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Geotechnical Performance and Pavement Potential of Kouria Lateritic Gravel in Guinea

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Abstract Lateritic gravels offer a valuable local resource for road construction in Guinea. This study evaluates the pavement potential of Kouria gravel through complementary physical and mechanical indicators. The programme combined eight field sampling locations, laboratory identification, compaction, bearing-capacity and particle-resistance tests, with complementary direct-shear and oedometer investigations. Cross-analysis quantified moisture windows, effort-normalised bearing gains and wet-abrasion variability while retaining separate test batches. The material exhibited a plasticity index of 5.7 percentage points. The complementary compaction series reached a maximum dry density of 1.82 Mg/m³. Interpolated moisture intervals were 18.8–25.6% and 21.1–24.5% at 95% and 98% of that reference density, respectively, corresponding to a 51% contraction in window width. Between 10 and 56 blows per layer, the two recorded bearing-ratio columns increased by factors of 4.89 and 6.71, with diminishing incremental gains. Mean Micro-Deval loss was 11.49%, with a coefficient of variation of 3.7%. Direct shear yielded apparent parameters of 54.8 kPa and 32.8°, while compression increased with applied stress. Kouria gravel presents favourable characteristics for pavement subbase development and promising base-course potential. The combined evidence identifies coordinated moisture, compaction and drainage control as practical priorities for mobilising this resource, with application-specific qualification defining its final use.

Keywords: *lateritic gravel, pavement materials, compaction, bearing capacity, Guinea*

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1. Introduction

Lateritic gravels provide an important opportunity to develop road infrastructure using locally available resources. Their value depends on how particle arrangement, fines, moisture and compaction combine to produce a stable pavement layer. International experience demonstrates that lateritic materials can perform successfully under specifications adapted to their geological character and service environment [1]. Laboratory investigations also show that penetration resistance depends on both compaction and moisture state [2,3]. These findings favour qualification through complementary engineering indicators.

This approach is particularly relevant to Guinea. Konaté et al. observed an initial reduction in bearing capacity during drying–immersion cycles applied to lateritic soils from Guéckédou and Dabola, followed by a tendency towards stabilisation [4]. In Burkina Faso, investigations have related bearing capacity to stiffness and examined granular improvement using crushed granite [5,6]. Work in Cameroon similarly connects geological characteristics with mechanical performance and pavement applications [7]. Together, these studies support the assessment of each deposit through the properties governing its intended use.

Kouria-Boghitagui is a source of lateritic gravel in the Kindia region of Guinea. Its road-building potential is examined here through an integrated experimental case study combining identification, compaction, California bearing ratio (CBR), particle resistance, direct shear and one-dimensional compression. The objective is to identify favourable material characteristics and translate the experimental responses into practical priorities for pavement subbase and base-course qualification.

The analysis quantifies moisture-window contraction, incremental CBR gains and wet-abrasion repeatability. Interpreting these responses alongside shear and compression identifies construction controls that can mobilise the material's potential. The assessment is organised by engineering function, without an arbitrary composite score.

2. Materials and Methods

2.1. Study Area and Experimental Programme

The quarry lies near Boghitagui at approximately 9.7872° N, 13.3659° W and 186 m elevation. The material is reddish to reddish-brown and contains gravel and rock fragments. Eight sampling positions, KB-01 to KB-08, covered accessible extraction faces and weathered zones, with approximately 5 m minimum spacing. About 25 kg was collected at each position in labelled, sealed containers. Laboratory preparation comprised homogenisation and subdivision into test portions.

The programme combined investigations at the GPC Group geotechnical laboratory with complementary compaction, direct-shear and oedometer testing at the Laboratoire du Bâtiment et des Travaux Publics (LBTP). The complementary tests concerned a separate quarry batch. Results were analysed within each test family; the eight field positions were not treated as eight replicated observations for properties reported only as pooled or batch-level values.

2.2. Test Methods and Reference Framework

Water content, particle-size distribution and consistency limits were interpreted using the methodological framework of ISO 17892-1, ISO 17892-4 and ISO 17892-12, respectively [8,9,10]. The liquid and plastic limits characterise the tested fine fraction. Four natural-water-content determinations were summarised using their mean and sample standard deviation. The plasticity index was recalculated by subtraction of the two limits.

The complementary compaction series comprised five water-content–dry-density pairs. NF P94-093 provides the reference framework for Proctor testing [11]. Because the compaction energy is not fully documented for this batch, its curve is designated the Proctor compaction response without assigning normal or modified energy. The adopted dry-density reference was 1.82 Mg/m³; the laboratory optimum water content was 23.2%, alongside a measured maximum at 22.75%.

