The Kano–Kazaure highway, north central Nigeria: the significance of the engineering geology in construction

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Abstract Kano–Kazaure highway traverses granitic rock with minor occurrences of metasediments and fine sandy deposits. The soil profiles were studied to determine their suitability in the proposed dualization of the highway route as part of the Trans-Sahara international highway construction project. The soils derived from the granitic rocks are well graded, with a high maximum dry density and low optimum moisture content. The soils derived from the schistose and quartzite zone are also suitable for road base and sub-base but the transported loose silty fine sand/sandy silty soils of the Chad Formation are only limited suitability.

Keywords Geology · Highway · Construction · Engineering · Soil · Rock

Résumé L'autoroute de Kano–Kazaure traverse des roches granitiques comportant des intercalations de roches sédimentaires métamorphisées et de dépôts sableux. Les profils de sols ont été étudiés afin de déterminer leurs utilisations possibles suivant deux tracés d'une section du projet de cette autoroute internationale trans-saharienne. Les sols issus des roches granitiques sont bien gradués, avec une forte densité sèche maximum et une faible teneur en eau optimale. Les sols issus de la zone à schistes et quartzites sont aussi adaptés pour les couches de base et les couches de forme mais les sols constitués de sables fins silteux ou de silts sableux lâches de la formation du Tchad sont peu réutilisables.

Mots clés Géologie · Autoroute · Construction · Ingénierie · Sol · Roche

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Introduction

Roads of various categories in Nigeria have shown signs of failure in the form of cracking, rutting, deformation and peeling (Abam et al. 2005). In some cases, these signs of distress are visible within a short period of commissioning the road yet the reasons have not been fully established. Some researchers (Arumalu and Akpokodje 1987; Jegede 2004; Osadebe and Omange 2005) have attempted to link these failures to poor construction materials, soil properties, poor workmanship, high traffic volume etc., but geological considerations in the design and construction have not been fully addressed.

Road contractors are often issued with specifications which characteristically state that 'approved laterites' must be located and used for base and sub-base courses and embankments. No definitions are offered with respect to the 'approved laterites'. Consequently, the use of diverse reddish soils ranging from micaceous clays to very sandy clay materials have been the practice; the contractors selecting the material mainly on the basis of convenience and cost rather than the performance and life expectancy of the road (Mesida 1987).

The purpose of this work was to investigate the geological nature and the variation pattern of the soil characteristics in the study area.

Location, geomorphology and geology of the study area

The study area is the 68 km highway linking Kano from Mile Tara in the Ungogo local government area of Kano State to Kazaure in the Kazaure local government area of Jigawa State. The road is a section of the proposed Trans-Sahara international highway that is proposed to link Nigeria, Niger and Libya. Kano is located at latitude 12°00′N and longitude 8°30′E while Kazaure is located at latitude 12°37′N and longitude 8°26′E (Fig. 1). The route crosses undulating terrain with the lowest section (Gada river) at an elevation of about 25 m asl and the highest portion (Mile Tara) at about 110 m asl. The climate of the area is very seasonal, controlled by the dry northeasterly air mass of Sahara origin and humid maritime air from the Atlantic Ocean. The vegetation is savannah with a few high trees.

The Kano–Kazaure highway traverses both granitic rocks of the Precambrian basement complex with minor meta-sediments and part of the sedimentary deposits of the Chad basin (Fig. 1). The regional geology of the area shows that the section from Mile Tara (chainage 0+000) to Dambarta (chainage 26+000) is dominated by a granitic intrusion. At Ajumawa (chainage 26+000 to 47+200) there is a transition zone between the crystalline basement complex rocks and sedimentary deposits of the Chad Formation while from Ajumawa to Kazaure (chainage 47+200 to 65+100) the silt/sandy and clayey deposits of the Chad Formation predominate. Residual soils (engineering soils) of variable thickness have been developed on these basement rocks. The soils derived from the granitic rocks are mainly lateritic sandy clay and lateritic clayey sand. The soils derived from the quartzite and schistose rocks are lateritic silty clayey sand. The sedimentary deposits consist of loose silty fine sand and sandy silt.

