Geotechnical Investigation of Road Failure Along Ogheghe, South-South, Nigeria

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DOI: 10.22178/pos.108-16

LCC Subject Category: T1-995

Received 25.06.2024
Accepted 28.09.2024
Published online 30.09.2024

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Abstract. To assess the geotechnical properties of the soil, three different soil samples were collected from both failed and unfailed sections of Ogheghe Road in South-South Nigeria. These samples were analysed for particle size distribution, liquid limit, plastic limit, maximum dry density (MDD), optimum moisture content (OMC), and California Bearing Ratio (CBR). The results showed that for Sample One, the OMC and MDD were 35.88% and 1.42 g/cm³, respectively, with plastic and liquid limits ranging from 20.88 to 20.92% and 39.42 to 49.62%. The CBR values ranged from 15.20% to 24.00% in unsoaked conditions and 11.61 to 17.53% in soaked conditions. For Sample Two, the OMC and MDD were 13.15% and 1.72 g/cm³, respectively, with plastic and liquid limits ranging from 18.91 to 20.38% and 31.25 to 40.35%. The CBR values ranged from 12.00 to 19.71% in unsoaked conditions and 10.63% to 11.75% in soaked conditions. For Sample Three, the OMC and MDD were 19.24% and 1.40 g/cm³, respectively, with plastic and liquid limits ranging from 17.95 to 18.15% and 31.22 to 40.73%. The CBR values ranged from 6.09 to 7.65% in unsoaked conditions and from 4.63 to 7.29% in soaked conditions. These results were compared to the specifications established by the Federal Government of Nigeria for roads and bridges (1997); overall, the result revealed noticeable deviations from standards. This implies that the soil along the Ogheghe road is unsuitable for use as subbase and base materials and is a significant contributing factor to the road's failure.

Keywords: Road failure; Ogheghe; Geotechnical laboratory test; Atterberg Limit; Sieve Analysis.

INTRODUCTION

Studies on road failure have extensively utilised Geophysical and Geotechnical methods. Geophysical techniques, including electrical resistivity and electromagnetic (EM) assess subsurface conditions to determine road integrity and identify potential fault zones that may lead to failure [1]. Geotechnical methods involve laboratory testing of foundation materials to evaluate engineering properties such as particle size distribution (PSD), plastic limit (PL), liquid limit (LL), compaction, and California Bearing Ratio (CBR). The stability and suitability of soil used in road construction are critical in preventing road failure. Soils with appropriate geotechnical properties, such as adequate bearing capacity, low compressibility, and proper drainage characteristics, provide a strong and durable road base.

Conversely, unsuitable soils, such as those with high plasticity, excessive moisture content, or poor compaction, can lead to structural weaknesses and premature road deterioration. Poor geotechnical and mineralogical properties of residual soils used in the construction of roads globally may result in road pavement deterioration [2]. Most countries have stipulated standards for the geotechnical properties of soils used for road construction. In Nigeria, road failure is one of the infrastructural facilities that are in total collapse, and road failure has not only caused setbacks to the Nigerian economy but also claimed lives resulting from road crashes and properties worth millions of naira are lost annually. A recent Federal Road Safety Corps (FRSC, 2011) study revealed that Nigeria currently ranks 191 of 192 countries with unsafe roads. This road network is poorly constructed and founded mainly on problematic soils.

The Federal Government of Nigeria, through the Ministry of Works for Roads and Bridges (1997), established guidelines to ensure the suitability of soils for road construction. These specifications mandate that soil used as a base course or subbase material must have no more than 35% of particles passing sieve No. 200. The liquid limit should be less than or equal to 50% for subgrade and 35% for subbase. The Plastic Index (PI) should be less than or equal to 30% for subgrade and 12% for subbase. Both subgrade and subbase should have an Optimum Moisture Content (OMC) of less than 18%. The Maximum Dry Density (MDD) should be less than or equal to 1.8 Mg/m^3 for the subgrade and 1.6 Mg/m^3 for the subbase.

Additionally, the California Bearing Ratio (CBR) for soaked conditions should be less than or equal to 7% for subgrade and 30% for subbase. For unsoaked conditions, the CBR should be less than or equal to 15% for subgrade and 80% for subbase [3]. Notably, not all soils meet these stipulated standards, as they exhibit varied behaviours depending on their geotechnical and mineralogical properties [4]. Roads are constructed on or with geological materials (rocks or soils); hence, geology is also fundamental to road construction. Soils formed in situ by chemical and mechanical weathering of parent rocks are termed residual soils [5], and they have chemical similarities to their parent formation material [6]. In Nigeria, some soils used for road construction were observed to have originated from parent formation materials with poor geotechnical properties.

