Original Research Article

Geotechnical Evaluation of Road Pavement Failure Along the Awotan-Akufo Road, Oyo State Southwestern Nigeria

ABSTRACT

In order to access the cause(s) of road failure and proffer preventive measures for the future reconstruction of the Awotan-Akufo road, southwestern Nigeria, the geotechnical engineering properties of the subgrade soil, asphalt pavement thicknesses, drainage and traffic load were evaluated. Soil samples were collected from test pits 1 m deep and at an interval of 50 m and subjected to geotechnical analyses in accordance to AASTHO specification. The grain size distribution revealed that 70% of the entire samples from Awotan-Lifeforte and Adaba failed sections along Akufo road contain amount of fines more than 35% passing through sieve No. 200. The Natural Moisture Content range from 5.73 - 20.21% (Awotan-Lifeforte section) and the entire samples from Adaba failed sections have high natural moisture content ranging from 16.20 - 23.20%. From Atterberg limit test, the Liquid limit of 12 - 56% (Awotan-Lifeforte section) and 26.00 - 40.00% (Adaba Section) were obtained. The Plastic Limit and Plasticity Index of the soils ranges from 8.43 to 49.10% and 1.01 to 7.0% (Awotan-Lifeforte section), and 23.10 - 35.50% and 1.50 - 7.10% (Adaba Section) respectively. Linear shrinkage vary from 0.80 to 9.60% and from 3.10 to 8.80% for Awotan-Lifeforte and Adaba sections, respectively. The Maximum Dry Density of the soils ranged from 1.625 - 1.835 mg/m^3 at Optimum Moisture Content of 13.4 - 17.3% (Lifeforte-Awotan section), and MDD of 1.752 - 1.975mg/m^3 at Optimum Moisture Content of 13.4-17.3% (Adaba section). The unsoaked California Bearing Ratio are 30.08, 70.14, 39.08%, and the soaked California Bearing Ratio values are 26.17, 11.41, 33.41% (Lifeforte-Awotan section) respectively. At Adaba section of the road, the unsoaked California Bearing Ratio are 3.46, 87.70, 70.14%, and soaked California Bearing Ratio values are 3.42, 32.56, 39.83%. The average asphalt pavement thicknesses around Awotan-Lifeforte section range from 0.60 - 1.10 inches, and that of Adaba section range from 0.57 to 1.46 inches. The study concluded that the road pavement subgrade is silty clay and the geotechnical properties rated below the specifications of the Federal Ministry of Works and Housing at some failed portions. Asphalt pavement thicknesses are grossly inadequate and far below NAPA 2007 recommendation. As such the road cannot withstand the heavily loaded trucks that ply it on regular basis. All aforementioned contributed to the untimely failure of the road.

Keywords: Road Failure, Geotechnical Engineering Properties, Asphalt Pavement Thicknesses, drainage and traffic load, Awotan-Akufo Road

1 INTRODUCTION

The significance of suitable foundation soil for stability in highway construction cannot be over emphasized since such structure is founded on the surface of the earth. Adequate knowledge of foundation soil therefore required since, quite often, nature does not always provide the ideal ground conditions. It is pertinent to note that the properties and structure of soil significantly influence the design and strength of any foundation and the supported super structure. Soil investigation helps to determine varying physical and engineering properties of soil, which can vary from place to place and from layer to layer. Adequate information about the engineering properties of soils and subsoil condition is highly required in construction of foundations of most engineering structures. The rate of failure of structures such as roads, buildings, dams, and bridges in Nigeria has been on the increase in recent years. Engineering properties have been identified as the major factors influencing the failure of many roads within and outside the country. Despite the technological improvement in the country, the cause of pavement failures has remained a serious concern in almost all major highways in Nigeria [1]. It has been noted that such structures fail shortly after construction and far less than their life expectancy [2]. Road failure is a discontinuity in road pavement resulting in cracks, potholes, bulges and depressions [3]. A good pavement is needed for the safe, comfortable and economic management of traffic [4].

Several factors have been considered as responsible for road failures. These include geological, geomorphological, geotechnical, road usage, construction practices and maintenance [5; 6]. Besides, inadequate knowledge of the characteristics and behavior of residual soils as well as poor drainage network contribute immensely to the collapse of highway pavement well before their design age. Poor routine maintenance also give rise to rapid decline of roads, like any other engineering structures, caused by aging of materials, variations in age, disuse, accidental damage, mismatch between design parameters and field condition during construction. These shorten the life span of the structures, resulting in high vehicular operating cost, public casualties from accidents and later expensive rehabilitation and reconstruction scheme (7; 8; 9; 10; 11; 12]. The Awotan-Adaba- Akufo road in Ido local government area of Oyo state is a major road that links Awotan, Lifeforte, Adaba, Tiper garrage and Akufo and its environs and its failure has brought about decrease in the economic growth and social development of the affected areas.

