

ORGANIC-TAINTED MINERAL SOILS PART II: NEUTRALISATION-FIRST STABILISATION FROM LABORATORY TO FIELD

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Abstract. Organic-tainted mineral soils remain predominantly mineral and physically compactable, yet reactive organic matter can interfere with conventional lime- and cement-based treatment. Building on the mechanistic framework established in Part I, this companion paper translates neutralisation demand into a laboratory-to-field validation procedure. The approach determines whether preliminary chemical conditioning can reduce organic interference, improve binder activation, and produce more consistent engineering performance than direct binder addition. Laboratory assessment integrates baseline characterisation, neutralisation response, compaction behaviour, strength development, soaked bearing capacity, stiffness, and durability across controlled treatment combinations. Field validation examines constructability, treatment uniformity, moisture control, and the retention of laboratory improvements under in-situ conditions. The framework distinguishes chemical input consumed in satisfying organic acidity and calcium demand from the subsequent binder requirement for structural cementation. Treatment dosage is therefore evaluated as a staged chemical-geotechnical requirement rather than as a single binder-content problem. The resulting procedure supports stabiliser selection, dosage optimisation, performance verification, and rejection where shallow treatment cannot be reproduced reliably.

Keywords: *reactive organics, binder efficiency, pavement subgrade, chemical conditioning, treatment uniformity*

Introduction

Part I of this twin-paper study defined organic-tainted mineral soil (OTMS) as a distinct geotechnical treatability category: A predominantly mineral, workable soil in which reactive organic matter can impair conventional chemical stabilisation. It introduced neutralisation demand as the governing treatability variable, arguing that neither organic content nor immediate pH adequately represents interference with binder response. The central premise was therefore that organic chemical demand must first be sufficiently satisfied before reliable cementitious strengthening can develop. Part II addresses the operational question arising from that premise. Neutralisation demand is useful only if it can be measured reproducibly, incorporated into treatment design and verified against engineering performance. Qiao et al. (2024) showed that humic-matter behaviour is governed by its functional characteristics and interactions with soil minerals, reinforcing the limitations of organic content as a stand-alone indicator. Luo and Zhang (2023) similarly reported differing effects of humic and fulvic

acids on strength and durability, while Sindete et al. (2024) demonstrated that elevated pH does not necessarily correspond to meaningful strength development. These findings reinforce the need to distinguish chemical compatibility from structural performance.

For road applications, treatment must extend beyond dry strength to compactability, achievable density, soaked bearing capacity, stiffness, durability and field uniformity. Such combined assessment is increasingly adopted for stabilised subgrades (Jwaïda et al., 2024). OTMS adds a further challenge because part of the added chemical capacity may be consumed by organic interference before contributing to cementation. Binder dosage alone may therefore overstate structural effectiveness and conceal vulnerability under wetting or field variability. This paper consequently develops a staged procedure for determining neutralisation demand, separating conditioning from structural binder contribution, establishing road-specific performance criteria, translating laboratory findings to field verification, and defining a performance-based treatment framework. It does not prescribe a universal neutraliser or binder dosage; rather, it establishes how OTMS treatment should be designed, compared, verified and, where adequate performance cannot be demonstrated, rejected.

Operational framework and research Propositions

Building on Part I, this section translates neutralisation demand into an operational framework for OTMS treatment. It defines how chemical interference is conditioned, distinguished from structural cementation, and evaluated against binder efficiency and road-relevant performance within the OTMS treatability boundary.

From neutralisation demand to treatment design

Section 1 established the need to convert Part I's treatability concept into a reproducible engineering procedure. OTMS stabilisation is therefore treated through six functional stages: Delineation of the treatable layer, characterisation of its mineral-organic-moisture condition, neutralisation of interfering chemical demand, activation of binder-compatible reactions, cementation of the soil skeleton and verification of retained performance. Although one material may ultimately fulfil several functions, these roles should first be isolated experimentally. This separation is essential for dosage interpretation. Conventional stabilisation often increases binder content until a target response is achieved, but for OTMS this can obscure whether additional binder is overcoming organic interference or contributing to structural bonding. Joy et al. (2025) reported that optimised chemical addition improved lime treatment of organic-rich clay, whereas excessive dosage reduced the benefit. Mohammed et al. (2024) likewise found that cement response depended on the balance between organic content and binder dosage, while Mostafa et al. (2024) observed distinct compaction, CBR, UCS and resilient-modulus responses among stabiliser combinations. Neutralisation-first design therefore conditions chemical interference before defining the structural binder requirement.