Geotechnical investigation of soil before the construction of roads is crucial in reducing road failures in Nigeria, given the country's diverse and challenging geological conditions [7]. By conducting thorough soil investigations, the soil's physical and mechanical properties, such as its bearing capacity, moisture content, susceptibility to erosion and potential for expansion or contraction, can be accurately assessed. This information is essential for designing road foundations that withstand local environmental conditions and traffic loads. Proper geotechnical investigation aids in identifying potential problem areas, such as soft soils, expansive clays, or areas prone to subsidence, which can lead to road deformation and failure if not adequately managed. Additionally, these investigations enable the selection of appropriate construction materials and techniques, ensuring that roads are built on stable ground and reducing the likelihood of premature failure. In Nigeria, where road infrastructure is vital for economic development and connectivity, investing in comprehensive geotechnical investigations can significantly enhance the durability and longevity of road networks, ultimately leading to safer and more reliable transportation systems.

The failure of Ogheghe road in Edo state, South-South Nigeria, frustrates regular users. A portion of its lanes has been completely blocked, resulting in poor conditions for those utilising it. These damages have led to numerous vehicles breaking down on the Benin highway. The road is so deplorable that most vehicles arrive at mechanics' workshops after each journey. Authors [8] categorised road failures into cracking, surface deformation and surface defects. These defects cause issues for road users, such as discomfort and increased travel time. Additionally, these defects often lead to loss of human life in road-precipitated motor accidents, loss of person-hours, and high costs of goods and services [9].

The primary objective of this study is to evaluate the underlying geotechnical factors contributing to the road failure of Ogheghe road in Edo State, South-South, Nigeria. This study seeks to identify the specific soil conditions that lead to road deformation, cracking, and other forms of failure ravaging the road. Several experimental techniques will be employed to evaluate the Geotechnical properties of the soil samples collected at different locations along Ogheghe road in Edo state, South-South, Nigeria. These techniques include geotechnical laboratory tests such as sieve analysis, compaction test, California bearing ratio (CBR) test, Atterberg's limit test (Liquid

Limit and Plastic Limit) and moisture content test. All tests would be carried out according to procedures outlined in the British Standard Code (BS 1377: 1990), and results would be compared to the regulatory standards of Road and Bridges stipulated by the Federal Government of Nigeria (1997).

The location of study area

The study area, Ogheghe Road, is in Benin City, Edo State (latitude 6.6342° N and longitude 5.9304° E), South-South, Nigeria. Benin City is the capital of Edo State. It is a vital transportation hub connecting Lagos and the eastern states along significant highways. The city is also connected to Sapele, Ekpoma, and Delta states through the road networks and has access to air travel and the Nigeria River Delta ports of Koko and Sapele. The area's elevation ranges from 155 m in the south to over 555 m in the north, and tropical rainforests predominantly cover it. The lithostratigraphy of the Benin Formation (Miocene-Recent) is characterised by 90% sand, conglomeratic gravels (pebbles and cobbles), clays, peat and lignite (infrequent, occurring as beds or dispersed fragments) deposited in a continental coastal plain (fluvial) depositional setting [10]. The sands of the Benin Formation are dominantly coarse-grained, poorly to moderately sorted, and generally loose, becoming progressively finer with abundant clay, some peat/lignite and ferruginous bands towards the top, which is commonly reddish due to Fe-oxide coating.

Ogheghe Road extends approximately 2.26 miles, starting from Sapele Road, and has a width of 7.4 meters without any existing drainage infrastructure. Although the road formerly experienced heavy vehicular traffic, it has recently seen a significant reduction due to the destabilised state of the road.

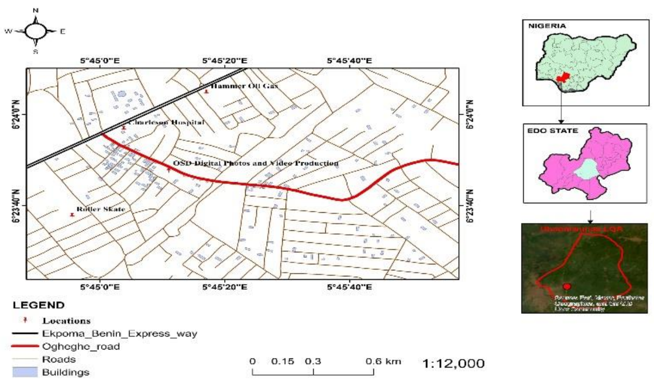

Figure 1 – Location map showing Ogheghe road, in Edo State, South-South, Nigeria

Figure 2 – Destabilised state of Ogheghe road, in Edo state, South-South, Nigeria