Before the road had greatly contributed to the socio-economic development of the area as it helps in the movement of men and materials as well as agricultural products. The road also serves one of the legal dumpsites in Ibadan metropolis, the Awotan dumpsite. As such, heavy refuse trucks breakdown and hold-up of vehicles along the road increases daily. Several appeals have been made by the inhabitants of the area to the government to extend the construction of Apete-Ijokodo road to Akufo or repair the damaged portions of the road but no positive response up till this moment. It is to this effect that a need to investigate the geotechnical characteristics of the soil and other causes responsible for the failure of the road and to suggest remedies that could be useful in the reconstruction of the road.

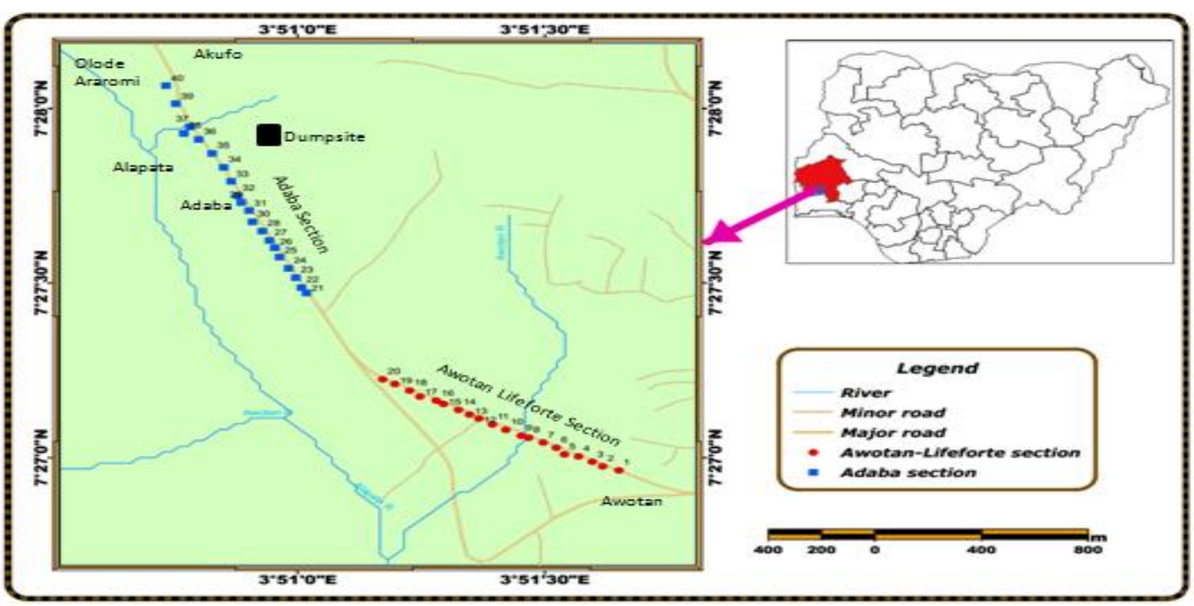

FIG. 1 Location Map of the Studied Area

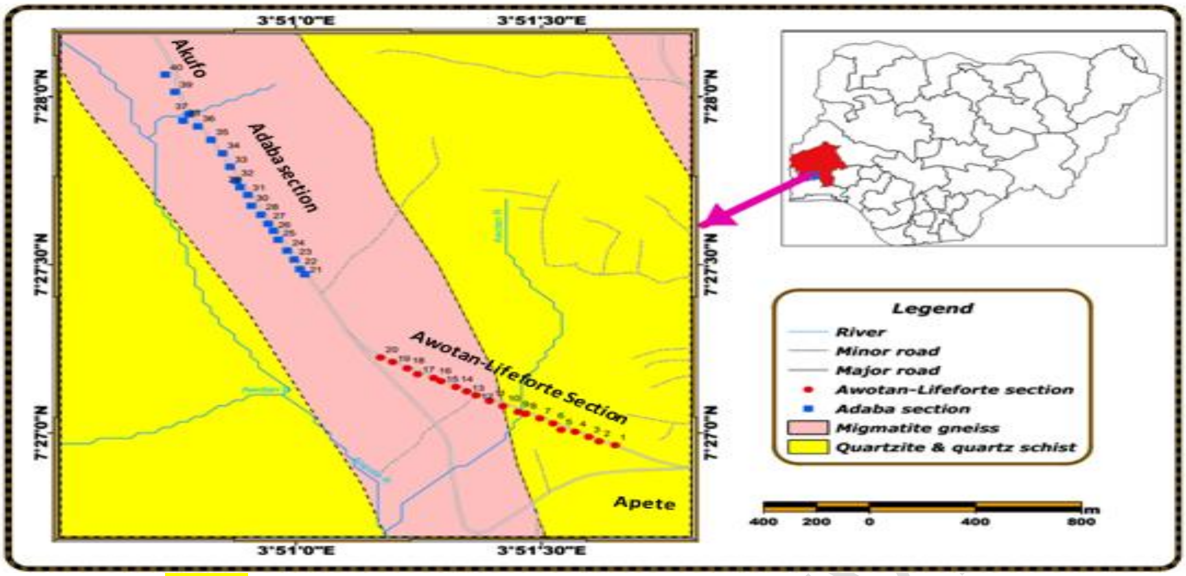

FIG. 2: Geological Map of the Area Around the Investigated Road [16]

2. MATERIAL AND METHODS

2.1 Site Description, Soil Type and Geology

The Awotan Akufo road is located within the Ido Local government area of Oyo State, southwestern Nigeria. The failed segments investigated lie within latitudes 7°26' 57.88''N and 7°26' 13.52''N, and longitudes 3°51' 38.99''E and 3°51' 10.32''E which comprises of areas like Awotan, Life-forte, Tipper garage, Adaba and Alapata all along Akufo road. The area has a unique environmental setting characterized by a wide range of land-use activities such as small-scale arable farming, animal husbandry, poultry, fish pond activity, residential and commercial settlements. The topography is gently undulating with elevation ranging from 199.8m to 244.6m above sea level and characterized with isolated inselbergs, drained dendritically by River Alapata and its tributaries (Fig.1). The soil type is characterized by fine to medium to coarse grain, brown to reddish brown sandy clay fraction (Table 1). The study area lies within the crystalline Basement Complex rocks of southwestern Nigeria. The rock types underlying the area belong to the Migmatite-gneiss-quartzite complex [13; 14; 15] consisting majorly of Quartzite, Quartz Schist ridges and minor Migmatite Gneiss (Fig. 2). Residual soils such as laterites, resulting from the weathering and decomposition of the Pre-Cambrian Basement rocks cut across the various rock types mentioned above

2.2 Geotechnical Engineering Tests

