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Geotechnical Properties of Subgrade Soil along Failed Portions of Akungba-Ikare Road Stabilised with Rock Fines

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Authors' contributions

This work was carried out in collaboration between all authors. 'All authors read and approved the final manuscript.

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ABSTRACT

There is an increasing incidence of road failures in Southwestern Nigeria. Many asphalt roads have failed sections soon after construction and rarely reach their design life span before major repair is required. The aim of this study is to conduct geotechnical properties of sub-grade soil along failed portions of Akungba-Ikare road in the Northern part of Ondo State, Southwestern Nigeria with a view of determining the possible causes of the failures experienced along the road. Four samples were collected from four different locations and stabilised with varying percentages of rock fines. Laboratory tests conducted on the soil samples were natural moisture content, liquid limit, plastic limit, grain size analysis, linear shrinkage, specific gravity, compaction and California bearing ratio (CBR). The test results showed that the natural moisture content of the soil samples ranges from 9.3 to 26.4%, the liquid limit from 0.0 to 46.4%, plastic limit from 0.0 to 40.0% and plasticity index from 0.0 to 31.61% which did not conform to specifications. The grain size analysis shows that the amount of fines passing 425μm sieve ranges from 33 to 51% which are higher than the standard specifications. The linear shrinkage ranges between 5.8 and 15.3%. The specific gravity ranging

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between 2.58 and 2.73 fall within the standard specifications. The maximum dry density ranges between 1497 and 1982 kg/m^3 and optimum moisture content between 4.7 and 12.8%. The California bearing ratio (CBR) values for the unsoaked soil samples range from 0 to 5% which fall below the standard. Despite the use of stabilisation material (rock fines) at different percentages, the poor geotechnical properties of the soils as indicated by the low maximum dry density, high linear shrinkage, high liquid limit values, high amount of fines, low CBR values and lack of drainage in the study area is the greater causes of the failure of the road portion, hence standard materials in conformity with the Federal Ministry of Works specifications for road constructions must be adhered to during repairs of the road.

Keywords: Geotechnical analyses; sub-grade soils; failed portions; Stabilisation; Akungba-Ikare road.

1. INTRODUCTION

Road networks play a vital role in the economy of any nation especially in developing ones like Nigeria, which require good roads for transportation of goods and services [1]. Roads aid easy and smooth vehicular movement. In developing countries where other means of transportation such as rail, underground tube, air and water transport systems have remained largely under-developed, roads remain indispensable in the transportation of people, goods and services from one point to another. Oguntuase [2] and Igwe et al. [1] broadly classified the road network in Nigeria into three distinct groups namely: Urban roads, inter-state and inter-city highways and the rural roads. Urban roads are wide paved roads found within cities and towns. The inter-state and inter-city 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 roads connect farms and villages with inter-city roads. Akungba-Ikare road falls within the second category of roads (inter-state and inter-city road). A sub-division of the Nigerian road system was done by Fadaka [3]; Nnama [4] and Akobi [5] considering important details such as ownership, construction and maintenance responsibility. The road serves as inter-links between towns, states and countries and therefore is known as the common means of transportation.

Road failure is generally detected and observed as cracks, depressions and removal of the bituminous pavement, which exposes the sub-base. The punctuation in a smooth ride is generally regarded as road failure [6]. Consequently, the pavement will no longer be able to absorb and transmit the wheel loading through the fabric of the road without causing a fairly rapid deterioration of the road pavement. The rate at which roads (highways) fail in Nigeria is quite alarming in recent times and this has been causing concerns among the stakeholders in the maintenance of Nigerian highways. Most of these roads have become death traps in many places across the country with the attendant loss of lives and properties. The failed segments of major highways across the country usually display a variety of failed pattern ranging from pitting, rutting and waviness patterns. A number of contributing factors have been identified, such as mis-use of highways or over-use of highway, lack of maintenance culture, poor construction practices and geotechnical factors [7].

