GEOTECHNICAL INFLUENCE OF UNDERLYING SOILS TO PAVEMENT FAILURE IN SOUTHWESTERN PART OF NIGERIA

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ABSTRACT

Roads in Nigeria are usually constructed without in-depth knowledge of the subsoil that serves as the foundation for the road elements. Road failures are often associated to poor construction materials or inadequate design without cognisance of the underlying soils. Engineering properties of ten bulk soil samples collected from the subgrade of Arigidi/Oke-Agbe highway were investigated to determine their suitability for highway pavement. Results show that all the subgrade soils below the failed locations have higher plasticity indices, which is an indication of their high swelling potential, and they are classified as A-7-6 clayey soils with high-water adsorption capability (16.1 – 22.4%) compared to subgrade soils from the stable locations. Low compacted density (1325 – 1928 Kg/m^3), extremely poor CBR values; 8 – 31% (unsoaked) and 3 – 8% (soaked) which indicate percentage reduction in strength of the soils up to 77% on exposure to excessive moisture and the predominance of fines (> 59%) in the soils are responsible for the degree of instability. Furthermore, soft to low stiffness (49 – 131 kN/m^2) and poor permeability of the subgrade materials underlying the pavement result to the failure characteristics witnessed. This study shows that the suitability and behaviour of subgrade soil is dependent on its engineering properties.

Keywords: *Engineering properties; Failure characteristics; Permeability; Strength; Subgrade*

INTRODUCTION

The abundance and widespread presence of soil makes it an important construction material. Unless placed on rock, most land-based engineering works founded on soil must have strong foundation to support the weight of the structure. Ademila (2015) revealed that thorough and detailed geophysical/geotechnical investigation acts as a necessary task needed to be carried out before constructing any engineering structure as it guarantees post construction stability. The suitability of a soil for a particular use depends on its response to that use. So, utilization of soils needs adequate knowledge of their properties and factors affecting their behaviour and performance. This is encouraged to constitute a precondition for its use in civil engineering construction works. Road network plays a vital role in socio-economic development of many nations. Nigeria is among the countries with the highest records of road accidents with continuous loss of lives and properties due to bad roads. One cannot drive through one kilometer along a single road or highway in Nigeria without encountering a failed section. Since, the design and construction of a road are finalized without assessing the geology and geotechnical behaviour of the underlying soils. The relationship between highway pavements and their foundation soils cannot be overemphasized in any nation that desires to develop.

Performance of highway pavement mostly the flexible one depends on the functions of the component layers especially subgrade. Subgrade is compacted layer of soil which provides lateral support to the pavement. Construction over weak/soft subgrade affects the performance of pavement and results in instability of pavement. Failures on Nigeria highways are generally due to poor geotechnical properties of the underlying soils which constitute the entire road pavement. Adeyemi (1995) also emphasized the role of parent rock factor on index and moisture-density relationship of subgrade soils developed over certain Precambrian parent rocks of Southwestern Nigeria. A review of the factors influencing the performance of a pavement has been described by Adlinge and Gupta (2010) including the different types of road failure ranging from cracks, potholes to road-cut leading to differential heave of the pavement material causing frequent bumps on the highways. Lack of adequate knowledge of the behaviour of soils and application of geotechnical parameters of soil have resulted in wrong design and wasteful construction of many of our roads. However, no investigative work on the geotechnical properties of the soils of the area has been reported in the literature to predict the stability of the flexible highway pavement. Ademila (2017) recommended that proper documentation of engineering evaluation of soils is essential for pavement design and construction of roads. Accordingly, the area was chosen because of the negligence on the side of the government, designers and constructors of the road which, after some reconstruction and rehabilitation works the failures still persist. This paper discusses the geotechnical properties of ten samples obtained along the failed road and compared with standard values. With the believe that the more the geotechnical data that are available on the subgrade layer the better, as this can lead to more effective understanding of their engineering performance.

LITERATURE REVIEW

Description and Geological Setting of the Study Area

Arigidi/Oke-Agbe highway is a road that links Abuja (Federal Capital City) and other parts of Southwestern Nigeria. It is within the North Senatorial district of Ondo State, Nigeria (Fig. 1). It lies within latitudes 7° 34’ N and 7°40’ N and longitudes 5° 47’ E and 5° 54’ E (Fig. 1). It covers an area extent of about 16 Km^2. It is situated in the humid tropical region of Nigeria, characterised by alternating wet and dry seasons with a mean annual rainfall of over 1500 mm (Fig. 2). The area is majorly drained by River Auga and other streams which are seasonal. The river dominates the drainage system of the study area, and it’s mainly dendritic. The area is moderate to highly undulating with an average surface elevation of about 371m.