This study adopted an integrated experimental methods of research which are concerned with both field and laboratory analyses. The design of the road was evaluated given consideration to drainage networks and asphalt thicknesses at failed sections at the Awotan-Lifeforte and Ababa sections. Two asphalt pavement test points were considered at each location. Test pits were dug to a minimum depth of 1m, below the asphaltic surface at 40 locations and at 50m interval and soil samples were collected. The soils were identified visually, suitably packed into air tight sacks and labeled for further laboratory analysis. The samples were analyzed for the following parameters: Particle Size Distribution, Natural Moisture Content (NMC), Atterberg's Limits (Liquid Limit, Plastic Limit and Plasticity Index), California Bearing Ratio CBR (Soaked and Un-Soaked) and Compaction. The samples used for particle size distribution were prepared in accordance with [17]. Consistency limits were carried out in accordance to Nigerian Specification as stipulated in [18] guidelines. The California Bearing Ratio CBR (Soaked and Un-Soaked) and Unconfined Compression Strength Test (UCS) were also carried out in accordance to the BS 1377 and checked for conformation with the Nigerian specifications for road construction [18].

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution Analysis

The result of the grain size distribution analysis is summarized in Table 1. The particle size distribution analysis shows not only the range of particle sizes present in a soil but also the type of distribution of various size particles. According to clause 6201 of Federal Ministry of Works and Housing (F.M.W.& H) Specification Requirement, for a sample to be used as both subgrade and base, the percentage by weight passing the No.200 sieve (75µm) shall be less than but not greater than 35%. And if the percentage passing sieve No. 200 for a Lateritic base course is greater than 35%, no need for further tests and material rejected.

Sequel to the above, percentages by weight passing sieve No. 200 for the subgrade soil sample ranges from 23.20 to 82.64% (Awotan-Lifeforte), and 18.30 to 80.45% (the Adaba Section). The samples under review are not suitable samples for subgrade because only samples 4,8 and 12m with percentage passing 30.70, 34.06% and 23.2% (Awotan-Lifeforte), and 1, 2, 3, 7, 10 and 14 with percentage passing 18.30, 34.39, 33.70, 27.57, 24.50 and 27.46% (the Adaba section) respectively do not exceed the specification 35% requirement which represent 30% of the whole samples. The remaining 70% of the entire samples collected at various failed sections of the road under investigation exceeded the standard requirement. Thus, greater percentage of soil samples along the studied failed section can be classified as unsuitable subgrade, sub-base and base material. The high fine content could be responsible for instability of road pavement along the studied sections.

