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Research Article

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Variability in the Highway Geotechnical Properties of Two Residual Lateritic Soils from Central Nigeria

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Abstract

Sixty-four bulk samples of two residual lateritic soils forming the subgrade of the failed sections flexible highway pavement linking Ilorin to Mokwa in central Nigeria were investigated. This was with a view to determining the level of variation in the geotechnical properties of soil samples taken systematically within restricted area in two locations underlain by different bed rocks. One set was developed over sandstone formation of the Southern Bida Basin while the other set was developed over migmatite-gneiss. Consistency limits, grain size distribution, specific gravity, compaction, California Bearing Ratio (CBR), permeability and compressibility characteristics of these soils were determined using the British standard procedures 1377. Coefficient of variation was used to measure the degree of variation in the determined properties. The coefficients of variations for the sandstone derived soil (1.68% and 56.86%) are higher than that of the migmatite-gneiss derived soil (1.28%-54.40%). Permeability, linear shrinkage, and coefficient of volume compressibility possess the highest variability. Atterberg limits and derived indices, amount of fines, soaked and unsoaked CBR possess moderate variability, while moisture density parameters (MDD and OMC), natural moisture content and specific gravity exhibits the least variability. In order to prevent design errors, field sampling should be very thorough involving collection of several samples. This approach will eliminate wrong inferences often associated with results of testing of few samples

Keywords: Highway geotechnics; Coefficient of variation; Sampling; Subgrade; Parent rock

Introduction

The Ilorin-Mokwa road is an economically important highway linking the Nigerian Southwest with the Northwest. This highway is the major transport route for agricultural goods, services and petroleum products between these regions. It is characterized by all manner of structural failures ranging from waviness to large potholes and completely failed sections. A number of reasons ranging from faulty designs, lack of drainage, thin wearing course coverings, negligible quality control, inadequate maintenance funding, geological and pedogenic factors to geotechnical factors have been adduced to the general poor conditions of Nigerian roads [1-3]. Although, there are many probable reasons for the failure of this important highway, certain observations were made while carrying out preliminary studies on it. Figure 1 shows that the thickness of the highway flexible pavement and its foundation are not good enough and do not meet up with recommended specification for upper layers of highly trafficked flexible highway pavements. It was also noticed that the highway lacks adequate crown and possesses little slope that give room for efficient drainage of rainwater away from the pavement surface. Water penetrates the pavement from the surface and infiltrates from the sides of the road because of holes in the pavement and the fact that most sections do not have shoulders bordered by ditches as shown by Figure 2. The road therefore sometimes serves as drainage path for rainwater because the pavement is not well elevated. Incidentally, this federal highway has the highest average daily traffic and percentage of heavy vehicles in Nigeria [3]. This road therefore, requires more skillful design and careful considerations of all possible factors that might affect its service life.

Researchers have reported the variability in geotechnical properties of Nigerian soils [4-7]. However the study area has not been covered in such research. Fundamentally there are many sources of variabilities and uncertainties associated with site characterization. This includes measurement errors and statistical uncertainty. While the actual variability involves only the variability of soil properties, the total variability includes other additional sources of uncertainties such as measurement errors and statistical uncertainties [8]. This research however assumes that the other sources of variabilities aside the actual

Figure 1: A deplorable section of the Ilorin-Mokwa Road at Onipako near Jebba.

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variability have been cancelled out by comparing two genetically different residual soils and observing the trend of variabilities in both soils.

It is often assumed that soil properties are the same throughout a rather wide area when sampling for geotechnical tests. However, undetailed sampling can lead to conclusions that significantly differ from true soil behavior. Therefore, there is a need to quantify the amount of uncertainties attached to highway subgrade sampling so as to minimize design errors attached to undetailed sampling. The aim of this paper was to establish the degree of variation of some highway geotechnical parameters within restricted area underlain by different bedrocks. Phoon and Kulhawy recommend a statistical analysis including the coefficient of variation and the scale of fluctuation for this purpose [9]. However scale of fluctuation for evaluating spatial variability of parameters that can be obtained from *in situ* tests because they provide continuous record of ground properties [10].

Figure 2: A failed section of the road exposing the roads foundation and relatively thin asphalt riding surface.

