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Geotechnical Evaluation of the Causes of Road Pavement Failure Along the Mbaitoli-Ikeduru-Mbaise Highway, Southeastern Nigeria

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Abstract - **The incessant failed spots in the road pavement along the 27.61km Mbaitolu-Ikeduru-Ahiara Mbaise highway in Imo state, southeastern Nigeria, has necessitated this geotechnical study to evaluate the impact of the subgrade material quality on the road pavement failure. The study entailed both physical and geological assessment of the predominantly sandy to clayey silt Benin Formation underlying the area, as well as field and laboratory engineering tests on the subgrade materials underlying the road alignment. The engineering tests carried out included the grain size distribution, specific gravity, natural moisture content, Atterberg (liquid and plastic) limits, compaction (to determine maximum dry density and optimum moisture content), California bearing ratio (CBR), and shear strength (to determine cohesion and angle of internal friction). The engineering test results indicate that the natural moisture content values range between 10.4 and 18.9%, liquid limit between 36.0 and 48.6%, plastic limit ranges from 26.1 to 31.6, with corresponding plasticity index values that range from 9.2 to 17.0%. The grain size distribution test results connote the predominance of sand, with number of fines-sized particles that ranges from 22 to 38% and amount coarse to medium sand-sized particles ranging from 62 to 78%.Maximum dry density ranges from 1.29to 1.93 kg/m^3. (CBR) ranges from 3.7 and 91.9%. Specific gravity ranges between 2.56and 2.61, while cohesion and angle of internal friction range from 39 to 42 kPa, and 14 to 20°, respectively. Some failed portion especially in Inyishi area were likely due to moisture fluctuation in the subgrade due to closeness of the water table. Proper compaction, chemical stabilization, and appropriate drainage would likely boost the efficiency of the subgrade material and the durability of the road pavement.**
Keywords: **Failure, Geotechnical Analysis, Road Pavement, Specification, Subgrade Quality**

I. INTRODUCTION

The stability of transportation infrastructure which includes paved roads is significantly dependent on their blueprint and construction. Some paved roads have experienced failure soon after construction while others long after construction. There is a widespread occurrence of pavement failures in Nigerian roads, with most roads not able to attain the projected stability duration. Once failed, these roads are reconstructed or rehabilitated with little or no effort to ascertain the reason for failure. Thus, preventing both functional (surface pavement failure) and structural (deep-seated pavement failure) and funds used in their continuous reconstruction and rehabilitation. The construction of a road starts from outset, planning and blueprint. Some of the factors that commonly influence road pavement failures in Nigeria include the geology and geotechnics of the underlying unit, geomorphologic factors, engineering design, construction material selection, construction procedure and practices, and usage and maintenance plans.

Aigbedion (2007) describes road collapses as the occurrence of discontinuity in a road pavement and presents in forms of cracks, potholes, bulges and depressions. The presence of these discontinuities interrupts the continuous stretch of asphalt or concrete pavement for a smooth drive through. Other visible signs of collapsed road include 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 (Federal Ministry of Works and Housing (FMW&H 1992). All these are prominently visible in several spots along the27.16 km Mbaitoli-Ikeduru-Mbaise Road, in Imo state, southeastern Nigeria (see Fig. 1).

In addition to the geological, geomorphological, geotechnical, road usage, design and construction inadequacies, and maintenance (Adegoke-Anthony and Agada, 1980; Ajayi, 1981). Abynayaka (1977) observed that natural factors such and rainfall and flooding can also result in road collapse, contrary to the opinion of the Transport Road Research Laboratory (1991). The temperature variations and acid rain impact on the base material of the road pavements in water-logged terrains, according to previous researchers (Nelson 1990),can deteriorate the sub-base of the road material through capillary action, causing a reduction in the support provided by the road pavement components. The aim of this research is to establish the position of soil geotechnical distinctiveness in the collapse of the Mbaitoli-Ikeduru-Mbaise Road by means of geotechnical characterization of the subgrade materials along the highway route. The findings will assist in providing solution to the road pavement collapse in the area and other areas with similar subgrade quality and climatic conditions.

