APPRAISAL OF THE CAUSES OF PAVEMENT FAILURE ALONG THE ILESA - AKURE HIGHWAY, SOUTHWESTERN NIGERIA USING REMOTELY SENSED AND GEOTECHNICAL DATA

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ABSTRACT

Remotely sensed and geotechnical data have been used to establish some of the causes of perpetual pavement failure along the Ilesa Akure highway in the southwestern part of Nigeria. Four failed segments and two control stable segments were selected for the geotechnical study. The remote sensing investigation involved the processing and interpretation of Landsat-7 ETM+ images covering the study area and it's environ for lineaments. The geotechnical investigation involved grain size analyses, Atterberge Limits, Compaction Test and California Bearing Ratio (CBR) determination. Lineaments were identified across virtually all the failed localities with a predominantly N-S structural trend. The geotechnical properties of the soils beneath the stable and failed segments of the highway show significant overlap which suggests that the cause of road pavement failure along the highway may be due to factors other than or complimentary to the geotechnical factors. The pavement failure may have resulted from suspected near-surface linear (geological) features such as faults/fractures and lithologcal contacts beneath the highway pavement. Clayey substratum and ponded embankment toe could also have contributed to the pavement failure.

Keywords: Remote Sensing, Geotechnical Investigation, Road Pavement Failure, Basement Complex Environment

INTRODUCTION

Pavement failures are very common features on Nigeria in roads after few years of performance and often before attaining the design age. These roads are continuously reconstructed or rehabilitated without any effort made to identify factor(s) responsible for their perpetual failure. Pavement failures can either be functional (surface pavement failure) or structural (deep-seated pavement failure). There are many factors that can influence the performance of highway pavement structure. These include: geological, geomorphological, geotechnical, design, material selection, construction practices, maintenance and usage factor.

Many studies have been carried out on flexible pavement designs in general and on its failure in particular. Adeyemi and Oyeyemi (2000) examined the geotechnical basis for failure of sections of the Lagos-Ibadan expressway southwestern, Nigeria. The authors concluded that the soils beneath the unstable zones are more mechanically stable than those beneath stable zone, hence opined that mechanical properties cannot be used to predict the stability of road pavements and recommended that further investigation of the geotechnical properties of as many subgrade soils as possible is undertaken in order to elucidate the influence of geotechnical and geological factors. Oladeji and Adedeji (2001) used environmental observations in addition to geotechnical test to study the causes of non-uniform occurrence of deformation features on highway pavement in Ogbomoso Township. It was concluded that the observed localized failure is primarily due to shallow groundwater level. Adewole *et al.* (2004) reported on the Oyo-Ogbomoso Road southwestern Nigeria. They concluded from geotechnical points of view that flexible highway failure, which manifested on the road like waviness/corrugation rutting and potholes are due to environmental factors like poor drainage, lack of maintenance and misuse of the highway pavement and that seepage of runoff, due to precipitation, largely finds its way into the pavement structure damaging them in the process.

Bala et al. (2000) used Landsat 5 imagery in the assessment of groundwater resources in the crystalline rocks around Dutsin-Ma, northern Nigeria. With this approach they mapped lineaments and areas of lush vegetation on the basis of which they were able to divide the study area into three main hydrogeological zones. Onyedim and Ocan (2001) used SPOT-XS imagery to map the two major sets of fracture in part of Ilesa area, southwestern Nigeria. They drew the conclusion that the NE-SW and NNE-SSW trending structures were responsible for the emplacement of the Itamerin granite and the formation of the Ifewara fault zone respectively. Awoyemi *et al.* (2005) extracted structural and drainage lineament from enhanced SPOT-XS imagery and topographic maps of the Ilesa area southwestern Nigeria. The authors obtained a positive above average correlation coefficient between structural and drainage linear, indicated that there is a significant control of drainage in the area by geological structures. A lineament analysis using a LANDSAT Thematic Mapper (TM) dataset of the Gölmarmara (Manisa) region was performed by Kavak and Cetin, 2007 to identify linear geological features that could be attributed to paleotectonic and/or neotectonic structures. There results shows that extensive NE and ENW trending lineament systems have developed in the region and most of ENW-SSE trending lineaments are associate with the recent normal faulting of the western Anatolia after the middle Miocene Period.

The Ilesa-Akure highway (Fig. 1) which is underlain by the Basement Complex rocks (Fig. 2) is a major road that links the southwestern part of Nigeria with the northern and eastern parts of the country. The highway lies within latitudes 7^0 14' N and 7^0 45' N and longitudes 4^0 45' E and 5^0 15' E (Fig. 1). Ten segments of the Akure-Ilesa highway (Fig. 3) as at the time of study have experienced perpetual failure after several rehabilitations. The topography of the highway is relatively flat with mean elevation ranging between 300m and 400m along the 70 km long highway. The investigated failed segments are neither previously sand fill nor cut into clayey saprolite.

These failed segments have been responsible for many tragic human and material losses. Enormous amount of money had been spent on for the rehabilitation works without any success. The various types of highway failures identified along the highway are: (a) Distress arising from the failure of the bitumen layer, especially along wheel tracks, (b) 'Wavy' or heaving surface due to settlement of the pavement material causing frequent bumps on the highway, (c) Pitting or minor dent, longitudinal cracks running more or less parallel to central line of the roadway and (d) Shear or massive failures (potholes) extending through the pavement, occasionally to the subgrade. This study attempts to identify possible geological and geotechnical factors that may be

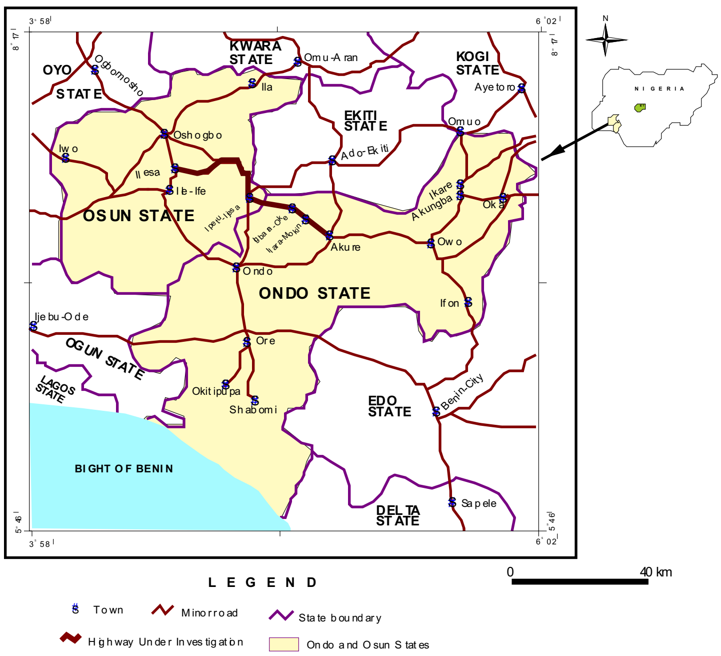

Fig. 1: Road Map of Part of Southwestern Nigeria Showing the Ilesa Akure Highway (Modified After Spectrum Road Map, 2002)

