GEOPHYSICAL AND GEOTECHNICAL ASSESSMENT OF THE SUBSOIL ALONG IKORODU – SHAGAMU ROAD, SOUTHWESTERN, NIGERIA

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ABSTRACT

Electrical resistivity imaging (ERI) and Vertical electrical sounding (VES) surveys were carried out on a portion of Ikorodu - Shagamu road, Lagos State Polytechnic area in order to investigate the subsurface geological structures, depth to bedrock and thickness of weathered basement of the area. ABEM Automatic LUND Imaging System (Terrameter SAS 1000 and ES 464) employing the Wenner array, was used for the investigation of 2-D resistivity data sets along two profiles and seven VES conducted on the profiles. The acquired data were processed and interpreted using RES2DINV software to produce the 2-D image of the study areawhileIPI2Win software was firstly applied to perform an automatic approximation of the initial resistivity and thickness of the various geo electric layers and later filtered with Win Resist iteration. The geochemical method employed California Bearing Ratio (CBR) test conducted on four samples at a depth of 0.6m to determine the load bearing capacity of the soil samples. The results of the geophysical methods showed three to five geo electric layers described as topsoil, clay, sandy clay, clayey sand and dry sand based on corresponding resistivity values while the results of the California Bearing Ratio (CBR) of the soil samples ranged between 16% and 21%.Thus, the higher the CBR value of a road's subgrade, the lower the thickness of the required road pavement. The correlation of the integrated geophysical and geotechnical results implied that, at the weathered layer we have clay/sandy clay with a depth 1.2m – 17.2m interpreted as fairly competent and moderately stable while at the last layer, are clayey sand and dry sand with depth 2.1m – 31.0m interpreted as competent and stable soil. The subsoil assessed is suitable as subgrade, especially after the removal of the topsoil/weathered layer. The unsuitable portion along the length of the road can be excavated and replaced with a competent stable soil as subgrade.

Keywords: Assessment, California Bearing Ratio, Competence Rating, Inferred Lithology, Subsoil

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Introduction

Subsurface investigations employing geophysical and geotechnical techniques are of paramount importance in assessing the suitability of an area for the construction of buildings, roads, bridges, etc. It is common knowledge that these structures among other reasons, collapse because appropriate subsurface investigations were not carried out to determine the nature of the subsurface soil. Most of these structures were built on soils that have inadequate bearing capacity to support the weight of the structure. The geology of an area is critical in assessing its suitability for the type of structure to be erected. Geophysical techniques of investigating the composition, structure and nature of the subsurface have reached a high degree of sophistication with the convergence of the need to investigate the earth for scientific and societal problems (Coker *et al.,* 2017).

Jegede (1994) worked on the pavement failure at a section along Ikere – Igbara-Odo road in Ekiti state of Nigeria. He found out that the California Bearing Ratio (CBR) of the soil ranges around 50% which showed poor soil physical properties. Lack of drainage facilities combines with the excess fine soil grade ranging between 20-40% was responsible for the failure along the area.

Coker (2015b) measured resistivity using 1-D and

2-D resistivity probing techniques and Geotechnical methods using Cone Penetrometer Test (CPT) to delineate the subsurface geology at the School of Management area, Lagos State Polytechnic, Ikorodu. The resistivity measurements were made with Allied Ohmega Resistivity meter. The 1-D vertical electrical resistivity sounding data were obtained using the Schlumberger electrode array while the 2-D resistivity data were obtained using the Wenner array. Two 2.5 tonnes Cone Penetration Test (CPT) and one borehore log was used for control. The author concluded that, the northern part of the study area consist of sandy clay, a mechanically unstable soil formations which is capable of being inimical to building structures and the southern part consist of the sand layer which is viewed as the only competent geo-material for the foundation of any engineering structures within the study area.

According to **Ayolabi *et al.* (2012)**, methods of observing the soils below the surface (to obtain information about the soil conditions), obtaining samples, and determining physical properties of the soils and rocks below the surface, include test pits, trenching (particularly for locating faults and slide planes), boring, and in situ tests such as cone penetration tests (CPT) or SPT are important in geotechnical survey. There is no absolute classification rating of rock competence based on resistivity value only, but moreover, the higher the resistance of a geologic material to the current flow, the better the material and vice versa.

Nonetheless, the classification scheme by Ariyo and Alaka (2017) is reliably adopted because of the high consistency of the scheme with reviewed literatures by notable scholars where there is relationship between the resistivity and soil competence. Integrating geophysical with geotechnical methods provide discrete information not usually obtained from conventional engineering soil characterization methods that lack complete imaging of the subsurface.

Location and Geology of the Study Area

The site of investigation is along the I**korodu-Shagamu road, between the first gate (with coordinate 63551.5N and 33094.1E)and second gatearea (with coordinate 64342.3N and 33284.8E)of the Lagos State Polytechnic, Ikorodu campus.**Ikorodu is a suburb of Lagos which is purely sedimentary and falls in Dahomey Basin. The climate is predominantly the rainforest characterized by two seasons-the wet season (between April-October) and the dry season (between November-March).Nigeria lies approximately between latitudes 4^0N and 15^0N and longitudes 3^0 E and 14^0 E, within the Pan African mobile belt in between the West African and Congo cratons(Figure 1). The Geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions **(Coker, 2015a and Coker *et al.,* 2017)**. The crystalline rocks are made up of Precambrian basement complex and the Phanerozoic rocks which occur in the eastern region of the country and in the north central part of Nigeria.