Location of Study Area

A study location was located in Shao near Ilorin on latitude N08°33.268' and longitude E004°30.730', while the second location was located near Mokwa and it lies on latitude 09°12.484' and longitude E 004°52.459'. These two locations belong to the same climatic belt and but underlain by different bedrocks. Ilorin is underlain by Precambrian Basement Complex rocks, while Mokwa is underlain by the Cretaceous Sandstone Formation of the Bida Basin. The Bida Basin is a NW-SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south. It is delimited in the Northeast and Southwest by the Precambrian Basement Complex [11]. Figure 3 shows the location and geology of the study areas. Nigeria is located within the tropics and therefore experiences high temperatures throughout the year. The mean temperature for

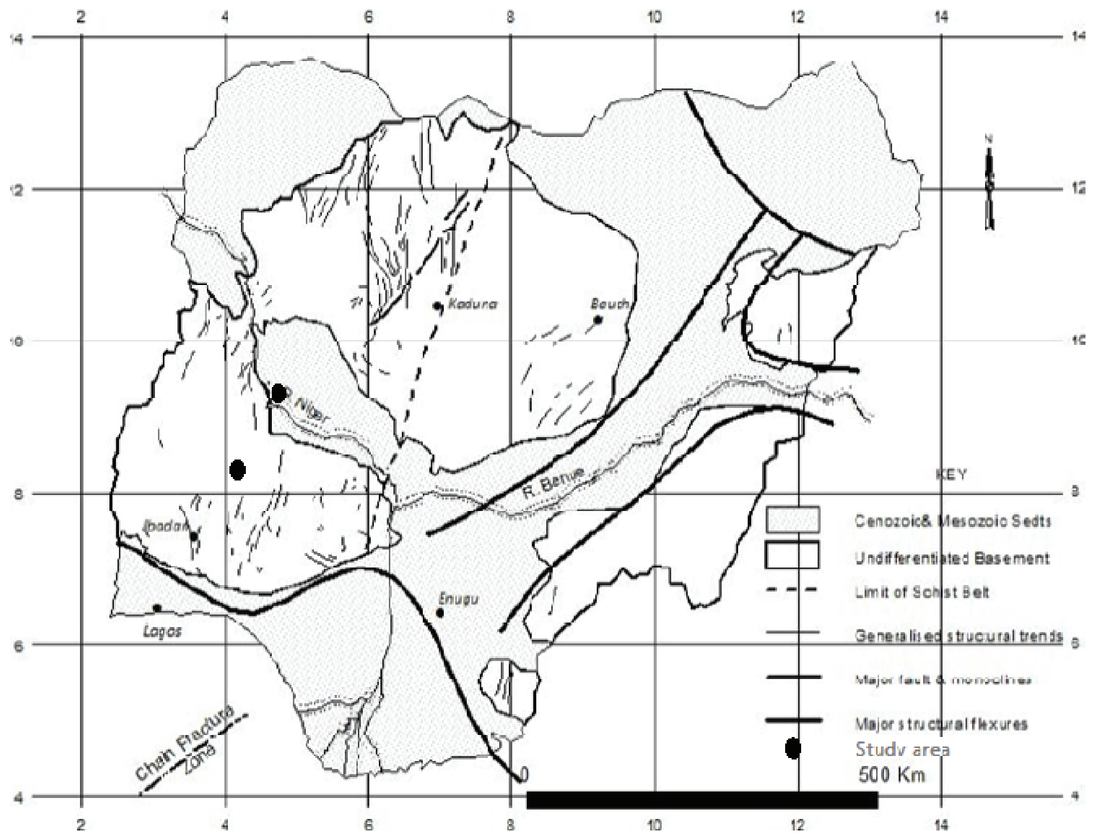

Figure 3: Generalized geology of Nigeria showing the study area [12].

the country is 27 °C. Average maximum temperatures vary from 32°C along the coast to 41°C in the far north, while minimum figures range from 21°C in the coast to below 13°C in the north. The climate of the country varies from a very wet coastal area with annual rainfall greater than 3,500 mm to the Sahel region in the north eastern parts with annual rainfall less than 600 mm. Generally, there is a distinct wet and the dry season within a year. The length of the rainy season decreases from 9-12 months in the south to only 3-4 months in the extreme Northeast. Average rainfall in the northern limit of the belt is about 254 mm annually. Mean monthly relative humidity is about 29%. The study area falls within the zone that receives 140-160 mm of rain per annum.

Method

Two locations 15 m away from the highway with different exposed bedrocks (Migmatite-Gneiss and Sandstones) were selected. In each location, disturbed samples were taken at 5 m sampling interval within gridded as shown in Figure 4. Index and engineering tests relevant in highway geotechnics were carried out on the samples. All tests were carried out in accordance with the British standard method of testing soil 1377, modifications where necessary were however made [13]. Determined parameters include consistency limits, grain size distribution, specific gravity, compaction, soaked and unsoaked California bearing ratio (CBR) permeability and compressibility. The variability in the values of measured parameters was presented using contour plots while coefficient of variation was used to measure the degree of variation of these properties. The contour plots were made using MATLAB curve fitting method. The higher the coefficient of variation, the greater the dispersion in a set of variables and values up to 10% is believed to show significant variability within any set of data.

