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Article

Geotechnical evaluation of road failure: A case study of Zaria/Sokoto Road along Federal University of Gusau, Zamfara State

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Abstract

Pavement failure has contributed immensely to the loss of lives, disruption to normal activities, and increased amount of money being spent on maintenance annually. One of the causes is associated with inadequate investigations of subgrade materials. This current work aimed at examining the geotechnical parameters as factors of pavement failure at Zaria/Sokoto road, along Federal University Gusau. Sufficient soil samples were obtained at the failed section of the road. However, laboratory investigation such as Natural moisture content determination, Sieve analysis, Atterberg limit test, Compaction test, and California bearing ratio test by using (BSL) in order to have a better understanding of the factors causing the road failure. The result from Natural moisture content shows that the soil sample obtained contained an amount of water for each sample while sieve analysis shows that only sample B have satisfied the requirement. In addition, the Atterberg limit test indicates that only soil sample A is good for road construction while for compaction, the OMC and MDD values have also satisfied the requirements. More so, the California bearing ratio test also shows that the sub-base materials are good which makes the layers of good strength except for sample A. Unquestionably, this led to the conclusion that construction materials of the road are mostly good and excellent while some are not, and some complied to the requirements. Hence by visual observation, the drainage system of the road is very poor and the road surface is not cambered to the direction of the drainage so as to drain off water, especially during the rainy season. Water poses a lot of threat to roads which gradually creates voids and allows infiltration of water causing severe damage to the subsoil and pavement. Therefore, it is recommended that the drainage system should be properly built while cambering the road to either direction for proper running off of water.

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Keywords
Pavement failure; geotechnical parameters; soil samples; natural moisture content

Introduction

This project focuses on road failure (using geotechnical evaluation) of Zaria/Sokoto road along federal university Gusau, which lies within the sheet 54 NE; in the Gusau Local Government, Zamfara state Nigeria. The stability of transportation infrastructure which includes paved roads is significantly dependent on their blueprint and construction. Some paved roads have

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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 (Adegoke and Olomolaiye, 2023). The construction of a road starts from the 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 procedures and practices, and usage and maintenance plans. Aigbedion (2007) describes road collapses as the occurrence of discontinuity in road pavement and presents in the form 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 the3.3 km (via Gusau Rd/A126) Zaria Road, in Gusau, Northwest Nigeria.). Pavement deterioration in Nigerian roads may be caused by residual soils with poor geotechnical qualities *(Olofinyo et al.., 2029*) There are several types of highway failure, including potholes, cracking, raveling, rutting, shove, depression, corrugation, water bleeding and the temperature variations and acid rain impact on the base material of the road pavements in water-logged terrains.

According to (Gupta and Amit, 2003), highway engineering is a branch of transportation engineering that focuses on a number of phases, including development, planning, alignment, highway geometry and design, location, highway materials, and overall pavement design, as well as its construction and maintenance. In line with (Gutpa and Amit, 2003), the advancement of social and economic progress, including higher living standards and increased food production, depends on transportation, particularly highway engineering. The strength and characteristics of land usage are currently being changed mostly by road construction, which considerably balances the rise of regional and industrial development. The most developed and widely used form of transportation in developing nations like Nigeria is the road network (Okigbo, 2012). The development of a country is directly related to effective pavement planning and design. This is due to the fact that a properly constructed road network encourages the movement of products and services, hence enhancing economic growth in any country. Therefore, a good road network decreases haulage truck accidents by limiting the harm to people and property (*Akintorinwa et al., 2010).* The aim of this project is to ascertain the causes of highway failure along the Federal University Gusau, Zaria/Sokoto road with a view to proposing optimal solutions.

Method

Study Area

This study will be conducted from the junction of the Gusau Hotel to the Damba clinic section which is 2.6 km long. The road is linked with several roads such as Sokoto Road Bypass, Copas Heaven, and Damba quarters all along zaria road. The study area started at a latitude and longitude of 12°30′00″ N and 6°45′00″ E respectively with an elevation between 1379900 ft.

and 262300 ft. above sea level. The study area ends at Damba clinic at a latitude and longitude of 12°29′00.″ N and 6°45′3″ E respectively and on an elevation of 274800 ft. above sea level.

Figure 1. Map of the study area

Data Analysis

There are basically two types of data which are quantitative and qualitative. This study will collect its data and analyze it in form of Quantitative and Qualitative data;

1. Quantitative data: it deals with data that are numerical or that can be converted into numbers (Sheard, 2018).

2. Qualitative data: is defined as non-numerical data, such as text, video, photographs, or audio recordings. This type of data can be collected using diary counts or interviews and analyzed through grounded theory or thematic analysis (Saul, 2019).

Study Design

This aspect consists of an experimental design study that will be used to achieve the goal of this research and assist in coming up with optimal solutions. The experimental design consists of laboratory tests. Laboratory tests will help give more details on the engineering properties of soil used for the construction of the road. Material samples for laboratory tests were obtained from the study area at the failed section of the road in order to measure the strength of the soil, and physical properties of the soil and also to mitigate the occurrence of the defects on the flexible pavement.

Reasons For the Selection Approach

The soil investigations consist of the determination of natural moisture content, sieve Analysis, Atterberg limit test, Compaction test, and California bearing ratio test. The List below are the reasons why each test is selected for the investigation:

i. Natural moisture content: the natural moisture content is used in determining the bearing capacity and settlement of soil. This natural moisture content will give an idea of the state of the soil in the field.
ii. Sieve analysis: the purpose is to determine the percentage of different grain sizes contained within the soil. As the size of the grain affects the soil characteristics, creating problems like air voids which allow infiltration of water during the rainy season.
iii. Atterberg limit: to understand the behavior of the soil at which it transits from solid, semi-solid, plastic, and liquid state.
iv. Compaction test: the reason behind selecting the compaction test is to thoroughly understand the compaction characteristics of the soil. The value of maximum density achieved during the construction and the density of the soil.
v. California bearing ratio: this test was selected in order to determine the strength of the subgrade soil and base course materials.

Laboratory Test

It gives information about the method and the process followed in the study. Palatino Linotype style 9,5 font, single line spacing, first line indented 1 cm, 6 nk space after paragraphs. References should be prepared based on APA 7 reference and citing displaying essences. Citing should be given like this example (Adams, 2014; Brown & Caste, 2004; Toran et al., 2019). It gives information about the method and the process followed in the study. Palatino Linotype style 9,5 font, single line spacing, first line It includes information about the purpose, significance, conceptual – theoretical framework and study in general. Palatino Linotype style 9,5 font, single line spacing, the first line indented 1 cm, 6 nk space after paragraphs. References should be prepared based on APA 7 reference and citing displaying essences. Citing should be given like this example (Adams, 2014; Brown & Caste, 2004; Toran et al., 2019). Direct quotations are written within “”. If the direct quotation is longer than 40 words, then it should be written without using “” as a separate paragraph, indented and in 8,5 fonts.

