Geotechnical Investigation of Soils and Underlying Basement Rock for the Construction of Southern Parkway Bridge at Federal Capital Territory (FCT), Abuja, Northcentral Nigeria

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ABSTRACT

It has been shown in several studies that factors such as composition, texture, degree of weathering, and presence of fissures or discontinuities have a first order control on engineering properties and behavior of soils and rocks. This paper investigates geotechnical properties of soils and the underlying basement rock at the site of the proposed Southern Parkway Bridge in Federal Capital Territory (FCT), Abuja, Nigeria with a view to assessing their strength and suitability to carry the load of the bridge and support the road under construction.

The study involved two exploration borings to about 30 m on either side of the road using percussion drilling rig. A total number of six soil samples and four rock samples were collected for various geotechnical analyses. The borehole logs showed that the subsoil is composed of a suite of residual materials such as silty laterite with traces of clay, underlain by migmatite as the basement rock; with a subtle difference in the composition of materials from the two drilled borehole pits.

The results of the particle size analysis revealed that the soils are generally poorly graded, while the Atterberg's Limits indicated that the analyzed soils have high natural moisture content (14.3 – 21.3%), high Liquid Limit (31 – 49%), high Plastic Limit (22 – 34%) and high Plasticity Index (9 – 16%); all suggesting that the studied soils (regolith) can be regarded as poor for sub-base or base course materials, and thus could not be considered suitable for bridge construction. The results of unconfined compressive strength (170.21 – 184.63 MPa) and point load strength (3.42 – 6.60 MPa) show that the underlying basement rock (migmatite) has medium to high strength, and this implies that it has the desired load-bearing capacity to support the overlying weight of the proposed bridge.

It is therefore concluded that the regolith at the site for the proposed bridge are unsuitable to support the bridge and for road construction, while the underlying basement rock has the desired capacity or strength to carry the bridge. We therefore recommended that the soils should be excavated and replaced with a higher grade, better quality material of improved geotechnical properties.

(Keywords: Southern Parkway Bridge, federal capital territory, Nigeria, geotechnical survey, geotechnical analyses, strength, basement rock)

INTRODUCTION

Professionals such as the civil engineers, mining engineers and engineering geologists require a thorough knowledge of the engineering properties and behavior of soils and rocks (Bell, 1992); since the engineering strengths and industrial applications of these earth materials and their aggregates are dependent upon factors such as composition, texture, degree of weathering, presence of fissures or discontinuities which vary widely. Thus, it is of paramount importance to investigate the properties and qualities of earth materials that are to be used as foundation elements for the construction of roads, bridges, and other civil structures.

A lot of work has been done on bridges owing to their great importance in road transport system. Structural studies of bridges have provided an insight into the maximum loads to be anticipated that the pile supports can withstand.

However, in order to fully actualize the master plan of the Federal Capital Territory (FCT), Abuja, the capital of Nigeria, there is a need for continuous provision for road infrastructures and construction of associated bridges within the city center and its suburbs. Obviously, one of the main causes of road failures as well as bridge collapses in Nigeria and elsewhere are not far from poor understanding or assessment of the geological, geotechnical and engineering properties of the surficial soils and the underlying basement rocks on which these structures are built. The proposed road construction that links Christian Centre S8/S9 to Ring Road 1, FCT Abuja is one of such roads that are about to be executed in the Nigeria capital. Thus, this paper investigates the geological and geotechnical properties of earth materials that constitute foundation elements for the Parkway Bridge, and upon which the bridge and road are to be built.

Geological Setting: Description of Study Area

The FCT is surrounded by Nasarawa, Kaduna, Niger and Kogi States in the East, North, West and South, respectively. The Southern Parkway Bridge is to be situated on the road that links Christian Centre S8/S9 to Ring Road 1, Abuja. The proposed bridge site has geographic coordinates: longitude 007° 29′ 45.9″ E and latitude 09° 02′ 55.7″ N (Figure 1).

