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# Geotechnical Studies of the Sub-grade Material beneath Akure-Ijare Highway, Ondo State, Southwestern Nigeria

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***Abstract:***
*In order to solve the incessant road failures along Akure-Ijare Highway in Ondo State Nigeria, geotechnical investigation was carried on the subgrade material to know its competence/load bearing capacity for the reconstruction of the road along the failed segments. The failed segments were extended at both ends into classified stable segments. The geotechnical investigation involved natural moisture content test, grain size analyses, specific gravity test, linear shrinkage test, Atterberg's Limits, Compaction test and California Bearing Ratio (CBR) determination. The natural moisture content of soils from the classified stable segments is 4.0 % while that of failed segments ranges from 3.0 % to 5.0 %. The percentage of fines, specific gravity, Liquid Limits, Plastic Limits, Plasticity index, Linear shrinkage and CBR of the soils taken from classified stable segments are 46 - 48.3 %, 2.67 - 2.68, 32 - 33 %, 22 - 23 %, 10 - 11 %, 2 - 12 %, 46 - 70 % respectively, while that of failed segments are 27 - 58%, 2.65 - 2.73, 22 - 54 %, 17 - 29 %, 5 - 25 %, 6 - 7 %, 26 - 57 % respectively. All the soil samples from both classified stable and the failed segments have high Maximum Dry Density at low Optimum Moisture Content. The significant overlap in the geotechnical properties of the soils in the classified stable segments and failed segments of the road suggests that the cause(s) of road pavement failure along the studied highway may be due to factors other than or complementary to geotechnical factors.*

***Keywords:*** *Geotechnical, Subgrade, Highway*

## 1. Introduction

Geotechnical investigation is carried out as feasibility study before road construction with the aim of studying the competence of the subgrade where the road will rest on and for competence of the selected materials for the road construction. The soil mass on which a structure is to be built is heterogeneous in character and no theory can simulate field conditions. Soil deposits in nature exist in an extremely erratic manner producing thereby an infinite variety of possible combinations which would affect the choice and design of foundations (Das, 1994). During the design, the designer has to make use of the properties of soils, the theories pertaining to the design and his own practical experience to adjust to suit field conditions; so as to prevent failure.

The properties desired in soils for foundations under roads and airfields are: adequate strength; resistance to frost action (in areas where frost is a factor); acceptable compression and expansion; adequate drainage and good compaction. Some of these properties may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water-collecting system. Strength requirements for base course materials are high, and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying base materials or using a geotextile. Proper design of road and airfield pavements requires the evaluation of soil properties in more detail than possible by use of the general soils classification system. However, the grouping of soils in the classification system gives an initial indication of their behavior in road and airfield construction, which is useful in site or route selection and borrow source reconnaissance (Casangrade, 1948).

### *1.1. General Classification of Nigeria Road System*

In broad perspective road network in Nigeria according to Oguntuase (1989) may be classified into three distinct categories namely urban roads, interstate and intercity highways and the rural roads. Urban roads are wide pave roads found within cities and towns. The

interstate and intercity highways are those that connect two or more states together. The third category of roads is the rural roads, which are mainly earth roads. These are roads connecting farms and villages with intercity road.
Another subdivision of the Nigeria road system was done taking into consideration such important details as ownership, construction and maintenance responsibility. Accordingly, Nigeria road system was further classified into three distinct groups, Federal, State and Local Government roads (Fadaka, 1989; Nnama, 1990). The federal roads are trunk A and F roads. The trunk F roads were formerly jointly owned by States and Federal Government but were taken over by the Federal Government in 1980. All federal roads are constructed or reconstructed and maintained by the Federal Government of Nigeria. State roads are designed Trunk B roads. All state roads are constructed and maintained by the state governments. Example of this is the Akure-Ijare roadway (investigated road). Rural roads form the third category of modern road system in Nigeria. State and the local government of the area in which the road is situated or constructed often jointly own these categories of roads.
Townsend *et al.* (1982), based on required traffic density and load limitation, also carried out further classification. Road pavement structure was then classified and grouped into three: class 1 (heavy traffic), class 2 (moderate traffic) and class 3 (lower traffic).

### *1.2. Design of Highway Pavement*
Highway pavements are generally classified into two major categories rigid and flexible road pavements.

#### 1.2.1. Rigid Pavement
The rigid pavement refers to wearing surface that is constructed of cement concrete which consists of a singular layer of uniform cross-section with thickness ranging from 6 to 11 inches (15 cm to 28 cm). This type of pavement is capable of carrying very large amount of traffic with ease, comfort and safety. In this country, they are restricted to airport runways, parks and petrol filling stations (Akintorinwa *et al.,* 2010).

#### 1.2.2. Flexible Pavement
Generally, flexible highway pavements are designed to transfer or distribute wheel or traffic loads over a sufficient area of the underlying materials so that induced stress do not exceed the bearing capacity of the interlocking aggregates (Krynine and Judd, 1957). It is one that relies solely on the strength of the sub-grade. It is made up of one or two layers of bitumen surfacing lying over a compacted base course (Figure 1).

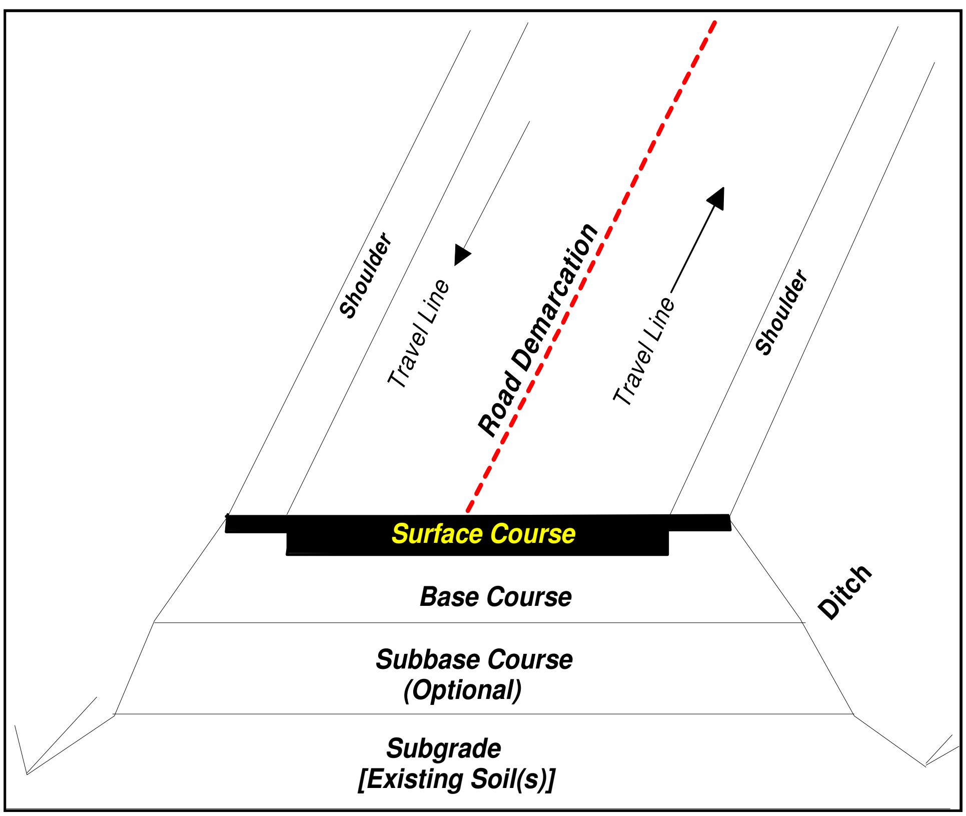


*Figure 1: Flexible Road Pavement*

A typical flexible pavement is made of the following:

i. Sub-grade: This is the in-situ material upon which the pavement structure is placed. It may be the material reworked in-situ or even the imported material from another source such as a cut. The sub-grade serves as the foundation for the highway pavement and distributes load from the upper layers to the soil underneath. A satisfactory sub-grade is able to resist the effect of both traffic and weather. Under heavy traffic loads, sub-grade soils may deform and contribute to distress in the overlying pavement structure manifesting as failure. It is therefore very important to adequately prepare this layer if the road is to last.

ii. Sub-base: This is the layer directly on the sub-grade. The sub-base material comprises of crushed rock of aggregate sizes. The aggregates are laid by paver and compacted by double drum compactor machine to the design specified thickness. The sub-base receives the traffic load from the upper layers and distributes it to the sub-grade which in turn distributes it to the sub soil.
iii. Road Base: The road-base is a material layer of very high stability and density. This is the layer directly beneath the surface of the pavement. Its principal function is to distribute the stresses imposed by traffic evenly to the sub-grade and sub-base thereby avoiding deformation damage or displacement of the foundation layer. The material used for the base are crushed rocks of aggregate sizes.
iv. Surface Course: The surface or wearing course is the upper course of aggregates layer of flexible pavement. This is the riding surface or the surface dressing of a road which comprises of the combination of bitumen and different sizes of crushed stones, stone dust, sharp sand and filler; all mixed together. It is designed to withstand high tyre pressure, resists the abrasive force due to traffic, provides a skid resistant driving surface and prevents penetration of surface water into the underlying layers. The laying of asphalt is usually done by a paver and compacted with a roller. Asphalt is laid while it is hot usually at temperature close to 150˚C and the surface is usually watered to produce a smooth finish. The road is opened to traffic as soon as the surface is cold.

*1.3. Road Failure*

Road failures could be defined as a discontinuity in road networkresulting in cracks, potholes, bulges anddepressions. A road network is supposed to be acontinuous stretch of asphalt lay for a smooth ride or drive. Visible cracks, potholes, bulges and depressions may punctuate such smooth ride. Road failure is generally detected and observed as cracks, depression and removal of the bituminous pavement, which exposes the sub-base. The punctuation in smooth ride is generally regarded as road failure (Aigbedion, 2007).

Therefore the pavement will no longer able to absorb and transmit the wheel loading through the fabric of the road without causing fairly rapid further deterioration of the road pavement. While the failures have become a common phenomenon, as they are permanently on the increase, the problem seems to be precarious on cut sections of roadways. The highway failure along the studied roadway manifested as potholes and depression, distress, pitting, diverse cracks and surface rutting {Figure 2(a-j)}.

*1.4. Description of the Project Environment*

The Akure-Ijare road, which is about 12 km, is the major road that links Akure and Ijare, both in Ondo-State, Nigeria (Figure 3). It lies within longitudes $5^{\circ} 10^{l}$ E and $5^{\circ} 09^{l}$ E and latitudes $7^{\circ} 21^{l}$ N and $7^{\circ} 17^{l}$ N. Expressed in the Universal Traverse Mercator (UTM) coordinates, the road is located within Northings 0806719 mN and 0812694 mN and Eastings 0738567 mE and 0739035 mE (Figure 4). At the time of study, two segments of the road have failed (Orita-Obele axis and Ikota-Ijare axis) and these segments are named locality 1 and locality 2.

A reconnaissance survey was carried out along the study road in order to establish the failed segments. Two failed segments were established, with Road-Block Junction (Figure 4) as the reference point (000 km).

The terrain of the road is relatively flat and it slopes gently from western to eastern part of the road. The location topography of the road ranges from 358 m to 412 m above sea level. The area lies geographically within the tropical rain forest belt of hot and wet equatorial climatic region characterized by alternating wet and dry climate seasons (Iloeje, 1981), which is strongly controlled by seasonal fluctuation in the rate of evaporation. The available rain data shows that mean annual rainfall ranges from 1000 mm - 1500 mm and mean temperature of 24˚C to 27˚C. The vegetation is of tropical rainforest and is characterized by thick forest of broad-leaved trees that are ever green. The vegetation of the area is dense and made up of palm trees, kolanut trees and cocoa trees.

The study area lies within the Crystalline Basement Complex rocks of Southwestern Nigeria which is part of the Nigeria Basement Complex (Figure 5). The Southwestern Basement Complex Crystalline rocks have been described in considerable detail by authors like Jones and Hockey (1964), Rahaman (1989), Olarewaju (1988) and others.

However, from the geological map (Figure 6), the road cut across two rock units namely charnockite and medium coarse grained biotite-granite. However the major part of the road cut across charnockitic rock. However, the area is drained by many streams and rivers such as Ogudo stream, Agbasa stream, Oniyo river etc.

## 2. Materials and Methods of Study

*2.1. Sample Collection*

Disturbed soil samples were collected from the failed and classified stable sections (Figure 7), at each of the studied localities at a depth not exceeding 1 m. At locality 1, four samples were collected and labeled ST.1A, ST.1B, FL.1A and FL.1B. At locality 2, five samples were collected and labeled ST.2A, ST.2B, FL.2A, FL.2B and FL.2C. Theabbreviations ST and FL denote samples taken from the classified stable and the failed segments respectively. These