Data Collection

Sieve Analysis

The Sieve analysis was conducted for the purpose of determining the soil particle size distribution. The soil material used was weighed at 400g and was soaked in water for 24 hours. Soil sample was used for the test after being washed and dried in the oven. The sample was washed using the BS 200 sieve and the portion retained on the sieve was dried. The 27 dried soil samples were used for the sieve analysis which was done manually using a set of sieves.

Atterberg Limit Test (Ll & Pl)

The Atterberg limit test helps in understanding the behavior of soil at which it transits from solid, semi-solid, plastic, and liquid. The test was like a 2-in-1 test, for liquid limit determination and for plastic limit determination. About 120gm of dried soil was thoroughly mixed with a portion of the material passing through 425 micron BS sieve, water was mixed with soil to create a uniform paste. For liquid limit determination: the paste was placed inside the Casagrande's apparatus using a grove to divide the soil into two. The number of blows to close the divided gap was recorded. For the purpose of determining the plastic limit, about 20gm of the soil material passing through a 425-micron BS sieve was mixed with water till it became a uniform paste. On a glass plate, the soil was placed and rolled until the thread crumbled at a diameter of about 3 millimeters. The 3 mm diameter piece of the rolled soil was heated to 105°C in an oven in order to get the plastic limit (Smith and Ahmed, 2021).

Compaction Test

The Compaction test was conducted based on the BSL test procedure for compaction. The level of water was used at 3%, 6%, 9%, and 12% respectively to conduct the test. This gives an idea of the optimum moisture content and maximum dry density that will be achieved to get the strength of the soil. A 3.5kg rammer was used to compact the soil into 5 layers. Compaction also reduces the permeability of soil, decreases porosity, and increases density.

California Bearing Ratio (CBR)

California bearing ratio (CBR) test is used to access strength pavement levels like base course, sub-base, and sub-grade soil material. The soaked method of CBR was conducted for 24 hours. The same procedures were done as for the Compaction test using optimum moisture content while compacting the sol in 5 layers, with each layer compacted with 62Atterberg Limit Test (LL & PL) This test helps in understanding the behavior of soil at which it transits from solid, semi-solid, plastic and liquid state when loads are applied. blows using a 4.5 kg hammer. A load was applied after the compacted mold soil was put underneath the CBR machine. At a penetration of 0.0, 9, 15, 24,35, 57 75, 108, 118, 125, 129, 135, 143, 0, 10, 17, 30, 45 78 114, 129, 136, 139, 142, 146, and 157 the load was recorded.

Results and Discussion

Natural Moisture Content Determination

Natural moisture content is a critical parameter in soil mechanics and geotechnical engineering, as it influences the behavior of soils under various conditions. This determination is essential for understanding soil properties, including its strength, compressibility, and permeability. Natural moisture content determination gives an idea of the amount of water present at the soil when been obtained at that particular period of time. The state of the soil for sample A has a Natural moisture content of 24.81% while the state of the soil for sample B has a Natural moisture content of 25.10%. However, the state of soil for sample C has a Natural moisture content of 26.70%. This result therefore shows that there is much water in the soil obtained, the availability of water in the soil affects the test that is going to be conducted as before conducting the test all the obtained samples were dried in order to make sure the water content that is going to be used in each test were highly maintained by following the BS procedures. Determining natural moisture content is fundamental in various applications related to soil mechanics. Accurate measurement ensures reliable data for engineering and environmental assessments, ultimately aiding in effective soil management and construction practices.

Table 1. Sample A natural moisture content

Natural Moisture Content		
Container No.	N2	TO
Wt. of wet soil & container (g)	52.4	49.2
Wt. of dry soil & container (g)	47.5	45
Wt. of container (g)	10.1	11.2
Wt. of dry soil (g)	37.4	33.8
Wt. of moisture (g)	4.9	4.2
Moisture content (%)	13.10	12.43
Average Moisture content (%)	12.76	

Table 2. Sample B natural moisture content

Natural Moisture Content		
Container No.	20B	20K
Wt. of wet soil & container (g)	57.9	60
Wt. of dry soil & container (g)	50.1	53.5
Wt. of container (g)	10	9.8
Wt. of dry soil (g)	40.1	43.7
Wt. of moisture (g)	7.8	6.5
Moisture content (%)	19.45	14.87
Average Moisture content (%)	17.16	

Table 3. Sample C natural moisture content

Natural Moisture Content		
Container No.	N3	V8
Wt. of wet soil & container (g)	55.2	64.8
Wt. of dry soil & container (g)	47.5	56.4
Wt. of container (g)	10.3	9.4
Wt. of dry soil (g)	37.2	47
Wt. of moisture (g)	7.7	8.4
Moisture content (%)	20.70	17.87
Average Moisture content (%)	19.29	

Sieve Analysis

The particle size distribution analysis shows the range of particle sizes present in the soil. The size of the soil particles can create voids and allow the penetration of water through the soil which tends to cause damage by gradually creating small holes which later then develop into potholes and another kind of distress on the road. According to the Federal Ministry of Work and Housing specification requirements, for a sample to be used for road construction, the percentage by weight passing the No. 200 sieves should be less than but not greater than 35%. Sequel to the above results, sample A under review was a good sample because the percentage by weight passing sieve No. 200 for the soil does not exceed 35% except for soil samples B and C. The results show the weight retained(g) and the percentage retained (%) for each sieve size(mm). The cumulative percentage retained (%) column indicates the percentage of soil particles retained at each sieve size and smaller.

Observations

1. Diverse Grain Size Distribution: The soil contains particles ranging from 4.76mm to 0.075mm, indicating a diverse grain size distribution. High Percentage of Fines:60.05 of the soil particles are finer than 0.075mm, which is a high percentage of fines (silt and clay). This can lead to poor drainage, settlement, and stability issues in road construction.
2. Lack of Cohesion: The low percentage retained in the 0.3mm and 0.212mm sieves (4.1% and 3.4% respectively) indicates a lack of cohesion in the soil. This can result in poor binding properties and susceptibility to erosion. Based on the results for samples B and C the soil is not suitable for road construction, because the soil's high fine content and lack of cohesion make it potentially unsuitable for road construction, especially as a base or subbase material. The soil may be prone to settlement and rutting under traffic loading, leading to uneven road surfaces and potential failures.

