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# PERMEABILITY AND GRAIN-SIZE CHARACTERISTICS OF SAGAMU AND IBADAN-TOLL-GATE LATERITIC SOILS IN SOUTHWESTERN NIGERIA

**[1]S. O. Idowu, [2]G. O. Adeyemi and [3]S. S. Dada**
*[1&3] Department of Earth-Sciences, Salem University, Lokoja, Nigeria.*
*[2]Department of Geology, University of Ibadan, Ibadan, Nigeria.*

## ABSTRACT
Permeability and grain-size tests were performed on three samples each from two locations to provide direct as well as indirect measures for highway failure. All samples tested show a significant degree of permeability with low volume of fines [average value of $\sim 51\%$] for soils developed over Ibadan basement complex, while those of Sagamu sandstone show a high proportion of fine materials of $\sim 89\%$ with low flow gradient rate [$\sim 1.5 \mathrm{mm/s}$]. Comparing these parameters with the values obtained from compacted soils, the grain sizes and gradient flow, the Sagamu samples show a significant increase in the proportion of fines, over that of Ibadan. Applying these data to highway geotechnics, the flexibility characteristics of low permeability terrains can be checked provided fluid flow especially out of the sediments is not impeded and can therefore solve susceptibility of shear failure.
**Keywords:** permeability, grain-size, highway-geotechnics Sagamu-Ibadan, Shear-failure

## INTRODUCTION
The study areas in southwestern Nigeria contain residual soils that are laterized. The study areas fall within latitudes 3°52′N and 4°10′N and longitudes 7° 20′E and 7° 31′E the tropical region of the world's lateritic zones. The heterogeneous nature of some basement complex lateritic soils necessitated the deployment of different approach to study their geotechnical characteristics. In his study of tropical soils, Little (1971) found that parent rock factors, geochemical and mineralogical factors influenced both engineering, index and geotechnical properties of lateritic soils. Lateritic soils rich in Kaolinite, microcline, silica, goethite, hematite, anatase, gibbsite and quartz was described by Correla (1969) he concluded that parent rock, rock horizons and weathering conditions determines particulate constituents of lateritic soils.

Adeyemi and Oyeyemi (2000) investigated the geotechnical basis for failure of the Lagos-Ibadan expressway in the southwestern Nigeria. The results of their investigations show that the sub-grade soils below the stable sections have a higher maximum dry density, unsoaked California Bearing Ratio (CBR) and uncured, unconfined compressive strength than those below unstable sections. Samples studied were taken at depth intervals of 0.5m at 1.0m – 3.0m for Permeability and grain-size distribution tests. Apart from basic classification tests; permeability and grain-size approach was adopted to find out the soils basic variation in characteristics. These tests enable the study of southwestern Nigeria residual soils in relation to foundation conditions. The data generated were then statistically treated.