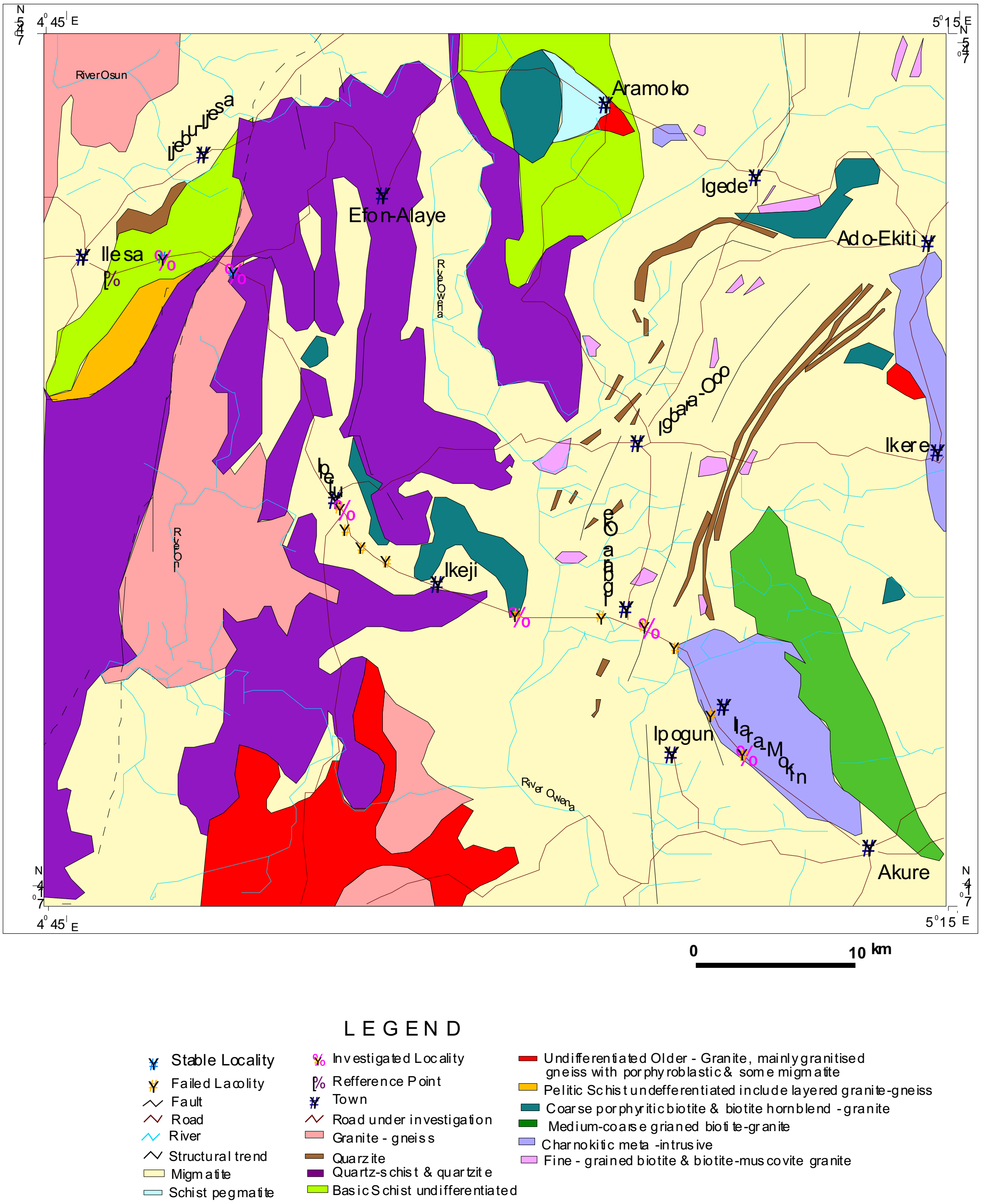

Fig. 2: Geological Map of the Area around Ilesa-Akure Showing the Ilesa-Akure Highway (Modified After Geological Survey of Nigeria, 19 76)

responsible for the road pavement failure.

MATERIALS AND METHODS

The study involved interpretation of Landsat images, geotechnical investigation and subsoil condition review along the highway. Based on spatial resolution, satellite data can be classified into three types: low-resolution data (e.g. NOAA/AVHRR), medium-resolution data (e.g. Landsat, SPOT, IRS) and high-resolution data (e.g. IKONOS, SPIN-2). The cost of the satellite data increases with resolution (Janssen and Bakker, 2001). For this reason, to meet the information requirements for geological application in developing countries, satellite data of medium-resolution are often used. Thus, Landsat-7 ETM+ imagery was acquired for this research. The sub-scene covering Ilesa-Akure area (Fig. 4) was created from the full scene Landsat-7 ETM+ image. Image pre-processing involving geometric correction and digital image enhancement of the created sub-scene image were carried out in order