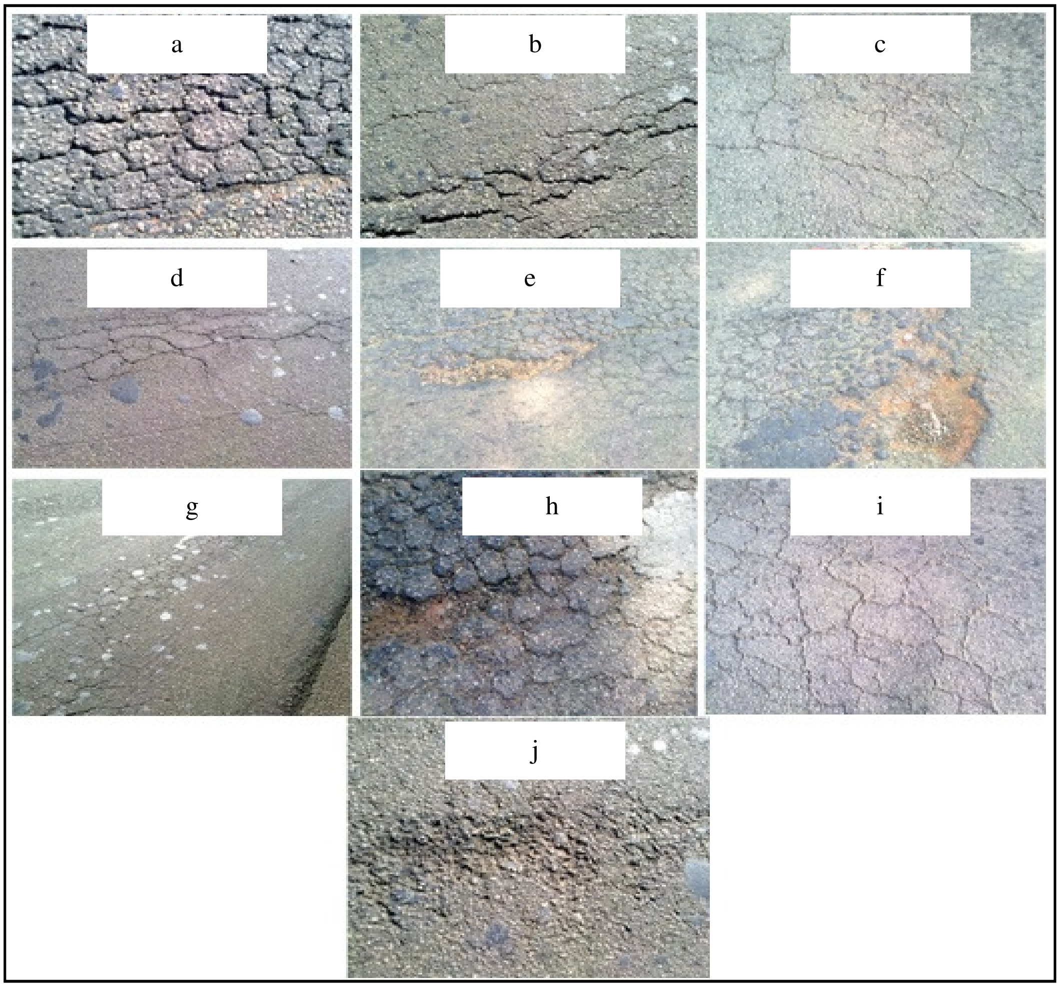



*Figure 2: Failed Section along the studied Highway*

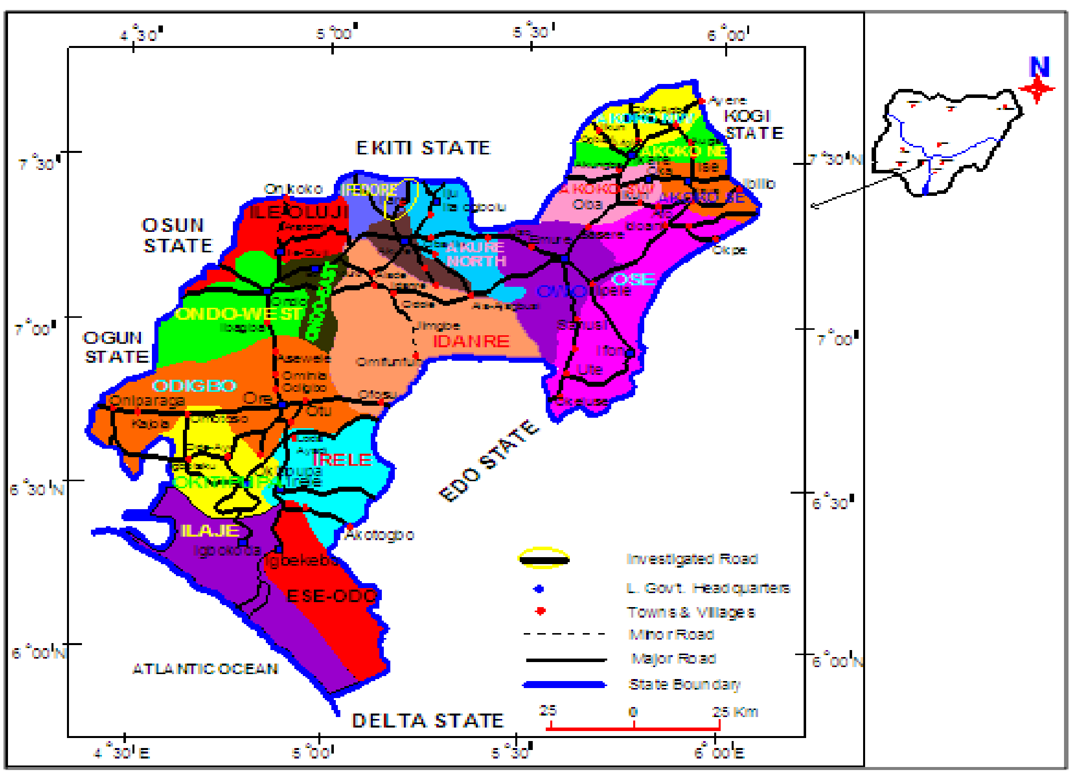



*Figure 3: Road map of Ondo State showing the investigated road.*

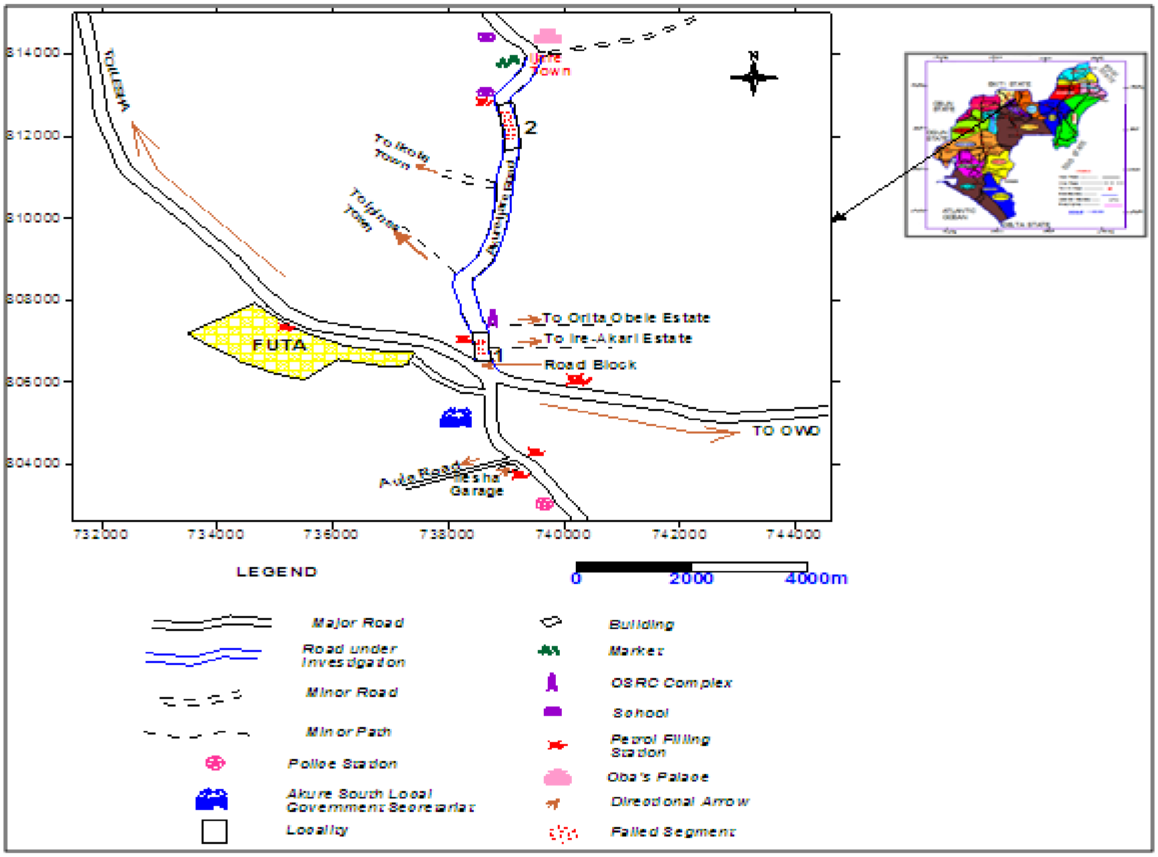



*Figure 4: Road map of part of Akure-Ijare Area showing Akure-Ijare Road.*

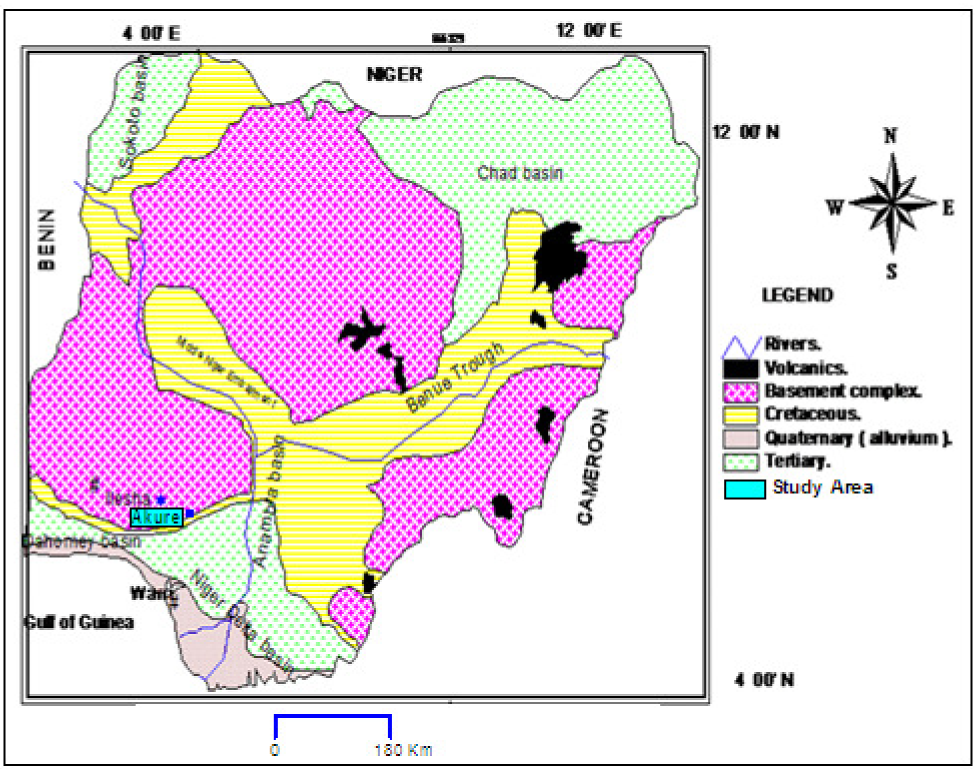



