OPEN ACCESS

Saudi Journal of Civil Engineering
Abbreviated Key Title: Saudi J Civ Eng
ISSN 2523-2657 (Print) |ISSN 2523-2231 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com/journal/sjce/home

Original Research Article

Geotechnical Investigation of Soils at Settlement of Bridge Approach Slab in Kaduna State, Nigeria

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DOI: https://doi.org/10.36348/sjce.2025.v09i03.002 | **Received:** 05.01.2025 | **Accepted:** 10.02.2025 | **Published:** 08.03.2025

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Abstract

The study was conducted to investigate the geotechnical properties of soils at settlements of bridges approach slabs in Kaduna State, Nigeria. Five soil samples were collected from bridge settlement sites within Zaria and Kaduna Metropolis of Kaduna State, and were designated as KDM-A, KDM-B, KDM-C, KDM-D, KDZAR-A, and KDZAR-B. The index properties of the soils were determined, and tests conducted on the soil samples were in- situ dry density, dynamic cone penetration test, California bearing ratio, unconfined compressive strength, vane shear test, direct shear test, and consolidation test in accordance with British Standard (BS) and American Society for Testing and Materials (ASTM) standards. Results from the findings showed that the soils at KDM-A, KDM-B, KDM-C, KDM-D, KDZAR-A, and KDZAR-B were classified as A-2-6(2), A-6(4), A-6(3), A-2-6(1), A-2-6(2), and A-2-6(3) respectively, having OMC and MDD values ranging from 9.1 to 16.4% to 1.66 – 2.29 mg/m³ respectively. More results showed that KDM-A had the highest CBR at 0 – 150mm, and 151 – 300mm depth of 20 and 24 % respectively, whereas KDZAR-B had the highest CBR value of 20 % at >300mm depth for dry soil samples, while KDM-A and KDM-D sites had the highest soaked CBR values. Furthermore, KDM-A had the highest shear strength of 130kPa, and 7, 14, 28 days UCS at various compaction efforts, while KDM-B had the highest cohesion value of 16, 17, and 19 kPa, and lower angle on internal friction for BSL, WASC, and BSH compaction efforts. Finally, KDM-B has a soil settlement of 0.903 mm followed by KDM-A with settlement of 1.003 mm, indicating that these soil samples has better geotechnical properties compared to others.

Keywords: Bridge approach slab; Bridge settlement; California bearing ratio (CBR); Geotechnical properties; Shear strength; Soil properties.

1.0 INTRODUCTION

1.1 Background of the Study

Bridges are multipurpose, very efficient structures designed to support several types of services, such as public utilities, railroad traffic, pedestrian walkways, and roads, and to shift the weight of these services from overhead to the ground level foundations (Mehrabi *et al.*, 2024). A bridge in general comprises of few key components such as the superstructure (beams and diaphragms) and substructure (crossheads, columns, foundations, etc.). Owing to the bridge's significance to society, each part of the construction must be meticulously developed by experts in their field (Dolati *et al.*, 2023). But because it's so big and important in relation to other parts, one part of the bridge that neither designers nor engineers appear to focus as much attention on throughout the design phase is the bridge itself (Löfgren, 2020).

Bridge approaches provide smooth and safe transition of vehicles from highway pavements to bridge decks and vice versa. Nonetheless, a bump in the road is typically caused by heave and/or settlement-related motions of the bridge approach slabs in relation to the bridge decks (Hassani *et al.*, 2017). This is a common occurrence at the end of the bridge decks and needs to be fixed because the uneven transition could seriously harm the bridge decks, cause passengers' discomfort, reduce travellers' steering control, distract drivers, damage the transportation agency's reputation, and cause on-going delays in rehabilitating the distressed lanes (Kong *et al.*, 2022).

Bridge approach slab settlement is a differential settlement problem faced by highway agencies (Yasrobi *et al.*, 2016). It is characterized as the difference in height of approach pavement and superstructures of the bridge (Davis *et al.*, 2018), which may be caused by different magnitudes of settlement of embankments and bridge abutment, which subsequently leads to a bump in the roadway (White *et al.*, 2007; Bahumdain *et al.*, 2022). Motorists usually experience discomfort when driving onto or off a bridge due to the uneven settlement of the approach fill compared to the bridge deck. This differential settlement creates inconvenience, as it causes bumps at the junction between the bridge deck and the approach embankment (Prakash *et al.*, 2024). This bump formation in a bridge approach is a safety concern for drivers, as it can cause discomfort, vehicle damage, and potentially hazardous conditions. These bumps result in higher impact loads on vehicles, reduced lifespan of the bridge and embankment, creation of accident-prone zones and increased maintenance costs. The primary reason for this inconvenience is the significant difference in the settlement between the rigid abutment structures and the embankment, which occurs due to factors like consolidation settlement of embankment soil or natural soil settlement under repeated traffic loads (Prakash *et al.*, 2024).

For the past two decades, researches have been conducted to investigate the highway bridge approach slab settlement and setbacks (Yasrobi *et al.*, 2016; Bahumdain *et al.*, 2022; Du *et al.*, 2022; Al-Hashmi *et al.*, 2023; Su *et al.*, 2023). In spite of that, differential settlement has been identified to be the leading cause of failure in approach slabs (Seo, 2003; Abo El-Khier and Morcous, 2021; Prakash *et al.*, 2024) and its supporting backfill, causing the approach slab to be displaced, losing its support from soil and bend in a concave shape (Seo, 2003, Abo Elkhier, 2020). Consequently, this condition causes distractions to drivers and vehicle discomfort, which is dangerous and mostly resulting in a bump (Zhang, 2016; Rahman *et al.*, 2019; Abo El-Khier and Morcous, 2021). Thus, this condition compels the road user to suddenly reduce speed when approaching the bridge (Rahman *et al.*, 2019). As a result, this induces additional impact load and influences the dynamic response of a bridge (Masirin and Zain, 2013) preventing adequate performance of bridge transition slabs (Yasrobi, 2014), as well as additional expenses for maintenance operations on both the bridges and vehicles (Masirin and Zain, 2013).