Results and Discussions

Linear shrinkage

The linear shrinkage of the sandstone derived soil ranges from 1.5% to 7.3% while that of the soil developed over migmatite ranges from 2.2% to 10.1%. Although the linear shrinkage of the sandstone soil is averagely lower than that of migmatite soil, it has higher standard deviation, variance and coefficient of variation. Figure 5 compares the contour plots of the linear shrinkage values of the migmatite derived (MG) soil samples and the sandstone derived (SS) soil samples. It can be seen from this figure, that the contours for SS are more closely spaced with highly contrasting colours than MG. This indicates higher variability in the linear shrinkage values of the SS soil samples.

Atterberg limits

Table 1 shows the values obtained from the statistical treatment of data obtained from liquid limit, plastic limit and plasticity index of the studied soils. The degree of variability in Atterberg limits values for the sandstone soil is generally higher than that of the migmatite soil. This can be observed in the consistently higher values of the coefficient of variation characteristic of the sandstone soils. The coefficient of variation in the Atterberg limit for the migmatite derived soil ranges from 17.00% to 21.64% while that of the sandstone soil ranges from 11.26% to 17.32%. Figures 6-8 show the contour plots of the Atterberg limit of the studied soils. It can be noticed from these figures that the Atterberg limit values of the SS soil samples vary more within the gridded sampling area than the MG soil samples.

Grain size distribution parameters

Table 2 shows coefficient of variation of the grain size distribution parameters of the studied soils. Variation up to 150% was recorded in the grainsize distribution parameters of the studied soils. The high coefficient of variation values associated with the grain size distribution characteristics of these soils implies that their grain size distribution characteristics vary significantly within restricted area. Except for coefficient of curvature, the sandstone derived soil has higher coefficient of variation than the MG soil. This implies that the sandstone derived soil has higher level of heterogeneity than the SS one. Figure 9 compares

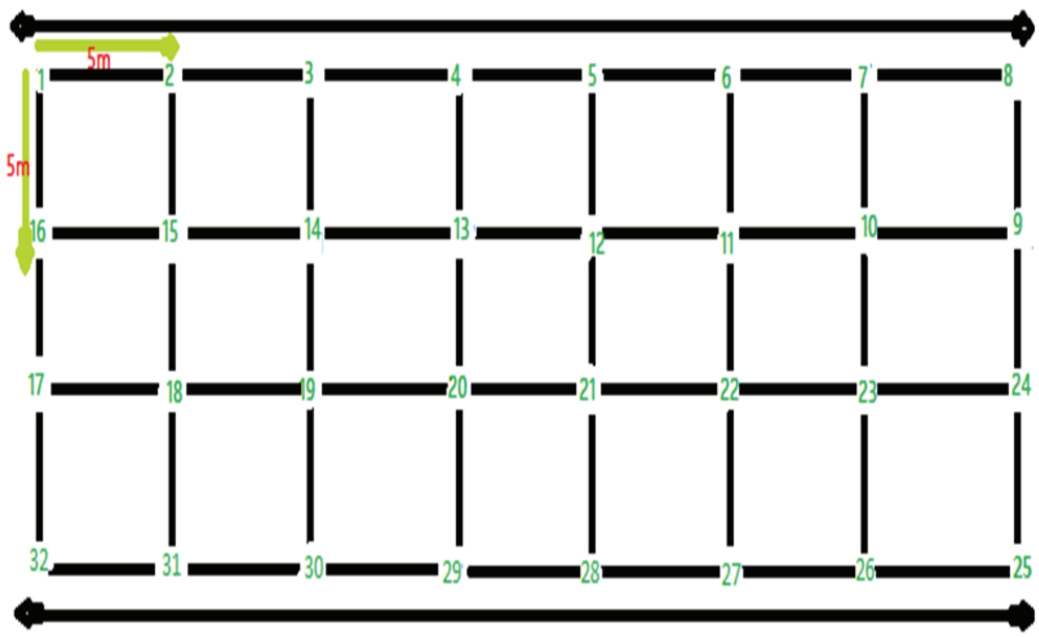

Figure 4: A sketch of the sampling area showing the spatial distribution of the sampling points.