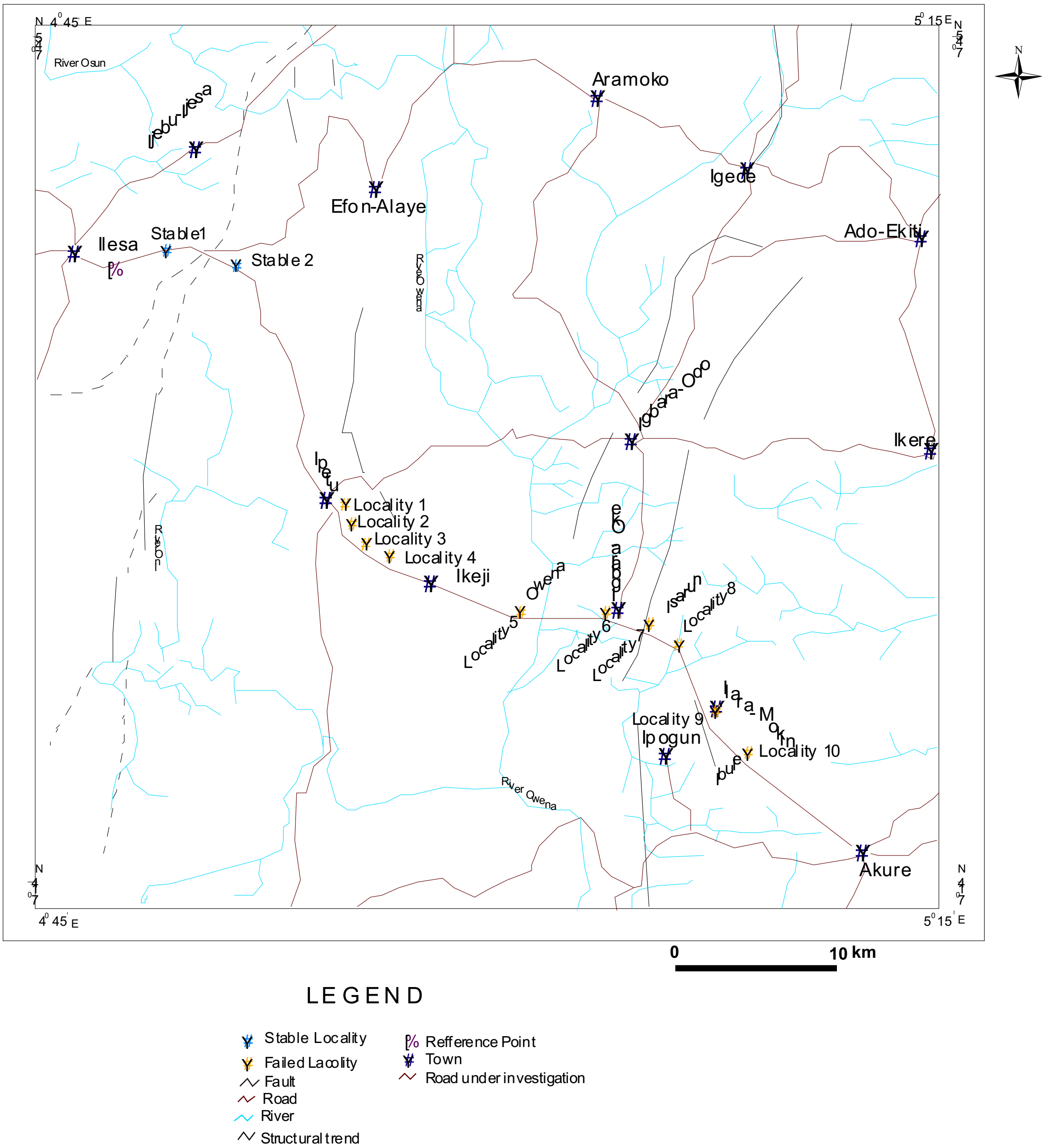

Fig. 3: Map of the Area around Ilesa-Akure Highway Showing the Specific Sites Studied

to create better and improved images from the original image. The image acquired already georeferenced with the reference datum and ellipsoid of the 1984 World Geodetic System (WGS). The original image was georeferenced using the UTM zone number 31 map projection and the subscene covering Ilesa-Akure area was created and resampled to 20 m pixel size. Because of the large variations in the spectral response as shown by band 7, which was selected during the preprocessing phase for the mapping of linear features, image histogram equalization was carried out with 10% stretching interval. The stretched image was then sharpened through filtering in order to emphasize the linear features (e.g., edges) with high spatial frequency. Using the convolution method, directional filters of 3x3 kernels were used to enhance linear trends with different orientations. The resulting enhanced image (Fig. 5) revealed most of the lineaments in the study area which were digitized using 'Acrview GIS 3.2a' computer software to produce the lineament map of the area. This was realized from the combination of the principal linear features and the delineated traces of the strong curvilinear geomorphic trend. A total of 167 lineaments were identified, interpreted and used to generate an Azimuth- Frequency diagram (Rose Diagram), showing the number of the lineaments in each 10^0 azimuth class.

Disturbed soil samples were collected from the two control stable segments and four failed segments. The soil samples were taken at a depth of 0.5 m. At each of the stable segments St1 and

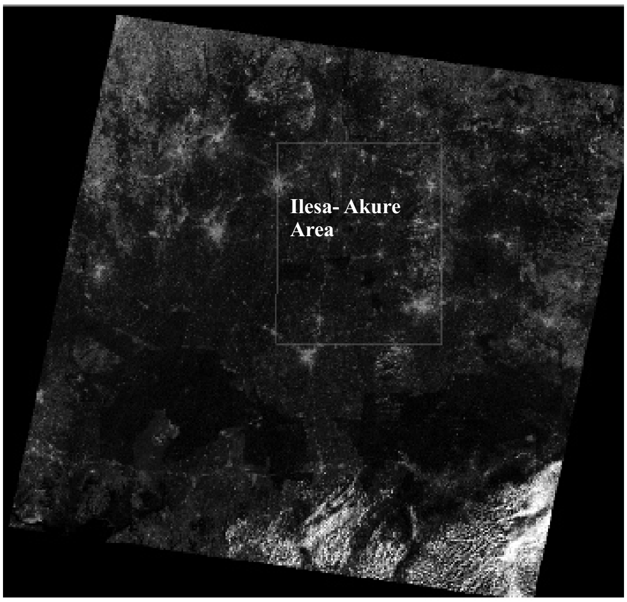

Fig. 4: The full Landsat scene showing the location of Ilesa-Akure area.

St2 samples were collected at two different locations and four samples were collected at each of the failed segments FS1, FS5, FS7 and FS10. The moisture content of the samples collected from the field was determined in the laboratory within 24 hours after collection. Methods of soil testing for engineering purposes were conducted in accordance with B.S. 1377 for all the soil samples and the soils were compacted to the West African Standard. The tests included grain size analysis, liquid limit, plastic limit, linear shrinkage, compaction test and California Bearing Ratio (CBR).

RESULTS AND DISCUSSION

Lineament Map

Figure 6 shows the lineament map of Ilesa-Akure area. Lineaments, because they are presumed to reflect subsurface phenomenon, can generally be