Geologically, the area falls within the Precambrian Basement Complex rocks of southwestern Nigeria. Rocks of the region include the migmatite-gneiss-quartzite complex that is characterised by granite and granite gneiss (Fig. 3) with a minor amount of grey gneiss, charnockite and quartzite. Granite gneiss is the metamorphosed granites, widely distributed in the study area and it is of two types; the biotite-rich gneiss and the banded-gneiss. The biotite-rich gneiss is fine to medium grained and shows strong foliation trending westwards. The banded-gneiss occurs mostly as hills, boulders and low lying exposures which are dark to light grey in colour and porphyroblastic in texture.

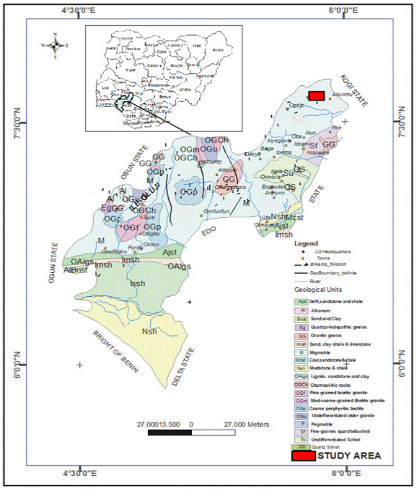


Figure 1: Geological map of Ondo State showing the study area

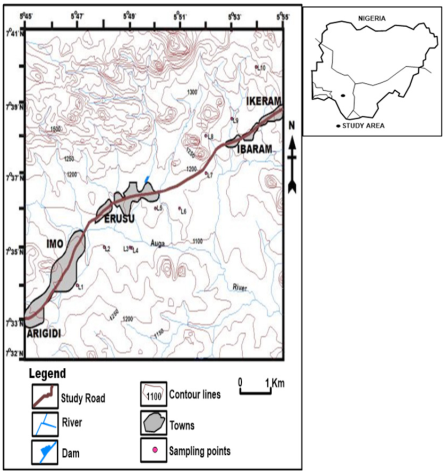


Figure 2: Topographical map of the part of Southwestern Nigeria showing the study road and sampling locations.

Grey gneiss in the study area varies from light to dark grey. There are different textural varieties, but the most common type is the medium-grained rock with regular and persistent banding of varying thickness. The gneissic rocks occur as highly weathered and low-lying outcrop. The granite rocks are of the older granite suite. Based on the textural characteristics, there are fine-grained biotite granite, medium to coarse porphyritic biotite-hornblende granite. In this studybarea migmatite gneiss is the dominant rock unit.

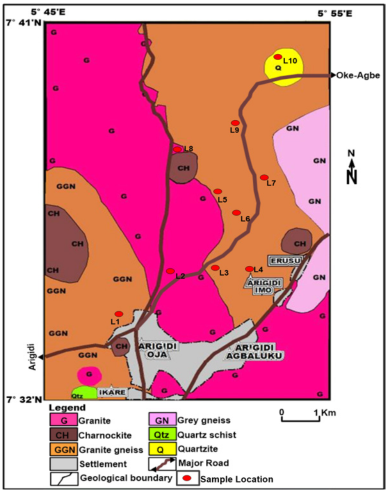


Figure 3: Geological Map of the part of Southwestern Nigeria showing the study road

