



ORIGINAL RESEARCH ARTICLE

GEOTECHNICAL PERFORMANCE EVALUATION OF FLOOD-IMPACTED
SUBGRADE OF FORI ROAD, MAIDUGURI, BORNO STATE, NIGERIA

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ABSTRACT

This research investigates the properties and suitability of subgrade soils in Fori area of Maiduguri for road pavement foundations in flood prone environments. Soil samples were collected from three locations along Fori road over an approximately 300 m stretch, after the Fori community bridge area, Maiduguri. Some of the soil sample properties analysed includes grain size distribution, Atterberg limits, Standard Proctor compaction and California Bearing Ratio (CBR) tests on soil samples from 0.5 m and 1.0 m depths. The results of the Particle size distribution and Atterberg limits show that the soils is classified as fine sand A-3(0) according to the America Association for State Highway and Transportation Officials (AASHTO), exhibiting low cohesion and high moisture sensitivity. However, compaction results indicated a relatively flat moisture density curves, with maximum dry densities of 1.71 g/cm³ (0.5 m) and 1.55 g/cm³ (1.0 m) corresponding to optimum moisture contents of 12.89 % and 19.4 %, respectively. Soil compressibility was quantified using the liquid limit, yielding values of 0.11 and 0.10, which indicates moderate compressibility of the flood impacted subgrade. Similarly soaked CBR values showed a significant strength reductions down to 1.36 % (0.5 m) and 2.85 % (1.0 m) after 48 hours. The soil is thus, regarded as “very poor” category for subgrades according to TRRL standards. Comparative analyses with existing literature shows that these characteristics are typical of fine grained, non-cohesive soils under flooding and are consistent with global observations of weakened subgrades. The study therefore concludes that the native soils are unsuitable for direct use as pavement subgrades in their natural state. To ensure durable road performance in Fori's flood prone environment, measures such as chemical stabilization, profile elevation, improved drainage and possible geosynthetic reinforcement are recommended.

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1.0 Introduction

Road networks plays a vital role in economic growth, trade, and social interaction, serving as the backbone of transportation systems worldwide (Aderamo, 2012). However, the functionality of road infrastructure is increasingly being threatened by flooding, particularly in developing countries where drainage systems are often inadequate (Akinyemi *et al.*, 2020). Flooding results in widespread road damage, including pavement washouts, cracks, potholes, and complete functional and structural failures, leading to high maintenance costs and disruption of socio-economic activities (Macharia, 2024). The subgrade forms the foundation of any pavement structure and significantly influences its strength and durability. A properly evaluated subgrade ensures that loads are adequately supported and distributed, reducing the risk of surface deformation and premature pavement failure (Onyelowe *et al.*, 2019). Geotechnical evaluation of subgrade soils, including tests for compaction, moisture content, plasticity, and California Bearing Ratio (CBR), is essential for proper design and long-term maintenance of roads (Rahman *et al.*, 2021). Flooding alters the physical and mechanical

properties of soils, often causing excessive saturation, reduced shear strength, and decreased bearing capacity (Osinubi and Nwaiwu, 2005). Prolonged inundation leads to increased moisture contents and reduced CBR values, rendering the subgrade incapable of sustaining traffic loads (Okeke et al., 2020). Several studies have documented the effect of flooding on subgrades in tropical and semi-arid regions. Rahman et al. (2021) found that inundated clayey soils exhibited a drastic reduction in CBR and bearing capacity, requiring soil stabilization for sustainable road use. Several experiments conducted by Ismail et al. (2020) to study the effect of flooding on subgrade soil reported that CBR value of subgrade reduced by 41% after flooding. According to him, the subgrade of pavement is reported to be in poor condition immediately after flooding. Sultana et al. (2014) reported that structural and functional performance of flood affected flexible pavements in Australia, showing significant deterioration in load bearing capacity and surface conditions due to prolonged submergence. Similarly, Mustapha et al. (2022) investigated road failures in Northern Nigeria and identified flooding as a major factor behind the poor performance of subgrades, particularly in areas with silty and clayey soils. These studies justify the need for a localized geotechnical investigation into flood impacted subgrades, particularly in regions where recurring inundation threatens pavement performance. Despite extensive global and regional research, soil behavior under flooding conditions varies with local geology and environmental factors, making site specific evaluation essential for effective road design. Therefore, this study seeks to assess the engineering properties of subgrade soils in Fori, Maiduguri, to provide reliable data that will guide appropriate stabilization methods and improve the resilience and longevity of road infrastructure in flood prone areas.

2. Materials and Methods

2.1 Study Area Description



Figure 1: Map of Fori ward, Maiduguri.

The study was conducted in Fori ward, a low lying residential area in Maiduguri, Borno State, Nigeria (11.8398° N, 13.1679° E; approximately 320 m elevation). Fori is located along Fori Street Road, behind the Hadeeza and Sadeeq LPG plant, opposite the timber shed, after the Fori community bridge area of Maiduguri. The area is characterized by flat terrain, unlined drains and unregulated development, all of which make it highly susceptible to flooding. A major flood event occurred between 9 and 11 September 2024, following the overflow from the rainfall intensity and partial failure of Alau Dam, inflow of water from the Laddo dam and other catchments such as Ngada bull. Reports from the National Emergency Management Agency (NEMA) and the West Africa Network for Peacebuilding (WANEP) confirmed that this flood submerged several residential communities, including Fori, displacing over 400,000 residents and destroying critical infrastructure such as culverts and bridge abutments (NEMA, 2024; WANEP, 2024).