*Figure 5: Geological Map of Nigeria Showing the Study Area*

(Modified After Geological Survey Division, 1974)

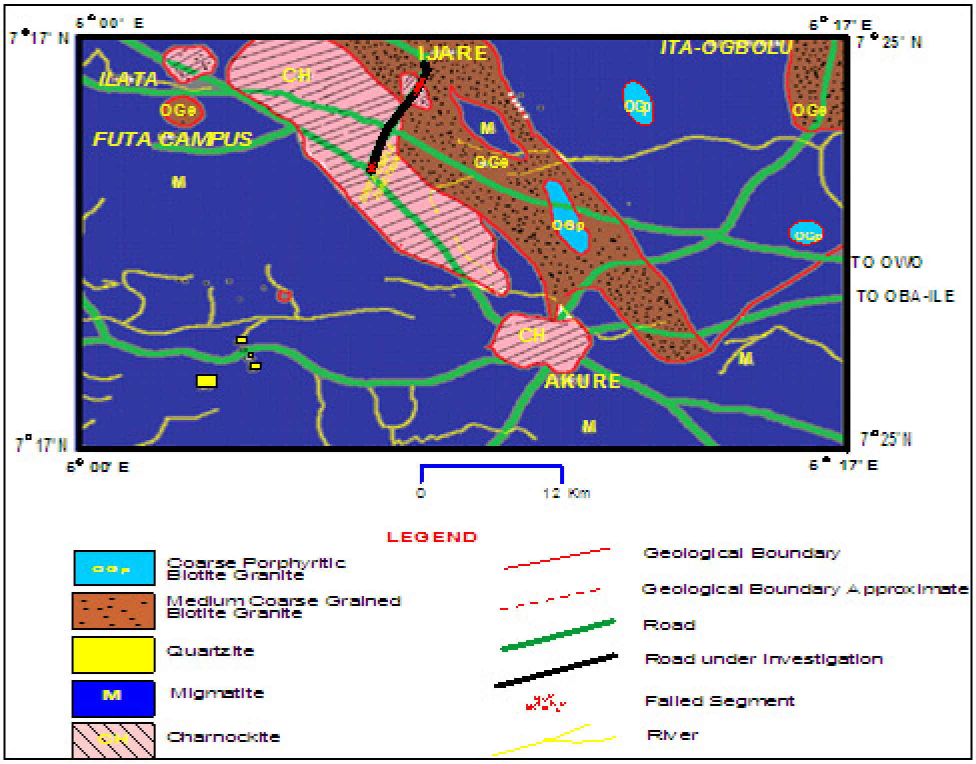


Figure 6: Geological Map of Akure Area Showing the Road under Investigation

(Modified After Geological Survey of Nigeria, Sheet 61, 1966). samples were preserved in polythene bags and transported to the laboratory.