Accessibility into the area is made possible through the Banex - Apo Bridge route. The relief pattern in Abuja varies from the south-western part with low altitudes of close to 76 m above sea level at the deltas of River Gurara to the north-westward at an altitude of 760 m. The area drains in most parts through the surrounding rivers and follows trellis to dendritic drainage pattern.

The tropical climatic conditions in FCT possess two peculiar periods, the period of dryness and the period of general wetness. The period of wetness is substantially placed to be within the ranges of the third and fourth months of the year to the ninth and tenth month, while in the case of the periods of dryness, it starts from the later part of the tenth month to the middle of the fifth month with an intermediate yearly meteoric precipitation of about 1631 millimeters. However, the temperate condition falls within the ranges of 22˚C in the months of December and January to about 35˚C in March and April. The weather resonates the rough nature of the terrain with the highlands rarely influencing the topography of the direct surrounding. This is characterized by the thick thorny floras accompanied by the mango species and the general region being in the contemporaneous zone of the forest in guinea that exist in the Nigerian region.

In terms of geology, most part of FCT lies on the Nigerian Precambrian basement complex (Rahaman, 1976; 1988), and the major lithologic unit in the site is migmatite-gneiss. They are the oldest rocks of the Nigerian Basement Complex and exhibit great variations in composition due to the differences in their protoliths (pelitic, psammitic, or igneous) and the metamorphic (pressure-temperature, P/T) conditions under which they were formed. They are composed essentially of gneisses and migmatites with supra-crustal relicts referred to as Older Meta-sediments (Obiora, 2005). This unit is also referred to as a diverse group including migmatites, ortho-gneisses, para-gneisses and a series of basic/ultra-basic altered rocks (Rahaman, 1988). The general foliation trend is in the N-S to NNE-SSW directions and occasional E-W. This foliation trend coincides with the structural trend that was imprinted by the Pan-African (~ 600Ma) orogeny (McCurry, 1971). The rocks possess gradational contacts with high grade metamorphic rocks suggesting origin by granitization (Obiora, 2005).

Aim and Objectives of the Study

The aim of this work is to carry out the geotechnical investigation of the soil and the underlying basement rock at the proposed Southern Parkway Bridge with a view to assessing their strength and suitability to carry the load of the bridge in Federal Capital Territory (FCT), Abuja.

The objectives of this research work are to:

1) carry out geotechnical survey in the study area during which layers of stratified soil as well as the basement shall be delineated;
2) evaluate the competence of subsoil materials and strength of the basement rock; and
3) assess the general feasibility of the site for the proposed bridge project based on the strengths of the soils and underlying basement rock.