2.1.1 Sample collection

For this research, soil samples were collected from three locations along Fori Road over an approximate 300 m stretch opposite the timber selling center. The sampling coordinates corresponds to the flood affected zone. At each location, samples were taken at 0.5 m and 1.0 m depths below the ground surface to evaluate

vertical variations in soil behavior. The soils are predominantly silty and sandy soils with low plasticity, poor drainage, and high moisture sensitivity. All samples were collected following American Society for Testing and Materials (ASTM) procedure, sealed in airtight containers, labeled, and transported to the Geotechnical Laboratory, Department of Civil and Water Resources Engineering, University of Maiduguri, where testing was conducted to determine their engineering properties.

2.2 Methods

2.2.1 Specific gravity test

The initial weight of the empty density bottle was weighed and recorded as M_1 , then the density bottle was filled with 250g of the air dried sample weighed and then recorded as M_2 . Distilled water was added to the oven dried sample in the density bottle to its fullest capacity, thoroughly stirred then weighed and recorded as M_3 . The density bottle was filled with distilled water only, then weighed and recorded as M_4 . The procedure was repeated for two more observations for the same soil sample, and the specific gravity was calculated using the equation:

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1)(M_3 - M_2)} \quad 1$$

2.2.2 Consistency limits test

The soil samples were pulverized, oven dried, and sieved through 0.425mm sieve. 250g of each sample was measured and mixed with distilled water to a stiff consistency. The paste was placed in the cup of the liquid limit device and a groove was cut using the spatula. Then the crank was turned continuously with the cup lifted and dropped at the rate of two revolutions per second until the groove closed. The number of blows required to close the groove was recorded and a portion of the sample was taken for moisture content determination. The test was repeated for different ranges of blows between 10 and 45 according to ASTM D4318 and BS 1377 - 2:1990, in order to establish the flow curve. However, during testing, the soils exhibited no plasticity, and attempts to form a thread at 3.2 mm diameter crumbled, classifying the soil as non-plastic (NP).

2.2.3 Particle size distribution

1000g from each of the samples were weighed and soaked in water for 24 hours. The soaked samples were sieve and washed using BS sieve No 200 (75 μ m) according to BS 1377: part 2:1990, the washed samples were then oven dried for 24hours and reweighed. These were poured on the set of sieves and placed on an electric sieve shaker. Each sieve was cleaned and the weight of the sample retained on each sieve was recorded. Percentage passing sieves were plotted against sieve sizes on a logarithmic graph to obtain the particle size distribution curve.

2.2.4 Compaction characteristics

The cylindrical mould with the base plate were weighed without the extension collar, then 3000g of the soil sample was mixed thoroughly with assumed quantity of distilled water in an increment of 4%. The soil was then poured into the mould with the collar fixed on it, then 2.5kg rammer is gently place on the soil vertically, and given 27 blows on the 3 layers from a 305mm which corresponds to Standard Proctor (BS 1377 Light Compaction).

$$\rho = \frac{\text{Weight of Compacted Soil}}{\text{Volume of Mold}} \quad 2$$

$$\rho_d = \frac{\rho}{1 + \frac{w}{100}} \quad 3$$

Where ρ is the dry density of a soil sample, ρ_d is the wet density of a soil sample and W is the moisture content of soil.

The blows were uniformly distributed over the whole area of the layer, all layers were of equal thickness, after all the successive blows were given, the extension collar was removed, then the compaction mould with

the base plate as well as the compacted soil were weighed and recorded. Some Portion of the compacted sample soil were taken for moisture content test. The mould was then emptied and the same procedure was repeated for an increment percentage of assumed moisture of 8, 12, 16, 20 and 24% until a maximum weight of the mould with compacted soil started falling.

2.2.5 California bearing ratio test

Compaction tests were conducted on soil samples to determine the maximum dry densities (MDD) with their corresponding optimum moisture contents (OMC). The OMC and MDD of each sample was used to calculate the water content. In this test, the standard CBR mould, with 4.5kg rammers were used. Then 5000g of the soil sample was mixed thoroughly at OMC with the equivalent quantity of distilled water, and given 27 blows on the 5 layers as specified by the test standard. The blows were uniformly distributing over the whole area of the layer of equal thickness. Sample specimens for CBR test were prepared and soaked for 24 and 48 hours, the specimen was placed on the CBR machine. Load was applied at a constant penetration of 1.25 mm/min and corresponding loads were recorded at penetration of 2.5 mm and 5.0 mm, and the average CBR for top and bottom of the samples were calculated.

3. Results and Discussion

3.1 Index Properties of the Samples

The index properties of the samples were determined to provide preliminary information on their physical characteristics and classification. Tests such as natural moisture content, particle size distribution and Atterberg limits were conducted to evaluate grain composition, consistency and plasticity. These properties are essential for understanding soil behavior and assessing its suitability for use as a pavement subgrade.

