Engineering geology of failed sections of four flexible pavements in southwestern Nigeria

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Abstract

This paper presents a study on the index and engineering properties of some subgrade soils in parts of southwestern Nigeria. This is with a view to establishing likely geotechnical basis for the instability of portions of some flexible pavements in the area. The British Standards (BS) 1377 was followed in investigative tests that include, grain size distribution, specific gravity of grains, consistency limits, compaction, Californian Bearing Ratio (CBR), and unconfined and triaxial compressions. The Casagrande charts classification indicated low plasticity for the soils underlying stable pavements. Their counterparts below unstable sections possess medium to high plasticity. The Optimum moisture contents and Maximum dry densities range from 12.2% to 16.8% and 1775 Kg/m^2 to 1964 Kg/m^2 for soils at stable locations, and from 13.2% to 25.1% and 1438 Kg/m^2 to 1923 Kg/m^2 for soils at unstable locations respectively. The Unconfined compressive and triaxial Shear strength for soils underlying stable locations range from 50.21 KPa to 209.62 KPa and 42.20 KPa to 170.10 KPa respectively while the values are from 25.19 KPa to 62.85 KPa and 19.00 KPa to 88.90 KPa respectively for unstable locations. Soils from stable locations exhibited relatively higher CBR values, better compaction characteristics and higher strengths than those from unstable locations. The stability of the flexible highway pavements is largely a function of the geotechnical properties of the subgrade soils.

1. Introduction:

Most often than not, the socioeconomic development of a nation is directly or indirectly a function of good transportation network. It is sad to note that many roads in Nigeria are in deplorable states thereby limiting national development. Several factors can lead to the degradation and eventual failure of highway pavements. Such factors may include: (1) seasonal moisture and volume changes in expansive soils resulting in soil volumetric changes; (2) poor engineering properties of subgrade soils which fall short of highway subgrade standard specifications; (3) poor drainage conditions; (4) construction defects and excessive traffic/vehicular load (Adewoye and Adeyemi, 2004; Van Der Merwe, 1980). Road failure can take different forms, such as, waviness, soil movement by creep, slides, settlement and compressibility. In such situations, soil stabilization becomes inevitable in order to improve on the engineering geological properties of the soils for better engineering performance.

This study evaluates the geotechnical properties of soils at stable sections (longitudes N07^o 12.822', N07^o 26.470', N07^o 32.014', N07^o 15.091' and latitudes E005^o 33.323', E005^o 45.850', E005^o 46.271', E005^o 11.175' respectively) and unstable sections

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(longitudes N07^o 12.867', N07^o 26.290', N07^o 32.016', N07^o 15.090' and latitudes E005^o 33.303', E005^o 45.850', E005^o 46.218', E005^o 11.137' respectively) along four major roads in southwestern Nigeria. This is with a view to determining the geotechnical basis, if any, for the failure or stability of sections of the flexible pavements.

2. Geological setting:

The study area falls within the part of the country that is underlain by the crystalline Basement rocks of Precambrian age. The soils investigated are weathering products from migmatite-gneiss-quartzite complex of southwestern Nigeria (Figure 1) as described by Elueze (2002) and Adekoya et al. (2003). The rocks exhibit marked textural differences, with structural features such as veins, veinlets, foliations, intrusions and rock-to-rock contacts. Joints, faults and folds are common as well in the area. Shear zones follow a general North-South trend while foliation trends are mostly NNW-SSE and NNE-SSW (Olorunfemi et al., 1999).

