Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Geotechnical Characterisation of Subgrade and Sub-Base Materials for Road Pavement Design in Kasese District, Western Uganda

Itafe Victor Adacha

victor.adacha@kiu.ac.ug

Kampala International University

Chikadibia Kalu Awe Uche

Kampala International University

Paul Yohanna

Kampala International University

Research Article

Keywords: Keywords: Subgrade, sub-base, geotechnical properties, pavement, AASHTO, Kasese District, Uganda.

Posted Date: November 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11613492/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.

Geotechnical Characterisation of Subgrade and Sub-Base Materials for Road Pavement Design in Kasese District, Western Uganda

[1*]Itafe Victor Adacha, [2]Chikadibia Kalu Awe Uche, [2] Paul Yohanna

[1,2]Department of Civil Engineering, School of Engineering and Applied Sciences, Kampala International University, Kampala Uganda

Emails: *victor.adacha@kiu.ac.ug, uche.chikadibia@kiu.ac.ug, paulyohanna45@yahoo.co.uk

Abstract

Pre-design and construction geotechnical assessment of subgrade and sub-base materials was carried out for optimal pavement performance and sustainability in Kasese District, Western Uganda. The method involved boring 30 trial holes, sampling, and geotechnical testing. Soil profile indicates a top organic clay layer (OL/OH) from surface to 0.45 m, a silty clay layer (CL/CI) to 1.2 m, and a poorly graded sand with gravel layer (SP/GP) to 2.0 m. Subgrades classify as USCS CL-CI, AASHTO A-2-6, A-2-7, and A-7-6, with 62% rated as poor to fair and 38% good to excellent due to high seasonal moisture from nearby Rwenzori Mountains and Nyamwamba River floods. Clay activity ranges from 0.9 to 38.7, expansivity from 5.2 to 62.4, indicating presence of sensitive and expansive clays. 48-hour soaked CBR varies from 5% to 32%, surface modulus (E_s) from 55 MPa to 150 MPa. Sub-base fills have moisture content 14-22%, liquid limit 22-35%, plastic limit 12–20%, plasticity index 8-14, composed of 32% fines and 68% sands; AASHTO A-2-6 rated excellent to good. Soaked CBR of sub-base ranges 18-42% with 12-58% strength reduction upon soaking. Resilient modulus varies from 200-500 MN/m². Recommended pavement thickness is 350-400 mm based on CBR and group index, with coarse granular sub-bases recommended for moisture egress to improve effective stress.

Keywords: Subgrade, sub-base, geotechnical properties, pavement, AASHTO, Kasese District, Uganda.

1. Introduction

Road pavements are critical infrastructure for economic development in Uganda, particularly in rapidly urbanizing districts like Kasese. The district experiences heavy traffic from tourism (Queen Elizabeth National Park, Rwenzori Mountains), mining (copper, cobalt), and cross-border trade with DR Congo. However, premature road failures are common due to poor geotechnical characterization, high annual rainfall (1,200-1,600 mm), and flood-prone topography (Kasese District Local Government, 2020; Uganda National Roads Authority, 2018).

Subgrade strength, degree of saturation, and behaviour under soaked conditions control pavement stability (Lillian et al., 2025). In Kasese, seasonal flooding from Nyamwamba, Nyamugasani, and Mubuku rivers frequently inundates road foundations, reducing effective stress and causing rutting (Muwanga & Barifaijo, 2019). Despite this, most road designs rely on empirical correlations rather than site-specific geotechnical data (Tugume & Nyende, 2017).

This study aims to characterize subgrade and sub-base materials in Kasese District to inform rational pavement design, drawing methodological parallels from similar deltaic environments in Nigeria (Akpokodje et al, 2025; Abija, 2019).

2. Study Location

Kasese District is located in Western Uganda, between latitudes 0°05'N and 0°20'N, and longitudes 29°45'E and 30°15'E. It lies in the Rwenzori foothills, with elevations ranging from 900 m to 1,500 m above sea level (Jess et al., 2020). The area experiences a tropical wet climate with two rainy seasons (March-May and September-November). Mean annual rainfall is 1,400 mm, with peak intensities of 50-80 mm/hr (Uganda National Meteorological Authority, 2021).

