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# EFFECT OF SOIL QUALITY USED AS SUB-GRADE MATERIAL AND ROAD PAVEMENT FAILURE ALONG THE BENIN- ORE ROAD, NIGERIA.

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ABSTRACT
The Benin –Akure road has undergone various degrees of failures. Road failures (potholes, surface cracks, ruts and depressions, washouts etc.) have a major strain on the economy of the nation as it affects transport of agricultural produce to urban areas.This research was carried out by evaluating the plasticity indices of the brought in soils used for the subgrade material for the road bed as one of the possible causes of the failure of the road under review. The Benin –Sobe section of the road was divided into four segments representing the four parent materials (Coastal Plain Sand, Bendel Ameki, Basement Complex and Imo Shale) Soil samples were collected at four depths (0 - 30 cm, 30 - 60 cm, 60 - 90 cm, 90 - 120 cm) from the four segments and the imported subgrade laterite from failed and non-failed sections of each segments. The Atterberg's limits and particle size determinations were carried out.
The liquid limits and plastic indices were found to be in the ranges of 38 - 72 and 20 - 45 respectively which indicated imported laterite ranged from high to very high plasticity. The high plasticity index indicates susceptibility to expansion and cracking. The clay content of the in-situ soils were also found to be very high and poorly drained except for the Basement complex soil resulting in poor drainage causing expansion and consequently cracking. The result of this research indicated that lateritic materials used as subgrade were of poor soils quality probably leading to high road failures among other factors.

## INTRODUCTION

The road network of any nation plays a very important role in its economy, especially in developing countries like Nigeria where the road is the major means of transporting goods and services and even people across the country (Okechukwu and Celestine, 2011). Incessant failure of highways has become a common phenomenon in many parts of Nigeria (Adiat *et al.,* 2009). The Edo section of the Benin – Akure road falls into the category of failed roads in Nigeria with different forms and degrees of failures. Failure of roads is a major experience which occurs in Nigeria (Osuolale *et al*., 2012). The failure has been attributed to some factors such as properties of construction materials, sub grade conditions (Haider and Chatti, 2009) environmental conditions, traffic loading, lack of drainage and poor workmanship, buried channels, poor designs and specifications (Emujakporue, 2012; Arumala and Akpokodje, 1987; Ogundipe, 2008) and setting fires on the road due to breakdown of vehicles and fire due to accidents.

The road is built on soil and majority of the materials used in the construction of the road is soil. Therefore a good understanding of the properties of the soil and its behaviour under load before usage is highly essential in highway pavement construction. Studies on road failure have been widely carried out using geophysical and geotechnical methods. Geophysical methods involves the use of electrical resistivity and electromagnetic (EM) approaches (Aigbedon, 2007; Adiat et *al.,* 2009) which tries to evaluate the sub surface condition of road to establish integrity of road and likely fault zones which could result to road failure while geotechnical method employs the use of laboratory equipment to investigate foundation materials of roads with a view to testing various engineering properties such as particle size distribution (PSD), plastic limit (PL), liquid limit (LL), compaction test, California bearing ratio (CBR) test among others. This study therefore tries to analyze the effect of Atterbergs limit of the soil material used as road subgrade and its impact on road failure. Atterberg limits are a basic measure of the critical water content of a fine grain soil such as its shrinkage limit, plastic limit and liquid limit used to estimate strength and settlement characteristic.The Atterberg limits are the limit of water content used to define soil behavior (Seed, 1967). The plasticity is the moisture content that determines when the soil changes from a semi-solid to a plastic state. Atterbergs limits are used extensively by soil scientists and soil engineers for measuring plasticity. Three values used are; the upper plastic limit (liquid limit) or the moisture content at which the soil will barely flow under applied stress, second the lower plastic limit or the moisture content at which the soil can barely be rolled out into a wire and thirdly the plastic number (index) or the difference between the liquid and plastic limits, taken as an index of plasticity (Atterberg, 1911)

Burmister (1949) classified the plasticity index in a qualitative manner as follows (Table 1).

