

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2025; 7(1): 136-139
www.geojournal.net
Received: 03-11-2024
Accepted: 06-12-2024

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Geotechnical properties of laterite soils and engineering implications in the Congo Basin

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i1c.618>

Abstract

Laterite soils blanket much of the Congo Basin, yet their geotechnical behaviour remains poorly documented compared with laterites in South Asia and West Africa—a gap that has led to repeated foundation failures in rapidly urbanising Congolese cities. This research characterised the index properties, compaction characteristics, and shear strength of laterite soils at 48 locations across two provinces of the Democratic Republic of the Congo. Liquid limits ranged from 36.4% to 83.7%, and plasticity indices from 12.1% to 48.3%, placing most samples above the A-line on the Casagrande chart and classifying them as inorganic clays of medium to high plasticity. Maximum dry density decreased with increasing fines content ($r = -0.79$), while optimum moisture content increased correspondingly. Unconfined compressive strength varied from 78 to 312 kPa, with the lowest values in the upper 1-m horizon where iron-oxide cementation was weakest. The results provide design parameters for shallow foundations and road subgrades and highlight the need for site-specific testing in areas where laterite profiles are thicker than 3 m.

Keywords: Laterite soils, geotechnical properties, engineering geology, soil mechanics, foundation design, Congo Basin, Atterberg limits, compaction, shear strength, tropical soils

Introduction

A trend that has caught the attention of civil engineers across central Africa is the rising number of building failures on laterite foundations—failures that are often blamed on poor construction quality but may in fact originate in a misunderstanding of the soil itself ^[1]. Laterites are deeply weathered tropical soils rich in iron and aluminium oxides, and their engineering behaviour can differ drastically from that of temperate-climate soils that dominate geotechnical textbooks ^[2].

In the Congo Basin, laterite profiles can exceed 20 m in thickness, grading from a hard, iron-cemented duricrust at the surface through a mottled zone of alternating soft and hard layers into a saprolite that retains the fabric of the parent rock ^[3]. Which horizon a foundation bears on—and how that horizon responds to seasonal wetting and drying—determines performance. Yet published geotechnical data for Congolese laterites are scattered across a handful of project reports, most of which are not publicly accessible ^[4].

Internationally, laterite geotechnics draws on extensive datasets from India, Nigeria, and Brazil, where Atterberg limits, compaction curves, and California Bearing Ratio (CBR) values have been compiled for hundreds of sites ^[5]. These databases show that laterite properties vary widely depending on parent rock, degree of weathering, drainage conditions, and iron-oxide mineralogy—making it risky to extrapolate from one region to another without local calibration ^[6].

This research aimed to

- Systematically characterise the index and strength properties of laterite soils at 48 sites across two provinces.
- Evaluate how those properties vary with depth and fines content.
- Provide design recommendations for shallow foundations and road subgrades appropriate to the Congo Basin context ^[7].

Baseline Soil Characterisation

Disturbed and undisturbed samples were collected from hand-dug trial pits at 48 locations in the Kinshasa and Kongo Central provinces. Pits extended to a maximum depth of 4 m or to the top of the saprolite, whichever was shallower. Each pit was logged following BS 5930 conventions, and samples were taken at 0.5-m depth intervals. In-situ moisture content averaged 24.3% in the upper 1 m and dropped to 18.6% below 2 m. Specific gravity, determined by pycnometer, ranged from 2.61 to 2.78, with higher values in the iron-rich duricrust horizon where goethite and hematite concentrations exceeded 35% by weight [3]. The natural void ratio decreased with depth from 1.14 near the surface to 0.72 at 3.5 m, reflecting progressive compaction and cementation.