Geologically, the area is underlain by Precambrian basement complex rocks (granites, gneisses, schists) and recent alluvial-colluvial deposits from the Rwenzori Mountains. The soils are predominantly clayey sands and silty clays derived from weathered schist and granite. Recent investigations have demonstrated the importance of lithology, active faults, and topographic characteristics in assessing landslide susceptibility and infrastructure vulnerability in western Uganda (Mazimwe et al., 2026; Oleng et al., 2024). Figure 1 illustrate the study location map.

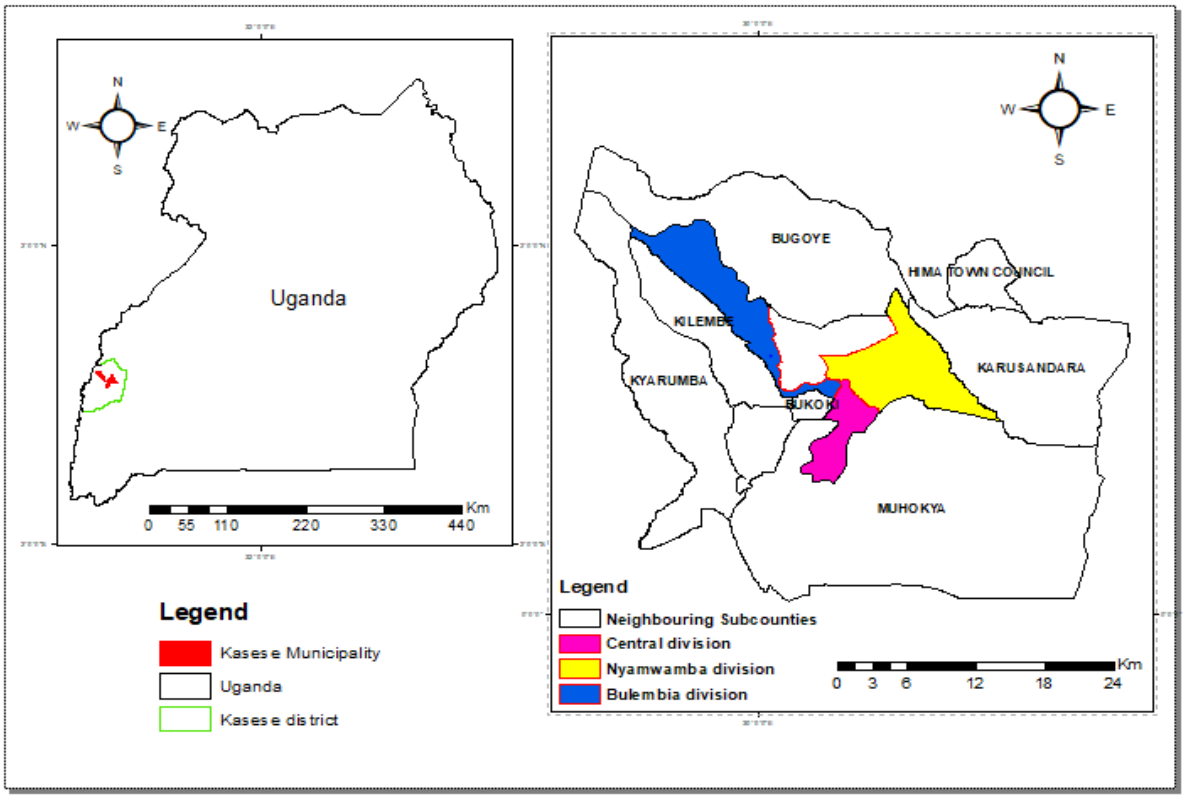


Figure 1: Map of Kasese District showing study locations (Kilembe, Hima, Bugoye, Bukoki, Muhokya, Karusandara, Kyarumba, Nyamwamba floodplain).

3. Methods of Study

3.1 Field and Laboratory Methods

Thirty trial pits were excavated up to 2.0 m depth using hand augers. Disturbed and undisturbed samples were collected at 0.5 m, 1.0 m, 1.5 m, and 2.0 m. Laboratory tests followed BS 1377-

2 (2022) and Uganda National Bureau of Standards (UNBS) guidelines (British Standards Institute, 2022; Uganda National Bureau of Standards, 2015):

- Particle size distribution (wet sieving + hydrometer)

- Atterberg limits (Casagrande method)

- Moisture content, specific gravity

- Standard Proctor compaction (WASC variant)

- Soaked and unsoaked CBR (48 hours soaking)

- Clay activity and expansivity indices (Olinic, 2026; Ayalew et al., 2026).

