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RESEARCH ARTICLE

GEOTECHNICAL ASSESSMENT OF SUB-GRADE SOILS ALONG STABLE AND UNSTABLE PAVEMENTS OF SUPARE-EMURE EKITI ROAD, SOUTHWESTERN NIGERIA

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ABSTRACT

The qualities of road construction materials are essential in their choice for various civil works. Therefore, engineering geological properties of the sub-soil that constitute sub-grade materials along Supare- Emure road were investigated in order to determine the causes of the failure of the pavement along the unstable sections. A total of twelve (12) sub- grade soil samples were collected from unstable and stable sections of the road and were subjected to various geotechnical tests. These tests include natural moisture content, atterberg limits, linear shrinkage, plasticity index and grain size. Results showed that the natural moisture content of the stable sections range from 5% to 11%, while those of unstable sections range from 23.8% to 37.2%. The range of the unstable sections fell short of required specification. For the plasticity index, both sections have values less than required 30%, while the unstable sections had linear shrinkage above 8%. On the grain size results, unstable sections have values greater than the specified 35% passing. Bedrock chemistry and clayey nature of sub-grade soils have been found to be responsible for the failed sections of the road investigated.

KEYWORDS

plasticity index, moisture content, atterberg limits , linear shrinkage, grain size

1. INTRODUCTION

Many newly constructed and rehabilitated roads in the country do not last long enough before they failed. Roads are built to provide safe passage of vehicles and must be properly designed and constructed. After construction, there is need for appropriate maintenance so as to attain its design life span and to ensure that the objectives of safety, strength and durability are met. Road failure leads to most accidents recorded on Nigerian roads. Maintenance is imperative for preserving the integrity of any road network and consequently, an essential component of managing road pavements. Such planning relies heavily on a collaboration of historical network trends and inventory data. Also, current condition, reports and field inspections are necessary for predicted performance of road pavements. Predicting the likelihood of road pavement failure and the associated causes is an important aspect of maintenance. Road is an important infrastructure in a nation or community of people. It greatly affects the economy of any nation (Aigbedion, 2007).

Roads must be properly designed and constructed. After construction, they need to be maintained to ensure that the objective of safety, strength and durability are met. Failure on most Nigerian roads had become a normal norm. Adams and Adetoro explained that there are many different types of roads, ranging from multilane freeways and expressways to two-way country roads (Adams and Adetoro, 2007). One important quality of a road is known as control of accessibility. Roads can be classified into three broad categories: highways, urban and rural roads. Modern road construction was first developed in the 18th century. Innovation of the time included waterproof surfaces and better drainage systems. New-aged engineers make use of the knowledge of the geotechnical properties of soil and different construction techniques to build roads that can handle high volume of stresses of modern automobiles and truck traffics. Road failure could be defined as a discontinuity in road network resulting in cracks, potholes, bulges raveling, edges failure, polished aggregate, patching and depressions A road network is supposed to be a continuous stretch of asphalt lay for a smooth ride, but visible cracks, potholes, bulged and depressions may punctuate such smooth ride and this punctuation is generally regarded as road failure.

The majority of the expressway failure in the tropics can be traced to geotechnical factors (Gidigasu, 1972 and Adeyemi, 1992). These authors reiterated that expressway failure often occur when pavement is built on saprolite, instead of been built on lateritic soils. Failure of these roads can also be traced to misuse of expressway amongst others. Road failure occurs most in form of waviness, pitting and cutting. Such failure often leads to the loss of lives and properties. It becomes imperative to investigate the causes of failure along the unstable sections of the road. This will however enhance future designing and constructions of durable roads. Some researchers considered poor construction materials, bad design, poor drainage network as some of the factors responsible for road failure (Momoh et al., 2008; Adeyemi et al., 2012). A group researchers worked on geotechnical basis for failure of some sections along Lagos-Ibadan express way, southwestern Nigeria (Adeyemi et al., 2000).