MATERIALS AND METHODS

This research includes detailed geological field mapping to ascertain the local geology of the area and identity failed and stable sections of the studied road. On the field, the rock and soil exposures were observed and described. Ten bulk soil samples from the subgrade were collected from ten different locations along the road. Eight samples from eight failed sections and two samples from two stable sections of the road were obtained at sampling depths of 1 m in order to obtain true representative samples of the sub-grade which is the placement level of flexible highway pavement. The sample collection was done systematically to ensure proper collection of samples and total coverage of the study area. A global positioning system (GPS) was used at each sampling point to measure coordinates of the station and heights above sea level. All the soil samples were carefully labelled in sample bags and then taken to the laboratory in sealed polythene bags to prevent contamination and loss of moisture. The natural moisture content was determined immediately in the laboratory. Soil samples were air dried for two weeks to allow partial removal of natural water before other analysis. After the drying, lumps in the samples were gently grounded with minimal pressure as not to reduce the sizes of the individual particles. The following laboratory tests were conducted on the samples: natural moisture content, specific gravity, consistency limits, linear shrinkage, grain size distribution, compaction, California bearing ratio (CBR) and unconfined compressive strength. These laboratory analyses were carried out according to British Standard Methods of test for soils for civil engineering purposes (BS 1377:1990) and ASTM Standard D1557 (2009). Samples for grain size analysis were soaked in a weak Calgon solution to facilitate disaggregation during wet sieving. The compaction test was conducted on soil samples that were compacted in three layers in a CBR mould each 25 mm thick and appllied 56 number of blows of 4.5 kg rammer falling freely through a height of 450 mm. The CBR test was carried out with a mould of capacity 945×10^{-6} m^3 at optimum moisture content and 96 hours of soaking period which simulated the prolonged inundation and submergence encountered during the peak of rainy season between July and October.

RESULTS AND DISCUSSIONS

Satisfactory pavement performance is attributed to a good foundation that provides adequate strength and low compressibility. This pavement performance is dependent upon the index and engineering properties of the underlying subgrade layer that serves as the foundation of pavement structure to distribute loads uniformly.

Index Properties

The results of the index tests carried out on the soil samples are summarised in Table 1.

Natural Moisture Content

Moisture and movement of water are the determining factors in the potential subgrade condition . This is becausse they influence the design and construction of highway pavement structure. It is used as an indicator of groundwater level of the area. Although natural moisture content is not a constant property of soils, these values are consistent with the fines of the soils. The high moisture content obtained conform to the accepted high porosity and low permeability properties of the soils. However, the natural moisture content of the analysed soil samples from the failed sections of the road varied from 16.1 – 22.4% (Table 1) while, those from the stable sections varied from 8.0 – 8.8%. This shows that soils from the failed sections have high natural moisture, because these values are higher than the average range (5 – 15%) specified by FMWH (2000) for engineering construction. This high moisture is an indication of a high water adsorption capability of the soil material.

Specific Gravity

The specific gravity (SG) of the samples varied from 2.64 – 2.75 (Table 1). All the soil samples met the specific gravity standard (≥ 2.6). The results showed that the soil samples contained sodium and calcium feldspar (2.62 – 2.76) in nature (Das, 2000). By this specific gravity, the studied soils can be categorised as inorganic soils (Ramamurthy and Sitharam, 2005).

Consistency Limits

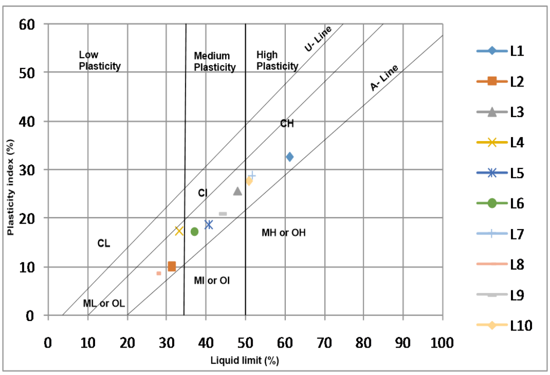
Atterberg limit tests are tests required to determine the limits of water contents of soil corresponding to the transition from one state to another. It is useful for the suitability of soils for highway construction. The results of the liquid limit, plastic limit, plasticity index and linear shrinkage tests were summarised in Table 1. The liquid limit, plastic limit and plasticity index of the soils from the failed sections ranged from 37 – 61%, 20 – 29% and 17 – 33% respectively while those from stable portions ranged from 28 – 31%, 19 – 21% and 9 – 10% respectively. According to Whitlow (1995), liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate, between 50% and 70% high plasticity and between 70% and 90% very high plasticity. By this classification, the soils of the stable portions have low plasticity, while soils from the failed sections have moderate to high plasticity characteristics. Thereby causing significant deformation under load. The Casagrande chart classification (Fig. 4) also places the soils of the failed sections in the medium and high plasticity/compressibility region. The plots on the plasticity classification chart revealed that the soils mostly fall above the A-line, indicating that they composed of inorganic materials with low-medium-high plasticity. The degree of scattering on the plasticity chart reflects the degree of variability of the soils, particularly in clay types and percentage content of fines. Results from the modified plasticity classification chart also revealed three clay minerals. These include montmorillonite, illite and kaolinite. The presence of montmorillonite in the soils is detrimental to the stability of engineering structures. However, the Federal Ministry of Works and Housing (2000) specified a maximum liquid limit of 40% and a maximum plasticity index of 20% for the applied highway subgrade material. The results showed that the soils from the failed sections are not suitable subgrade material for the foundation of pavement structures because of their poor geotechnical properties. Plasticity index tends to have influence on the activity of the subgrade. The plasticity index of failed sections is higher than 12% and hence, it is not suitable for use as subgrade and practically subbase materials for roads and bridges as specified by FMWH (2000). The high plasticity indices of the samples ascribed to their high proportion of clay content (40 - 63.2%), which is an indication of their high swelling potential.