The mitigated solution to the aforementioned problems from previous researchers focused on the performance and characteristics of soil-supported approach slabs. For example, Khodair and Nassif (2005) found that increasing the thickness and compressive strength of the approach slab enhanced its cracking load-carrying capacity, which was later confirmed through field implementation and long-term settlement monitoring by (Nassif *et al.*, 2009). Ajgaonkar (2010) performed a linear simplified analysis, focusing on specific soil subgrade modulus and AASHTO vehicular loading. Aziz and Edan (2018) highlighted the significance of concrete strength, slab thickness, and longitudinal ribs in reducing vertical settlement. Aziz and Edan (2018) reported that the vertical settlement could be reduced significantly when the compressive strength of concrete is greater than 25 MPa, the slab thickness is more than 200 mm, and by providing longitudinal ribs along the approach slab. Al-Hashmi *et al.*, (2023) highlighted that increasing the length of approach slab too much, especially in soft soil, can lead to significant settlement. Liu *et al.*, (2023) reported that enhancing the thickness of approach slab, and integrating it with the bridge abutment, resulted in an increased load transfer to the abutment.

However, none of the studies addressed/investigated the geotechnical properties of the underlying soil where bridge approach slab settlement occurs. Also, to the best of the authors' knowledge, no research has been conducted in Nigeria to address the problem of bridge approach slab settlement. Hence, this study was conducted to fill the gap in literature and to investigate the geotechnical properties of soils at bridge approach slab settlement in Kaduna State, Nigeria. The aim will be achieved by determining the index properties, in- situ dry density, dynamic cone penetration test, California bearing ratio, unconfined compressive strength, vane shear and direct shear strength, and consolidation properties of the soils settlement at bridge approach slabs at five (5) various study sites.

2.0 MATERIALS AND METHODS

2.1 Materials

The material used in this study is the soil samples which were collected in polythene bags from around the case study sites for laboratory investigations.

The soil samples were collected from five (5) study sites, among which three of these samples were collected from bridge settlement site within Kaduna Metropolis, and two (2) samples were collected within Zaria, Kaduna State. The soil samples were designated as KDM-A, KDM-B, and KDM-C for soil samples collected within Kaduna Metropolis, and soil samples collected within Zaria were designated as KDZAR-A, and KDZAR-B.

2.2 Methods

2.2.1 Soil index properties

The natural soils were classified from the particle size distribution analysis and consistency test results based on the American Association of State Highway and Transportation Officials (AASHTO) soil classification system, AASHTO:M-145 (2000). The following tests were conducted in order to determine the soil classification as shown in Table 1.

Table 1: Soil Index Properties Laboratory Tests

Laboratory Test carried out	Test standard
Natural Moisture Content	BS:1377-2 (1990)
Sieve analysis	BS:1377-2 (1990)
Specific gravity of soil solids test	BS:1377-2 (1990)
Consistency limits test	BS:1377-2 (1990)
Determination of the degree of Compaction	BS:1377-4 (1990)

2.2.2 In- situ dry density test

The in-situ dry density test was carried out according to ASTM-D1556 (2015) to determine the level of the laboratory compaction achieved on site. The in-situ dry densities for the soil samples were measured by sand replacement method and expressed as percentages of the BSL, WASC and BSH MDDs.

2.2.3 Dynamic Cone Penetration Test (DCPT)

The Dynamic cone penetration test was carried out in accordance with ASTM:D6951/D6951M (2018) at 0 – 150mm depth, 151 – 300mm depth, and >300mm depth.

2.2.4 Soaked California Bearing Ratio (CBR)

The soaked CBR was done on samples after 24hrs soaking in accordance with Federal Ministry of Works and Housing (FMWH) specification for pavement and materials (FMW, 2013). The soaked CBR values for all test samples tested under the three different compaction efforts

2.2.5 Unconfined Compressive Strength (UCS) Test

The UCS test was carried out on samples compacted under the British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) compactive efforts in accordance with BS:1377-4 (1990).

2.2.6 Vane shear test

The vane shear test was carried out in accordance with ASTM-D2573 (2015) on the various soil samples. A GEONOR H-60 model hand held vane shear apparatus was used for this test, and the maximum shear strength that can be measured with the vane tester is 260kPa with a force of about 40 to 50 kg for pressing the vane down into the clay.

2.2.7 Direct shear test

The direct shear test was carried-out in accordance with BS:1377-7 (1990), on samples compacted under the three compactive efforts (BSL, WAS, BSH) to measure the Cohesion and angle of internal friction of the soil samples.

2.2.8 Consolidation test

The test was conducted on soil samples in accordance with BS:1377-6 (1990) standard and information on the rate of soil consolidation and intensity of the soil compression settlement was obtained.

3.0 RESULTS AND DISCUSSION

The result based on the test conducted at settlement of approach slabs of various bridge sites are discussed below.

3.1 Soil Index Properties

Table 2: Index Properties of Backfill Materials

Soil Properties	KDM-A	KDM-B	KDM-C	KDM-D	KDZAR-A	KDZAR-A
NMC (%)	12.28	17.35	13.86	12.74	9.76	12.84
LL (%)	39	39	40.5	35	32.4	40.5
PL (%)	19.5	16.7	22.22	18.6	16.7	14.86
PI (%)	19.5	22.3	18.28	16.4	15.7	25.64
SG	2.53	2.37	2.18	2.29	2.39	2.56
% Passing 75µm sieve	32.3	43	46	27.3	32.3	30.2
AASHTO	**A-2-6(2)**	**A-6(4)**	**A-6(3)**	**A-2-6(1)**	**A-2-6(2)**	**A-2-6(3)**

The results from Table 2 showed that the natural moisture content values of the soil range from 9.76% to 17.35%, the liquid limit values range from 32.4% to 40.5%, plastic limit values range from 14.86% to 22.22%, plasticity index values range from 15.7% to 25.64%, specific gravity values range from 2.18 to 2.56, and the material passing through a 75-micron sieve ranges from 27.3% to 46%. Therefore, based on the materials engineering properties, soil samples KDM-A, KDM-B, KDM-C, KDM-D, KDZAR-A, and KDZAR-B were classified as A-2-6(2), A-6(4), A-6(3), A-2-6(1), A-2-6(2), and A-2-6(3) respectively.