They made a comparison between stable and unstable portions of the road and concluded that significant differences need not to be in existence between the geotechnical properties of soils below stable and unstable sections, before such parameter can serve as basis for predicting the stability of flexible highway pavement in the tropics. A group researchers opined that highway engineers must look into the causes of failures of

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bituminous pavements caused due to many reasons or combination of reasons (Oladapo et al., 2008). He observed that only three parameters i.e. unevenness index, pavement cracking and rutting must be considered. Structural failure is the loss of load carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the structure of the road without causing further deterioration. Furthermore, the following will lead to highway failure such as; poor highway facilities, no knowledge base, inadequate sanction for highway failure, no local standard of practice, poor laboratory in situ tests on soil and weak local professional bodies in highway design, construction and management (Aghamelu et al.,2013; Hussein et al.,2013; Agbonkhese, 2013).

A large number of defects are associated with road pavement failure, depending on the pavement types, the construction of road pavements, loading environments, and underlying subgrade properties (Agbonkhese, 2013; Adegoke-Anthony et al., 1980; Adebiyi et al., 2018). Serious site investigation and laboratory equipment work confirm that the stability of the road pavement depends on a number of factors which include the type of soil and materials or aggregate used, design techniques, construction procedures, age of pavement and more importantly the geology, soil type, climate and drainage conditions. There is no published work on causes of road failure along ever busy road linking Ondo and Ekiti States in southwestern Nigeria. Thus, this paper is aimed at investigating the causes of road failure along Supare – Emure Ekiti, Southwestern Nigeria. The study area lies within latitudes $07^{0}24.487''$ N and $07^{0}27'358''$ north of the equator and longitudes $05^{0}28'.074''$ E and $05^{0}35'.043''$ E east of the Greenwich meridian. The elevation varied from 055ft to 165ft above the sea level (Figure1). The covers an estimated distance of about 27km.

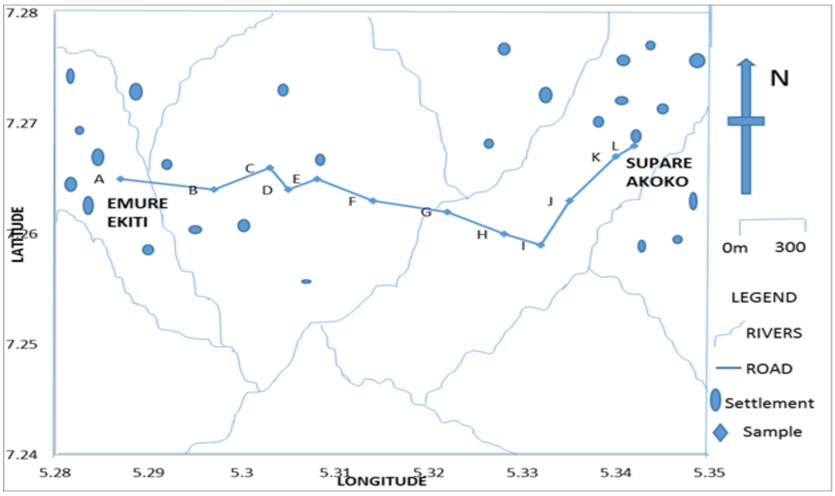

Figure 1: Location map of the study area showing sampling points

The study area is underlain by the Basement complex rocks of the southwestern Nigeria, which comprises dominantly of undifferentiated migmatitic gneisses, granite gneiss, charnockite and granite as proposed by (Rahaman, 1988). Migmatite gneiss constitute the predominant rock types found along Supare-Emure Ekiti road section, with other minor rocks such as charnockites and granitic rocks. The weathered rocks and the transported soils are found along the river channels and slopes of the hills and ridges. There are variations in the colour of grey-gneiss; they vary from light to dark grey. They are coarse-grained in texture and are strongly foliated. Their planar fabric marked by mineralogical and lithological banding, the grey gneiss is the paleosome and consist of mineral such as biotite, alkali feldspar and quartz. The neosome include the pegmatite and granite and they consist of light coloured minerals rich in alkali feldspar and quartz. The north-eastern and the south-western regions show a higher topography. The area is mostly undulating to uplands and lowlands.