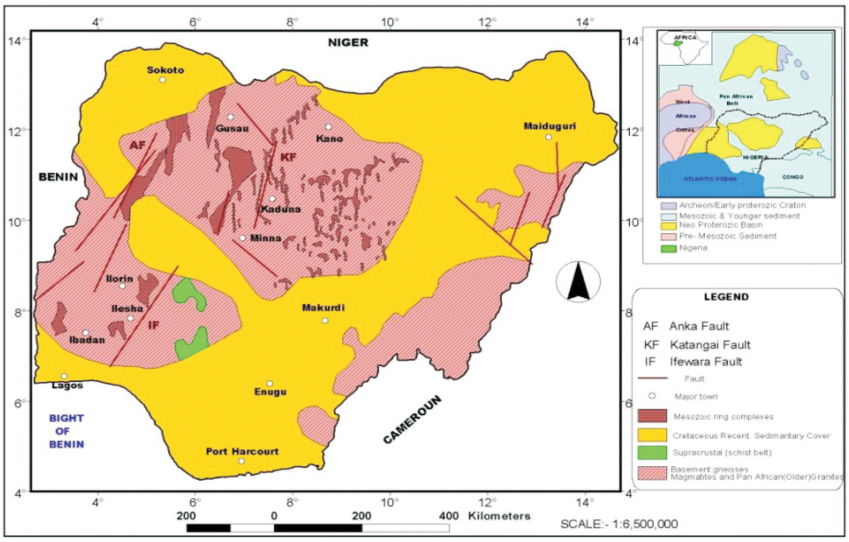

Figure 1:Regional Geology of the Pan-African Shield of Nigeria, Inset Geological Map of Africa (Modified after GSN, 1994 and Coker *et al*., 2017).

Materials and Methods

The geophysical Investigation employed two traverses across the study area with four electrodes of equal spacing moved along each profile of the traverses. The spacing was varied for 3m, 6m, 9m, and 12m in turns. Using this method, features with electrical properties differing from those of the surrounding material may be located and characterized in terms of electrical resistivity, geometry and depth of burial. The electrical resistivity tomography data were collected using computer-controlled measurement systems connected to multi-electrode arrays. The data acquisition process was completely controlled by the computer software which checked that all the electrodes were connected and properly grounded before measurement started. After adequate grounding was achieved, the software scanned through the measurement protocol selected. The Wenner array was chosen for this survey.

The Terrameter SAS 1000, Electrode Selector ES 464, stainless steel electrodes, cable jumpers or electrode connectors, cables and reels, hammers, external 12 volts' battery were used. The two electrode cables 1 and 2 depending on the current position along the line of survey were rolled out in the direction of the profile, with the cable reel end facing the highest coordinates. Each cable had 21 take-outs.The 2D data were presented in form of pseudosections and interpreted by DiproWin software version 4.0 to provide both lateral and vertical information of the study area. The interpretation was qualitative. The Diprowin software gives a 2-D inverted resistivity value as a function of depth. The investigation was done in the N-S direction and seven Vertical Electrical Sounding (VES) stations were occupied along the traverses using the Schlumberger configuration (figure 2). The electrode spacing (AB/2) was varied from 1 – 200m. The resistivity measurements were made with Allied Ohmega Resistivity meter. The acquired VES data were processed and interpreted using partial curve matching technique and 1D computer assisted forward modeling using Resist version 1.0 software. The final interpreted results were used for the preparation of geoelectric sections.

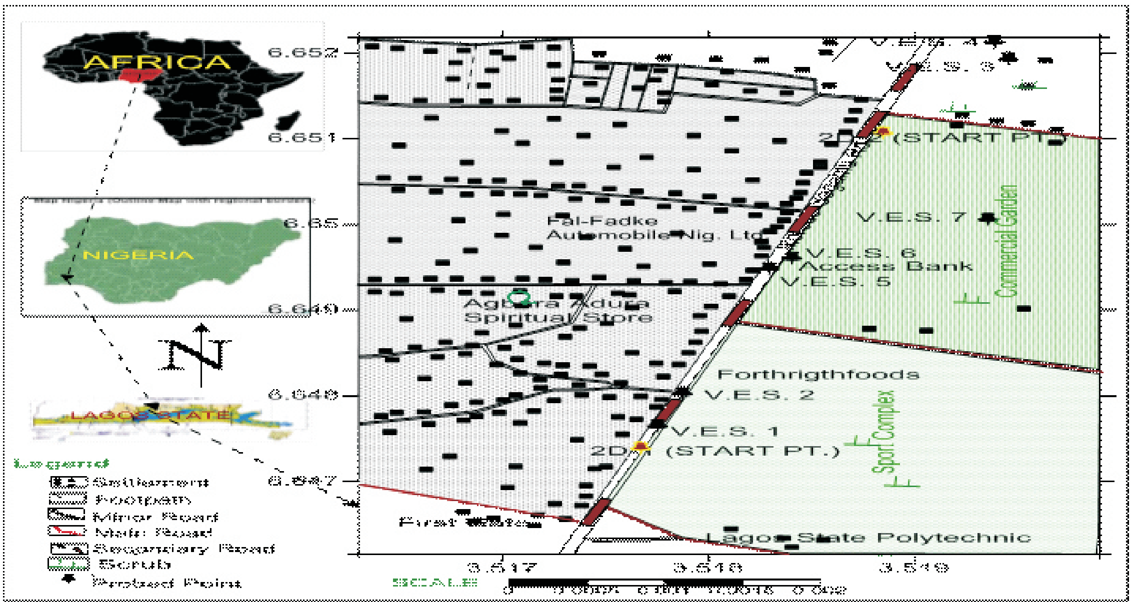

Figure 2: Location Map of the Study Area Showing VES, 2D and the samples points

The geotechnical method involves the California Bearing Ration Test (CBR)

Samples were collected and sieved through 20mm sieve at different coordinates (table 1) and 5kg of each sample was mixed with 8% volume of water. Spacer disc was place over the based plate at the bottom of mould and a coarse filter paper also was placed over the spacer disc. The soil sample was poured into the mould in three layers. Each layer was compacted by giving 56 evenly distributed blows using hammer of weight 4.5kg., After compaction of the third layer, the collar is removed and excess soil was struck off. The base plate was removed and inverted the mould then, clamped to base plate.

