**Nigerian Journal of Technology (NIJOTECH)**
Vol. 42, No. 1, March, 2023, pp.99 - 106
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i1.12

# GEOTECHNICAL INVESTIGATION OF THE SUB-SOILS CONDITION AROUND YELWA NORTH CENTRAL PART OF NIGERIA FOR THE CONSTRUCTION OF INFRASTRUCTURES

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**Article history: Received 25 September, 2021. Revised 08 May, 2022. Accepted 08 May, 2022**

**Abstract**

*Investigation of the geotechnical conditions of the Sub-soils around Yelwa North Central part of Nigeria was carried out in order to know the possible causes of the infrastructural failures in the area. The investigation involves in-situ collection of the disturbed and undisturbed soil samples and were analysed in the laboratory based on British Standard (BS) method for soil testing for civil engineers. Results of the study reveals that; The Atterberg limit (Liquid limit ranged from 33.0% to 43.0%, Plastic limits from 16.23% to 26.37%, Linear shrinkage from 7.86% to 15.71%, Plasticity index from 7.63% to 24.77%). The Sieve analysis shows that; the percentage passing of the soil samples ranges from 31.62% to 67.60% which indicates poor materials. The Direct shear test revealed that the cohesive strength (c) ranges from 13 kN/m$^2$ to 24 kN/m$^2$, angle of internal friction (ø)° from 12° to 16° and unit weight (ϒ) from 18.17 kN/m$^3$ to 20.87 kN/m$^3$. From the Consolidation test; the Total settlement (Pc) ranges from 0.0008 m to 0.013 m, Coefficient of Consolidation (Cv) from 87.657 m$^2$/yr to 109.325 m$^2$/yr and Volume Compressibility (Mv) from 0.0048 kN/m$^2$ to 0.0205 kN/m$^2$. The Soil pH ranges from 6.4 to 7.4, Specific gravity (SG) from 2.57 to 2.73, and Natural Moisture Content (NMC) from 8.48% to 25.77%. The Compaction test revealed that; the Optimum Moisture Content (OMC) ranged from 13.22% to 20.60%, Maximum Dry Density (MDD) from 1.59 g/cm$^3$ to 1.88 g/cm$^3$which shows that the soil are mostly of silty-clay material and Un-soaked value of California Bearing Ratio (CBR) ranges from 50.88% to 96.51%. The findings have revealed that, the sub-soil is characteristically fair to poor, and this required a form of geotechnics. Information acquired from the findings are expected to serve as guide in the choice of design and construction and as a baseline subsurface soil compendium for the construction of infrastructure in the study area and for further studies.*

**Keywords:** Construction, Geotechnical, Infrastructures, Investigation, Sub-soil.

## 1.0 INTRODUCTION

Infrastructures fall in the category of civil constructions that involves the use of water, earth, or transport. It has been observed in recent times, that many property developers in Nigeria ignore drastically the role of geotechnical investigation of the sub soil condition in the planning, design, construction, operation as well as safety of infrastructures. This neglect has resulted to the failure of structures according to [1], [2], [3]. The needs to significance foundation materials for the construction of infrastructures cannot be over emphasized since structures are built on the earth [4]. Geotechnical assessment of the sub-soil condition of an area for infrastructural development will help to mitigate the causes of structural failure in order to avoid loss of lives and property. Geotechnical investigation of sub-soil involves the application of soil and rock mechanics to the design of foundations for retaining and earth structures [5]. Geotechnical parameters are very necessary in order to obtain accurate soil foundation design at the initial phase and improvement of failure mitigation in future [6].

The most important geotechnical problems associated with soil in construction is the presence of silty-clayey materials in a construction site. This is due to their poor bearing capacity such as; low strength, durability and high compressibility and the swell-shrink nature of the over-consolidated swelling soils [7]. [8] is of the opinion that seasonal moisture changes, percentage of fine materials, Atterberg limits, dry density, permeability, and presence of vegetation trees are responsible for the volume changes associated with expansive soils. Hence, the determination of geotechnical properties such as swelling potential, index properties and clay mineralogy are very significant to understand swelling characteristics of soil [9]. The characteristics and durability of a soil as a foundation material is a function of its efficiency in response to the load applied on it [10]. According to [11], infrastructures forms part of civil engineering that plays an important role in societal development and that described its endeavours as diverse and complex that involves nonstandard challenges. Common infrastructures like bridges, dams, buildings, roads, and railways helps to improve human lives and our society. The performance of soil in engineering practice is greatly influenced by the environmental conditions and conditions imposed by construction of structure [12].