Engineering properties have been identified as the major factors influencing the failure of many roads within and outside the country. Despite the technological improvement in the country, the cause of pavement failures has remained a serious concern in almost all the major highways in Nigeria. A pavement is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as road or walkway. The terms base and sub- base are sometimes used interchangeably to refer to the sub-surface layers of a pavement, sub-base is the layer of aggregate material laid on the sub-grade on which the base course layer is located. It may be omitted when there will be only foot traffic on the pavement, but it is necessary for surfaces used by vehicles. The base and sub-base layers at the study area were exposed by the different grades of pitting along the road. Road failures are almost invariably linked directly to the underlying soil (sub-grade soil) which usually bears the load carried by the road. The term "sub-grade" as used in Civil Engineering refers to 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. Sub-grades are also considered layers in the pavement design, with their thickness, assumed to be infinite and their material characteristics assumed to be unchanged or unmodified. The sub-grade serves as the foundation for the highway pavement and distributes the 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.

The causes of roads failure in Nigeria have been attributed to several factors such as poor construction materials, poor design and specification, road usage, poor drainage, geological and geotechnical factors [8,9]. Geological factors are usually not considered as precipitators of road failure even though the highway pavement is founded on the geology. The proper design of highway requires adequate knowledge of subsurface conditions beneath the highway route. Previous studies have revealed that the integrity of the highway pavement can be undermined by the existence of geological features and/or engineering characteristics of the underlying geologic/geoelectric sequences [10,11]. Field observations and laboratory experiments carried out by Ajayi [9] showed that road failures can arise from inadequate knowledge of the geotechnical characteristics and behaviour of residual soils on which the roads are built and non-recognition of the influence of geology and geomorphology during the design and construction phases.It is crucial to develop a sub-grade with a California Bearing Ratio (CBR) value of at least 10 [12]. Islam [13] reported that if a sub-grade has a CBR value less than 10, the sub-base material will deflect under traffic loadings in the same manner as the sub-grade and cause pavement deterioration. The stability and durability of pavement depends on the traffic load or intensity and the strength of pavement layers [14]. Pavement failure is certain to occur if the pavement is not perfectly designed with the present traffic condition being considered. If it is designed without considering incremental traffic in the near future, the pavement life will be successively reduced. A flexible pavement surface reflects the entire behaviour of the sub grade layer, it thereby, emphasises more attention on making the soil sub-grade of superior soil properties. In previous research, road failure occurred due to the following reasons: Inadequacies in pavement structural design [15,16], poor sub-grade soil properties [17], insufficient pavement drainage [18] and effect of seasonal fluctuations of temperature over base course aggregates [19] and poor visco-elastic properties of asphalt binder [20]. Adewoye et al. [21] observed that the flexible highway failures along the Oyo-Ogbomoso road, which manifested as waviness/corrugation rutting and potholes were due to environmental factors such as poor drainage, lack of maintenance and misuse of the highway pavement. It was also noted that runoff due to precipitation, largely found its way into the pavement structure damaging them in the process. A road is usually divided into different parts namely: pavement, base, sub-base and sub-grade. Sub-grade is the soil foundation which directly receives the traffic loads from the pavement and a satisfactory subgrade resists the effects of both traffic load and weather.

The aim of this research is to examine the effect of rock fines on the geotechnical properties of sub-grade soil materials along failed portions of Akungba-Ikare road, South-western Nigeria in order to reassess their direct productive application as soil materials or the need for incorporating the stabilisation method to enhance their properties for flexible road construction.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The area of study, Akungba – Ikare road, is located in the northern part of Ondo state (Fig. 1). The area lies between latitude 07^0 27^1N and 07^0 31^1N and 05^0 43^1E and 05^0 47^1E of Greenwich Meridian (Fig. 2). It is moderately populated and is surrounded by settlement such as Ogbagi, Iwaro-Oka and Ugbe-Akoko [22]. The segment stretches over a distance of 112 m, with characteristics patterns of a distress, failure and stable pavement as haunchings, potholes, ruts and cracks. Field observations revealed the severe intense repair on the pavement structure on several occasions. The area occupies part of the northern half of East-West elongated lowland that is bounded in the north and south by basement ridges.The topography is relatively flat with a gentle slope running downward towards the south into the river valley on to the road. The failed segment is located on the lowland area while the stable segment extends upland with an elevation between 350 and 365 m above sea level respectively. Akungba – Ikare road which is the study area is located within the tropical climate region of Nigeria with the amount of annual rainfall ranging between 1000 – 1500 mm

