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Geotechnical Evaluation of Road Failure along 20th Street BDPA, Benin City, Nigeria

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ABSTRACT: This work investigated the cause of road failure using geotechnical analysis along the 20th Street, BDPA, Benin-city, Nigeria. Soil samples from the failed section of the road were analyzed to ascertain their particle size distribution, limit liquid, plastic limit, maximum dry density, optimum moisture content and California bearing ratio using the British Standard Institution (BS 1377 1990). The result from the particle size distribution analysis showed that soils were well graded (GW) with percentage fines ranging from 26 to 49.7%, specific gravity from 2.4 to 2.6, liquid limit from 21.52-29.79%, plastic limit ranged from 11.73-18.80%, plasticity index 8.29-12.49% and California bearing ratio(unsoaked) from 9-29%. The compaction test results showed that the Maximum Dry Density (MDD) ranged from 1.7mg/m^3-1.8mg/m^3 and Optimum Maximum Content from 11-14%. It was found that there is a significant difference between the geotechnical characteristics of the soil and the standard for geotechnical characteristics set by the Federal Ministry of Works. This led to the conclusion that the soil geotechnical characteristics is a causative factor of road failure as well as the geology. Hence, it was recommended that the geotechnical and geological characteristics of sub-grades and fill materials be taken into consideration during road construction.

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Geotechnical properties include all geologic earth materials which may undergo laboratory analysis before any civil engineering construction can take place. Geotechnical analysis is required because it provides useful information on foundation soils before any civil engineering projects are carried out. Engineering geologist, geotechnical engineers, geomorphologist among other professionals play an integral role in modern engineering project this is because report on geotechnical analysis make them aware of problem soil with a view to avoid structural failure, defects or collapse of civil engineering projects. It has been observed that problem soils pose a serious threat to civil engineering projects which results to defect or collapse of infrastructures such as roads, buildings, dams, among others. Nigeria soils for example are characterised by various problem-soils zones which several works have reported (Ola1983; Durotoye1983). In Nigeria, road failure is one of the infrastructural facilities that is in total collapse, road failure has not only caused set back to Nigerian economy but it has claimed lives which results from road crashes and properties worth millions of naira are lost annually. A recent study conducted by Federal Road Safety Corps (FRSC 2011) revealed that Nigeria currently rank 191 of 192 countries of the world with unsafe roads. Majority of this road network are poorly constructed and they are largely founded on problematic soils such as clay soils, sandy clayey soils and clayey sandy soil. Therefore, the objective of this work is to investigate the causes of road failure using geotechnical analysis along the 20th Street, BDPA in Ugbowo, Benin City Nigeria by collecting soil samples from the failed section of the road.

MATERIALS AND METHODS

Description of study Area: The study area is located in the housing Estate in Ugbowo opposite University of Benin, in Ovia North East Local Government Area in Edo state of Nigeria which lies between latitudes N 6° 20’ to N 6° 24’ and longitudes E 5° 36’ to E 5° 40’ . The area is bounded to the North–east by Kogi state,

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to the South by Delta and to the East by Anambra. Ovia North East. The lithostratigraphy of the Benin Formation (Miocene- Recent) is characterized 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 (Nwajide, 2013). The sands of the Benin Formation are dominantly coarse grained; poorly to moderately sorted, sub angular – to well rounded, generally loose (although weakly to moderately cemented in some areas) becoming progressively finer with abundant clay, some peat/ lignite and ferruginous bands towards the top, which is commonly reddish due to Fe-oxide coating.

Table 1: Typical Stratigraphic sequence of the Benin region after Akujieze, 2004

Sedimentary Unit	Lithological Description
Drift	Loose Light Gray-Dirty white Sands, Silts, and Mudflows.
Alluvium(Only at River Banks)	Light Gray-Brown-Dirty White Sands, silts, clays gravel and pebble.
Benin Formation	Top reddish brown clays sands, crapping thick sequences of poorly bedded friable-loose sands gravelly-pebble sands and pinkish-white clay stingers.
Asaba-Ogwashi (Azagba-Ogwashi Formation)	Dark gray-woody clays, alternating with dark clay and lignite