II. DESCRIPTION OF THE STUDY AREA

A. Location, Accessibility, and Climate

Mbaitoli-Ikeduru-Mbaise highway is a major road that connects Mbaitolu through Ikeduru LGA to AhiaraMbaise, all in Imo state of southeastern Nigeria. The area is within longitudes 7°15’E and 7°70’E and latitudes 50 30N and 5°37’N. It falls within the humid tropics with rainfall value of about 2,000 mm of per annum, with a mean annual temperature of approximately 27°C. The area has two major seasons, the rainy season which spans March/April to October/November, and dry season that lasts from November/December to February/March. It is typically characterized by the rainforest vegetation.

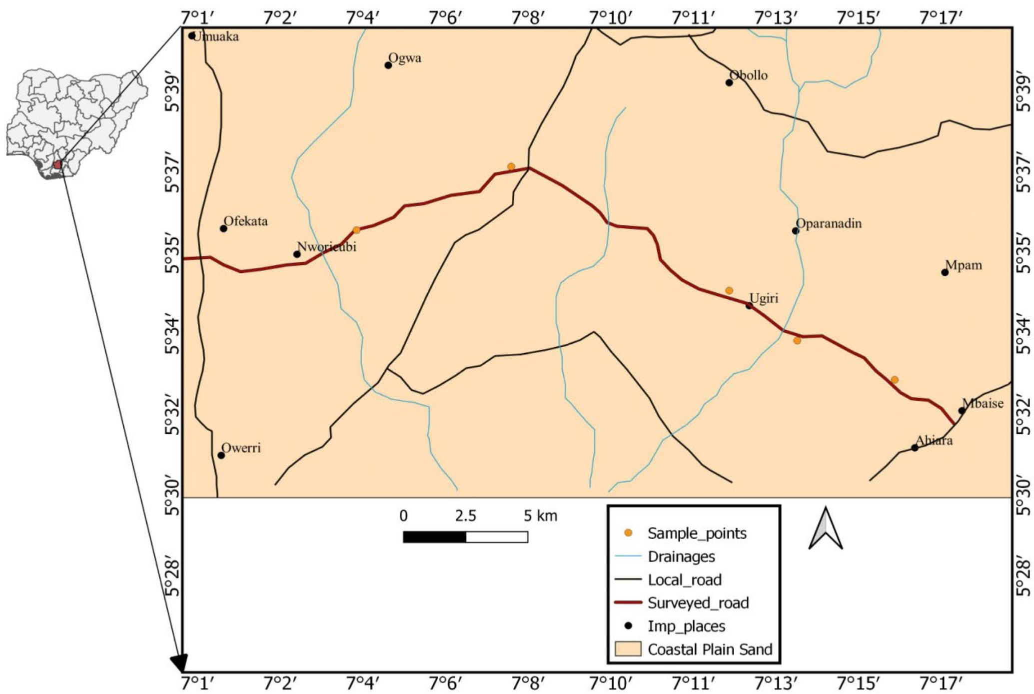

Fig. 1 Geologic map and chainage map of the study area

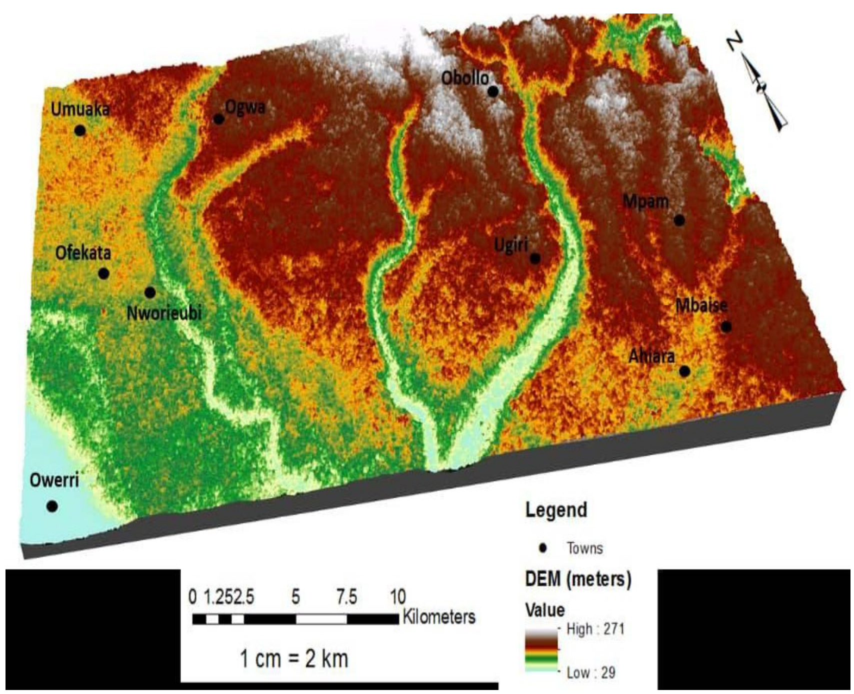

Fig. 2 Digital elevation model of the study area

B. Geology

The studied area belongs to the tertiary period of the geological era with coastal plain sands of the Benin Formation which are reticular, unconsolidated and sandy, deposited in the continental Niger Delta during the Pliocene-Pleistocene period. The formation has an average thick of about 2000m, according to Short and Stauble (1967). It consists of friable, loose, and coarse-grained sandstones with shale intercalations (Simpson, 1954; Reyment, 1965). It is a continental deposit with over 90% loose and freshly white to grey, weathered sandstone and is predominantly made up of yellow and white continental sands, alternating with pebbly layers and occasional sandy clay beds. The geology map of the studied area is shown in Fig. 2. The rivers and streams that drain the area include the Mbaa, Okatankwo, Oramiriukwa Rivers and their tributaries. Some are seasonal, while others are perennial. River Mbaa crossed the studied road in several places including in sample 3 and sample 4 collection spot.

III. MATERIALS AND METHODS

A. Sampling

This disturbed soil samples for the research work were collected at five different burrow pits used for the construction after reconnaissance mapping and chainage activities along the road using open drive sampler. Two of these borrow pits are located Ugiri Ike town which was dug by Hadel and Enic Contractors and the Umuedo Town in Mbaise and currently excavated by local sand dealers. The order samples were collected at failed portions in Ogwa town in Mbaitolu, Atta in Ikeduru and Inyishi in Ikeduru too. The samples collected were sealed in a polythene bags to preserve their *in-situ* moisture condition. The five samples were labeled 1 to 5; sample 1chainage 5km + 500m, sample 2 chainage 10km +10m, sample 3 chainage 19km + 200m, sample 4 chainage 21km + 105m (a borrow pit), and sample 5 chainage 26km+150m (a borrow pit). The sample locations are presented in Table I and Fig. 2.