METHODS

To conduct this investigation, three trial pits were excavated from the existing ground level of the road in Edo state, South-South, Nigeria. Excavation was carried out at a depth of 2 m. The trial pit locations were selected based on the road's topography and overburden conditions. Three different disturbed soil samples were obtained from these trial pits and sent to the Civil Engineering laboratory at the University of Benin, Benin City, Nigeria, for the Geotechnical laboratory test. The following Geotechnical laboratory tests were conducted to evaluate the underlying Geotechnical factors contributing to the road failure of Ogheghe road in Edo State, South-South, Nigeria. All tests were carried out according to procedures outlined in the British Standard Code (BS 1377: 1990), and the results were compared to the regulatory standards of Roads and Bridges stipulated by the Federal Government of Nigeria (1997): Sieve analysis; Compaction Test; California Bearing Ratio (CBR) test; Atterberg's limit test (Liquid Limit and Plastic Limit); Moisture content test.

Sieve Analysis. A stack of test sieves (ranging from 0.15 to 4.75 mm), a weighing balance (with an accuracy of 0.01 g), a sieve shaker, a rubber pestle and mortar, and an oven are materials used for this Geotechnical Laboratory test. For the test, a representative sample of around 500 g was utilised. The wet sieving method was used, and 500 g of soil from sample one was collected, washed thoroughly, and then oven-dried. The sieves are stacked in order, with the largest aperture size at the top and the smallest at the bottom. A receiver was placed underneath to collect samples. The sample was poured into the top sieve, covered with a lid, and the stack was placed in a sieve shaker with the clamps fixed. The timer was set between 10 and 15 minutes, and the shaker was switched on. After shaking, the mass of each sieve and the retained material were measured. The sample retained on each sieve was weighed, and the results were then analysed and recorded. This procedure was repeated for sample two and sample three.

Compaction Test. The material used for this test includes a compaction mould with a capacity of 1000 ml, a rammer (2.6 kg), a detachable base plate, a collar (60 mm high), a sieve 275 mm, a drying oven, a drying oven, a plastic squeeze bottle with water, a desiccator and 32" gauge for measuring compaction.

3 kg of air-dry soil was used for the compaction test; all soil lumps were broken and sieved through a No. 4.75 US sieve, and all of the material was collected in a tray. Water was added and mixed thoroughly to achieve the desired moisture content required for the test. The weight of the Proctor mould with the base plate (excluding the extension) was determined, and the extension was attached to the mould. The moist soil was poured into the mould in three equal layers, each compacted uniformly with 23 blows from a Proctor rammer (2.6 kg) dropped from a height of 450 mm. The top attachment was carefully removed, and the excess soil was trimmed with a straight edge to level it with the mould's top. The compacted soil and mould were weighed, and a seating load of around 4.5 kg was applied when placed under the CBR machine. The load values were recorded at different penetration depths: 0.625, 1.9, 2.25, 6.25, 7.5, 10 and 12.5 mm. This procedure was repeated five times for samples one, two, and three.

California Bearing Ratio (CBR). The materials and apparatus used for the California Bearing Ratio test included an ASTM "Casagrande" grooving tool, a sieve, a wash bottle, a spatula, distilled water, a balance with a sensitivity of 0.01g, drying oven, No. 40 sieve, pan, lid, plastic limit glass plate, aluminium moisture cans and rod comparator (3 mm diameter rod, 10 cm long) or callipers for measuring.

A 5.5 kilogram of dried clay soil was collected in a tray and mixed with water. The sample was divided into five portions and poured into a lubricated mould with filter paper and a spacer disc at the bottom. Each layer received at least 55 blows from a 4.89kg rammer. The top attachment was carefully removed, and the excess soil was trimmed with a straight edge to level the compacted soil with the mould's top. The mould with the test specimen was placed on the lower plate of a penetration testing machine, and the penetration piston was placed on the centre of the specimen with the minor possible load, but in no case over 4 kg, to ensure complete contact with the sample. The load and deformation gauges were set to read zero. The load was applied to the piston so that the penetration rate was about 1.25 mm/min using a standard plunger with a diameter of 50 mm. The load readings were recorded at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10 and 12.5 mm. The plunger was raised, and the mould was detached from the loading equipment. The readings at 2.5 and 5.0 mm penetration were taken. The CBR is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads on crushed stone. A load penetration curve is drawn. The load values on standard crushed stones were 13.44 KN and 20.15 KN at 2.5 mm and 5.0 mm penetrations, respectively. This procedure was carried out for samples one, two and three.