Table 3. Sieve analysis

DRY SIEVE ANALYSIS
SAMPLE A

B.S Sieve Size (mm)	Weight retained (g)	percent retained (g)	Cum. % retained (%)	Finer passing (%)
4.76	1.4	0.7	0	100
2	7.4	3.7	3.7	96.3
1.18	12.2	6.1	9.8	90.2
0.6	16.2	8.1	17.9	82.1
0.425	7.4	3.7	21.6	78.4
0.3	6.3	3.15	24.75	75.25
0.212	7.4	3.7	28.45	71.55
0.15	11.8	5.9	34.35	65.65
0.075	87.9	43.95	78.3	21.7
	D_{10}	0	C_C	0
	D_{30}	0	C_U	0
	D_{60}	0		

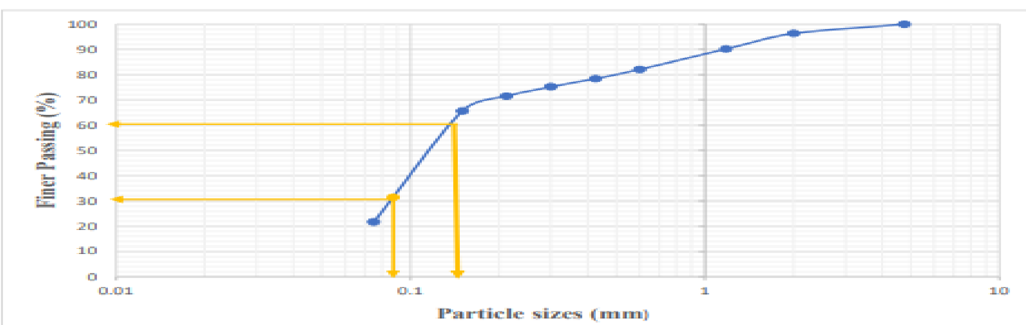


Table 4. Sieve analysis

DRY SIEVE ANALYSIS
SAMPLE B

B.S Sieve Size (mm)	Weight retained (g)	percent retained (g)	Cum. % retained (%)	Finer passing (%)
4.76	19.4	9.7	0	100
2	36.5	18.25	18.25	81.75
1.18	17.8	8.9	27.15	72.85
0.6	21.2	10.6	37.75	62.25
0.425	10.1	5.05	42.8	57.2
0.3	8.2	4.1	46.9	53.1
0.212	6.8	3.4	50.3	49.7
0.15	5.9	2.95	53.25	46.75
0.075	13.6	6.8	60.05	39.95
	D_{10}	0	C_c	0
	D_{30}	0	C_u	0
	D_{60}	0		

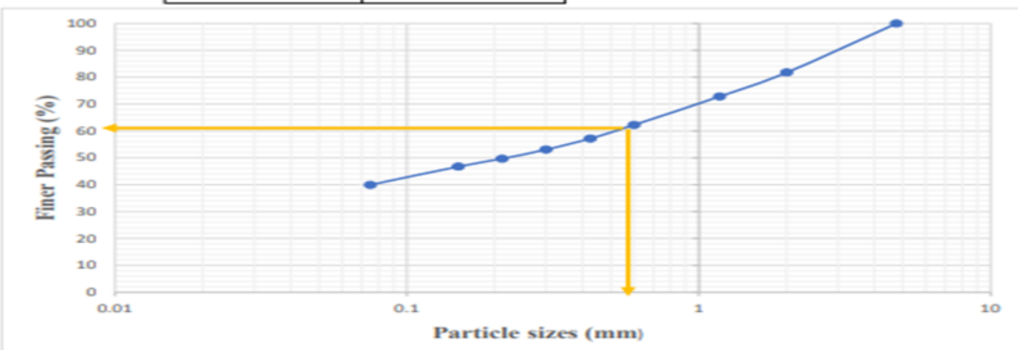
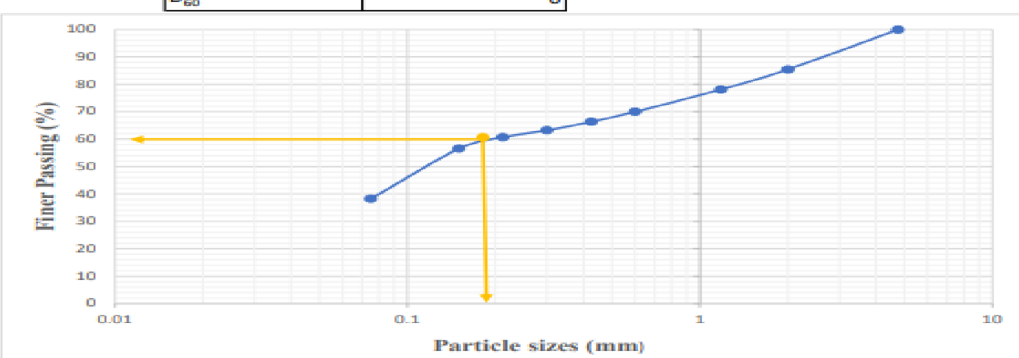


Table 5. Sieve analysis

DRY SIEVE ANALYSIS
SAMPLE C

B.S Sieve Size (mm)	Weight retained (g)	percent retained (g)	Cum. % retained (%)	Finer passing (%)
4.76	26.6	13.3	0	100
2	29.1	14.55	14.55	85.45
1.18	14.6	7.3	21.85	78.15
0.6	16.3	8.15	30	70
0.425	7.3	3.65	33.65	66.35
0.3	6.2	3.1	36.75	63.25
0.212	5.1	2.55	39.3	60.7
0.15	8.3	4.15	43.45	56.55
0.075	36.6	18.3	61.75	38.25
	D_{10}	0	C_c	0
	D_{30}	0	C_u	0
	D_{60}	0		



Atterberg Limit Test

This test helps in understanding the behavior of soil at which it transits from solid, semi-solid, plastic, and liquid states when loads are applied. Based on the Atterberg Limits test results, the soil's suitability for road construction can be evaluated as follows:

1. Liquid Limit (LL): The average LL value is 46.70%, which indicates a high plasticity soil.
2. Plastic Limit (PL): The average PL value is 18.47%, which indicates a relatively low plasticity soil.
3. Plastic Index (PI): The PI value is 38.23%, which indicates a moderate plasticity soil.

Based on the Atterberg limits test results, the soil may be suitable for road construction, but with some limitations. The soil's high plasticity and moderate plasticity index suggest that it may be prone to settlement and deformation under loading but to a lesser extent than sample B. More so, these results show that the materials used for the construction are suitable for road construction as they can withstand applied loads without transiting to the poorest state.