According to [19] in classification of soil samples for highway, almost all soil samples from the Awotan-Lifeforte and Adaba sections along Akufo road contain amount of fines more than 35% of the soil passing through sieve No. 200, hence the soils are in the Silty-Clay Group. All the aforementioned samples fall under group A4-6 (Table 2). On this basis, they can therefore be classified as fair to poor subgrade material for road construction. The soils therefore are likely to have volume expansion causing pavement instability and rapid failure. This condition, however, can be addressed by stabilizing the soil with lime to increase its engineering properties.

3.2 Natural Moisture Content

According to [18], soils with natural moisture content (>16%) are not suitable for road construction, while soil with Moisture Content (<16%) exhibit good subgrade materials for road construction. Table 1, shows the range of Natural Moisture Content of 5.73% to 20.21% for soils in the study area (Awotan-Lifeforte). Only soil samples from location A-L1, A-L6 and A-L11 display Natural Moisture Content greater than 16%. On the other hand, the entire samples from Adaba failed sections have high moisture content in their natural state ranging from 16.20% to 23.20%. Such soils that have more than 16% natural moisture content is considered to be a saturated soil and poor construction materials. These results indicate the reason why the level of failure in the Adaba section is more pronounced than that of the Awotan-Lifeforte section.

TABLE 1 SUMMARY OF THE RESULT OF GRAIN SIZE DISTRIBUTION AND CONSISTENCY LIMIT TESTS

	Sample Location	A-L 01	A-L 02	A-L 03	A-L 04	A-L 06	A-L 07	A-L 08	A-L 09	A-L 11	A-L 12	A-L 16	A-L 17	A-L 18	A-L 19	A-L 20
	Awotan-Lifeforte Section															
Grain size Distribution	Gravel %	7.82	35.88	9.42	53.88	26.14	10.54	27.40	4.04	25.40	56.64	17.56	4.16	1.54	11.02	32.46
	Sand %	20.92	23.88	53.20	15.42	32.94	32.18	38.54	20.66	37.90	20.16	45.42	13.20	27.85	33.44	31.44
	Amt of Fines (Silt & Clay) %	**71.26**	**40.24**	**38.38**	**30.70**	**40.92**	**57.28**	**34.06**	**75.30**	**36.70**	**23.20**	**37.02**	**82.64**	**70.61**	**55.54**	**36.10**
Consistency Limits	Liquid Limit %	48.00	34.00	20.00	42.00	21.00	27.00	12.00	33.00	22.00	25.00	34.00	51.00	56.00	37.00	25.00
	Plastic Limit %	43.80	31.35	18.70	40.48	16.32	24.77	8.43	30.60	20.75	22.38	31.71	49.10	49.00	33.20	23.20
	Plasticity Index	4.20	2.65	1.30	1.52	4.75	2.23	3.57	2.40	1.25	2.62	2.29	1.90	7.00	3.80	1.01
	Linear Shrinkage %	9.60	7.70	0.80	7.70	6.40	6.40	7.20	4.61	1.60	2.84	4.00	2.86	5.00	7.10	3.20
	NMC %	18.64	15.74	5.73	11.11	16.42	7.80	9.21	15.60	20.21	12.38	8.76	8.48	11.11	9.29	15.20
	Adaba Section															
	Sample Location	AD 01	AD 02	AD 03	AD 04	AD 05	AD 06	AD 07	AD 08	AD 09	AD 10	AD 11	AD 12	AD 13	AD 14	AD 15
Grain size Distribution	Gravel %	37.70	19.86	23.00	20.84	14.94	5.96	10.88	3.78	6.04	14.06	21.48	12.78	12.16	34.00	13.52
	Sand %	44.00	45.75	43.30	43.72	41.20	31.09	61.55	15.76	44.15	61.44	38.10	26.32	39.74	38.54	45.02
	Amt of Fines (Silt & Clay) %	**18.30**	**34.39**	**33.70**	**35.44**	**43.86**	**63.01**	**27.57**	**80.46**	**49.81**	**24.50**	**40.42**	**60.90**	**48.10**	**27.46**	**41.46**
Consistency Limits	Liquid Limit %	26.00	29.00	34.00	38.00	40.00	34.00	37.00	32.00	33.00	36.00	34.00	34.00	40.00	29.00	31.00
	Plastic Limit %	23.10	25.30	32.00	33.70	33.00	31.00	35.50	29.00	30.50	32.00	27.30	30.70	33.90	24.60	26.20
	Plasticity Index	2.90	3.70	2.00	4.30	7.10	2.90	1.50	3.00	2.50	3.60	2.70	3.30	6.10	4.40	4.80
	Linear Shrinkage %	6.00	3.10	8.80	6.40	6.90	7.20	5.40	6.30	4.50	3.30	5.30	4.40	7.70	6.80	6.50
	NMC %	17.00	16.20	19.70	18.30	20.00	17.40	16.50	21.90	19.10	18.90	22.60	16.80	21.60	23.20	19.50