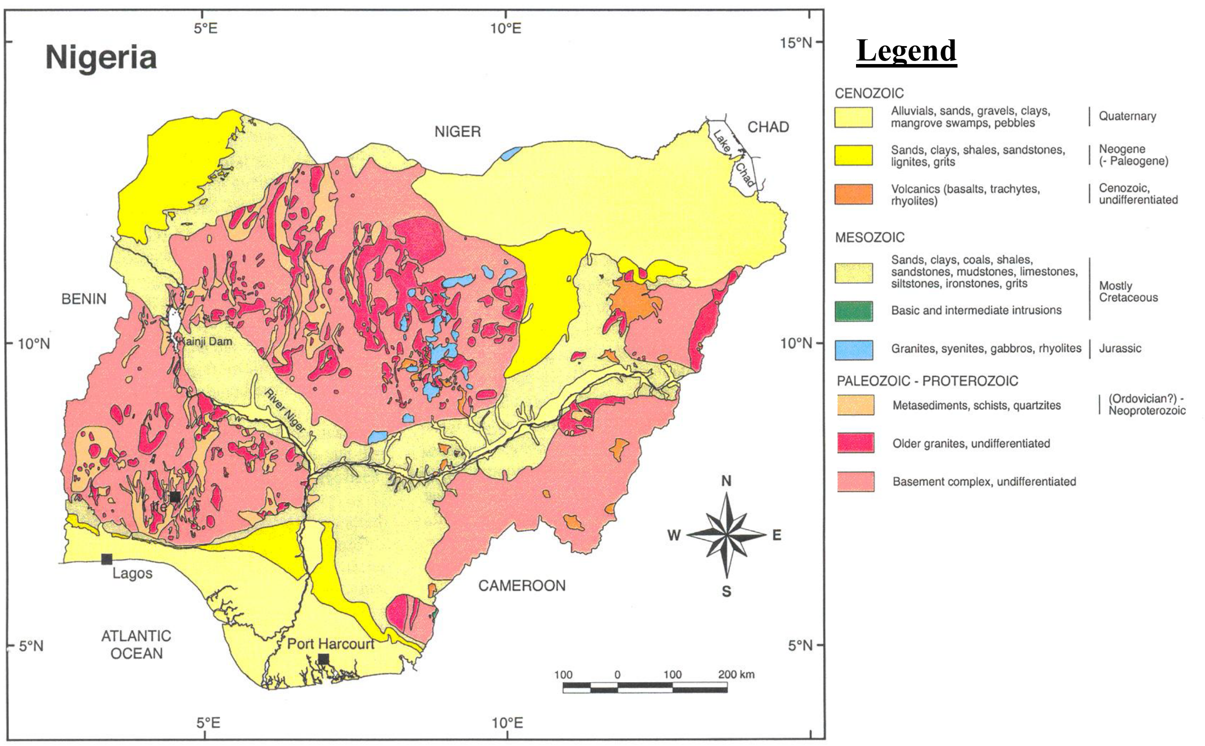

Figure 1: Geologic map of Nigeria (Nigerian Geological Survey Agency)

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Table 1
Some Index and Engineering Properties of soils investigated.

Properties	***Location 01***		***Location 02***		***Location 03***		***Location 04***	
	S01	***U01***	***S02***	***U02***	***S03***	***U03***	***S04***	***U04***
Natural moisture content (%)	6.30	14.30	8.20	15.30	11.20	15.10	20.00	22.10
Specific gravity, G_s	2.75	2.66	2.70	2.64	2.75	2.71	2.75	2.70
Shrinkage limits, SL (%)	9.30	10.70	6.40	15.00	7.10	12.10	8.60	12.90
Liquid limits, LL (%)	34.60	37.20	27.60	53.00	19.70	37.80	34.80	56.00
Plastic limits, PL (%)	17.10	17.90	16.70	25.00	N.P.	17.40	18.50	27.70
Plasticity Index, PI (%)	17.53	19.28	10.92	28.00	0.00	20.44	16.33	28.26
OMC (%)	12.30	13.20	12.20	13.70	16.80	18.90	15.70	25.10
MDD (kg/m^3)	1956	1923	1964	1902	1775	1688	1820	1438
CBR unsoaked (%)	59.00	6.00	26.00	23.00	16.00	59.00	25.00	3.00
CBR soaked (%)	15.00	3.00	15.00	9.00	11.00	10.00	13.00	2.00
UCS (KPa)	209.6	49.87	50.21	23.98	50.22	25.19	97.44	62.85
Triaxial shear strength (KPa)	42.20	19.00	97.30	52.70	110.7	59.90	170.1	88.90

**N.P. – Non-plastic*

Table 2
Grading characteristics of soils investigated.