An illustration of typical particle size distribution curves for subgrade (clayey sand) and sub-base (sandy gravel) figure 2 and Moisture-density relationship curves (Proctor) for representative subgrade and sub-base samples figure 3.

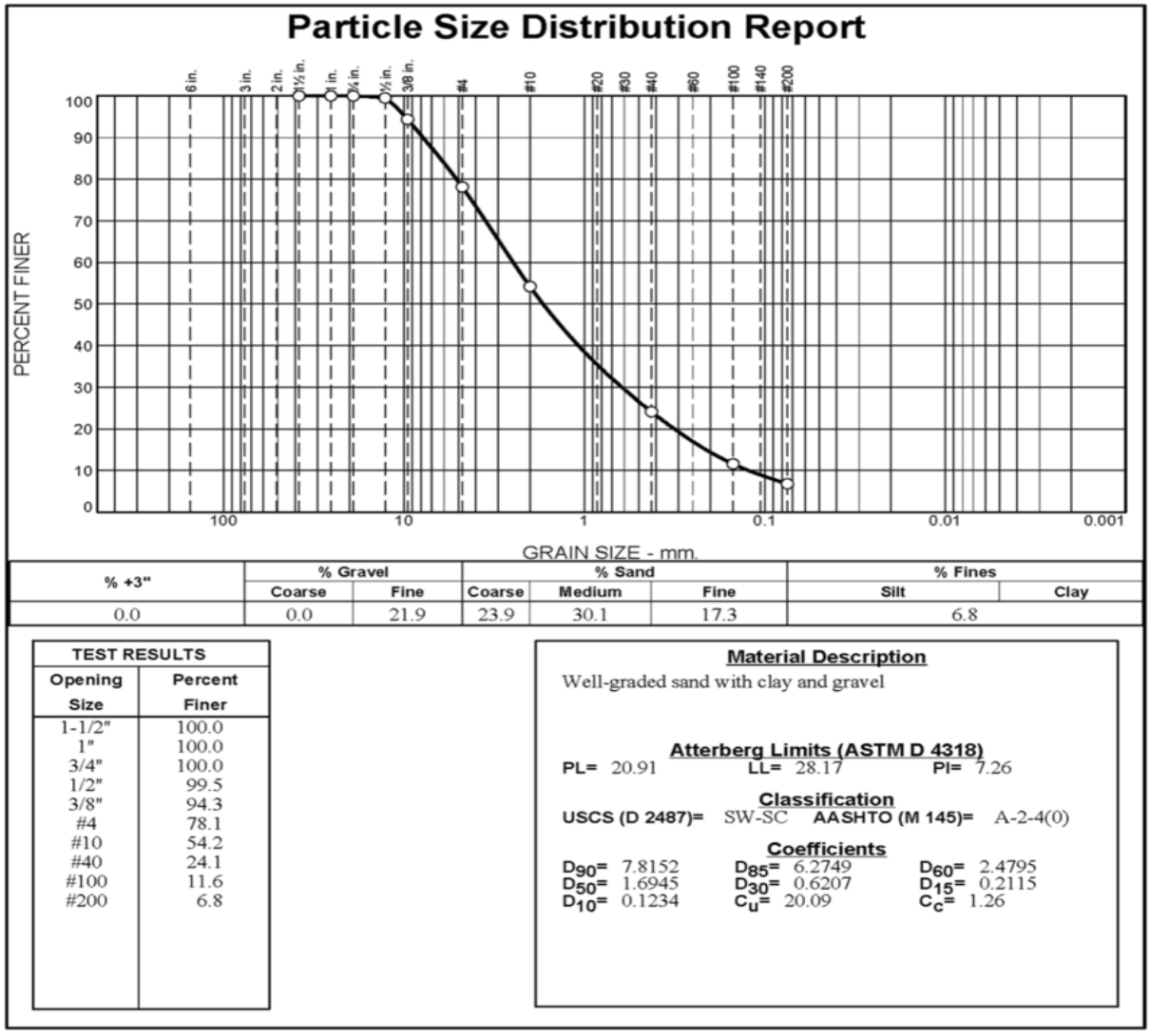


Figure 2: Typical particle size distribution curves for subgrade (clayey sand) and sub-base (sandy gravel).