TABLE I SAMPLES LOCATION AND COORDINATES RESULTS

Sl. No.	Sample No.	Location(0km from Nwaorieubi	Sample Coordinates	Spot Condition	Depth of Sampling(m)
1	SAMP1	Ogwa town 5km + 500m	5.634040E/7.086680N	Collapsed	2m
2	SAMP2	Atta town(11km + 880m)	5.616982E/7.126043N	Collapsed	2m
3	SAMP3	Inyishi town(19km + 200m)	5.599386E/7.161019N	Collapsed	1m
4	SAMP4	Ugiri-ike town(21km+105m) (Borrow Pit)	5.578543E/7.192862N	Borrow pit	2m
5	SAMP5	Umuedo town(26km+150m) (Borrow Pit)	5.555819E/7.245519N	Borrow pit	2m

B. Laboratory Testing

All the engineering tests on the soil samples were carried out at the engineering geology laboratory of the Department of Geology, Gregory University, Uturu, Abia State, and in accordance with the relevant British Standard Institute (BS1377, 1990) parts. The CBR tests were both soaked (24 hours) and Unsoaked, according to guideline provided in the Federal Ministry of Works and Housing (FMWH, 1997).The laboratory tests carried out on the samples were as follows, grain size distribution, specific gravity, natural moisture content, Atterberg limits, compaction, California bearing ratio (CBR), and shear strength.

IV. RESULTS AND DISCUSSION

A. Grain Size Distribution

The results of the grain size distribution tests are summarized in Table II. From Table II, it can been seen that samples from location 1 (around Ogwa town) has 29% fines, 11% fine sand, 33% medium sand and 27% coarse sand, location 2 (Atta Town) 38% fines, 09% fine sand, 32% medium sand and 19 % coarse sand, location 3 (Inyishi town) 27% fines, 13% fine sand, 31% medium sand and 29% coarse sand, location 4 (Ugiri-ike borrow pit) 34% fines, 12% fine sand, 35% medium sand and 19% coarse sand, and location 5 (Umuedo Town) 22% fines, 8% fine sand, 43% medium sand and 36% coarse sand. Taking into account the specification limits for sub-grade material, as shown in Table III, it is clear that all the samples, except sample no. 2, fell within the acceptable fines limit. For grading test, good subgrade materials should have ≤35% passing for sieve 75 um or 200 sieve (FMWH. 1997).