Table 1: Depths/Coordinates of the soil samples

Sample Points	Coordinates	Depth/m	Remarks
A	063852.1N 0033104.2E	0.6	Excellence Portion
B	063900.7N 0033106.9E	0.6	Very Good Portion
C	063907.1N 0033108.5E	0.6	Worst Portion
D	063910.7N 0033109.9E	0.6	Bad Portion

Results and Discussion

Table 2 presents the stability assessment of inferred lithology in the study area. The number of layers inferred ranges from three to five as shown in table 2. The layers are described as topsoil, clay, sandy clay, clayey sand and dry sand based on the values of their corresponding resistivity. Figure 3 gives the typical iterative curves of VES 2 and 5. The first layer interpreted as topsoil has low resistivity values ranging from 36.3Ωm to 180.4Ωm with the corresponding thickness value ranging from 0.6m to 4.4m. The second layer interpreted as sandy clay has resistivity values ranging from 101.0Ωm to 173.2Ωm with an average of 134.5Ωm and thickness ranging from 1.2m to 4.4m having an average layer thickness of 2.7m. This layer is moderately stable and fairly competent under competence ratingin table 2 and table 3 (Ariyo and Alaka, 2017). VES 1and 2 has five layers where their layers 3 and 4 are interpreted as clayey sand and clay. The last layer of the VES data which is the terminating layer, has resistivity values ranging from 253.0 Ωm to 1273.3 Ωm, with an average of 585.8Ωm and it is interpreted as the clayey sand and dry sand. This layer is competent and stable for any pavement work. The total depth for this study ranges from 2.6m and 31.0m

Table 2: Stability Assessment of Inferred Lithology in the Study Area

VES NO	LAYER NUMBER	RESISTIV- ITY (Ωm)	THICK-NESS (m)	INFERRED LITHOLOGY	COMPETENCE RATING	STABILITY EVALUA TION
1	1	94.1	0.6	Topsoil	Incompetent	Unstable
	2	146.4	3.4	Sandy Clay	Fairly competent	Moderately Stable
	3	398.5	9.8	Clayey Sand	Competent	Stable
	4	83.8	17.2	Clay	Incompetent	Unstable
	5	253.0	---	Clayey Sand	Competent	Stable
2	1	180.4	0.6	Topsoil	Fairly Competent	Moderately Stable
	2	101.0	2.8	Sandy Clay	Fairly Competent	Moderately Stable
	3	372.5	17.9	Clayey Sand	Competent	Stable
	4	96.0	9.6	Clay	Incompetent	Unstable
	5	300	---	Clayey Sand	Competent	Stable
3	1	36.3	1.9	Topsoil	Incompetent	Unstable
	2	130.6	4.2	Sandy Clay	Fairly Competent	Moderately Stable
	3	322.9	---	Clayey Sand	Competent	Stable
4	1	64.1	4.4	Topsoil	Incompetent	Unstable
	2	159.5	3.3	Sandy Clay	Fairly Competent	Moderately Stable
	3	255.6	---	Clayey Sand	Competent	Stable
5	1	50.0	0.9	Topsoil	Incompetent	Unstable
	2	113.6	1.2	Sandy Clay	Fairly Competent	Moderately Stable
	3	1273.3	---	Dry Sand	Competent	Stable
6	1	55.4	1.0	Topsoil	Incompetent	Incompetent
	2	117.0	2.1	Sandy Clay	Fairly Competent	Moderately Stable
	3	1001.9	---	Dry Sand	Competent	Stable
7	1	51.3	0.8	Topsoil	Incompetent	Incompetent
	2	173.2	1.8	Sandy Clay	Fairly Competent	Moderately Stable
	3	694.0	---	Dry Sand	Competent	Stable

Table 3: Competence Rating of Geo -electric Lithology based on Resistivity Value Relationship (Ariyo and Alaka, 2017)

Resistivity Value Range (Ωm)	Inferred Lithology	Subdivision	Competence Rating
<100	Unconsolidated Sediment	Clay	Incompetent
100 – 200		Sandy Clay	Incompetent Fairly Competent
200 – 500		Clayey Sand	Fairly Competent - Competent
400 – 3500		Sand	Competent
400 7000		Laterite	Competent
500 – 20,000	Consolidated Sedimentary Rock		Competent
100 – 1500	Weathered/Fractured Bedrock		Incompetent
200 – 10000	Fresh Bedrock		Competent