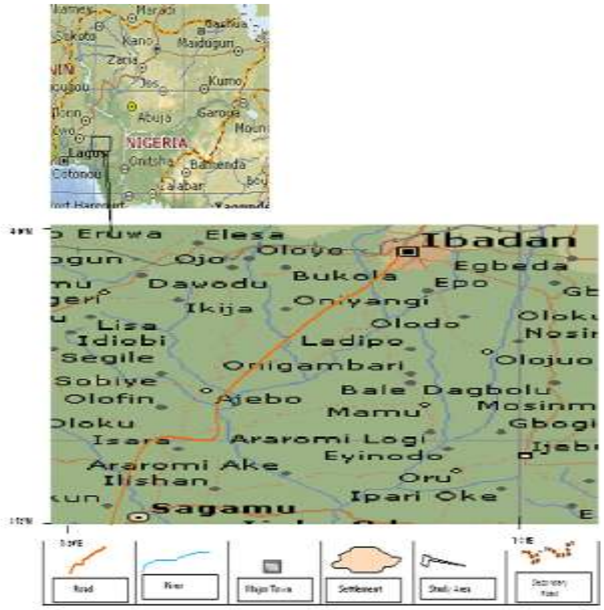


**Fig.1** Location map of the study area

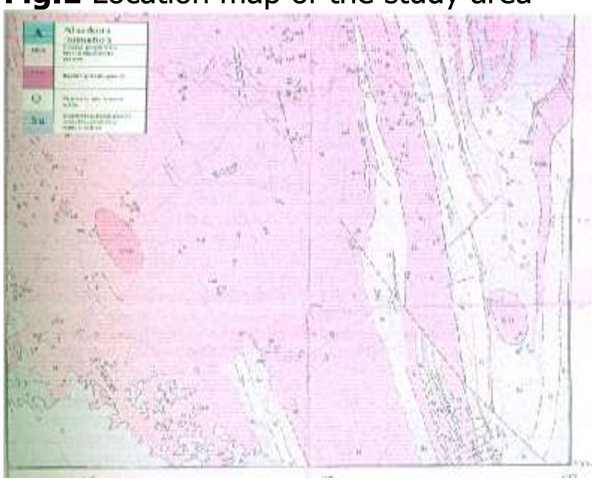

**Fig.2** Generalized geological map of part of Ibadan: The study area.

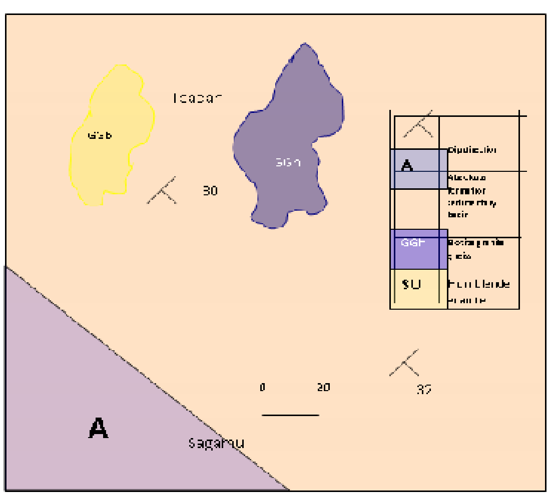


**Fig.3** Geological map of the study area.

## GEOLOGICAL SETTING

### Ibadan Basement Complex

The general morphological description of southwest topography of crystalline basement rises northwards and the physiographic factor is influenced by the geology of the area (Falconer, 1911). It is believed that active chemical subsurface decomposition resulted in an unevenly weathered surface, which is reflected by the insebergs. The drainage pattern of this setting is trellis with river system draining the area and flowing southward to join the coastal lagoon. Southern Nigeria is underlain by gneiss, migmatite and metasediments of Precambrian age, which have been intruded by series of granitic rock of late Precambrian to lower Paleozoic age. Neoproterozoic granitoids in Nigeria consist of several contemporaneous petrologic groups. Their formation ages are well constrained between 640 and 580 Ma (Tubosun et al., 1984; Dada & Respaut, 1989; Dada et al., 1989; Rahaman et al., 1991). The oldest rocks are represented by a series of gneisses and older metasediments believed to be Archaean and Birrimian in age respectively.

These rocks have been variously metamorphosed and granitized through at least two tectono-metamorphic cycles and so have been largely converted to Migmatite and granite-gneisses. The rocks of southwestern Nigeria basement complex have been classified into five (Rahaman, 1988). These are; The migmatite-gneiss complex, which comprises Biotite-Hornblende-gneisses, quartz-schist and small lenses of calc-silicate rock bearing imprint of Liberian and Eburnean events (Oversby,1975). The third is slightly migmatized to unmigmatized paraschist and meta-igneous rocks, which consists of pelitic schist, quartzite amphibolites talcose rocks, meta-conglomerates, marble and calc-silicate rocks. The Pan-African granitoids charnokitic rocks consist of older granodiorites and granites and potassic syenites. The youngest is the unmetamorphosed dolerite dykes. The rock types encountered in the study area at Ibadan Toll-gate are migmatite, gneiss, biotite-granite-gneiss and amphibolites that were exposed by river Ona in Ibadan as well as some pegmatite to quartzo-feldspartic intrusion. Southwestern sedimentary terrain is made up of the following stratigraphic units, coastal plains sand, Ilaro, Ewekoro, Abeokuta formations and crystalline basement complex (Jones and Hockey, 1964) of which Sagamu study area is a part.