While other factors are considered before the verdict can be given of which material is high-quality. Itshould be noted that high amount of clay in subgrade denotes poor quality materials (Okagbue and Uma, 1988; Jegede, 1997; Akpan, 2005). Grain size distribution test therefore is test is important in the selection and material evaluation as it estimates the relative proportion of various size grades in the samples. The physical and engineering properties of lateritic soils have been found to depend on their textural characteristics. The particle/grain size circulation of a soil is a noteworthy determinant of its geotechnical distinctiveness. In construction, clay materials are seen as complicated soil. This is for the reason that, clay though porous is less permeable and to find out the percentage clay present in the natural soil of an area to know whether it will serve as a good subgrade or not.

TABLE II SUMMARY RESULT OF THE GEOTECHNICAL ANALYSIS OF THE STUDIED ROAD

Sl. No.	Natural Moisture Content	Atterberg Limit			Compression (%)		Particle Size Distribution(%)				CBR(%)		Cohesion (kPa)	SP.G	Angle of Internal Friction(Ø)
		LL	PL	PI	MDD (mg/m3)	OMC (%)	C sand	M sand	F sand	Fines	US	S			
SAMP1	10.4	36.0	26.8	9.2	1.93	11.3	27	33	11	29	83.7	35.0	40	2.56	14
SAMP2	12.6	37.8	26.1	11.7	1.88	11.2	19	32	9	38	90.1	37.2	40	2.59	15
SAMP3	18.9	39.0	28.3	10.7	1.29	13,2	29	31	13	27	91.3	32.7	39	2.56	18
SAMP4	11.8	47.0	30.5	16.5	1.91	10.1	19	35	12	34	87.3	31.7	40	2.61	20
SAMP5	10.6	48.6	31.6	17.0	1.90	9.9	36	43	8	22	91.9	34.4	42	2.58	18

B. Atterberg Limit

The results of the Atterberg limits tests on the samples are presented in Table II. The results showed locations 1, 2 and 3 (collapsed sections) of the road to be of medium liquid and plastic limits. A medium plastic limit suggests the occurrence of medium proportions of clay minerals. The two borrow pits (samples 4 and 5) have high liquid limit These clays are infamous for their vulnerability to volume changes, capable of distension in the presence of high moisture content and contracting when dry. Alternate expansion and contraction of these clays would likely be the cause of road pavement failure at these road sections. The clays also decrease permeability, hamper water conductivity and causes meager drainage thereby extra aiding the road collapse. From the result above, all the samples have good liquid limit qualities for subgrade but failed plastic limits for subgrade material according to Nigeria federal ministry of work 1997 specification shown in Table III. Moderate liquid limit while suggesting moderate acceptance for moisture may not be sufficient opposition when field conditions surpass that moisture content limit as often would be the case during high water influx.

TABLE III SPECIFICATIONS FOR SUB-BASE MATERIALS, FEDERAL MINISTRY OF WORKS AND HOUSING (ADAPTED FROM FMWH 1997)

Parameters	Specification for Sub-base Material (FMWH, 1997)
Sieve analyses % Passing No 200 (75µm)	<35%
Atterberg limits	
-LL	>30%
-PI	>80%
CBR (24hours soaked)	
-Soaked	>30%
-Unsoaked	>80%
Linear Shrinkage	0-6%
Field dry density	>100%