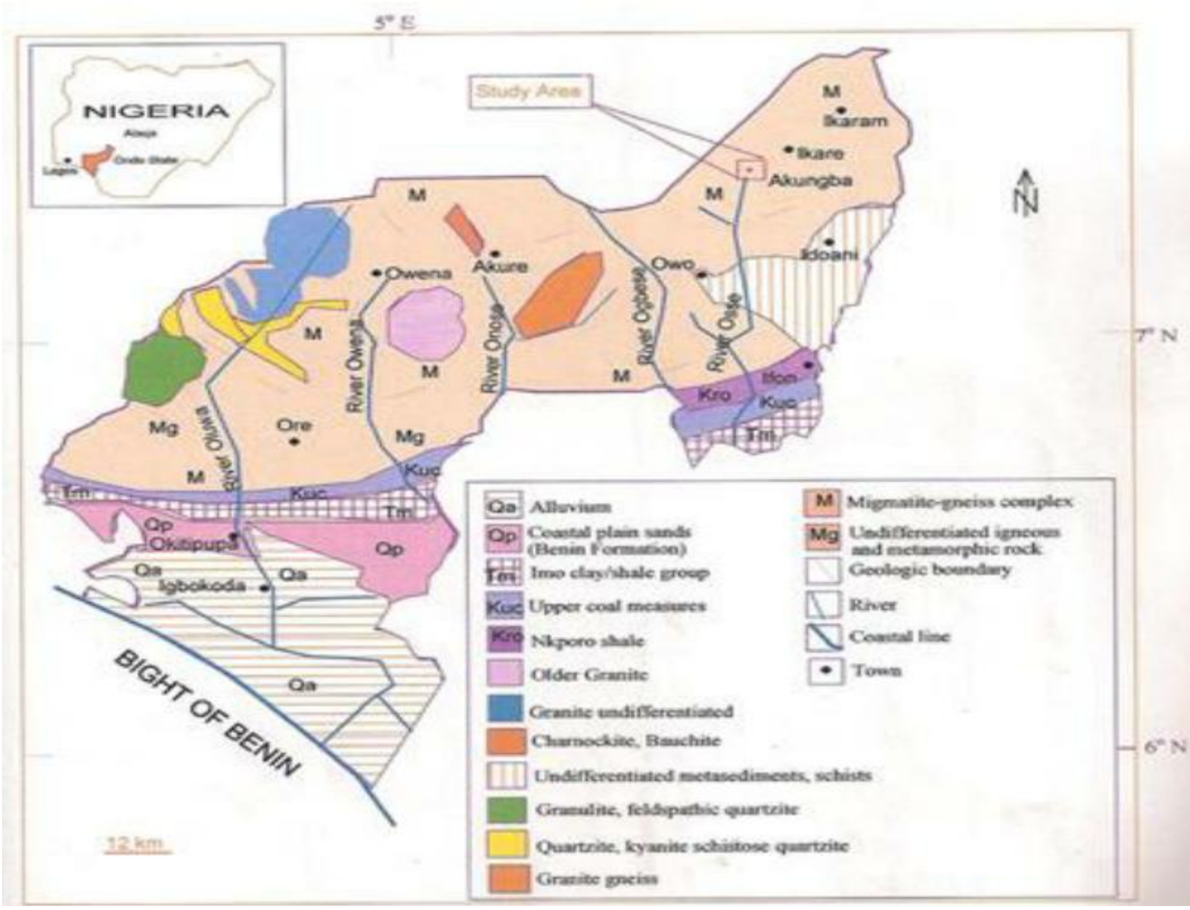

Fig. 1. Map of Nigeria showing Ondo State and the study area

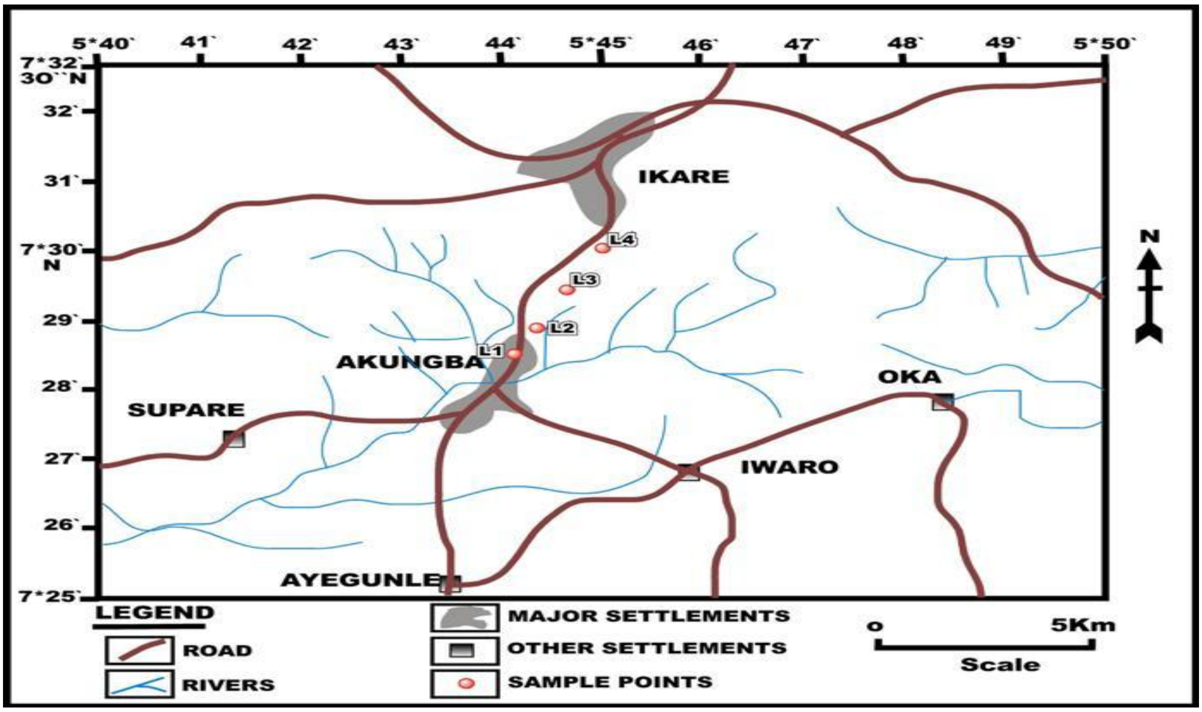

Fig. 2. Map of the study area showing sample locations

with about four months of dry season [22]. The rainy season is usually experienced between April and October, and the dry season between October and March. The mean annual temperature of the study area ranges between 270ºC and 360ºC while the relative humidity is about 37% from November to March and about 90% around August. Generally, the vegetation is characterised by woody shrubs, oil palms, most semi-deciduous trees and well developed herbaceous plants and the dominant soil in the area is humus/clayey soil. The study area is characterised by dendritic drainage pattern and it is underlain by granite gneiss which constitutes part of the migmatite-gneiss-quartzite complex of the basement complex of south-western Nigeria (Fig. 2). The rock type is grey colour, varying in grain size between 2 and 3.5mm and is marked by inconsistent streak. The dominant minerals present are quartz and feldspar, while ferromagnesian minerals, mainly biotite are present in lesser amount. However, flat lying outcrops of the basement rocks occur in several places around the site [22].