The linear shrinkage of the soils from the failed sections varied from 9.2 – 20.0%. The value is higher than the maximum 8% recommended by Madedor (1983), based on this consideration, the soils have a significant ability to swell and shrink during alternate dry and wet seasons of the humid tropical climatic condition of southwestern Nigeria. Hence, they are unsuitable as highway subgrade material. These properties of the soils must be taken into cognisance by the engineers in the design of the foundation of pavement structures. The linear shrinkage of the soil from the stable sections varied from 5.7 – 8.3%, which is within the recommended value for subsoil material that is good for road construction as foundation material. The soil mixtures from the failed sections are made up of clay with higher plasticity index and linear shrinkage values. They are expected to create field compaction problem because of their high linear shrinkage. The lower the linear shrinkage, the lesser the tendency for the soil to shrink when dried (Jegede, 1999). From these results alone, the soils from the failed sections have proved their total unsuitability as fill or subgrade materials in their natural state. Therefore, some modification through stabilisation would be necessary to achieve the desired specifications.

Table 1: Index properties of the soils of the study area

Road condition	Pit No.	Moisture content (%)	SG (Gs)	Consistency limits				Soil type
				Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)	
Failed	L1	22.4	2.74	61.2	28.6	32.65	19.3	Clayey
Stable	L2	8.0	2.69	31.3	21.3	10.00	5.7	Silty of clayey gravel sand
Failed	L3	16.1	2.75	48.1	22.4	25.70	20.0	Clayey
Failed	L4	18.2	2.68	33.5	21.3	17.20	9.2	Clayey
Failed	L5	17.8	2.65	40.9	22.4	18.50	9.9	Clayey
Failed	L6	19.6	2.64	37.0	19.6	17.40	11.0	Clayey
Failed	L7	16.3	2.72	51.8	23.1	28.75	10.0	Clayey
Stable	L8	8.8	2.64	27.7	19.1	8.65	7.8	Silty of clayey gravel sand
Failed	L9	21.3	2.72	44.2	23.2	20.95	10.0	Clayey
Failed	L10	17.1	2.73	50.8	23.1	27.70	10.7	Clayey

Figure 4: Casagrande chart classification of the soil samples



Grain Size Distribution

The results of the grain size distribution are summarized in Table 2. The soils from failed sections have percentage passing No. 200 (0.075 mm) ranged from 58.5 – 80.2%, while those of stable sections ranged from 21.3 – 29.2%. It can be observed that the soils from failed sections have high proportion of fines (> 59%) This indicates that the soils have the tendency to shrink and swell repeatedly during alternate dry and wet seasons of the humid tropical climatic condition of the southwestern Nigeria. Thereby causing distress which later foundn noticeable on the road. Failures observed in the study area are believed to be caused by pressures developed by the swelling soils. Also, the high clay content of the soils from the failed sections (40.8 – 63.2%) is an indication of their high swelling potential, hence unsuitable for subgrade material. The tested soils of the stable sections (L2 and L8) have percentage passing 0.075 mm of less than 35%, with less amount of clay (14.7%), and fall under group A-2-4 of American Association of State Highways and Transport Officials (AASHTO) classification that is rated as good subgrade highway material (FMWH, 2000). The soils of the failed sections fall under group A-7-6 of AASHTO classification (Table 2) suggests poor highway subgrade materials being clayey soil type (Table 1). Subsequently, the dominance of fines in the subgrade materials of the failed sections of the road is one of the factors that has caused for the degree of instability witnessed of the road condition.