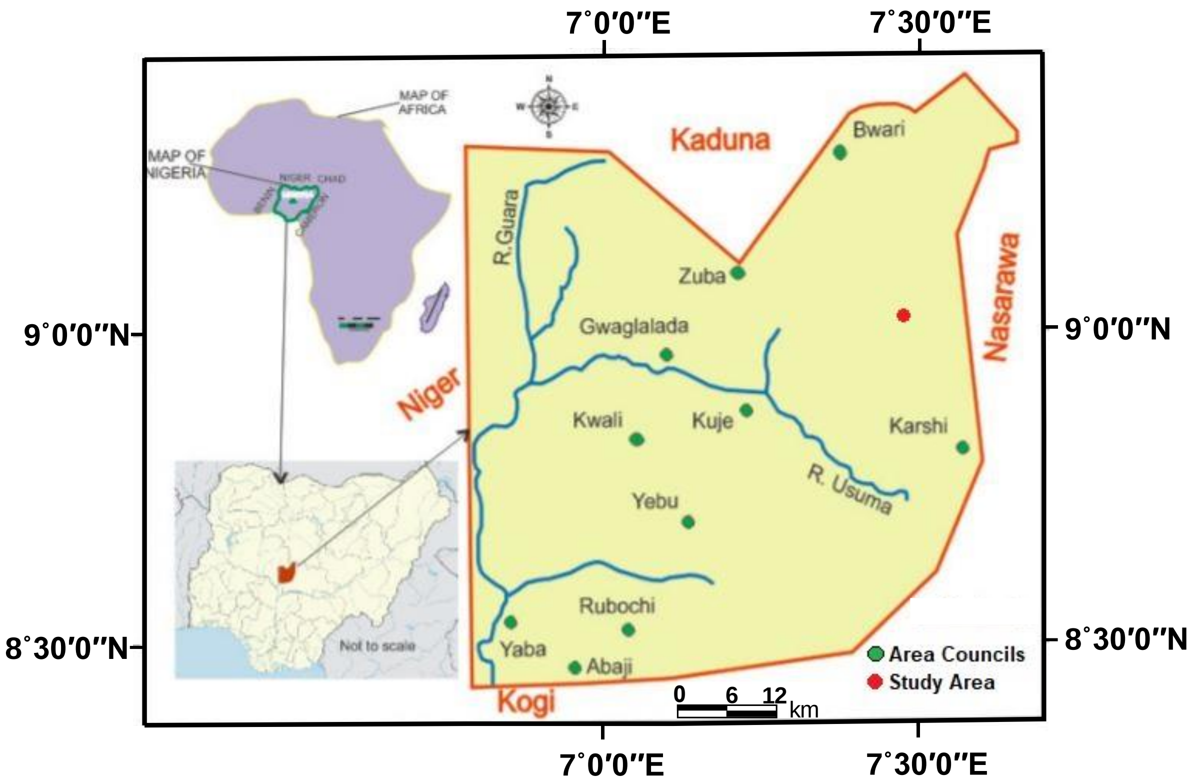

Figure 1: Location Map of Federal Capital Territory, Abuja showing the Study Area (Agunleti and Arikawe, 2014).

The two boreholes were drilled to the depth of about 30 m with the aids of an auger for the regolith and percussion drilling rig for fresh bedrock. Soil and rock samples were collected during the exploration process. The samples were examined and described visually in the field and were later taken to Setraco Construction Company Laboratory in Abuja for further analyses: particle size distribution, Atterberg's Limits, natural moisture content for soil samples; and Unconfined compressive strength and Point Load Test of intact rock specimens.

The particle size analyses were performed on soil samples using the traditional coarse sieve and fine sieve methods. The standard procedures for natural moisture content and Atterberg's Limits determinations as described by Das (2010) were adopted. The unconfined compressive strength (UCS) and point load test analyses were also carried out on the collected rock samples. For the former, the samples were trimmed into cylindrical shapes and weighed; measurements of the diameter and length were done using a Vernier caliper. The weighed sample is placed in the UCS machine and the plates are tuned such that they come in sync with the sample**.** Force was then applied to the sample until failure occurred, and the strength and force attained when the failure took place were recorded from the machine. For the fresh bedrock (Diametrical Test, Figure 2), the length and diameter of the dry rock used for the test were initially measured, and the specimen was then placed between the platens and compression load is applied until failure occurred and the force was calculated. The point load index is deduced from the division of the applied force by square of the diameter.

RESULTS AND DISCUSSION

This section systematically presents the results of geotechnical surveys, natural moisture content, particle size, Atterberg's Limits, unconfined compressive strength (UCS) and point load strength analyses carried out in this study.

Figure 2: A. The UCS, and B. Point Load Test (Diametrical Test) Machines at the Setraco Construction Company Laboratory in Abuja, Nigeria (with the permission of the Company).