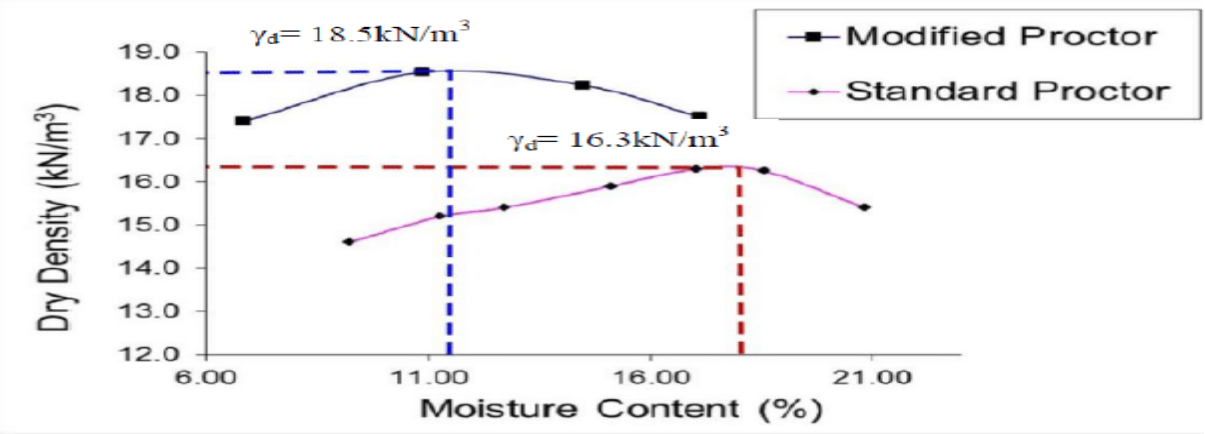


Figure 3: Moisture-density relationship curves (Proctor) for representative subgrade and sub-base samples.

3.2 Data Analysis

Subgrade quality was assessed using Group Index (GI), CBR, elastic modulus (E = 10 × CBR in MPa), surface modulus ($E_s = 17.6 \times CBR^{0.64}$), and resilient modulus (MR = 10.342 × CBR in MN/m^2) (Lillian et al., 2025).

Clay activity: A = Ip / (% clay < 2 μm)

Expansivity: $E_x = (Ip \times F_{0.425}) / 100$ (Ayalew et al., 2026)

Subbase quality evaluated using grading modulus (Mg) and plasticity modulus (Mp) (Hallin et al., 2025).

4. Results and Discussion

4.1 Soil Profile and Geotechnical Characterization of Subgrade

The interpretation of soil profile and geotechnical characterization of subgrade as shown in table 1.

Table 1: Meaning of the soil classification symbols

Symbol	Meaning	Description
CL	Clay of low plasticity	Inorganic clay with a liquid limit (LL) below 50% under USCS.
CI	Clay of intermediate plasticity	Used in some extended classification systems, commonly for clay with LL between 35% and 50%. Not a standard USCS group symbol.
CL–CI	Low- to intermediate-plasticity clay	A descriptive designation suggesting clay with low to intermediate plasticity. Not an official USCS dual-group symbol.
OL	Organic silt or clay of low liquid limit	Organic fine-grained soil with LL below 50%.
OH	Organic silt or clay of high liquid limit	Organic fine-grained soil with LL of 50% or greater.
SP	Poorly graded sand	Sand with a relatively uniform particle-size distribution or

		insufficient range of particle sizes for well grading.
GP	Poorly graded gravel	Gravel with a relatively uniform or gap-graded particle-size distribution.

Source: ASTM D2487-17(2025), Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

The two classification systems do not use the same soil-group symbols as presented in table 2.

Table 2: Difference between AASHTO and USCS classifications

Soil description	USCS classification	AASHTO group
Low-plasticity inorganic clay	CL	A-6 or A-7, depending on test results
Intermediate-plasticity inorganic clay	Usually CL under standard USCS, depending on LL and PI	A-6 or A-7, depending on test results
Organic clay or silt	OL or OH	A-8 may apply to highly organic soils
Poorly graded sand	SP	A-1-b, A-3, or A-2, depending on grading and fines
Poorly graded gravel	GP	A-1 or A-2, depending on grading and fines

Important: AASHTO classification requires particle-size distribution, liquid limit (LL), and plasticity index (PI).