The topography is characterized by different, but impressive physiographic features with varying lithologic sections ranging from conspicuous highlands, older granites to fairly undulating terrain of ironstone (Rahaman,1976). The drainage pattern of the study area is dendrite type (Figure 1).They show the resistance of the underlying crystalline basement rock and displaced structural features. Streams and rivers are developed through major joint direction and foliation trend with generally straight courses. The vegetation is thickly forested. The climate of the area is tropical rain forest with annual temperature of about $28^{0}C$ (Figure 2). The tropical climatic conditions favour both physical and chemical weathering of the area. There are two seasons in the area; the dry seasons and the rainy seasons in which the dry seasons starts from November and run through March.

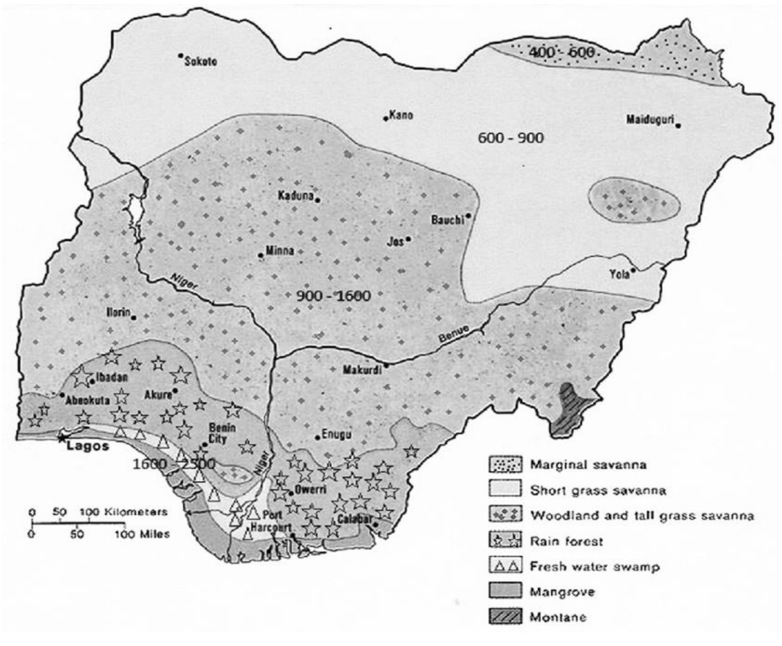

Figure 2: Map of Nigeria showing the vegetation types (after Iloeje, 1976)

2. MATERIALS AND METHODS

The reconnaissance survey of the study area was thoroughly carried out to assess the integrity of the road pavement. Global Positioning System (GPS) was used for taking the coordinates, sledge hammer, masking tape and marker for labelling the samples, sampling bags for the collection of samples, pick axe and cutlass were used to dig and collect soil samples. Fresh samples were collected and immediately wrapped in the polythene bags (sample bags) to minimize the loss of moisture which will hinder the actual value in calculating the natural moisture content. In order to get accurate results, obstructions such as organic soils, decayed debris, plant residues and animal remains such as snail shells, animal bones etc, were removed from the samples. The collection of samples was done with pick axe, hoes, soil auger and stored in polythene bags. All features of geological significance such as drainage pattern and system, topography vegetation and weathering surface were closely observed and recorded. All the laboratory tests conducted were in conformity with the procedures specified in the British Standard Institution (Akpokodje, 1985; BS 1377, 1990). Twelve (12) bulk samples were taken from the area of field of investigation at vertical depth of about 1.0m -1.2m across the sections (stable and unstable).