Table 6. Sample A atterberg limit test

ATTERBERG LIMITS
SAMPLE A

Type of Test	LL	LL	LL	LL	LL
No of blows	13	18	25	39	45
Container No.	T1	N34	MA	N7	AK
Wt. of wet soil & cont...g	30.3	21.7	25.3	23.1	28.5
Wt. of dry soil & cont...g	22.9	16.9	19.8	18	21.7
Wt. of container.. g	10.1	8.6	10.2	8.3	8.6
Wt. of dry soil(W_d)..g	12.8	8.3	9.6	9.7	13.1
Wt. of moisture(W_w)..g	7.4	4.8	5.5	5.1	6.8
Moiture content..g	57.81	57.83	57.29	52.58	51.91
Type of Test	PL	PL	PL		
No of blows					LL
Container No.	C2	13H	F		46.70
Wt. of wet soil & cont...g	10.5	10	10.6		
Wt. of dry soil & cont...g	10.2	9.8	10.3		
Wt. of container.. g	8.6	8.7	9.2		
Wt. of dry soil(W_d)..g	1.6	1.1	1.5		
Wt. of moisture(W_w)..g	0.30	0.20	0.30	AVERAGE PL	
Moiture content..g	18.75	18.18	20.00	18.47	

56.71		10
56.71		25
	0	25
56.71		25

Results Summary	LL	PL	PI
	46.70	18.47	28.23

NON PLASTIC

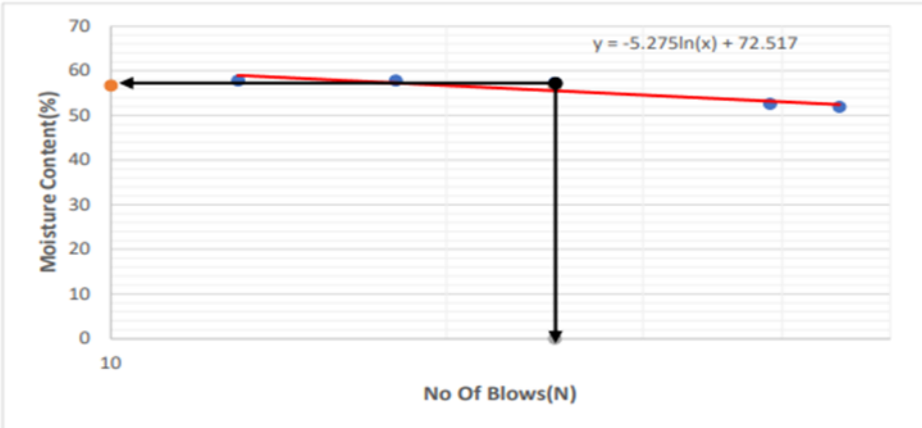


Table 7. Sample B atterberg limit test

ATTERBERG LIMITS
SAMPLE B

Type of Test	LL	LL	LL	LL	LL
No of blows	12	17	29	36	45
Container No.	A1	4C	3C	Z1	H1
Wt. of wet soil & cont…g	34.2	23.5	31.3	31	30.9
Wt. of dry soil & cont…g	28.1	17.8	22.9	22.9	23.3
Wt. of container.. g	18.4	8.1	7.8	8	8.7
Wt. of dry soil(W_d)..g	9.7	9.7	15.1	14.9	14.6
Wt. of moisture(W_w)..g	6.1	5.7	8.4	8.1	7.6
Moiture content..g	62.89	58.76	55.63	54.36	52.05
Type of Test	PL	PL	PL		
No of blows					LL
Container No.	MV	B2	B5		55.54
Wt. of wet soil & cont…g	10.3	10.6	10.5		
Wt. of dry soil & cont…g	10	10.4	10.2		
Wt. of container.. g	8.1	9	9		
Wt. of dry soil(W_d)..g	1.9	1.5	1.8		
Wt. of moisture(W_w)..g	0.30	0.20	0.30	AVERAGE PL	
Moiture content..g	15.79	13.33	16.67	16.23	
	56.71	10			
	56.71	25			
	0	25			
	56.71	25			
Results Summary	LL	PL	PI		
	55.54	16.23	39.31		

NON PLASTIC

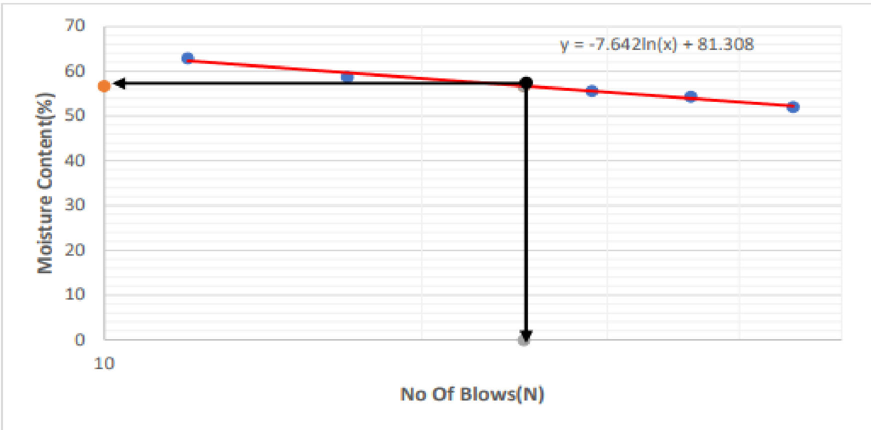
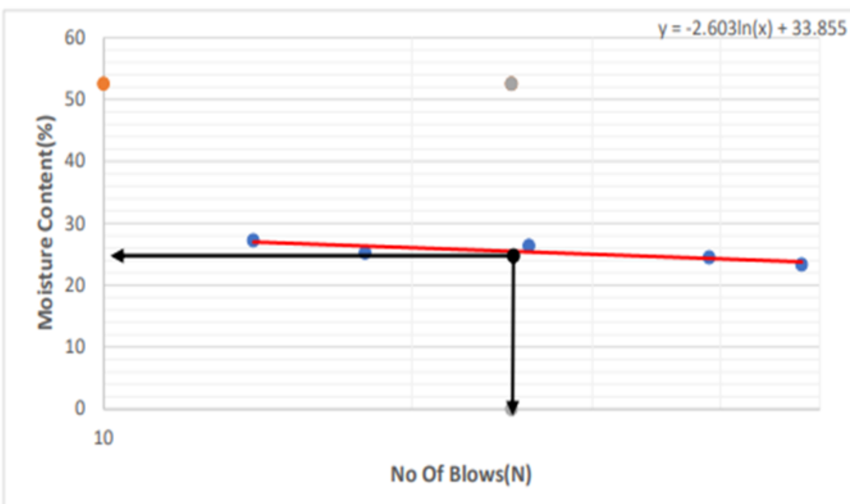


Table 8. Sample C atterberg limit test

ATTERBERG LIMITS
SAMPLE C

Type of Test	LL	LL	LL	LL	LL
No of blows	48	39	26	18	14
Container No.	V5	X6	UU	N42	N12
Wt. of wet soil & cont...g	29.9	27.1	29	29.8	32.2
Wt. of dry soil & cont...g	27.1	24.7	25.7	25.5	28.6
Wt. of container.. g	15.1	14.9	13.2	8.5	15.4
Wt. of dry soil(W_d)..g	12	9.8	12.5	17	13.2
Wt. of moisture(W_w)..g	2.8	2.4	3.3	4.3	3.6
Moiture content..g	23.33	24.49	26.40	25.29	27.27
Type of Test	PL	PL	PL		
No of blows					LL
Container No.	C3	X7	A3		25.48
Wt. of wet soil & cont...g	14.4	14.2	12.3		
Wt. of dry soil & cont...g	14	14	12		
Wt. of container.. g	11.9	11.7	10.6		
Wt. of dry soil(W_d)..g	2.1	2.3	1.4		
Wt. of moisture(W_w)..g	0.40	0.20	0.30	AVERAGE PL	
Moiture content..g	19.05	8.70	21.43	13.87	