In geotechnical engineering soils with properties that are not safe and cannot be economically used for the construction of engineering structures without adopting some stabilization measures are considered to be problematic [13]. Infrastructural development involves different sub-disciplines that includes; construction, structural, water resources, geotechnical, transportation, municipal or urban, materials, coastal, architectural engineering and surveying. Previous works written by different authors from the literatures in relation to the construction of infrastructures includes; [14], [15], [16], [17], [18], [19], [20], [21], [22], [23]. However failure of some infrastructures in the study area is due to the presence of deformations such as; cracks, potholes, ruts, peeling, depression, differential heave and tilting as observed on the buildings, roads, retaining walls and this has results to the needs to carry out the geotechnical assessment of the sub-soil condition in other to mitigate the failure of these structures and the effects it creates to the humanity. It is for this reason that a clear understanding of the occurrence, composition, distribution, geologic history as well as the geotechnical properties of subsoil is necessary in the area to generate relevant information. However, the persistent failure of these structures has become a source of worry to all g Stakeholders. One of the factors responsible for these failures as adjudged by professionals are lack of geotechnical assessment of sub-soil properties which is a pre-condition for its use in construction either as a construction material or foundation for structures [24]. Consequently the objective of the research is to access the engineering properties of the sub-soil condition around Yelwa in Jos North, Local Government area of Plateau State for infrastructural development.

## 1.1 The Study Area

The study area falls within the coordinates; Latitude 9° 00′ 00″N to 9° 59′ 00″N and Longitude 8° 16′ 30″E to 8° 56′ 00″E (Figure 1). It is located in Jos North, a Local Government in Plateau State on a topographical map (Naraguta Sheet 168NE). The presence of roads in the area makes it to be accessible. The climatic condition is cold, with mean annual temperature that ranges from 19.4ºC to 24.5ºC [25], with an average rainfall between 1050-1403mm, peaking between July and August. The vegetation pattern of the area is of guinea savannah type, classified as woodland savannah vegetation with the understory dominated by grasses according to [26]. Physiographically the area is drain by River Dilimi tributaries which cut across the Basement areas in Russo and Farin Gada.

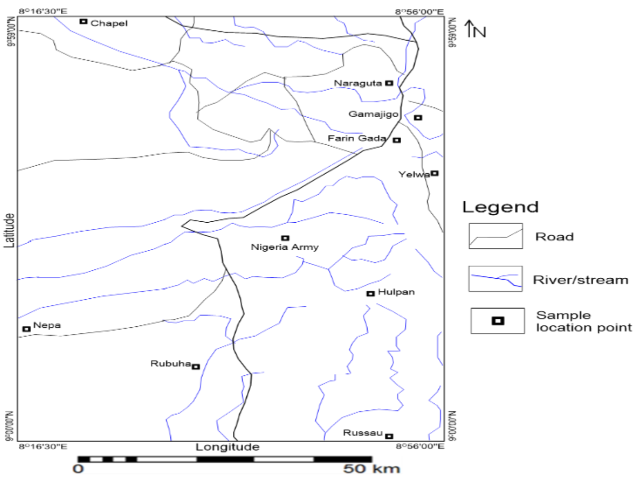


**Figure 1:** Location map of the study area.

This is due to the undulating nature of the terrain that generally slopes in different directions in different locations. The area is underlain by the Basement Complex rock and Younger Granites of the North Central part of Nigeria. The Basement rock consists of mainly Migmatite and the Granite gneiss. According to [27], the Basement rock have undergone series of Orogenic episodes such as; Eburnean (2000±200Ma), Kibaran (1100±150Ma) and Pan-African (6000±150). According to [28], the Younger Granite rocks intruded into the Basement rocks. It occurs as rocky hill massifs, sharply differentiated from the smother topography of the surrounding Basement rocks [29]. Prominent hilly features in the area are inselbergs, and whalebacks which are the category of residual hills [30]. They occur as Sub-volcanic intrusive complexes of ring dykes and related annular and cylindrical intrusions [31]. The soils associated with these rocks are basically clays, lateritic clays or laterite emerging from the weathering of the minerals in the rocks.