Methods of study

The methodology adopted for the study included both field and laboratory studies as well as geophysical investigations. One hundred and twenty-six (126) 100 mm diameter holes were hand augered to depths of 0.15–1.5 m following British Standard Institute BSI 5930 (1990) and the soil samples recovered examined, identified and classified in the field. In addition, 15 test pits were excavated for the collection of bulk samples.

Thickness of the soil profile and depth to the bedrock were determined using the vertical electrical sounding (VES) technique with the Schlumberger electrode configuration based on significant geological features. A digital ABEM Terrameter (SAS) 4000/1000 (2004) was used for the data acquisition and the interpretation of the field depth sounding curves was achieved by the partial curve matching method and computer iteration using Orellena and Mooney (1988).

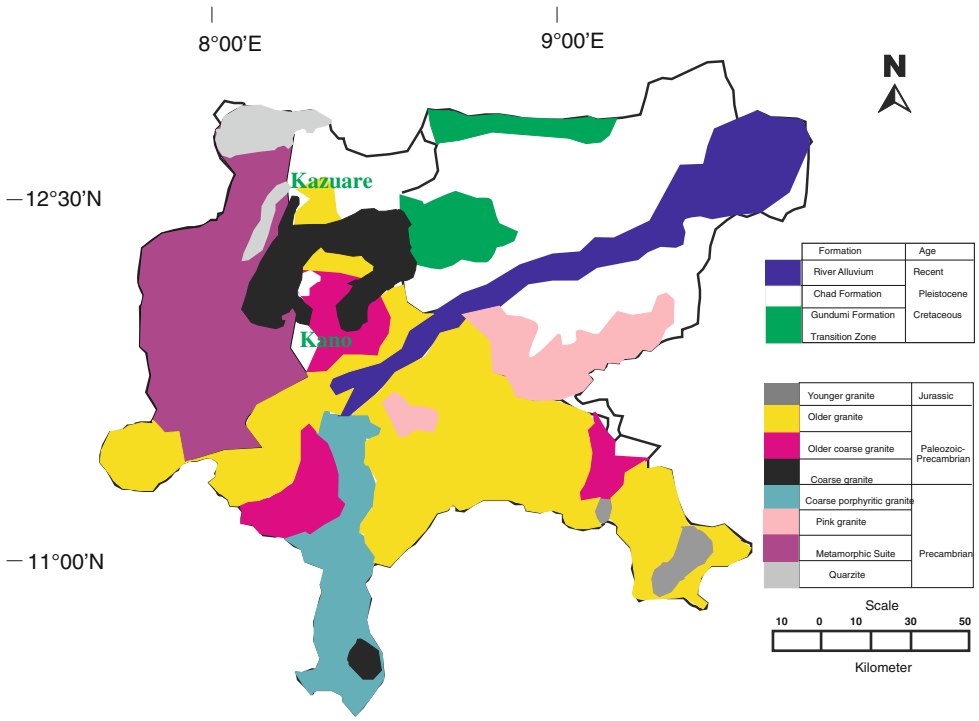


Fig. 1 Geological map of Kano State showing Kano–Kazuare road

Table 1 Typical results of particle size distribution analysis

S/No	Location	Percentage passing (%)				AASHTO	Soil description	Parent rocks/materials
		4.75 mm	2.0 mm	0.425 mm	0.075 mm			
1	3+950	100	99	94	48	A-2-7	Lateritic clayey sand	Granitic rock
2	5+600	84	24	9	5	A-1-a	Lateritic clayey sand	Granitic rock
3	9+525	62	46	37	22	A-2-4	Lateritic clayey gravel	Granitic rock
4	11+200	100	97	92	34	A-2-4	Lateritic silty sand	Granitic rock
5	14+650	87	85	81	27	A-1-b	Clayey gravelly sand	Granitic rock
6	15+400	83	78	72	23	A-2-6	Lateritic clayey gravelly sand	Quartzitic/schistosic rock
7	18+000	100	100	96	30	A-2-7	Clayey silty sand	Quartzitic/schistosic rock
8	19+000	60	52	43	3	A-1-a	Lateritic clayey gravelly sand	Granitic rock
9	22+000	72	71	48	23	A-1-b	Lateritic clayey sand	Granitic rock
10	25+000	87	84	77	31	A-2-7	Lateritic clayey gravelly sand	Granitic rock
11	26+000	84	80	62	35	A-2-7	Lateritic clayey sand	Transition zone granitic rock and sedimentary deposit
12	30+000	100	100	96	23	A-2-4	Lateritic clayey sand	Transition zone granitic rock and sedimentary deposit
13	30+550	100	100	94	25	A-2-4	Silty fine sand	Transition zone granitic rock and sedimentary deposit
14	33+500	100	100	93	18	A-2-4	Silty fine sand	Transition zone granitic rock and sedimentary deposit
15	35+000	97	91	70	33	A-2-6	Lateritic clayey silty sand	Transition zone granitic rock and sedimentary deposit
16	36+000	93	94	90	34	A-2-6	Lateritic clayey gravelly sand	Transition zone granitic rock and sedimentary deposit
17	37+500	94	92	41	34	A-2-4	Lateritic clayey silty sand	Transition zone granitic rock and sedimentary deposit