CBR results were available at 10, 25 and 56 blows per layer, with two recorded columns retained as A and B. The programme specifies four-day soaking within the CBR framework of NF P94-078 [12]. The columns were analysed separately because their correspondence to penetration depth or replicate specimens is unresolved. Specimen-level density and conditioning records were unavailable, so CBR was related to recorded compaction effort rather than assigned to the complementary Proctor densities.

Wet-abrasion losses were calculated for three Micro-Deval test portions of the 6.3/10 mm fraction using their initial and retained masses. Fragmentation and cleanliness were characterised by the Los Angeles coefficient and the visual and piston sand equivalents. Their methodological references are EN 1097-1, EN 1097-2 and EN 933-8+A1 [13,14,15]. The cited standards define the test indicators and provide the reference framework for their interpretation.

Direct shear involved applied normal stresses of 100, 200 and 300 kPa in a box with a 36 cm² cross-section and approximately 4.2 cm initial specimen height. Failure stresses were fitted by a linear Mohr–Coulomb envelope. The framework for direct shear is ISO 17892-10 [16]. Without pore-pressure or suction measurements, the fitted intercept and angle are apparent parameters expressed against applied normal stress. Oedometer loading covered 5–1,000 kPa and was analysed in the void-ratio–log-stress plane, following the incremental-loading framework of ISO 17892-5 [17].

2.3. Quantitative Cross-Analysis

Relative compaction was calculated within the complementary batch. Moisture bounds were obtained by linear interpolation between the adjacent measured points on each side of the compaction peak. The 95% and 98% levels are analytical scenarios, not prescribed acceptance limits.

$$D_c = \frac{100\rho_d}{\rho_{d,\max}} \tag{1}$$

$$w_t = w_i + \frac{(\rho_t - \rho_i)(w_{i+1} - w_i)}{\rho_{i+1} - \rho_i} \tag{2}$$

For each CBR column, the ratio to the 10-blow value quantified relative mobilisation. The incremental gain divided the CBR increase by the additional blows per layer. These quantities describe the tested intervals without extrapolation.

In Eq. (1), relative compaction expresses dry density as a percentage of the batch maximum. In Eq. (2), subscript t denotes the target density or interpolated water content.

$$R_j(N) = \frac{CBR_j(N)}{CBR_j(10)} \tag{3}$$

$$g_j = \frac{\Delta CBR_j}{\Delta N} \tag{4}$$

Micro-Deval dispersion was expressed by the sample standard deviation and coefficient of variation across three test portions. The direct-shear fit and secant compression index were calculated as follows, with stresses in kPa and the logarithm to base 10:

$$\tau_f = c_{app} + \sigma_n \tan\varphi_{app} \tag{5}$$

$$C_{\sec} = \frac{e_1 - e_2}{\log_{10}(\sigma_2 / \sigma_1)} \tag{6}$$

The integrated assessment considered five functions: granular skeleton, fine-fraction plasticity, attainable compacted state, penetration resistance and particle integrity. Shear and compression provided complementary mechanical context. Cross-analysis was functional rather than a specimen-matched multivariate regression; no significance tests or quarry-wide confidence intervals were inferred from the small, differently structured datasets.

3. Results

3.1. Material Characteristics

The identification tests reveal a predominantly granular material with low-plasticity fines (Table 1). The natural water contents average 7.28%, with a sample standard deviation of 0.25 percentage point across four determinations. Subtracting the plastic limit from the liquid limit gives a plasticity index of 5.67 percentage points. This narrow plastic interval is a favourable characteristic for a granular road material, while the liquid limit confirms that moisture remains relevant to its fine fraction.

Table 1. Identification and Supporting Indices

Property	Result
Natural water content	7.28% (SD 0.25; n = 4)
Gravel; passing 80 µm	70.5%; 11%[a]
Liquid; plastic limits	43.77%; 38.10%
Plasticity index	5.67 percentage points
Sand equivalent	48 visual; 40 piston
Los Angeles coefficient	29%[b]
Particle density	3.046 Mg/m³
Loose bulk density	1.505 Mg/m³

[a] Separate grading descriptors; component fractions require reconciliation. [b] Supporting index pending confirmation of preparation details. SD, sample standard deviation.