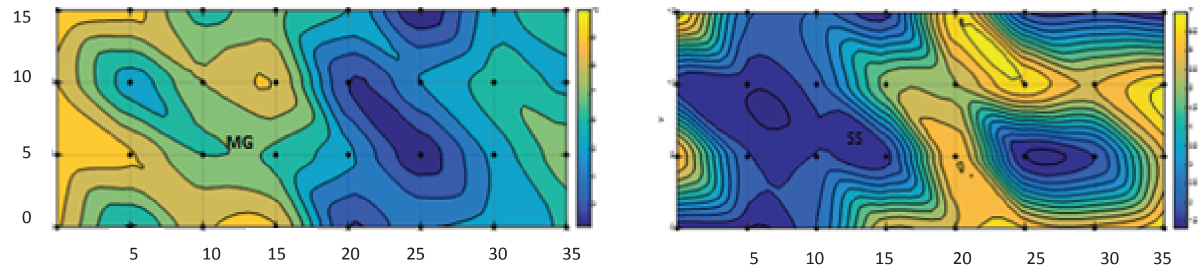

Figure 5: Contour plots of the linear shrinkage values of the studied soil samples.

Soil type	Statistical parameter	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Migmatite derived soil	Range	28.4-49.1	16.0-30.8	11.03-27.06
	Variance	21.05	14.26	8.87
	Standard deviation	4.59	3.78	2.98
	Coefficient of variation (%)	11.29	16.35	17.32
Sandstone derived soil	Range	20.8-44.2	10.9-27.7	8.34-17 .04
	Variance	32.07	18.34	8.2
	Standard deviation	5.66	4.28	2.86
	Coefficient of variation (%)	17	21.34	21.64

Table 1: Statistical analysis of Atterberg Limits data.

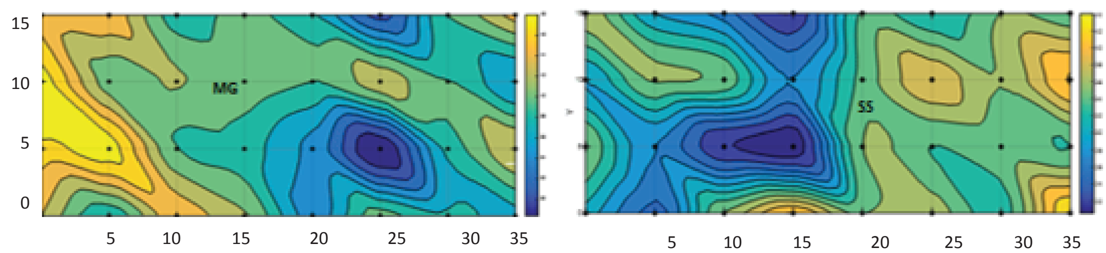

Figure 6: Contour plots of the liquid limit values of the studied soil samples.

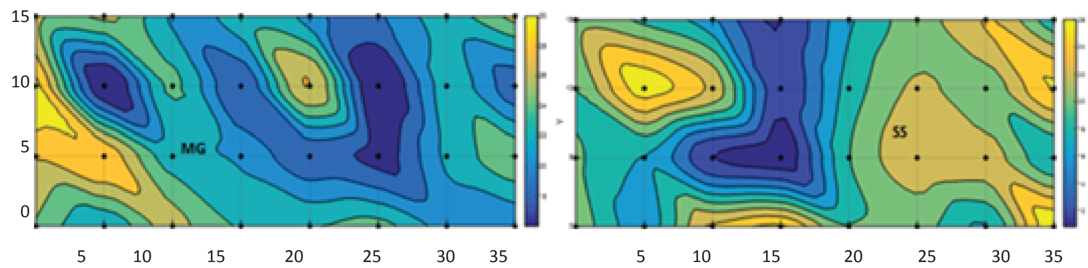

Figure 7: Contour plots of the Plastic limit values of the studied soil samples.

the contour plots of the amount of fines present in the SS soil with the amount present in the MG soil.

Specific gravity, moisture content and derived atterberg indices

Table 3 shows the summary of the statistical evaluation of spatial variability in the specific gravity, moisture content derived indices of both soils. The coefficient of variation in specific gravity values for the MG soil is similar to that of the sandstone ones. There is also little spatial variation in specific gravity values across the gridded area. Since specific gravity is a measure of degree of weathering, it implies that the two set of soil have similar degree of weathering and are uniformly weathered [14]. There is little variation in the spatial distribution of moisture content for both set of soils. The degree of variations in the values of parameters derived from index properties for the MG soil is lower than those recorded for the SS soil. This trend can also be

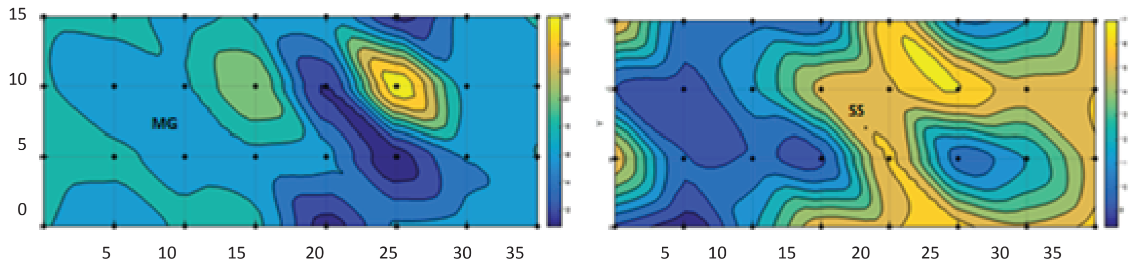

Figure 8: Contour plots of the plasticity index values of the studied soil samples.