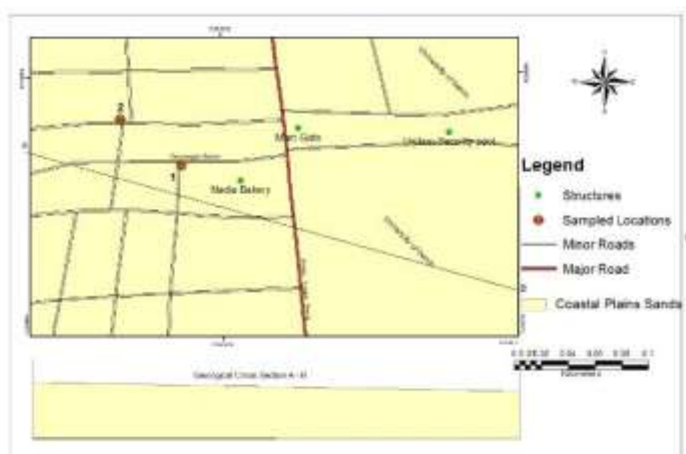

Fig 1: Geology map of study area

Soil Sample collection: The soil samples were collected randomly with the disturbed sampling techniques using hand auger within 400m interval, 2m and 4m deep. A total of four samples (2 per location based on depth). The Instruments used were the Global positioning system (GPS), hand auger, shovel, measuring tape and sample bags. The samples were put in sample bags to keep the moisture.

Laboratory Analysis: All the laboratory tests were carried out in accordance with standard procedures, such as those recommended by the American Society for Testing and Materials (ASTM), British Standard (BS) and Indian Standard (IS) method for testing materials.

Grain Size Analysis: The grain size analysis expresses quantitatively the proportion by mass of various size of particle present in the soil sample. It aims at the separation of soil particles into separate ranges of size. Coarse soil makes use of the dry sieve analysis and fine soil makes use of the wet sieving method. For the purpose of this study, the wet sieving method was used. The oven dried sample was left to cool after which it was weighed again and recorded. The dried sample was then passed through set of sieves ranging from 2 to 0.75 mm. The weight of the soil retained in each of the sieve was determined and recorded.

Specific gravity: Specific gravity is the ratio of the mass of unit volume of gas-free distilled water at a stated comparative See eqn 1. This laboratory test is performed to determine the specific gravity of soil by using pyconometer. The pyconometer was cleaned and dried. The cap was tightly screwed and the weight was taken to the nearest 0.1 g. The cap was unscrewed and about 200g of oven dried sample was placed in the pyconometer. The cap was screwed again and the weight of the sample and pyconometer was also determined. Sufficient amount of distilled water was added to the sample inside the pyconometer so as to completely cover the sample and the cap replaced afterwards. The vacuum pump was used to remove entrapped air for about 20 minutes. The outer part of the pyconometer was dried and the weight of the pyconometer + water + soil was recorded. Calculation of the specific gravity of soil is done using the formula below:

$$Specific\ gravity, G_S = \frac{W_O}{W_O + (W_a - W_b)} \qquad (1)$$

Where, W_o = weight of sample of oven dry soil; W_a = weight of pyconometer; W_b = weight of pyconometer filled with water and soil; W_p = mass of empty pyconometer; W_{Ps} = mass of empty pyconometer + sandy soil, $W_o = W_{ps} - W_p$.

Atterberg Limit Test: Liquid Limit (Cassagrande method): The liquid limit (W_L) is conceptually defined as the boundary were the minimum water content at which the soil mass still flows like a liquid. The relationship between the moisture contents and the corresponding number of blows in plotted on a linear scale with the moisture contents as ordinate and number of blows as the abscissa, the moisture content in percentage that corresponds to the 25th blow is denoted as the liquid limit of the sample

Plastic Limit: Plastic limit is defined as the water content at which the soil mass can be rolled into a thread of 3 mm diameter and the thread first sign of cracking is noted. Plastic limit is denoted by W_P and is the boundary between the semi-solid and plastic states of consistency.

$$\text{PL} = \frac{(\text{weight of water})}{(\text{Weight of oven} - \text{dry soil})} \text{x } 100$$

Where PL = plastic limit

Plasticity index: Plasticity index (P.I) is a difference between the plastic limit and the liquid limit and it is given as

$$PI = W_L - W_P \qquad (2)$$

Where, PI = Plasticity Index; W_L = liquid Limit; W_P = Plastic limit

Plasticity index is defined as a measure of the plasticity of a soil. The plasticity index is the measure of the range of water contents where the soil exhibits plastic properties. See eqn 2

Compaction and California bearing ratio: Compaction is defined as a process of increasing the density of a soil by the application of mechanical energy, such as by tamping, rolling, and vibration. Compaction is achieved by expulsion of air from the air voids thereby forcing the particles closer together. It may also involve a modification of the moisture content as well as gradation of the soil.

Standard compaction test for sample is the determination of the dry density moisture content relationship. Compaction involves the application of mechanical energy to soil to rearrange the particles and reduced settlement under working load. This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a Specified compactive effort. The compactive effort is the mechanical energy that is applied to the soil. For a compactive effort, the particular moisture content at which the dry density is greatest (the peak) before it starts dropping is called the optimum moisture content (OMC) the density associated with this is the maximum dry density (MDD).