TABLE 2. CLASSIFICATION OF SOILS AND AGGREGATE MIXTURES WITH THE SUGGESTED SUBGROUPS

General Classification	Granular Materials (35% or Less of Total Sample Passing No. 200)							Silt-Clay Materials (More than 35% of Total Sample Passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7 A-7-5 A-7-6
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				
Sieve Analysis, Percent passing No. 10 No, 40 No. 200	50 max 30 max 15 max	50 max 25 max	51 min 10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40. Liquid Limit Plasticity Index	6 max		NP	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11min
Usual Types of Significant Constituent Materials	Stone Fragment Gravel & Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soil		Clayey Soils	
General Rating As Subgrade	Excellent to Good							Fair to Poor			

3.3 Consistency Limits

The consistency of a fine-grained soil has been described to be largely influenced by the water content of the soil [20]. Soil passes from the liquid state to a plastic state and the plastic state to a semi-solid state, and finally to the solid state as a result of gradual decrease in water content of a fine-grained soil slurry.

The summary of the results of the consistency limits test for the soil samples investigated are presented in Table 1.

The results of the liquid limit of the soil samples ranged from 12.00% to 56.00% (the Awotan-Lifeforte section) and 26.00% to 40.00% (the Adaba Section). According to the [18] guideline, the liquid limit should not exceed 35% to be suitable for use as subgrade and sub-base or base course materials. Only location A-L1, A-L04, A-L17 and A-L18 (the Awotan-Lifeforte section) and location AD05, AD07, AD10 and AD13 (the Adaba Section) failed to meet the requirements. Liquid limit of 40 - 60% and above are typical of clay soils while values of 25 - 50 are typical of silty soils as outlined in [17] [21]. As such, the soils investigated cannot be confidently regarded good subgrade materials but a silty soil with pocket of clayish materials at some locations.

The Plastic Limit and Plasticity Index of the soil ranges from 8.43 to 49.10% and 1.01 to 7.0% (the Awotan-Lifeforte section), and 23.10 to 35.50% and 1.50 to 7.10% (the Adaba Section) respectively. The Plasticity Indices of the soil samples in all the locations of the two sections were lower than 30% as specified [18]. Such soils display good engineering property because the lower the PI of the soil, the more competent the soil as foundation material [22]. Based on the plasticity index, the soils are categorized as majorly silty (PI < 7%) and partly silty clay (PI: 7 - 17%), low to medium plastic and partly cohesive and cohesive [23; 20].

Linear shrinkage is the decrease in length of a soil sample when oven-dried, starting with a moisture content of the sample at the liquid limit. The values obtained for linear shrinkage vary from 0.80 to 9.60% and 3.10 to 8.80% for the Awotan-Lifeforte and the Adaba sections respectively. The Federal Ministry of Work and Housing [18] recommended linear shrinkage of 8% maximum for highway soils. Based on this, the entire samples at both sections fall within the specified range except A-L01 and AD03 that displayed slightly high values. The shrinkage index (SI) (Table 1) classified the swell potential of the soil samples at both sections as low - medium. Such soils are expected to exhibit low to medium swelling potentials and intermediate shrinkage, and thus good engineering property as subgrade soil but the absence of drainage channel on the road could lead to serious complications that **result in** the failure of the road.

3.4 Compaction Test

This test is used to establish a dry density/moisture content relationship of a soil under controlled condition which can form a standard for comparison with field specifications [24]. Table 3 shows that the maximum dry density (MDD) of the soils ranged from 1.625 to 1.835 µg/m^3 at Optimum Moisture Content (OMC) that ranges from 13.4- 17.3% (Lifeforte-Awotan section), and MDD that ranges from 1.752 to 1.975mg/m^3 at Optimum Moisture Content (OMC) that ranges from 13.4-17.3% (Adaba section) respectively (Table 3). Samples characterized with low or intermediate optimum content is best suitable as subgrade materials. According to [25], the soils investigated exhibited characteristics of fair subgrade material. The MDD of the samples at the failed locations could be regarded to be ranged from very poor to fair [26]. Such soils are not excellent subgrade materials.