## 2.0 MATERIALS AND METHODS

Ten (10) disturbed and undisturbed soil samples were collected for geotechnical investigation of the sub-soils conditions at the depth of 1.0 m (Figure 2). The geographical coordinates of the various sampling spots are taken via the use of Global Positioning System (GPS) (Table 1) during the reconnaissance survey of the study area to ascertain surface geological condition of the study area. The disturbed samples were collected by using digging tools and other field equipment while the undisturbed soil samples were collected by using core cutter. The rock samples encountered were only studied in-situ to observe the physical properties that of engineering significance. Visual observation of the soil was also under taken to examine the soil texture for systematic description of the soils. Detailed laboratory analyses were carried out on the representative undisturbed and disturbed samples for classification and strength test parameters. The test was conducted based on the [32], methods of test for soil for civil engineering purposes.

**Figure 2:** Depth of soil sample collected

The soil samples were subjected for laboratory testing of; Natural Moisture Content (NMC), Specific gravity (SG), Sieve analysis (grain size analysis), Soil ph, Atterberg limits (Liquid limit, Plastic limit and Linear shrinkage test), Compaction, Consolidation, Direct shear and California Bearing Ratio (CBR). The Preparation of the soil samples for each test depends on the procedure required for such test to be carried out. Some soil samples were first sun dried before making use of them in the laboratory while some were used in their natural state. Laboratory equipment such as: Electric oven, Sieve shaker, Casagrande cup, Grooving tool, Cans and Spatula, Weighing balance, Cutting collar, Mould, Tampering road, Shear box machine, Collar, Funnel, Spoon, pH meter, Density bottle, Distilled water, Rammer, Dial gauge, Mixing pan, Loading frame, Porous stone, Sample tray, Stop watch, Oedometer and California Bearing Ratio (CBR) machine were used for the analysis. The laboratory results are presented in the tables and were interpreted based on scientific (engineering) perspective to give the prediction and some facts on the possible causes of the structural failures in the study area.

**Table 1:** The GPS Reading of the Sample Locations of the study area

| S/N | LOCATIONS | LATITUDE (N) | LONGITUDE (E) | ELEVATION (M) |
|---|---|---|---|---|
| 1 | Naraguta | 09° 49′ 23.0″ | 008° 51′ 23.4″ | 1150 |
| 2 | Rubaha | 09° 10′ 14.2″ | 008° 33′ 24.3″ | 1065 |
| 3 | Hulpan | 09° 20′ 54.8″ | 008° 49′ 12.0″ | 1089 |
| 4 | Yelwa | 09° 37′ 49.0″ | 008° 55′ 18.2″ | 1141 |
| 5 | Chapel | 09° 58′ 28.1″ | 008° 22′ 38.2″ | 1119 |
| 6 | Nepa | 09° 15′ 43.0″ | 008° 17′ 07.3″ | 1157 |
| 7 | Russau | 09° 00′ 36.8″ | 008° 50′ 48.3″ | 1195 |
| 8 | Nigerian Army | 09° 28′ 14.7″ | 008° 41′ 11.3″ | 1139 |
| 9 | Gamajigo | 09° 45′ 13.9″ | 008° 53′ 12.9″ | 1107 |
| 10 | Farin Gada | 09° 41′ 52.6″ | 008° 50′ 59.9″ | 1178 |

**Source:** Fieldwork 2021

## 3.0 RESULTS AND DISCUSSIONS

The results of the laboratory analyses of the soil samples were based on; the soil classification test (Atterberg limit, Sieve analysis, Specific gravity, Natural moisture content and Soil pH) and the strength test (Direct shear, Consolidation, Compaction, and California Bearing Ratio) and these are presented in Table 2 and Table 3, 4, 5 and 6. While the Engineering Classification using Plasticity Index (PI) according to liquid limit and Compaction classification are presented in Table 7, and 8. The Atterberg limit which consist of the; liquid limits ranges from 33.0% to 43.0%, plastic limits from 15.83% to 26.37%, plasticity index from 7.63% to 23.67% and linear shrinkage from 8.57% to 15.71% (Table 2).

According to [33], and [34], Atterberg limit is one of the important geotechnical properties in civil engineering works that describe the consistency of a cohesive soil in order to provide useful information regarding the soil strength, behaviour, stability, type and state of its consolidation. Based on the Engineering Plasticity using plasticity index (Table 7), the soil are mostly classified as medium to high, with the exception of location 6 which is low. These imply that any structures founded on the soils may results to excessive deformations like cracks, potholes, settlement and tilting. The values of the plastic limit and linear shrinkage are very important for the construction of civil engineering structures such as; earth roads, clay core in an earth fill dam, foundation design, building, retaining walls, slab bridges, suitability of the soil on a slope and other excavation works. According to [35], soil with plasticity index greater than 17 is classified as clay and these can exhibit high plasticity with cohesive nature. These can cause cracks and settlement problem in structures when it shrinks and swells as a result of water absorption. The value of the shrinkage limit can also be used for understanding the swelling and shrinkage properties of cohesive soils as a construction material in foundations, roads, embankments and dams [35].