Table 2: Grain size distribution parameters

Road condition	Pit No.	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Amount of fines (%)	AASHTO Classification
Failed	L1	0	19.8	17.0	63.2	80.2	A-7-6
Stable	L2	1.3	69.5	14.5	14.7	29.2	A-2-4
Failed	L3	1.2	40.3	17.4	41.1	58.5	A-7-6
Failed	L4	1.0	33.1	14.9	51.0	65.9	A-7-6
Failed	L5	1.0	36.1	17.3	45.6	62.9	A-7-6
Failed	L6	1.3	34.1	16.3	48.3	64.6	A-6
Failed	L7	1.0	35.1	17.1	46.8	63.9	A-7-6
Stable	L8	5.4	73.3	9.2	12.1	21.3	A-2-4
Failed	L9	1.0	40.2	18.0	40.8	58.8	A-7-6
Failed	L10	1.0	38.6	17.2	43.2	60.4	A-7-6

Compaction Characteristics

Subgrade is generally made up of locally available natural soils. The strength and performance of a pavement is dependent on the load bearing capacity of the subgrade soil. Design of pavement also depends upon the strength of the subgrade soil, which affects the thickness of pavement. In addition, compaction reduces the detrimental effects of water. Lower optimum moisture content is expected to achieve maximum dry density for stability of soil under field conditions. The maximum dry density and optimum moisture content of the soils at standard proctor compaction energy are shown in Table 3. Dry density is an important parameter that affects soil reaction to stress. The maximum dry density (MDD) of the soils from failed sections of the highway ranged from 1325 – 1928 Kg/m^3 at optimum moisture content (OMC) of 15.3 – 32.7%, while those from stable sections ranged from 1960 – 1995 Kg/m^3 (MDD) at 13.4 – 14.4% (OMC) (Table 3). This low range in density with high moisture content of the soils from failed sections indicates low strength with wetness. The absence of drainage observed in the study area correlates with the high moisture content given the low permeability and high porosity characteristics of the soil types. However, the best soil for foundation is the soil with high maximum dry density (MDD) at low optimum moisture content (OMC) (Jegede, 1999).

The essence of compaction is to improve the desirable load bearing capacity of pavement structures. Failure of civil engineering structures and road pavements increase when the underlying soils are always soaked with water. The results showed that the compacted densities were very low. So, the subgrade must always be compacted above the MDD and OMC to yield maximum strength, prevent ingress of water and distribute wheel loads uniformly into the pavement structures. Removal and replacement of the subgrade materials or soil stabilisation/modification are necessary because that would improve the pavement strength and its performance.

California Bearing Ratio (CBR)

California bearing ratio is a semi-empirical test which is used to evaluate highway subgrade/subbase soils. The soaked CBR test is also used in simulation of the condition that soils are exposed to in-situ upon ingress of water. It is the resistance a soil possesses when it experiences stressed or under load. The values of unsoaked and soaked CBR of the soils from the failed sections ranged from 8 – 31% and 3 – 8% respectively. It shows reduction in strength up to 77% with wetness (Table 3). The soaked CBR showed that subgrade soils at failed sections are susceptible to volume change on exposure to excessive moisture. It was observed that unsoaked (32 – 37) and soaked (10 – 11) CBR values of samples from stable sections are higher than those from failed sections. The soaked CBR values obtained showed that subgrade soils of the failed sections are liable to critical changes in strength and load bearing capacity as a result of inundation. The CBR values of the study area are generally low indicating low strength of the soil. As a result, the subgrade soils become prone to erosion on exposure to surface runoff. Soil improvement measures would be necessary for stable structures. The minimum CBR requirements for subgrade, subbase and base courses are 10% (soaked), 30% (soaked) and 80% (unsoaked) respectively

(FMWH, 2000). However, none of the analyzed samples have the required 30% soaked and 80% minimum unsoaked CBR value that is recommended for highway sub-base and base course. All the soil samples taken from stable sections are within the specification of 10% minimum soaked CBR value for subgrade, which means they are adequate as subgrade material. The tested soils of the failed sections yielded extremely poor CBR values, both in the unsoaked and soaked types. From these results, it can derived that the soils are unsuitable to be used as fill or subgrade materials in their natural state.