Grain size distribution parameter	Coefficient of variation (%)	
	Migmatite derived soil	Sandstone derived soil
Amount of gravel sized particles	70.22	145.37
Amount of Sand sized particles	23.34	22
Amount of silt sized particles	33.58	53.92
Amount of clay sized particles	68.94	95.86
Amount of fine particles	32.47	45.22
Coefficient of Uniformity	115.54	130.63
Coefficient of curvature	136.75	150.9

Table 2: Statistical analysis of grain size parameters.

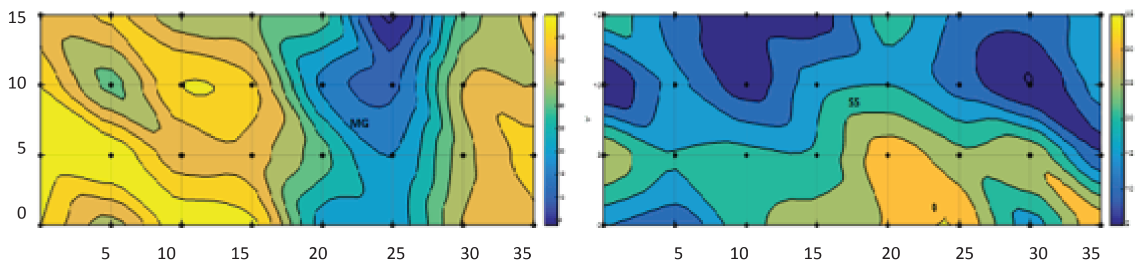

Figure 9: Contour plots of the amount of fines present in the studied soil samples.

Soil	Statistical parameter	Specific gravity	Moisture content (%)	Derived atterberg indices	
				Flow index	Toughness index
Migmatite derived soil	Range	2.6 –2.7	19.2 -25.66	15.30-32.4	0.45-1.22
	Variance	0.001	3.81	12.05	0.04
	Standard deviation	0.03	1.95	3.47	0.19
	Coefficient of variation (%)	1.28	8.59	17.14	21.67
Sandstone derived soil	Range	2.55 –2.7	13.98 -1.52	7.36-4.90	0.47-1.60
	Variance	0.002	3.27	19.86	0.08
	Standard deviation	0.04	1.81	4.46	0.29
	Coefficient of variation (%)	1.68	10.51	26.45	34.55

Table 3: Statistical analysis of data for specific gravity, moisture content and derived units.

observed in the contour plots of the values of natural moisture content and specific gravity of the studied soil shown in Figures 10 and 11.

Moisture density relationship and California bearing ratio

CBR is a measure of road subgrade strength and important parameter used in highway design. Table 4 presents the summary of the statistical treatment of the results of CBR and compaction test carried out on both soils. While the coefficient of variation of the unsoaked CBR and maximum dry density for the MG soil is higher than that of the SS soil, the soaked CBR is higher for the sandstone soil. The coefficient of variation for optimum moisture content for the SS soil is higher than that of the MG soil. The differences in the coefficient of variation for CBR and OMC of the studied soils are marginal. This is

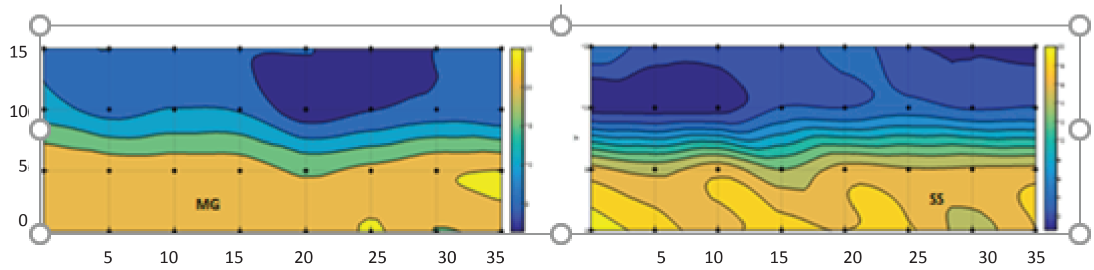

Figure 10: Contour plots of the specific gravity values of the studied soil samples.