3.2. Moisture Control and Densification

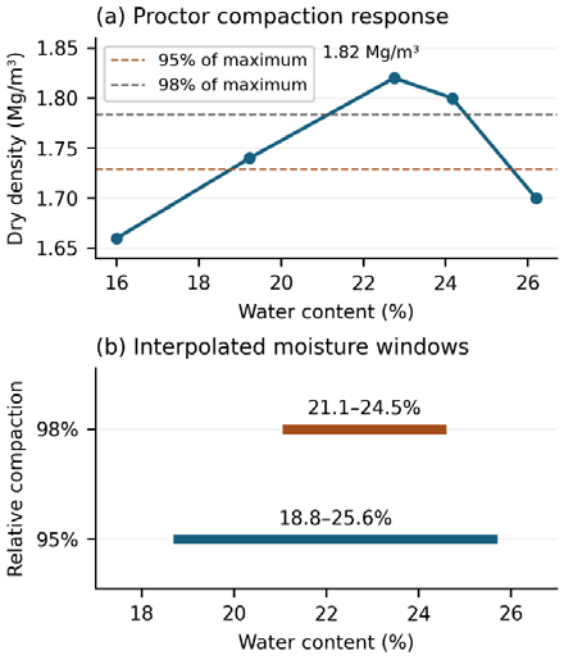


Figure 1. Compaction response and interpolated moisture windows of the complementary batch. Lines join measured points; 95% and 98% are analytical relative-compaction targets

The five compaction measurements define an increase in dry density from 1.66 to 1.82 Mg/m³, followed by a decrease to 1.70 Mg/m³ (Figure 1a). The density targets corresponding to 95% and 98% of the reference maximum are 1.729 and 1.784 Mg/m³. Piecewise interpolation gives moisture intervals of 18.8–25.6% and 21.1–24.5%, respectively (Figure 1b). Using unrounded bounds, their widths are 6.82 and 3.35 percentage points: increasing the target by three percentage points contracts the calculated moisture window by 51%.

The response also identifies a steeper density reduction over the measured wet-side interval from 24.16 to 26.20% than the increase from 19.23 to 22.75%. Their absolute slopes are 0.0490 and 0.0227 Mg/m³ per percentage point of water content, respectively. The ratio of 2.16 describes these particular intervals and shows why excess water deserves attention when working near the upper end of the tested moisture range.

3.3. Bearing-Capacity Mobilisation

CBR rises consistently with increasing effort in both recorded columns (Figure 2a). Between 10 and 56 blows per layer, it increases by factors of 4.89 in column A and 6.71 in column B, equivalent to gains of 389% and 571%. Values exceeding 100% are valid because CBR is a resistance ratio relative to a reference material, not a bounded material percentage.

The incremental response is positive but decreases over the second effort interval (Figure 2b). Gains fall from 3.68 to 2.04 CBR percentage points per additional blow in column A and from 4.36 to 2.82 in column B. These reductions, approximately 45% and 35%, demonstrate diminishing incremental returns over the tested range. Both columns support the same practical interpretation: compaction strongly mobilises penetration resistance, with smaller gains per additional blow at the highest investigated effort.

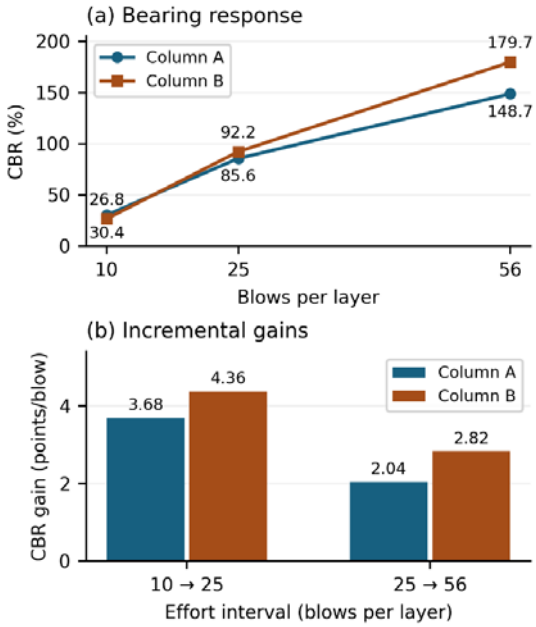


Figure 2. CBR mobilisation and incremental gains with compaction effort. Recorded columns A and B are analysed separately. These measurements are not paired with the complementary Proctor densities

3.4. Particle Integrity, Shear and Compression

Micro-Deval losses recalculated from the mass measurements are closely grouped around a mean of

11.49% (Figure 3a). The sample standard deviation is 0.42 percentage point and the coefficient of variation is 3.7%. This repeatability supports the favourable wet-abrasion response of the tested coarse fraction. The Los Angeles index and sand-equivalent readings provide complementary indicators of fragmentation and fine-particle cleanliness (Table 1).