Table 1: Index Properties of Fori Soil Samples

Property	Quantity at 0.5 m	Quantity at 1.0 m
Liquid Limit (LL) %	26.3	24.4
Plastic Limit (PL) %	0	0
Plasticity Index (PI) %	NP (0)	NP (0)
AASHTO Classification	A-3 (0)	A-3 (0)
Unified Soil Classification System (USCS)	SP (Poorly graded Sand)	SP (Poorly graded Sand)
Group Index	0	0
Maximum Dry Density at Light Compaction (MDDL) (g/cm^3)	1.71	1.55
Optimum Moisture Content at Light Compaction (OMCL) %	12.89	19.44
Compression Index (Cc)	0.11	0.10
California Bearing Ratio (CBR) % (48 Hours Soaked)	1.36	2.85
California Bearing Ratio (CBR) % (24 Hours Soaked)	3.53	4.65
California Bearing Ratio (CBR) % (Unsoaked)	5.74	6.26

3.1.2 Index properties

The summary of the soil index properties is presented in Table 1, showing Atterberg limits, PSD, soil classification as fine sand A-3(0) according to AASHTO soil classification system and Compaction values. The results aligned with Das and Sobhan, 2018; Craig, (2017) who found similar values for Atterberg limits, PSD, USCS, AASHTO, GI, Compaction and CBR tests. Low specific gravity and non-plastic behavior indicate high moisture sensitivity, consistent with Osinubi and Nwaiwu (2005).

3.2 Moisture-Density Relationship

Moisture content varies with depth, with higher values occurring in the near surface soil and lower values at greater depths. This trend reflects increased water retention in the upper layers due to direct exposure to rainfall infiltration and surface processes, while deeper layers experience reduced moisture movement.

Figure 1 illustrate that the tested soil exhibits non-plastic behavior (NP), indicating the absence of clay minerals or plasticity characteristics within the sample with liquid limits of 26.3% and 24.4% at 0.5 m and 1.0 m depths

respectively. The inability to form a plastic thread during rolling confirms the absence of significant clay minerals. Similar observations were reported by Rahman *et al.* (2021), who found that sand soils in Bangladesh showed negligible plasticity, making them structurally weak when inundated. Okeke *et al.* (2020) also noted that soils with low or no plasticity have poor shear resistance and are unsuitable as subgrades under wet conditions. Thus, the non-plasticity observed in Fori soils aligns with the literature and confirms their vulnerability in flood prone environments.

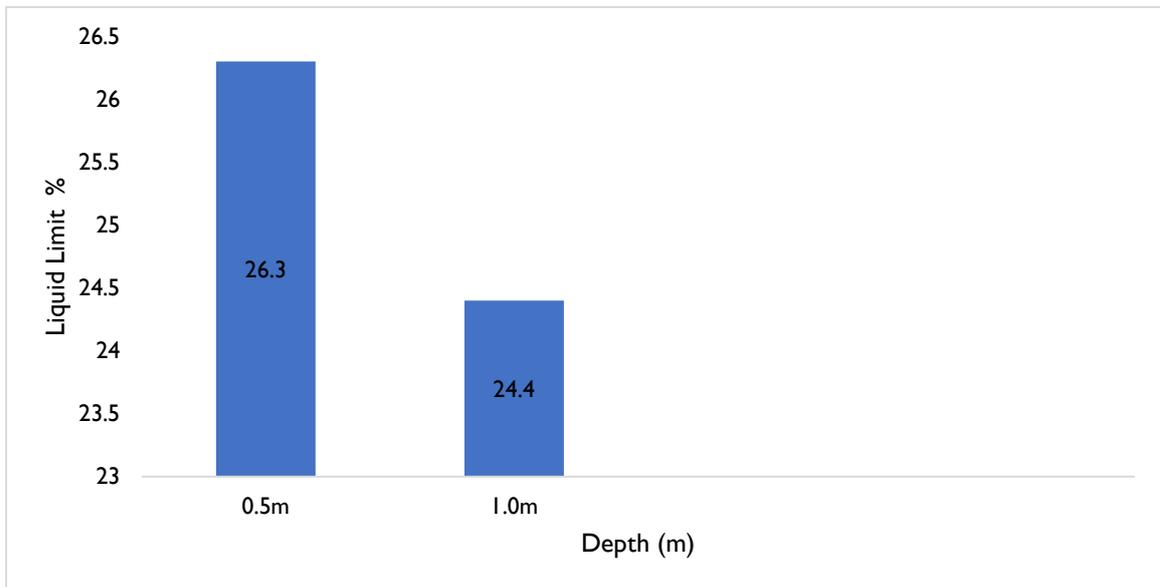


Figure 1: A column Bar-Chart showing the variation Of moisture content with depth.

3.3 Particle Size Distribution

Particle size distribution analysis was carried out to determine the gradation characteristics of the soil and to facilitate classification for pavement design purposes.