The sampling points vary from one another at a range of 1km- 2km (Figure 1). The samples were labelled from A to L respectively. The choices of sampling localities were determined during preliminary investigation along the road. Topographic observations confirmed that similar residual soil profiles were developed along similar slope within the same lithological units. Laboratory testing of the disturbed soil samples were collected from the established locations or field of investigation. These bulk samples were obtained from different locations within the stretch of the road and were subjected to geotechnical analyses at the soil and water laboratory of the Federal Department of Water Resources, Ibadan, Nigeria. The description and coordinates of the sampling points are presented in Table 1. The analyses conducted on the samples are Natural moisture content, atterberg limit or consistency limit test (liquid limit, plastic limit, plasticity index, linear shrinkage), Specific gravity and Grain size or Sieve analysis. The soil samples collected were oven dried at 105^{0}C for twenty four hours immediately after the collection of the samples in order to determine their moisture content. The results of some of the classification test on the lateritic soil are considerably affected by presents preparation and testing procedures because of the vulnerability of the weak structure and degradation (Gidigasu, 1972; Akpokodje, 1985).

Table 1: Showing the sample description and the coordinates

Sampled points	Latitude (^{0}N)	Longitude (^{0}E)	Colour	Depth(m)	Description of sections
A	7^0 26' 387''	5^0 29' 074''	Reddish brown	1.1	Stable
B	7^0 26' 388''	5^0 29' 089''	Reddish brown	1.0	Unstable
C	7^0 26' 389''	5^0 29' 128''	Brown	1.1	Unstable
D	7^0 26' 386''	5^0 28' 555''	Light brown	1.1	Unstable
E	7^0 26' 389''	5^0 28' 934''	Light brown	1.2	Stable
F	7^0 26' 386''	5^0 31' 733''	Reddish brown	1.1	Unstable
G	7^0 26' 314''	5^0 32' 298''	Dark brown	1.0	Unstable
H	7^0 26' 858''	5^0 35' 983''	Dark grey	1.2	Unstable
I	7^0 26' 866''	5^0 37' 024''	Reddish	1.2	Unstable
J	7^0 26'946''	5^0 38' 941''	Reddish brown	1.1	Unstable
K	7^0 26' 861''	5^0 38' 941''	Light brown	1.0	Stable
L	7^0 27' 358''	5^0 43' 043''	Reddish brown	1.0	Stable

All engineering soil tests were conducted in accordance with (BSI, 1990) specification. However, particular laboratory inadequacies in equipment could lead to a slight inaccuracy in the results, but this was tried as much as possible to be minimized. The empty cans were labelled from A-L respectively, weighed and recorded as M_1. Representative soil samples of each of the soil collected in the field were placed in the cans and weighed as M_2. The weighed wet samples were inserted in to the large capacity electric drying oven for 24 hours and at a temperature between 100^{0}C and 110^{0}C, after 24 hours, the sample was taken out, allowed to cool down and weighed and recorded as M_3. The natural moisture content in percentage was calculated using the formula below:

M_1 =Mass of empty cans

M_2 = Mass of can + wet soil

M_3 =Mass of can + dried soil

M_3-M_1 =Mass of dried soil

M_2-M_3 =Mass of water

$$\text{Moisture content} = \frac{Mass\ of\ water}{Mass\ of\ dried\ sample} \times 100$$

$$= \frac{M2-M3}{M3-M1} \times 100$$

The specific gravity of an earth material is defined as the ratio of the weight or mass of a volume to water. In soil mechanics, the most important specific gravity is that of the actual soil grains and is denoted as GS. Generally, sand has an average value of GS of 2.65 and clay with an average GS value of 2.75. Organic soils vary in their specific gravity. Organic clays can have GS value of about 2.60 whereas peat (immature coal) can have a value of 1.3. Specific gravity determination is carried out in the laboratory with the aid of glass jar, a glass cover slip, weighing balance. The GS is very useful in the identification of and evaporation of lateritic soils, rocks and aggregates for pavement construction. The empty glass jar along-side with the glass lid is weighed and recorded as M_1. The glass jar was then half filled with soil and weighed as M_2, then water was added to the setup and mixed, excluding air bubbles, weighed and recorded as M_3, then the glass jar is washed and filled with water and weighed as M_4. Therefore,

$$GS = \frac{W2-W1}{(W4-W1)-(W3-W2)}$$

Where;