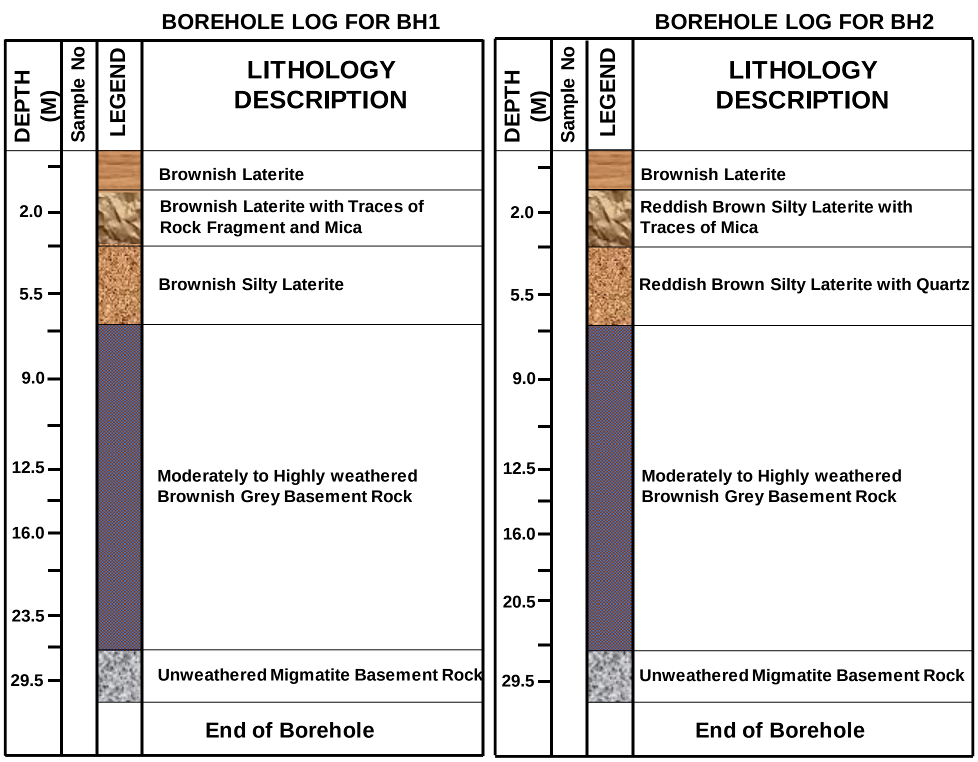

Figure 3: Lithologic Logs of the two Boreholes Drilled at the Southern Parkway Bridge Site (Left = Borehole BH1, Right = Borehole BH2). Note that the depth values are not very strictly drawn to scale.

Borehole Logging Observations

The borehole logs (Figure 3) reveal that the regolith is composed of a suite of residual materials such as silty laterite with traces of clay while the fresh bedrock is composed of migmatite. The result shows that there is a slight difference in the lithological properties of the two borings. For instance, the regolith of borehole 1 are reddish brown laterite with traces of rock fragments and mica while that of borehole 2 has reddish brown silty laterite with high quartz content and traces of mica. This observation indicates that there is a possibility for variations in properties of earth materials even within a relatively short distance.

Soil Index Properties

The natural moisture content (NMC) as shown in Table 1 ranges from 14.3 to 21.3 %.

Particle Size Analysis

The grain particles present in a soil are not made up of the same dimensions and forms, and this may lead to diverse geotechnical properties and behaviours of various soil types. Therefore, geotechnical engineers often need to assess the distribution of particle sizes and the shapes of the particles in the soil which often has a significant effect on soils engineering behaviour. The particle size distributions in the analysed soil samples are as shown in Figures 4 and 5 for borehole logs 1 and 2, respectively.

Table 2 shows the generalized guideline used for the gradation of soil particles. For the analyzed soils to be classified as well graded, both criteria for coefficient of uniformity (Cu) and coefficient of curvature (Cc) must be met. In cases where one of the criteria is not met, the material is therefore classified as poorly graded **(**NEH, 1994). Table 3 shows that Cu ranges from 4.04 to 7.51, while Cc ranges between 0.71 and 1.08.

The results of the Atterberg's Limits are presented in the Table 4. The table shows that the Plastic Limit (PL) ranges from 22 to 34%, Liquid Limit (LL) ranges between 31 and 49%,

and Plasticity Index (PI) from 9 to 16%. The plasticity index chart which summarizes the characteristics of these soils as a function of their Atterberg's Limits is shown in Figure 6 and Table 5.