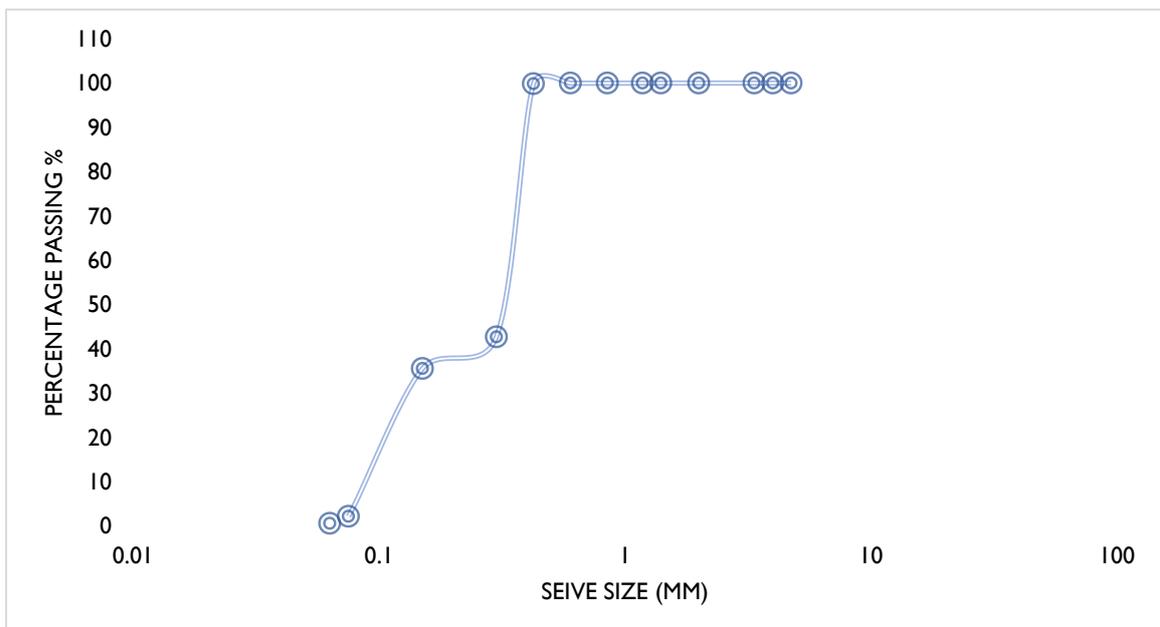


Figure 2: Particle Size Distribution Curves for Soil Sample (a) at 0.5m depth

Figure 2 shows the particle size distribution curve for the soil at 0.5m depth, indicating dominance of fine particles with poor gradation.

Figure 3 presents the corresponding curves for the soil at 1.0m depth, exhibiting a similar gradation pattern. The shapes of both curves confirms that the soils are poorly graded fine sand (A-3) according to AASHTO soil classification, which are known to be moisture sensitive and prone to loss of strength under saturated

conditions. This agrees with Onyelowe *et al.* (2019), who noted that A-3 soils are highly moisture sensitive and lose inter particle friction upon saturation. Mustapha *et al.* (2022) similarly identified silty or poorly graded sandy soils as a key factor in flood related pavement failures in Northern Nigeria. Therefore, the particle size results reinforce the conclusion that Fori subgrades are poorly suited for pavement support without modification.

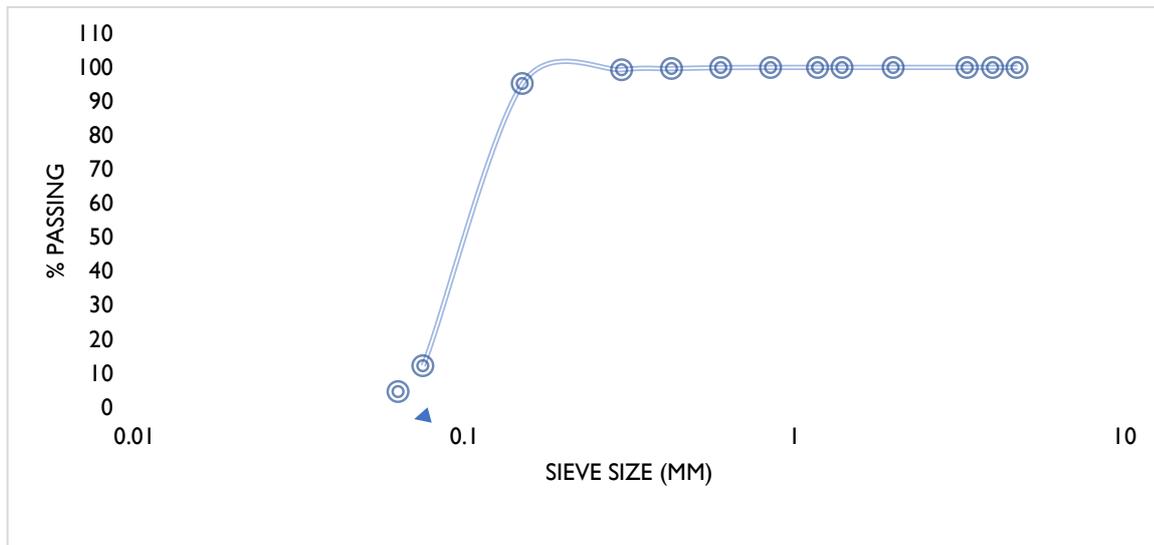


Figure 3: Particle Size Distribution Curves for Soil Sample (b) at 1.0m depth

3.5 Compaction Test (Standard Proctor BS 1377 Light Compaction)

The compaction test was performed to establish the relationship between moisture content and density of the soil under standard Proctor effort. The resulting moisture-density relationship is used to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), which are essential parameters for achieving adequate field compaction.