2.2 Field Sampling

The method adopted in this project involves reconnaissance survey of the road to determine the failed sections. The samples of subgrade were collected at the edge of the shoulder of the road and dug out using digger and shovel from depth 1200 mm below the asphaltic surface. They were suitably packed into sacks and labelled in such a manner that each material can be identified distinctly. They were transported to the laboratory where the natural moisture content of the soils were determined immediately. The soil samples were then air-dried for about three weeks before carrying out Atterberg limit, grain size analysis, specific gravity, compaction and California Bearing Ratio, these were carried out in accordance with BS 1377 (4).

2.3 Stabilisation of Soils

After the engineering tests and analysis of the soil samples were carried out, further detailed tests were conducted on the soil samples with varying percentages of rock fines as the stabilising agent. A rock fine collected from a stone crush company located at Supare-Akoko was used. Due to the fine nature of the rock fines, no analysis was done on it. This was introduced directly to the soils in percentages of 2, 4, 6, 8 and 10% in order to characterise the effects of the rock fines on the engineering properties of the soil.

3. RESULTS AND DISCUSSION

3.1 Natural Moisture Content

The natural moisture contents of the soils are 16%, 9%, 7% and 26% for locations 1, 2, 3 and 4 respectively. The natural moisture content is required to provide information on the moisture conditions of the soil in the field. This provides useful method for classifying the cohesive soils. The strength, as well as the state of consistency of a soil, can be inferred by relating its moisture content to its index properties [23]. All the samples have low moisture content in their natural states indicating that the soils have moderate percentage of clay. This suggests that there is no interaction of sub grade and sub base soils with water from numerous fractures in the basement rock which increases the wet-ability of the soils. This condition is expected to greatly increase the shear strengths of soil and therefore no incessant failure of the overlying pavements.

3.2 Grain Size Analysis

The results obtained for grain size analysis are shown in Fig. 3. The % finer passing 425μm sieve range between 33 and 51. These values show that the samples are not suitable as sub-grade materials because their values are higher than the standard specifications [23].

3.3 Atterberg Limits

The Atterberg limits are the basic measure of the water contents of a fine-grained soil: its shrinkage limit, plastic limit and liquid limit. Depending on its water content, a soil may appear in one of four states: solid, semi-solid, plastic and liquid. The results of liquid limit (LL), plastic limit (PL) and plasticity index (PI) are presented in Table 1. The liquid limit ranges from 0.0% - 45.9%. Locations 3 and 4 did not flow and did not roll; hence, having liquid and plastic limits values of 0.0% each.The liquid limits of locations 1 and 2 are all above 35% while their plastic limits are all below 30%. They fall below the acceptable requirements for soil sample that can be used as subgrade or fill during construction of highway in Nigeria [24,25,26,27]. Therefore the failures may be due to infiltration of water into the subgrade layer. But for locations 3 and 4, which even after adding the different percentages of rock flour to serve as stabilisation material still had no liquid nor plastic limit values are to be worked upon. They are non-plastic, hence they fall within the range of cohesion less soil, which will cause problem during compaction therefore resulting in road failure.