**Table 2:** Results of the Soil Classification test

| S/N | Liquid Limit (LL)% | Plastic Limit (PL)% | Linear Shrinkage (LS)% | Plasticity Index (PI)% | Sieve Analysis | Specific Gravity | Natural moisture Content | Soil pH |
|---|---|---|---|---|---|---|---|---|
| 1 | 34.00 | 19.14 | 10.00 | 14.86 | 40.76 | 2.69 | 9.9 | 6.5 |
| 2 | 43.00 | 22.15 | 15.71 | 20.85 | 38.42 | 2.57 | 19.01 | 6.9 |
| 3 | 39.00 | 25.66 | 12.86 | 13.34 | 50.54 | 2.63 | 17.43 | 6.6 |
| 4 | 39.00 | 18.33 | 11.43 | 20.67 | 62.68 | 2.64 | 14.61 | 7.0 |
| 5 | 42.00 | 24.05 | 10.71 | 17.95 | 31.62 | 2.73 | 12.62 | 7.4 |
| 6 | 34.00 | 26.37 | 10.00 | 7.63 | 67.66 | 2.63 | 25.77 | 6.7 |
| 7 | 42.00 | 18.33 | 9.29 | 23.67 | 57.84 | 2.68 | 19.16 | 6.4 |
| 8 | 33.00 | 20.00 | 10.71 | 13.00 | 47.50 | 2.71 | 24.93 | 6.9 |
| 9 | 33.00 | 16.23 | 8.57 | 16.23 | 36.32 | 2.65 | 8.48 | 7.1 |
| 10 | 37.00 | 15.83 | 10.00 | 21.17 | 45.06 | 2.73 | 14.02 | 7.2 |

The result of the sieve analysis (Table 2), shows the percentage passing, which ranges from 31.62% to 67.66% [36], explained that sieve analysis is widely used in the classification of soils. Data obtained from the sieve analysis can be used in the design of filters for earth dams and to determine the suitability of the soils for road, building, airfields, levee, bridge and other embankment constructions [37]. [38], the specification requirement for a soil to be used for the constructions of infrastructures such as road and bridge, the percentage by weight passing the No. 200 sieves shall be less than but not greater than 35%. Sequel to the above, the samples under investigated were not good samples because the percentage by weight passing sieve No. 200 for the soil has exceed 35% except the sample collected at location 5. These indicate that structures erected in those locations may collapse due to poor bearing capacity of the soil because of high percentage of silts and clay content which can exhibit high compressibility. The specific gravity for the studied soil samples ranged from 2.57-2.73 (Table 2).

According to specification, a good soil material should have specific gravity that ranges from 2.50-2.75. Based on the samples investigated it has falls within the acceptable specification. [39], increase in specific gravity can increase the shear strength parameters (cohesion and angle of shearing resistance). The results showed that most of the soil will be good for the construction of engineering structures such as roads, bridges, buildings, airfield and retaining walls since it falls within the required specifications. The specific gravity is an important index property of soils that is closely linked with mineralogy or chemical composition [40], and also reflects the history of weathering. The result of the Natural moisture content test of the soil ranges from 8.48% to 25.77% (Table 2). According to [41], moisture content is one of the factors that affect dry density of soils. The moisture content of various soils varies generally ranging from about 10% to 15% for sand, 15% to 30% for silt and 30% to 50% for clay, Bay mud 100% to 200% [42]. Locations 1, 4, 5, 9 and 10 indicate soil with sandy material while the remaining locations 2, 3, 6, 7 and 8 indicate soil with silty materials.