Atterberg Limit Test. The apparatus and materials used included an evaporating dish, a spatula, aluminium containers, mortar and pestle, a digital scale with 0.01 g readability, a drying oven, plastic limit test apparatus including plastic limit roller and glass plate, shrinkage limit test apparatus including shrinkage dish, microcrystalline wax, petroleum jelly, fine thread, glass plate, and wax melting pot. For the Liquid Limit, weights of different cans were taken, wet samples were added at varying weights, containers were oven-dried, and the differences in weight before and after drying were recorded. The weight of the empty cans, the weight of the can plus wet soil, and the weight of the can plus dry soil were all recorded. For the Plastic Limit, clean cans were prepared, ellipsoidal-shaped soil masses were formed and rolled into threads until they crumbled. The crumbled threads were collected, filled into cans, covered, and oven-dried. This procedure was carried out for samples one, two and three.

Moisture Content. Balance (accurate to 0.01 grams), Soil sample container (usually a tin or aluminium dish), spatula, graduated cylinder, Stopwatch and drying oven are the materials that were used for this test. The procedure involved cleaning, drying, and weighing the container, ensuring the sensitive weight balance was tarred before use. The next step was to weigh a specimen sample placed in the container. The container was then kept in an oven for 24 hours, with the specimen dried to a constant weight at a temperature between 105°C and 115°C. However, the time required could vary depending on the soil type, with 16 to 24 hours generally sufficient. Finally, the constant weight of the container with the dried soil sample was to be recorded, noting that peat and other organic soils required drying at a lower temperature of approximately 60°C for a longer duration.

RESULTS AND DISCUSSION

All the results obtained from the tests are tabulated and provided in the graphs below.

Sieve Analysis. The sieve analysis results for soil samples one, two, and three are detailed in Tables 1, 2, and 3, respectively. Each soil sample utilised 500 grams for the sieve size analysis. For sample one, only 3.12% of the sample passed through the 0.3 mm sieve, which weighed 12.2 g, while for sample two, 1.65% of the sample passed through the 0.15 mm sieve, which weighed 0.17 g, and then for sample three, 9.00% of the sample passed through the 0.15 mm sieve which weighed 45g. According to the Federal Government specification requirement for roads and bridges, for a sample to be used for road construction, the percentage by weight passing the sieves should be less than but not greater than 35%. Based on these criteria, all three samples are considered suitable for road construction, as the percentage by weight passing through the sieves did not exceed 35%.

Table 1- Sieve analysis of Sample 1

Sieve Size	Weight (g)	Weight Retained (%)	Cumulative Passing (%)
2.8	0.0	0.00	100
2.00	35.0	9.09	90.91
1.40	76.0	19.74	71.17
1.00	98.0	25.45	45.72
0.71	80.0	20.78	24.94
0.5	50.0	12.99	11.95
0.3	34.0	8.83	3.12
The sample passed through a 0.3 mm sieve	12.0	3.12	0.00

Table 2- Sieve analysis of Sample 2

Sieve Size	Weight (g)	Weight Retained (%)	Cumulative Passing (%)
4.75	0.03	2.65	97.35
2.36	0.03	3.05	94.30
1.18	0.12	12.1	82.20
0.6	0.238	23.80	58.40
0.3	0.37	36.70	21.65
0.15	0.15	15.30	6.35
The sample passed through a 0.15 mm sieve	0.17	1.65	0

Table 3 – Sieve analysis of Sample 3

Sieve Size	Weight (g)	Weight Retained (%)	Cumulative Passing (%)
4.75	10	2.0	98.0
2.36	18	3.6	94.4
1.18	60	12.0	82.4
0.56	135	27.0	55.4
0.30	145	29.0	26.4
0.15	56	11.2	15.2
The sample passed through a 0.15 mm sieve	45	9.0	6.2

Compaction test. Table 4 below presents the result of the compaction test for soil sample one.

Table 4 – Compaction test result of Sample One

Wt. of mould & wet soil (W2) g	6350		6495		6541		6637		6662	
Wet of mould (W1) g	4735.00		4735.00		4735.00		4735.00		4735.00	
Wt. of wet soil (W2 – W1) g	1615		1760		1806		1902		1927	
Bulk density, Pb (W2 – W1) /1000g/cm3	1.615		1.760		1.806		1.902		1.927	
Container no	III	V13	C	V18	SSG	JAN	JK	ETE	2F	L
Wt. of wet soil & container	55.44	51.74	51.71	53.75	54.91	53.20	52.94	46.69	56.92	52.08
Wt. of dry soil & container	46.69	44.89	43.05	45.20	45.30	44.79	42.36	40.23	45.36	43.97
Wt. of can	14.85	14.85	16.63	18.79	16.19	15.52	15.33	17.40	14.19	18.73
Wt. of dry soil (wd)	33.49	29.49	27.62	27.45	28.75	30.04	26.99	22.53	31.22	25.33
Wt. of moisture (wm)	8.22	8.02	7.87	7.94	8.96	9.40	9.30	7.84	11.23	9.34
Moisture content (wm/wd) x 100 %	24.54	27.20	29.49	28.93	31.17	31.29	34.46	34.80	35.97	36.87
Average moisture content (m)%	25.39		28.35		30.85		34.42		35.88	
Dry density = Pb/1+(m/100) (g/cm3)	1.29		1.37		1.38		1.41		1.42	