The direct-shear results increase almost linearly with applied normal stress (Figure 3b). The fitted relationship is $\tau = 54.83 + 0.645\sigma$, giving an apparent cohesion of 54.8 kPa and an apparent friction angle of 32.8°. Specimen water contents range from 21.11 to 21.68% and dry densities from 1.492 to 1.562 Mg/m³. The envelope therefore describes the tested specimen states rather than a density-controlled comparison.

The oedometer loading sequence shows a progressive decrease in void ratio (Figure 4a). Interval secant compression indices increase from approximately 0.029 at the lowest stresses to 0.259 between 500 and 1,000 kPa (Figure 4b). The combined 250–1,000 kPa interval gives 0.243. The response identifies increasing compressibility along the loading path and provides a useful complement to the penetration and shear results.

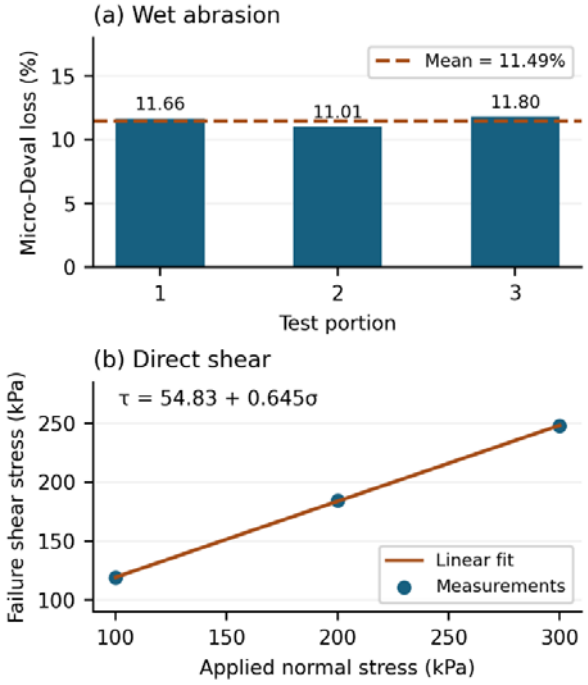


Figure 3. Coarse-particle wet abrasion and direct-shear response. Micro-Deval losses concern three test portions; the shear envelope describes apparent parameters over 100–300 kPa

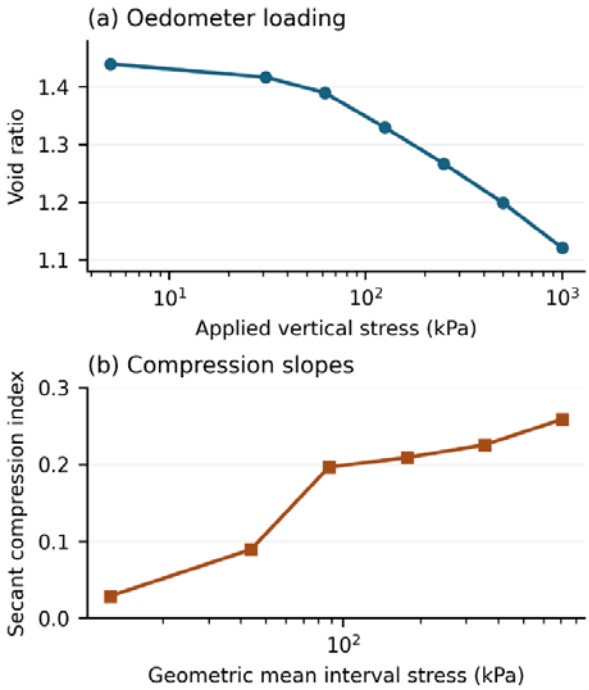


Figure 4. One-dimensional loading response and interval compression slopes. Secant indices are plotted at geometric mean interval stresses; lines guide the eye

4. Discussion

4.1. Integrated Assessment of Pavement Potential

The results establish a coherent case for developing Kouria gravel as a pavement resource. Low plasticity supports the use of its granular skeleton; increasing compaction effort mobilises substantial penetration resistance; and the limited Micro-Deval losses indicate favourable particle integrity under wet abrasion. Each result addresses a different engineering function. Their convergence provides a stronger basis for subbase qualification than the largest CBR value alone (Table 2).