### Sagamu Geology

The sedimentary rocks of the study area were deposited in a coastal basin which extended from Nigeria westward across Republic of Benin and Togo to the Volta river in Ghana. The east was partially cut off from the Niger Delta basin by a ridge of crystalline basement rocks whose outcrop now approaches 40km within the coast. Southwestern sedimentary terrain is made up of the following stratigraphic units: coastal plain sand, Ilaro, Ewekoro, Abeokuta formations and crystalline basement (Jones and Hockey, 1964).

| Soil Lithology | Ages of Deposition |
|---|---|
| Alluvium | Recent |
| Ilaro Formation | Pleistocene to Oligocene |

| | |
|---|---|
| Ewekoro Formation | Paleocene |
| Abeokuta Formation | Upper Senonian |
| | Senonian to lower cretaceous |
| Crystalline basement | Lower Paleozoic to Cambrian |

**Table1: Stratigraphy of Sagamu sedimentary terrain**

## MATERIALS AND METHOD

A total of five samples were collected for analysis at depths: 1.0m, 1.5m, 2.0m, 2.5m, and 3.0m. The undisturbed samples were carefully packed and labeled in the core cutters and the disturbed were sealed properly to prevent loss of moisture. These samples were subjected to the following tests: permeability, grain size distribution and natural moisture content. The data generated from these samples were critically analyzed and discuss below.

## Results

| Location | Parent rock | Sample No | % Gravel size particles | % sand size particles | % Silt size particles | % Clay size particles | % Amount of fine particles | Uniformity Coefficient (UC) |
|---|---|---|---|---|---|---|---|---|
| Ibadan | Migmatite giess | A | 0.00 | 45.00 | 21.15 | 55.00 | 76.15 | - |
| | | B | 0.00 | 42.40 | 18.91 | 57.60 | 76.51 | - |
| | | C | 0.00 | 47.62 | 31.08 | 52.38 | 83.46 | - |
| Sagamu | Sedimentary Soil | D | 0.00 | 9.37 | 4.44 | 89.68 | 94.12 | - |
| | | E | 0.00 | 12.96 | 10.96 | 87.04 | 98.00 | - |
| | | F | 0.00 | 12.51 | 10.51 | 87.49 | 98.00 | |

**Table 2: Grain size distribution of uncompacted soils**

| Location | Parent rock | Sample No | NMC (%) | Significance of data |
|---|---|---|---|---|
| Ibadan | Migmatite gneiss | A | 16.9 | Significant |
| | | B | 16.6 | |
| | | C | 16.7 | |
| Sagamu | Sedimentary soil | D | 25.0 | |
| | | E | 21.0 | |
| | | F | 26.0 | |

**Table 3: Natural moisture content of soils**

| Location | Parent rock | Sample No | Permeability mm/s | Amount of fines (%) |
|---|---|---|---|---|
| Ibadan | Migmatite gneiss | A | 1.45 | 76.15 |
| | | B | 1.56 | 76.51 |
| | | C | 1.48 | 83.46 |
| Sagamu | Sedimentary soil | D | 1.27 | 94.12 |
| | | E | 1.21 | 98.00 |
| | | F | 1.42 | 98.00 |

**Table4: Proportion of fines in relation with permeability**

## Discussion

### Grain Size Distribution

The data evaluated from both basement and sedimentary derived soils have the grain size tabulated below. The samples have no gravel size particles that was retained when sieved for both sedimentary and basement soils. The sand size material for basement complex soils have 45% while that of the sedimentary derived is 15.95%. Silt and clay size particles of these soils have 23.71% and 90.30% for the basement and sedimentary soils respectively. The above data show clearly that geology has influenced the engineering characteristic behaviour of the soil samples. The comparison of the terrain permeability gradient shows a significant difference between the sedimentary and basement soils.

Basement derived laterites:
Sand = 21.31%
Silt = 21.15%
**Clay = 55.00%**
**Reddish brown medium grained sandy-silty clay.**
Sedimentary derived laterites:
Sand = 7.31%
Silt = 8.64%
**Clay = 84.05%**
**Grayish silty-clay soil.**

UC = $D_{60}/D_{10}$ UC = Uniformity coefficient
$D_{60}$ = Diameter of sieve at 60%
$D_{10}$ = Diameter of sieve at 10% (effective size)

The uniformity coefficient of the lateritic soils form both sites could not be determined because the soils are largely clay materials. The soils plot for the basement derived materials is well graded as shown by the particle size semi-logarithm graph, while that of the sedimentary derived are poorly graded. The data reliability difference for these soils (basement and sedimentary derived) show a significant difference for the proportion of fines and sand size particles.