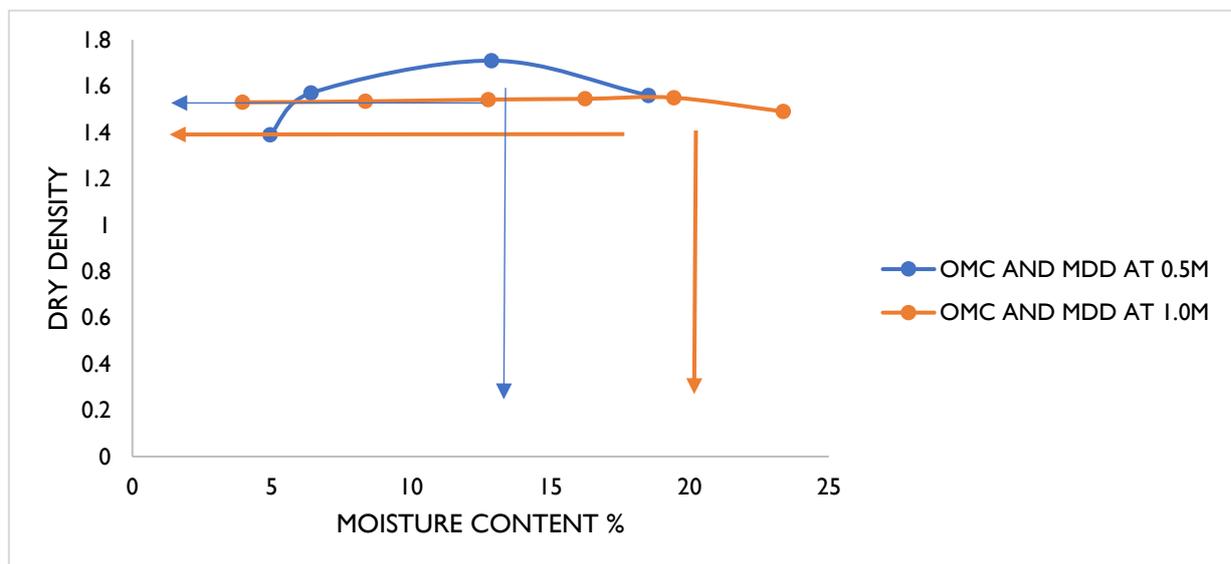


Figure 4: A combined graph of OMC and MDD at 0.5m and 1.0m depth

Figures 4 present the moisture–density relationships for tested soil samples, where the compaction results revealed Maximum Dry Densities (MDD) of 1.71 g/cm³ (0.5 m) and 1.55 g/cm³ (1.0 m), with corresponding Optimum Moisture Contents (OMC) of 12.89% and 19.4%. The relatively low densities and broad compaction curves are typical of non-cohesive soils. Sultana *et al.* (2014) reported similar behavior in Australia, where flood affected sandy soils exhibited poor densification and rapid strength loss. Adom-Asamoah and Afrifa (2016) also observed that lateritic subgrades in Ghana displayed weak compaction resistance after inundation. These parallels confirm that the compaction behavior of Fori soils is consistent with global literature on flood weakened subgrades.

3.6 Compression Index

The compression index (C_c) is a key parameter used to measure the compressibility of cohesive soils when subjected to increased loading. It represents the rate at which a soil decreases in volumes as effective stress rises and is determined from the slope of the virgin compression line obtained during a consolidation test on an e - $\log \sigma^1$ curve. Soils with a high compression index undergo greater settlement while those with a low value experience relatively minor deformation.

The compression index (C_c) was directly estimated from the Liquid Limit (LL) using the empirical Terzaghi and Peck (1967) correlation equation:

$$C_c = 0.007(LL - 10)$$

4

At 0.5m

$$C_c = 0.007(26.3 - 10) = 0.11$$

At 1.0m

$$C_c = 0.007(24.40 - 10) = 0.10$$

3.6. California Bearing Ratio (CBR)

3.6.1 Load – penetration test for different soaking periods

The load–penetration behavior of the soil was evaluated under unsoaked, 24 and 48 hour-soaked conditions to assess the effect of moisture ingress and soaking duration on subgrade strength. In general, an increase in soaking period resulted in a progressive reduction in penetration resistance at both depths, indicating deterioration of soil stiffness with saturation.