However, KDM-A, KDM-D, KDZAR-A, and KDZAR-A soils exhibits coarse to fine sand with some silt or clay, whereas and KDM-B, and KDM-C exhibits silty or clayey gravel and sand in accordance with AASHTO:M-145 (2000) soil classification.

3.2 OMC, MDD, and Compaction Results of Backfill Materials

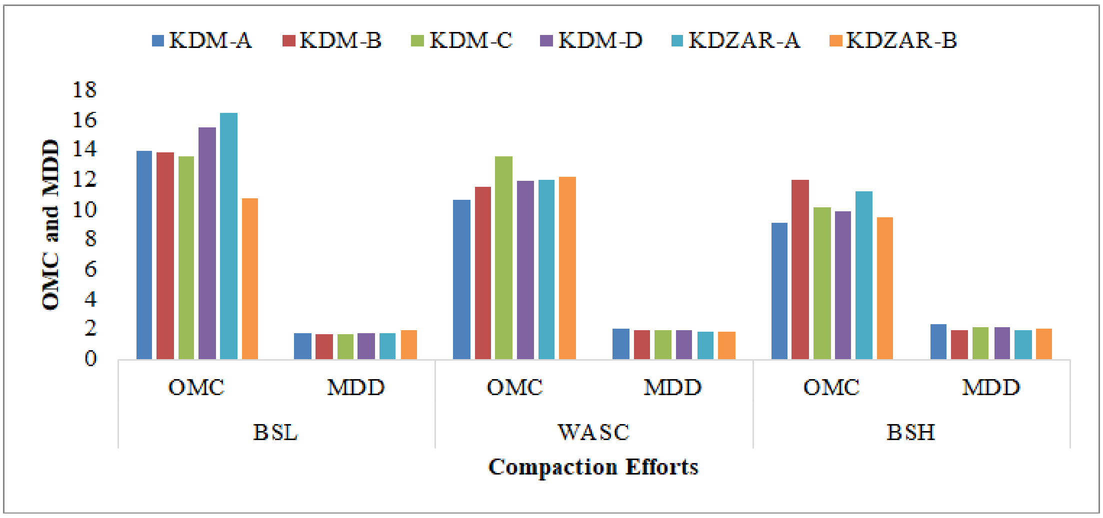

Figure 1: OMC and MDD at Various Compaction Efforts

The result showed that the soil OMC ranges from 9.1 to 16.4%, whereas the MDD ranges from 1.66 – 2.29 mg/m³ for all the compaction efforts. However, the highest OMC for BSL compaction was recorded at KDZAR-A (16.4%), followed by soil sample obtained at KDM-D (15.5%), also, the highest OMC for WASC compaction was recorded at KDM-C (13.5%), while the highest OMC for BSH compaction was recorded at KDM-B (12%). More also, the lowest MDD for BSL, WASC, and BSH compaction efforts were recorded at KDM-B (1.66 mg/m³), KDZAR-A (1.86 mg/m³), and KDM-B (1.95 mg/m³) respectively. The outcome of the findings shows that since the OMC is low, the soil requires less water to achieve its maximum dry density during compaction, and reduces the risk of swelling (Etim Udom and Ehilegbu, 2018).

More also, the relationship between the OMC and MDD indicates an inverse relationship, where higher OMC results in lower MDD and vice versa. This is typical in soil mechanics, where materials with higher moisture content tend to be less compact. Similar findings were reported by Osinubi *et al.*, (2012); Ijimdiya (2014); Roksana *et al.*, (2018); Driss *et al.*, (2022); Koirala *et al.*, (2023).

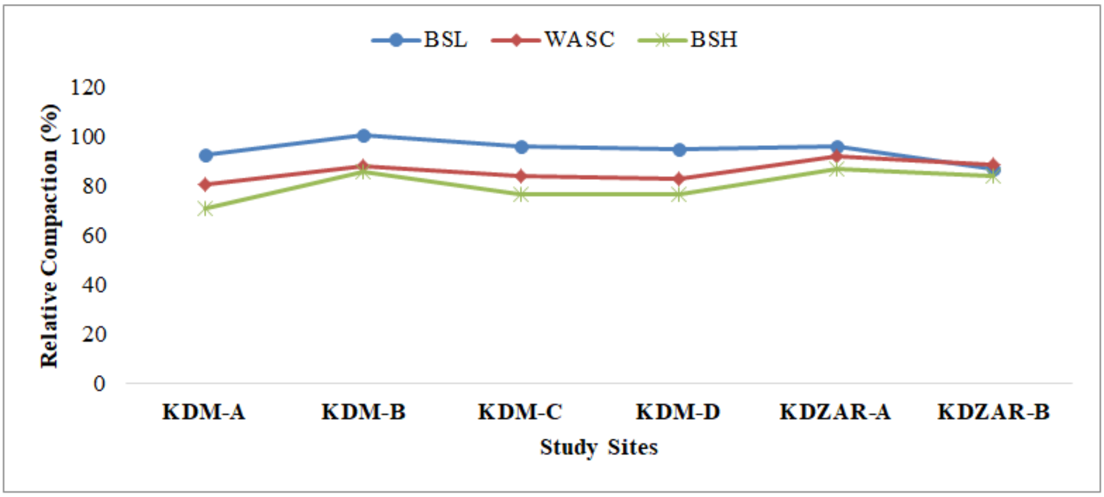

Figure 2: Soil Compaction

The result of the various compaction efforts from Figure 2 showed that soil sample at KDM-A is relatively high under BSL (93%) but significantly drops for WASC (81%) and BSH (71%) standards, KDM-B showed excellent compaction under BSL standard where it exceeds 100%, which indicates optimal or possibly over-compaction, and values for WASC and BSH (88% and 86%) are also higher than other trial points, indicating good material performance under different compaction loads. KDM-C showed good relative compaction under BSL at 96%, suggesting fairly effective compaction for lighter loads. However, the lower compaction under WASC and BSH (84% and 77%) indicates that compaction might not be sufficient for heavier loads or more stringent standards, similar to KDM-A. Also, KDM-D is similar to KDM-C, with relatively good compaction under BSL but a significant drop under WASC and BSH. This pattern reinforces the observation that the material may not handle heavier compaction efforts well in this area.