18	40+600	96	94	42	35	A-2-4	Lateritic silty sand	Transition zone granitic rock and sedimentary deposit
19	48+000	100	100	97	32	A-2-4	Lateritic silty sand	Transition zone granitic rock and sedimentary deposit
20	50+000	100	92	90	30	A-2-5	Clayey silty sand	Sedimentary deposit
21	51+000	100	98	90	28	A-2-5	Clayey silty sand	Sedimentary deposit
22	54+000	84	82	77	16	A-2-4	Silty fine sand	Sedimentary deposit
23	56+500	86	78	75	20	A-2-4	Silty fine sand	Sedimentary deposit
24	58+500	100	100	86	38	A-4	Sandy silt	Sedimentary deposit
25	61+000	100	96	78	28	A-2-4	Silty fine sand	Sedimentary deposit
26	63+000	100	100	92	41	A-4	Sandy silt	Sedimentary deposit
27	65+000	100	100	96	37	A-4	Sandy silt	Sedimentary deposit
28	67+000	100	100	88	36	A-4	Sandy silt	Sedimentary deposit

Table 2 Typical results of consistency test in the study area

S/No	Location	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Natural moisture content (%)	Linear shrinkage (%)	Parent rocks/materials
1	3+950	44	31	13	10	–	Granitic rock
2	5+600	34	22	12	4	7	Granitic rock
3	9+525	26	17	9	–	5	Granitic rock
4	11+200	38	23	15	–	8	Granitic rock
5	14+650	25	21	4	–	–	Granitic rock
6	15+400	40	22	18	8	10	Quartzitic/schistose rock
7	18+000	44	23	21	12	11	Quartzitic/schistose rock
8	20+500	18	12	6	–	7	Transition zone granitic rock and sedimentary deposit
9	21+500	22	14	8	–	7	Transition zone granitic rock and sedimentary deposit
10	22+000	22	16	6	5	7	Transition zone granitic rock and sedimentary deposit
11	24+000	32	20	12	–	9	Transition zone granitic rock and sedimentary deposit
12	25+000	47	20	27	–	12	Transition zone granitic rock and sedimentary deposit
13	25+500	45	22	23	–	11	Transition zone granitic rock and sedimentary deposit
14	26+000	42	20	22	8	12	Transition zone granitic rock and sedimentary deposit
15	35+000	45	26	19	7	11	Transition zone granitic rock and sedimentary deposit
16	36+000	38	20	18	5	11	Transition zone granitic rock and sedimentary deposit
17	37+500	32	14	18	6	9	Transition zone granitic rock and sedimentary deposit
18	40+600	48	22	26	–	–	Transition zone granitic rock and sedimentary deposit
19	50+000	22	15	7	5	8	Sedimentary deposit
20	51+000	21	15	6	4	6	Sedimentary deposit

The laboratory tests included natural moisture content, liquid and plastic limits and grain size distribution. In addition, compaction tests were undertaken to determine the density and moisture content relationship. Soaked and un-soaked California bearing ratio (CBR) tests were performed on the soil samples at optimum moisture content and maximum dry density, using a 48 h soaking period.