**Table 1: Plastic Index (PI) values of soil and their description.**

| PI | Description |
|---|---|
| 0 | Non-plastic |
| 1-5 | Slightly plastic |
| 5-10 | Low plasticity |
| 10-20 | Medium plasticity |
| 20-40 | High plasticity |
| >40 | Very high plasticity |

The ability of the soil to shrink and swell under different moisture content is a very important factor to consider in road construction for the work to be successful (Osuolale *et al.,* 2012).

There are many causes of road failures, the performance of a road pavement depends on the quality of its subgrade and subbase layers, these foundational layers play a key role in mitigating the effects of climate and stresses generated by traffic. Therefore building a stable subgrade and a proper subbase is vital for constructing an effective and long lasting pavement system (Schaefer *et al.*, 2008).

The purpose of this study was to evaluate (i) the effect of Atterberg limits of imported soils used as subgrade on road failure and (ii) the influence of the parent materials on which the roads are built as factors contributing to the high incidence of the road failures along the Benin-Sobe section of the Benin-Akure road.

## MATERIALS AND METHODS

The Benin – Akure road is located on the latitude 6.524094$^0$ E and longitude 5.630493 $^0$N. The area is characterized by a tropical climate with an annual average rainfall amount of 1900 mm and mean annual temperatures ranging from 23$^0$C to 37$^0$C, recorded over a period of 18 years (NIFOR, 2011). The soil samples were collected from four profile pits in the identified four parent materials of the road. In each of the four sections soil samples were collected from failed and non-failed subgrade portions of the road for evaluation.

The locations where the profile samples were collected and their latitudes and longitudes are listed below

1. *Coastal Plain*: Latitude 6.55636$^0$ N and Longitude 5.73139$^0$ E. asl 139 m elevation
2. *Bende-Ameki:* Latitude 6.67100$^0$ N and Longitude 5.677257$^0$ E. asl 250m
3. *Imo Shale:* Latitude 6.77806$^0$ N and Longitude 5.77344$^0$ E. asl 138m
4. *Basement Complex*: Latitude 6.86478$^0$ N and Longitude 5.77712$^0$ E. asl 100m.

Samples were collected from four different depths at each point of collection (0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm). The samples were collected from three points for each parent material sections; two from the failed portion and one from the not failed portion.

The samples were air dried before being carried to the laboratory for chemical and physical analyses.

## LABORATORY ANALYSIS

### Atterberg Limit Tests

Standard test method for liquid limit, plastic limit, and plasticity index of soils was carried out using the ASTM D 4318 procedure (University of Texas at Arlington Geotechnical Engineering Test Procedure (2004).

### Soil Analysis

Soils collected from the different locations and depths were air-dried and passed through a 2 mm sieve. Particle size distribution was determined by the hydrometer method (Bouyoucos, 1962). Available P was determined by Bray-1 method (Murphy and Riley, 1962). The pH was determined with glass electrode pH meter with a ratio of 1:1 soil and water in KCl media. Exchangeable Bases ($Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$) were extracted with neutral normal ammonium acetate ($CH_3COONa$ at pH 7.0). $Na^+$ and $K^+$ were determined by flame photometry while $Ca^{2+}$ and $Mg^{2+}$ were determined by atomic absorption spectro- photometry (Page, 1982). Total N was determined by Macro Kjedhal method (Bremner and Mulvaney, 1982). Exchangeable Acidity ($H^+$ and $Al^{3+}$) was determined by titration method (Anderson and Ingram, 1993). Organic Carbon was determined by Walkley and Black method (Bremner and Jenkinson (1960). Effective Cation Exchange Capacity (ECEC) was obtained by the summation of Exchangeable Bases and Exchangeable Acidity (Tan, 1996).