However, KDZAR-A exhibits strong relative compaction values across all standards, with 96% under BSL, 92% under WASC, and 87% under BSH, which indicates that the material is well-compacted, and can handle both light and heavy compaction efforts effectively, making it suitable for various construction load requirements, whereas KDZAR-B showed a slightly different pattern, where the relative compaction under WASC and BSH (89% and 84%) is higher than that under BSL (87%), which suggest that the material becomes more compact under heavier loads, potentially due to its initial looseness or higher moisture content.

The outcome from the findings showed that KDM-B and KDZAR-A sites obtained the best compaction results, with high relative compaction values across all standards. These locations have soil material or compaction methods that are particularly effective in achieving good density and stability, suggesting they would perform well as backfill under both light and heavy construction loads.

3.3 In- situ dry density

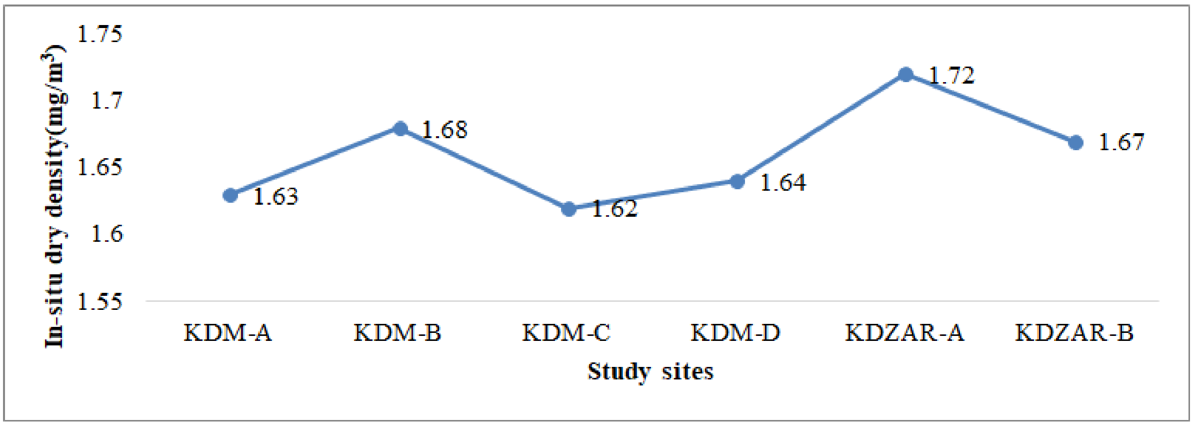

Figure 3: In-Situ Dry Densities for Soil Samples Collected at Study Site

The in-situ dry density test of the soil samples at KDM-A, KDM-B, KDM-C, KDM-D, KDZAR-A, AND KDZAR-B are 1.63, 1.68, 1.62, 1.64, 1.72, and 1.67 mg/m^3 respectively. However, KDZAR-A has the highest dry density of 1.72 mg/m³, indicating denser material at this location, which suggests better compaction. KDM-C has the lowest dry density of 1.62 mg/m³, which implies looser material at this trial point compared to others. Generally, the soil in-situ dry density values are within 1.60 – 2.0 mg/m³ specified by ASTM-D1556 (2015), which is an indication that it is a well compacted and stable soil.

3.4 Dynamic Cone Penetration Test (DCPT)

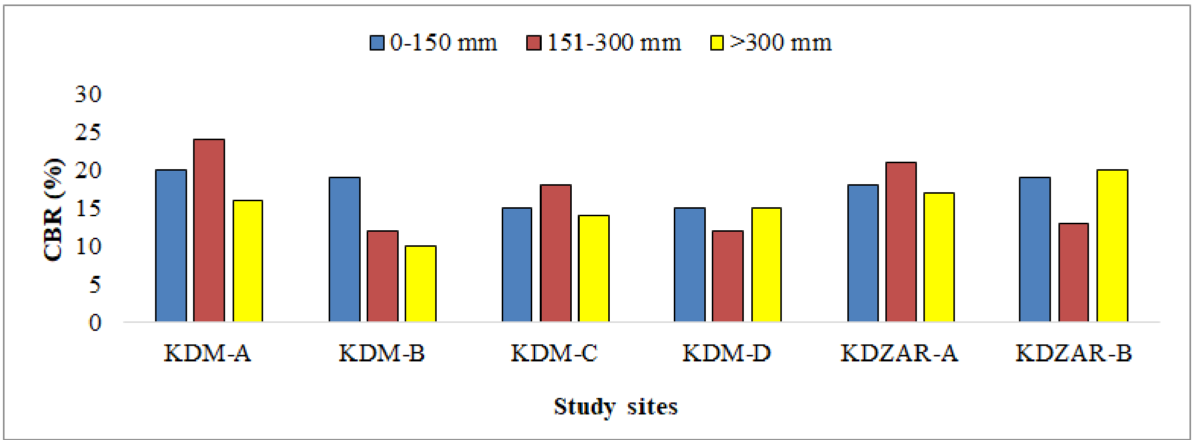

Figure 4: In-Situ CBR at Various Depths

The result of the in-situ CBR test in Figure 4 showed that the trend in the CBR value with increasing depth is irregular. However, the highest CBR value recorded at 0 – 150 mm depth was in KDM-A site (20%), between 151 – 300 mm depth, CBR was also highest at KDM-A (24%), KDM-C (18%), and KDZAR-A (21%) sites, while at >300mm depth, CBR was highest at KDZAR-B (20%) site. The outcome of the findings showed that majority of the sites with highest CBR values were recorded at a depth of between 150 – 300 mm. Generally, according to the Nigerian General Specifications for Roads and Bridges (NGSRB), these CBR values are less than 30% for sub-base material and 80% for base course material NGSRB (2016). Hence, there is need for the soil to be stabilized.