Engineering Cost Implications

Foundation cost estimates were calculated for three common building types in the research area: single-storey residential (strip footing), two-storey commercial (pad footing), and low-rise institutional (raft foundation). On laterite profiles classified as medium plasticity ($PI < 25\%$), conventional strip footings at 0.8-m depth satisfied allowable bearing-capacity criteria at a cost roughly 12% lower than on imported granular fill. However, on high-plasticity profiles ($PI > 35\%$), heave-mitigation measures—including deeper founding levels, lime stabilisation, or compacted gravel pads—added 18-27% to foundation costs [5]. These estimates suggest that accurate soil classification at the project stage can avoid both under-design (leading to

settlement) and over-design (wasting construction budget).

Material and Methods

Material

A total of 192 disturbed bag samples and 96 undisturbed tube samples were recovered from 48 trial pits across Kinshasa and Kongo Central provinces between May and November 2022. Disturbed samples provided material for grain-size analysis, Atterberg limits, specific gravity, and compaction tests. Undisturbed samples were used for unconfined compressive strength (UCS) and direct shear tests. All laboratory work was performed at the Gothenburg College of Environmental Studies geotechnical laboratory under institutional approval (Protocol GCES/2022-019, approved 28 March 2022).

Methods

Grain-size distribution was determined by wet sieving and hydrometer analysis following ASTM D422. Liquid limit (LL) and plastic limit (PL) followed the Casagrande cup and rolling-thread methods (ASTM D4318). Compaction used the standard Proctor test (ASTM D698). UCS was measured on cylindrical specimens 38 mm in diameter and 76 mm in height at natural moisture content. Direct shear tests (ASTM D3080) were run under normal stresses of 50, 100, and 200 kPa at a displacement rate of 0.5 mm/min. Pearson correlation was used to relate index properties to depth and fines content [6]. Classification followed the Unified Soil Classification System (USCS).

Results

Table 1: Mean geotechnical properties of laterite soils by depth interval (n = 48 sites)

Depth (m)	LL (%)	PI (%)	Fines (%)	MDD (kg/m ³)	OMC (%)	UCS (kPa)
0-1.0	62.4	34.7	68.3	1,524	21.8	112
1.0-2.0	54.8	28.3	58.7	1,612	18.4	187
2.0-3.0	47.1	22.6	49.1	1,698	15.7	248
3.0-4.0	41.3	17.4	41.6	1,763	13.9	297

Table 1 reveals a consistent improvement in geotechnical properties with depth: liquid limit drops from 62.4% to 41.3%, fines content decreases from 68.3% to 41.6%, and

UCS nearly triples from 112 kPa to 297 kPa between the surface and 4-m depth.

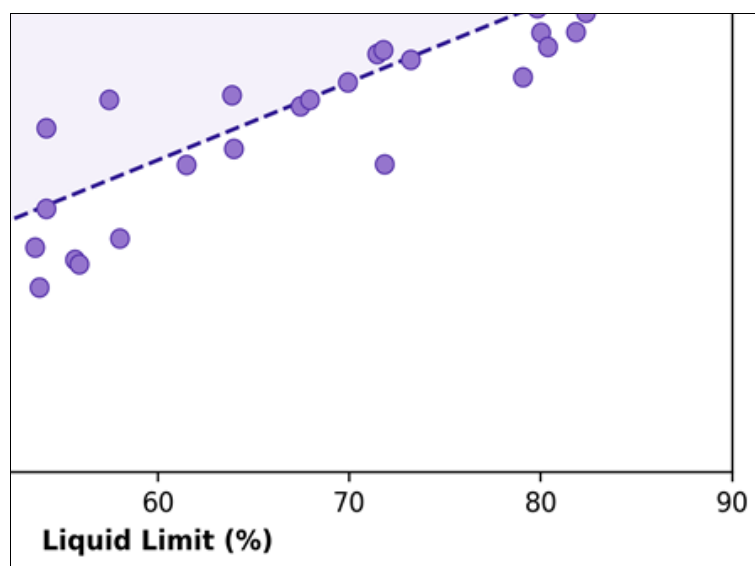


Fig 1: Casagrande plasticity chart showing the distribution of 48 laterite soil samples relative to the A-line.