Operational definition of neutralisation demand

For Part II, neutralisation demand is defined as the minimum conditioning dosage that establishes sustained binder-compatible chemistry and produces a verified improvement in structural-binder efficiency. It must address acidity and buffering, together with reactions that reduce the calcium or alkalinity available for cementation.

Meng et al. (2026) showed that organic matter continued to affect hydration and strength development in activated slag-treated sediment, while Long et al. (2025) recorded non-linear modifier responses as organic contamination increased. These findings support a response-based rather than content-based threshold. Persistence is equally important. Conditioning must maintain compatible chemistry after equilibration and wetting, not merely produce an immediate alkaline response. Johney et al. (2026) showed that lime-treated organic marine clay could lose strength after initial improvement, whereas activated geopolymer systems sustained longer-term development. Finally, effectiveness must be demonstrated at a fixed structural-binder dosage. A rise in pH without improved soaked CBR, retained strength, stiffness or durability does not satisfy the definition. Neutralisation demand is therefore a coupled chemical-geotechnical parameter identifying the conditioning threshold at which subsequent binder addition becomes measurably more effective.

Parametric evaluation of treatment response

The experimental programme is structured around five parameter-response relationships that test whether neutralisation-first treatment improves binder efficiency, retained strength and moisture resistance within the OTMS treatability boundary. *Table 1* summarises the principal comparisons and their geotechnical significance. The propositions deliberately prioritise retained road performance rather than peak dry strength. Soaked CBR and durability remain essential indicators of service suitability in stabilised pavement soils (Mezie et al., 2025), while properly activated blended systems can maintain favourable bearing and durability performance at reduced cement contents (Liu et al., 2024). P3 and P5 establish the principal decision boundaries: Treatment remains viable only while mineral-soil behaviour dominates, and satisfactory dry strength cannot compensate for persistent moisture sensitivity. This is particularly important because wetting-drying can progressively weaken stabilised soil structure (Zeng et al., 2024). The parametric programme therefore tests whether OTMS treatment is structurally efficient, moisture-resistant and geotechnically acceptable.

Table 1. Parametric propositions for evaluating OTMS treatment response.

Proposition	Principal comparison	Expected response	Geotechnical significance
P1	Neutralisation-first vs. cement-only at equal structural-binder dosage	Higher soaked CBR and retained strength	Tests improved binder efficiency
P2	Neutralisation demand and equilibrated alkalinity vs. TOC and immediate pH	Stronger association with performance	Tests predictive value of response-based indicators
P3	Increasing reactive organic interference within OTMS	Greater conditioning benefit up to the treatability boundary	Defines viable treatment range
P4	Neutralisation-first blended binder vs. cement-dominant treatment	Comparable soaked performance at lower cement demand	Tests binder optimisation potential
P5	Dry strength vs. post-wetting response	Rejection where moisture sensitivity persists	Prevents acceptance based on dry UCS alone

Materials and Methods

Laboratory validation programme and JKR performance alignment

The laboratory programme translates the operational framework into controlled comparisons aligned with Malaysian road practice. For the present JKR-linked investigation, the purpose is not merely to optimise a binder mixture, but to determine whether neutralisation demand can distinguish OTMS that can be treated reliably from material that should remain unsuitable for shallow stabilisation.

Material selection and baseline characterisation

Representative OTMS should be sampled across the affected layer to capture variations in depth, natural moisture, drainage, mineral grading and organic occurrence, since spatial heterogeneity may govern both neutralisation demand and treatment response. Baseline testing should include particle-size distribution, Atterberg limits, moisture content, specific gravity, LOI, pH, electrical conductivity, compaction characteristics, untreated UCS and four-day soaked CBR. Selected specimens should additionally be assessed for buffering capacity, reactive organic fractions, calcium interaction, mineralogy and compressibility. This characterisation is particularly relevant to the JKR context. JKR/SPJ/2020-S2 (Jabatan Kerja Raya Malaysia, 2020) classifies organic clay, organic silt and material exceeding 2.5% LOI as unsuitable, yet permits deficient material within the upper 300 mm of subgrade to be stabilised where it is suitable to do so; otherwise removal and replacement are required. The present study addresses this decision boundary rather than assuming that all organic-tainted material is either treatable or unsuitable. Stabilisation response is known to depend jointly on soil properties, binder dosage, curing and loading condition (Rahman et al., 2026). The objective is therefore to establish a minimum practical characterisation set capable of distinguishing chemically disruptive OTMS from mineral soil that retains credible treatment potential.