## RESULTS AND DISCUSSION

The results of the physico-chemical properties of the soils brought in for the subgrade soil on which the pavement and sub-base is laid is shown in Table 2. The sand content was higher in the Coastal plain sand but not significantly different from Imo-shale and the Bende-Ameki section but different from the False bedded. The Imo Shale has significantly higher silt values compared with the others. Then Bende-Ameki

**Table 2: Physiochemical properties of the soils used as subgrade materials.**

| LOCATION | PARTICLE SIZE | | | PH | COND | ORG C | TOTAL N | AV.P | EXCHANGEABLE BASES | | | | EA | ECEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | g/kg | | | % | Us/cm | g/kg | g/kg | g/kg | Cmol/kg | | | | Cmol/kg | Cmol/kg |
| | SAND | SILT | CLAY | | | | | | Ca | Mg | K | Na | | |
| Coastal plain | 619.70a | 69.8c | 310.5ab | 4.19d | 33.33ab | 5.09a | 0.27a | 1.47b | 1.45a | 0.71a | 0.03a | 0.03c | 2.78c | 4.08b |
| Imo shale | 610.81ab | 121.7a | 267.5c | 4.7a | 50a | 2.30a | 0.11a | 1.09a | 0.89b | 0.36b | 0.03a | 0.04b | 2.79bc | 4.11b |
| Bende ameki | 595.00ab | 72.5b | 332.5a | 4.2c | 24.17b | 3.45a | 0.25a | 0.19d | 0.81c | 0.32c | 0.03a | 0.03d | 3.89a | 5.08a |
| False bedded | 586.67b | 69.8c | 287.5bc | 4.5b | 40.83ab | 4.22a | 0.22a | 1.19c | 1.45a | 0.37b | 0.03a | 0.05a | 3.22b | 5.12a |

**Table 3: Particle size analyses of parent materials.**

| | Coastal plains sands (g/kg) | | | Bende Ameki (g/kg) | | | Imo shale (g/kg) | | | False bedded (g/kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DEPTH(cm)** | **sand** | **Silt** | **Clay** | **sand** | **silt** | **clay** | **sand** | **silt** | **clay** | **sand** | **Silt** | **Clay** |
| **0-20** | **850** | **120** | **30** | **890** | **50** | **60** | **720** | **130** | **150** | **690** | **190** | **120** |
| **20-40** | **830** | **40** | **130** | **840** | **60** | **100** | **730** | **100** | **170** | **450** | **270** | **280** |
| **40-60** | **756** | **84** | **160** | **806** | **34** | **160** | **620** | **120** | **260** | **560** | **20** | **420** |
| **60-80** | **550** | **130** | **320** | **730** | **30** | **240** | **550** | **110** | **340** | **356** | **120** | **520** |
| **80-100** | **370** | **270** | **360** | **610** | **50** | **340** | **572** | **98** | **330** | **470** | **170** | **360** |
| **100-120** | **610** | **40** | **350** | | | | | | | | | |

had higher values followed by the Coastal Plain soils, the Imo-Shale with the least value of 267.5 g/kg. The sand and clay percentages of the brought-in-soil for the subgrade were above the values of 850 and 50 g/kg recommended by the FMWH (Federal Ministry of Works and Housing).

The particle size analysis of the parent materials is shown in Table 3. The clay contents of the parent soil indicated that in the Coastal Plain Sands at depths below 40 cm, the clay content increased to an average of 340 g/kg, for the Bende-Ameki soil, at 40 cm depth the clay content was 160 g/kg and increased to 240 g/kg and 340 g/kg at 40-80 and 80-100 cm depths respectively. The clay content of the Imo-shale soil had values of 260, 340 and 330 g/kg for the 40-60, 60-80 and 80-100 cm depths respectively. The False Bedded parent material at 40-60, 60-80 and 80-100 cm depths had clay content of 420, 520 and 360 g/kg respectively, however the soil fraction ( less than 2 mm) contributed only 20 % of the soil material other fractions, >2 mm particles contributing 80 %.

