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The Place of Soil Geotechnical Characteristics in Road Failure, a Study of the Onitsha-Enugu Expressway, Southeastern Nigeria.

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Abstract

This work investigated the place of soil geotechnical characteristics along the road in the road failure. Soil samples from both failed and un-failed sections of the road were analyzed to ascertain their particles size distribution, liquid limit, plastic limit, maximum dry density, optimum moisture content and California bearing ratio. The data so generated from the eight sample stations established across the road were tested using Students T-test. It was found that there is significant difference between the geotechnical characteristics of the soil and the standard for geotechnical characteristics set by the Federal Ministry of Works at the failed sections but there is no significant difference at the un-failed sections. This led to the conclusion that the soil geotechnical characteristics is a causative factor of the road failure. Hence, it was recommended that the geotechnical and geological characteristics of sub-grades and fill materials be taken into consideration during road construction while relevant geologists, meteorologists/climatologists should be enlisted during the pre-construction design and planning of highway pavements. Also recommended are the following: proper compaction during construction, adequate maintenance programme for the road after construction, installation of good drainage channels for flooded sections, axle load control, careful choice of consulting engineers, prosecution of corrupt consulting engineers and ministry officials, prompt payment of contractors by the government and motivational packages for distinguished contractors so as to mitigate the problem of the failure of the road.
Keywords: road failure, causes, environmental implications and remedies.

1.0 Introduction

1.1 Background to the Study

Road Failure is defined as the inability of a normal road to carry out its functional services by not providing a smooth running surface for operating vehicles.

According to Aigbedion (2007), Road Failure could be defined as a discontinuity in a road pavement resulting in cracks, potholes, bulges and depressions. A road pavement is supposed to be a continuous stretch of asphalt lay for a smooth ride or drive. Visible cracks, potholes, bulges and depressions may punctuate such smooth ride. The punctuation in smooth ride is generally regarded as road failure. The Federal Ministry of Works and Housing (FMW&H 1992), failed roads are characterized by potholes, polishing / pavement surface wash, block and longitudinal cracks, drainage collapse, depressions / sinking of roadway, over flooding of the carriageway, gullies and trenches, rutting and raveling all of which are evident along the Onitsha -Enugu expressway under study confirming it's failure.

Several thousands of lives and properties worth several million dollars are lost as a result of frequent motor accidents, caused by failed highway pavements in Nigeria. Several factors are responsible for road failures, which include geological, geomorphological geotechnical, road usage, construction practices, and maintenance factors. Field observations and laboratory experiments carried out by Adegoke–Anthony and Agada (1980), Mesida (1981), and Ajayi (1987) showed that road failures can arise from inadequate knowledge of the geotechnical characteristics and behavior of residual soils on which the roads are built and non-recognition of the influence of geology and geomorphology during the design and construction phases. Thus the treatment of troublesome materials like clays are not been considered by the construction engineers. This was also supported by the works of Gidigasu (1983), Graham and Shields (1984), Akpokodje (1986), Alexander and Maxwell (1996), Jegede (1997), Gupta and Gupta (2003) and Ajani (2006).

Momoh et al (2008) and Adiat et al (2009) in their study of failed highway pavements using geophysical methods, found that some geological factors influence road failure such as the near surface geologic sequence, existence of geological structures like fractures and faults, presence of laterites, existence of ancient stream channels, and shear zones. The collapse of concealed subsurface geological structures and other zones of weakness controlled by regional fractures and joint systems along with silica leaching which has led to rock deficiency are known to contribute to failures of highways and rail tracks (Nelson and Haigh, 1990). The geomorphological factors are related to topography and surface/subsurface drainage system.

Other factors considered by some researchers and scholars include: Faulty Design and Poor Road Construction as in the works of Paul and Radnor (1976), Abynayaka (1977), World Bank (1991), UNESCO (1991), FMWH (1995), Jain and Kumar (1998)**;** Poor Maintenance according to John and Gordon (1976), Oglesby and Garry (1978), TRRL (1991); and Traffic Effects and Human Impacts on the Roads according to AASHTO (1976), ANSMWH (1998), FMWH (1995) and Ibrahim (2011).