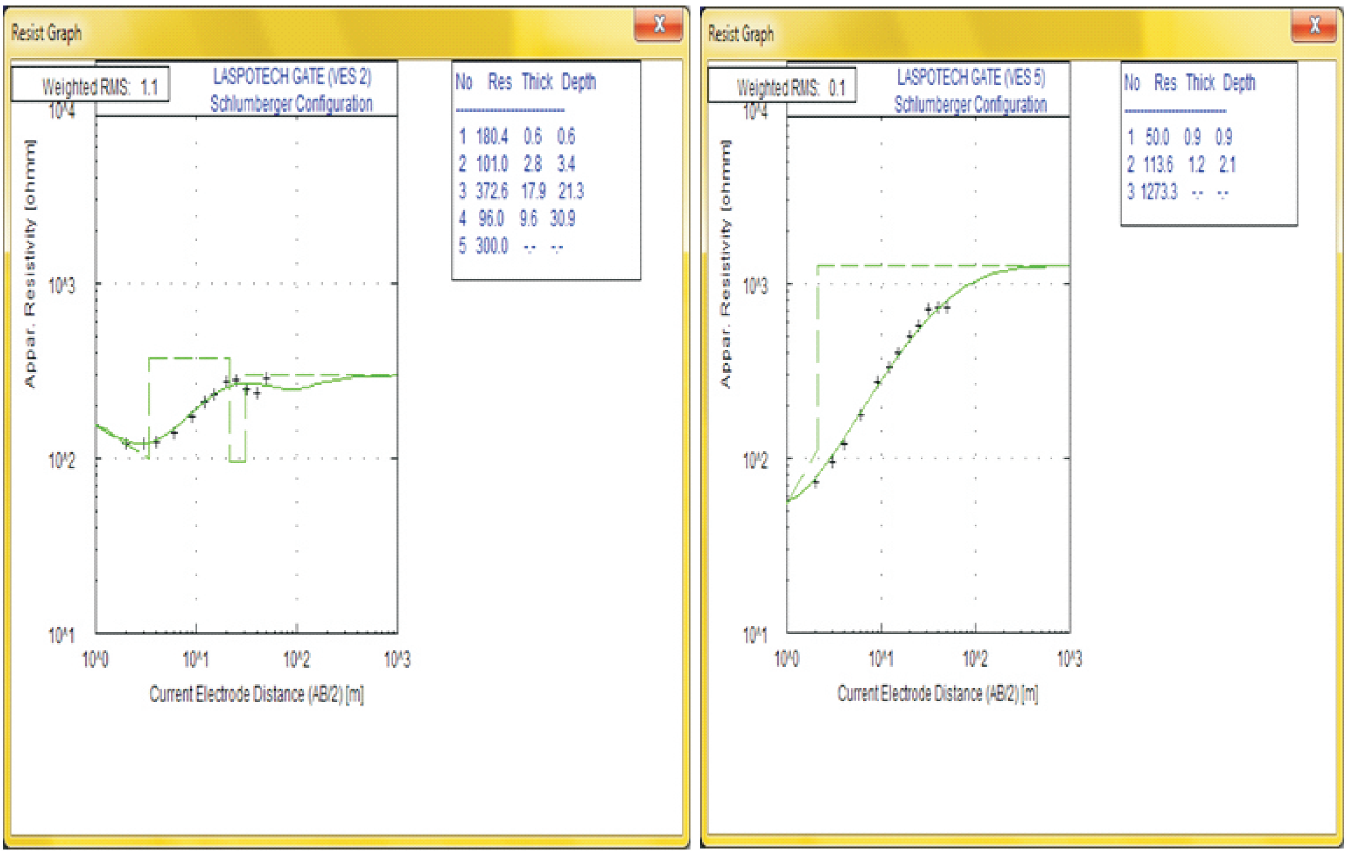

Figure 3: Typical iterative curves of VES 2 and 5

The2-D resistivity imaging pseudosection distinctively reveals the lithology underlying the investigated pavement segments. The lithology sequence of the first profile reveals three inferred lithology layers (figure 4).The first layer gives a resistivity values ranging from 65Ωm –95Ωm, found at the topmost layer interpreted as clay (blue colour) from a depth of 0 to 7m which is incompetent for construction work. The second layer is found immediately after the first layer running through to a depth of 16m interpreted as sandy clay which is fairly competent with resistivity values between 130Ωm and 180Ωm (green colour) and the last layer interpreted as clayey sand (wine colour)competent for pavement work with resistivity values ranging from 220Ωm–450Ωm.

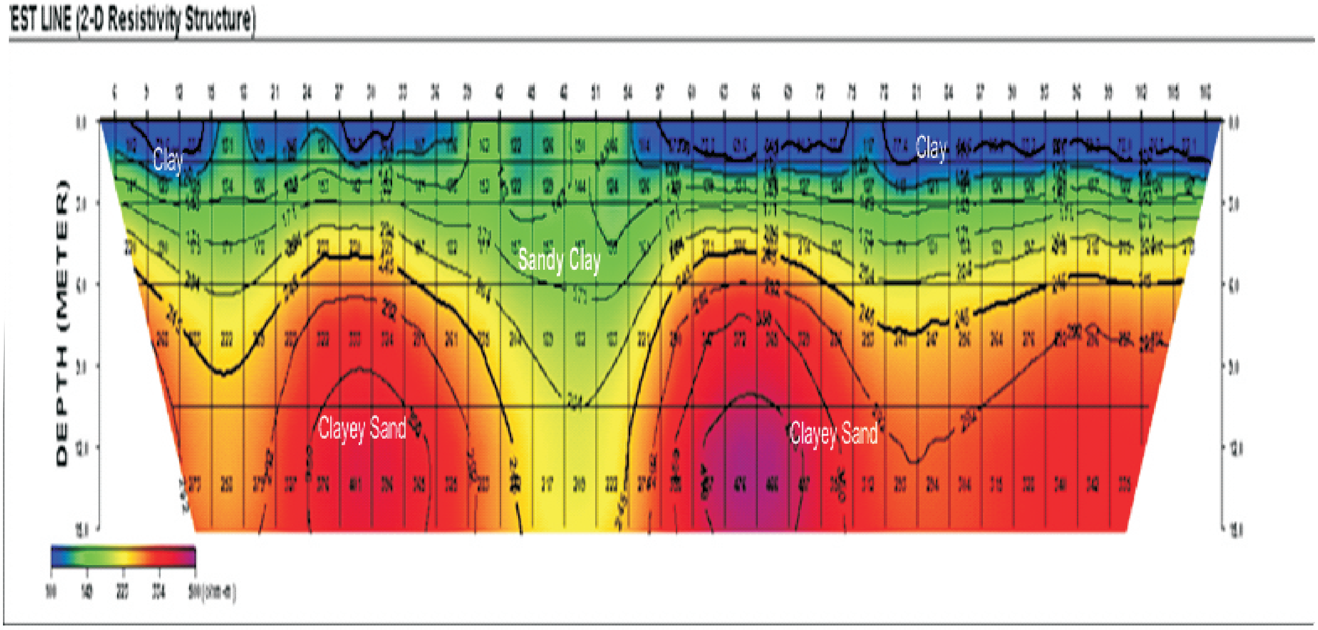

Figure4: 2D Pseudosection of Profile 1

Profile 2 delineates four lithology layers (figure 5), namely (from top to bottom): layer 1 inferred as clay with resistivity values between 30Ωm and 53Ωm;layer 2 interpreted as sandy clay with resistivity ranging from 144Ωm – 175Ωm; layer 3 interpreted as clayey sand with resistivity values between 250Ωm – 420Ωm and the last layer inferred as sand more competent (purple colour) with resistivity ranging from 500Ωm – 650Ωm).