Also, the implication of the findings from this study showed that the reduction in CBR value with increasing depth can be attributed to moisture content, soil composition, or compacting effort which occur during construction stage, whereby the surface soil receives high mechanical compaction, while deeper layers might not receive the same compaction effort, thereby leading to lower CBR values. Similar findings were reported by Humayoon and Gopinath (2016); Suresh *et al.*, (2018) and Singh and Yadev (2016).

3.5 Soaked California Bearing Ratio (CBR)

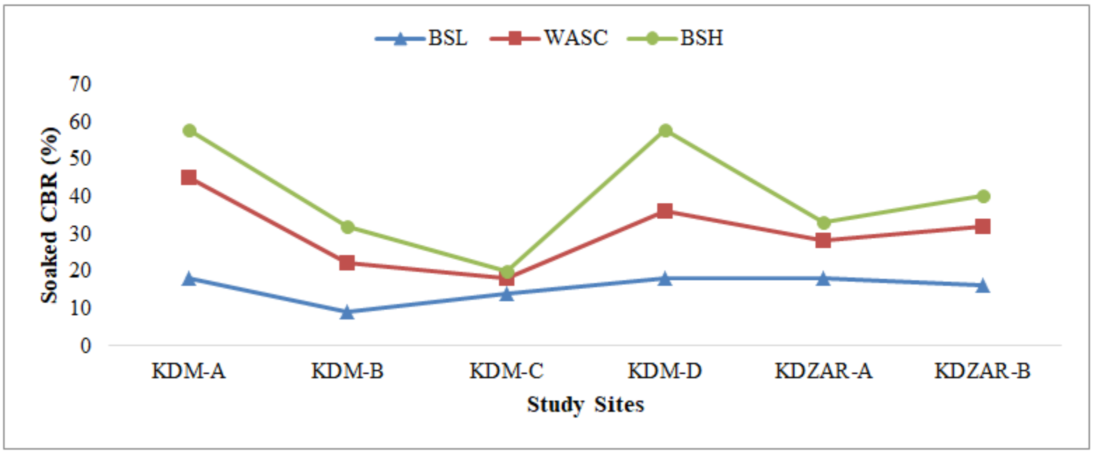

Figure 5: Soaked CBR of Backfill Materials at Various Compaction Efforts

The result from Figure 5 showed that the value of the soaked CBR ranges from 9 – 18% for BSL, 18 – 45% for WASC, and 20 – 58% for BSH compaction efforts. However, the highest soaked CBR values for BSL was achieved at KDM-A (18%), KDM-D (18%), and KDZAR-A (18%), for WASC was achieved at KDM-A (45%), and for BSH was achieved at KDM-A (58%) and KDM-D (58%). Also, the least soaked CBR values for BSL was obtained at KDM-B (9%), for WASC was obtained at KDM-C (18%), and for BSH was also obtained at KDM-C (20%).

The outcome of these findings showed that KDM-A and KDM-D have the highest soaked CBR strength among the samples, particularly under heavy compaction. This suggests that the backfill materials at these sites are more robust and capable of handling higher traffic loads without significant settlement. In contrast, soil samples that shows relatively poor performance, may require stabilization or improvement techniques to enhance its load-bearing properties and prevent issues such as excessive settlement or deformation under traffic.

3.6 Unconfined Compressive Strength

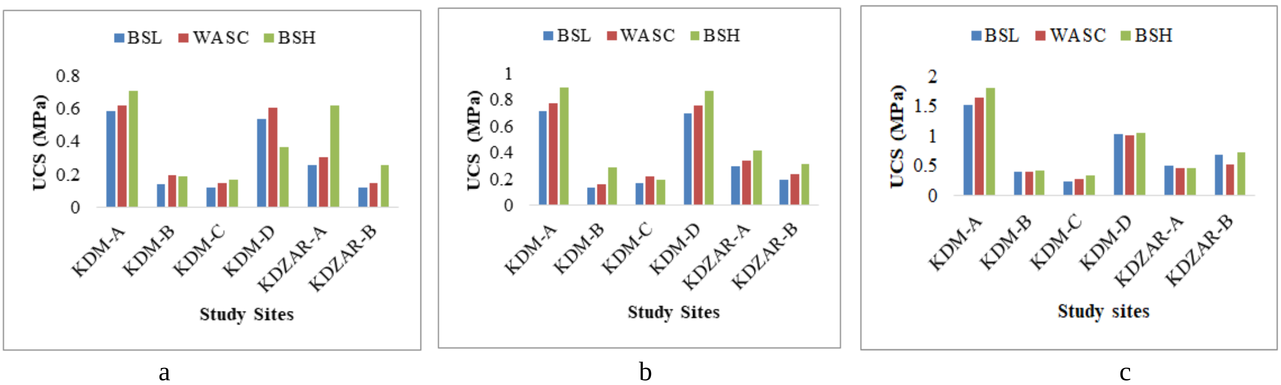

Figure 6: Soil UCS at (a) 7 days; (b) 14 days; and (c) 28 days

The result from Figure 6 showed that the UCS of the soil increases as the day's increases, and as compaction effort increases. Also, the soil UCS at 7 days ranges from 0.12 – 0.71 MPa, at 14 days it ranges from 0.14 – 0.9 MPa, and at 28 days it ranges from 0.25 – 1.81 MPa for all the compaction efforts. However, at 28 days, the soil UCS for BSH compaction effort was high at KDM-A, KDM-B, KDM-C, KDM-D, and KDZAR-B, whereas BSL compaction effort has the highest UCS at KDZAR-A.