Determination of neutralisation demand

Neutralisation demand should be determined through incremental conditioning with selected alkaline or calcium-bearing agents. For each dosage, immediate pH should be followed by measurements after controlled equilibration and water exposure. Plasticity, moisture demand, workability and volumetric response should also be monitored because chemical conditioning that impairs compaction, handling or dimensional stability remains unsuitable for road construction. The critical dosage is not that producing the highest initial pH, but the lowest dosage that establishes a persistent binder-compatible condition. Jiang et al. (2025) showed that pH, exchangeable calcium and related chemical states continue to evolve during lime treatment, demonstrating the limitations of instantaneous measurements. As demonstrated by Regasa et al. (2023), stabiliser dosage should be verified through compaction, soaked CBR, swelling and workability rather than pH alone. Neutralisation demand should therefore be established from sustained chemical response coupled with measurable geotechnical improvement, converting stabiliser screening from simple dosage selection into a treatment-efficiency criterion.

Treatment matrix and mixing protocol

The experimental matrix separates chemical conditioning from structural cementation by changing one treatment function at a time (*Table 2*). Series A provides the untreated OTMS baseline, while Series B represents conventional cement treatment. Series C is the key conditioning-only control, showing whether neutralisation alters pH stability, workability, plasticity, compaction behaviour or early mechanical response before cement is added. Series D then combines the same conditioning stage with cement. Holding the structural cement dosage constant in Series B and D allows any improvement in Series D to be attributed more confidently to enhanced binder

efficiency rather than greater cement addition. The B-C-D comparison forms the core experimental test. Series C identifies the contribution of conditioning alone; C-D quantifies the additional benefit of cementation after conditioning; and B-D determines whether prior neutralisation improves performance at an equivalent cement dosage. Series E examines whether this improved chemical environment can support a lower-cement blended binder, while Series F and G test neutraliser compatibility and the upper treatment boundary. Such controlled comparisons are preferable to unrelated binder percentages because soil-cement performance depends jointly on binder chemistry, dosage, soil properties, mixing and curing conditions (Zhao and Wong, 2025). Besides, Petti et al. (2025) emphasised the value of corresponding cement-only controls when distinguishing structural from chemo-mechanical effects. Mixing sequence should also be treated experimentally. Immediate binder addition should be compared with controlled mellowing after conditioning. The selected interval must allow acidity, buffering and calcium demand to stabilise without causing excessive drying, carbonation or loss of workability. The laboratory programme should therefore define the treatment composition, mellowing duration and moisture-control window required for translation to the JKR field trial.

Table 2. *Proposed laboratory treatment matrix for OTMS.*

Series	Conditioning	Structural binder	Primary purpose
A	None	None	Establish untreated baseline
B	None	Cement	Represent conventional treatment
C	Neutraliser	None	Isolate conditioning response
D	Neutraliser	Cement	Test neutralisation-first treatment
E	Neutraliser	Cement-GGBFS/blended binder	Assess cement-reduction potential
F	Alternative neutraliser	Selected binder	Compare chemical compatibility
G	Advanced conditioning	Selected binder	Examine severe-interference cases