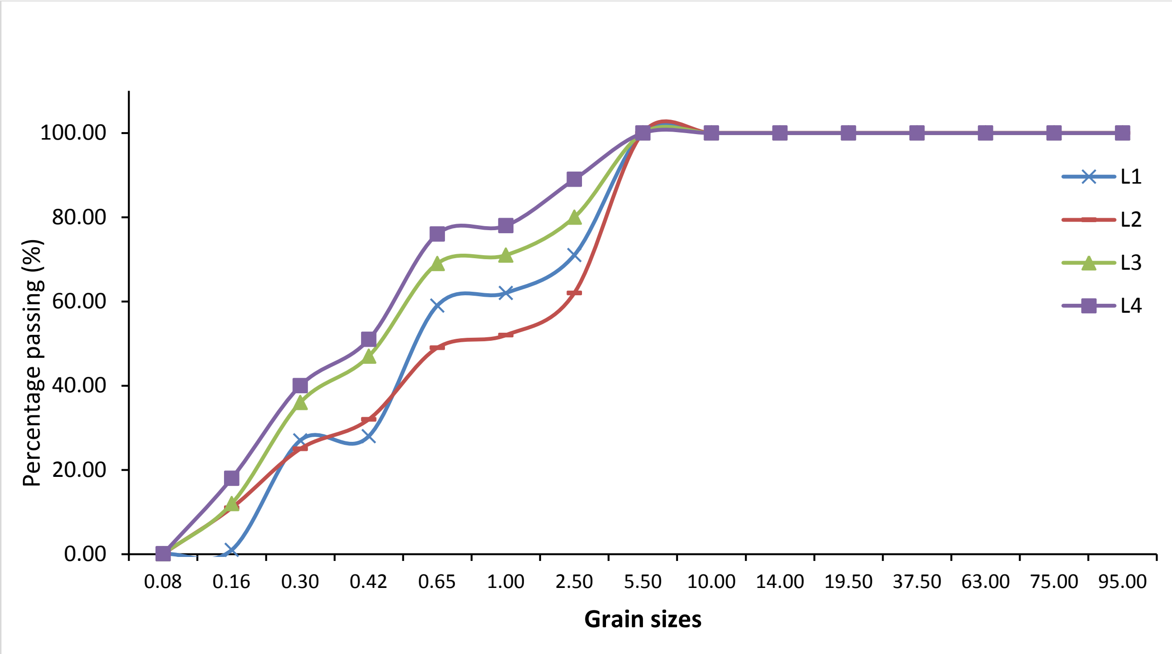

Fig. 3. Graph showing grain size analysis

Table 1. Summary of liquid limit, plastic limit, plasticity index and shrinkage limit

Sample	**Liquid limit** (%)	**Plastic limit** (%)	**Plasticity index** (%)
L1 0% rock flour	46.4	28.6	17.83
L1 2% rock flour	38.9	28.6	10.33
L1 4% rock flour	43.0	24.7	18.3
L1 6% rock flour	44.6	21.7	22.86
L1 8% rock flour	41.4	9.8	31.61
L1 10% rock flour	41.7	21.7	19.96
L2 0% rock flour	47.8	21.1	26.75
L2 2% rock flour	44.8	26.7	18.13
L2 4% rock flour	45.9	30.8	15.13
L2 6% rock flour	45.1	40.0	5.10
L2 8% rock flour	43.9	15.0	28.90
L2 10% rock flour	45.5	22.2	23.28
L3 0% rock flour	0.0	NP	NP
L3 2% rock flour	0.0	NP	NP
L3 4% rock flour	0.0	NP	NP
L3 6% rock flour	0.0	NP	NP
L3 8% rock flour	0.0	NP	NP
L3 10% rock flour	0.0	NP	NP
L4 0% rock flour	0.0	NP	NP
L4 2% rock flour	0.0	NP	NP
L4 4% rock flour	0.0	NP	NP
L4 6% rock flour	0.0	NP	NP
L4 8% rock flour	0.0	NP	NP
L4 10% rock flour	0.0	NP	NP

NP – Non Plastic

3.4 Specific Gravity

The specific gravity is a very useful index in the identification and evaluation of laterite aggregates for pavement construction. An increase in specific gravity has been found to be associated with a decrease in void ratio [28]. The specific gravity values of the tested soils range from 2.58 to 2.73, the values for each sample are average of their determinations. Generally, the specific gravity of the samples fall within the reported specific gravity for lateritic soils (2.50 to 4.60) in accordance with the standard reported by Gidigasu [29]. The results obtained for the different locations are shown in Table 2.