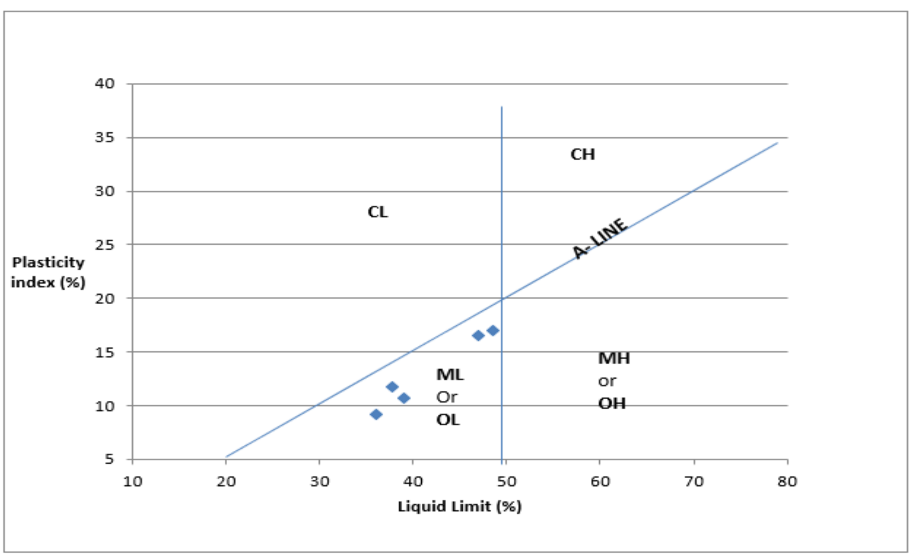

Fig. 3 Casagranda Plasticity Chart

C. Compaction Test

The results of the compaction tests, as presented in Table II, showed that sample numbers 4 and 5 were of lower values of OMC compared to that of sample numbers 1 to 3. This would mean more stability over locations 4 and 5, where the sections showed worn-out conditions. Such moisture content request keeping the samples 1-3 section stable may not be possible in such a plainly controllable conditions prevailing in the field. In the absence of drainage such moisture content could easily be exceeded given the low permeability and high porosity characteristic of the soil types and gently sloping topography.

Optimum moisture content, the water content corresponding to maximum dry density bears an opposite relationship with strength (Idowu, 2015). The lower the optimum moisture content required achieving maximum dry density, the more stable the soil would be under field conditions. Maximum dry density is proportional to resistance to stress. The greater the density of a soil the more internal friction can be mobilized and the greater its load bearing capacity (Idowu, 2015). Samples from locations 1, 2, 4 and 5 were found to have higher average maximum dry densities than sample 3 (Inyishi town). Dry density is a significant parameter that affects soil reaction to stress. Low value of dry density suggests that the natural deposit is loose as exhibited by its high void ratio and porosity. The implication of low density being easy vulnerability to spreading by high water influx and/ or subterranean erosion in form of piping was concluded by (Arora, 2011).

D. California Bearing Ratio

The resistance a soil possesses when stressed or loaded before it fails is the bearing capacity of such soil. This is a function of its bulk density and moisture content characteristics. (AASHTO, 1972). As shown in Table 2, the unsoaked CBR ranges from 83-92%. The values are between 90-95% above the specified standard which requires the sub-base and base course not be less than 30 and 80% respectively (FGN, 1997).

E. Shear Strength

The tested samples recorded reasonably moderate values of cohesion (c) with moderately values of angle of shearing resistance (∅). The low c in the soil samples is attributable to the presence of expansive clay and vice versa (Aghamelu 2012).