52.58	10
52.58	25
0	25
52.58	25



Compaction Test

This test is used to establish a dry density/moisture content relationship of soil under controlled conditions. According to 0'Flaherty (1988), the ranges of values that may be anticipated when using the standard proctor test methods are: for clay, Optimum moisture content (OMC) may fall between 20-30% and MDD fall 1.44-1.685mg/m3. For Silty clay, OMC ranged between 15-25% and Maximum dry density (MDD) fell between 1.6- 1.845mg/m3. For Sandy Clay, OMC is between 8 and 15%, and MDD is between 1.76- 2.165mg/m3 (O'Flaherty, 1988).

The type of soil being analyzed is likely a sandy clay soil from samples A, B, and C, given the high moisture content and bulk density values. The high moisture content also suggests that the soil may be prone to swelling, so it's essential to consider this in the road design and construction process. Furthermore, the results for compaction gave the idea of the percentage of water used in order to maintain the strength of the soil thereby decreasing the porosity also by maintaining the percentage of water gotten from the test, it tends to provide the total number of compaction to be employed in road construction while the in-situ test is done after the compaction to check whether the value gotten from the test of dry density is maintained in order to ensure that the road is stabilized and it has attended its maximum strength.

Table 9. Sample A Compaction Test

COMPACTION
BSL A

No of Trials	1		2		3		4		5
Wt. of mould and wet soil(W2)g	6850		7000		7150		7250		7150
Wt. of mould.........(W_1) g	5000		5000		5000		5000		5000
Wt. of wet soil.......(W_2-W1) g	1850		2000		2150		2250		2150
Bulk Density()..........Mg/m	1.85		2		2.15		2.25		2.15
Container No.	F	K2B	X1	FG	B8	D6	H5	6BP	C8
Wt. of wet soil & cont...g	33.4	32.1	27.6	29.5	31.1	33.4	38.9	29.5	42.4
Wt. of dry soil & cont...g	31.8	30.2	25.1	27.2	27.4	29.7	33.0	25.7	34.7
Wt. of container.. g	10.0	9.6	9.8	10.1	8.1	7.8	8.3	8.7	8.2
Wt. of dry soil(W_d)..g	21.8	20.6	15.3	17.1	19.3	21.9	24.7	17.0	26.5
Wt. of moisture(W_w)..g	1.6	1.9	2.5	2.3	3.7	3.7	5.9	3.8	7.7
Moiture content....%	7.3	9.2	16.3	13.5	19.2	16.9	23.9	22.4	29.1
average moisture content %	9.90		12.00		15.90		23.50		25.60
Dry Density	1.50		1.58		1.62		1.59		1.48

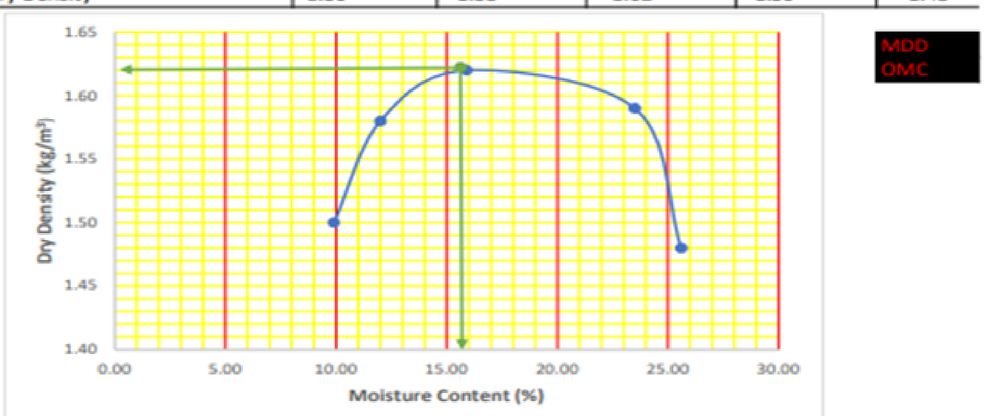
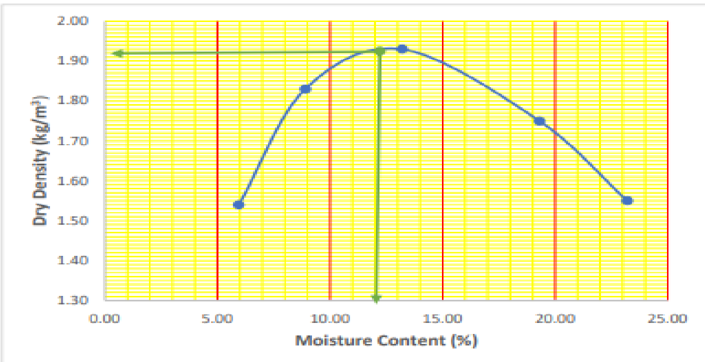


Table 10. Sample B Compaction Test

COMPACTION
BSL B

No of Trials	1		2		3		4		5	
Wt. of mould and wet soil(W2)g	7100		7200		7350		7300		7200	
Wt. of mould.........(W_1) g	5000		5000		5000		5000		5000	
Wt. of wet soil.......(W_2-W1) g	2100		2200		2350		2300		2200	
Bulk Density().........Mg/m	2.1		2.2		2.35		2.3		2.2	
Container No.	N15	N27	53	A14	V9	N5	N33	H	AI	O
Wt. of wet soil & cont...g	49.3	39.0	50.8	36.5	46.5	49.0	48.1	52.7	55.6	55.2
Wt. of dry soil & cont...g	48.2	38.1	48.7	35.0	43.7	45.8	44.2	48.3	49.2	49.0
Wt. of container.. g	13.7	10.5	12.1	10.2	9.9	8.6	9.0	8.8	10.5	7.7
Wt. of dry soil(W_d)..g	34.5	27.6	36.6	24.8	33.8	37.2	35.2	39.5	38.7	41.3
Wt. of moisture(W_w)..g	1.1	0.9	2.1	1.5	2.8	3.2	3.9	4.4	6.4	6.2
Moiture content....%	3.2	3.3	5.7	6.0	8.3	8.6	11.1	11.1	16.5	15.0
average moisture content %	5.95		8.90		13.20		19.30		23.20	
Dry Density	1.54		1.83		1.93		1.75		1.55	