The present condition of most of the roads in the Precambrian basement complex of south western Nigeria and the sedimentary terrain of the southeast and the entire Niger-Delta region has stimulated the interest of various stakeholders in the usage and maintenance of our road ways. Rehabilitating these roadways has become a financial burden on the Federal, State, and Local Governments. The Enugu-Onitsha Expressway is a typical example of Nigerian roads whose failure bugs the mind of regular users. Almost every section of the road has failed, resulting to;

- Loss of lives and properties, human injuries etc. through accidents,
- retardation of the rate of economic growth and development in affected areas,
- environmental pollution and degradation,
- impedance of human movement and the flow of economic activities and
- numerous cases of armed robbery attacks along affected areas.

In the light of the foregoing therefore, some questions constantly come to mind: what exactly is the cause of this problem? Again, since not all sections of the road failed, or at least failed equally, does soil characteristics (geotechnical properties) play any role in the durability of the roads. Considering the cost of constructing and maintaining this road, the answers to these questions have become a necessity particularly now that the impacts are multiplying. It is to this effect that a need to investigate on the place of the geotechnical characteristics of the soil on which the road is built arises.

1.2 Aim and Objectives

The aim of this work is to determine the place of soil geotechnical characteristics in the failure of the Onitsha-Enugu Highway pavement.

To achieve the above aim, the following objectives will be used:

1. to determine the geotechnical characteristics of the soils along the highway pavement under study,
2. to establish whether the geotechnical characteristics of the soil of the area is a factor of the road failure or not and
3. to suggest some solutions for the mitigation of road failure problems.

1.3 Research Hypothesis

$H_{0:}$ There is no significant difference between the geotechnical characteristics of the soil along Onitsha-Enugu Expressway and the Standard for geotechnical characteristics set by the Federal Ministry of Works.

1.4 Description of the Study Area

The Onitsha-Enugu Expressway under study is situated within longitude 6°45'E to 7°30'E and latitude 6°00'N to 6°30'N. For clarity of the location, see Fig.1 (the Map of Nigeria showing the study area) and Fig. 2 (Extract Modified by Author from Map of Old Anambra State Showing the Road Under Study).

Fig. 1.1: Map of Nigeria Showing the Study Area. (Source: http://www.ngex.com/nigeria/places/states/enugu.htm).