Table 4:Effect of Atterberg's limits on depth and sections(failed and non failed) interactions.(% moisture on g/g)

| Depth (cm) | Section | LPL lsmeans % Θ g/g | UPL or LLlsmeans %Θg/g | Plasticity index PI=UPL-LPL Lsmeans. %Θg/g |
|---|---|---|---|---|
| 0-30 | Failed | 18.58 | 50.13 | 31.25 |
| 0-30 | Not failed | 15.50 | 47 | 31.5 |
| 30-60 | Failed | 16.75 | 49.75 | 33 |
| 30-60 | Not failed | 15.5 | 46.5 | 31 |
| 60-90 | Failed | 18.75 | 45.25 | 31 |
| 60-90 | Not failed | 16.75 | 49.25 | 25.87 |
| 90-120 | Failed | 17.35 | 46.38 | 30 |
| 90-120 | Not failed | 17 | 52 | 35 |

Highly plastic soils are usually clay soils which have low aggregate performance and high expansive potential. The high clay fraction causes shrinking and swelling which leads to cracks. The results of the plasticity indices were higher than the requirement of FMWH specification for materials that should be used for road construction. In addition, since the samples contain high amount of clay particles, in the event of rise in water table because of reduced infiltration and low hydraulic conductivity in the rainy seasons, the soils may not be susceptible to flooding especially for the Coastal Plains, Imo shale and to a lesser extent the Bende-Ameki. The rocky nature of the False Bedded does not allow flooding and to a greater extent hence the rate of failure in this segment was considerably reduced.

Geotechnical investigation of the highway is aimed at ascertaining geotechnical bases for the road failure. Tables 4 showed the Atterberg limits results for subgrade soils. From the result, the liquid limit range from 45.25 to as high as 52 while the plastic index range from 25.87 to 35 %. The high values of the liquid limit and the plastic limit at some locations and depths indicate high amount of clay content which could lead to swelling and subsequently cracking. The value of the plasticity index with range from 25 to 35 falls into the description of highly plastic to very highly plastic (Burmister, 1949).The liquid limit and plastic index of the area under review are also very high which also means that it has high amount of clay. It was also observed that the clay content and also liquid limit/plastic index of both the failed portion of the road and the non-failed portion were equally high indicating that the parent material has contributed to a large effect in causing the failure of the road. In

Table 5: .Atterbergs limit results of lsmeans of transported soils infailed and non-failed sections

| Location | Portion | LPL LSMEAN % Θ g/g | UPL or LLLsmeans % Θ g/g | Pl lsmean % Θ g/g |
|---|---|---|---|---|
| Ba | Failed | 20.75 | 51.88 | 31.13 |
| Ba | Non failed | 17.75 | 51 | 33.25 |
| CPS | Failed | 16 | 46 | 31.87 |
| CPS | Non failed | 18.25 | 55 | 36.75 |
| FB | Failed | 22.25 | 51.5 | 29.25 |
| FB | Non failed | 14.75 | 41.25 | 26.5 |
| IS | Failed | 11.5 | 37.75 | 26.25 |
| IS | Non failed | 14 | 47.5 | 33.5 |

Table 5, the failed and non-failed portions, the plasticity indices ranged between 26.5 and 33.5. In Table 6, the failed section had plasticity of 33.12 and the non failed had the value of 30.03 %, although these values were not significantly different, the failed portions had higher values. Generally the plasticity values of the imported soil for the road foundation fall under high plasticity as shown in Table 1.

## CONCLUSION AND RECOMMENDATION

The above results show that the clay content of the subgrade soils used was very high. Soils with high clay content are usually not suitable for road bed construction because of the high degree of shrinking and swelling. This shrinking and swelling usually leads to cracks which leads to high road values failures. It is therefore recommend that soil materials used for subgrade of roads should adhere strictly to recommended

Table 6: Mean effect of Atterbergs limit on failed and non failed sections.

| Not failed | LPL | UPL % Θ g/g | P.I. % Θ g/g |
|---|---|---|---|
| Failed | 16.19b | 48.69a | 33.12a |
| Non failed | 17.94a | 47.88b | 30.06a |

standards of the Federal Ministry of Works and Housing regarding the quality of soil and soil analyses be carried out before soils are used for subgrade for our roads to reduce the failure of the road to its barest minimum. The False bedded parent section of the road had less failed portion due to the masking effect of the pebbles.

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