The result showed that most of the soils within the study area are silty-sand material. The presence of silty material encountered in some location indicates poor water absorption capacity and can be problematic to civil engineering structures. The reason for high moisture content of the silty and clay soil could be attributed to the fact that, high rainfall which could increase the water table. The low value of natural moisture content of some soil like sand indicates that the water table fluctuates during the dry season. The soil pH values ranged from 6.4 to 7.4 (Table 2). Soil pH from 0-7 is acidic, 7 are neutral and from 8-14 is alkaline [43]. The result has showed that most of the soil samples are within the acidic limit except the sample collected at location 4, 5, 9 and 10 which are neutral. According to [44], acidic soil can lead to extreme corrosion rate and pitting of metallic objects. A neutral (pH of 7) is most desirable to minimize the potential damage to earthen structures. [45], reported that, fine-grained soils such as clays and silts are considered to have a greater corrosion potential because they typically have low hydraulic conductivity resulting from the accumulation of acid and base forming materials which cannot be leached out very quickly.

**Table 3:** Results of the Direct shear test

| S/N | Direct shear Test | | |
|---|---|---|---|
| | Cohesive strength (c) (kN/m²) | Angle of internal friction (Ø°) | Unit weight ϒ (kN/m³) |
| 1 | 13 | 14 | 19.14 |
| 2 | 15 | 13 | 19.74 |
| 3 | 16 | 12 | 20.12 |
| 4 | 23 | 12 | 18.17 |
| 5 | 17 | 14 | 19.09 |
| 6 | 13 | 14 | 18.64 |
| 7 | 18 | 13 | 20.87 |
| 8 | 22 | 12 | 20.20 |
| 9 | 24 | 12 | 19.27 |
| 10 | 16 | 16 | 18.39 |

**Source:** Laboratory test of the soil samples 2021

The Direct shear test shows that; the values of angle of internal friction (Ø) ranges from 12° to 16°, cohesive strength (c) from 13 kN/m$^2$ to 24 kN/m$^2$ and unit weight (ϒ) from 18.17 kN/m$^3$ to 20.87 kN/m$^3$ (Table 3). From the results of this test it shows that the soil is of silty-clay material. According to [46], soils with high plasticity like clay have high cohesive strength and low angle of internal friction. Low angle of internal friction of a soil is attributed to the presence of expansive clay [47]. The results has showed that due to the presence of silty-clayed materials in the soil it will not be useful for the construction of infrastructures like, highway, road, building, air field and bridge except for earth dam.

**Table 4:** Results of the Consolidation test

| S/N | Coefficient of consolidation Cv (m²/year) | Volume compressibility Mv (kN/m²) | Total settlement Pc (m) |
|---|---|---|---|
| 1 | 98.806 | 0.0136 | 0.013 |
| 2 | 100.519 | 0.0098 | 0.0009 |
| 3 | 90.674 | 0.0201 | 0.0019 |
| 4 | 109.325 | 0.0048 | 0.0005 |
| 5 | 104.433 | 0.0089 | 0.0008 |
| 6 | 92.237 | 0.0168 | 0.0016 |
| 7 | 87.657 | 0.0205 | 0.0019 |
| 8 | 100.888 | 0.0095 | 0.0009 |
| 9 | 108.368 | 0.0082 | 0.0008 |
| 10 | 101.327 | 0.0115 | 0.0011 |

**Source:** Laboratory test of the soil samples 2021

The consolidation test has reveals that the total settlement (Pc) ranges from 0.0008 m to 0.013m, coefficient of consolidation (Cv) from 87.657 m$^2$/yr to 109.325 m$^2$/yr and that of volume compressibility (Mv) from 0.0048 kN/m$^2$ to 0.0205 kN/m$^2$ (Table 4). [48], gave $0.05\times10^{-3}$ kN/m$^2$ as the permissible limit of Coefficient of Volume change (Mv) for heavy over-consolidated clays, stiff weathered rocks and hard clays. On the basis of this the soil has not falls into the specification because of its relatively high coefficient of consolidation and this may be problematic to infrastructures due to poor hydraulic conductivity. Hence, the soil will continue to reduce in volume over a long period of time after the immediate settlement and may be several times greater than the immediate settlement. According to [49], information obtained on the consolidation test of the soil samples helps to known the compressibility of the soils for use in determining the magnitude and rate of settlement of structures.