3.5 California Bearing Ratio (CBR)

The California Bearing Ratio gives information about the mechanical strength and good estimate of the bearing capacity of road subgrade materials. The values for the unsoaked CBR are 30.08, 70.14, 39.08%, and soaked CBR values of 26.17%, 11.41%, 33.41% for location A-L01, A-L14 and A-L18 (Lifeforte-Awotan section) respectively. At Adaba section of the road, the unsoaked CBR values varies from 3.46%, 87.70%, 70.14%, while soaked CBR values vary from 3.42, 32.56, 39.83% for location AD13, AD18, and AD20 respectively (Table 3). Federal Ministry of Works and Housing recommended that for soils to be used as sub-grade, sub-base and base materials, the un-soaked California Bearing Ratio (CBR) values must be ≤ 10%, ≤ 30% and ≤ 80% respectively while soaked CBR greater than 15% and 30% have been specified as suitable subgrade and good subbase respectively. On the basis of soaked CBR values obtained, the soil samples are suitable as subgrade except sampled locations A-L 14 (Life-forte - Awotan section) and AD 13 (Adaba section). Such values obtained at locations AL-14 and AD13 indicate that the subgrade is substandard and weak in strength and such soils are not likely to provide a stable compacted subgrade material. The shortage could be attributed to high clay content in the soils and poor drainage as evidenced in the area which gives way for ingress of water.

TABLE 3 SUMMARY OF CBR AT OPTIMUM MOISTURE CONTENT AND COMPACTION PARAMETERS

Location	Sample Number	Unsoaked CBR %	Soaked CBR %	% Strength Reduction	MDD mg/m^3	OMC %	O' Flaherty 2000 Rating
Awotan - Lifeforte Section	A-L 01	30.03	26.17	12.85	1.835	13.4	Silty Clay
	A-L 14	70.14	11.41	83.73	1.961	13.4	Sandy Clay
	A-L 18	39.08	33.41	5.67	1.652	17.3	Silty Clay
Adaba Section	AD 13	3.46	3.42	1.16	1.762	15.2	Silty Clay
	AD 18	87.17	32.56	62.65	1.975	9.8	Sandy Clay
	AD 20	70.14	39.83	30.31	1.778	12.8	Sandy Clay

3.6 Asphalt Pavement Design

The measured asphalt pavement thicknesses obtained at each failed location as presented in Table 1 indicate lesser values compared to the standard recommendations for highway construction according to [27]. The average values obtained around the Awotan-Lifeforte section range from 15.24 mm to 27.94 mm, and that of the Adaba section range from 14.48 mm to 37.08 mm (Table 4). These values are far below [27] recommendation. NAPA stated that in many cases a 4-inch (101.60 mm) thickness may be adequate, but 5-inch (127 mm) or even 6-inche (152.40 mm) of full-depth asphalt will assure a stronger, stable driveway under wider range of climate and loads. However, the design of pavement is very much dependent on the sub-grade strength of soil [4]. Weaker sub-grade needs thicker pavement layer than the stronger sub-grade. As such, some contractors use 6-inch (152.40 mm) to 8 inches (203.20 mm) of compacted aggregate or gravel as a base for 3-inche (76.20 mm) of asphalt pavement. It is therefore evident that the road was wrongly designed, weak subgrade and inadequate asphalt thickness are strong factors that are likely responsible for the failure of the road.

TABLE 4: ASPHALT PAVEMENT THICKNESSES MEASURED AT FAILED SECTIONS

Sample Location	Pt 1 (mm)	Pt 2 (mm)	Ave. (mm)	Sample Location	Pt 1 (mm)	Pt 2 (mm)	Ave. (mm)	Sample Location	Pt 1 (mm)	Pt 2 (mm)	Ave. (mm)	Sample Location	Pt 1 (mm)	Pt 2 (mm)	Ave. (mm)
AWOTAN-LIFEFORTE SECTION								ADABA SECTION							
A-L 01	21.08	18.03	19.05	A-L 11	26.92	22.00	25.40	AD 01	22.00	19.00	20.57	AD 11	35.99	37.85	36.96
A-L 02	29.97	22.86	26.67	A-L 12	17.98	21.84	20.32	AD 02	31.98	22.00	27.05	AD 12	28.98	25.91	27.43
A-L 03	14.99	17.02	24.13	A-L 13	16.00	19.00	16.51	AD 03	19.99	16.99	18.54	AD 13	36.98	19.81	28.45
A-L 04	11.94	18.03	15.24	A-L 14	29.97	24.89	27.94	AD 04	34.98	26.92	30.99	AD 14	33.00	11.00	21.97
A-L 05	22.02	14.99	19.05	A-L 15	21.23	17.98	19.69	AD 05	24.99	20.07	22.48	AD 15	19.00	24.89	21.97
A-L 06	ND	ND	ND	A-L 16	19.00	22.99	21.08	AD 06	16.99	28.96	22.99	AD 16	24.99	16.00	20.45
A-L 07	ND	ND	ND	A-L 17	15.01	24.99	19.94	AD 07	30.00	31.98	30.99	AD 17	18.80	23.00	20.96
A-L 08	10.92	17.78	19.05	A-L 18	17.98	21.00	19.56	AD 08	26.92	15.98	21.46	AD 18	33.00	35.99	34.54
A-L 09	24.89	20.83	15.24	A-L 19	24.99	20.98	22.99	AD 09	34.98	23.98	29.46	AD 19	11.00	18.00	14.48
A-L 10	17.78	13.97	16.51	A-L 20	20.98	17.98	19.56	AD 10	27.99	13.97	20.96	AD 20	22.00	14.99	18.54