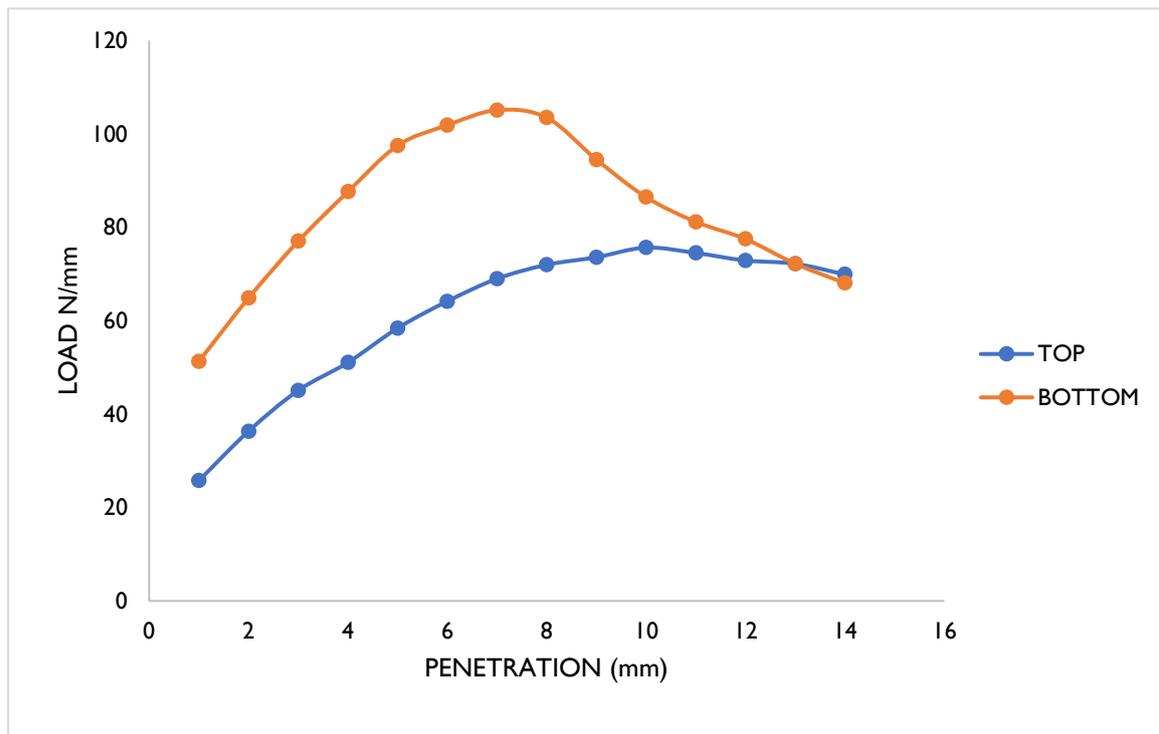


Figure 5: Load against penetration at 0.5m depth for 0 Hour-soaked soaked sample

At 0.5 m depth, Figure 5 (unsoaked) shows relatively higher load resistance at lower penetrations, reflecting temporary strength due to partial saturation. After 24 hours of soaking, Figure 10 shows a noticeable flattening of the curve, indicating reduced stiffness and lower resistance to penetration.

This effect becomes more pronounced after 48 hours of soaking, as shown in Figure 7, where penetration increases rapidly under minimal load, demonstrating severe strength loss due to prolonged saturation. A similar trend was observed at 1.0 m depth. Figure 8 shows the unsoaked load–penetration relationship with slightly improved resistance compared to the shallow depth, attributed to greater confinement.

Following 24 hours of soaking, Figure 9 indicates reduced load resistance. While Figure 10 shows further flattening of the curve after 48 hours of soaking. Although the degradation at 1.0 m is less severe than at 0.5 m, the progressive loss of strength with soaking duration remains evident.