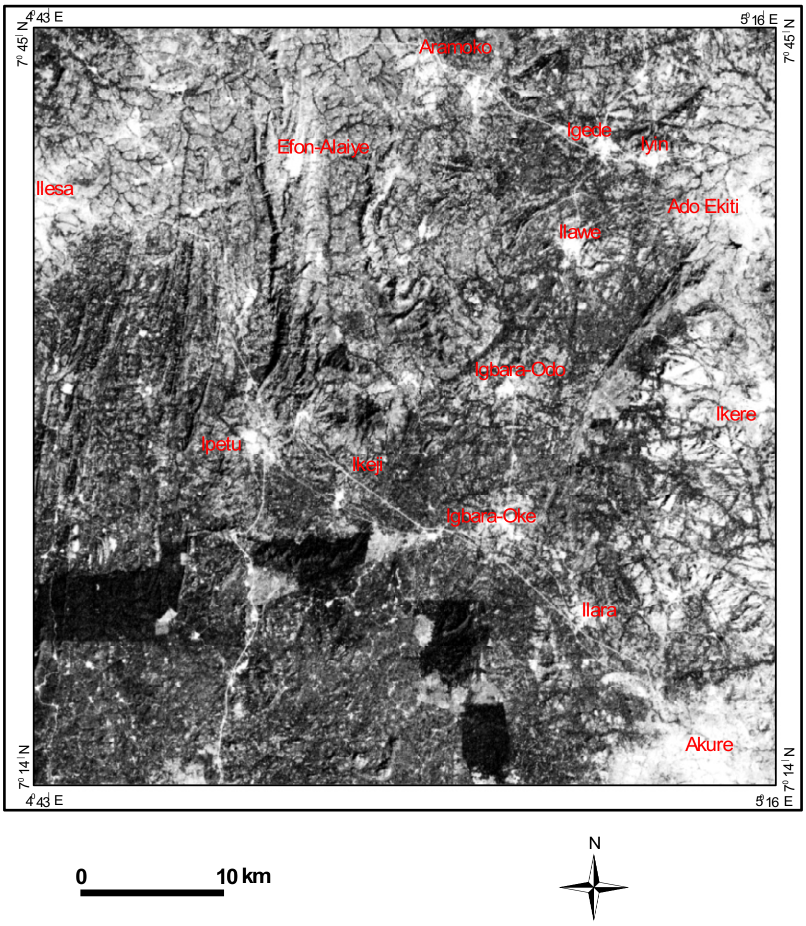

Fig. 5: Enhanced Landsat ETM + Band 7 of Ilesa- Akure Area

equated with structural elements such as folds, fractures, faults and joints (Viljoen et al., 1983). Some of the lineaments in which the road cut across may be fault particularly those that show relative displacement. Other linear features are suspected to be fracture and fissure zones. As shown in the rose diagram (Fig. 7), the four major structural trends (N-S, NNE-SSW, NW-SE, and E-W) that are typical of the Nigerian Basement Complex (Rahaman, 1989) are represented in this area. The N-S lineament trend constitutes the dominant structural trend. As shown in Figure 6, several of the linear features cut across the highway investigated and most especially within

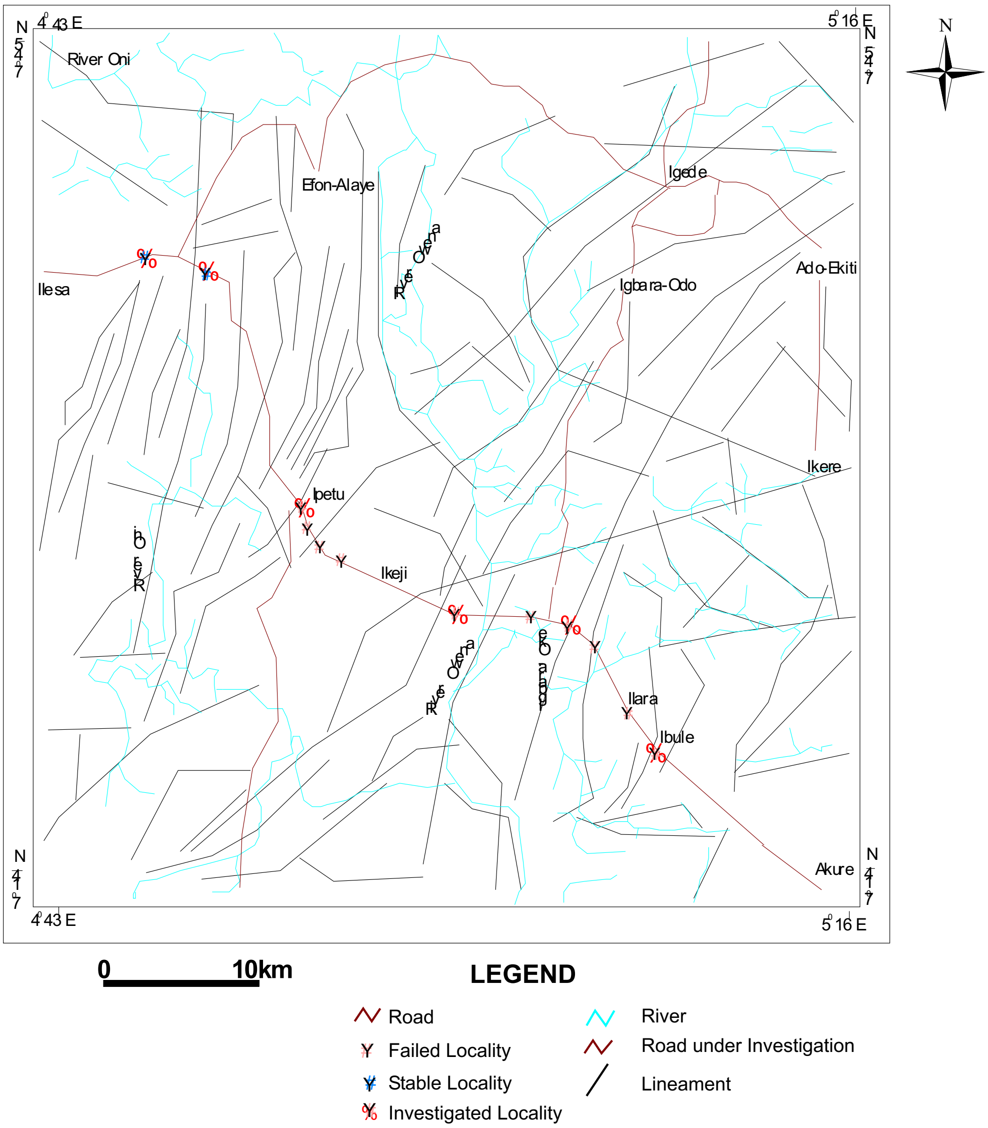

Fig. 6: Lineament Map of Ilesa Akure Area

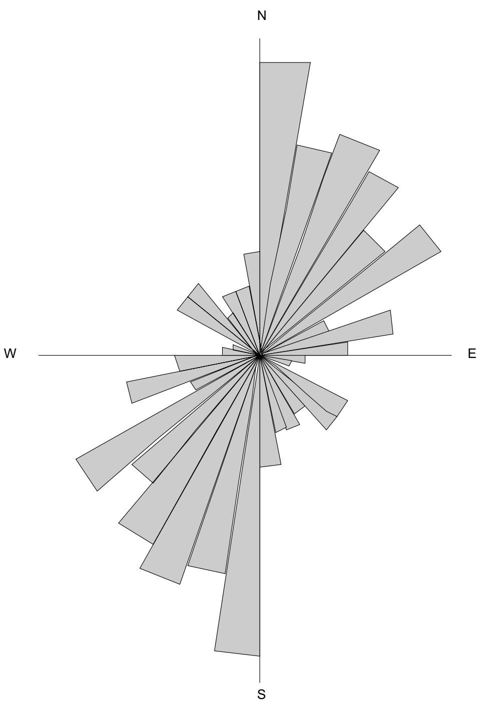

Fig. 7: Rose Diagram of the Lineaments

and around failed segments of the highway. It is suspected that such linear features may be one of the factors responsible for the perpetual failure of the failed segments of the highway, since linear features are characteristic zones of weakness.