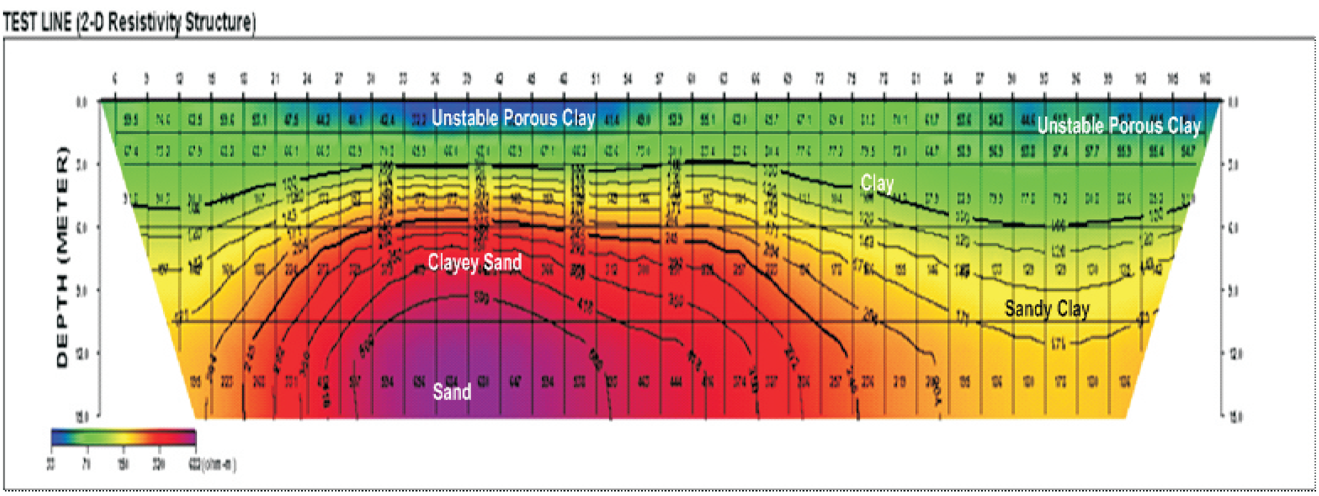

Figure5**: 2D Pseudosection of Profile 2**

Isoresistivity Map

Contrast in resistivity behaviour of a probed area can be very vital for the lithology changes, and more uniquely for the mapping of variation in the competence, porosity and permeability changes, differential compaction, affinity for moisture absorption. The isoresistivity map of the first probed lithology layer is found at the top of the Stacked Isoresistivity Map of the three lithology layer (figure 6) the apparently revealed an anomalous low resistivity zone inferred as clay, attributable to low competence, unstable, poor compaction, high porosity or higher moisture content.

The second probed lithology layer is at the middle of figure 6. The northern part reveals a relatively high resistivity interpreted as clayey sand and almost half of the isoresistivity of the map which shows competence and stable while it is fairly competence and moderately stable at the southern part interpreted as sandy clay. The last probed lithology layer is at the bottom of the isoresistivitymap with three-quarter of the total map from the northern part showing more competence with higher resistivity values.

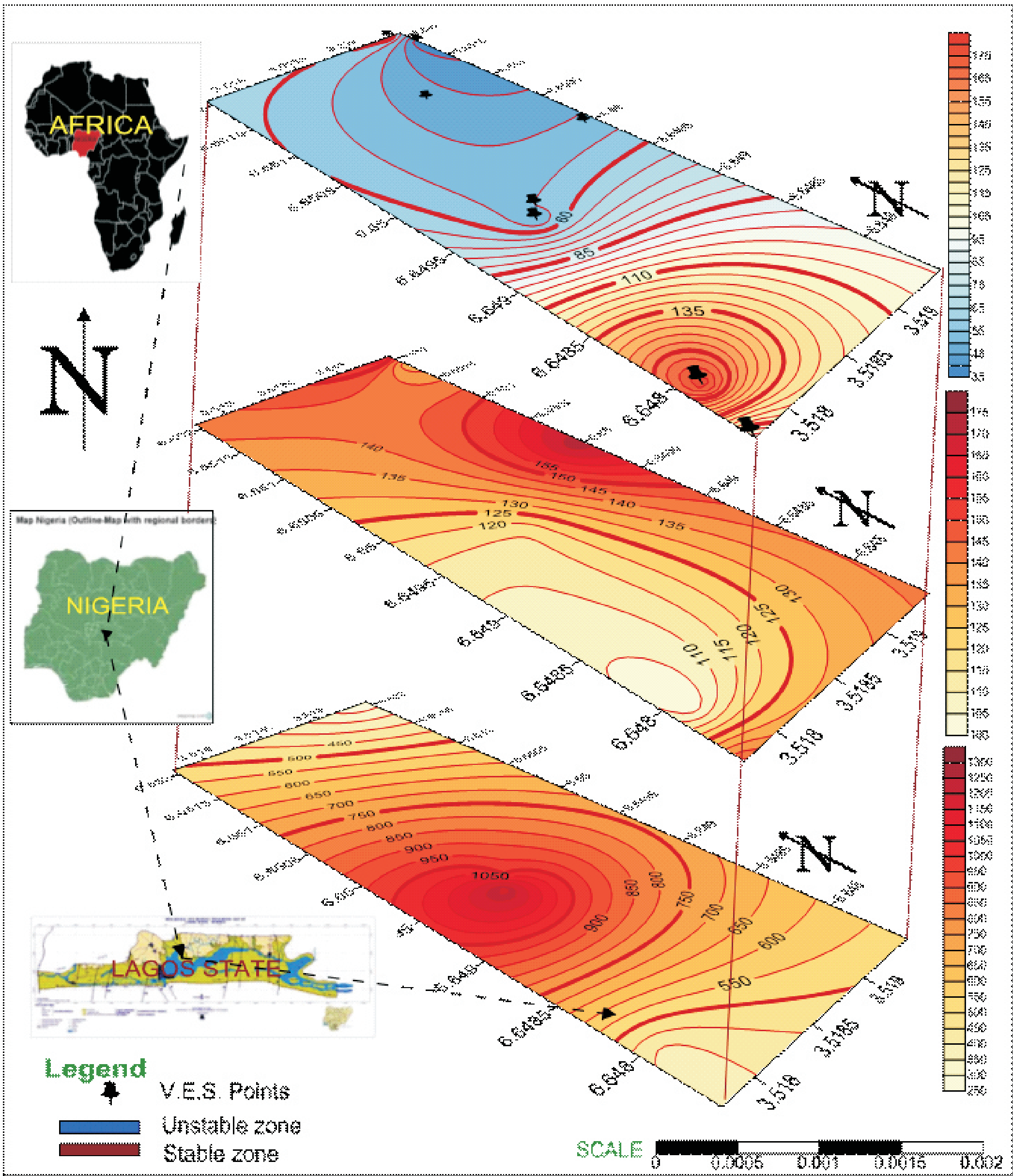

Figure 6: Stacked Isoresistivity Map of the three Lithology Layer

The geotechnical assessment of the subsoil of the study area involves the California Bearing Ratio (CBR) of the soil samples. Table 4 gives the California Bearing Ratio of Sample A and figure 7 shows the CBR test result (unsoaked)