Generally, KDM-A has the highest UCS values from 7 – 28 days, particularly at 28 days, with UCS ranging from 1.53 MPa (BSL) to 1.81 MPa (BSH), indicating a strong backfill material. KDM-B and KDM-C, in contrast, have much lower UCS values. For instance, at 28 days, KDM-B has a UCS range of 0.40 to 0.43 MPa, while KDM-C shows values between 0.25 and 0.34 MPa. The differences in UCS can be attributed to variations in material composition, such as the type of soil used, its grain size distribution, and mineral content. Hence, the variability in UCS values between the soil samples highlights the importance of testing and selecting suitable backfill materials for each specific bridge project. Stronger materials (like KDM-A) would be preferable for high-load applications, while weaker materials may require stabilization or alternative treatment methods.

3.7 Vane Shear Strength

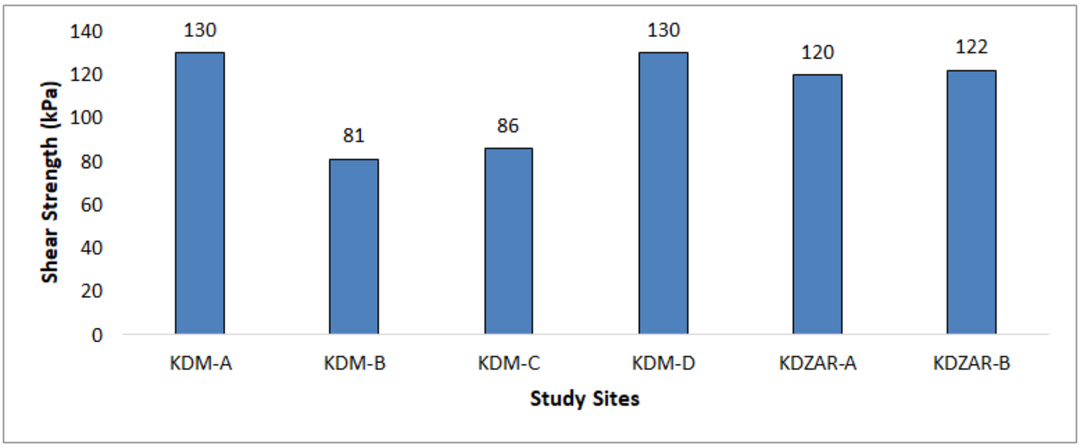

Figure 7: In-situ Shear Strength of The Backfill Materials

The shear strength result from Figure 7 shows that the soils from are in the range of 81-130 kPa indicating good in-situ shear strength as stipulated in ASTM-D2573 (2015). However, KDM-A and KDM-D have the highest shear strength values at 130 kPa, indicating that these materials are relatively stronger and more stable compared to the other materials tested, whereas KDM-B and KDM-C have lower shear strength values at 81 and 86 kPa respectively, suggesting that these materials may be less stable and could potentially exhibit greater deformation under stress. Also, KDZAR-A and KDZAR-B have shear strength values of 120 and 122 kPa respectively, indicating that these materials have moderate shear strength compared to the others.

3.8 Direct shear strength

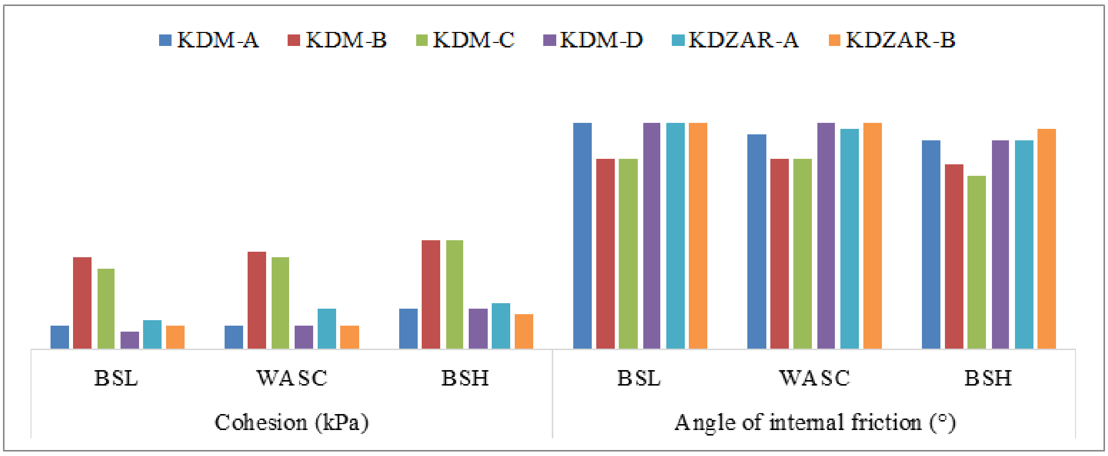

Figure 8: Shear Strength Parameters of the Backfill Materials

The result from Figure 8 showed that the soil cohesion ranges from 3 – 19 kPa, whereas the soil angle of internal friction ranges from 33 -39°. Also, soil sample KDM-B had the highest cohesion value of 16, 17, and 19 kPa at BSL, WASC, and BSH compaction efforts respectively, followed by KDM-C soil sample with cohesion values of 14, 16, and 19 kPa at BSL, WASC, and BSH compaction efforts respectively.

More also, only soil samples from KDM-B and KDM-C have lower angle on internal friction values for BSL, WASC, and BSH compaction efforts. This reduction in the angle of internal friction with higher compaction could be due to increased particle rearrangement and densification, which reduces the resistance to sliding between particles. However, this decrease is relatively small (typically 1° to 3°), indicating that the frictional resistance remains fairly stable across different compaction efforts.

The result from these findings confirmed the analysis in Table 1, which showed that KDM-B and KDM-C soils are cohesive soils (e.g., clay), whereas KDM-A, KDM-D, KDZAR-A, and KDZAR-B soils with higher internal friction angles, are coarse and granular soils which relies on particle friction for stability.