Table 2. Engineering Functions and Qualification Priorities

Engineering function	Qualification priority
Skeleton and low-plasticity fines	Verify grading of production lots
Attainable compacted state	Control moisture and field dry density
Bearing mobilisation	Calibrate rolling and matched CBR tests
Particle integrity	Control segregation and grading changes
Shear and compression response	Extend assessment to repeated loading and moisture cycles

The principal analytical result is the interaction between attainable density and moisture tolerance. A three-percentage-point increase in the relative-compaction target halves the interpolated moisture window. This quantifies the additional moisture-control demand associated with seeking a denser compacted state. The simultaneous CBR increase with effort shows why such control is worthwhile, although the separate batches preclude a numerical CBR–density calibration. This distinction preserves the useful engineering relationship without implying that unmatched measurements describe the same specimens.

4.2. Relation to Previous Research

Toll's lateritic-gravel investigation links CBR to compaction and moisture conditions, while Tatsuoka and Gomes Correia emphasise saturation state in compaction control [2,3]. Kouria contributes deposit-specific moisture windows and effort-normalised bearing gains to this established framework. The results favour coupled moisture and density checks during construction. These controls provide a direct route from laboratory characterisation to field implementation.

The Burkina Faso study by Gansonré et al. demonstrates the value of locally calibrated relationships between CBR and stiffness [5]. Its implications support extending Kouria testing towards resilient response rather than converting the present CBR values directly into a design modulus. Mbengue et al. and Nzabakurikiza et al. demonstrate how granular correction can improve selected lateritic materials [6,7]. For Kouria, the encouraging untreated response makes direct use the first qualification option; blending or stabilisation can be targeted to a specific deficiency if project testing identifies one.

The Guinean drying–immersion study provides a complementary environmental perspective: bearing resistance can evolve after the first hydraulic cycle [4]. Kouria's wet-abrasion response is encouraging, but it characterises the coarse particles rather than the hydraulic stability of the whole compacted layer. Drainage and moisture management therefore act together with particle quality to preserve performance. Apparent shear cohesion likewise concerns the tested state; suction may contribute to unsaturated strength and should be distinguished from permanent saturated bonding [18].

4.3. Implications for Road Construction In Guinea

The immediate application is a structured route to subbase qualification. A project can use the measured properties to select representative production lots, establish a grading envelope and a verified compaction reference, then confirm CBR under the specified density and conditioning. Field trials can translate the laboratory response into lift thickness, water addition, roller type and pass count. The diminishing laboratory gains suggest a useful optimisation question: determine the effort that consistently meets the required state, rather than prescribing additional rolling without evidence of benefit.

Base-course development is also promising because high penetration resistance and favourable wet abrasion are already demonstrated in the investigated material. Qualification should then focus on the higher demands of the selected traffic and drainage conditions, particularly cyclic moisture response and permanent deformation under repeated loading. This progression gives the resource a clear development pathway: prioritise subbase use, and extend to base layers as the application-specific performance is established.

For procurement, the study supports distinguishing quarry potential from production-lot consistency. Sampling by extraction zone, controlling segregation during stockpiling and checking grading after compaction are practical ways to retain the favourable laboratory characteristics. Local sourcing can also reduce haulage requirements where Kouria is close to the works, although economic and environmental savings require a project-specific transport assessment.

4.4. Scope and Next Stage

The evidence concerns the tested fractions and batches. Quarry-wide variability remains unquantified, and the complete grading distribution requires reconciliation because the component fractions and the stated 80 µm passing value do not fully agree. The unidentified CBR columns, incomplete compaction-energy documentation and Los Angeles preparation details limit formal specification-based acceptance. The oedometer loading trend is usable, but inconsistent initial-void-ratio and unloading entries prevent reliable swelling or preconsolidation estimates. These issues define a focused next stage: traceable lot-level grading, matched density–CBR measurements, cyclic wetting and repeated-load testing. This programme would build directly on the favourable characteristics demonstrated here.

5. Conclusion

Kouria lateritic gravel combines low-plasticity fines, a strong increase in penetration resistance with compaction effort and repeatable wet-abrasion behaviour. These characteristics provide a positive experimental basis for its development as a local pavement subbase resource and a promising candidate for selected base-course applications.

The cross-analysis turns laboratory measurements into practical construction insights. Increasing the relative-compaction target from 95% to 98% narrows the calculated moisture window by 51%, while CBR increases by factors of 4.89 and 6.71 between the lowest and highest tested efforts. The Micro-Deval mean of 11.49%, with a 3.7% coefficient of variation, adds evidence of consistent coarse-particle resistance. Shear and compression results complement this assessment by identifying frictional resistance and stress-dependent deformation.

The practical priority is to mobilise these advantages through coordinated grading, moisture, compaction and drainage control. The study provides a quantitative framework for qualifying Kouria production lots and directing further testing towards the performance requirements of the intended pavement layer.

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Competing Interests

The authors declare no competing interest.

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