*2.2. Sample Preparation*

The natural moisture content of the samples collected from the field was determined in the laboratory within a period of 24 hours after collection. This was followed by air-drying of the samples by spreading them out on trays in a fairly warm room for four days. Large soil particles (clods) in the samples were broken with a wooden mallet. Care was taken not to crush the individual particles.

Methods of testing soils for engineering purposes were conducted in accordance with B.S. 1377 for all the soil samples and the soils were compacted at the West African standard. The tests include Natural Moisture Content, Grain Size Analysis, Liquid Limit, Plastic Limit, Linear Shrinkage, Compaction Test and California Bearing Ratio (CBR).

*2.3. Laboratory Test*

2.3.1. Natural Moisture Content

Dry, clean cans of weight $(M_1)$ were filled each with a crumbled soil sample and then weighed to give weight $(M_2)$. The cans with its content were oven dried at a temperature range between 105˚C and 110˚C. After drying, the cans were removed from the oven and weighed $(M_3)$ as soon as it was cooled enough to handle.

$TheMoistureContent(MC) = \frac{M_2-M_3}{M_3-M_1} \times 100$ ……………………………………………….. (1)

Where $M_2 - M_3$ is the weight of water and $M_3 - M_1$ is the weight of the dry soil sample.

2.3.2. Grain Size Analysis

Representative sample of approximately 500g was used for the test after washing and oven-dried. The oven dried sample was put into a set of sieves and base pan with mesh sizes of 2.00, 1.18, 0.850, 0.425, 0.300, 0.150 and 0.075 mm; which was arranged serially with 2.00 mm mesh size at the top with the base pan at the bottom. These arranged set of sieves with the dry sample was put on the automatic sieve shaker pre-set to run for 10 minutes. On the expiration of the time, the individual sieves content were collected and weighed and the data obtained were plotted on the grading curve.

2.3.3. Liquid Limit Determination

Soil sample passing through 425µm sieve, weighing 200g was mixed with water to form a think homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was recorded. Also, moisture contents were determined. The rest of the sample was re-mixed with small addition of water and the procedure repeated five times covering various values of penetration. The cone penetration (mm) was plotted as ordinate against the corresponding moisture (%) as abscissa both on linear scale.

2.3.4. Plastic Limit Determination

Soil sample weighing 200g was taken from the material passing the 425µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3mm diameter. Therefore, the moisture contents were determined by oven drying. The test was repeated on four sub-samples to give more moisture content determination. The average value of the moisture content determined was taken as the plastic limit.

2.3.5. Compaction Test

About 3000 g of air dried and pulverized soil was mixed thoroughly with a small quantity of water. This was compacted into the mould in three equal layers by giving the layer 25 uniformly distributed blows of the rammer falling from the top over the soil. The compacted soil was carefully leveled up to the top of the mould by means of a straight edge knife. The mould and soil was then weighed. A sample was collected for moisture content determination. The soil was then broken up and appropriate percentage of water was added. These series of tests were continued until there was a decrease in weight of the moisturized sample. Bulk density$\rho_b$ of each compacted soil sample was calculated.

2.3.6. California Bearing Ratio (CBR)

Air-dried soil was mixed with about 5% of its weight of water. This was put in C.B.R mould in 3 layers with each layer compacted with 55 blows using 2.5kg hammer at drop of 450mm (standard proctor test). The compacted soil and the mould was weighed and placed under C.B.R machine and a seating load of approximately 4.5kg was applied. Load was recorded at penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0 mm. The moisture content of the compacted soil was determined.

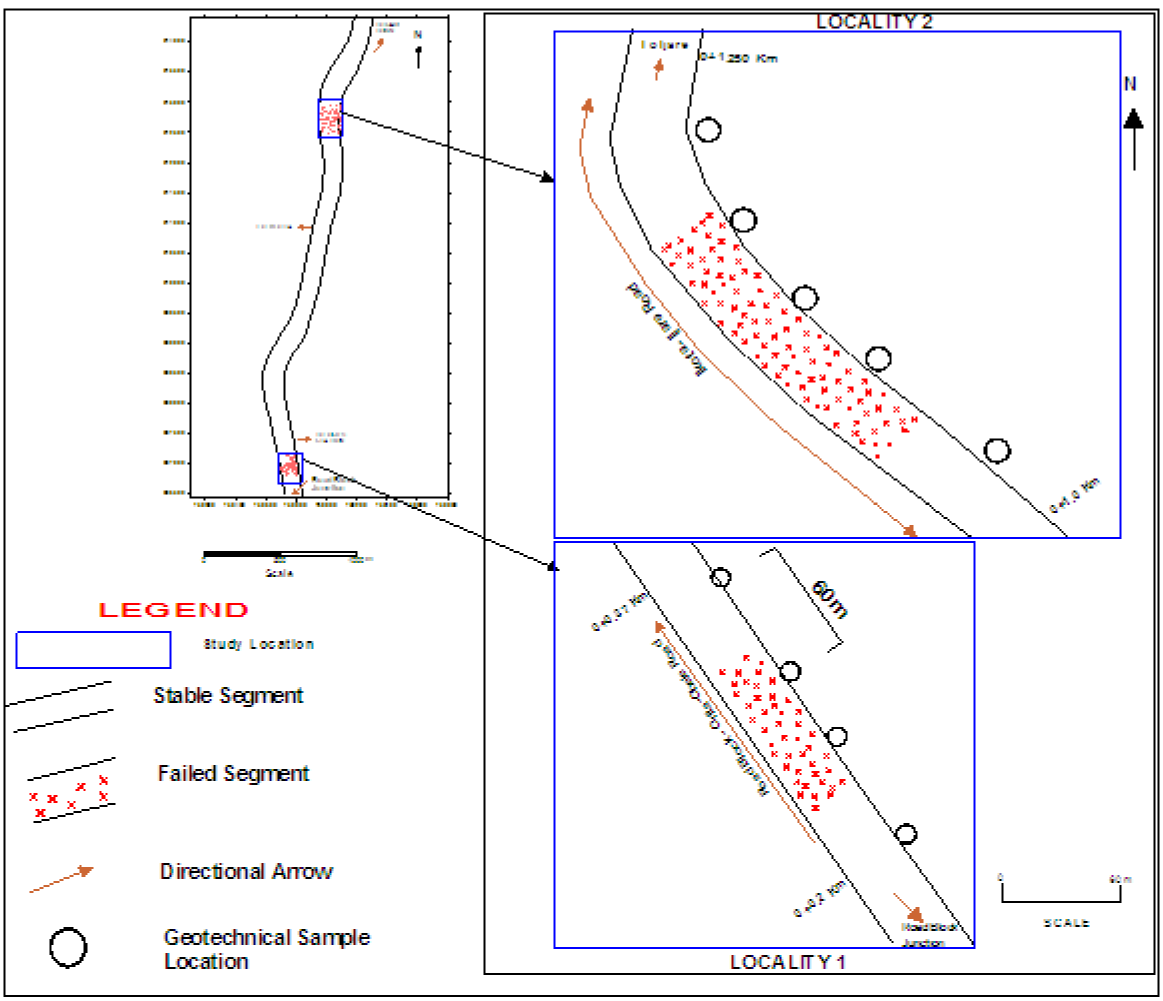



*Figure 7: Field Layout at Locality 1 and 2 Showing Geotechnical Sampling points.*

2.3.7. Specific Gravity and Shrinkage Limit

The determination of specific gravity, shrinkage limit and natural moisture content tests followed the standard as outlined in BS 1377 of 1975.