Unconfined Compressive Strength

Unconfined Compressive Strength (UCS) evaluates the shear strength, durability, and potential of rock to degrade in order to determine their usefulness as either a construction material or for the design and analysis of stable foundations. The summary of the result of UCS in this work is presented in Table 6, while Table 7 shows the guideline used for the interpretation of the analyzed intact rock specimen (NEH, 2012). Table 6 shows that the UCS ranges from 170.21 to 184.32 MPa, and the analyzed rock samples are thus classified as having high strength.

Table 1: Summary of Results of the Natural Moisture Content for the Analyzed Soils.

Depth (meters)	Moisture Content (%)	
	BH1	**BH2**
1.5	20.4	17.6
3.0	21.3	17.1
5.0	14.3	18.8

Table 2: Grain Size Distribution based on Calculated Cu and Cc (NEH, 1994).

Gradation of soil particles	For Coarse Grained (Gravel)	For Fine Grained (Sand)
Well graded	Cu≥4 and 1<Cc<3	Cu>6 and 1<Cc<3
Poorly graded	Cu<4 and 1<Cc<3	Cu<6 and 1<Cc<3
Gap graded	Cc not between 1 and 3	Cc not between 1 and 3

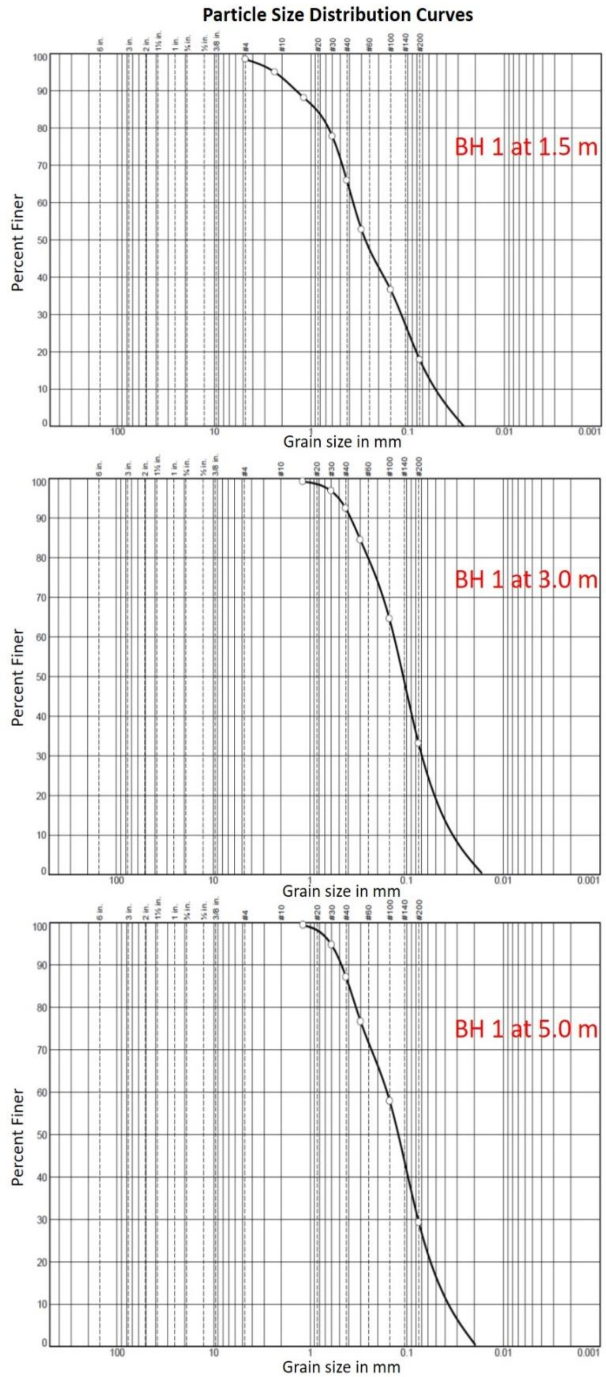

Figure 4: Results of Particle Size Analysis in Soil Samples Taken from BH 1.