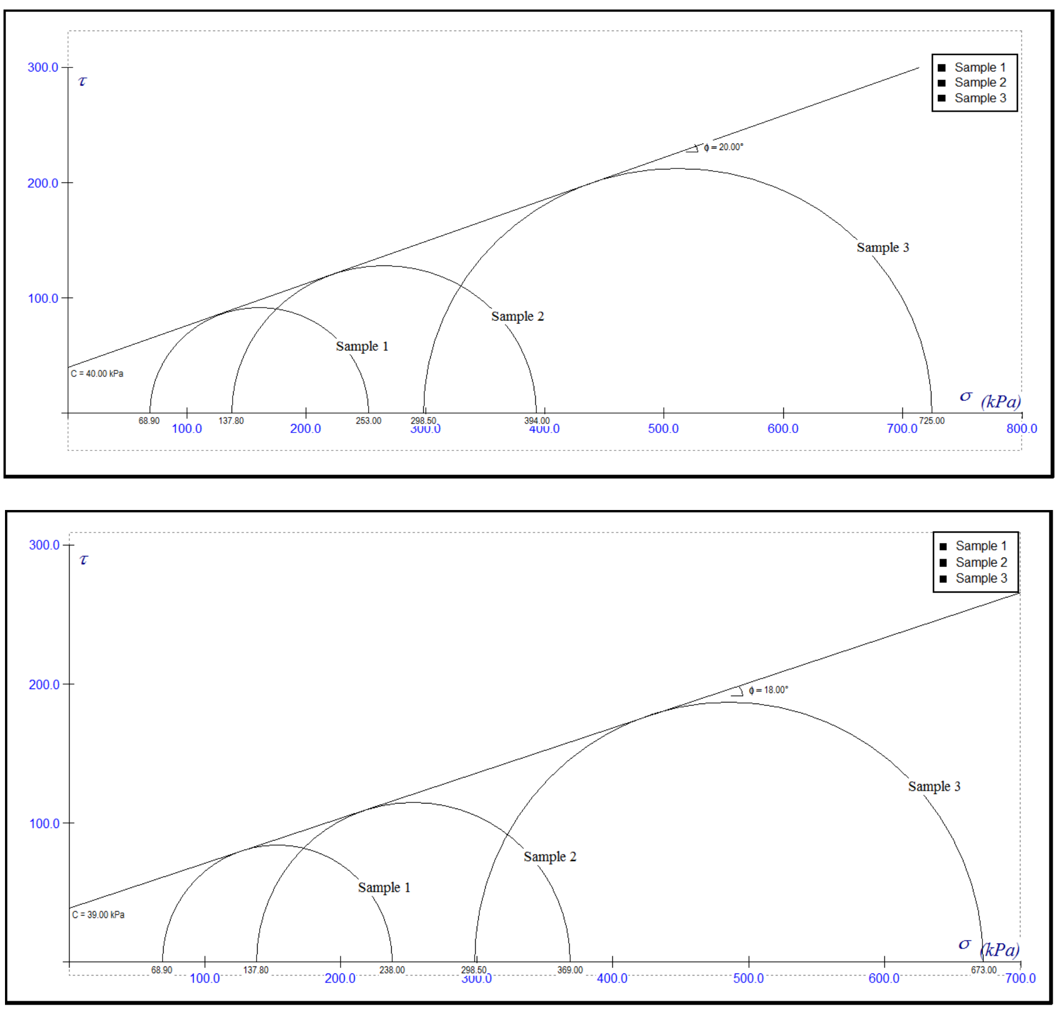

Fig. 4 Shear strength graph of the studied area

F. Specific Gravity

The results of the specific gravity tests on the five samples, as indicated in Table II, suggest that the samples have specific gravity values that denote stable materials. The higher the specific gravity of a soil sample, the higher its load bearing capacity and the better its engineering properties provided water can be kept out (Idowu, 2015). Excessive moisture builds up during periods of high water influx such as the rainy season reduce their shear strength.

G. Natural Moisture Content

A shown in Table II, the moisture content values range from 10.4 to 12.6 %, which are within 5-15 % specified in the FMHW (1997) are standard limits, except sample 3 that recorded natural moisture content of 18.9 %. These values fall within standard specification, denoting stable and suitable subgrade materials.

V. CONCLUSION

The geotechnical properties of soils obtained from stable road sections were better than those from unstable sections. The geotechnical distinctiveness of the soils from the failed sections changes extensively from the standard limits set by the Nigerian Federal Ministry of Works and Housing (1997) which signify that the geotechnical situation of the soil alongside the failed sections is challenging thus making it understandable that the soil geotechnical attributes is a part of the road collapse. In line with the results and ending of this research the accessibility of road amenities and appropriate designs: For road to be of obligatory normal, the drainages, highway signs, shoulders and markings are needed for the good functionality and preservation of the roads in Nigeria. The need for good shoulder helps prevent early highway failure and erosion encroachment. With a good design of the road, the functionality of the road will be achieved. Appropriate filling should be carryout to done when needed to reduce rate of road collapse. Collapsed section with (Sample 3 Inyishi town) shows that water table is above six feet, and it is causing fluctuation of moisture content thereby affecting the subgrade of the area and aiding road failure in the area. The geotechnical attributes of the soils alongside the roadway fluctuate from spot to another point and should be handled as such. Region of high clay material to be treated with watchfulness throughout renovation/ construction actions. Fill resources must be tested and take care of before use to evade troubles after the construction. Data of soil geotechnical uniqueness and principal geology of an area is very indispensable prior to any construction project inaugurate as the firmness of the base layers mostly depends on this analysis. Appropriate Highway geologists and other related expert should be enlisting for the time of pre-construction design and development of highway pavements.

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