Table 4: California Bearing Ratio of Sample A

Penetration	Top Plunger force Unsoaked	Bottom Plunger force Unsoaked	CBR%
0.25	45	50	
0.50	66	78	
0.75	79	94	
1.00	88	126	
1.25	96	147	
1.50	111	153	
1.75	132	166	
2.00	160	189	
2.25	199	201	
2.50	247	246	18.03
2.75	262	257	
3.00	274	280	
3.25	288	288	
3.50	299	296	
3.75	300	312	
4.00	320	331	
5.0	350	371	17.03

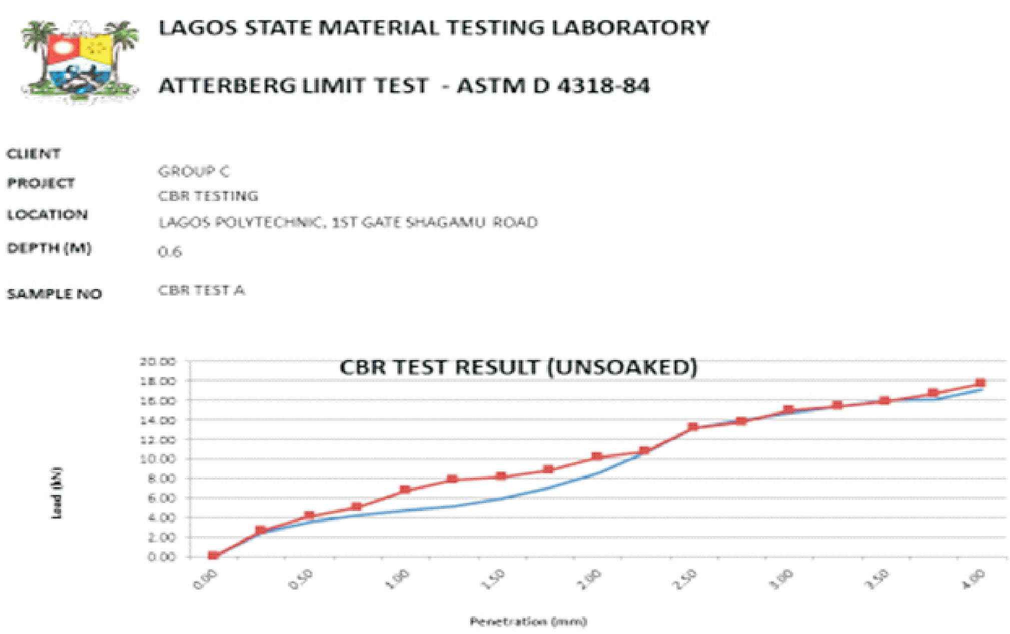

Figure 8: CBR Test Result (unsoaked) for Sample A

The CBR at sample A is calculated below:

$$\text{CBR at 2.5mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \text{x}100\%$$

$$\text{CBR at 2.5mm penetration} = \frac{247}{1370} \text{x}100\%$$

= 18.03%

$$\text{CBR at 5.00mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \text{x}100\%$$

$$\text{CBR at 5.00mm penetration} = \frac{350}{2055} \text{x}100\%$$

= 17.03%

Total CBR = (18.03% + 17.03%) / 2

= (35.06%) /2

= 17.53%

Therefore CBR at Sample A is approximately 18%

Table 5 gives the California Bearing Ratio of Sample B and figure 8 shows the CBR test result (unsoaked)

Table 5: California Bearing Ratio of Sample B

Penetration	Top Plunger force Unsoaked	Bottom Plunger Force Unsoaked	CBR%
0.25	32	50	
0.50	76	72	
0.75	81	80	
1.00	100	110	
1.25	120	140	
1.50	160	180	
1.75	200	210	
2.00	220	220	
2.25	240	240	
2.50	265	263	19.3
2.75	267	275	
3.00	273	281	
3.25	280	290	
3.50	300	310	
3.75	320	320	
4.00	340	340	
5.0	421	421	20.5