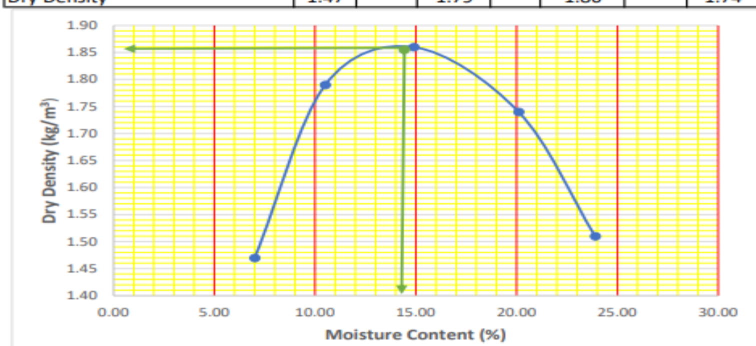


MDD	1.93
OMC	12.00%

Table 11. Sample C Compaction Test

COMPACTION
BSL C

No of Trials	1		2		3		4		5	
Wt. of mould and wet soil(W2)g	7000		7120		7250		7200		7100	
Wt. of mould.........(W_1) g	5000		5000		5000		5000		5000	
Wt. of wet soil.......(W_2-W1) g	2000		2120		2250		2200		2100	
Bulk Density().........Mg/m	2		2.12		2.25		2.2		2.1	
Container No.	N18	X3	N4	N12	N26	JJ	HSM	N42	N20	N19
Wt. of wet soil & cont...g	71.1	54.3	51.6	57.9	46.2	54.4	44.1	34.3	62.2	52.8
Wt. of dry soil & cont...g	69.8	53.3	49.9	55.5	37.8	51.4	40.1	31.6	55.6	47.7
Wt. of container.. g	26.2	14.2	14.3	15.1	9.5	13.3	8.6	8.5	14.6	13.6
Wt. of dry soil(W_d)..g	43.6	39.1	35.6	40.4	28.3	38.1	31.5	23.1	41.0	34.1
Wt. of moisture(W_w)..g	1.3	1.0	1.7	2.4	8.4	3.0	4.0	2.7	6.6	5.1
Moiture content....%	3.0	2.6	4.8	5.9	29.7	7.9	12.7	11.7	16.1	15.0
average moisture content %	7.00		10.50		14.90		20.10		23.90	
Dry Density	1.47		1.79		1.86		1.74		1.51	



MDD	1.86
OMC	14.10%

California Bearing Ratio Test

California Bearing Ratio Test the California bearing ratio test determines the strength of sub-grade and sub-base material. The Federal Ministry of Works and Housing, (1997) specified that the Minimum CBR value of Sub-base material is 30% after 24 hours of soaking. Based on these specifications, all three samples corresponded with the value given by the Federal Ministry of Works and Housing except for sample A. According to the Federal Ministry of Works and Housing (1997), the minimum CBR value for sub-base materials is set at 30% after 24 hours of soaking. This specification ensures that the materials used can adequately support structural loads under wet conditions.

Sample Analysis

In analysis, it was noted that all three samples met the specified minimum CBR value except for Sample A. This indicates that Sample A may not be suitable for use as sub-base material under the given conditions. The failure to meet the CBR requirement suggests potential issues with its strength or composition, necessitating further investigation or alternative material selection

Table 12. CBR sample 0% Soaked A1

CALIFORNIA BEARING RATIO
SAMPLE A

SOAKED			SOAKED		
TEST ON BOTTOM			TEST ON TOP		
PEN (mm)	READING	FORCE	PEN (mm)	READING	FORCE
0.00	0.0	0.00	0.00	0.00	0.00
0.64	10.0	0.24	0.64	7.00	0.17
1.27	17.0	0.41	1.27	12.00	0.29
1.91	19.0	0.46	1.91	15.00	0.36
2.54	25.0	0.60	2.54	19.00	0.46
3.81	29.0	0.70	3.81	22.00	0.53
5.08	30.0	0.72	5.08	25.00	0.60
6.35	32.0	0.77	6.35	29.00	0.70
7.62	35.0	0.84	7.62	32.00	0.77
8.89	45.0	1.08	8.89	35.00	0.84
10.16	51.0	1.22	10.16	50.00	1.20
11.43	58.0	1.39	11.43	61.00	1.46
12.70	63.0	1.51	12.70	65.00	1.56

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	0.60	13.2	4.55	2.54	0.46	13.2	3.45
5.08	0.72	20	3.60	5.08	0.60	20	3.00
	ACCEPTED CBR VALUE			4.55			

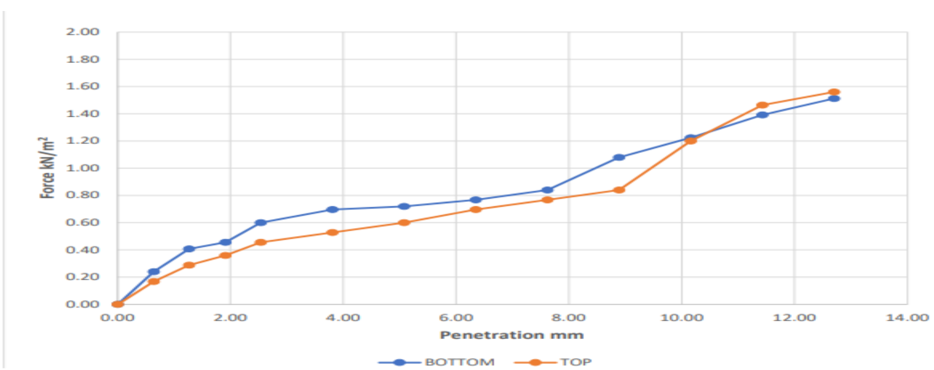


Table 13. CBR sample 1% Soaked A1

CALIFORNIA BEARING RATIO
SAMPLE A

SOAKED TEST ON BOTTOM		
PEN (mm)	READING	FORCE
0.00	0.0	0.00
0.64	9.0	0.22
1.27	15.0	0.36
1.91	24.0	0.58
2.54	35.0	0.84
3.81	57.0	1.37
5.08	75.0	1.80
6.35	108.0	2.59
7.62	118.0	2.83
8.89	125.0	3.00
10.16	129.0	3.10
11.43	135.0	3.24
12.70	143.0	3.43

SOAKED TEST ON TOP		
PEN (mm)	READING	FORCE
0.00	0.00	0.00
0.64	10.00	0.24
1.27	17.00	0.41
1.91	30.00	0.72
2.54	45.00	1.08
3.81	78.00	1.87
5.08	114.00	2.74
6.35	129.00	3.10
7.62	136.00	3.26
8.89	139.00	3.34
10.16	142.00	3.41
11.43	146.00	3.50
12.70	151.00	3.62