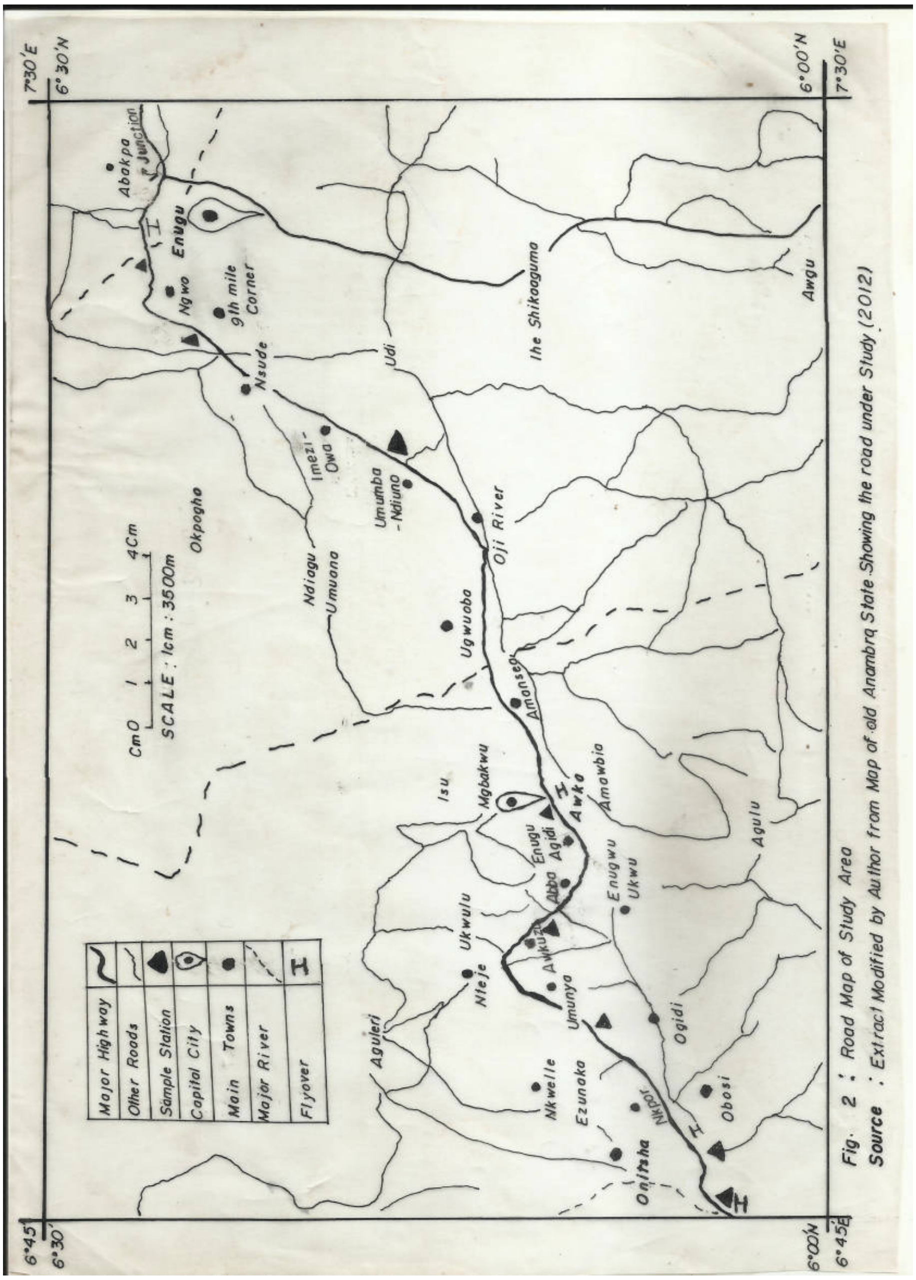

Fig. 2 : Road Map of Study Area
Source : Extract Modified by Author from Map of old Anambra State Showing the road under Study (2012)

Geology

The Onitsha/Enugu Expressway is sitting on Anambra basin of the Southeastern Nigeria it cuts across the following geologic formations:

Ameki Formation (Nanka Sand, Umunya Shale and other units), Imo Shale, Nsukka Formation, Ajalli Sandstone, Mamu Formation and Nkporo/Enugu Shale (which underlies Mamu Formation and is gradationally seen immediately after the New market Flyover in Enugu).

2. 0 Research Methodology

The study adopted experimental method of research which was mainly concerned with the laboratory analysis of the soil samples collected from various locations in the site. For the purpose of studying both the failed and un-failed sections of the road as well as recognizing the various geologic formations cut across by the roadway under study, eight samples were collected and analyzed, four from the failed sections and four from the un-failed sections of the road. Samples were collected from Bridgehead in Onitsha, Omoba Guest Hall, Umunya near Odumodu Junction, Awkuzu, Awka, Umumba Ndiuno, Ngwo and Enugu after New Market Flyover. These samples were analyzed for the following parameters: Particle Size Distribution, California Bearing Ratio (CBR), Atterberg's Limit (Liquid Limit, Plastic Limit and Plasticity Index) and Compaction.

2.1 Results and Discussions

The results of the laboratory analyses of the eight samples collected from eight stations selected along the roadway under study (four from the failed sections and four from the un-failed sections) are presented in Table 1 and discussed in line with the Standard of the Federal Ministry of Works shown in Table 2.