The dry density value ranged from 1.29 g/cm^3 to 1.42 g/cm^3 while the average moisture content ranged from 25.39% to 35.88%. The primary purpose of the compaction test was to identify the optimal moisture content at which the soil sample can be compacted to achieve the highest maximum dry density. The Optimum Moisture Content (OMC) and the Maximum Dry Density were attained at 35.88% and 1.42 g/cm^3, respectively. According to [11], samples with high maximum dry density and low optimum moisture content are unsuitable as subbase and sub-grade materials. Also, according to Federal Government specifications for roads and bridges (1997), OMC should be less than 18% for sub-base and sub-grade materials. Based on these specifications, sample one is unsuitable as a sub-base and sub-grade material.

The compaction test result for sample two is shown in Table 5 below.

Table 5 – Compaction test result for Sample 2

Wt. of mould & wet soil (W2) g	6365		6575		6680		6648		6604	
Wet of mould (W1) g	4735.00		4735.00		4735.00		4735.00		4735.00	
Wt. of wet soil (W2 – W1) g	1630		1840		1945		1913		1869	
Bulk density, PB (W2 – W1)/1000 g/cm3	1.630		1.840		1.945		1.913		1.869	
Container no	III	V13	C	V18	SSG	JAN	JK	ETE	2F	L
Wt. of wet soil & container	49.61	42.04	57.71	59.17	54.08	60.58	54.60	55.12	54.85	60.65
Wt. of dry soil & container	45.98	39.24	53.35	54.30	49.65	55.62	49.48	50.04	49.40	54.42
Wt. of can	15.02	6.98	15.12	14.60	15.16	18.75	14.83	15.25	16.44	17.74
Wt. of dry soil (w)	30.98	32.26	38.23	39.70	34.49	36.87	34.65	34.79	32.96	25.33
Wt. of moisture (wm)	3.63	2.80	4.36	4.87	4.43	4.96	5.12	5.08	5.45	6.13
Moisture content(wm/wd) %	11.72	8.68	11.40	12.27	12.84	13.45	14.78	14.60	16.54	24.20
Average moisture content (m)%	10.20		11.84		13.15		14.69		16.60	
Dry density = Pb/1+(m/100) (g/cm3)	1.48		1.65		1.72		1.67		1.60	

The dry density value ranged between 1.48–1.60 g/cm^3 while the average moisture content ranged from 10.20% -16.60%. The Optimum Moisture Content (OMC) and the Maximum Dry Density were attained at 13.15% and 1.72 g/cm^3, respectively. According to the Federal Government specifications for roads and bridges (1997), subgrade and subbase should have an Optimum

Moisture Content (OMC) of less than 18% while Maximum Dry Density (MDD) should be less than or equal to 1.8 Mg/m^3 for subgrade and subbase. Based on these specifications, sample two is suitable as a sub-base and sub-grade material.

Table 6 presents the compaction test result for soil sample three.

Table 6 – Compaction test on sample 3

Wt. of mould & wet soil (W2) g	6252		6418		6516		6490		6468	
Wet of mould (W1) g	4735.00		4735.00		4735.00		4735.00		4735.00	
Wt. of wet soil (W2 – W1) g	1517		1683		1781		1755		1733	
Bulk density, PB (W2 – W1)/1000 g/cm3	1.517		1.683		1.781		1.755		1.733	
Container no	III	V13	C	V18	SSG	JAN	JK	ETE	2F	L
Wt. of wet soil & container	51.60	48.66	52.11	59.15	51.79	52.68	50.52	43.66	63.78	54.78
Wt. of dry soil & container	47.46	44.96	47.38	53.45	46.07	47.29	44.63	38.77	55.09	47.72
Wt. of can	18.00	16.79	17.52	17.80	17.39	18.21	16.97	15.50	19.86	17.82
Wt. of dry soil (wd)	29.46	28.17	29.85	35.65	28.68	29.08	27.66	23.27	35.23	29.90
Wt. of moisture (wm)	4.14	3.70	4.73	5.70	5.72	5.39	5.89	4.89	8.69	7.06
Moisture content 100(wm/wd) %	14.05	13.14	15.85	15.99	19.94	18.54	21.29	21.01	24.67	23.61
Average moisture content (m)%	13.59		15.91		19.24		21.15		24.14	
Dry density = Pb/1+(m/100) (g/cm3)	1.34		1.45		1.49		1.45		1.40	

The dry density value ranged between 1.34–1.40 g/cm^3 while the average moisture content ranged from 13.59-24.14%. The Optimum Moisture Content (OMC) and the Maximum Dry Density were attained at 19.24% and 1.49 g/cm^3, respectively. Based on the specifications stipulated by the Federal Government for roads and bridges, sample three is unsuitable as a sub-base and sub-grade material.