3.7 Traffic Level

The primary factor that is responsible for pavement problems due to the loads applied through axles and tires of vehicles is the traffic which could be in form of load intensity, frequency, and axle and tire configuration. Heavy traffic causes the most important failures in a pavement producing fatigue cracking and rutting that require pavement rehabilitation [28]. The effects of truck traffic on a pavement can be dramatic. Tests have shown that a single-unit, fully loaded, 80,000-pounds truck can cause pavement damage equivalent to that caused by 6,000 automobiles. This illustrates why carefully made estimates of expected traffic are critical to proper pavement design [29]. Thus, vehicle mass has a cumulative effect on pavement damage. Movement of heavy trucks along Awotan - Akufo road is common due to the movement of men and materials as well as agricultural products and, most importantly, because of the presence of the Awotan dumpsite which is one of the legal dumpsites in Ibadan metropolis. As such, heavy refuse trucks breakdown and hold-up of vehicles along the road is on the increase. The road cannot withstand the heavily loaded trucks plying the road and this, of course, also contributed to the untimely failure of the road.

4. CONCLUSIONS

Geotechnical assessment of pavement failure along Awotan - Akufo road, Oyo State, Southwestern Nigeria has been carried out at failed sections (Awotan-Lifeforte section) and Adaba section). From the results of various tests conducted, the following conclusions are made:

a. (i) Almost all the entire samples from both failed sections of the road exhibited Natural Moisture Content (NMC) greater than 16% maximum value recommended for a suitable subgrade for road construction. Such soils are considered to be saturated and poor construction materials.

b. (ii) The particle size analysis revealed that the soils are silty clay, containing a number of fines more than 35% of the soil passing through sieve No. 200. The AASHTO classification rated such soils to be fair to poor subgrade materials. The Plasticity Index (PI) categorized the soil as majorly silty and partly silty clay, low to medium plastic and partly cohesive.

c. (iii) The linear shrinkage of most of the sampled soils at both failed sections of the road show values less than the 8% minimum recommendation. However, poor drainage system on the road gives way to the reduction in the strength character of the soil as a result of ingress of water. This reduces the bearing capacity of the soil which also contributed to its failure.

d. (iv) The Maximum Dry Density (MDD) classify the soils as poor to fair foundation material. Such soils are not excellent subgrade materials. The poor compaction character can also result in the failure of the section of the road.

e. (v) The California Bearing Ratio (CBR) shows that almost all the soil samples have values greater than 15% minimum value recommended for soil to be used as subgrade except samples A-L 14 and AD 13 from the Awotan-Life-forte and Adaba sections of the road respectively. This indicates that the soil is averagely standard except at few locations as indicated. Soil materials at A-L 14 and AD 13 from the Awotan-Life-forte and Adaba sections of the road respectively are thus classified as weak in strength and such soils are not likely to provide a stable compacted subgrade material.

f. (vi). National Asphalt Pavement Association (NAPA) classifies the asphalt layer thickness of the road pavement as inadequate due to shortage in asphalt thickness used for road surfaces. As such, the road cannot withstand the intensity as well as the wheel load that the road is being subjected to, and this may have contributed to the untimely failure of the road.

COMPETING INTERESTS

Authors declare that no competing interest exists.