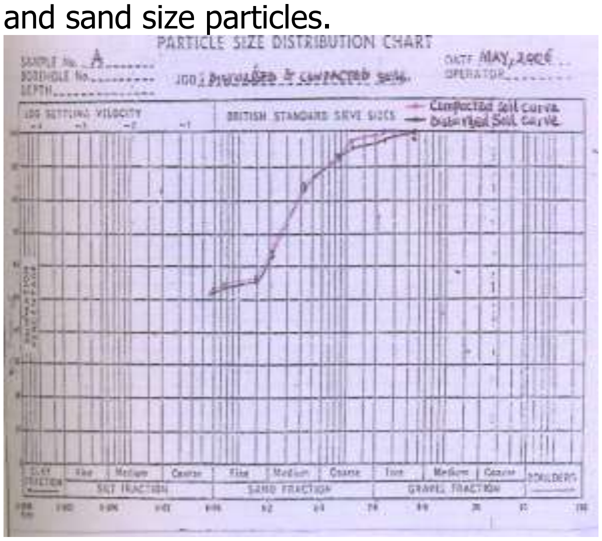

Fig.4: Grain size distribution for sample A

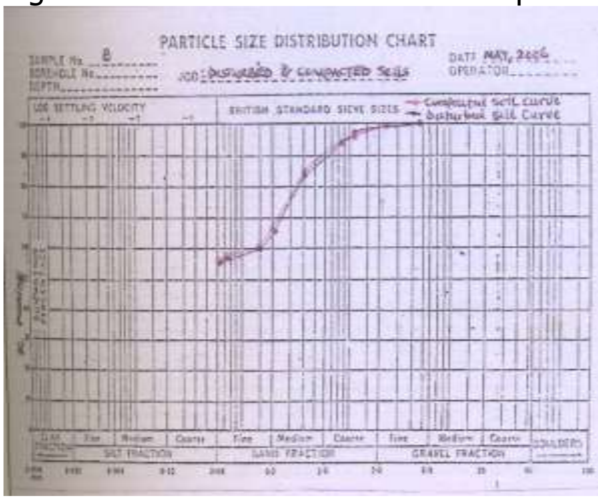


Fig.5. Grain size distribution for sample B

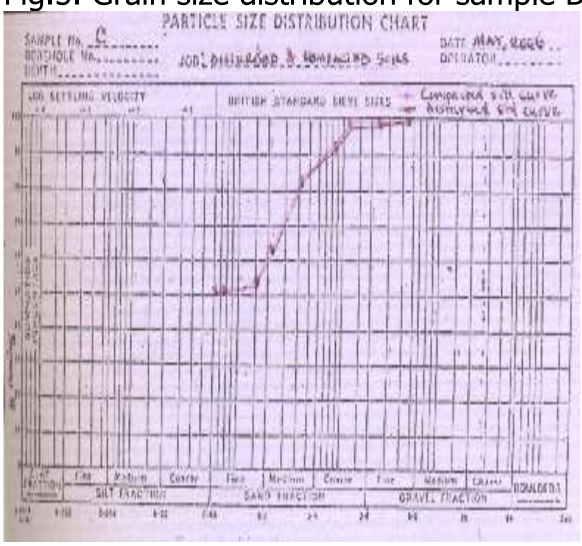


Fig.6 Grain size distribution for sample C

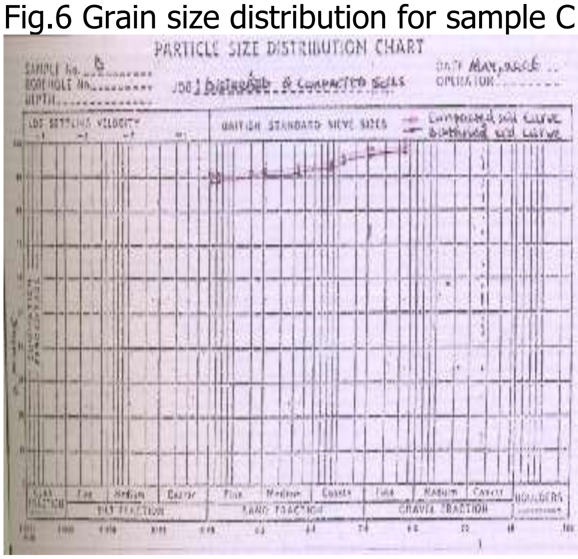


Fig.7 Grain size distribution for sample D

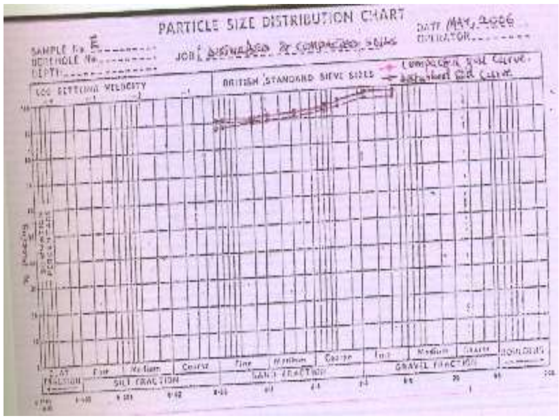


Fig.8 Grain size distribution for sample E


Fig.9 Grain size distribution for sample F

## Natural Moisture Content

The natural moisture content (NMC) is the water content a soil holds as at the time of sampling. The values of NMC obtained from basement complex soils are much lower (16.73% average value) than those from the sedimentary terrain (24% average value). The plot of natural moisture content against proportion of fines show that soils from the sedimentary terrain is more easily compacted and result into waviness as observed along the dual carriage way in Sagamu- Lagos Expressway.

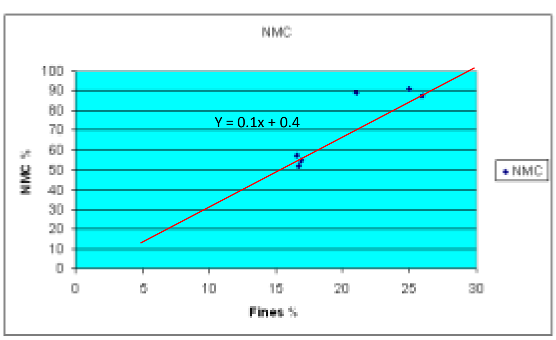


**Fig 10:** Plot of the relationship between fines, NMC and permeability

This graph shows a direct proportionality, which means the higher the percentage of fines the higher the amount of moisture the soil hold and the lower the permeability.

As a result of less permeable soils from the sedimentary terrains, which are easily compacted upon loading result into the waviness observed along Sagamu axis of the Lagos-Ibadan expressway.

## Permeability

The lateritic soil developed over basement complex was found to be more permeable than those derived from sedimentary terrain. The proportion of fines for basement complex laterites was evaluated as 55%, which is significantly lower than 89.87% of the sedimentary derived laterites. Their value for permeability show also a significant difference with average values $1.5x10^{-6}$mm/s and $1.3x10^{-6}$mm/s.

## SUMMARY

The proportion of fines (78.71% and 96.71%) gives an indication that the sedimentary soils are less permeable than those from the basement complex. The permeability test measured are $1.49x10^{-6}$mm/s and $1.3x10^{-6}$mm/s for sedimentary and basement complex soils respectively. Upon statistical treatment it indicates significant difference between the batches of parameters determined for soils from two contrasting terrains respectively. The geotechnical properties of soils developed over migmatite gneiss have better engineering value than those from sedimentary terrain. The observed stability and failure of the highway pavement were due to the analyzed data, which are geotechnical and/or geological factors.

## CONCLUSION

Comprehensive geologic and engineering investigations are required before a lateritic soil is certified a good engineering soil. The soils studied were classified as medium silty-clay and fine grained reddish brown soil that fall into A7 of the AASHTO classification for both migmatite-gneiss derived soils and those from the sedimentary terrain. The various data generated show a significant difference when treated statistically for both soils.

## RECOMMENDATION

Engineering geological evaluation of the failed flexible pavement should be further studied to evaluate the behaviour of soil-asphalt interphase, behaviour of asphalt to temperature after it was laid and its compressibility characteristic. This road is under construction and it posed a constraint during the research.

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