## 3. Result and Discussion

### *3.1. Natural Moisture Content*

The various values of Natural Moisture Content (NMC) obtained from laboratory tests are presented in Table 1. The natural moisture content gives information on the condition of the soil. The natural moisture content of soils from the classified stable segments is 4.0 % while that of failed segments ranges from 3.0 % to 5.0 %. The entire samples have low moisture content in their natural state. The ranges of natural moisture content of the soil samples taken from the classified stable and failed segments of the highway show significant overlap as they both exhibit low moisture content in their natural state. Therefore it is difficult to explain the causes of pavement failure at these localities from the point of the natural moisture content of the soil.

| LOCATION | LOCALITY 1 | | | | LOCALITY 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SAMPLE | FL. 1A | ST.1A | FL. 1B | ST.1B | ST.2A | FL. 2A | ST.2B | FL. 2B | FL. 2C |
| Natural Moisture Content (%) | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 3 | 3 |
| % Finer (0.075mm) | 48.2 | 47.1 | 51.8 | 47.0 | 48.3 | 58.3 | 46.0 | 28.2 | 27.1 |
| Specific Gravity | 2.73 | 2.67 | 2.72 | 2.68 | 2.67 | 2.72 | 2.68 | 2.65 | 2.66 |
| Liquid Limits (%) | 54 | 33 | 52 | 33 | 32 | 49 | 33 | 23 | 22 |
| Plastic Limits (%) | 29 | 23 | 28 | 23 | 22 | 26 | 23 | 18 | 17 |
| Plasticity Index (%) | 25 | 11 | 24 | 10 | 10 | 23 | 10 | 5 | 5 |
| Linear Shrinkage (%) | 12 | 6 | 11 | 6 | 6 | 11 | 6 | 2 | 2 |
| MDD (Kg/m³) | 1664 | 2040 | 1575 | 1890 | 2096 | 1645 | 2058 | 1975 | 1978 |
| OMC (%) | 19 | 12 | 19 | 15 | 12 | 22 | 12 | 10 | 10 |
| CBR (%) | 26 | 66 | 28 | 46 | 70 | 25 | 68 | 57 | 54 |
| AASHTO classification | A-2-7 | A-2-7 | A-2-7 | A-4/A-6 | A-4/A-6 | A-2-7 | A-6 | A-2-4 | A-2-4 |
| USCS | CH | CL | CH | CL | CL | CI | CL | CL | CL |
| General Rating as sub grade | Good | Good | Good | Fair to poor | Fair to poor | Good | Poor | Good | Good |
| Condition at the Time of Sample Collection | failed | stable | Failed | stable | stable | failed | Stable | failed | failed |

*Table 1: Summary of the Geotechnical Results*

### *3.2. Grading Characteristics*

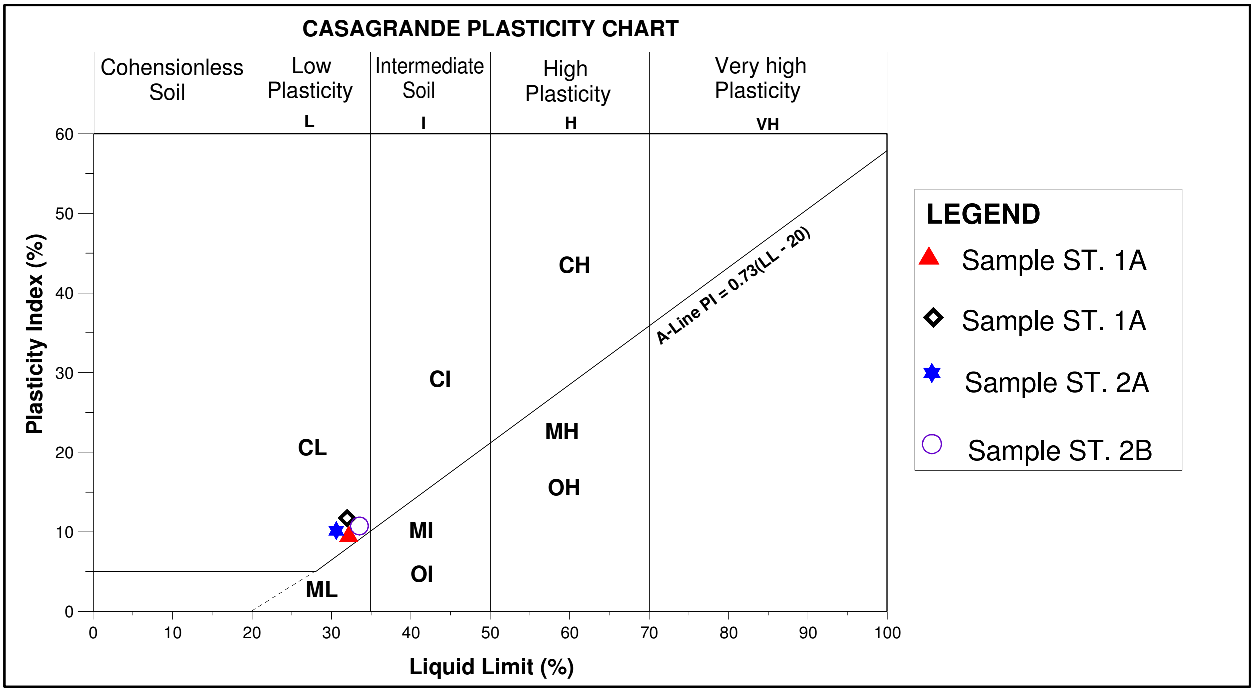
The results of the grain size distribution analyses based on British Standard 1377 (1975) are summarized in Table 1. The tested soils from the classified stable and failed segments have percentage finer (percentage passing 0.075 mm) ranges from 46.0 - 48.3 % and 27 - 58 % respectively. From the grading curves, the soils can be classified as fine graded soil. Generally soils from classified stable and failed segments have percentage passing (0.075 mm) of more than 35 % with average of 45 %.

The plot of the characteristics of the soil samples in the Casagrande plasticity chart (Figure 8) show that all the samples tested from classified stable and failed segments fall within CL group and CL-CH group respectively. This implies that the soil from the classified stable contains clay fractions of low plasticity (low swelling potential) which could account for the stability of this zone while those from failed segments exhibits low to high swelling potential. All the samples fall above the A-line, indicating that they consist of clayey inorganic material (Casagrande, 1948 and Jegede, 2000).