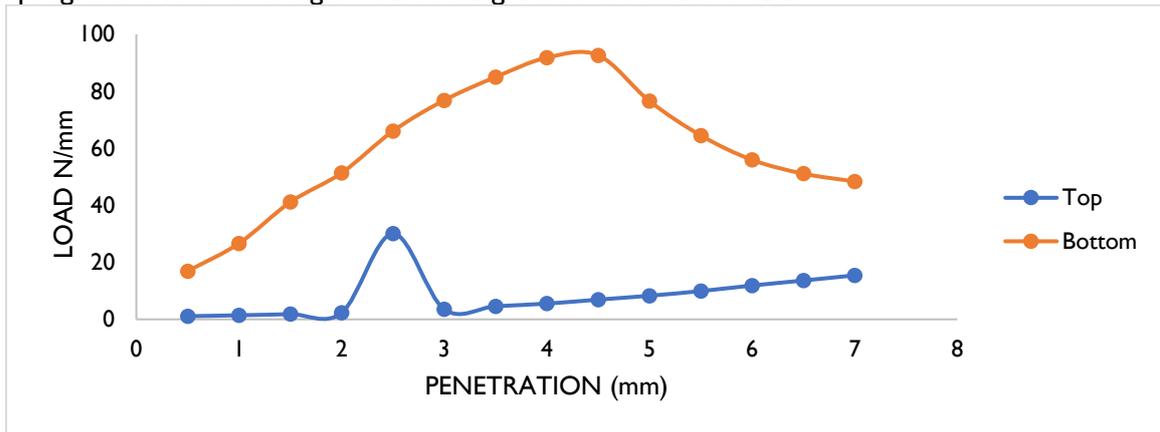


Figure 6: Load against penetration at 0.5m depth for 24 Hour soaked sample

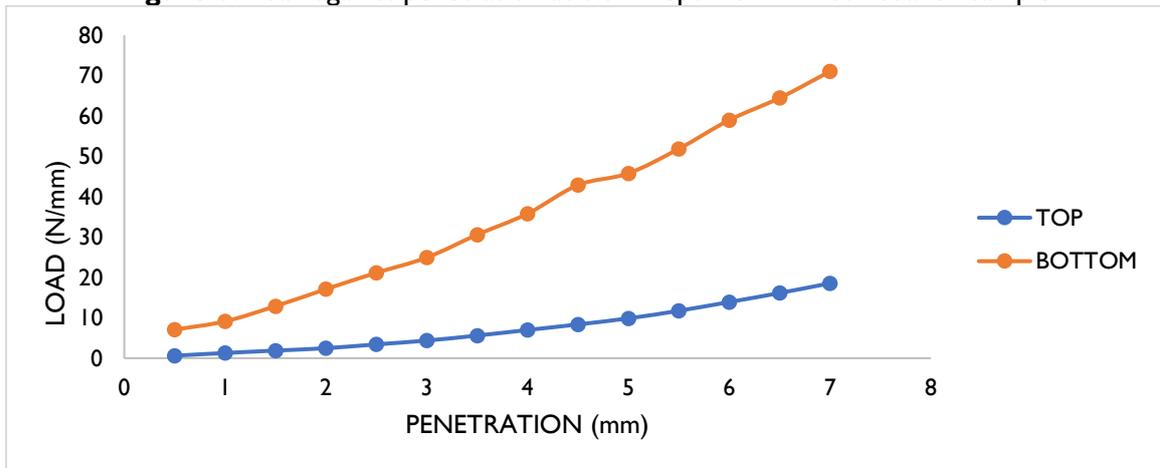


Figure 7: Load against penetration at 0.5m depth for 48 Hour soaked sample

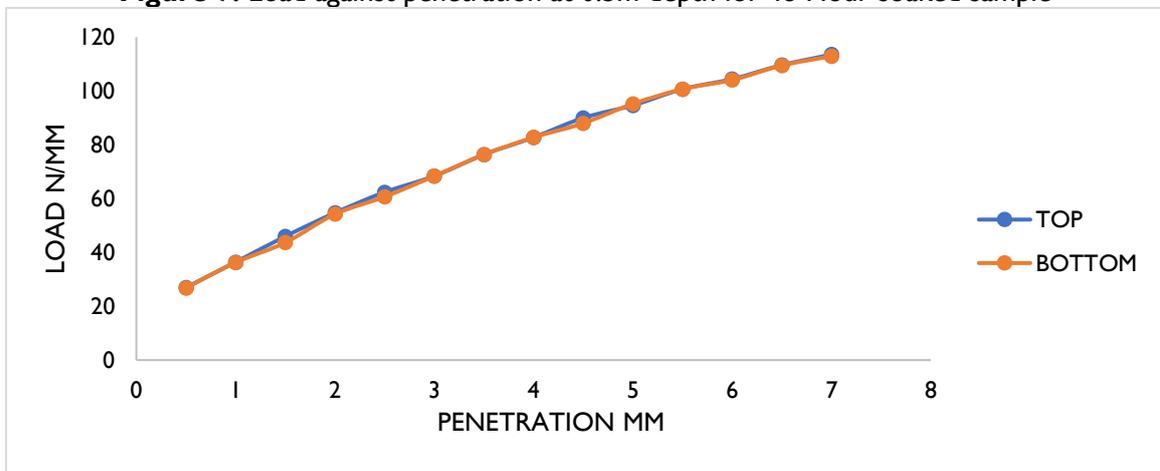


Figure 8: Load against penetration at 1.0m depth for 0 Hour soaked sample

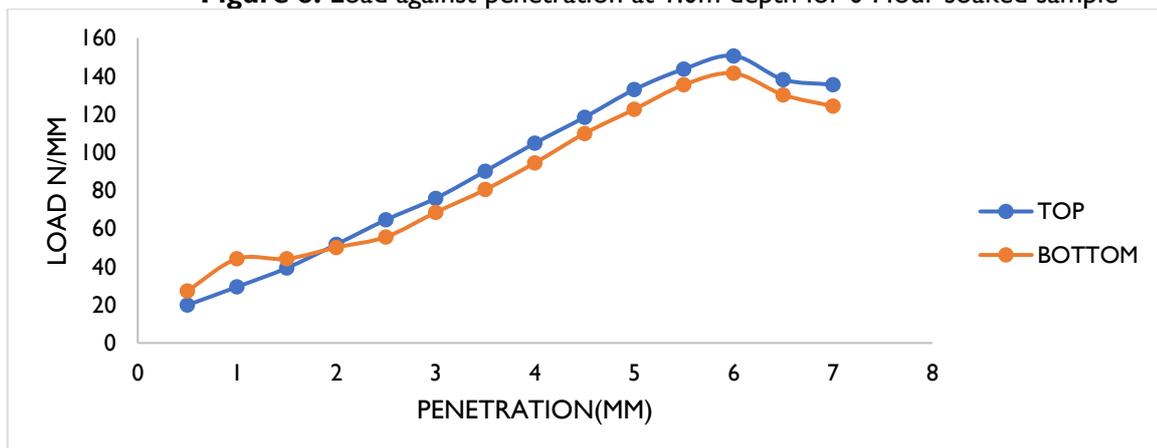


Figure 9: Load against penetration at 1.0m depth for 24 Hour soaked sample

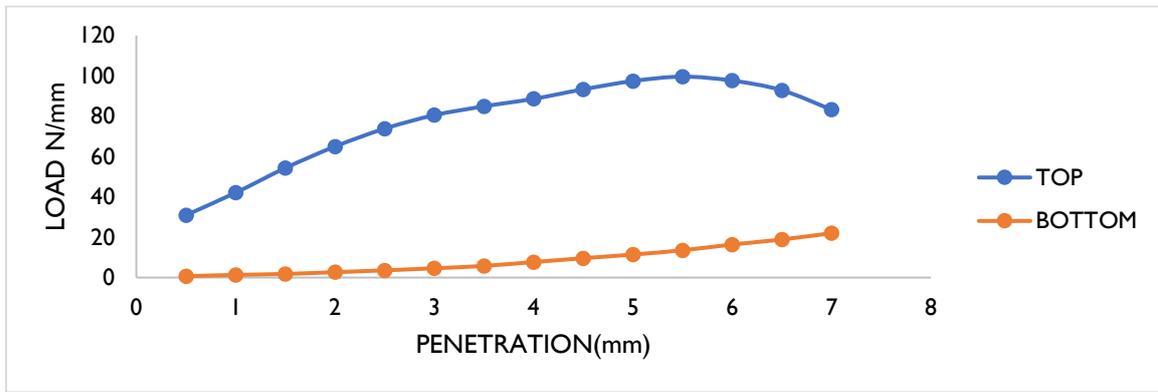


Figure 10: Load against penetration at 1.0m depth for 48 Hour soaked sample

3.6.2 CBR variation with depth for different soaking periods

The variation of CBR values with depth under different soaking conditions is presented to highlight the combined influence of depth and moisture on subgrade performance. Generally, CBR values decrease with increasing soaking duration but show slightly higher values at greater depth.