W_1 = Weight of empty glass jar + glass lid

W_2 = Weight of glass jar + glass lid + soil sample

W_3 = Weight of glass jar + glass lid + soil sample + water

W_4 = Weight of glass jar filled with water + glass lid

The consistency limit or atterberg limit represents the moisture content of soil at which certain changes on the physical behaviours can be observed. These changes correspond to the following limit: Liquid limit (from a liquid to a plastic condition); Plastic limit (from a plastic to a semi solid condition) and linear shrinkage (from a semi solid to a solid condition). Plasticity index (PL) = LL-PL. Generally, atterberg limits means the plastic, liquid and the shrinkage limits which are applied to fine grained soil, in which the water content affects the physical properties, thereby changing a clay soil from a solid to a liquid or slurry. Silty and clayey particles are formed by particular minerals that show the capability of absorbing a great deal of water with respect to their size so that they change their characteristics and structures (Terzaghi et al., 1967).

This implies that the fine grains depend on the water on the soil system, which also show the behaviour of the soil. The liquid limit can be defined as the minimum water content at which the soil will flow under a specified small force, or in other words, the maximum water content the soil takes without losing its structure and dissolving with water. The equipment used is the cassagrande apparatus. The soil is air dried and thoroughly mixed and at least 200g soil is sieved through a 425 micro-meter sieve. The plastic limit is the minimum moisture content at which the soil can be rolled into a thin thread of 3mm in diameter without breaking up.

The limit at which plastic changes to brittle failure is known as plastic limit

PL. The plastic limit is the lowest moisture content at which the soil is plastic. About 20g of soil is prepared as in the liquid limit rest is used. The soil is mixed on which is then rolled out between the palm and glass plate to form a thread. The soil is said to be at its PL when is just begins to crumble at a thread diameter of 3mm. At a stage, a section of the thread is removed for moisture content determination. The plasticity index (PI) is the range of water content within which a soil is plastic, the finer the soil, the greater its plasticity index. This can be defined mathematically as:

Plasticity index (PI) = liquid limit (LL) – plastic limit (PL)

The linear shrinkage limit is the water content that is just sufficient to fill the pore spaces when the soil is at maximum volume it will allow by drying. This was obtained by cleaning the shrinkage mould thoroughly and a thin film of grease was applied to its inner walls to prevent the soil from sticking to the surface of the shrinkage mould. The sieved soil sample was mixed and gently placed on the mould excluding air bubbles until it is homogenous, and placed in the drying oven at about 105°C for 24 hours.

$$percntage\ of\ linear\ shrinkage = \frac{\text{lenght of oven dried soil}}{\text{initial lenght of soil}} \times 100$$

Therefore, the linear shrinkage is calculated as a percentage and not contain uniform particle of even sizes. This makes it more important to know the particle size of distribution of a given soil for the purpose of its engineering behaviour and classification. This was carried out to determine the proportion of percentage of clay and silty particle in a measured sample. 500g of the representative sample was soaked in different containers for about 24hours and about 1.5g to 2g of sodium salt (cargon) is added to act as dispersant agent. The soaked samples were washed and dried in the oven for about 24hours. The dried samples were then weighed as initial weight and then put in the set of sieves as follows starting from the coarse: 2mm, 1.18mm, 850mm, 600mm, 425µm, 300mm, 150mm, 63µm/ 75µm and the pan. The samples were then sieved conventionally through the set of sieves. At the end of the procedure, the soil particles retained on each sieve was then expressed as a percentage of the total sample. From this a graph was plotted for the particle size distribution curve. The result of particle size analysis was used for means of quality control for soil material when stabilizing the soil. It is frequently used for mix design or control purpose. It is often used to determine the size and percentage of coarse to fine materials needed to obtain dense impermeable road pavement and it can also be used to estimate the permeability of a soil, this increases the dry density of the soil.