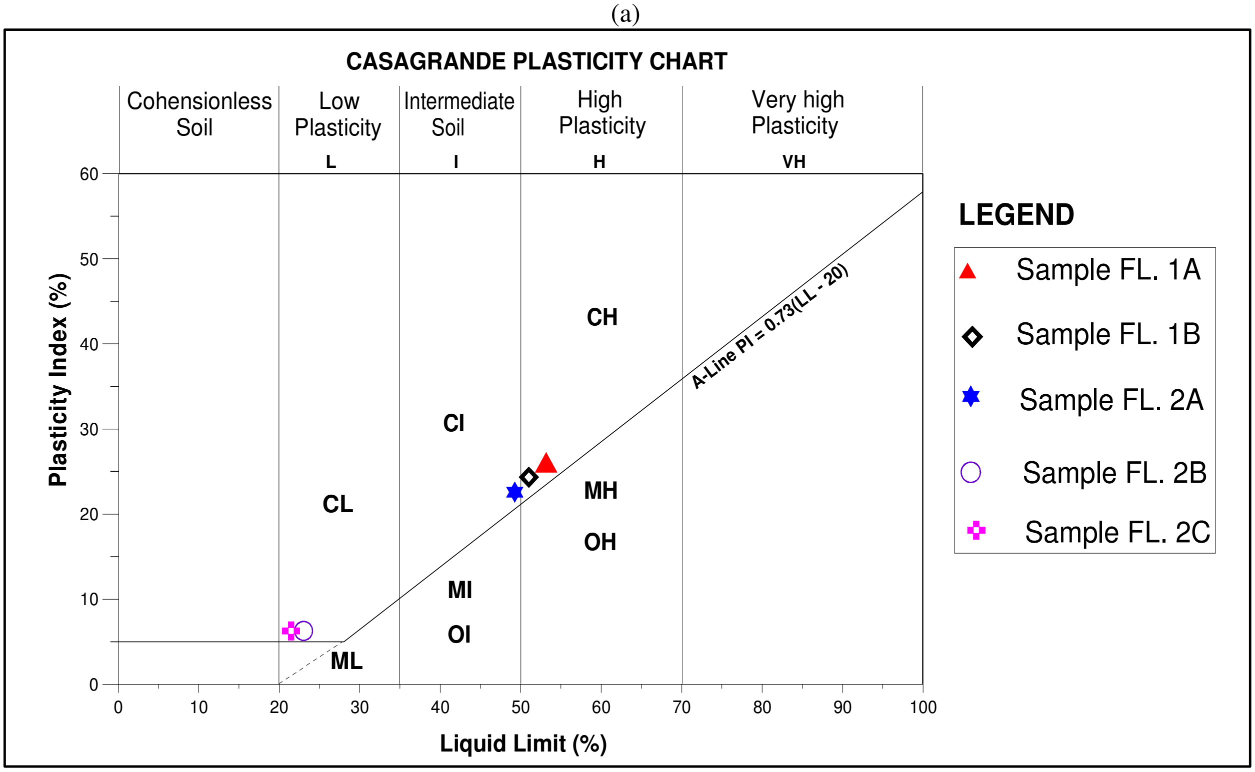
The soil is generally of fine-grained. Based on British Standard BS 1377 (1975) if percentage fine is less than 35 % it is adjudged a good subgrade material. The soil samples along the studied classified stable segments shows a range that is greater than 35 % which can be classified as unsuitable sub-grade, sub-base and base material; even though stable as at the time of conducting this study, while some of the samples tested from the failed segments at locality 2 (FL. 2B and FL. 2C) (Figure 9) have values less than 35 %, but failed. Generally, most of the samples fall within A-2-7 AASHTO classification, which is rated good subgrade material. Hence the failure of the failed segments of this highway cannot be explain from the point of view of grain size distribution. However, the result shows that, the present classified stable segments may still fail in the future.

### *3.3. Specific Gravity*

The specific gravity correlates well with the mechanical strength of sub grade (Mesida, 1981). Table 1 presents the results of the specific gravity (Gs) for all the soil samples. The tested soils from the classified stable and failed segments ranges from 2.67 - 2.68 and 2.65 - 2.73 respectively. These values are moderately low which indicate a fine grained and within the reported range for lateritic soils (2.50 - 4.60) (Gidigasu, 1976).

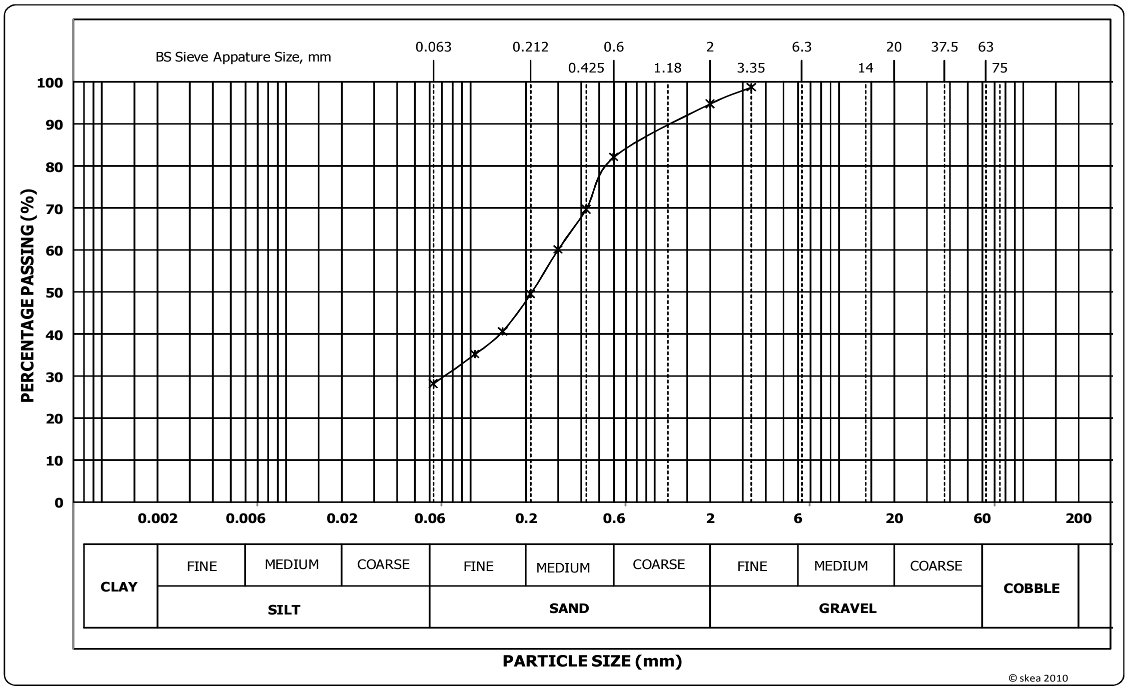



(a)