Geotechnical Results

Moisture Content

The moisture content of the analyzed soil samples from both the control stable and failed segments of the highway are shown in Table 1. The moisture content of soils from the stable segments (control and classified stable (?)) ranges from 4-31%, while that of failed segments ranges from 4-28%. The entire soil samples have moderate to high moisture content. The ranges of moisture content of the soil samples taken from the stable and failed segments of the highway show significant overlap. It is therefore difficult to explain the causes of failure of the failed road pavement from the point

Table 1: Summary of the Geotechnical Results

Location	Sample No	Natural Moisture Content (%)	% Finer (0.075mm)	Liquid Limits (%)	Plastic Limits (%)	Plasticity Index (%)	Linear Shrinkage (%)	MDD (Kg/m^3)	OMC (%)	CBR (%)	Condition at the Time of Sample Collection
Stable 1	St1a	24	49	56	35	21	6	1660	21	38	Stable
	St1b	19	83	40	25	15	4	1457	28	37	Stable
Stable 2	St2a	5	36	47	38	9	1	1880	11	50	Stable
	St2b	4	33	38	21	17	8	1950	7	55	Stable
Failed Segment 1	FS1a	31	42	46	33	13	11	1720	20	24	Stable?
	FS1b	24	32	38	26	12	8	1720	25	51	Failed
	FS1c	17	36	42	23	19	5	1748	17	25	Failed
	FS1d	25	36	39	18	21	4	1760	16	28	Stable?
Failed Segment 5	FS5a	19	26	44	24	20	6	1780	12	49	Stable?
	FS5b	14	33	21	19	1	4	2040	9	57	Failed
	FS5c	11	31	20	10	10	3	1740	17	62	Failed
	FS5d	12	41	24	16	8	3	1900	10	50	Stable?
Failed Segment 7	FS7a	13	25	40	25	15	8	1786	17	59	Stable?
	FS7b	4	31	35	19	16	7	1984	11	84	Failed
	FS7c	19	70	34	23	11	10	1704	24	28	Failed
	FS7d	5	33	55	32	23	9	1748	20	30	Stable?
Failed Segment 10	FS10a	22	55	48	36	12	12	1797	21	72	Stable?
	FS10b	15	39	44	24	20	10	1571	29	46	Failed
	FS10c	28	66	66	61	25	16	1885	16	70	Failed
	FS10d	22	59	48	20	28	9	1620	17	20	Stable?

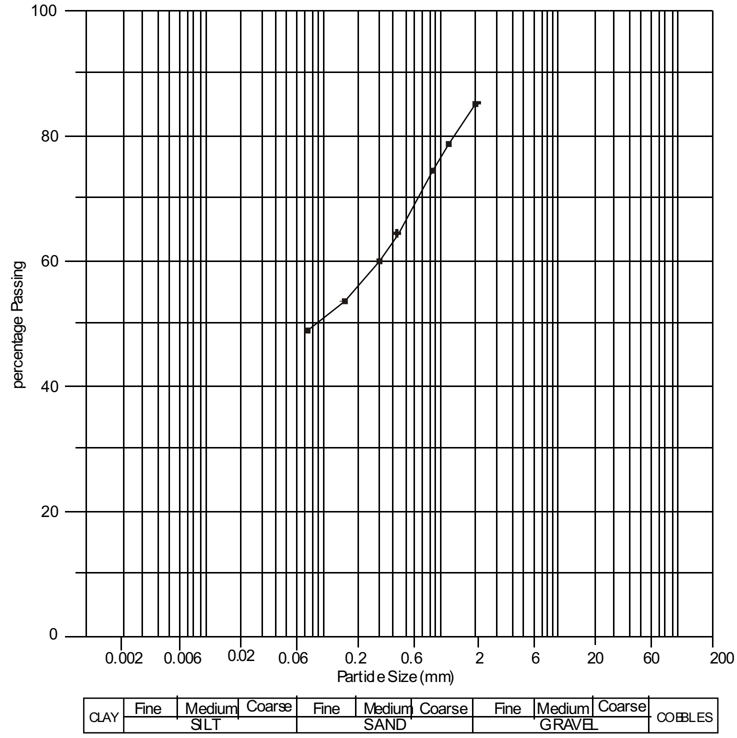

Fig. 8: Grain Size Distribution Curve for Soil Sample taken from Stable Segment 1 (St1a)

Table 2: AASHTO 1962, Soil Classification System

	Granulary Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
General Classification	A-1			A-2							A-7
											A-7-5
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-6
Sieve analysis, percentage passing:											
No. 10 (2.00mm)	50max	...…	...…	……	…...	……	…..	……	……	……	……
No. 40 (0.425mm)	30max	50max	51max	……	…...	……	…..	…...	…...	…...	……
No. 200 (0.075mm)	15max	25max	10max	35max	35max	35max	35max	35max	36min	36min	36min
Characteristics of fraction passing No. 40 (0.425mm)											
Liquid Limit	…..	…..	…….	40max	40min	40max	41min	40max	41min	40max	41min
Plasticity Index	6max		N.P	10max	10max	11min	11min	10max	10max	11min	11min
Usual types of significant Materisls	Stone fragments Gravel and sand		Fine Sand	Silty of Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General rating as subgrade	Excellent to good							Fair to poor			

Table 3: Threshold Geotechnical Properties for Highway (Extracted from FMWH, 1972)

% Finer (0.075mm)	Liquid Limits (%)	Plastic Limits (%)	Plasticity Index (%)	Linear Shrinkage (%)	Unsoaked CBR (%)
≤ 35	50 Maximum	30 Maximum	20 Maximum	8 Maximum	80 Minimum

of the view of the moisture content of the soils only.

Grading Characteristics

The results of the grain size distribution analyses are presented in Table 1. Typical grading curve is presented in Figure 8. The soils from control stable segments have percentage finer (percentage passing 0.075mm) ranging from 33 - 83%, while that of failed and classified stable (?) segment ranges from 31-70% and 25 59% respectively. From the grading curves, the soils can be classified as well graded soil. Most of the soils have percentage passing No. 200 (0.075 mm) of more than 35%, hence, the soils range in group classification from A-4 to A-7 and are generally rated as fair to poor sub-grade highway materials (Table 2). Most of the studied soils (stable and failed localities) did not fall within the Federal Ministry of Works and Hosing (FMWH) ((1972) grading specification (Table 3). The ranges of the percentage finer of the soils beneath the stable and failed segments (Table 1) show significant overlap; hence the perpetual failure of the failed segments of this highway can not be explained base on grain size distribution only.