TABLE 1 : Geotechnical Characteristics of Soil Samples Collected Along Onitsha Enugu Expressway

Sample Station	Sampling point/ location	Horizontal Distance of Sampling point from road pavement	Condition of road as at the collection	Depth of sample collection	PARAMETERS ANALYSED								
					Particle size Distribution %		Atterberg Limit			Compaction		CBR %	
					Sand	Silt & Clay (passing Sieve 75 um 200)	LL %	PL %	PI	MDD	OMC	Soaked %	Unsoaked %
STN 1	Bridge Head Onitsha	Centre of the Road	Failed	About 2m	45.9	54.1	85.5	18.3	67.2	1.74	18.2	11.0	5.5
STN 2	Omagba Guest Hall	About 15 meters	Failed	3-4 m	49.9	50.1	50.5	12.0	38.5	1.85	14.2	26.0	24.0
STN 3	Umunya near Odumodu Junction	About 15 meters	Failed	About 1 m	31.7	68.3	88.5	31.4	57.1	1.55	17.4	8.0	6.0
STN 4	Awkuzu	About 10 meters	Un-failed	About 1 m	61.9	38.1	46.0	14.2	31.8	2.03	10.2	30.0	24.0
STN 5	Unizik Junction Awka	Centre of the Road	Failed	About 2m	42.1	57.9	71.5	9.8	61.7	1.50	17.2	16.0	12.5
STN 6	Umumba near market	About 5 meters	Un-failed	About 1 m	68.7	31.3	44.0	21.2	22.8	1.94	12.2	20.0	13.0
STN 7	Ngwo before 9th Mile	About 15 meters	Un-failed	About 1 m	75.1	24.9	30.0	14.1	16.0	2.13	10.1	43.0	36.0
STN 8	Between New market flyover & Trans-Ekulu	About 15 meters	Un-failed	About 1 m	47.7	52.3	78.5	21.1	57.4	1.61	17.2	10.5	7.5

TABLE 2 : SPECIFICATION LIMITS FOR SUB-GRADE/FILL MATERIALS FOR ROADS

Material/Layer	Test	Specified Limits	Desired Limits	Requirement of Tests	Specification Clause No
Sub-grade/Fill	**Plasticity Tests**			1 per 1000mm	6181
	(a) Liquid limit	≤ 80 %	≤ 50 %		6122
	(b) Plasticity Index	≤ 55	≤ 30		6122
	Grading Test			1 per 1000mm	6181
	a) Sieve Analysis	≤ 35% Passing 75 um or 200 Sieve			6102
	Density Moisture Content			1 per 500m	6181
	a) Compaction Test	B.S. Compaction			6180
	Insitu Dry Density Test			1 per 100m	6181
	Top 600mm	≥100% of the MDD in BS Compaction			6125
	After 600mm	≥95% of the MDD in BS Compaction			6125
	Next to Structure	≥100% of the MDD in BS compaction			6125
Unsuitable	a) Peat, logs, stumps. Roots, & other perishable or combustible materials				6122
	b) Materials from swamps, marshes & bogs				6122
	c) Top soil and highly organic clay & silt				6122
	d) Clay having a liquid limit exceeding 80% or PI exceeding 55				6122
	e) Highly micaceous materials				6122

Source: Extracted from General Specification for Roads and Bridges F.M.W. (1997)

2.1.1. Particle Size Distribution: The particle/grain size distribution of a soil is an important determinant of its geotechnical characteristics. In construction, clay materials are seen as troublesome. This is because, clay though porous is less permeable and to determine the percentage clay present in the natural soil of an area to know whether it will serve as a good sub-grade or not. This particle size distribution analysis becomes necessary.

From Table 1, it is obtained that samples studied at Station 1 (around Bridgehead Onitsha) has a higher amount of clay with a lower amount of sand-size particles. The clay here is over 54% while the sand is 45.9%. At Station 2 (Omagba Guest Hall near Borromew roundabout) the sand size particles are 49.9% while the clay particles has 50.1%. The result of the analysis of Station 3 (Umunya near Odumodu Junction) has it that sand is 31.7% while clay is 68.3%, but in the case of Station 4 (around Awkuzu/Nteje area) sand is 61.9% while clay is 38.1%. A different was recorded at Station 5 (Unizik Junction, Awka), where sand became lower 42.1% while the clay went up to 57.9%. Another station with a high clay content is Station 7(After Zion Housing Estate near New Market Flyover, Enugu) having clay of 52.3%. Considering the specification limits for Sub-grade material in Table 2, it is obvious that only samples from Stations 6 and 7 fell within the limit of the specification, followed by sample from Station 4. For grading test, good materials are materials having ≤35% passing for sieve 75 um or 200 sieve. Although other parameters are considered before the verdict can be given of which material is good and which is bad. It should be noted that the more the clay, the more troublesome the material is. This is in line with the works of Okagbue and Uma (1988), Jegede (1997), and Akpan (2005) among others.