REFERENCES

1. Olubanjo, AM., Ogunribido, THT, Ojo, OB., Aduloju, MD., Ololade, OP. Geotechnical Properties of Subgrade Soil along Failed Portions of Akungba-Ikare Road Stabilized with Rock Fines. Asian Journal of Geological Research, 2018;1(2):1-9,
2. Falowo OO, Akintorinwa OJ. Geophysical Investigations of a Pavement Failure Along Akure-Ijare Road, Southwestern Nigeria. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG), 2015; Volume 3, Issue 6 Ver.II:PP 45-54.
3. Aigbedion. Geophysical Investigation of Road Failure using Electromagnetic Profiles along Opoji, Uwenlenbo and Illeh in Ekpoma Nigeria. Middle-East Journal of Scientific Research 2007;2 (3-4) :pp.111-115.
4. Panchal Gayesh, Avineshkumar. Properties of Sub-grade Soil of Pavement Construction. International Journal of innovative research in science, engineering and technology, 2015; Vol.4, Issue 9.
5. Adegoke-Anthony, WC., Agada, AO. Geotechnical Characteristics of some Residual Soils and their Implications on Road Design in Nigeria. Technical Lecture, Lagos,1980: pp. 1–16.
6. Ajayi LA. Thought on Road Failures in Nigeria. The Nigerian Engineer. 1987; 22(1):10-17.
7. Abam, TKS., Ofoegbu, CO., Osadebe, CC., Gobo, AE. Impact of Hydrology on the Port-Harcourt-Patani-Warri Road. Environmental Geology 2000;4(2):153-162
8. Abam TKS., Osadebe CC Omange GN. Influence of Geology on Pavement Performance: A case study of Shagamu-Benin City road, South- western Nigeria. Global Journal of Geological Sciences. 2005;3(1):17-24.
9. Jegede, G. Effect of Soil Properties on Pavement Failure along the F209 Highway at Ado Ekiti Southwestern Nigeria. Nigeria Journal of science, (2000; Vol.14:121 - 126.
10. Oladapo, MI. Geophysical Investigation of Road Failures in the Basement Complex area of Ondo State. Unpublished M.Tech. Thesis,Dept. of Applied Geophysics, Federal University of Technology, Akure. 1997:109pp.
11. Omange, GN. Road Traffic Accidents in Nigeria. An international publication of the Nigerian building and Road institute, Lagos,1997.
12. Yahya, AJ. Appraisal of Transport Maintenance in Nigeria with Reference to the Role of NITT conf. Pap. MTT. Kano, Nigeria, 1989.
13. Rahaman, MA. Review of the Basement Geology of the Southwestern Nigeria. Kogbe, CA. (ed), Geology of Nigeria. Elizabeth Publishing Co. Surulere, Lagos, 1976, pp 41-58.
14. Rahaman MA. Review of the Basement Geology of Southwestern Nigeria. C.A. Kogbe (Ed.), Geology of Nigeria, Elizabethan Publ., Lagos 1988, pp. 41-58.
15. Oyawoye MO. The Basement Complex of Nigeria. in Dessauvagie TFJ, Whiteman A.J (Eds.) African Geology, Ibadan University Press, 1972, pp 66 - 102.
16. Nigeria Geological Survey Agency (NGSA). Geological and Mineral Resources Map of Oyo State. Published by the Authority of the Federal Republic of Nigeria, Nigeria. 2004
17. British Standard Institution. Methods of test for soil for Civil Engineering.BS 1377: British Standard Institution, London. 1990: pp.80.
18. Federal Ministry of Works and Housing. General Specification for Roads and Bridges, Volume II, Federal Highway Department, FMWH: Lagos, Nigeria, 1997:317, p.14.
19. AASHTO. AASHTO Guide for Design of Pavement Structures, Washington, DC. 1993.
20. Surendra Roy, Sanjeev Kumar Bhalla. Role of Geotechnical Properties of Soil on Civil Engineering Structures. Resources and Environment 2017;7(4):103-109.

21. Oyelami AC. and Alimi SA. Geotechnical Investigation of some Failed Sections along Osogbo-Awo road, Osun state, Southwestern Nigeria. Ife Journal of Science. 2015;17(1):87-95.
22. Akintorinwa OJ., Adeusi FA. "Integration of Geophysical and Geotechnical Investigations for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, SW, Nigeria". Ocean J App Sci 2009;2: 241-254.
23. Prakash, S, Jain PK. Engineering Soil Testing, Nem Chand & Bros, Roorkee, 2002.
24. Layade GO. and Ogunkoya CO. Geotechnical Properties of Lateritic Soil as Subgrade and Base Material for Road Construction in Abeokuta, Southwest Nigeria'. International Journal of Advanced Geosciences, 2018;6(1):78–82.
25. Wood Compaction Classification, 1997.
26. Emesiobi FC. Testing and Quality Control of Materials in Civil and Highway Engineering. ISBN O78-2009-38-16, 2000: PP5 -7.
27**.** National Asphalt Pavement Association (NAPA). Recommended Asphalt Pavement Thickness. Journal for road construction, 2017; Vol.6:1-3.
28. Pais, JC., Amorim, SIR, Minhoto, MJC. Impact of Traffic Overload on Road Pavement Performance. Journal of Transportation Engineering. 2013; 139: 873-879.
29. The Asphalt Institute. Asphalt Pavement Thickness Design, Information Series No.181 (IS-181). College Park, Maryland, 1983.