Consistency Limits

As shown in Table 1, the Liquid Limit of the soil samples from the control stable segments ranges from 38-56%, while those from presently classified stable (?) and failed segments range from 24 - 55% and 20-66% respectively. Typical Liquid Limit curve is shown in Figure 9. The Plastic Limit of the soils ranges from 21-38%, 16 - 36% and 10-41% for the control stable, current classified stable (?) and failed segments respectively. The Plasticity Index of soils beneath the control stable segments ranges from 9-21%, while that of the currently classified stable? and failed segment ranges from 8 28% and 1-25% respectively. Most of the soils (stable and failed localities) investigated fall within the FMWH (1972) specification (Table 3), and are suitable sub-grade materials. Using the America Association of State Highway and Transportation Officials (AASHTO) (1962) classification system shown in Table 2, the soil samples from both the stable and failed segments belong to group A-4 to A-7, hence the soil can be rated to be of fair to poor sub-grade materials. The Casagrande (1948) Chart (Figs. 10a and 10b) generally indicate medium plasticity for both the soils beneath the stable and failed segments, hence , the soils are expected to exhibit low to medium swelling potential (Ola, 1982). The Linear Shrinkage of the soils beneath the stable and classified stable (?) segment ranges from 1-8% and 3-12% respectively, while that of the failed segments ranges from 3-16% (Table 1). The Linear Shrinkage of most of the soils are 8% recommended by Brink *et. al.* (1982) and Madedor (1983) for highway sub-grade, hence the soils are good sub-grade materials. As discussed above, the consistency limits of the soil beneath the stable and failed segments of the studied highway did not exhibit significant difference and generally fall within the recommended specification by FMWH, 1972. Both soils are rated poor to fair for pavement materials, hence, the cause of failure along the failed segments of this highway may be difficult to explained from the point of view of consistency limits only.

Compaction Characteristics

The Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) obtained from the tested soils are presented in Table 1 while Figure 11 shows typical compaction curve. The The

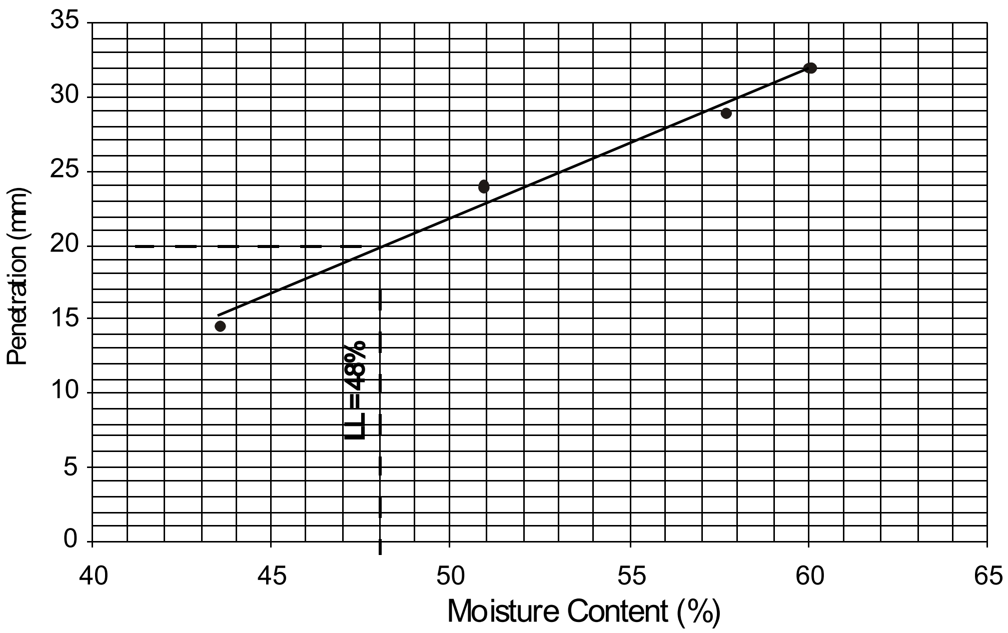

Fig. 9: Liquid Limit Graph for Soil Sample taken from Failed Segment 10 (Fs10a)

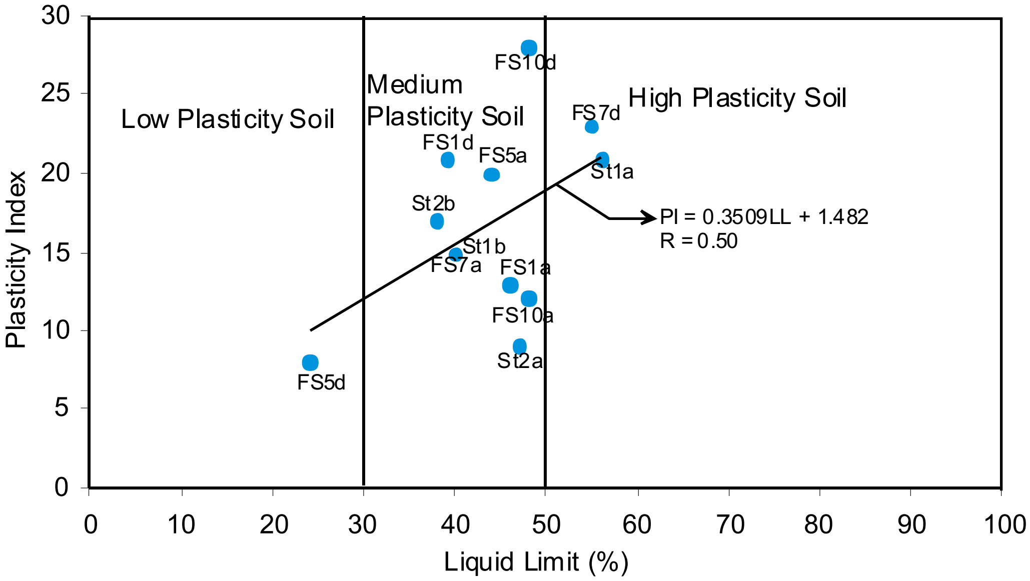

Fig. 10a: Casagrande Chart Classification of the Soils beneath Stable Segments (Based on Casagrande, 1948)