2.1.2. Atterbergs Limit: From the result of the laboratory analyses, Station 1 has a high liquid limit of 85.5% with a plasticity limit of 18.3% thus a high plasticity index of 67.2 which is greater than the standard limit of plasticity index of 55. At Station 2 the liquid limit is less than the standard limit of liquid limit (which is 80%) and with a moderate plasticity limit. From Table 2, it is clear that a soil with PI >35 is described as highly plastic this is in line with the work of Sowers and Sowers (1970). Such a soil usually has the ability to retain appreciable amount of total moisture in the diffuse double layer, especially by means of absorption. This fact was buttressed by the higher Optimum Moisture Content recorded in samples from stations1,3,5 and 8 (Table 1). High plasticity materials are usually susceptible to high compressibility (Seed and Woodward, 1964; Sowers and Sowers, 1970; Coduto, 1999). An increase in plasticity of material also decreases its permeability and hydraulic conductivity (Sowers and Sowers, 1970) which may be a factor of water logging and flooding both of which results in road failure as evident in the failure around Station 5 (near UNIZIK Junction Awka where flooding led to the failure of the road and the drainage system leading to the loss of lives recorded along that area sometime in August 2012.

It is noted that Stations 1 and 3 have liquid limits greater than that of the set standard by Federal Ministry of Works while station 2,4,5,6, 7 and 8 have liquid limits lower than the set liquid standard. But due to the plastic limit of the samples collected at the various stations, station 1, 3, 5 and 8 exceeded the standard limits of plasticity index set by the Federal Ministry of Works as can be seen in Table 2. It is crystal clear that all the materials with geotechnical characteristics greater than the set standard are troublesome, seeing that they are all clay materials (weathered shale) showing the different formations t6hat are clay which underlie these stations along the roadway (Ameki formation, Umunya Shale Unit, Imo Shale and Enugu Shale, that is, Stations 1,3,5 and 8 respectively). This` agrees with the woks of Gidigasu (1983), Graham and Shields (1984), Akpokodje (1986), Alexander and Maxwell (1996) and Jegede (1997) which stipulates that clay materials are troublesome materials in construction and must be treated with caution.

Thus one can conclude based on the atterberg limit test that stations 1, 3, 5 and 8 have bad Sub-grade materials while station 2, 4, 6 and 7 are underlain by good Sub-grade materials although other geotechnical parameters must be put into consideration before a final conclusion can be drawn as to the quality of the sub-grade. It can thus be inferred that the failure of the road at stations 1, 3 and 5 is as a result of the soil geotechnical characteristics of these sections of the road.