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	0.84	13.2	6.36	2.54	1.08	13.2	8.18
5.08	1.80	20	9.00	5.08	2.74	20	13.68
	ACCEPTED CBR VALUE			13.68			

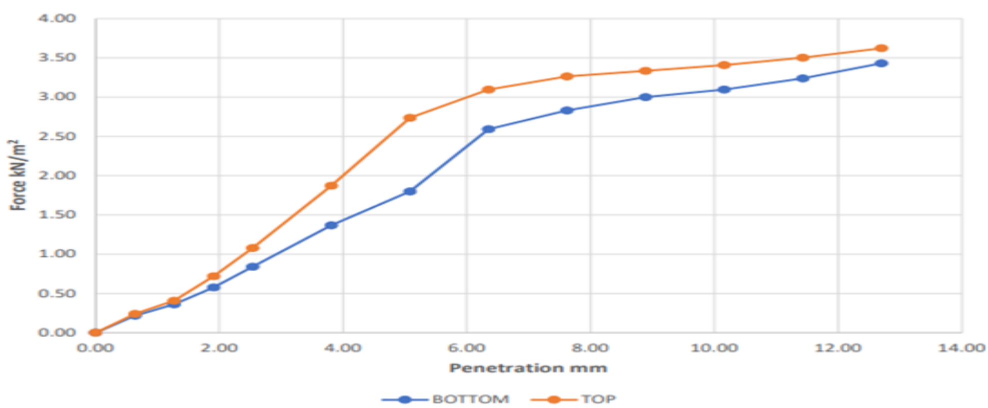


Table 14. CBR sample 3% Soaked A2

CALIFORNIA BEARING RATIO
SAMPLE B

SOAKED TEST ON BOTTOM		
PEN (mm)	READING	FORCE
0.00	0.0	0.00
0.64	38.0	0.91
1.27	78.0	1.87
1.91	110.0	2.64
2.54	147.0	3.53
3.81	192.0	4.61
5.08	215.0	5.16
6.35	225.0	5.40
7.62	242.0	5.81
8.89	260.0	6.24
10.16	280.0	6.72
11.43	308.0	7.39
12.70	325.0	7.80

SOAKED TEST ON TOP		
PEN (mm)	READING	FORCE
0.00	0.00	0.00
0.64	17.00	0.41
1.27	37.00	0.89
1.91	63.00	1.51
2.54	92.00	2.21
3.81	143.00	3.43
5.08	167.00	4.01
6.35	220.00	5.28
7.62	275.00	6.60
8.89	305.00	7.32
10.16	340.00	8.16
11.43	365.00	8.76
12.70	380.00	9.12

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	3.53	13.2	26.73	2.54	2.21	13.2	16.73
5.08	5.16	20	25.80	5.08	4.01	20	20.04
	ACCEPTED CBR VALUE			26.73			

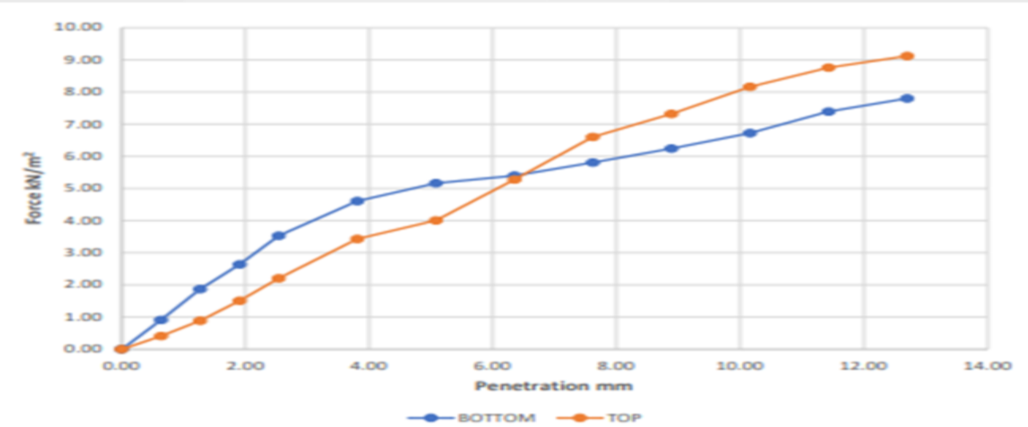


Table 15. CBR sample 1% Soaked B2

CALIFORNIA BEARING RATIO
SAMPLE B

SOAKED		
TEST ON BOTTOM		
PEN (mm)	READING	FORCE
0.00	0.0	0.00
0.64	17.0	0.41
1.27	28.0	0.67
1.91	32.0	0.77
2.54	35.0	0.84
3.81	38.0	0.91
5.08	40.0	0.96
6.35	42.0	1.01
7.62	44.0	1.06
8.89	46.0	1.10
10.16	47.0	1.13
11.43	49.0	1.18
12.70	50.0	1.20

SOAKED		
TEST ON TOP		
PEN (mm)	READING	FORCE
0.00	0.00	0.00
0.64	16.00	0.38
1.27	24.00	0.58
1.91	29.00	0.70
2.54	35.00	0.84
3.81	39.00	0.94
5.08	44.00	1.06
6.35	46.00	1.10
7.62	48.00	1.15
8.89	51.00	1.22
10.16	53.00	1.27
11.43	57.00	1.37
12.70	60.00	1.44

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	0.84	13.2	6.36	2.54	0.84	13.2	6.36
5.08	0.96	20	4.80	5.08	1.06	20	5.28
	ACCEPTED CBR VALUE			6.36			