Maximum Dry Density: The maximum dry density is the density of a soil at which materials can no more be compacted. Generally, the higher the strength of the earth material soil, the higher the maximum dry density. See eqn 3 & 4

Optimum Moisture Content (OMC): This is the moisture content at which a specified amount of compaction will produce the maximum dry density.

$$Bulk\ Density = \frac{Weight\ of\ wet\ soil\ (^{g}/_{cm})}{Volume\ of\ mould} \qquad (3)$$

$$Dry\ Density = \frac{Bulk\ Density}{1 + w} \qquad (4)$$

Where, w = Moisture Content; Factors that affect compaction characteristics of soil include:

Compaction of soil increases its density and yield three important effects: A mass of 3000 g sample was crushed with a hand trowel and then quartered into three equal parts (1000 g each). A rammer of 2.5 Kg was used to apply pressure to the samples. 2% of water was gradually added to the sample, but because of the nature of the material, we started with 14% (420 ml) of water, and consequently added 2% of water to the sample (this was done to achieve the maximum dry density quickly). 27 blows per layer were applied to the sample after each 2% of water was added. The surface was smoothened, the mould and the content was also weighed. The moment the weight dropped, the compaction test was stopped. However, if the weight does not drop, it is required to continue compaction until it drops. The graph of Dry density against moisture content is plotted. When the graph is plotted, the maximum dry density is denoted as the peak before it starts dropping while the Optimum Moisture Content (OMC) is traced from the peak downwards. The value of Optimum Moisture Content (OMC) is then used for the California bearing ratio in order to check the Strength of the material. 6000 g of sample was used for the California bearing ratio test. The weight of the empty mould was recorded. The Optimum Moisture Content (the maximum amount of water the sample can retain before it is saturated) for each sample was used to determine the amount of water that would be added to the sample (OMC for each sample were 14.4%, 14.6%, 16.4% for Samples 1, 2, 3 and 4 respectively). The empty weight of the mould with base plate, with extension collar removed was recorded; the correct mass of the wet soil was placed in the mould in five layers, with each layer compacted with 25 blows before adding another layer of sample. The weight of the sample + compacted soil was recorded. The sample was soaked for 48 hours in water in a soaking tank to understand the behaviour of the soil in case of rainy season. The mould with the compacted sample was removed from the soaking tank and allowed to drain. The proving ring factor of CBR (28 KN) was noted. Each layer was compacted with the swell disc; a filter paper was also placed on top of the soil followed by a displacer disc. The mould was compacted by pressing it between the platens of the compression testing machine (Plate 10), until the top of the swell disc aligned with the top of the mould. As the plunger penetrated the sample, the rate of penetration in mm were recorded. The procedure was repeated for the top and bottom of the sample.

RESULTS AND DISCUSSION

Particle Size Analysis: For the grain size analysis, the percentage passing sieve No. 200 (0.75 mm) samples 1, 2,3 and 4 are 26%, 42.2%,49.7% and 28.5% respectively, with a mean value of 36.6%. The samples were from Silty or Clayey Gravel and Sand according to the British standard BC1377 (1990).

Table 2: Summary of Atterberg limits result

Sample No.	Locations	Liquid Limit (W_L)	Plastic Limit (W_P)	Plasticity index (P.I)
1.	**CH0+000 RHS**	25.11%	16.82%	8.29%
2.	**CH0+150 LHS**	29.79%	17.23%	12.47%
3.	**CH0+300 RHS**	27.93%	18.80%	9.13%
4.	**CH0+500 LHS**	21.52%	11.73%	9.79%
Average values>>>		26.08%	16.14%	9.94%

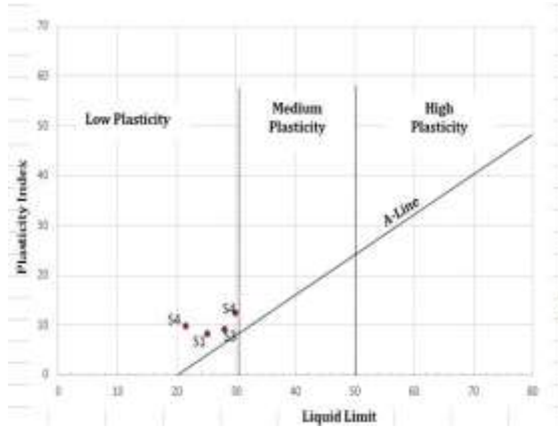

Fig 2: Plasticity Chart

From the Cassagrande plasticity chart in Fig 2, according to Casangrande 1948, Gidigasu 1991 all the samples fall within the CL group and of low plasticity which implies that the clay soils have low swelling potential thus making them suitable soils for roads and can't be the cause of failure.

Table 3: Summary of Compaction Results.