Results and discussion

The soil profile

Three types of soils were observed in the study area, two residual and a transported soil. The residual soils derived from the granitic rocks (chainage 0+000 to 26+000) are predominantly reddish or yellowish red lateritic sandy clay/clayey gravelly sand, generally firm to stiff with occasional gravelly particles. Soils within the transition zone occurring between the crystalline rock and the sedimentary deposits of the Chad Formation (chainage 26+000 to 48+000) are composed of alluvial silty fine sand and lateritic silty sand/lateritic sandy silty clay. The transported soil is the loose silty fine sand and silt deposits of the Chad Formation found from chainage 48+000 to 68+000.

Soil engineering properties

The engineering properties of the soils are presented in Tables 1, 2 and 3 and the grading envelopes in Figs. 2, 3 and 4. It can be seen that the soils derived from the granitic rocks and the metasediments are well graded with appreciable fines and medium to coarse particle sizes. They are classified as mainly A-2-.7, A-1-b and A-2.4 (AASHTO classification system) and constitute excellent to good subgrade soil materials. In contrast, the transported loose silty

Table 3 Typical results of compaction and California bearing ratio (CBR) tests

S/No	Location (chainage)	MDD (mg/m^3)	OMC (%)	Unsoaked CBR (%)	Soaked CBR (%)	Parent rocks/materials
1	3+950	2.03	14.0	45	35	Granitic rock
2	5+600	2.16	8.5	78	53	Granitic rock
3	9+525	2.15	12.0	48	32	Granitic rock
4	11+200	1.83	14.0	28	16	Granitic rock
5	14+650	1.96	9.6	55	42	Granitic rock
6	15+400	1.92	14.0	32	19	Quartzitic/schistose rock
7	18+000	1.96	15.0	27	12	Quartzitic/schistose rock
8	19+000	2.12	15.0	63	48	Granitic rock
9	22+000	1.91	16.0	45	27	Granitic rock
10	30+550	1.72	21.0	27	10	Transition zone granitic rock and sedimentary deposit
11	40+600	1.92	11.0	42	31	Transition zone granitic rock and sedimentary deposit
12	54+000	1.69	20.0	31	14	Sedimentary deposit
13	63+000	1.65	23.0	30	12	Sedimentary deposit
14	67+000	1.60	21.0	32	14	Sedimentary deposit