The typical soil profile (0-2.0 m) consists of:

- 0-0.45 m: Dark brown organic silty clay (OL/OH) - unsuitable for direct pavement construction

- 0.45-1.2 m: Light brown silty clay of low to medium plasticity (CL/CI)

- 1.2-2.0 m: Poorly graded sand with gravel (SP/GP) - good drainage but low cohesion

The summary of subgrade engineering properties (Kasese District) is analyzed in table 3.

Table 3: Summary of subgrade engineering properties (Kasese District)

Property	Min	Max	Mean
Natural moisture content (%)	14.2	38.5	28.1
Specific gravity	2.40	2.62	2.51
Bulk unit weight (KN/m³)	14.8	24.9	16.5
Dry unit weight (KN/m³)	11.9	16.1	13.4
Liquid limit (%)	24	56	29.5
Plastic limit (%)	7	38	15.8
Plasticity index	4	29	13.7
% Clay (<2 μm)	0.5	9.2	3.1
% Silt	1.8	14.2	6.2
% Fines	3.9	21.0	9.3
% Sand	72	94	83.5
% Gravel	0	8	6.2
Clay activity	0.9	38.7	10.8
Expansivity	5.2	62.4	18.9

Interpretation:

- High natural moisture (mean 28.1%) exceeds the 5-15% range recommended for engineering construction (Nwa, 2025), indicating potential instability.

- 62% of subgrades rated poor to fair (AASHTO A-7-6, A-2-7) due to high plasticity and fines content (Table 2).

- Clay activity (mean 10.8) indicates moderate to extra-sensitive clays, likely montmorillonitic from weathered schist (Olinic, 2026).

- Expansivity (mean 18.9) suggests moderate to high swelling potential, consistent with seasonal cracking observed on Kasese-fort-portal road (Bagampadde & Bwana, 2016). Subgrade classification according to AASHTO is index in table 4 and figure 4a.

Table 4: Subgrade classification (AASHTO)

AASHTO Group	% Samples	Rating
A-2-4	10.0	Excellent-Good
A-2-6	25.0	Excellent-Poor
A-2-7	15.0	Fair-Poor
A-7-5	5.0	Fair–Poor
A-7-6	35.0	Fair–Poor
A-3	10.0	Fair–Poor
Total Good–Excellent	38%	
Total Poor–Fair	62%	