Sample No.	Locations	MDD (mg/m^3)	OMC (%)
1.	**CH0+000**	1.7	11.6
2.	**CH0+150**	1.8	11.0
3.	**CH0+300**	1.7	14.0
4.	**CH0+500**	1.7	11.6
Average value>>		1.7	12.05

Specific Gravity Test: The soil sample obtained from CH0+000 has a specific gravity of 2.5; CH0+150 has a specific gravity of 2.4; CH0+300 has a specific gravity of 2.5; CH0+500 has a specific gravity of 2.6. The average value of specific gravity is 2.5. According to Gidigasu (1991), a soil is good subgrade if its Gs range between 2.50-4.60 and all the samples fell in the range of 2.4 -2.5, which indicative of a soil with fair specific gravity mineral hence fair subgrade.

Compaction: Comparing the values with the standard specifications of sub-grade materials for road shown construction by Federal Ministry of Works (1997), Maximum Dry Density (MDD) > 1.6 mg/m^3 and Optimum Moisture Content (OMC) < 18%), all the soil samples(see Table 3) satisfies the desirable limits for Maximum dry density and Optimum moisture content. In effect the road failure in the area cannot be attributed to failed compaction test.

California Bearing Ratio (CBR) Test: The soil sample obtained from CH0+000 has a CBR (after soaking for 48 hours) value of 4%, while that at CH0+150 is 14%. The mean value for the California Bearing ratio is 9%. Comparing these values with the general specifications of sub-grade materials for roads by

Federal Ministry of Works (1997) shown in Table 4 (CBR > 5% for 48 hours soaking). The soil samples do not satisfy the CBR standard and as such is not qualified to be used as subgrade material for road construction. The CBR is used to estimate the bearing capacity and the mechanical strength of the soil samples, low CBR in the area is another reason for the failed road system in the area.

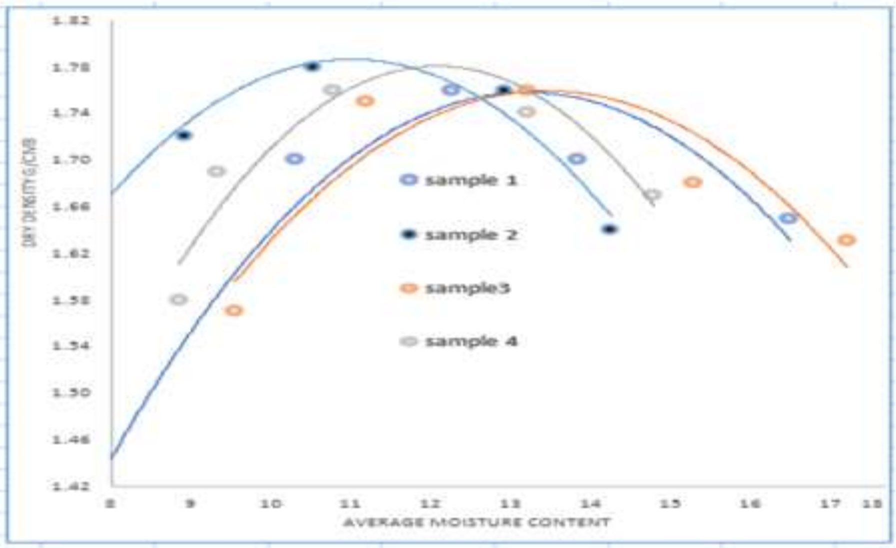

Fig 3: Compaction curves

California Bearing Ratio (CBR) Test: The soil sample obtained from CH0+000 has a CBR (after soaking for 48 hours) value of 4%, while that at CH0+150 is 14%. The mean value for the California Bearing ratio is 9%. Comparing these values with the general specifications of sub-grade materials for roads by Federal Ministry of Works (1997) shown in Table 4 (CBR > 5% for 48 hours soaking). The soil samples do not satisfy the CBR standard and as such is not qualified to be used as subgrade material for road construction. The CBR is used to estimate the bearing capacity and the mechanical strength of the soil samples, low CBR in the area is another reason for the failed road system in the area.

Table 4: Summary of California Bearing Ratio Results

Sample No	Location	Soaked		Un-soaked	
		Top (%)	Bottom (%)	Top (%)	Bottom (%)
1	CH0+000	4	2	12	9
2	CH0+150	14	15	21	29
3	CH0+300	4	3	6	7
4	CH0+500	16	11	22	22

The soil samples do not satisfy the CBR standard according to the FMWH 1997 and as such is not qualified to be used as subgrade material for road construction. The CBR is used to estimate the bearing capacity and the mechanical strength of the soil samples, low CBR in the area could be another reason for the failed road system in the area.

Conclusion: In conclusion, the soils having adverse effects owing to the low CBR and particle size distribution which made the road susceptible to erosion and ultimately leading to the failure of road. Construction works in the area need not mean complete abandonment. To improve the efficiency of roads in the area, the top soil in the area can be excavated prior to construction work and stabilized, also a well-constructed drainage along the route reducing the water content of the soil thereby improving the overall quality of the soil.

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