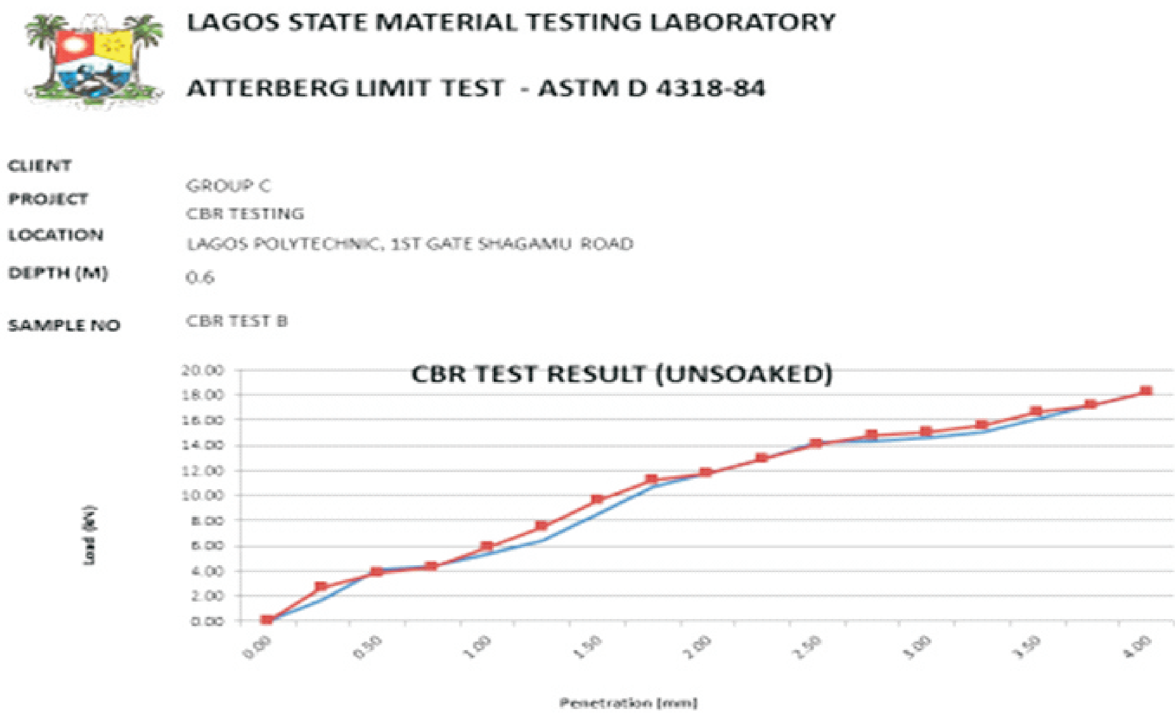

Figure 9: CBR Test Result (unsoaked) for Sample B

$$\text{CBR at 2.5mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \text{x}100\%$$

$$\text{CBR at 2.5mm penetration} = \frac{265}{1370} \text{x}100\%$$

= 19.3%

$$\text{CBR at 5.00mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \text{x}100\%$$

$$\text{CBR at 5.00mm penetration} = \frac{421}{2055} \text{x}100\%$$

= 20.5%

Total CBR = (19. 3% + 20.5%) / 2

= (39.8%) / 2

= 19.9%

Therefore CBR at Sample B is approximately 20%

Table 6 gives the California Bearing Ratio of Sample C and figure 10 shows the CBR test result (unsoaked)

Table 6: California Bearing Ratio of Sample C

Penetration	Top Plunger force Unsoaked	Bottom Plunger force Unsoaked	CBR%
0.25	39	48	
0.50	84	57	
0.75	97	82	
1.00	114	101	
1.25	138	122	
1.50	156	139	
1.75	187	156	
2.00	202	189	
2.25	222	233	
2.50	281	280	20.5
2.75	374	286	
3.00	390	319	
3.25	394	332	
3.50	410	386	
3.75	412	389	
4.00	439	391	
5.0	441	433	21.5

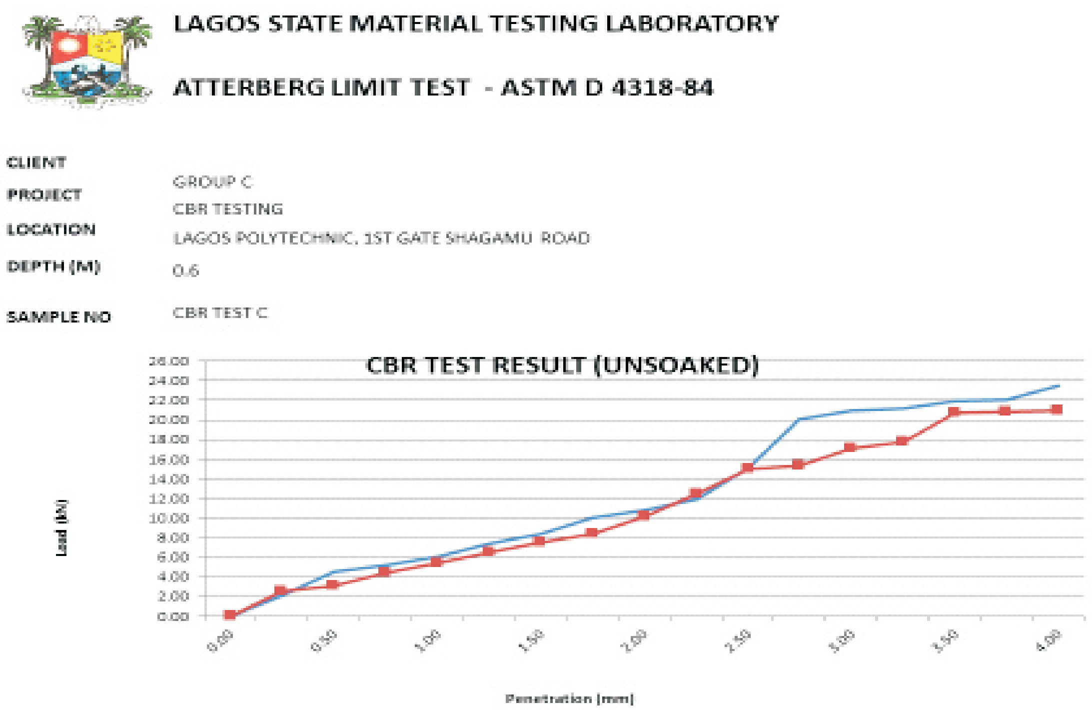

Figure10: CBR Test Result (unsoaked) for Sample C

The CBR at sample C is calculated below:

$$\text{CBR at 2.5mm penetration} = \frac{\text{Test load}}{\text{Standard load}} x100\%$$

$$\text{CBR at 2.5mm penetration} = \frac{281}{1370} x100\%$$

= 20.5%

$$\text{CBR at 5.00mm penetration} = \frac{\text{Test load}}{\text{Standard load}} x100\%$$

$$\text{CBR at 5.00mm penetration} = \frac{441}{2055} x100\%$$

= 21.5%
Total CBR = (20.5% + 21.5%) / 2
= (42.0%) / 2
= 21.0%
Therefore CBR at Sample C is approximately 21%

Table 7 gives the California Bearing Ratio of Sample D and figure 11 shows the CBR test result (unsoaked)