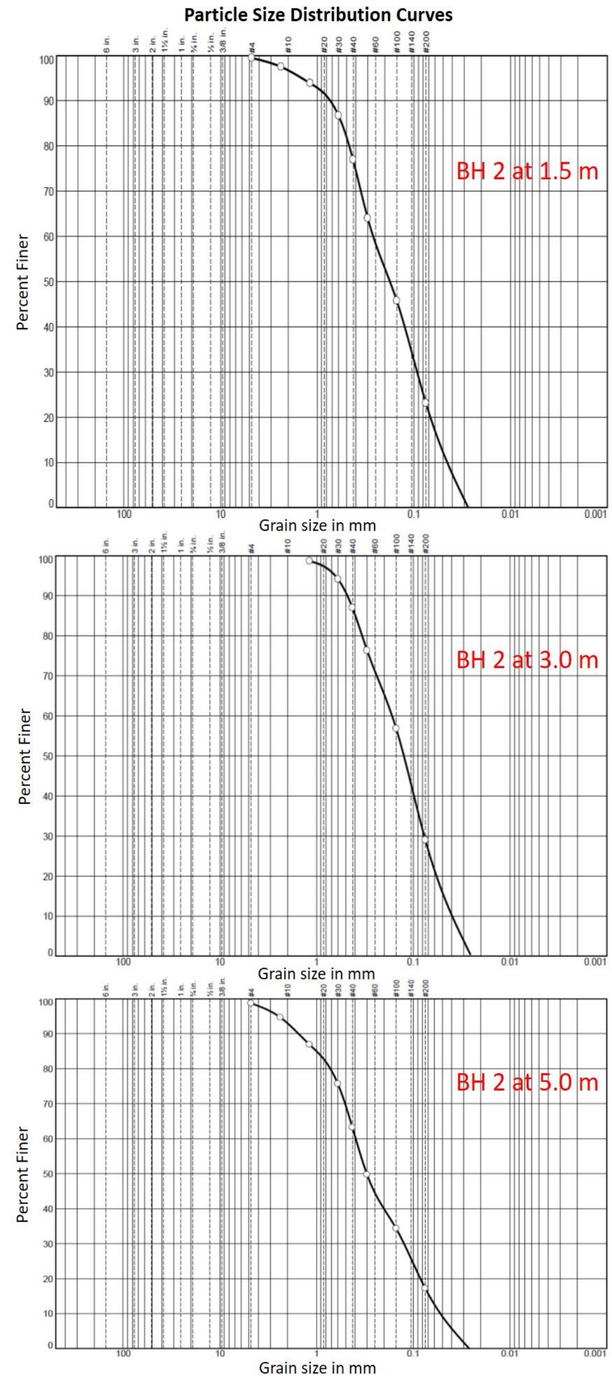

Figure 5: Results of Particle Size Analysis in Soil Samples Taken from BH 2.

Table 3: Results of the Particle Size Analyses Carried Out on Collected Soil Samples from the Drilled Boreholes (BH 1 and BH2) in the Study Area.

Borehole	Depth (m)	*Cu	**Cc	Gradation
BH 1	1.5	7.05	0.71	Poorly graded
	3.0	4.04	1.08	Poorly graded
	5.0	4.31	0.99	Poorly graded
BH 2	1.5	5.84	0.72	Poorly graded
	3.0	4.17	0.90	Poorly graded
	5.0	7.51	1.00	Poorly graded

*Cu = $\frac{D_{60}}{D_{10}}$ and **Cc = $\frac{{D_{30}}^2}{D_{60} \times D_{10}}$ (NEH, 1994)

Table 4: Results of the Atterberg's Limits for the Analyzed Soils.

Borehole	Depth (meters)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	*Plasticity Index (PI) (%)
BH1	1.5	37	22	15
	3.0	49	33	16
	5.0	42	26	16
BH 2	1.5	31	22	9
	3.0	45	31	14
	5.0	48	34	14

*PI = LL – PL

Table 5: Plasticity Index Chart Showing the Characteristics of the Analyzed Soil Samples (ASTM, 2004).