2.1.3. Compaction: Results of the compaction test showed higher Maximum Dry Density (MDD) for samples from stations 2,4,6 and 7. of 1.85, 2.03, 1.94 and 2.13 mg/m^3 respectively with Optimum Moisture Content (OMC) ranging from 10.1 to 17.2. Stations 1,3,5 and 8 showed lower MDD of 1.74, 1.55, 1.50 and 1.61 mg/m^3 respectively with OMC ranging from 17.2 to 18.2 thus higher (see Table 1). This implies that in construction, the soils of stations 2,4,6 and 7 will be more suitable for Sub-grades and easily compactible than those of stations 1,3,5 and 8. The MDD of Station 3, 5, and 8 (1.55, 1.50 and 1.61 mg/m^3 respectively) which is on the Umunya Shale, Imo Shale and Enugu Shale respectively also agreed with the work of Okogbue and Aghamelu (2010) which states that Shales from Southeastern Nigeria has MDD ranging from 1.50 to 1.68 mg/m^3 the high clay content of these samples must be responsible for their lower MDD and CBR as evident in Table 1. It should be noted that the density of the soil mass affects the strength of the soil. Generally, the strength of a soil increases as its dry density increases. Also the potential for the soil to take on water at later times is decreased by higher densities. This is due to the decreased presence of air space in the soil mass. The in-place moisture content of a soil is often used, along with the soil classification, to determine the suitability of the material as a Sub-grade. Generally, as the moisture content of a soil increases its strength decreases and the potential for deformation and instability increases. There is no doubt then why these sections of the road consistently fail with time unlike other sections. This further implies that the geotechnical factors of these sections of the road might not have been considered during the construction. In addition, this further confirms the assertion by the respondents that part of the reasons for the failure of the road is incompetence of the contractors

2.1.4. CBR: Results of the laboratory CBR tests showed that Stations1,3,5 and 8 showed lower soaked and unsoaked CBR values of 11.0% & 5.5%, 8.0% & 6.0%, 16.0% & 12.5% and 10.5% & 7.5% respectively. While Stations 2,4,6 and 7 showed higher soaked and unsoaked CBR values of 26.0% & 24.0%, 30.0% & 24.0%, 20.0% & 13.0% and 43.0% & 36.0% respectively. The reduction in CBR of Stations 1,3,5 and 8 suggests that moisture influx would be detrimental to the Sub-grades of pavements constructed on them. The higher clay content of the samples might also be responsible for reduction in CBR, which is a geotechnical signal for caution when used as pavement materials. Thus the materials at Stations 2, 4, 6 and 7 will make better sub-grades all other parameters being equal. This again strengthens the conclusions made earlier from the compaction test.

Therefore, in conclusion of the discussions on Tables 1 and 2, it is evident that the failure of the road at Stations 1, 3 and 5 is from their soil geotechnical characteristics as shown by the results of their PI and grading test, all of which are not in conformity with the standard set by the FMW.

2.2. Test of Hypothesis

$H_{0:}$ There is no significant difference between the road characteristics of the soils along Onitsha-Enugu Expressway and the Standard set by the Federal Ministry of Works.

$H_{1:}$ There is significant difference between the road characteristics of the soils along Onitsha-Enugu Expressway and the Standard set by the Federal Ministry of Works.

Statistical tool: having observed that the geotechnical characteristics of the failed section differ from that of the un-failed section, it is therefore necessary to check the geotechnical characteristics of the individual stations with the standard set by the FMW. To test this hypothesis, the observed values in each station were compared with the standard using Student T- test since the sample size is 3 for each station. Data was analyzed using computer software (SPSS and Minitab).

Level of significance: 5% (0.05)

Decision; Accept the null hypothesis if the p-value is greater than 0.05, otherwise, reject. The selected data for this test is as stated in Table 3.

2.2.1 Two-Sample T-Test and CI: Actual, Station 1

Two-sample T for Actual vs Station 1

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 1	3	68.9	15.8	9.1

Difference = mu (Actual) - mu (Station 1)
Estimate for difference: -12.3
95% CI for difference: (-56.4, 31.8)
T-Test of difference = 0 (vs not =): T-Value = -0.77 P-Value = 0.048 DF = 4
Both use Pooled St.Dev = 19.4561

Since the P-value is less than 0.05, the null hypothesis was rejected. Meaning that there is significant difference between the geotechnical characteristics of the soil samples collected from station 1 and the Standard for geotechnical characteristics set by the Federal Ministry of Works. This is likely to be the reason for the failure of this section of the road.

2.2.2 Two-Sample T-Test and CI: Actual, Station 2

Two-sample T for Actual vs Station 2

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 2	3	46.37	6.82	3.9

Difference = mu (Actual) - mu (Station 2)
Estimate for difference: 10.3
95% CI for difference: (-27.5, 48.1)
T-Test of difference = 0 (vs not =): T-Value = 0.76 P-Value = 0.049 DF = 4
Both use Pooled St.Dev = 16.6551

Since the P-value is less than 0.05, the null hypothesis was rejected. Meaning that there is significant difference between the geotechnical characteristics of station 2 and the Standard for geotechnical characteristics set by the Federal Ministry of Works. This must have contributed to the failure of this section of the road.

