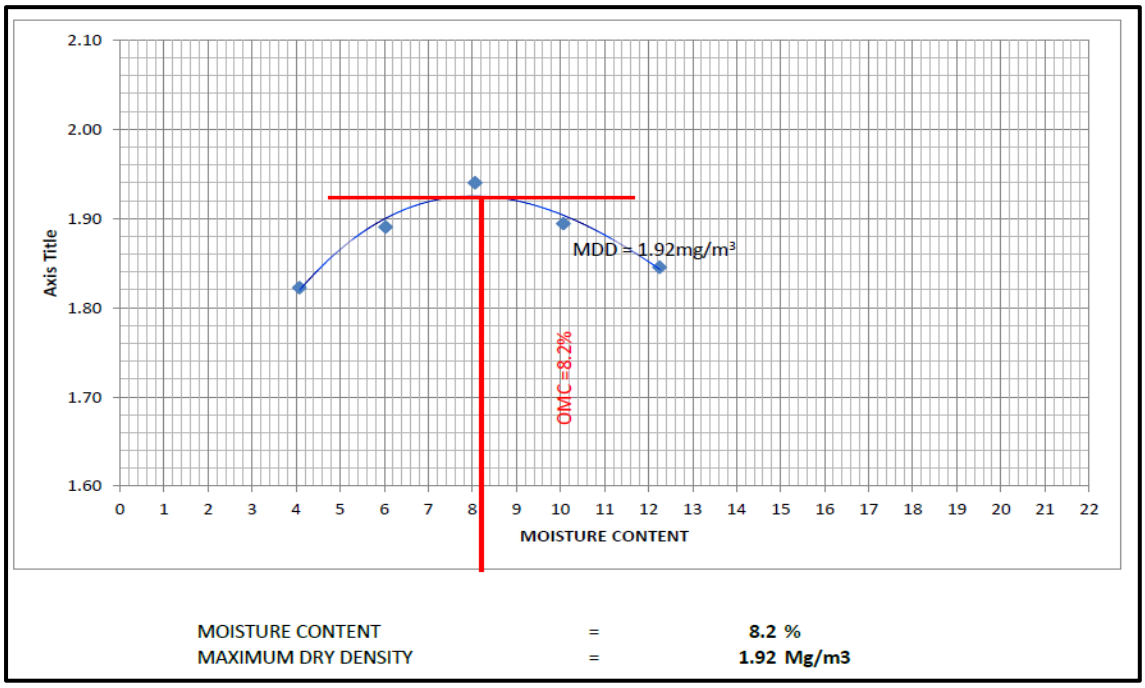

Figure 9. Proctor curve for samples from TP13 showing the optimum moisture content (8.2%) and maximum dry density (1.92 Mg/m3)

3.1.7 Specific Density of soils

Result showing the average specific density of 19 samples is summarised in Table 6. In most of the samples, the values fall between 2.4 to 2.9 which are consistent with most natural soils. However, unusually high specific gravity values (>3) were obtained in samples 5 and 19. Although sample 5 was a coarse-grained material taken at the upper 30 cm of the soil profile

and could contain some foreign materials which accounts for the high specific gravity value, there was no direct evidence for sample 19 having only 10% fine particles. It was therefore concluded that the high specific gravity value obtained for sample 19 could be due to experimental errors. Generally, the specific gravity values indicate the soil within the area to be reasonably strong to support engineering structures.

Table 6. A summary of specific gravity results showing a range of 2.4 to 2.9 for most samples. Unusually high values are obtained in 2 samples

S/N	LOCATION	AVERAGE SPECIFIC GRAVITY
1	N7 51’36” E10 57’ 40”	2.5
2	N7 51’04” E10 58’42”	2.6
3	N7 51’30”E10 48’51”	2.5
4	N7 51’34” E10 57’10”	2.7
5	N7 51’22”E10 58’39”	3.1
6	N7 52’44” E10 58’55”	2.8
7	N7 51’7”E10 58’3”	2.7
8	N7 51’34” E10 57’40”	2.5
9	N7 52’34” E10 58’35”	2.7
10	N7 50’51” E10 58’7”	2.7
11	N7 51’13”E10 56’55”	2.7
12	N7 51’19” E10 57’22”	2.4
13	N751’19” E10 58’74”	2.7
14	N7 52’54” E10 58’88”	2.5
15	N7 52’41” E10 58’14”	2.7
16	N7 51’19” E10 58’14”	2.9
17	N7 49’21” E10 48’31”	2.7
18	N7 56’13” E10 57’21”	2.4
19	N7 52’16” E10 57’6”	3.3