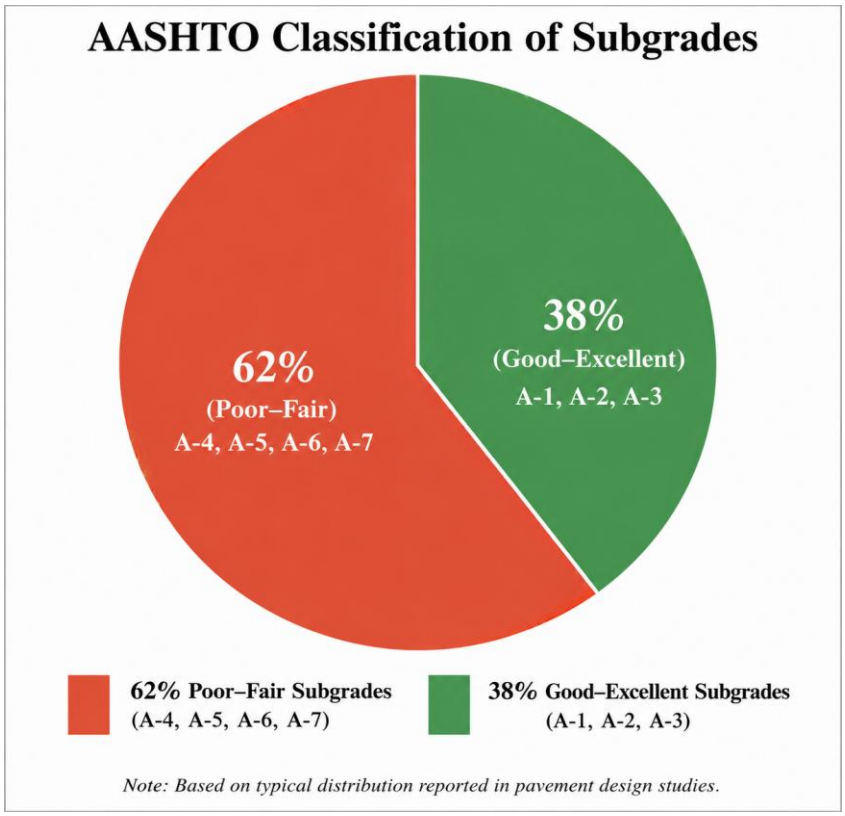


Figure 4a: AASHTO classification pie chart for subgrades (62% poor-fair, 38% good-excellent).

Strength properties:

- 48h soaked CBR: 5-32% (mean 8.6%) classified as soft to medium hard ground (National Highways, 2025)

- Surface modulus E_s: 55-150 MPa (mean 65 MPa) Class 1-2 foundation (Lillian et al., 2025)

- Resilient modulus MR: 51-331 MN/m² (mean 89 MN/m²)

These values are lower than the Nigerian study (CBR mean 9.9%), likely due to more active weathering and higher rainfall in Rwenzori foothills (Abija, 2019).

4.2 Sub-Base Materials

Sub-base samples from approved borrow pits (e.g., Kilembe, Hima, Bugoye) were characterized. Table 5 and table 6 analyze the index properties of sub-base materials and Compaction and strength of sub-base.

Table 5: Index properties of sub-base materials

Property	Min	Max	Mean
Moisture content (%)	14	22	17.5
Liquid limit (%)	22	35	28.5
Plastic limit (%)	12	20	16.5
Plasticity index	8	14	12.0
% Fines (<0.075 mm)	24	38	32.0
% Sand	58	72	64.5
% Gravel	2	10	3.5
AASHTO class	A-2-6		Excellent–Good
Group index	0 – 1.2		0.25

Table 6: Compaction and strength of sub-base

Property	Min	Max	Mean
OMC (%)	10.5	24.0	14.2
MDD (KN/m³)	12.0	19.0	17.8
Soaked CBR (%)	18	42	28.5
Unsoaked CBR (%)	32	60	46.0
Strength reduction (%)	12	58	38.0
Elastic modulus (MPa)	180	360	285
Resilient modulus (MPa)	186	535	360
Grading modulus	0.65	1.10	0.88
Plasticity modulus (MPa)	580	1420	920

Interpretation:

- Sub-base materials are generally excellent to good for A-2-6 classification.

- Soaked CBR (mean 28.5%) exceeds UNBS minimum of 25% for sub-base (Uganda National Bureau of Standards, 2015).

- However, strength reduction of up to 58% upon soaking highlights the need for rapid drainage.

AASHTO Soil Classification System (from ASTM M 145)

General Classification	Granular Materials 35% or less passing the 0.075 mm sieve							Silt-Clay Materials >35% passing the 0.075 mm sieve			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % passing											
2.00 mm (No. 10)	50 max	---	---	---	---	---	---	---	---	---	---
0.425 (No. 40)	30 max	50 max	51 max	---	---	---	---	---	---	---	---
0.075 (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid limit	---		---	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
Usual types of significant constituent materials	stone fragments, gravel and sand		fine sand	silty or clayey gravel and sand				silty soils		clayey soils	
General rating as a subgrade	excellent to good							fair to poor			

[a]Plasticity index of A-7-5 subgroup is equal to or less than the LL - 30. Plasticity index of A-7-6 subgroup is greater than LL - 30

Figure 4b: AASHTO classification for sub-base materials (all A-2-6, excellent-good).

4.3 Comparison with Nigerian Case Study

Table 7: Comparison of present study (Kasese District) with Nigerian Case Study

Parameter	Eastern Niger Delta (Abija, 2019)	Kasese District (This study)
Subgrade CBR (soaked) mean	9.9%	8.6%
Subgrade activity (range)	0.8-41.25	0.9-38.7
Expansivity (range)	4.8-68.9	5.2-62.4
Subgrade rating (% poor–fair)	58.85%	62%
Sub-base soaked CBR mean	28.2%	28.5%
Pavement thickness recommended	300-350 mm	350-400 mm

Kasese soils are slightly weaker and more expansive, requiring thicker pavement and enhanced drainage compared to case study soil from Nigeria as shown in table 7 in accordance with AASHTO classification figure 4b.