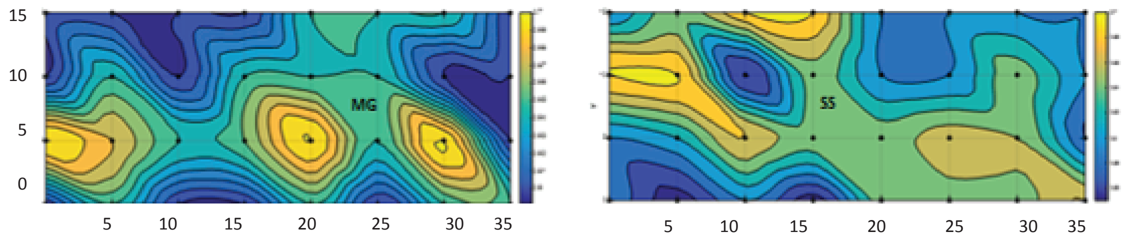

Figure 11: Contour plots of the natural moisture content in the studied soil samples.

Soil	Statistical parameter	MDD(Kg/m³)	OMC (%)	Unsoaked CBR (%)	Soaked CBR (%)
Migmatite derived soil	Range	1830.05-1970.16	16.0-19.20	22.0-88.7	12.53-36.25
	Variance	41996.37	0.72	274.48	37.98
	Standard deviation	204.93	0.85	16.57	6.16
	Coefficient of variation (%)	11.3	4.86	29.07	27.39
Sandstone derived soil	Range	1070.02-1960.04	13.0-16.0	43.1-126.9	16.53-45.32
	Variance	1811.84	0.77	608.66	84.31
	Standard deviation	42.57	0.88	24.67	9.18
	Coefficient of variation (%)	2.23	6.03	27.51	28.31

Table 4: Summary of the statistical treatment of the CBR and moisture dry density values of the studied soil.

also evident from Figures 12 and 13 which shows the contour plots for OMC and CBR values respectively.

Permeability and compressibility

The coefficient of variation of the coefficient of permeability for the MG soil is higher than that of the SS soil. Table 5 shows the summary of the determined statistical parameters for permeability and coefficient of (volume) compressibility. The coefficient of variation of the coefficient of (volume) compressibility for the MG soil is higher than that of the SS soil.

Figure 14 shows the contour plot of the coefficient of Permeability values of the studied soil, while Figure 15 shows the contour plot of the coefficient of (volume) compressibility values. These figures also show that the variability in the coefficient of permeability values of the MG soil samples is more than that of the SS ones.

Degree of variation and sampling

Comparing Figures 16 and 17, it can be observed that the degree of variability of the laboratory determined highway geotechnical parameters for both set of soil vary similarly. The variation associated with the properties of the studied soils appears to be higher for some parameters than it is for others. On this basis, for this work, the observed coefficient of variations of the studied soils has been grouped into three. Category one consist of parameters with relatively high coefficient of variation, these include permeability, linear shrinkage and coefficient of volume compressibility. Category two consist of parameters with relatively moderate coefficient of variation, which include atterberg limits, amount of fines, soaked and unsoaked CBR. Category three consists of parameters with relatively low coefficient of variation, which include moisture density parameters (MDD and OMC), natural moisture content and specific gravity. Therefore, sampling for the determination of properties belonging to category one should be most detailed and more samples should be tested to minimise design error due to using values that do not correctly represent the soil mass being investigated.

Conclusions

Highway geotechnical parameters of two genetically different residual lateritic soils were treated statistically to determine the degree of variation associated with them within a restricted area. The coefficient of variation for the migmatite derived soil samples range

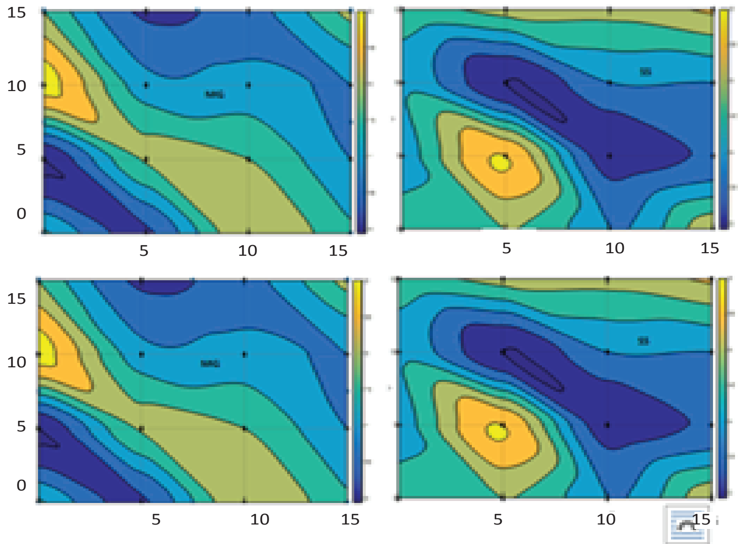

Figure 12: Contour plots of the OMC values of the studied soil.