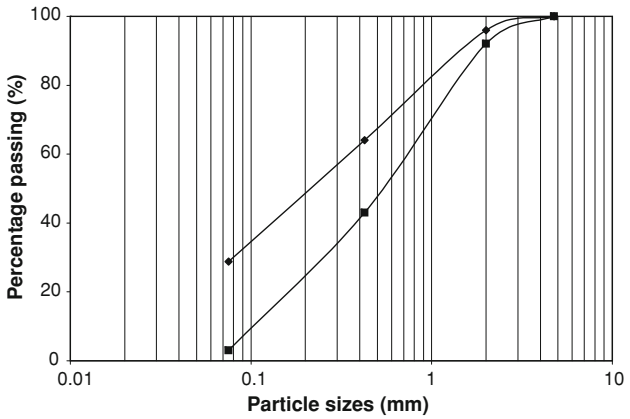


Fig. 2 Particle size envelope for soils from kilometer 0–26

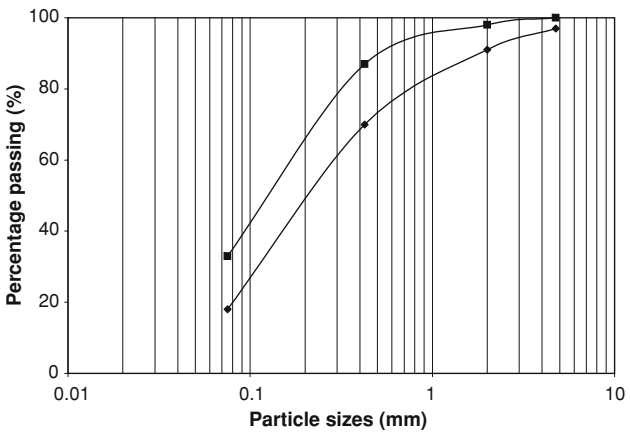


Fig. 3 Particle size envelope for soils from kilometer 26–48

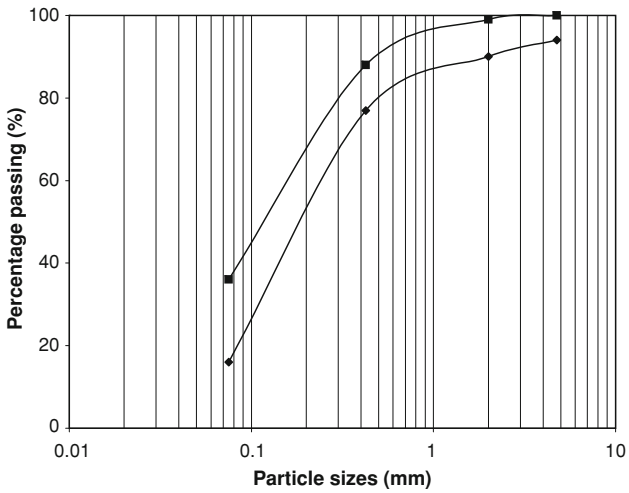


Fig. 4 Particle size envelope for soils from kilometer 48–68

fine sand/sandy silt deposits are relatively very poorly graded. With a classification of mainly A-4, they are rated as fair to poor sub-grade soil materials. The soils within the transition zone fall within soil groups A-2-4 to A-7-6 and exhibit good to fair sub-grade properties. A summary of the geotechnical properties of the subgrade soils and the variation in geology along the road is presented in Fig. 5. The Casagrande (1947) chart (see Fig. 6) shows the consistency characteristics of the three soil types. The soils derived from the granitic rocks and the meta-sediments of quartzitic and schistose rocks have medium plasticity while the transported silty fine sand of the Chad Formation is non-plastic.

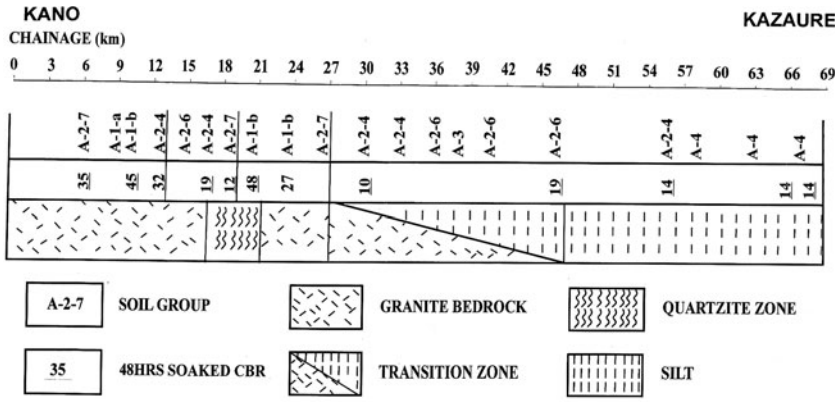


Fig. 5 Summary of geotechnical properties of the subgrade soils and variation in geological nature along the road