Borehole	Depth (m)	Classification (ASTM, 2004)		
BH1	1.5	CL	Inorganic clay of medium plasticity	Medium Plasticity
	3.0	ML	Inorganic silt of medium compressibility and organic silts	Medium Plasticity
	5.0	CL-ML	Falls directly on the A-line i.e. boundary between Inorganic clay of medium plasticity and Inorganic silt of medium compressibility and organic silts	Medium Plasticity
BH2	1.5	CL	Inorganic clay of medium plasticity	Medium Plasticity
	3.0	ML	Inorganic silt of medium compressibility and organic silts	Medium Plasticity
	5.0	ML	Inorganic silt of medium compressibility and organic silts	Medium Plasticity

Table 6: Results of Unconfined Compressive Strength for the Analyzed Intact Rock Specimens.

Borehole	Depth (meters)	Strength (MPa)	Strength Category
BH1	20.8	178.63	High Strength
	26.8	170.21	High Strength
BH2	14.8	184.32	High Strength
	22.0	181.27	High Strength

Table 7: Classification of Rock Materials Strength using Unconfined Compressive Strength and Point load Index Strength (NEH, 2012).

Description	Uniaxial Compressive Strength (MPa)	Point-load Strength (MPa)
Very High Strength	> 200	> 8
High Strength	100 – 200	4 – 8
Medium Strength	50 – 100	2 – 4
Low Strength	25 – 50	1 – 2
Very Low Strength	< 25	< 1

Table 8: Results of the Point Load Strength for the Analyzed Intact Rock Specimens.

Borehole	Depth (meters)	Strength (MPa)	Strength Category
BH1	20.8	3.42	Medium Strength
	26.8	6.23	High Strength
BH2	14.8	3.98	Medium Strength
	22.0	6.60	High Strength

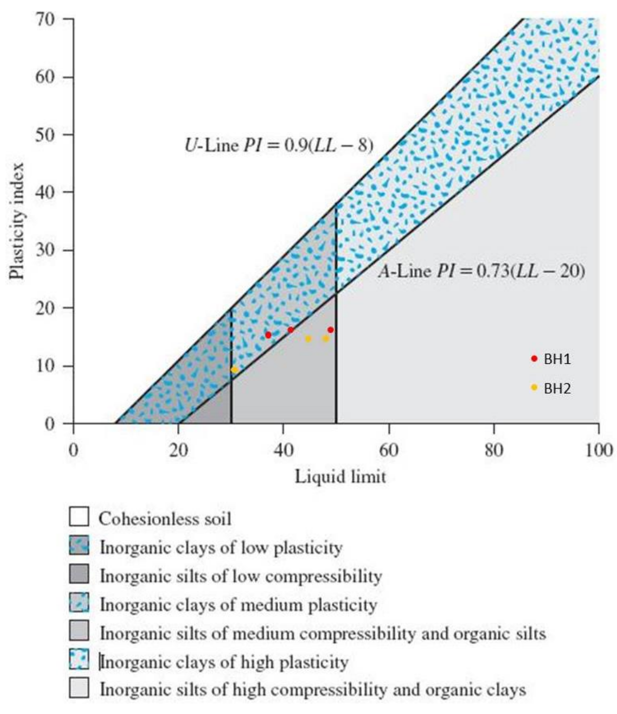

Figure 6: Plasticity Index Chart Showing the Location of the Analyzed Soil Samples from the Two Boreholes, BH1 and BH2 (ASTM, 2004).

Point Load Strength

Point Load Strength is used to determine the resistance of a rock to compressed load. It can be seen from Table 8 that the point load strength of the rocks range from 3.42 to 6.60 MPa. Table 7 already shows the guideline used for the interpretation of point load strength of the analyzed intact rock specimen (NEH, 2012).