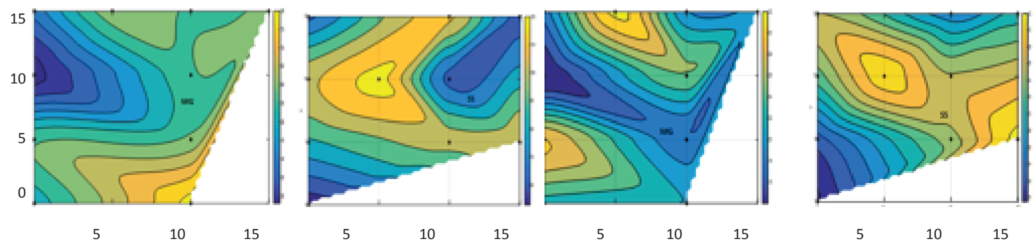

Figure 13: Contour plots of the soaked and unsoaked CBR values of the studied soil.

Soil	Statistical Parameter	Permeability coefficient (cm/sec)	Coefficient of Volume Compressibility (m^2/KN)
Migmatite soil	Range	9.2×10^{-7}-3.5×10^{-6}	4.4×10^{-5}-6.1×10^{-4}
	Variance	9.91 × 10-^{13}	3.2×10^{-8}
	Standard deviation	9.96×10^{-7}	1.8×10^{-4}
	Coefficient of variation (%)	54.35	43.38
Sandstone soil	Range	1.0×10^{-6}-3.1×10^{6}	2.4×10^{-4}-7.1×10^{-4}
	Variance	8.4×10^{-13}	3.3×10^{-8}
	Standard deviation	9.17×10^{-7}	1.8×10^{-4}
	Coefficient of variation (%)	46	54.38

Table 5: Summary of the statistical treatment of the permeability and consolidation data.

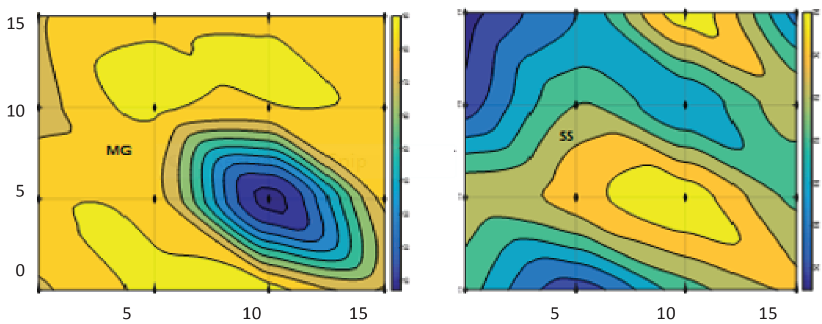

Figure 14: Contour plots of the coefficient of Permeability values of the studied soil.

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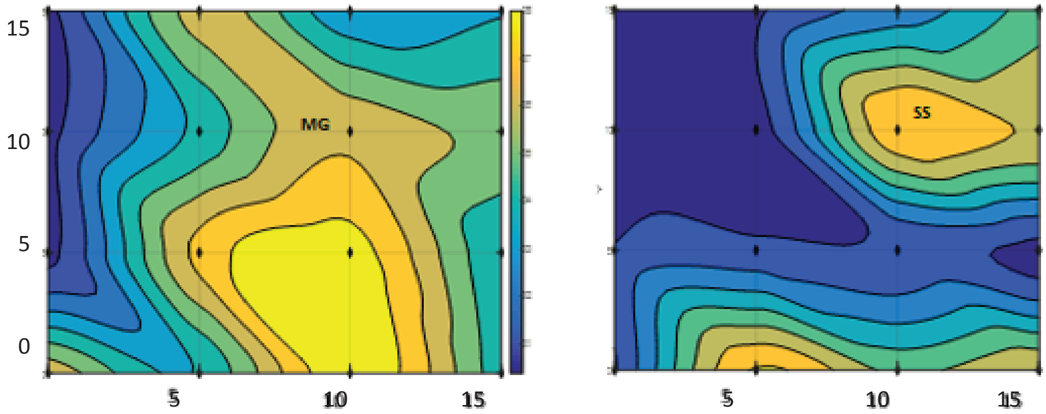

Figure 15: Contour plots of the coefficient of volume compressibility values of the studied soil.