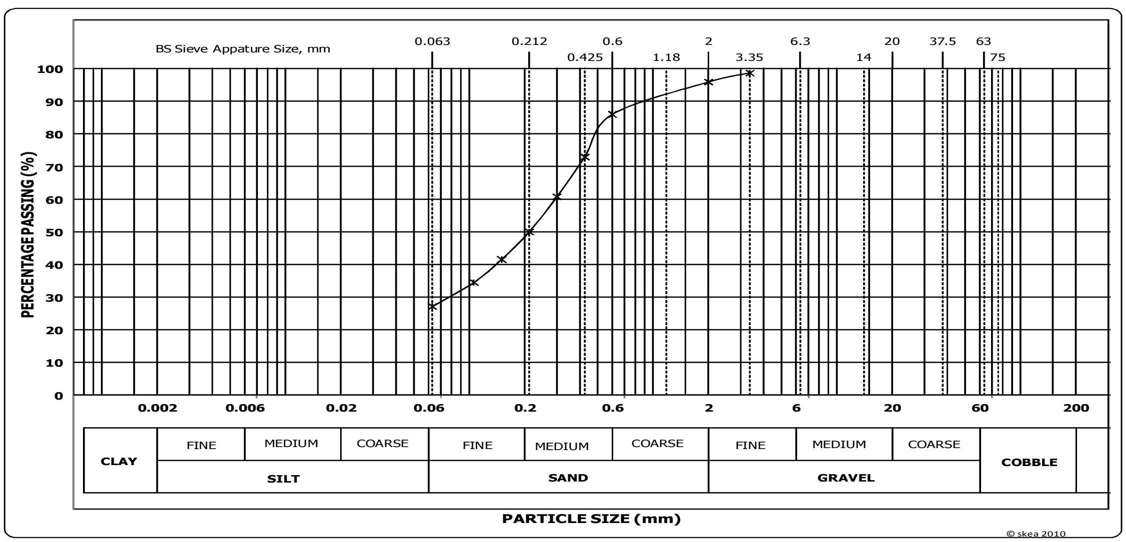



(b)

*Figure 8: Casagrande Chart Classification of the Studied Soils (a) Stable? Segments (b) Failed Segments*




**(a)**




**(b)**

*Figure 9: Grain size analysis curves obtained for: (a) Sample FL. 2B (b) Sample FL.2C*

*3.4. Consistency Limits*

The summary of the results of the consistency limits test for the soil samples are presented in Table 1. The liquid limit of the soil samples from the classified stable and the failed segments range from 32 % to 33 % and 22 % to 54 % respectively. The plastic limit of the soils ranges 22-23 % and 17-29 % respectively. The plasticity index of soil beneath the classified stable and failed segments ranges from 10 % to 11 % and 5 % to 25 % respectively.

Good sub-grade materials must among other significant criteria be of low plasticity such that its resistance to swelling, total expansion and linear shrinkage should be minimal. The high plasticity index and liquid limit values are indicative of poor engineering and geological properties of subgrade soils (Jegede, 1995).

The Federal Ministry of Works and Housing (FMWH) (1972) recommended Liquid Limits of 50 % maximum, Plastic Limits of 30 % maximum, Plasticity index of 20 % maximum for sub-grade materials for highway construction. As shown in Table 1, the Liquid Limit of the soils beneath the classified stable and the failed segments at both localities are generally less than 50 %, while the Plastic Limits are generally lower than 30 % and the Plasticity Index are generally lower than 20 %. Hence, most of the studied soils fall within the specification, thus, they are suitable sub-grade materials.

*3.5. Linear Shrinkage*

Linear shrinkage is an important parameter in the evaluation of sub grade materials soils for highway construction. It has been suggested that a linear shrinkage (LS) value below 8 % is indicative of a soil that is good for highway sub grade materials (Brink *et al.,* 1992; Mededor, 1983). The results of the linear shrinkage tests are presented in Table 1. The values range between 2 % and 12 % with an average value of 6 % and 7 % for classified stable and failed segments respectively. This shows that the soil within the studied area is constructed on a competent subgrade material. This implies that the failure of the failed segments of this highway cannot be explain from the point of view linear shrinkage.

*3.6. Compaction Characteristics*

The importance of compaction test is to improve the desirable load bearing capacity properties of a soil as a subgrade material. The Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) obtained from the tested soil are presented in Table 1. The OMC from the classified stable segments and failed segments ranges from 12-15 % and 10-22 % respectively. The MDD ranges from 1890 - 2096 Kg/m³ and 1575 - 1978 Kg/m³ for the soil beneath the classified stable segments and failed segments respectively.

The degree of compaction is sensitive to moisture content, thus the higher the value of MDD and the lower OMC, the more suitable the subgrade material to sustain any load imposed. However the ranges of MDD and OMC did not show much significant contrast. All the soil samples from both localities have MDD at low OMC. Hence compaction characteristic of the soils may not be a good index for the highway pavement failure.

*3.7. California Bearing Ratio*

The results of the California Bearing Ratio tests are presented in Table 1. The values of CBR beneath the classified stable segments and failed segments range from 46-70 % and 26-57 % respectively. The standard specification of CBR recommended by the Federal Ministry of Works and Housing (FMWH) (1972) is 80 % minimum for subgrade materials for highway construction. All the soil samples have CBR less than 80 % indicating that the subgrade is substandard and weak in strength.Therefore there is no much correlation between the values of CBR of sub-grade soils and the degree of stability of highway pavement, suggesting that CBR may not be a good index in predicting the failure of pavement structure.

Therefore; from the above, there are no significant differences in the geotechnical properties of all the soil samples tested under the classified stable and failed segments. The pavement failure along the highway may be due to factors other than poor geotechnical properties.

**4. Conclusion**

The geotechnical studies of the subgrade of Akure-Ijare Highway, Ondo State, Southwestern Nigeria has been carried out in compliance with BS 1377 (1975). The tested soils beneath the classified stable and failed segment at locality 1and II indicates that the soil is composed of clay and silt (>35 %), indicating a poor geotechnical characteristic. The plasticity index values were lower than 20 % maximum recommended, and the plasticity shows that all the samples tested from classified stable and failed segments fall within CL group and CL-CH group respectively. This implies that the soil from the classified stable? segment contains clay fractions of low plasticity (low swelling potential) which could account for the stability of this zone while those from failed segments exhibits low to high swelling potential. The linear shrinkage values of the soils are generally lower than 8 % maximum recommended for highway subgrade soils. The soils at both localities have Maximum Dry Density (MDD) at relatively low Optimum Moisture Content (OMC); however, the values did not show much significant contrast. The California Bearing Ratio (CBR) of both the currently classified stable and failed segments falls below the 80 % minimum for subgrade materials, as recommended Federal Ministry of Works and Housing (1972). The significant overlap in the geotechnical properties of the soils in the classified stable segments and failed segments of the road suggests that the cause(s) of road pavement failure along the studied highway may be due to factors other than or complementary to geotechnical factors.

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