3.1.8 California Bearing Ratio (CBR) Analysis

CBR test conducted on 4 trial pit (TP5, TP6, TP7, TP8, TP9) samples indicate their bearing ratios at maximum dry density (100% MDD). Results are summarised in Table 7. But individual values are also described in preceding tables.

TP5 is a reddish silty SAND sample with intercalated mottled clay. At corrected 2.5 mm and 5.0 mm penetration, CBR values of 14.9 and 17.1 respectively were obtained. When calculated at 100% MDD, CBR was 19.

Table 7. CBR Test result for sample of TP5 at 2.5mm and 5.0mm penetration (corrected)

	Applied Load L_a KN	Standard Load L_s	CBR=La/Ls*100%
At Corrected 2.5mm Penetration	1.97	13.2KN	14.9
At Corrected 5.0mm Penetration	3.42	20.0KN	17.1

In sample TP6, the soil materials consist of lateritic clay and reddish gravelly sandy CLAY. At corrected 2.5 mm and 5.0 mm penetration, CBR values of 18.8 and 19.7 respectively were obtained. When calculated at 100% MDD, CBR was 20.

Table 8. CBR Test result for sample of TP6 at 2.5mm and 5.0mm penetration (corrected)

	Applied Load L_a KN	Standard Load L_s	CBR=La/Ls*100%
At Corrected 2.5mm penetration	2.48	13.2KN	18.8
At Corrected 5.0mm penetration	3.93	20.0KN	19.7

TP7 is a stiff dark grey CLAY with some whitish clay. At corrected 2.5 mm and 5.0 mm penetration, CBR values of 20.4 and 18.7 respectively were obtained.

Table 9 CBR Test result for sample of TP7 at 2.5mm and 5.0mm penetration (corrected)

	Applied Load L_a KN	Standard Load L_s	CBR=La/Ls*100%
At Corrected 2.5mm penetration	2.69	13.2KN	20.4
At Corrected 5.0mm penetration	3.73	20.0KN	18.7

Similarly, TP8 is a stiff lateritic CLAY. At corrected 2.5mm and 5.0 mm penetration, CBR values of 20.4 and 18.7 respectively were obtained. When calculated at 100% MDD, CBR of 19 was obtained.

Table 10. CBR Test result for sample of TP8 at 2.5mm and 5.0mm penetration (corrected)

	Applied Load L_a KN	Standard Load L_s	CBR=La/Ls*100%
At Corrected 2.5mm penetration	2.69	13.2KN	20.4
At Corrected 5.0mm penetration	3.73	20.0KN	18.7

Results in Table 11 show that TP6 composed of lateritic clay and gravelly sandy clay has the highest bearing ratio among the tested samples. This is really significant in terms of strength of the material and potential use for pavement and road. TP 6 is shown in Figure

Table 11. Summary of CBR analysis for soil samples from TP5, TP6, TP7 and TP8

Sample	**CBR at MDD (%)**
TP5	17
TP6	20
TP7	19
TP8	19

Furthermore, results from the trial pits show reasonably thick overburden overlying partially weathered basement rocks. From the CBR and Compaction test results, soil around TP6 composed of lateritic clay sand and gravelly materials have the highest strength with CBR of 20% compared to other soil types in the area. This is corroborated with high specific gravity values (up to 2.9) and low moisture content.