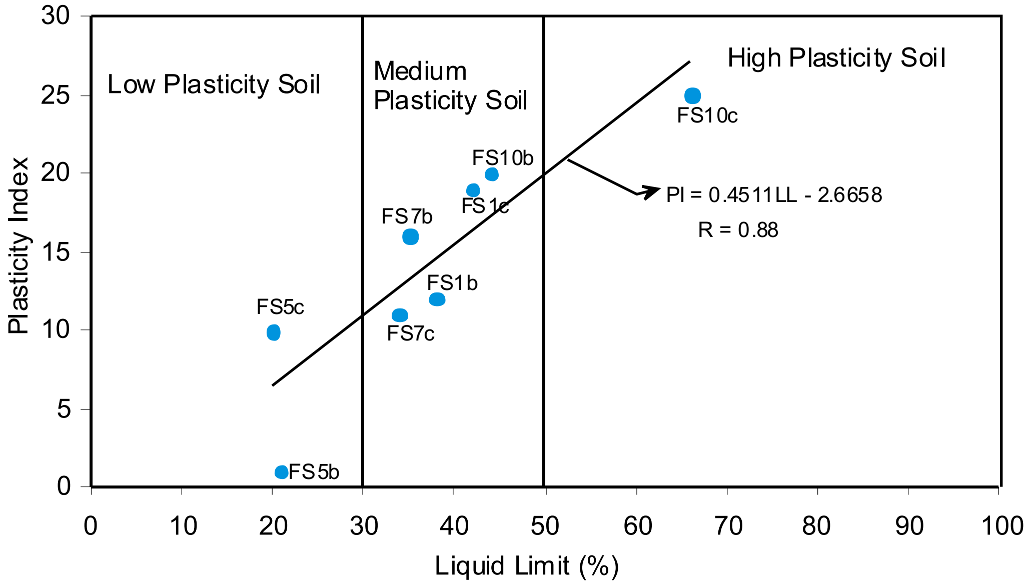

Fig. 10b: Casagrande Chart Classification of the Soils beneath Failed Segments (Based on Casagrande, 1948)

Optimum Moisture Content (OMC) ranges from 7-28% for soil beneath the control stable segments and 10 -20% for soil beneath the classified stable (?) segments, while that of failed segments ranges from 9-29%. The Maximum Dry Density (MDD) ranges from1457-1950 Kg/m^3,1620 - 1900 Kg/m^3 and 1571-2040 Kg /m^3 for subsoil beneath control stable, classified stable (?) and failed segments respectively. There is significant overlap between the values of compacted parameters of the soils beneath the control stable segments and failed segments; hence compaction characteristic of the soils may not be a good index for the highway pavement stability.

California Bearing Ratio (CBR)

The unsoaked California Bearing Ratio (CBR) values for soil beneath the control stable segments ranges from 38 - 55%, while those of the classified stable (?) and failed segments range from 20 to 72% and 25 to 84% respectively (Table 1). Figure 12 shows the CBR curve for sample FS1d. The unsoaked CBR value stipulated by the FMWH standards (1972) for sub-grade soils is 80% minimum (Table 3). The only soil sample with CBR value within this specification is the soil sample FS7b taken from the failed segment at locality 7. There is thus, no clear-cut correlation between the values of CBR of sub-grade soils and the degree of stability of highway pavement. The

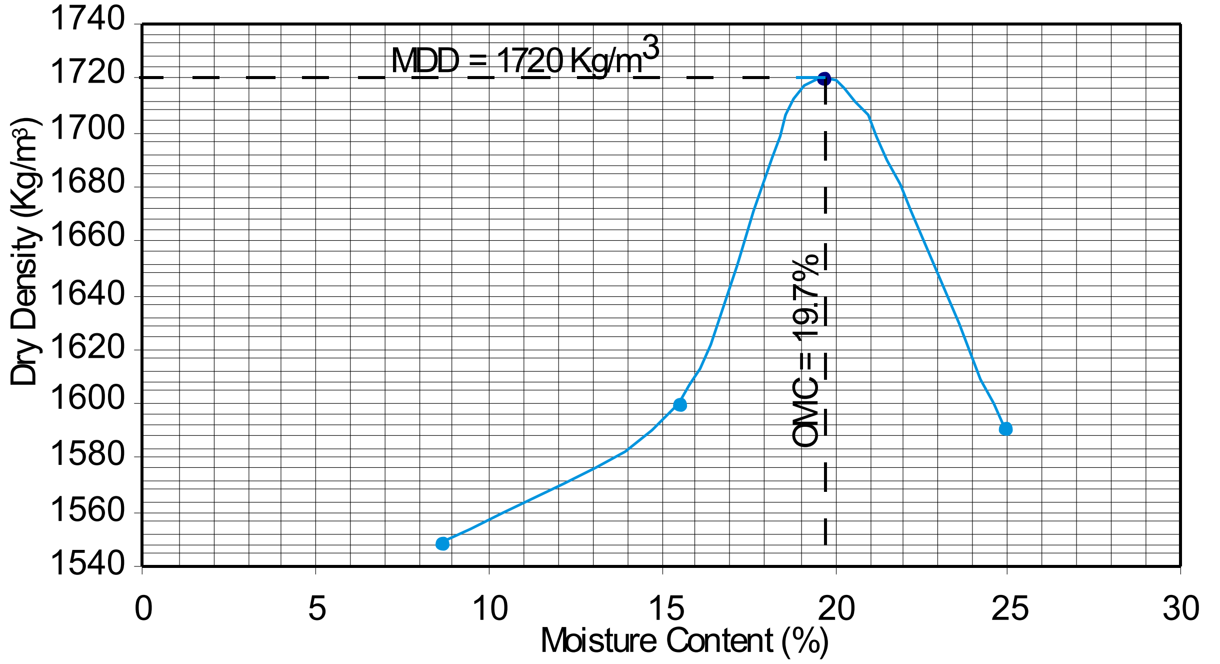

Fig. 11: Compaction Curve for Soil Sample taken from Failed Segment 1 (FS1d)

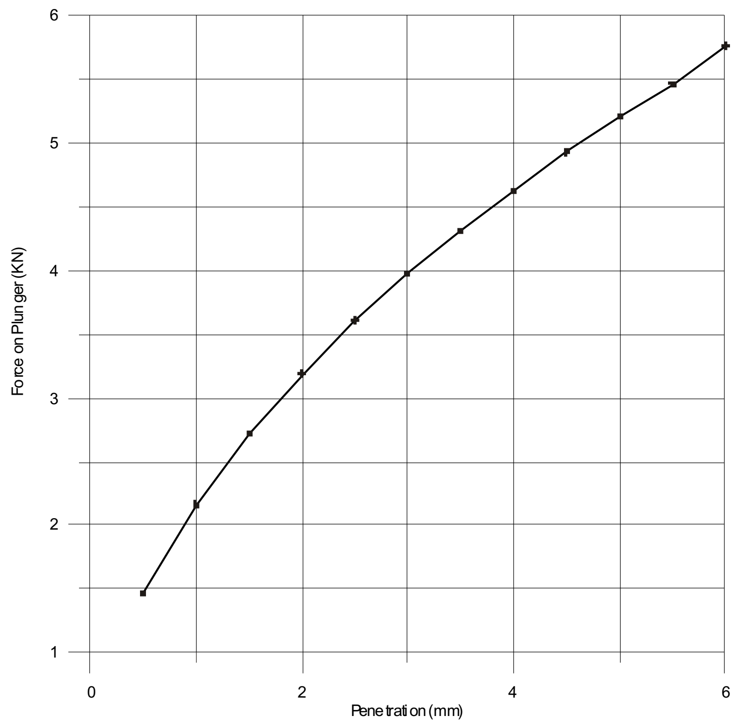

Fig. 12: Typical CBR Curve Soil Sample taken from Failed Segment 1 (Fs1d)

cause of perpetual failure of the failed segments along this highway may therefore not be related to the CBR. From the above, there seems to be a poor correlation between the geotechnical properties of soils and the road stability.