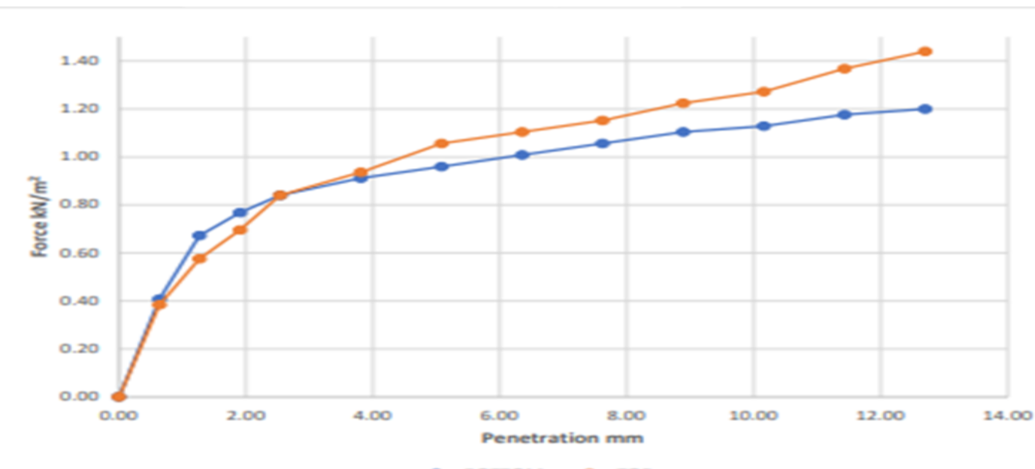


Table 16. CBR Sample 1% Soaked C1

CALIFORNIA BEARING RATIO
SAMPLE C

SOAKED			SOAKED		
TEST ON BOTTOM			TEST ON TOP		
PEN (mm)	READING	FORCE	PEN (mm)	READING	FORCE
0.00	0.0	0.00	0.00	0.00	0.00
0.64	10.0	0.24	0.64	7.00	0.17
1.27	14.0	0.34	1.27	9.00	0.22
1.91	18.0	0.43	1.91	12.00	0.29
2.54	20.0	0.48	2.54	15.00	0.36
3.81	22.0	0.53	3.81	17.00	0.41
5.08	24.0	0.58	5.08	18.00	0.43
6.35	25.0	0.60	6.35	19.00	0.46
7.62	26.0	0.62	7.62	20.00	0.48
8.89	27.0	0.65	8.89	21.00	0.50
10.16	27.0	0.65	10.16	22.00	0.53
11.43	28.0	0.67	11.43	23.00	0.55
12.70	28.0	0.67	12.70	24.00	0.58

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	0.48	13.2	3.64	2.54	0.36	13.2	2.73

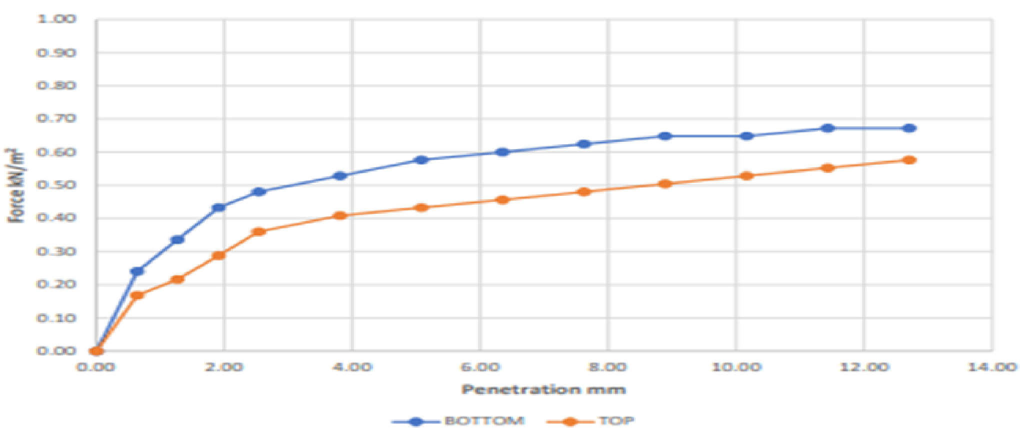
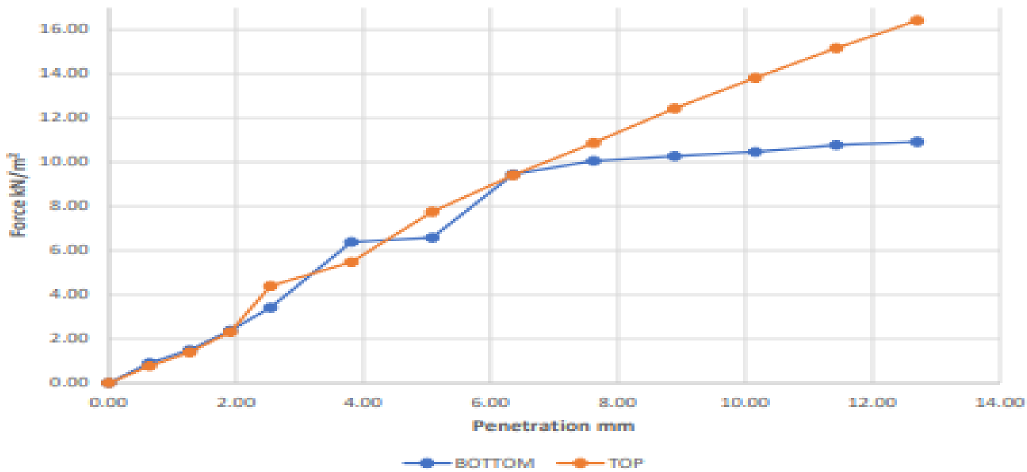


Table 17. CBR Sample 6% Soaked C2

CALIFORNIA BEARING RATIO
SAMPLE C

SOAKED			SOAKED		
TEST ON BOTTOM			TEST ON TOP		
PEN (mm)	READING	FORCE	PEN (mm)	READING	FORCE
0.00	0.0	0.00	0.00	0.00	0.00
0.64	38.0	0.91	0.64	32.00	0.77
1.27	62.0	1.49	1.27	58.00	1.39
1.91	99.0	2.38	1.91	96.00	2.30
2.54	142.0	3.41	2.54	183.00	4.39
3.81	266.0	6.38	3.81	228.00	5.47
5.08	274.0	6.58	5.08	323.00	7.75
6.35	394.0	9.46	6.35	392.00	9.41
7.62	419.0	10.06	7.62	453.00	10.87
8.89	428.0	10.27	8.89	518.00	12.43
10.16	436.0	10.46	10.16	576.00	13.82
11.43	449.0	10.78	11.43	632.00	15.17
12.70	455.0	10.92	12.70	684.00	16.42

SOAKED (BOTTOM)				SOAKED (TOP)			
Penetration	Load kN	Standard Load kN	CBR %	Penetration	Load kN	Standard Load kN	CBR %
2.54	3.41	13.2	25.82	2.54	4.39	13.2	33.27
5.08	6.58	20	32.88	5.08	7.75	20	38.76
	ACCEPTED CBR VALUE			38.76			



Conclusion and Implications

In conclusion, the investigation revealed that the road failure in Zaria/Sokoto road along Federal University Gusau was mostly not due to the quality of construction materials, which most of the samples met the required standards, but rather the poor drainage system and lack of cambering of the road surface, which led to water accumulation and infiltration, causing damage to the subsoil and pavement. Therefore, the study recommends improving the drainage system and cambering the road to prevent water accumulation and ensure proper drainage, thereby extending the lifespan of the road.

Based on the findings of the laboratory experiment, the following recommendations are made:

i. The nearby drainage system should be repaired or rebuilt to prevent water accumulation and extend the lifespan of the road.
ii. The road surface should be sloped to facilitate efficient drainage and pavement water from accumulating on the pavement.
iii. The damaged road section should be repaired using appropriate materials to ensure durability.
iv. The road shoulder should be properly treated to prevent erosion and ensure stability.
v. Regular maintenance should be carried out to address any defects or issues on the road in a timely manner.

Declarations

Competing interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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