Table 7: California Bearing Ratio of Sample D

Penetration	Top Plunger force Unsoaked	Bottom Plunger force Unsoaked	CBR%
0.25	24	43	
0.50	38	87	
0.75	67	99	
1.00	80	112	
1.25	96	128	
1.50	109	139	
1.75	130	160	
2.00	156	182	
2.25	216	250	
2.50	237	259	15.8
2.75	247	261	
3.00	254	265	
3.25	268	274	
3.50	278	300	
3.75	284	320	
4.00	298	360	
5.0	310	375	15.1

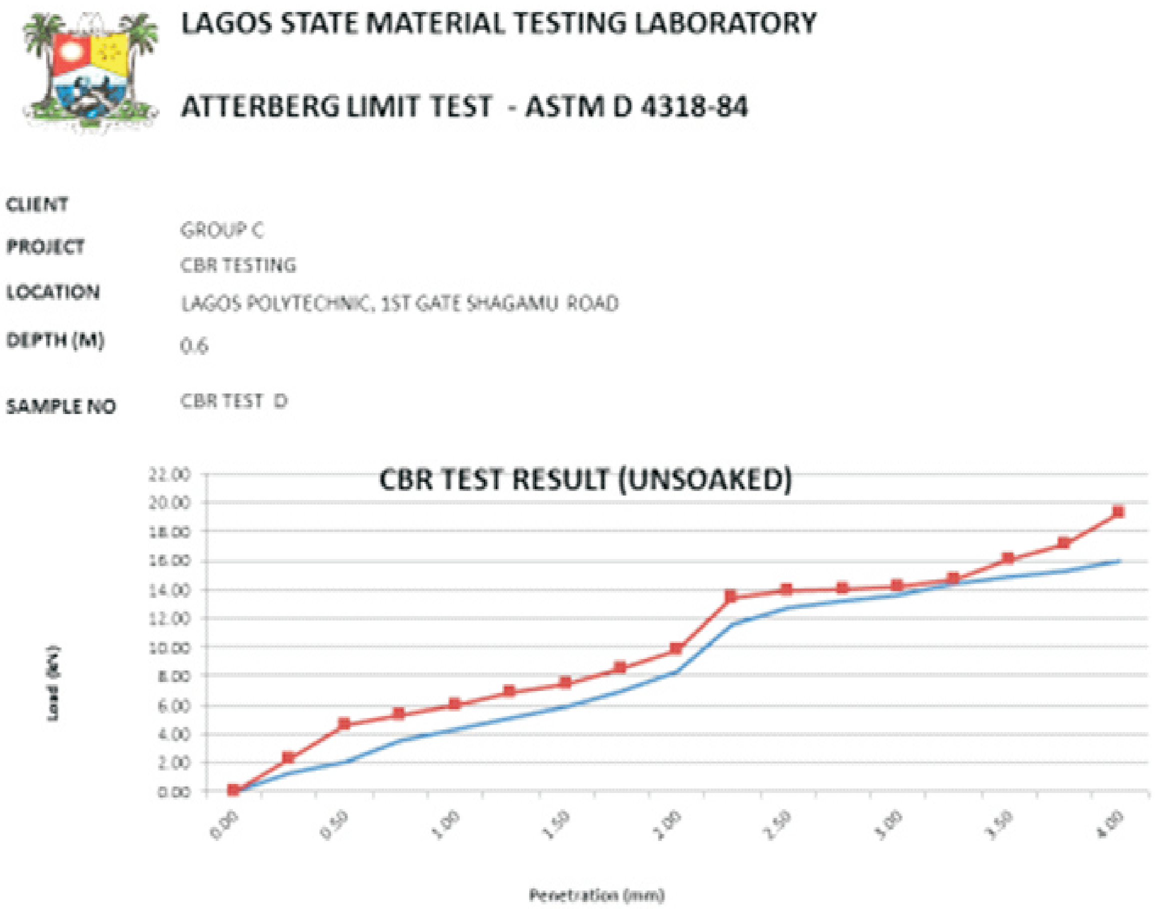

Figure11: CBR Test Result (unsoaked) for Sample D

The CBR at sample D is calculated below:

$$\text{CBR at 2.5mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \times 100\%$$

$$\text{CBR at 2.5mm penetration} = \frac{237}{1370} \times 100\%$$

= 15.8%

$$\text{CBR at 5.00mm penetration} = \frac{\text{Test load}}{\text{Standard load}} \times 100\%$$

$$\text{CBR at 5.00mm penetration} = \frac{310}{2055} \times 100\%$$

= 15.1%

Total CBR = (15.1% + 15.9%) / 2

= (31.0%) / 2

= 15.5.0%

Therefore CBR at Sample D is approximately 16%

The CBR values of the soil samples A, B, C and D obtained are 18%, 20%, 21% and 16% respectively. According to Yashas. *et al.* (2016) the higher the CBR value of a road's subgrade, the lower the thickness of the required road pavement. Making use of the least CBR value obtained from the soil samples, which is 16%, a pavement thickness of 350mm would be adequate for the highest amount of traffic (Oguara, 2006). This would be made up of 150mm sub – base, 100mm of base and 100mm of surface. This shows that the soil is moderate as subgrade for the construction of a flexible road pavement.

Conclusion

The observed differential settling along Ikorodu-Shagamu highway, amongst other non-geological factors, can be largely connected to the presence of incompetent porous unstable clay subgrade directly beneath the pavement structure. The correlation of the integrated geophysical and geotechnical results obtained in the study area shows that, at the weathered layer we have clay/sandy clay with a depth ranging between 1.2m to 17.2m interpreted as fairly competent and moderately stable while at the last layer, the lithology inferred are clayey sand and dry sand with depth ranges from 2.1m and 31m interpreted as competent and stable soil. The subsoil assessed is suitable as subgrade, especially after the removal of the topsoil/weathered layer. But any unsuitable portion along the length of the road can be excavated and replaced with a competent stable soil as subgrade.

It is suggested that Deep Penetration Test (DPT) be conducted on the soil especially if a bridge (pedestrian or fly over bridge) is to be erected along the corridor of the road that was examined. Also side drains should be installed whenever the road is to be totally rehabilitated because the corridor of the road is no longer rural but now urban as a result of development that has taken place along the route of the road.

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