Subsoil Conditions of the Highway

Field observation and results of geophysical investigation carried out by Akintorinwa *et al.* (2010) along the highway showed that failed segments 1 and 10 are underlain by low resistivity (<100 ohm-m) clay substratum. The toe of the failed segment 1 was also ponded as at the time of the investigation due to poor embankment drainage system.

The highway is underlain by the Okemesi, Ondo, Egbeda and Itagunmodi soil associations (Fig. 13). The Okemesi Association are composed of well-drained coarse texture, very gravelly soils derived from quartz schist and massive quartzite. The soils underlie stable segment 2. The Ondo Asiciation underlie failed segment 1. The soils are well-

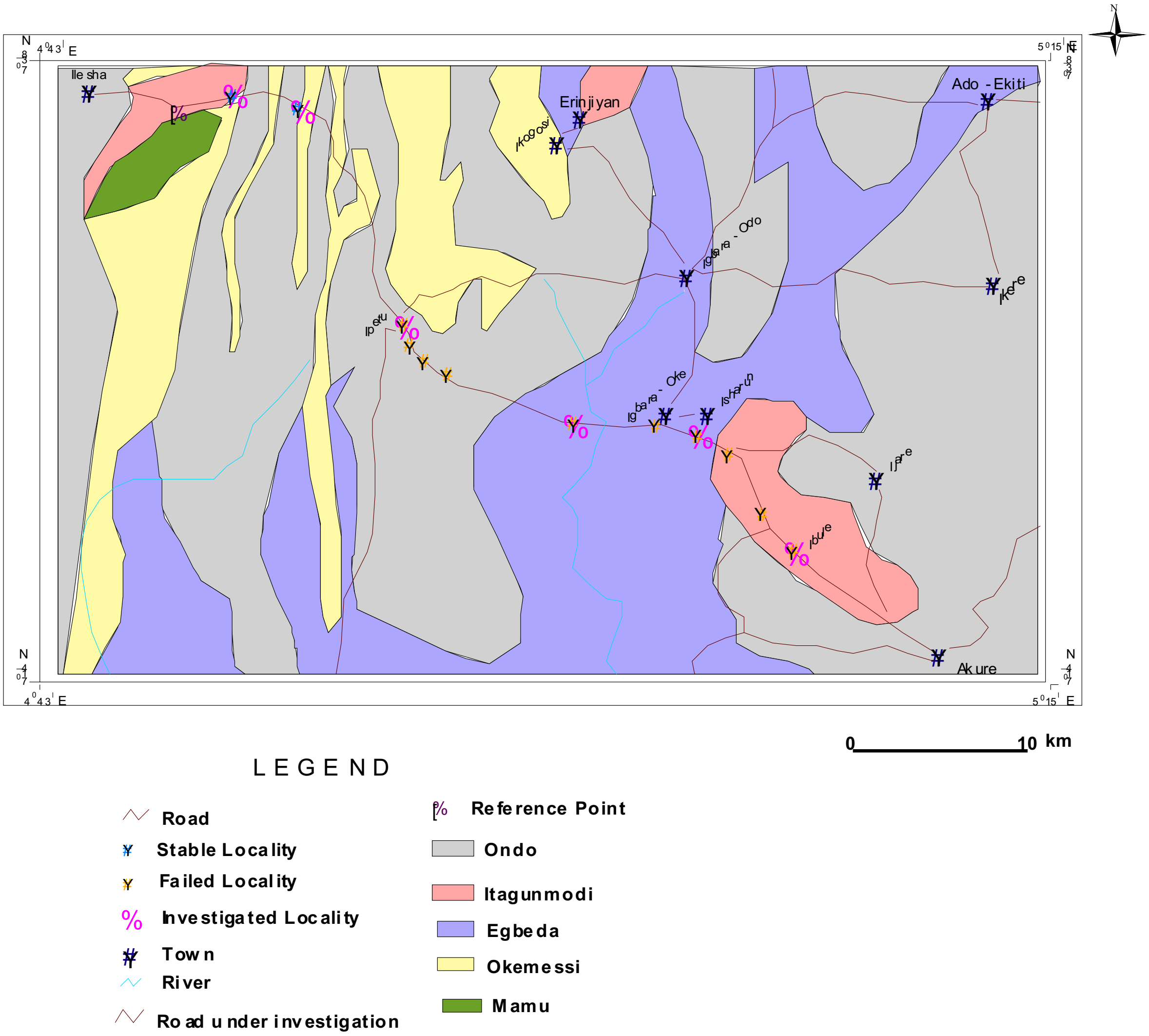

Fig. 13: Soil Map along the Ilesa-Akure Highway (Modified After Smyth and Montgomery, 1962)

drained, medium to fine texture soils overlying orange, brown, yellow brown and brown mottled clay derived from medium-grained granitic rocks and gneisse. The Egbeda Association are also well-drained fine textured soils overlying red , brown yellow brown and white mottled clay mainly derived from fine-grained biotite gneiss and schist. The soils Association underlie failed segments 5 and 7. The Itagunmodi Association underlie failed segment 10. The soils are composed of brownish red very clayey soils derived from amphibolites and charnockite rocks. It follows from the above that the failed segments are underlain by clayey subsoils.

CONCLUSIONS

Remote sensing and geotechnical methods have been used to study the causes of road pavement failure along the Ilesa-Akure highway. Four failed segments and two stable segments were selected for the study. The two stable segments served as control. The remote sensing derived lineament map of the area shows that several linear features cut across the highway investigated. Lineament features were identified virtually across all the failed localities with a predominant structural trend in N-S direction. The geotechnical results generally show largely unsuitable geotechnical properties at the stable segments (stable1 and 2) and the failed and classified stable (?) sections of all the failed localities. The geotechnical properties of subsoil beneath both the failed and stable segments show significant overlap. Suspected near surface linear (geological) features may have acted as zones of weakness that enhance the accumulation of water leading to pavements failure as observed in the failed segments. Clay substratum and ponded embankment toe could also have contributed to the pavement failure.

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