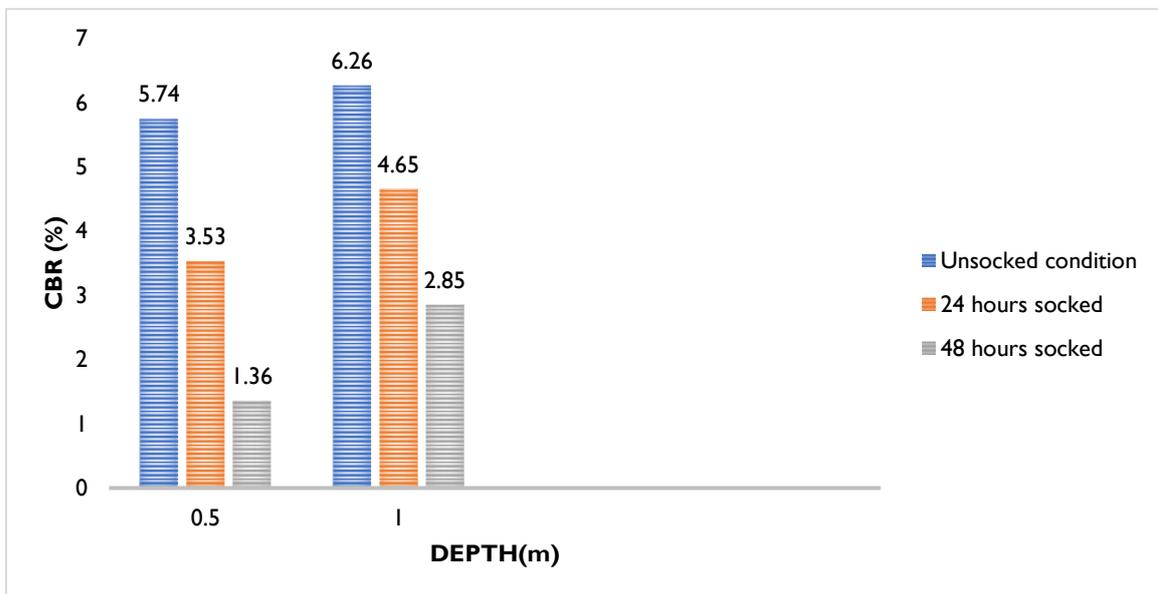


Figure 11: CBR Variation with Depth for Different Soaking Periods

Figures 5-11 depict California Bearing Ratio (CBR) penetration curves and Variation with depth for the tested soil samples, illustrating the relationship between load and penetration at varying depths and moisture conditions. The CBR results highlight the most critical weakness of the soils. At 0.5 m, the CBR reduced from 5.74% (unsoaked) to 1.36% (48-hour soaking), while at 1.0 m, it reduced from 6.26% to 2.85% after 48 hours. These represent strength losses of 76% and 54% respectively, placing the soils in the “very poor” category according to TRRL standards. This drastic reduction strongly correlates with Rahman *et al.* (2021), who reported CBR drops exceeding 50% in soaked sandy soils, and Hankare *et al.* (2018), who recorded a 41% reduction in subgrade strength after flooding. Mustapha *et al.* (2022) also emphasized that flood prone sandy soils in Northern Nigeria typically fail due to such rapid CBR degradation. The observed bulging during CBR testing is attributed to particle rearrangement, low confinement and absence of cohesion rather than clay-type compressibility. These correlations affirmed that the Fori soils are structurally unstable and unsuitable for direct subgrade application without stabilization.

4. Conclusion

This study evaluated the load–penetration behavior and bearing capacity of flood-impacted subgrade soils at depths of 0.5 m and 1.0 m under unsoaked and soaked conditions. The results reveal that the soils exhibit moderate resistance under unsoaked conditions but experience significant strength degradation with increasing soaking duration. Load–penetration curves and corresponding CBR values consistently showed that

prolonged saturation leads to substantial loss of stiffness and bearing capacity, with the shallow subgrade (0.5 m) being more severely affected than the deeper layer. The drastic reduction in CBR values after 24 and 48 hour soaking confirms the high moisture sensitivity of the sandy, non-plastic soils and their classification as “very poor” subgrade materials.

Based on these findings, the native soils are poorly graded fine sand with negligible fines, though it may exhibit silt-like behavior under saturated or flood condition due to loss of particle interlock. It is unsuitable for direct use as pavement subgrades in flood prone environments without improvement. It is therefore recommended that soil stabilization techniques such as lime, pozzolanic materials, flyer ash or cement treatment be adopted to enhance strength and moisture resistance. Additionally, effective surface and subsurface drainage systems should be incorporated into pavement design to limit water ingress and prolonged saturation. Where necessary, the use of geosynthetics and increased pavement layer thickness is advised to improve load distribution and long term pavement performance in flood affected areas.

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