	S01	U01	S02	U02	S03	U03	S04	U04
% Fines (Clay + Silt)	21.50	35.50	15.10	17.00	9.90	29.50	49.20	64.20
% Sand	50.30	41.70	50.10	43.80	47.40	51.40	34.90	31.20
% Gravel	28.20	22.80	34.80	39.20	42.70	19.10	15.90	4.60

3. Analysis of Results and Discussion:

Table 1 shows the results of some investigative index and engineering tests conducted on the subgrade soils from both stable and failed sections along the road pavements.

Specific gravity

The specific gravity of soil grains at stable locations range between 2.70 and 2.75 whereas the values are between 2.64 and 2.70 for soils at unstable locations. This clearly indicates higher degree of soil maturity and laterization, and hence stronger soils at the stable locations than the failed sections.

Particle size distribution

The grain-size distribution characteristics show that the soils are generally well-graded. However, the unstable locations exhibit higher percentage fines than the stable sections (Table 2). The implication of this is that the observed poor engineering behaviour of such portions of the pavements is partly a reflection of the relatively higher amounts of fines because the amount of fines is inversely proportional to the engineering performance of most lateritic soils (Adewoye and Adeyemi, 2004; Owoseni et. al., 2012).

Consistency limits

The Casagrande charts classification (Figure 2) indicated that the subgrade soils are all inorganic, plotting above the A-line. However, soils below stable pavements have low plasticity while their counterparts beneath unstable sections possess medium to high plasticity. The shrinkage limit values for soils at stable locations range between 6.4% and 9.3%. However, the values are relatively higher at unstable locations, ranging between 10.7% and 15.0%. This may have contributed largely to the failure of the pavements at unstable locations.

Compaction characteristics

The maximum dry density (MDD) values for soils below stable sections range between 1775 Kg/m^2 and 1964 Kg/m^2 while the values vary from 1438 Kg/m^2 to 1923 Kg/m^2 for soils beneath unstable sections. Similar characteristic trend was observed with the moisture content of the soils, in which case the soils below stable sections exhibit lower moisture contents than their counterparts beneath unstable sections of the roads (Figure 3). It is obvious from these that the subgrade soils underlying the stable sections possess better compaction characteristics than those associated with unstable portions of the flexible pavements.

California bearing ratio

The bearing capacity of subgrade and sub-base soils is often estimated using the CBR test results. Both the un-soaked and soaked CBR of samples from unstable sections are lower than the CBR of corresponding samples from stable sections (Table 1). This is an indication that the subgrade soils from beneath stable sections possess better load bearing and strength characteristics than those beneath unstable sections of the pavements.

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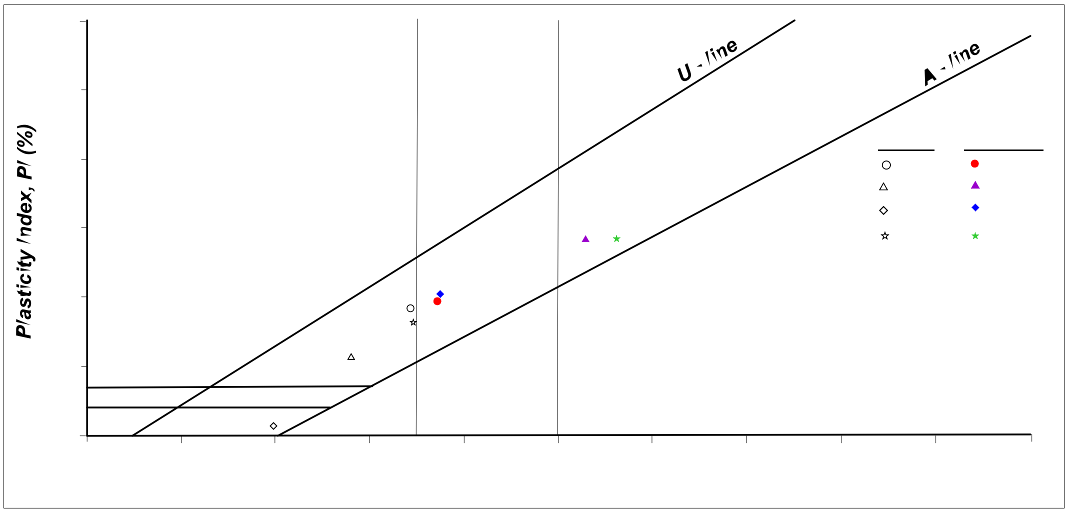