California Bearing Ratio Test. For all the graphical representations below, the x-axis typically represents the Penetration Load (KN), which is the force required to penetrate a plunger into the soil sample, and the y-axis represents the Load (KN), which is the total vertical load applied to the sample. The graph shows how the soil's resistance to penetration (CBR value) changes as the load increases, indicating the CBR values at specific depths or levels of loading.

Table 7- Test on Bottom (unsoaked) for Sample 1

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load indicator	0	39	80	116	157	172	195	243	283	380	475	565
Ditto corrected												
Load (KN)	0	0.43	0.883	1.278	1.727	1.88	2.132	2.66	3.10	4.15	5.20	6.18
CBR												

Table 8- Test on top (unsoaked) for Sample 1

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.0	12.5
Load indicator	0	204	234	247	263	281	301	339	372	460	519	612
Dino corrected												
Load (KN)	0	2.12	2.57	2.7122	2.896	3.08	3.391	3.70	4.07	5.04	5.57	6.70
C.B.R %												

Table 9 -Test on the bottom (soaked) for Sample 1

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.5
Load indicator	0	58	86	115	136	164	199	247	306	478	627	758
Ditto corrected												
Load (KN)	0	0.52	0.840	1.157	1.387	1.703	2.076	2.601	3.24	5.117	6.740	8.20
CBR												

Table 10 -Test on top (soaked) for Sample 1

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.5
Load indicator	0	47	72	97	122	141	181	248	311	450	552	617
Ditto corrected												
Load (KN)	0	0.41	0.676	1.080	1.234	1.442	1.880	2.612	3.41	5.020	6.047	6.75
CBR												

Table 11 -Summary of the Unsoaked and Soaked values for sample one

	UNSOAKED		SOAKED	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm
BOTTOM	15.02	16.045	13.513	16.712
TOP	24.003	20.877	11.613	17.534

Table 12 – Test on the bottom (Unsoaked) for Sample 2

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load indicator	0	79	115	124	147	167	177	209	220	275	323	354
Ditto corrected												
Load (KN)	0	0.864	1.203	1.256	1.508	1.727	1.826	2.187	2.306	3.02	3.433	3.772
CBR												

Table 13-Test on top (unsoaked) for sample two

Penetration (mm)	0.0	0.50	1.00	1.5	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load indicator	0	124	184	202	216	230	241	262	280	326	364	406
Ditto corrected												
Load (KN)	0	1.23	2.01	2.2	2.37	2.51	2.634	2.875	3.06	3.575	4.001	4.341
CBR												

Table 14 -Test on the bottom (soaked) for Sample 2

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load indicator	0	66.0	79	110	124	139	154	182	209	264	302	349
Ditto corrected												
Load (KN)	0	0.62	0.78	1.11	1.25	1.52	1.58	2.001	2.18	3.007	3.32	3.717
CBR												

Table 15 -Test on top (soaked) for Sample 2

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.0	12.5
Load indicator	0	50	76	99	117	129	149	163	199	234	265	299
Ditto corrected												
Load (KN)	0	0.43	0.731	1.083	1.180	1.31	1.530	1.80	2.07	2.57	3.01	3.18
CBR												

Table 16 – Summary of the Unsoaked and Soaked Values for Sample 2

	UNSOAKED		SOAKED	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm
BOTTOM	13.76	12.00	11.45	11.40
TOP	19.71	15.78	10.63	10.87

Table 17 -Test on the bottom (unsoaked) for Sample 3

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.0	12.5
Load indicator	0	37	52	64	79	92	101	120	136	169	202	231
Ditto corrected												
Load (kn)	0	0.41	0.569	0.722	0.875	1.02	1.127	1.32	1.49	1.95	2.32	2.64
CBR												

Table 18 -Test on top (unsoaked) for Sample 3

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.0	12.5
Load indicator	0	33.0	49	56	64	73	80	95	103	143	163	191
Ditto corrected												
Load (kn)	0	0.37	0.545	0.621	0.709	0.80	0.884	1.04	1.13	1.46	1.80	2.09
CBR												

Table 19 -Test on the bottom (soaked) for Sample 3

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.0	12.5
Load indicator	0	41	60	70	80	89	95	100	135	180	215	242
Ditto corrected												
Load (KN)	0	0.44	0.656	0.766	0.875	0.97	1.039	1.09	1.47	1.96	2.35	2.64
CBR												