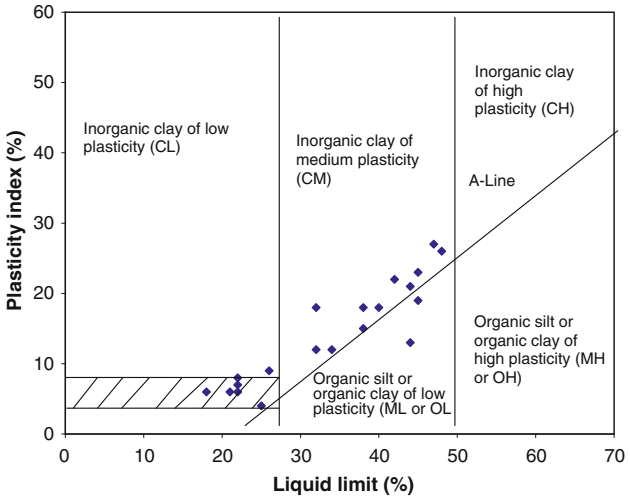


Fig. 6 Casagrande chart of the tested soils of the area

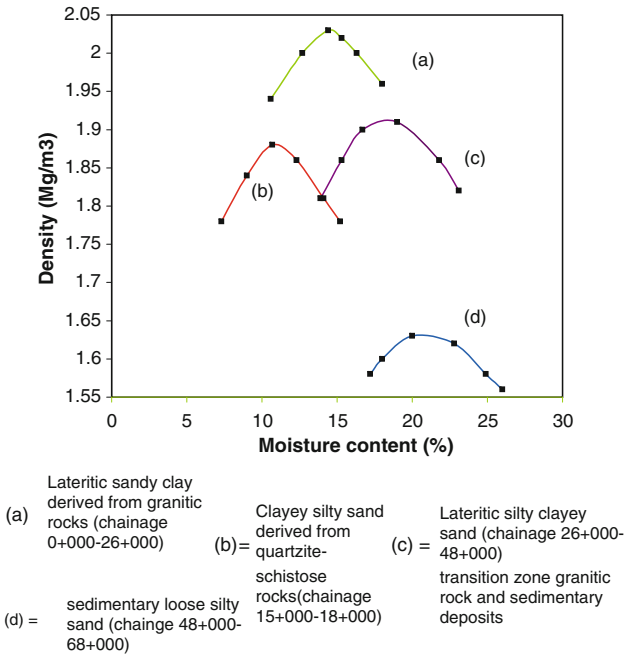


Fig. 7 The typical moisture/density relationship curves of the tested soil of the studied area

The moisture/density relationship of the soils is shown in Fig. 7. The loose silty fine sand of the Chad Formation attained the least maximum dry densities (MDD) ranging from 1.6 to 1.69 Mg/m^3 with an average of 1.65 Mg/m^3. The lateritic clay/silty sand derived from the porphyritic granitic rock attained the highest MDD values, ranging from 1.83 to 2.16 Mg/m^3 with an average of 1.98 Mg/m^3. The soils from the schistose and quartzite zone have MDDs ranging from 1.92 to 1.96 Mg/m^3 with an average of 1.94 Mg/m^3.

A summary of the compaction test results is given in Table 3. The loose silty fine sands of the Chad Formation have the highest optimum moisture content (OMC) ranging from 20 to 23% with an average of 21%. The soils derived from the granitic rock have the lowest OMC ranging from 8.5 to 21% with an average value of 13%. The relatively high OMC of the loose silty fine sand in due to the abundant fines content with a more pronounced plasticity than the soils derived from the granitic rocks. Clayey soils imbibe more water than cohesion-less soils to attain maximum compaction. The apparent lack of cohesion in the loose silty fine sand could be the reason for the frequent erosion on the Kazaure end of the Kano–Kazaure section of road.

The California bearing ratio (CBR) has been accepted as a useful test for evaluating the suitability or otherwise of soils for highway construction (Asphalt Institute 1962). The soaked and un-soaked CBR values are presented in Table 3. Generally, they range from 10 to 53% and 27 to 78%, respectively, with the results for the loose silty fine sand range from 12 to 14% and 30 to 32% and those for the quartzitic and schistose rocks from 10 to 48% and 27 to 63%, respectively. The loose silty fine sand is the most sensitive to soaking with about 18% increase in moisture content absorbed within the 48 h soaking period. Generally, the CBR values decreased from about 10 to 17%. The

Table 4 Typical results of vertical electrical sounding of the subsoil profile along Kano–Kazuare Road