**Table 5:** Results of the Compaction test

| S/N | Maximum Dry Density (MDD) (g/cm³) | Optimum Moisture Content (OMC) (%) | S/N | Maximum Dry Density (MDD) (g/cm³) | Optimum Moisture Content (OMC) (%) |
|---|---|---|---|---|---|
| 1 | 1.88 | 13.22 | 6 | 1.59 | 20.60 |
| 2 | 1.71 | 16.33 | 7 | 1.66 | 19.21 |
| 3 | 1.64 | 17.62 | 8 | 1.68 | 15.76 |
| 4 | 1.80 | 17.05 | 9 | 1.69 | 18.69 |
| 5 | 1.62 | 18.19 | 10 | 1.70 | 18.40 |

**Source:** Laboratory test of the soil samples 2021

The compaction test revealed that; the Optimum Moisture Content (OMC) of the soil samples ranged from 13.22% to 20.60% while that of maximum dry density (MDD) varied between 1.59 g/cm$^3$ to 1.88 g/cm$^3$ (Table 5). According to [50], the ranges of values that may be anticipated when using the standard proctor test methods are: for clay, OMC may fall between 20%-30% and MDD from 1.44 mg/m$^3$-1.685 mg/m$^3$. For silty clay OMC ranged between 15%-25% and MDD between 1.60 mg/m$^3$-1.845 mg/m$^3$. For sandy clay, OMC is between 8% and 15% and MDD between 1.76 mg/m$^3$-2.165 mg/m$^3$ (Table 8).

Looking at the results, it could be noticed that the samples are silty-clay which is not favourable for the construction of infrastructures except earthen dams and embankments. The results will help to evaluate the quality of compacted fills and the stability of earthen dams, embankments, roads, buildings and airfield. According to [51], [36], compaction increases the shear strength, reduces compressibility and permeability of the soil.

From the California Bearing Ratio (CBR) test; the un-soaked value ranges from 50.88% to 96.51%, Maximum Dry Density (MDD) from 1.59-1.88 g/cm$^3$ and Optimum Moisture Content (OMC) from 13.22-20.60% (Table 5). The California Bearing Ratio (CBR) is a semi empirical test that is often employed in the estimation of the bearing capacity of sub-grade, sub-base and base materials [52] and [53]. Based on the [38], recommendation for soils for use as: sub-grade, sub-base and base materials are: ≤ 10%, ≤ 30% and ≤ 80% respectively for un-soaked soil. This implies that soil samples taken from locations 1, 2, 3, 4, 5, 6, and 8 whose values are less than 80% are good base materials with the exception of locations 7, 9 and 10 whose values has exceeded the recommended value for base materials. The CBR test can be used to evaluate the potential strength of sub-grade, sub-base and base course materials for supporting road, railway, airfield, bridge, building and design of flexible pavements.

**Table 6:** Results of the Un-soaked value of the California Bearing Ratio (CBR) test

| S/N | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Un-soaked CBR (%) | 79.47 | 74.50 | 75.10 | 68.31 | 71.85 |
| **S/N** | **6** | **7** | **8** | **9** | **10** |
| Un-soaked CBR (%) | 74.76 | 95.46 | 50.88 | 96.51 | 91.08 |

**Source:** Laboratory test of the soil samples 2021

**Table 7:** Engineering Classification using Plasticity Index after [54].

| S/N | Plasticity Index Range | Index Classification | Classification Casagrande Plasticity | Studied Soils |
|---|---|---|---|---|
| 1 | 10 | Low | Low Plasticity/Low Compressibility/High Competence. | Sample 6 |
| 2 | 10-20 | Medium | Medium Plasticity/ Medium Compressibility/ Moderate Competence. | Sample 1,3, 5, 8 and 9 |
| 3 | 20 | High | High Plasticity/High Compressibity/Low Competence | Sample 2, 4, 7 and 10 |

**Table 8:** Compaction Classification modified from [50].

| S/N | Maximum Dry Density (Mg/m$^3$) | Optimum Moisture Content (%) | Classification |
|---|---|---|---|
| 1 | 1.44-1.685 | 20-30 | Clay |
| 2 | 1.60-1.845 | 15-20 | Silty-clay |
| 3 | 1.75-2.165 | 8-15 | Sandy-clay |

## 4.0 CONCLUSIONS

The geotechnical assessment of sub-soil condition for the construction of infrastructures around Yelwa area of Jos North, North Central Nigeria were carried out based on the British Standard (BS) method for soil testing. Results of the various analyses conducted shows that most of the soils are not fairly within the specifications required for the constructions of infrastructures due to the presence of silty-clay materials which indicate poor bearing capacity. Hence, some form of geotechnics such as; excavations, soil stabilization, site and geological investigation are necessary in order to improve the engineering properties of the soil. The acquired information in the study area based on the laboratory analysis will serve as baseline for contractor or civil engineers in order to mitigate the failure of the infrastructures in the study area and also for further studies.

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