Table 20 -Sample three of the top (unsoaked) for Sample 3

Penetration (mm)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	7.50	10.00	12.50
Load indicator	0	24	32	39	44	51	56	69	80	108	135	169
Ditto corrected												
Load (KN)	0	0.16	0.261	0.338	0.392	0.469	0.523	0.666	0.78	1.092	1.387	1.75
CBR												

Table 21 -Summary of the Unsoaked and Soaked Values for Sample 3

	UNSOAKED		SOAKED	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm
BOTTOM	7.65	7.408	7.249	7.298
TOP	6.754	6.092	4.194	4.338

Table 11 summarises the values for the soaked and unsoaked conditions. The un-soaked CBR values ranged from 15.02% to 24.00%, while soaked CBR values ranged from 11.61% to 17.53%. These values are generally less than 30% and 80% recommended for highway sub-base and sub-grade soils by the Federal Ministry of Works. The soils yielded fair to poor CBR values. Such low values are not likely to provide a stable compacted sub-grade material.

Table 16 summarises the values for the soaked and unsoaked conditions. The un-soaked CBR values ranged from 12.00 to 19.71%, while soaked CBR values ranged from 10.63% to 11.45%. These values are generally less than 30% and 80% recommended for highway sub-base and sub-grade soils by the Federal Ministry of Works. The soils yielded fair to poor CBR values. Such low values are not likely to provide a stable compacted subgrade material.

Table 21 summarises the values for the soaked and unsoaked conditions. The un-soaked CBR values ranged from 6.09 to 7.65%, while soaked CBR values ranged from 4.19 to 7.29%. These values are generally less than 30% and 80% recommended for highway sub-base and sub-grade soils by the Federal Ministry of Works. The soils yielded fair to poor CBR values. Such low values are not likely to provide a stable compacted subgrade material.

Atterberg Limit Test. Atterberg's limits (liquid limit and plastic limit) test was performed on the three different soil samples. The liquid limit of the various samples was obtained from the graphical representation of the moisture content of the different soil samples against the number of blows applied to the soil sample. For soil sample one, the value for the liquid limit ranged from 39.42 to 49.61%, and the value of the plastic limit ranged from 20.88 to 20.92%, as shown in Table 22, respectively. For soil sample two, the value of the liquid limit ranged from 31.25 to 40.35%, while the value for the plastic limit ranged from 18.91 to 20.38%, as shown in Figure 13. and Table 23, respectively. The liquid limit for soil sample three ranged from 31.22 to 40.73%, while the plastic limit ranged from 17.95% to 18.15%, as shown in Table 24, respectively. Liquid limits of 40-60% are typically classified as clay soil with a moderate plasticity index, while 25-50% values are typically classified as silty soils with lower plasticity characteristics, as outlined in BS 1377 of 1990. According to the Federal Government specifications for roads and bridges (1997), the liquid and plastic limits should have a maximum of 30% to be used as sub-base and base materials. As a sequel to the above, the samples are partially suitable as sub-base and base material for road construction.

Table 22 – Atterberg test result for Sample 1

Type of Test	LL		LL		LL		LL	LL
No of Blows / Shrinkage	42.00		34.00		24.00		18.00	14.00
Container No	PA3		VI		RT3		TA8	DEN
Wt. of wet soil & container (g)	52.08		54.54		54.88		50.71	58.39
Wt. of dried soil & container	42.73		43.99		43.43		40.22	44.90
Wt. of container	17.20		17.23		17.49		17.48	17.71
Wt. of dry soil (wd) (g)	25.53		26.76		25.94		22.74	27.19
Wt. of moisture (wm)(g)	9.35		10.55		11.45		10.49	13.49
Moisture content 100 x (wm/wd)	36.62		39.42		44.14		46.13	49.61
Type of test		PL		PL		PL		
Container No		TI		YT		9ZQ		
Wt. of wet soil & container (g)		22.87		21.78		25.36		
Wt. of dried soil & container		21.68		20.60		23.99		
Wt. of container		15.98		15.16		17.44		
Wt. of dry soil (wd) (g)		5.7		5.44		6.55		
Wt. of moisture (wm)(g)		1.19		1.18		1.37		
Moisture (wm/wd) (PL) Content 100		20.88		21.69		20.92		

Table 23 – Atterberg test result for Sample 2

Type of Test	LL		LL		LL		LL	LL
No of Blows/shrinkage %	42.00		32.00		24.00		18.00	14.00
Container No	OB		V2		OZ7		FR	TA2
Wt. of wet soil & container (g)	58.20		52.38		55.82		59.73	58.86
Wt. of dried soil & container	48.74		43.92		46.27		48.81	46.94
Wt. of container	16.01		16.85		17.60		18.57	17.40
Wt. of dry soil (wd) (g)	32.73		27.07		28.67		30.24	29.54
Wt. of moisture(wm) (g)	9.46		8.46		9.55		10.92	11.92
Moisture content 100 (wm/wd)	28.90		31.25		33.31		36.11	40.35