Location	Resistivity (Ω m)	Thickness (m)	Depth (m)
3+050	210.0	1.2	1.2
	420.0	2.4	3.6
	64.0	0.3	3.9
	360.0	8.1	12.0
	22.0	1.2	13.2
	240.0	–	–
9+000	185.4	1.6	1.6
	196.5	2.7	4.3
	34.5	0.4	4.7
	472.4	6.1	10.8
	40.7	7.4	18.2
	683.4	–	–
12+000	270.0	0.7	0.7
	338.0	2.0	2.7
	60.0	1.8	4.5
	75.0	13.5	18.0
	298.0	3.0	21.0
	20.0	5.0	26.0
	280.0	–	–
15+000	435.7	1.0	1.0
	339.9	6.2	7.2
	307.1	1.5	8.7
	21.8	–	–
18+000	183.2	0.8	0.8
	351.6	2.3	3.1
	59.3	0.8	3.9
	71.1	20.7	24.7
	416.2	–	–
21+000	80.3	1.2	1.2
	263.2	2.5	3.7
	198.4	3.4	7.1
	60.0	3.5	10.6
	1,002.0	–	–
31+450	323.4	1.2	1.2
	1588.3	3.3	4.5
	326.4	8.0	12.5
	129.8	–	–
38+000	238.5	1.1	1.1
	1,612.2	2.7	3.8
	273.2	7.9	11.6
	126.3	–	–
58+000	42.9	0.4	0.4
	87.2	5.2	5.6
	10.4	1.1	6.8
	501.8	–	–

soils derived from granitic rocks are the least sensitive, with about 13% moisture being absorbed within 48 h.

Soil electrical properties

The apparent resistivity values are presented in Table 4. At the Kano end, a clayey sand and clayey gravelly sand of about 4.0 m thickness with apparent resistivity values of 34–420 Ω m is underlain by a deposit of clayey silty fine sand of apparent resistivity values ranging from 22 to 472 Ω m with a minimum thickness of about 10 m. At the Kazaure end, the soil is a loose silty fine sand of 0.4–5.6 m thickness with apparent resistivity values of 43–87 Ω m.

Generally, the granitic rock derived soils have apparent resistivity values which range from 20 to 683 Ω m while the transported soils of the Chad Formation have apparent resistivity values ranging from 10 to 502 Ω m. The schistose-quartzite meta-sediment terrain recorded relatively high apparent resistivity values ranging from 126 to 1,612 Ω m. In this section of the road, the apparent resistivity values of the second layers are high, ranging from 1,588 to 1,612 Ω m.

The relatively higher resistivity values recorded for the residual soils in comparison with the transported soils is an indication of the extent of laterization resulting in the presence of significant iron oxide. The high resistivity values observed for the schistose-quartzite derived soils are attributed to the high ground elevation relative to the water table. This creates a relatively thick moisture deficient zone with high resistivity. Consequently, although the soils may be essentially identical, variations in moisture content can represent a significant difference in the soil resistivity.

Conclusions

The engineering properties of the three main soil types along the Kano–Kazuare road have been studied in relation to the geology of the area and its implications for highway design and construction. The basic engineering parameters of texture, consistency, compaction and California bearing ratio (CBR) were obtained through field and laboratory studies.

At the Kano end of the road, the lateritic clayey sand is darkish red, predominantly firm to stiff in consistency and has relatively high maximum dry density and low optimum moisture content. The soaked and unsoaked CBR values are also high in this section of the road. At the Kazaure end, the soil is sandy and loose in consistency. Generally, the soaked CBR values were widely variable, ranging from 10 to 53%.

The loose silty fine sand/sandy silt of the Chad Formation recorded less satisfactory results than other two soils types. Generally, the soils derived from granitic rock and quartzite/schistose rocks recorded better results. The tendency for excessive water absorption by the loose silty fine sand will make them less attractive as base or sub-base materials and would explain the premature failure of the pavement at the Kazaure end of the road. However, these loose silty fine sands are suitable for surfacing of earth roads and embankment fill.

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