3.9 Consolidation Properties of the Soil

Table 3: Consolidation Parameters of the Backfill Materials Bridges

Consolidation parameters	Kaduna Metropolis				Zaria City	
	KDM-A	KDM-B	KDM-C	KDM-D	ZAR-A	ZAR-B
Pre-consolidation pressure (kPa)	40	40	40	40	40	40
Compression index	0.029	0.0212	0.0276	0.0411	0.0577	0.0343
Coefficient of consolidation (m^2/yr.)	1.88	1.93	1.79	1.66	1.52	1.72
Coefficient of compressibility (Kpa^{-1})	0.00152	0.00129	0.00173	0.00277	0.00363	0.00212
Coefficient of volume compressibility (Kpa^{-1})	0.00130	0.00104	0.00143	0.00228	0.00283	0.00175
Total settlement (mm)	1.003	0.903	1.070	1.444	1.693	1.225

The result from Table 3 shows the consolidation properties of the soil at a constant pre-consolidation pressure of 40 kPa. The settlement of the soil at various sites ranges from 0.903 – 1.693 mm. However, KDM-B had the least compression index and the highest coefficient of consolidation of 0.0212 and 1.93 m^2/yr respectively. However, this translates to lower value of coefficient of volume compressibility of 0.00104 kPa, and lower soil settlement of 0.903 mm which is less than the allowable limiting maximum settlement of 25mm proposed by Terzaghi *et al.*, (1996).

4.0 CONCLUSION

The soils within the study areas are predominantly coarse to fine sand with some silt or clay, and the soils OMC and MDD were adequately achieved. More also, KDM-B and KDZAR-A soil samples achieved adequate compaction under BSL, WAS, and BSH compaction efforts, whereas KDZAR-A has the highest dry density of 1.72 mg/m³ followed by KDM-B (1.68 mg/m³).

The DCPT test showed that generally, the soils CBR did not meet <30% specified by NGSRB to be used as a sub-base material, since at 0 – 150mm, and 151 – 300mm, the highest CBR was recorded as 20 and 24 % respectively at KDM-A, while at >300mm, the highest CBR was recorded as 20 % at KDZAR-B site. Also, the soil samples at KDM-A and KDM-D sites have the highest soaked CBR strength compared to other samples, and the UCS of KDM-A from 7 – 28 days at various compaction efforts is the highest compared to other samples.

Furthermore, KDM-A and KDM-D have the highest shear strength values at 130 kPa, while KDM-B had the highest cohesion value of 16, 17, and 19 kPa, and lower angle on internal friction for BSL, WASC, and BSH compaction efforts. Finally, KDM-B had the least compression index, and highest coefficient of consolidation of 0.0212 and 1.93 m^2/yr respectively, which translates to lower coefficient of volume compressibility of 0.00104 kPa, and lower soil settlement of 0.903 mm followed by KDM-A with settlement of 1.003 mm.

Conclusively, soil samples KDM-A and KDM-B has adequate properties that yield less settlement. From the results analysed, KDM-A soil sample has the highest CBR and Soaked CBR, UCS, and shear strength values, whereas KDM-B had the highest compaction under BSL, WAS, and BSH compaction efforts, dry density, and cohesion. Hence, KDM-A and KDM-B soil samples had better properties compared to others.

REFERENCES

- AASHTO:M-145. (2000). *Classification of Soil and Soil-Aggregate Mixtures for Highway Construction Purposes*. https://www.scribd.com/document/518573017/AASHTO-M-145-2003-Soil-Classification
- Abo El-Khier, M., & Morcous, G. (2021). Design and Detailing of Bridge Approach Slabs: Cast-in-Place and Precast Concrete Options. Sustainable Issues in Infrastructure Engineering: The official 2020 publication of the Soil-Structure Interaction Group in Egypt (SSIGE),