Unconfined Compressive Strength (UCS)

Unconfined Compressive Strength (UCS) is an unconsolidated-undrained test which is used for clay specimens where the confining pressure (σ_3) is zero (0) and the major principal stress (σ_1) is the unconfined compressive strength (qu). Consistency of a soil can be expressed not only in terms of Atterberg limits but also in terms of unconfined compressive strengths of soils which in turn determines the strength of the soil. An understanding of the compressive behaviour is essential for geological and geotechnical engineering purposes and is the core basis for modeling the stress-strain relationships of soils (Liu et al., 2013). Its value indicates that is a measure of suitability such as soil as a foundation material. Table 3 shows the summary of unconfined compressive test results. According to Das, (2000), consistency of a clayey soil can be as follows; between 0-25 kN/m^2 indicates very soft, between 25-50 kN/m^2 indicates soft, between 50-100 kN/m^2 indicates medium, between 100-200 kN/m^2 indicates stiff, 200-400 kN/m^2 indicates very stiff and greater than 400 kN/m^2 indicates hard clay. On this note, consistency of soil samples from failed sections is soft, medium and low stiff (49 – 131 kN/m^2) while that of stable sections remained stiff (Table 3).

Table 3: Strength properties of the soils of the study area

Road condition	Pit No.	Compaction characteristics		California bearing ratio, CBR (%)		Percentage reduction in strength (%)	Unconfined compressive strength (kN/m^2)
		MDD (Kg/m^3)	OMC (%)	Unsoaked CBR (%)	Soaked CBR (%)		
Failed	L1	1325	32.7	8	3	62.50	48.72
Stable	L2	1960	14.4	32	10	68.75	149.92
Failed	L3	1606	24.6	16	4	75.00	89.14
Failed	L4	1890	16.4	31	8	74.19	123.03
Failed	L5	1854	17.4	28	7	75.00	98.15

Failed	L6	1928	15.3	31	8	74.19	131.76
Failed	L7	1529	26.8	13	3	76.92	71.44
Stable	L8	1995	13.4	37	11	70.27	165.11
Failed	L9	1581	25.3	17	6	64.71	78.07
Failed	L10	1546	26.3	14	6	57.14	75.29

Soft and low stiffness of the poor subgrade materials underlying the pavement may result on the failure characteristics witnessed. This initial consistency can be upgraded/modified by means of soil stabilisation.

Permeability Characteristics

The permeability characteristic of a soil is an important parameter. In it used for evaluation in engineering structures. According to Siddique and Safiullah (1995), permeability governs important engineering problems like consolidation of clay foundation under applied load and the flow of water through or around engineering structures. The coefficients of permeability of the soils from failed sections ranged from 3.11×10^{-8} cm/sec to 1.39×10^{-5} cm/sec while that of stable sections ranged from 4.00×10^{-5} cm/sec to 2.40×10^{-4} cm/sec (Table 4). Based on the classification made by Lambe (1954), the permeability of 10^{-5} cm/sec to less than 10^{-7} cm/sec indicates a very low to practically impermeable soil. The results showed that the drainage conditions of soils beneath the failed sections are generally poor to practically impervious, while the soils of the stable sections are good in poor drainage conditions. However, due to the poor permeability of these soils, water is retained within the soil matrix, resulting in weaker strength and lower bearing capacity. There is a good correlation with the results of the soaked CBR with significant reduction in strength up to 77% in the presence of excessive moisture influx. From this result, it can be deduced that adequate drainage is highly important in the area to prevent ingress of water beneath the pavement. This could lead to the significant reduction in strength of the subgrade soils and thus failure of the pavement.

In addition, this is observed on the road where soil of some sections of the road wear away dueto erosion that is caused by non provision of rainwater run-off. Thus, road designers and constructors need to put in place drainage channels on roads to ensure free flow of water throughout the seasons. Improvement in pavement design should include detailed description of weather conditions especially temperature and rainfall, as changes in temperature also influence distress in this flexible highway. According to Burt (1969), high temperatures have an adverse effect on the structural properties of bituminous materials.

Table 4: Coefficients of permeability of the studied soils

Road condition	Pit No.	Permeability, k (cm/sec)
Failed	L1	3.11×10^{-8}
Stable	L2	4.00×10^{-5}
Failed	L3	3.02×10^{-7}
Failed	L4	8.92×10^{-6}
Failed	L5	2.07×10^{-6}
Failed	L6	1.39×10^{-5}
Failed	L7	2.23×10^{-7}
Stable	L8	2.40×10^{-4}
Failed	L9	4.46×10^{-7}
Failed	L10	3.26×10^{-7}

CONCLUSIONS

Engineering property tests of subgrades encountered in part of southwestern Nigeria showed that the soils of the failed sections fall under group A-7-6 of AASHTO classification, suggesting poor highway subgrade materials in this study is clay soil type. The dominance of fines is responsible for the degree of instability witnessed.