2.2.3. Two-Sample T-Test and CI: Actual, Station 3

Two-sample T for Actual vs Station 3

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 3	3	71.3	15.9	9.2

Difference = mu (Actual) - mu (Station 3)
Estimate for difference: -14.6
95% CI for difference: (-58.9, 29.6)
T-Test of difference = 0 (vs not =): T-Value = -0.92 P-Value = 0.041 DF = 4
Both use Pooled St.Dev = 19.5138

The P-value is also less than 5% (0.05), thus the null hypothesis was rejected. This goes to say that there is significant difference between the geotechnical characteristics of the soil sample from station 3 and the Standard for geotechnical characteristics set by the Federal Ministry of Works. Inferring that the geotechnical status of the soil is a factor of the failure of this section of the road.

2.2.4. Two-Sample T-Test and CI: Actual, Station 4

Two-sample T for Actual vs Station 4

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 4	3	38.63	7.12	4.1

Difference = mu (Actual) - mu (Station 4)
Estimate for difference: 18.0
95% CI for difference: (-19.9, 55.9)
T-Test of difference = 0 (vs not =): T-Value = 1.32, P-Value = 0.525 DF = 4
Both use Pooled St.Dev = 16.7176

The P-value here is more than 5% (0.05), thus the null hypothesis was accepted. Meaning that there is no significant difference between the geotechnical characteristics of the soil sample from station 4 and the Standard for geotechnical characteristics set by the Federal Ministry of Works thus this section is not likely to fail. This result is supported by the real situation on site as this section is amongst the un-failed sections of the road sampled.

2.2.5. Two-Sample T-Test and CI: Actual, Station 5

Two-sample T for Actual vs Station 5

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 5	3	63.70	7.02	4.1

Difference = mu (Actual) - mu (Station 5)
Estimate for difference: -7.0
95% CI for difference: (-44.9, 30.8)
T-Test of difference = 0 (vs not =): T-Value = -0.52 P-Value = 0.033 DF = 4
Both use Pooled St.Dev = 16.6969

Considering that the P-value here is less than 0.05, the null hypothesis was rejected. Meaning that there is significant difference between the geotechnical characteristics of the soil samples collected from station 5 and the Standard for geotechnical characteristics set by the Federal Ministry of Works and this is likely to be the reason for the failure of this section of the road.

2.2.6. Two-Sample T-Test and CI: Actual, Station 6

Two-sample T for Actual vs Station 6

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 6	3	32.7	10.7	6.2

Difference = mu (Actual) - mu (Station 6)
Estimate for difference: 24.0
95% CI for difference: (-16.0, 64.0)
T-Test of difference = 0 (vs not =): T-Value = 1.66 P-Value = 0.227 DF = 4
Both use Pooled St.Dev = 17.6375

The P-value is 0.227, which is more than 0.05. considering the decision rule stated earlier, the null hypothesis was accepted. That is there is no significant difference between the geotechnical characteristics of the soil sample from station 6 and the Standard for geotechnical characteristics set by the Federal Ministry of Works no wonder this section did not fail and is amongst the un-failed sections of the road sampled.

2.2.7. Two-Sample T-Test and CI: Actual, Station 7

Two-sample T for Actual vs Station 7

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 7	3	23.63	7.09	4.1

Difference = mu (Actual) - mu (Station 7)
Estimate for difference: 33.0
95% CI for difference: (-4.9, 70.9)
T-Test of difference = 0 (vs not =): T-Value = 2.42 P-Value = 0.433 DF = 4
Both use Pooled St.Dev = 16.7113

The P-value here is also more than 0.05, thus the null hypothesis was accepted and the alternative hypothesis accepted. That is there is no significant difference between the geotechnical characteristics of the soil sample from station 7 and the Standard for geotechnical characteristics set by the Federal Ministry of Works thus this section is not likely to fail. This result is also supported by the real situation on site as this section is amongst the un-failed sections of the road sampled.