DISCUSSION OF RESULTS

Quality and Strength of the Investigated Soils

The results of Atterberg's Limit for the regolith within the study area show that the liquid limit (LL) ranges between 31 and 49, while the plasticity limit (PL) and plasticity index (PI) vary between 22 and 34, and 9 and 16, respectively. According to the guideline of Federal Ministry of Works, Nigerian General Specification (1997), the liquid limit should not exceed 35% to be suitable for use as sub-grade and sub-base or base course materials. The results obtained in this study (i.e., high LL, high PL and high PI) therefore indicate that the studied soils can be regarded as poor for sub-base or base course materials. Since the soils do not generally meet the local standard requirements of the Nigerian General Specification (Table 9), they are not suitable for road construction.

The results from the particle size analysis (soils are generally poorly graded) and natural moisture content (14.3 – 21.3%) also lend credence to this interpretation, as low average natural moisture content may constitute good construction materials such as subgrades for roads and foundations (Mallo and Akuboh, 2012). Berhane (2002) stressed that the high moisture content can have a significant effect on the soils behavioral properties when used for construction purposes and foundations.

The soils are unsuitable for engineering construction because they are susceptible to liquefaction since they possess fair shear strength, medium plasticity and compressibility (Wagner, 1957) but with proper control measures they can act as a load-bearing soil for foundations and can also be fairly used as a construction material. The poor strength of the investigated soils can be attributed to their parent source rock which is migmatite.

A similar recent work by Kayode and Akinwumi (2017) on the potential use of residual soils derived from charnockite and migmatite as road pavement layer materials revealed that the soils derived from migmatite generally have poor geotechnical properties. The work of Adeyemi (1995) have earlier proved the influences of the parent rock factor to be significant on engineering index properties such as the specific gravity of grains, plasticity index and grain size distribution characteristics of the soils. The slight differences found in the surface/sub-foundation to subsurface logging between the two drilled borehole pits and in the results of investigation within short distances and/or depth are expected in tropical region typical of the study area where the variability of geotechnical properties could be caused by different formation factors (Malomo and Ogunsanwo, 1983; and Ogunsanwo, 1986).

Strength of the Investigated Underlying Basement Rock

The borehole logs (Figure 3) reveal that the soils in the project site are underlain by migmatite. The strength or quality of rocks for engineering construction is not only a function of the geotechnical properties but it also depends on physical and mineralogical properties.

Using the criteria for classification of rock materials strength (NEH, 2012) as shown in Table 7, the results Unconfined of Compressive Strength analysis (170.21 to 184.63 MPa) and point Load Strength (3.42 to 6.60 MPa) obtained in this study show that the strength of the analyzed rock samples falls within medium and high category. Thus, the basement rock has the desired load-bearing capacity to support the overlying weight of the proposed bridge because it possesses a high shear strength and desirable hardness/toughness.

Table 9: Subgrade, subbase and base requirements (Nigerian General Specification 1997).

Criteria	Subgrade	Subbase	Base
Proportion passing 75μm sieve (%)	≤35	≤35	≤35
Liquid Limit (%)	≤80	≤35	≤35
Plastic Index (%)	≤55	≤12	≤12
Soaked CBR (24 hours)	Any value	≥30	≥80

Suitability of the Soils and the Underlying Basement Rock for the Proposed Southern Parkway Bridge

The results of this work and the foregoing discussion have demonstrated that the analyzed soils are not very suitable for the intended construction owing to its rather poor geotechnical properties, except for its upgrade with proper control. Hence, its excavation and replacement with better quality or grade materials could make the life span of the road longer. However, the underlying basement rock has the correct geotechnical properties that qualify it to be suitable for the proposed bridge construction.

CONCLUSIONS AND RECOMMENDATION

The results of geotechnical survey carried out in this study indicated that the underlying basement in the study area is migmatite-gneiss; it is capped by regolith as reddish brown, often silty laterite. Index properties of the regolith showed its incompetence and unsuitability for the proposed construction. On the other hand, the underlying fresh bedrock has medium to high strength capacity to carry the load of the proposed bridge. It is therefore concluded that the residual top soils in the study area are unsuitable for the proposed construction while the basement rock has the desired capacity. We recommend that the top soils should be excavated and replaced with a higher grade, better quality material of improved geotechnical properties.

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