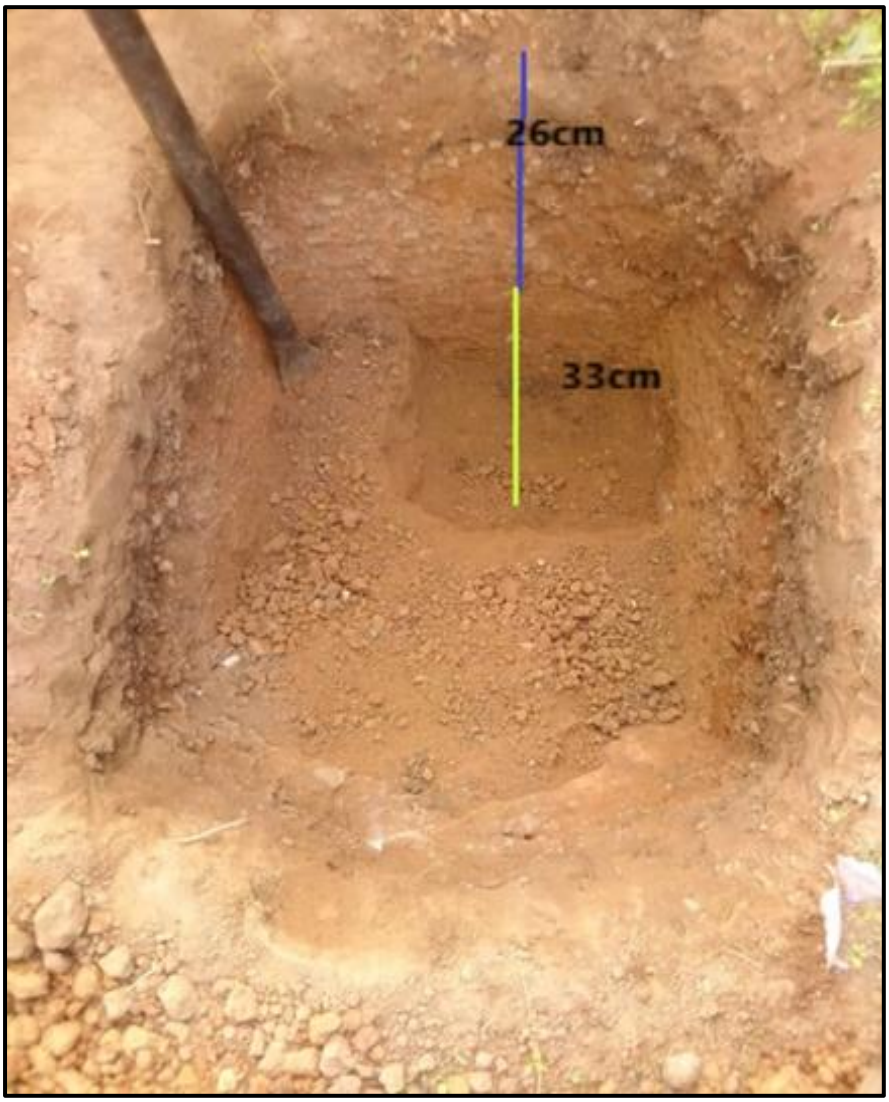

Figure 10. A photograph showing trial pit 6 (TP6) composed of lateritic material. This sample has the highest CBR value in the area.

4. CONCLUSION

Analyses of rocks and soils in Bali and environs were undertaken to characterise the materials and determine their suitability as engineering materials as well as to determine their ability to support engineering structures. The rocks in identified in the area including gneiss, granite, metasediments and pegmatites are typical Basement Complex rocks belonging the Older Granite Suite as also reported in the North-Central and North-western Nigeria. Significantly, the few macro-structures encountered in the area with NE/SW to N-S orientation further buttresses this fact. However, the limited occurrences of fissures in the granitic rocks make them more suitable engineering materials. Among these units, the ortho-gneisses and granites are the most important engineering materials which can be used as aggregates and dimension stones. Similarly, most of the soil types in the area have reasonable strength and can support small to large engineering structures, especially the lateritic soils. However, the occurrence of clay-rich soils envisaged to contain high amount of swelling clay around Unguwan Nepa, Mission, Tiv, and Rest House may pose significant risks to construction works. This is supported by the presence of structural failures on existing buildings in the area and may require special engineering design during construction. However, further work including the geochemical analysis of the clay samples need to be conducted in order to determine the types of swelling clays in the area. Further, in-situ testing of soil materials would add credence to the results reported in this study.

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