3. Results

This section present the results of various geotechnical analyses carried on sampled sub grade soils in both stable and unstable portions along Supare-Emure Ekiti road, southwestern Nigeria. The results of the natural moisture content, atterberg limits, which is made up of plastic and liquid limits, linear shrinkage, grain size analysis, plasticity index, compaction test, carlifornia bearing ratio (CBR), soaked and unsoaked test, specific gravity are shown on Tables 2-6. The natural moisture content of the stable sub-grade soil samples ranges from 5.07% to 10.75%, while those of unstable sub-grade soil samples ranges from 23.8% to 37.2%. Locations A, E, K and L that are stable portions of the road have lower values in natural moisture content. The results are as shown in Table 2.

For the specific gravity, the values for the unstable portions ranges between 2.62 to 2.88, while the stable portions ranges from 2.62 to 2.67. However, sub-grade soil samples at location K and L have similar specific gravities. Sub-grade soil samples at locations F, G and H have a higher specific gravity which may be due to presence of heavy mineral content from the underlying basement rocks which consist of either biotite or muscovite (Table 3). However, the general specification for specific gravity for sub soils ranges between 2.29 and 2.80 (Gidigasu, 1972; Meshida, 1987; Obiefuna, 2005). The values of the un-stable portions ranges between 2.83 to 2.88 which made them unstable, while the stable portions ranges from 2.62 to 2.67 which made them stable.

The soil samples at location K and L have similar specific gravities which makes them stable. Soil sample at locations F, G and H have a higher specific gravity which may be due to presence of heavy mineral content from the underlying basement rocks which consist of either biotite or muscovite (Table 3). However, the general specification for specific gravity for sub soils ranges between 2.29 and 2.80 (Gidigasu, 1972; Meshida,1987; Obiefuna,2005). All sub-grade soil samples from the stable portions fall within the permissible limit, while some from unstable portions of the road were higher than the specified limits. The liquid and plastic limits can be used to obtain the plasticity index, which is a measure of the plasticity of the soils. Soils with high liquid limit could encourage high linear shrinkage. For the purpose of road construction, a soil less than or equal to 50% liquid limit is a suitable soil for sub-grade and therefore need not to fail (FMWH, 1997). Apart from the location F with 50% liquid limits, all other values fall within the specified limit (Table 3). Therefore, all samples are suitable for sub-grade for road construction. All cohesive soils tend to fail due to the clayey mineralogy of the soil. Plasticity index for clayey soils is higher. Unstable sub-grade soils have higher plasticity index (Table. 3).

Table 2: Showing the results of the Natural moisture content of the sampled sub-grade soils

Sample Number	Natural moisture content (%)	Description of sections
A	9.72	Stable
B	27.7	Unstable
C	35.0	Unstable
D	25.46	Unstable
E	10.75	Stable
F	28.50	Unstable
G	37.20	Unstable
H	24.70	Unstable
I	28.20	Unstable
J	23.80	Unstable
K	8.39	Stable
L	5.07	Stable

Table 3: Showing the results of the Specific gravity of sampled sub-grade soils

Sample Number	Specific gravity	Description of sections
A	2.63	Stable
B	2.67	Unstable
C	2.64	Unstable
D	2.83	Unstable
E	2.62	Stable
F	2.88	Unstable
G	2.75	Unstable
H	2.76	Unstable
I	2.85	Unstable
J	2.86	Unstable
K	2.67	Stable
L	2.67	Stable

Table 4: Showing the results of the liquid limit, plastic limit and the plasticity index of sampled sub-grade soils

Sample Number	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Description of Sections
A	36	21	15	Stable
B	45	20	25	Unstable
C	44	20	24	Unstable
D	23	21	23	Unstable
E	29	19	10	Stable
F	51	22	29	Unstable
G	48	22	26	Unstable
H	50	21	29	Unstable
I	42	19	23	Unstable
J	46	20	26	Unstable
K	32	19	13	Stable
L	35	19	16	Stable

Table 5: Showing the results of the linear shrinkage on sampled sub-grade soil samples

Sample Number	Linear Shrinkage (%)	Description of sections
A	6.4	Stable
B	9.3	Unstable
C	9.3	Unstable
D	10.7	Unstable
E	5.7	Stable
F	7.7	Unstable
G	10.7	Unstable
H	11.4	Unstable
I	10.0	Unstable
J	10.7	Unstable
K	6.4	Stable
L	7.1	Stable