5. Considerations For Design and Construction

5.1 Pavement Thickness Design

Using the charts of (Lillian et al., 2025) and (Sakharkar et al., 2024):

- Based on Group Index (GI = 0-3.5) Curve D Thickness = 350-400 mm

- Based on soaked CBR (design value 6%) Road Note 29 Thickness = 375 mm (approx)

Recommended pavement structure (from top down):

- 50 mm Asphalt wearing course

- 150 mm Crushed stone base (CBR ≥ 80%)

- 200 mm Granular sub-base (CBR ≥ 30%)

- 150 mm Selected fill (capping layer) over subgrade

5.2 Drainage and Compaction Recommendations

Given the high rainfall and flood risk from Nyamwamba River:

- Use coarse granular sub-bases (river sharp sand + gravel) with grading modulus > 0.8 to allow moisture egress (Hallin et al., 2025).

- Install edge drains and cross culverts at 100 m intervals.

- Compact subgrade to 95% MDD (WASC) and sub-base to 100% MDD using vibratory rollers.

- Remove all organic topsoil (0-0.45 m) and replace with selected fill.

5.3 Stabilisation Needs

Subgrades with CBR < 6% and expansivity > 20% (approx. 40% of sites) should be stabilised with 4-6% lime or 2-3% cement to reduce swelling and increase strength (Imoh et al., 2025).

6. Conclusion

Pre-design geotechnical characterisation of subgrade and sub-base materials in Kasese District reveals:

1. Subgrades are predominantly silty clays (CL/CI) with high natural moisture (28% mean), 62% rated poor-fair, and expansive potential (expansivity up to 62.4).

2. Soaked CBR of subgrades (mean 8.6%) is below the 15% threshold recommended for unsurfaced roads, necessitating stabilisation or thick granular cover.

3. Sub-base materials from local borrow pits (A-2-6) are excellent-good in dry condition but lose up to 58% strength when soaked.

4. Recommended pavement thickness is 350-400 mm with coarse granular sub-bases and enhanced drainage.

5. Quality control during earthworks (compaction to 95–100% MDD) is critical for long-term performance.

Further studies should include resilient modulus testing under repeated loading and seasonal moisture monitoring.

7. Figures (Descriptions for Illustration)

Figure 1: Map of Kasese District showing study locations (Kilembe, Hima, Bugoye, Bukoki, Muhokya, Karusandara, Kyarumba, Nyamwamba floodplain).

Figure 2: Typical particle size distribution curves for subgrade (clayey sand) and sub-base (sandy gravel).

Figure 3: Moisture-density relationship curves (Proctor) for representative subgrade and sub-base samples.

Figure 4a: AASHTO classification pie chart for subgrades (62% poor-fair, 38% good-excellent).

Figure 4b: AASHTO classification for sub-base materials (all A-2-6, excellent-good).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets utilized and/or analyzed in this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declared that they have no competing interests.

Funding

Not applicable.

Clinical Trial Number

Not applicable.

Author contributions

AIV: Conceptualization; writing, methodology, analysis. CKAU: validation, investigation, review. YP: validation, investigation, review.

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

Acknowledgements

The writers expressed gratitude for the assistance received from Kampala International University. Also, School of engineering and applied science and department of civil engineering colleagues.

REFERENCES

Abija, F. A. (2019). Geotechnical assessment of subgrade and sub-base materials for optimal pavement performance, Eastern Niger Delta. International Journal of Scientific & Engineering Research, 10(7), 1865–1875.

Akpokodje, O. I., Akwenuke, M. O., Essaghah, A. E., Uguru, H., & Okolotu, G. I. (2025). Investigation of the geotechnical properties and chemical oxide composition of sub-soils at Delta State University of Science and Technology, Ozoro, for infrastructural development. NIPES Journal of Science and Technology Research, 7(1), 99–108. https://doi.org/10.37933/nipes/7.1.2025.8

Ayalew, W. T., Fentie, A. B., Workie, A. D., & Deresse, D. A. (2026). Prediction of swelling pressure in expansive soils from index properties using nonlinear regression. Advances in Civil Engineering, Article 3040706. https://doi.org/10.1155/adce/3040706

Bagampadde, U., & Bwana, I. (2016). Expansive soil problems along Kasese-Fort Portal Road. Uganda Journal of Civil Engineering, 2(1), 11–24.