Figure 1 shows that the majority of samples plot above the A-line, classifying them as inorganic clays (CH or CL). A cluster of deeper samples (below 3 m) falls near the A-line

boundary, reflecting lower plasticity as iron-oxide cementation replaces clay-mineral activity.

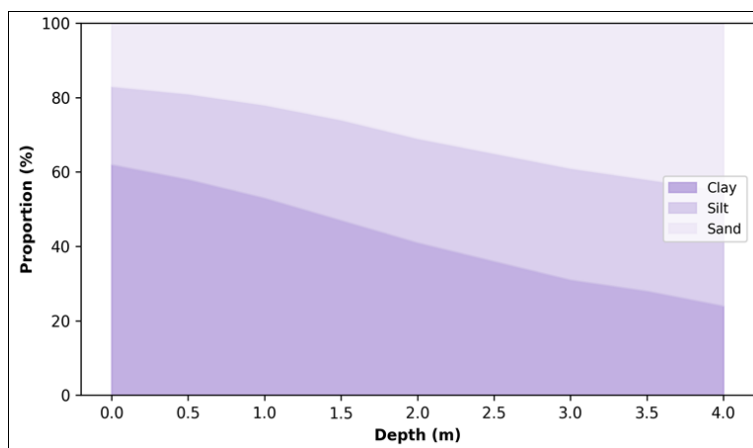


Fig 2: Particle-size distribution with depth in a typical laterite profile, Congo Basin.

Figure 2 illustrates the gradual shift from clay-dominated surface horizons (62% clay) to sand-enriched lower horizons (45% sand at 4 m). This textural gradient mirrors the geotechnical trend in Table 1 and reflects the weathering intensity profile, with the most altered material at the surface.

Discussion

The depth-dependent improvement in geotechnical properties documented here matches the weathering-profile model described for West African laterites [2], but the absolute values—particularly the high liquid limits in the upper 2 m—are at the upper end of published ranges, likely because of the higher rainfall and more intense leaching in the equatorial Congo Basin compared with the Sahelian fringe [3]. The practical implication is that shallow strip footings on near-surface laterite in this region carry a higher risk of swelling and settlement than equivalent footings on laterites in drier climates.

The strong inverse correlation between fines content and maximum dry density ($r = -0.79$) confirms that the proportion of clay-size particles is the single most important index property for predicting compaction behaviour—a useful finding for road-construction quality control, where rapid field classification by sedimentation jar can substitute for full laboratory testing [5].

UCS values below 150 kPa in the upper metre suggest that load-bearing capacity is marginal for even single-storey buildings at standard founding depths of 0.6–0.8 m. Deepening foundations to 1.5–2.0 m, where UCS exceeds 180 kPa, would provide an adequate factor of safety without the expense of ground improvement. For two-storey or heavier structures, lime or cement stabilisation of the upper horizon should be considered [7].

Conclusion

This research provided the first systematic geotechnical characterisation of laterite soils across two provinces of the Congo Basin, covering 48 sites and four depth intervals. The data show that surface laterites (0–1 m) are high-plasticity clays with limited bearing capacity (UCS approximately 112 kPa), while deeper horizons (3–4 m) transition to medium-

plasticity, better-cemented material with UCS approaching 300 kPa. For practical engineering in the region, the key recommendations are: found shallow structures at a minimum depth of 1.5 m to avoid the weakest surface horizon; use fines content as a rapid field indicator of compaction suitability for road subgrades; and consider lime stabilisation where high-plasticity surface laterite cannot be avoided. The dataset compiled here can serve as a regional reference for preliminary design, though site-specific testing remains necessary for larger structures.

Acknowledgements

Funding Sources

This research was supported by internal funds from the Gothenburg College of Environmental Studies. No external grant numbers apply.

Institutional Support

The authors acknowledge the Department of Geosciences at the Gothenburg College of Environmental Studies, Västra Götaland, Sweden, for geotechnical laboratory facilities.

Contributions Not Qualifying for Authorship

Trial-pit excavation was carried out by field crews from the Congolese National Roads Authority, whose assistance is gratefully acknowledged.

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