Table 6: Showing the results of the percentage passing sieve for different grain size

Sample Number	Percent Passing on Sieve 2μm	Percent Passing on Sieve 75μm	Percent Passing on Sieve 425μm
A	47	32	41
B	54	44	48
C	45	33	38
D	29	17	23
E	40	23	31
F	66	53	59
G	65	52	58
H	66	55	60
I	56	42	49
J	59	46	53
K	54	47	50
L	52	45	48

The general specification for plasticity index is value less than or equal to 30%, therefore, any soil with a lower plasticity index value if of great advantage. All the sub-grade soils sampled have values less than the required 30% and therefore, suitable for road construction**.** For the plasticity index, locations A, E, K and L have the lowest values and are stable The higher the plasticity value, the poorer the quality of the soil (Gidigasu, 1972). Locations B, C, F, G, H, I and J have higher plasticity index and must have been responsible for the pavement failure. This may be due to poor drainage system along the failed portions (Table.4). Linear shrinkage obtained from unstable portions of the road ranges from 9.3% to 11.4%, while those of the stable portions ranges from 5.4% to 7.7% (Table.5).

Gidigasu had recommended that the linear shrinkage for any soil which is to be used for sub-base or sub-grade soils of any pavement should not exceed 8% (Gidigasu, 1972). Samples from locations B, C, D, F, G, H, I and J have linear shrinkage more than 8%, which makes them not suitable for sub-grade or sub-base of any pavement (Table 5). Samples with higher linear shrinkage above 8% are subjective to swelling and shrinking due to changes in dry and wet seasons of the humid tropical condition of the southwestern Nigeria (Gidigasu, 1972). Sieve analysis shows the distribution of different grain sizes. From table 6, locations A, C, D and E have values below or equal to 35% passing sieve.

However, the values recorded for stable portions fall within the specified limit for road and bridges (FMWH, 1977). Samples from locations B, F, G, H, I, J, K and L collected from unstable portions have values greater than the required 35% passing sieve and are not suitable as sub-grade material for road construction. It was however observed during the sampling that soil profile along Supare-Emure Ekiti road is lateritic in nature. The soil typically displays a distinct layer and the individual horizons differ from one another in their properties and composition. The pedogenetic activities that occur in the area include re-arrangement of materials within the soil profile particularly by the leading of component rainwater percolating in the soil. Thus, the upper layer of the soil profile are either transported soil or residual soil and re-arranges in to surface horizon of evaluation, which has lost material to the sub soil horizon.

4. Discussion

The geotechnical investigation on the sub-grade soil samples collected along Supare-Emure Ekiti road showed that the unstable portions showed waviness, cracks and pot-holes. This is an indication of failure. Attempts have been made to probe the unstable portions that failed various geotechnical tests. Locations A, E, K and L which are the stable portions were taken to serve as control for the investigation process. All samples collected from these locations have plastic limits within the required specification for use as sub-grade soils for road construction (plasticity index with range of 18-22), while those of unstable portions were higher than specified requirements. This may be linked to their clay mineralogy and lack of drainage along the portions. From the results, samples from locations A, C, D and E passed the required specification test of less than or equal to 35% passing through the 2mm sieve, while samples from locations, B, F, G, H, I, J, K and L exceeded the required value of 35%.

5. Conclusion

The pavement failure along the Supare- Emure Ekiti can be linked to influence of bedrock chemistry. Clayey soils are not good engineering materials for any road construction. The failed portions must have been underlain by rocks that are rich in ferromagnesian minerals that weathers easily and contributes essentially for the failure. This paper will however recommend that detailed geology along the stretch of the road be carried out in order to establish any influence it may have on the pavement designs. Also, the soils could be stabilized for optimal usuage in the nearest future. Provision of adequate drainage will also be appropriate along the failed sections of the road. This paper has been able to establish the influence of bedrock geology on the causes of pavement failure especially in the tropics.

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