Type of test		PL		PL		PL		
Container No		TR		DAD		SUP		
Wt. of wet soil & container (g)		28.30		27.95		23.78		
Wt. of dried soil & container		26.59		26.32		22.48		
Wt. of container		17.55		17.69		16.10		
Wt. of dry soil (wd) (g)		9.04		8.63		6.38		
Wt. of moisture (wm) (g)		1.71		1.63		1.3		
Moisture content 100 (wm/wd) (PL)		18.91		16.88		20.38		

Table 24 – Atterberg limit test on Sample 3

Type of Test	LL		LL		LL		LL	LL
No of Blows/shrinkage %	44.00		34.00		24.00		18.00	14.00
Container No	RT4		OZ2		PLU		0Z5	TA7
Wt. of wet soil & container (g)	52.74		59.07		59.92		56.09	56.16
Wt. of dried soil & container	44.85		49.19		49.20		45.68	44.93
Wt. of container	17.41		17.54		17.93		17.44	17.36
Wt. of dry soil (wd) (g)	27.44		31.65		31.27		28.24	27.57
Wt. of moisture (wm) (g)	7.89		9.88		10.72		10.41	11.23
Moisture content 100 (wm/wd)	28.75		31.22		34.22		36.86	40.73
Type of test		PL		PL		PL		
Container No		FY		ZI		BUD		
Wt. of wet soil & container (g)		25.48		22.99		25.70		
Wt. of dried soil & container		24.21		21.80		24.54		
Wt. of container		17.20		15.17		18.15		
Wt. of dry soil (wd) (g)		7.01		6.63		6.39		
Wt. of moisture (wm) (g)		1.27		1.19		1.16		
Moisture content (wm/wd)x 100		18.12		17.95		18.15		

Moisture Content Test. Table 25 details the result of the moisture content test. According to the Federal Government specifications for roads and bridges (1997), samples with high moisture content are unsuitable for road construction, while those with low moisture content are most suitable for road construction. Samples 1A, 1B, 2A, and 2B are suitable soils, while the rest are poor soils for road construction.

Table 25 – Summary of Moisture content test result for samples one, two and three

	BH1		BH 2		BH3	
	Sample 1 (1 m)		Sample 2 (1.5 m)		Sample 3 (2.0 m)	
CAN NO	0Z7	0Z9	PA5	BO7	TA6	V6
CAN + WET	70.7	69.5	90.5	75.9	17.5	16.9
CAN + DRY	65.7	64.5	84.2	69.6	64.6	64.4
CAN + WEIGHT	17.5	17.1	17.5	18.6	69.6	69.2

CONCLUSIONS

This study assessed road failure in the geotechnical investigation of soil properties. All geotechnical soil tests were conducted according to the procedures outlined in the British Standard Code (BS 1377:1990). The results were compared to the specifications established by the Federal Government of Nigeria for roads and bridges, and overall, they revealed noticeable deviations from the standards. This suggests that the geotechnical condition of the soil along Ogheghe Road significantly contributes to road failure. The findings indicate that the examined soil samples are classified as silty clay, which exhibits low shear strength, poor drainage characteristics, high compressibility, and susceptibility to erosion and frost heave.

Additionally, the soil samples showed significant volume changes with variations in moisture content. These properties make the road unstable, prone to deformation under vehicle weight, and susceptible to cracking and pavement damage. Therefore, the soil samples are unsuitable for road construction.

Recommendations:

1. The geotechnical properties of the soils alongside the road exhibit variability from one location to another, necessitating tailored treatment strategies. It is advisable to exercise caution when dealing with areas with significant clay content during reconstruction efforts.

2. Understanding the soil's geotechnical properties and the underlying geological conditions in an area is of utmost importance before initiating any construction project, as the stability of the foundation layers relies heavily on this knowledge.

3. During the pre-construction design and planning phase of highway pavements, it is essential to involve pertinent experts such as Geologists and Geotechnical engineers.

4. 100% compaction must be observed during construction to avoid failure after construction due to settlement.

5. Effective drainage systems must be strategically designed and consistently implemented along the road corridor to ensure optimal water management and prevent accumulation.

6. Urging the government to streamline the payment process for contractors, with vigilant supervision to prevent fund diversions.

Conflict of interest

There is no conflict of interest between all authors involved.

Acknowledgements

The authors appreciate the Department of Civil Engineering, University of Benin, Edo state, where all the laboratory tests were carried out.

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