2.2.8 Two-Sample T-Test and CI: Actual, Station 8

Two-sample T for Actual vs Station 8

	N	Mean	St.Dev	SE Mean
Actual	3	56.7	22.5	13
Station 8	3	62.7	13.9	8.0

Difference = mu (Actual) - mu (Station 8)
Estimate for difference: -6.1
95% CI for difference: (-48.5, 36.4)
T-Test of difference = 0 (vs not =): T-Value = -0.40 P-Value = 0.412 DF = 4
Both use Pooled St.Dev = 18.7253
Since the P-value is less than 0.05, the null hypothesis was rejected. Meaning that there is significant difference between the geotechnical characteristics of the soil samples collected from station 8 and the Standard for geotechnical characteristics set by the Federal Ministry of Works. By this result, this section of the road is likely fail, but this is different from the situation on ground at the site because this section of the road is not failed as at the time of sampling. This goes to suggest that the geotechnical characteristics of this section might have been considered during the construction or periodic maintenance and or routine maintenance might have been taking place at this section making it to be stable till the time of this sampling considering its geotechnical status, the heavy traffic and the old age of the road amongst other factors.
All the sections of the sampled sections of the road with geotechnical characteristics having no significant difference with the set standard by the FMW were amongst the un-failed sections of the road showing that good geotechnical characteristics of the sub-grade can support the roads stability. While all the sections with geotechnical characteristics significantly different from the standard of geotechnical characteristics set by the FMW failed except for station 8 were many other factors are considered to be responsible for its stability since the section is un-failed as at the time of the sampling.

3.1. Conclusion

In conclusion, the geotechnical characteristics of the soils from the failed sections differ significantly from the standard set by the Federal Ministry of Works which indicates that the geotechnical status of the soil along the failed sections is problematic thus making it clear that the soil geotechnical characteristics is a factor of the road failure.

3.2. Recommendations

In line with the findings and conclusions of this work the following recommendations were made in order to mitigate the problem road failure.

- The geotechnical characteristics of the soils along the roadway vary from point to point and should be treated as such. Zones of high clay content to be treated with caution during reconstruction activities.
- Fill materials must be tested and treated before use to avoid problems after the construction.

- Knowledge of soil geotechnical characteristics and underlying geology of an area is very essential before any construction project commence as the stability of the foundation layers particularly depends on this.
- Relevant geologists, meteorologists/climatologists and geotechnical engineers should be enlisted during pre-construction design and planning of highway pavements.
- 100% compaction must be observed during construction to avoid failure after construction due to settlement.
- Ready data of the geological and geotechnical status of all major highways should be established to aid proper planning of road reconstruction and rehabilitation projects.
- Pronouncement of severe punishment for dishonest highway directors, inspectors and contractors caught in acts of bribery and corruption for others to learn their lesson.
- Awards by Government to outstanding contractors who distinguished themselves by quality Jobs.
- Careful choice of consulting engineers and prosecution of corrupt consulting engineers and ministry officials.
- A guaranteed period of use before affecting repairs and before final payment is made.
- There is need for the government to establish a construction ethics committee staffed by men and women of integrity who would have the authority to hear complaints against contractors and against government workers also.
- Government to establish an anti-corruption team made up of men and women of integrity who will not request the contractors to "grease their palms" in order to become lenient in enforcing specification. Also, it is necessary to establish a Contractor's Accountability Program where genuine complaints are lodged against contractors. For non-performance, poor performance, dereliction or repudiation, it is recorded against the said contractors. For continuous record of such offences, the contractor is banned from bidding future contracts for a period of time thus weeding out non performers and creating a contractor pool of proven performers.
- Establishment of a well-equipped library and a design office by the Federal Highways Department is recommended for ready availability of the information needed for construction, reconstruction and rehabilitation projects.
- Government should make the payment of there contractors very effective supervising the process to avoid fund diversions.

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