Figure 2: Casagrande chart classification of the studied subgrade soils

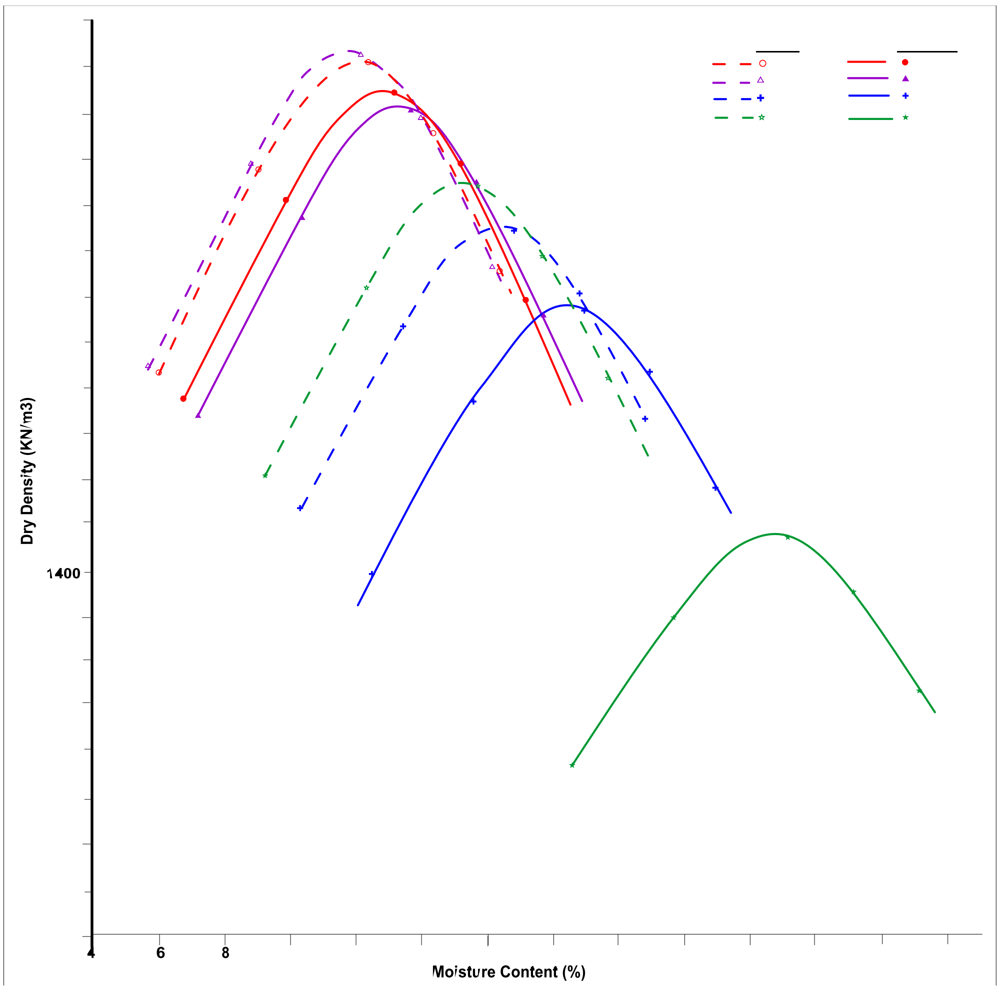

Figure 3: Compaction curves for the studied subgrade soils

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Compressive and Shear Strength

Both the compressive and shear strength values for soils in stable areas are relatively higher than those for unstable locations (Table 1). The better grading characteristics of soils beneath stable sections of the pavements are reflected here.

4. Conclusions:

The subgrade soils are generally well-graded. Those ones underlying stable sections of road pavement possess low plasticity while those beneath unstable portions of the roads exhibit medium to high plasticity. Moreover, the subgrade soils below stable pavements exhibited relatively higher CBR, UCS and shear strength values than their counterparts below unstable sections. Furthermore, soils from stable locations showed better compaction characteristics than their counterparts from unstable locations. Therefore, the stability (or failure) of the flexible highway pavements in the study area is largely a function of the geotechnical properties of the subgrade soils.

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