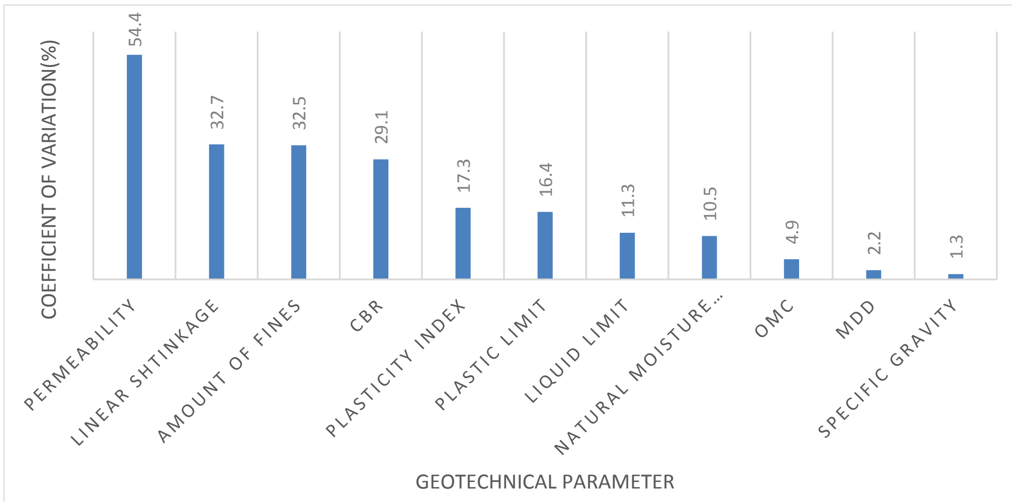

Figure 16: Coefficient of variation characteristic of the highway geotechnical properties of the sandstone derived soil.

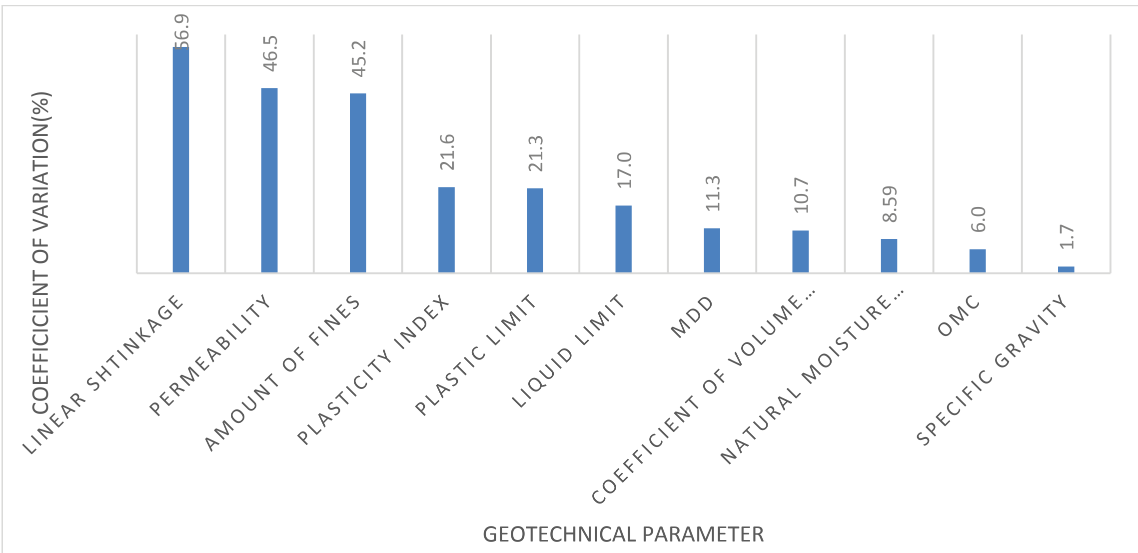

Figure 17: Coefficient of variation characteristic of the highway geotechnical properties of the migmatite derived soil.

between 1.28% and 54.40% while those of the sandstone derived soil range between 1.68% and 56.86%. Except for specific gravity, significant variability exists in the values of all determined highway geotechnical parameters of the studied soil samples within restricted area. Except for Permeability coefficient and unsoaked CBR, the Mokwa sandstone derived lateritic soil exhibits more heterogeneity than the Shao migmatite-gneiss derived one. Permeability coefficient, linear shrinkage and coefficient of volume compressibility possesses relatively high variability. Atterberg limits, amount of fines, soaked and unsoaked CBR have relatively moderate coefficient of variation while moisture density parameters (MDD and OMC), natural moisture content and specific gravity have relatively low variability. Therefore, detailed sampling, statistical analysis and geological considerations should be the basis for determination of parameters often utilised for foundation design for flexible highway pavement.

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