The natural moisture content of the analysed soil samples from the failed sections indicates a high water adsorption capability of the soil material. The Casagrande chart classification places the soils in the medium and high plasticity/compressibility region. The high plasticity indices of the samples of failed sections are attributing to their high proportion of clay content (40.8 - 63.2%), which is an indication of their high swelling potential. Low specific gravity and high water absorption capacity of the subgrade material are responsible for the failure of the flexible pavement. The soils exhibit high shrinkage and low strength properties (MDD, CBR and UCS), which is the main reason the flexible highway pavement constructed on these soils is relatively unstable. From the results, the soils showed the unsuitability to be used as fill or subgrade materials in their natural state. Furthermore, the permeability characteristics show poor to practically impervious drainage condition of the soils. The design reconstruction of the road should be on the engineering understanding of the underlying soil about the environmental conditions. Thus, the availability of drainage systems in the area is necessary to prevent pore water pressures to develop below pavement structures. Removal and replacement of the subgrade and subbase materials of the flexible pavement up to 1 m or soil stabilisation will improve the strength of stable structures. Results of this study will be useful in reconstruction works of the failed sections of the road and may guide future pavement design in the construction of roads. This study has proved that in-depth knowledge of the characteristics and behaviour of soils is necessary for design and construction of roads.

REFERENCES

Ademila, O. (2015). Integrated geophysical survey for post foundation studies in a typical Basement Complex of Southwestern Nigeria. The Pacific *Journal of Science and Technology. 16*(2):274-285.

Ademila, O. (2017), "*Engineering evaluation of lateritic soils of failed highway sections in Southwestern Nigeria*", Geosciences Research, 2(3), 210-218.

Adeyemi, G. O. (1995). The influence of parent rock factor on some engineering index properties of three residual laterised soils in southwestern Nigeria. *Bulletin of Association of Engineering Geologists, Paris, 52*:3-8.

Adlinge, S. S. and Gupta, A. K. (2010). Pavement deterioration and its causes. *Journal of Mechanical and Civil Engineering*, 9-15.

American Association of State Highways and Transportation Officials (AASHTO), Mil45. *Classification of soil and aggregate mixtures of highway for construction purpose, highway materials, 1*(1).

ASTM Standard D1557, (2009). *Standard test methods for laboratory compaction characteristics of soil using modified effort.* ASTM International West Conshohocken, PA. British Standard (BS) 1377, 1990. Methods of testing soils for civil engineering purposes. British Standards Institution, London.

Burt, M. E. (1969). *Research on pavement design. Road Research Laboratory,* Ministry of transport RRL, Report LR 243:1-20.

Das, B. M. (2000). *Fundamentals of geotechnical engineering*, 4th ed., USA: Thomson Learning USA. Frias M, and cement and concrete research.

Federal Ministry of Works and Housing (FMWH) (2000). *General specification for roads and bridges*, 2:137-275.

Jegede, G. (1999). Engineering geological significance of the superficial deposits in Carrington Hill area, Country Conc, Ireland. Nigeria *Journal of Sciences, 28:*153-158.

Lambe, T. W. (1954). *The permeability of fine-grained soils: Symposium on permeability of soils*. ASTM, Special Technical Publication, 163.

Liu, M. D., Xu, K. J., Horpibulsuk, S. (2013). A mathematic function for the s- shape relationship for geotechnical applications. Proceeding *ICE-Geotechnical Engineering, 166*(3):321-327.

Madedor, A. C. (1983). *Pavement design guidelines and practice for different geological area in Nigeria*. In: Ola S.A. (ed) Tropical soils of Nigeria in engineering practice. A.A. Balkema, Rotterdam, Netherland, 291-297.

Ramamurthy, T. N. and Sitharam, T. G. (2005). *Geotechnical engineering*. S. Chand, New Delhi, 28.

Siddique, A. and Safiullah, A. M. M. 1995. Permeability characteristics of reconstituted Dhaka clay. J*ournal of the Civil Engineering Division, the Institution of Engineers, Bangladesh, 23*(1):103-108.

Whitlow, R. 1995. *Basic soil mechanics,* 3rd ed., Edinburgh Gate, Addison Wesley Longman Limited.