3.5 Compaction Test

The result of the maximum dry densities (MDD) and optimum moisture content (OMC) for the subgrade samples are presented in Table 3. The MDD and OMC ranged from 1496 kg/m^3 to 1982 kg/m^3 and 4.70 to 11.70% respectively. The instability of the locations must have been as a result of lack of drainage system which eventually resulted into road failure.

3.6 California Bearing Ratio (CBR) Test

The result of California bearing ratio (CBR) test is presented in Table 3. The CBR values for the samples range between 0 to 5%. These values are generally less than 10% recommended for highway sub-grade soils by the Federal Ministry of Works. The soils yielded fair to poor CBR values. Such low values are not likely to provide a stable compacted sub-grade material. This deficiency could be attributed to high amount of clay present in the soil, ingress of water with a poor drainage and poor laterisation of the soil used. Therefore, in terms of strength, the soils samples are not suitable as subgrade materials because their CBR values fall below

Table 2. Results of specific gravity and grain size analysis

Sample	Specific gravity	425µm excess fines (%)
L1	2.73	38
L2	2.58	33
L3	2.62	47
L4	2.64	51

Table 3. Compaction test: (OMC AND MDD) and CBR values

Sample	OMC (%)	MDD (kg/m^3)	CBR (Unsoaked)
L1 0% rock flour	6.5	1900	3
L1 2% rock flour	12.8	1660	4
L1 4% rock flour	6.3	1528	5
L1 6% rock flour	6.1	1650	5
L1 8% rock flour	5.0	1650	5
L1 10% rock flour	5.7	1650	5
L2 0% rock flour	7.7	1497	4
L2 2% rock flour	6.5	1545	5
L2 4% rock flour	7.6	1523	4
L2 6% rock flour	6.4	1537	4
L2 8% rock flour	6.6	1531	2
L2 10% rock flour	6.0	1590	1
L3 0% rock flour	5.7	1918	2
L3 2% rock flour	6.3	1887	4
L3 4% rock flour	5.4	1924	4
L3 6% rock flour	4.7	1912	5
L3 8% rock flour	4.7	1929	5
L3 10% rock flour	6.0	1887	3
L4 0% rock flour	7.8	1954	2
L4 2% rock flour	10.2	1982	1
L4 4% rock flour	9.1	1969	1
L4 6% rock flour	9.6	1960	0
L4 8% rock flour	11.7	1923	0
L4 10% rock flour	9.9	1946	1

the standard [23,30,31,32]. This must have been as a result of lack of drainage system on Akungba-Ikare.

4. CONCLUSION

From the field observations and various laboratory tests carried out on the soil samples collected from the failed sections of the road, the following conclusions were made:

i) Lack of provision of the drainage system on the highway leads to the reduction in the strength character of the soil as a result of ingress of water. The values of natural moisture contents of this failed road indicating that the load bearing capacity of the soils increase rapidly as the moisture content values are lower than the plastic limit values. The higher liquid limit values obtained for most of the soils may have contributed to the failure of those sections as liquid limit correlates to the compressibility of soils.
ii) The linear shrinkage of most of the soils are greater than 8%, this indicates that there will likely be shrinkage problem; most of the samples have linear shrinkage values greater than 10%, hence will pose field compaction problem which might have also contributed to the failure of the sections of the road.
iii) The maximum dry density values of the soil samples classify them as poor highway foundation materials. This poor compaction character can also result in the failure of the sections of the road pavement.
iv) Despite the addition of the stabilisation material in different percentages of 0, 2, 4, 6, 8 and 10 to the soil samples, the CBR values obtained still fall below standard. This is likely to be caused by the poor laterisation of the soil used
v) Sequel to the above findings and conclusion, it is recommended that all the materials used for road construction should conform to specification. State and Local Government should have a maintenance agency to embark on routine, periodic and emergency maintenance; this will also prevent the road from deteriorating before their design life.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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