- Ajgaonkar, S. V. (2010). *Optimization of bridge approach slab*. University of Missouri-Kansas City.
- Al-Hashmi, H., Al-Hussein, A., & Al-Abboodi, I. (2023). A Parametric Study of Bridge Approach Slabs under Vehicle Loads Using SAP2000. *Mathematical Modelling of Engineering Problems*, *10*(5).
- ASTM-D1556. (2015). *Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*. https://www.astm.org/d1556_d1556m-15e01.html
- ASTM-D2573. (2015). *Standard Test Method for Field Vane Shear Test in Cohesive Soil*. https://www.astm.org/d2573-08.html
- ASTM:D6951/D6951M. (2018). *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*. https://www.astm.org/d6951_d6951m-18.html
- Aziz, A. H., & Edan, A. S. (2018). Settlement control for bridges approach slabs using longitudinal concrete ribs technique: numerical study. *Journal of Engineering and Sustainable Development (JEASD)*, *22*(2), 86-96.
- Bahumdain, A., Tabatabai, H., & Titi, H. (2022). Analysis of soil settlement behind bridge abutments. *Transportation Geotechnics*, *36*, 100812.
- BS:1377-2. (1990). *Methods of test for soils for civil engineering purposes - Classification tests*. https://knowledge.bsigroup.com/products/methods-of-test-for-soils-for-civil-engineering-purposes-classification-tests?version=standard
- BS:1377-4. (1990). *Methods of test for soils for civil engineering purposes - Compaction-related tests*. https://knowledge.bsigroup.com/products/methods-of-test-for-soils-for-civil-engineering-purposes-compaction-related-tests?version=standard
- BS:1377-6. (1990). *Methods of test for soils for civil engineering purposes - Consolidation and permeability tests in hydraulic cells and with pore pressure measurement*. https://knowledge.bsigroup.com/products/methods-of-test-for-soils-for-civil-engineering-purposes-consolidation-and-permeability-tests-in-hydraulic-cells-and-with-pore-pressure-measurement?version=standard
- BS:1377-7. (1990). *Methods of test for soils for civil engineering purposes - Shear strength tests (total stress)*. https://knowledge.bsigroup.com/products/methods-of-test-for-soils-for-civil-engineering-purposes-shear-strength-tests-total-stress?version=standard
- Davis, N. T., Hoomaan, E., Sanayei, M., Agrawal, A. K., & Jalinoos, F. (2018). Integrated superstructure-substructure load rating for bridges with foundation movements. *J. Bridge Eng*, *23*(5), 04018022.
- Dolati, A., Ghodratian-Kashan, S., & Maleki, S. (2023). End diaphragm and interior cross frame modeling in steel tub girder superstructures. Structures,
- Driss, A. A.-E., Harichane, K., Ghrici, M., & Gadouri, H. (2022). Assessing the effect of moulding water content on the behaviour of lime-stabilised an expansive soil. *Geomechanics and Geoengineering*, *17*(3), 896-908.
- Du, Y., He, X., Wu, C., & Wu, W. (2022). Long-term monitoring and analysis of the longitudinal differential settlement of an expressway bridge–subgrade transition section in a loess area. *Scientific reports*, *12*(1), 19327.
- Etim Udom, B., & Ehilegbu, J. (2018). Critical moisture content, bulk density relationships and compaction of cultivated and uncultivated soils in the humid tropics. *Asian Soil Research Journal*, *1*(2), 1-9.
- FMW. (2013). *Highway Manual Part 2: Maintenance*. Retrieved 24th August from https://worksandhousing.gov.ng/themes/front_end_themes_01/images/uploads_images/1569352121.pdf
- Hassani, R., Basirat, R., & Mahmoodian, N. (2017). Numerical simulation of approach slab under truck load. 3rd International Conference on Civil Engineering, Architecture & Urban Planning Elites,
- Humayoon, H., & Gopinath, B. (2016). A study on the improvement of CBR using waste plastic mat as Geocell. *Int J Eng Res Technol*, *5*(9), 423-427.
- Ijimdiya, T. S. (2014). Strength Characteristics of Lime Treated Oil Contaminated Lateritic Soil. *Advances in Civil Engineering Materials*, *3*(1), 404-412.
- Khodair, Y., & Nassif, H. (2005). Finite element analysis of bridge approach slabs considering soil–structure interaction. *Bridge Structures*, *1*(3), 245-256.
- Koirala, D., Awasthi, K., & Bohara, N. (2023). Association between CBR and Soil Index Properties: Empirical Analysis from Chitwan and Makwanpur District Soil Samples. *Koirala D, Awasthi KD & Bohara*, (2023), 7-15.
- Kong, X., Li, Z., Zhang, Y., & Das, S. (2022). Bridge deck deterioration: Reasons and patterns. *Transportation research record*, *2676*(7), 570-584.
- Liu, H., Huang, F., & Zhao, N. (2023). Performance of bridge approach system under a moving tandem load-numerical analysis. Structures,
- Löfgren, S. (2020). Designing with differences, cross-disciplinary collaboration in transport infrastructure planning and design. *Transportation research interdisciplinary perspectives*, *4*, 100106.
- Masirin, M. I. B. H. M., & Zain, R. B. M. (2013). Overview and preliminary study of approach-Slab design concept for bridges. *Procedia Engineering*, *54*, 774-784.
- Mehrabi, A., Torrealba, A., Abedin, M., Dolati, S. S. K., & Malla, P. (2024). *Available Accelerated Bridge Construction Options for Short Span Bridges*. Cambridge Scholars Publishing.
- Nassif, H. H., Abu-Amra, T., Suksawang, N., Khodair, Y., & Shah, N. (2009). Field investigation

and performance of bridge approach slabs. *Structure and Infrastructure Engineering*, *5*(2), 105-121.

- NGSRB. (2016). Nigerian General Specifications for Road and Bridges. Volume 2, Federal Ministry of Works and Housing, Nigeria.
- Osinubi, K., Eberemu, A., Bello, A., & Adzegah, A. (2012). Effect of fines content on the engineering properties of reconstituted lateritic soils in waste containment application. *Nigerian journal of Technology*, *31*(3), 277-287.
- Prakash, B., Tiwari, A. K., Dash, S. R., & Patra, S. (2024). Structural evaluation and performance based optimization of approach slab design for mitigating bridge approach settlement through an Indian case study. Structures,
- Rahman, E., Zainorabidin, A., & Mahfidz, H. (2019). Settlement of bridge approaches on soft soil area in Batu Pahat, Johor. IOP Conference Series: Materials Science and Engineering,
- Roksana, K., Islam, T., & Muqtadir, A. (2018). Relationship between CBR and soil index properties of Bangladesh soil samples. *Journal of Modern Science and Technology*, *6*(2), 1-9.
- Seo, J. B. (2003). *The bump at the end of the bridge: An investigation*. Texas A&M University.
- Singh, A. K., & Yadev, R. (2016). Improvement in CBR of expansive soil with jute fiber reinforcement. *International Research Journal of Engineering and Technology*, *3*(11), 2395-0056.
- Su, M., Liu, J., Lu, J., Ren, J., & Zhu, Y. (2023). Study on the vibration evaluation method and allowable differential settlement of road-bridge transition section with full-car model. *International Journal of Pavement Engineering*, *24*(1), 2090557.
- Suresh, A., Jose, D., & Maliyakal, G. J. (2018). CBR characteristics of soils stabilised with geogrid. *SSRG Int. J. Civil Engrg*, *5*(3), 30-34.
- Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*. John wiley & sons.
- White, D. J., Mekkawy, M. M., Sritharan, S., & Suleiman, M. T. (2007). "Underlying" causes for settlement of bridge approach pavement systems. *Journal of Performance of Constructed Facilities*, *21*(4), 273-282.
- Yasrobi, S. Y. (2014). *Investigation of approach slab and its settlement for roads and bridges*. University of Wyoming.
- Yasrobi, S. Y., Ng, K. W., Edgar, T. V., & Menghini, M. (2016). Investigation of approach slab settlement for highway infrastructure. *Transportation Geotechnics*, *6*, 1-15.
- Zhang, J. (2016). *Bridge end settlement evaluation and prediction*. University of Kentucky.