British Standards Institution. (2022). Methods of test for soils for civil engineering purposes Part 2: Classification tests and determination of geotechnical properties (BS 1377-2:2022). https://doi.org/10.3403/30427945

Hallin, C., Adell, A., Almström, B., Kroon, A., & Larson, M. (2025). RoadRAT - A new framework to assess the probability of inundation, wave runup, and erosion impacting coastal roads. Coastal Engineering, 199, Article 104741. https://doi.org/10.1016/j.coastaleng.2025.104741

Imoh, U. U., Apata, A. C., Bolorunduro, A. M., & Rad, M. M. (2025). Mechanistic and comparative laboratory assessment of lime dosage and uniaxial geogrid on the strength and durability of classified lateritic subgrade. Scientific Reports, 15, Article 42901. https://doi.org/10.1038/s41598-025-30041-1

Jess, S., Köhn, D., Fox, M., Enkelmann, E., Sachau, T., & Aanyu, K. (2020). Paleogene initiation of the Western Branch of the East African Rift: The uplift history of the Rwenzori Mountains, Western Uganda. Earth and Planetary Science Letters, 552, Article 116593. https://doi.org/10.1016/j.epsl.2020.116593

Kasese District Local Government. (2020). District development plan III: Infrastructure sector report.

Lillian, N., Ahmed, S. B., Krishnan, D., & Eze, V. H. U. (2025). Comprehensive evaluation of sub-base materials for road pavements, integrating California bearing ratio and triaxial compression tests for enhanced stability and durability: A systematic review. Discover Civil Engineering, 2, Article 116. https://doi.org/10.1007/s44290-025-00278-w

Mazimwe, A., Steven, O., Gidudu, A., Linda, A. B. L., & Shahnawaz, S. (2026). From landslides to debris floods: Understanding cascading hazard mechanisms in the Nyamwamba catchment, Mt. Rwenzori, Uganda. Natural Hazards Research, 6, 393–408.

Muwanga, A., & Barifaijo, E. (2019). Flood vulnerability assessment of Nyamwamba River catchment, Kasese. Journal of African Earth Sciences, 152, 45–56.

National Highways. (2025). Design for new pavement foundations (CD 225, Version 1.1.0). Design Manual for Roads and Bridges.

Nwa, I. G. (2025). Geotechnical assessment of lateritic soil for subgrade and sub-base applications in road construction: A case study from Akwa Ibom State, Nigeria. Journal of Civil, Construction and Environmental Engineering, 10(6), 253–261. https://doi.org/10.11648/j.jccee.20251006.15

Oleng, M., Ozdemir, Z., & Pilakoutas, K. (2024). Co-seismic and rainfall-triggered landslide hazard susceptibility assessment for Uganda derived using fuzzy logic and geospatial modelling techniques. Natural Hazards, 120, 14049–14082. https://doi.org/10.1007/s11069-024-06744-5

Olinic, E. D. (2026). Proposal of practical criteria for defining expansive soils subjected to moisture content variations for geotechnical design and calculation of settlement, shrinkage and heave. Geotechnics, 6(2), Article 52. https://doi.org/10.3390/geotechnics6020052

Sakharkar, S. C., Chitade, P. N., Bansod, P. S., Pekade, N. V., Parihar, Y. D., Gedam, N. J., & Marve, S. R. (2024). Design of flexible pavement by group index method. International Journal of Research Publication and Reviews, 5(5), 5726–5733. https://doi.org/10.55248/gengpi.5.0524.1268

Tugume, F., & Nyende, J. (2017). Premature pavement failures in Uganda: Causes and remedies. East African Journal of Engineering, 3(1), 22–34.

Uganda National Bureau of Standards. (2015). US 862:2015 - Standard specification for road sub-base materials.

Uganda National Meteorological Authority. (2021). Climate trends in Western Uganda: 1990–2020.

Uganda National Roads Authority. (2018). Geotechnical design manual for roads and bridges.