Road-relevant performance verification

Treatment qualification should be anchored to JKR requirements but extend beyond minimum compliance. Under JKR/SPJ/2018-S18 (Jabatan Kerja Raya Malaysia, 2018), stabilised material for paved-road subgrade should achieve a four-day soaked CBR of at least 12% at 95% of maximum dry density and a seven-day UCS of at least 0.3 MPa, with the stabilising-agent application rate determined through laboratory testing. These values provide baseline thresholds but do not, by themselves, demonstrate OTMS treatability. Specimens should therefore be assessed at early, intermediate and longer curing ages using UCS, soaked and unsoaked CBR, strength retention, moisture-density response, volumetric stability and wetting-drying durability. Resilient modulus or repeated-load response should be included for mixtures progressing toward field validation. Microstructural analysis should be limited to representative control, successful and failed mixtures to explain, rather than replace, geotechnical performance. Shi et al. (2024) showed that environmental cycling can alter both strength and pore structure in cement-fly ash-treated organic soil, reinforcing the need to assess durability beyond initial strength. Acceptance should consequently be stricter than simple CBR or UCS attainment. A mixture meeting JKR thresholds may still be unsuitable if moisture sensitivity, volumetric instability or treatment inconsistency persists. By contrast, OTMS that satisfies neutralisation demand, meets the relevant JKR criteria and retains performance after wetting provides stronger evidence of geotechnical treatability. The laboratory programme therefore supports a clear decision to advance treatment to field

validation, optimise the design further, or reject shallow stabilisation in favour of removal or alternative ground improvement.

Results and Discussion

Laboratory-to-field validation

Laboratory qualification establishes treatment potential; field validation determines whether that potential survives construction variability, moisture exposure and scale. For the JKR application, the field trial must therefore verify both geotechnical performance and construction reproducibility under representative roadwork conditions.

Field-trial configuration

The controlled road trial should comprise comparable sections of untreated OTMS, conventional cement treatment, neutralisation-first cement treatment and the selected blended-binder system. Wherever practicable, the sections should occupy the same geotechnical unit with similar treatment depth, drainage exposure and initial moisture condition. Baseline sampling should confirm material comparability before treatment. Furthermore, construction should use the spreading, pulverising, mixing, watering and compaction equipment intended for JKR implementation. This is critical because field performance depends on lift thickness, moisture condition, compaction sequence and treatment uniformity. Chen et al. (2025) showed that such variables materially influence field compaction and stiffness, while Ayers et al. (2024) reported measurable variations in density, UCS and elastic modulus even within controlled full-scale stabilisation trials. The untreated and cement-only sections provide field baselines. The neutralisation-first section determines whether laboratory improvements persist at construction scale, while the blended-binder section evaluates whether reduced Portland cement demand remains viable under actual mixing and compaction conditions.

Construction control and field verification

Field quality control should verify neutraliser spreading, pulverisation, treatment depth, mellowing duration, moisture condition, binder distribution and achieved density. Field pH should be measured at multiple locations and depths to confirm reproduction of the laboratory-defined conditioning state, but should remain a process-control indicator rather than an independent acceptance criterion. Also, mechanical verification should include early trafficking capability, dynamic cone penetration resistance and, where appropriate, field CBR or plate response. Testing should extend longitudinally and transversely across each section to identify local deficiencies. Subedi et al. (2024) noted that field-prepared soil-cement specimens can capture construction-related variability and provide mechanical properties comparable with recovered cores, supporting their use in quality assurance. In addition, post-rainfall or controlled-wetting behaviour is equally important because moisture changes within subgrades can be substantial and spatially variable, directly affecting bearing response (Wu et al., 2025). Field cores or block samples should therefore be recovered from representative and low-performing locations for strength and selected microstructural assessment. Laboratory-to-field strength and stiffness ratios should also be established as project-specific measures of treatment transferability, rather than assumed correction factors.

Field acceptance logic

Field acceptance should not rely on a single average strength or stiffness value. Each trial section should first satisfy the applicable JKR requirements established in Section 3, after which acceptance should consider individual test-location compliance, spatial coefficient of variation, minimum retained performance, density uniformity, post-wetting response and the absence of persistent weak pockets. This variability-based approach is particularly important for OTMS because local differences in reactive organic matter may produce corresponding variations in neutralisation demand. Savila et al. (2025) reported coefficients of variation of 0.12-0.61 in recovered stabilised-soil strength despite satisfactory site-average values, showing that acceptable means can conceal substantial local variability. Forsman et al. (2025) likewise demonstrated that in-situ strength development and variability must be assessed directly rather than inferred from laboratory values. Three outcomes are therefore proposed (*Figure 1*). Treatment is accepted where JKR requirements are consistently satisfied and moisture-resistant performance is reproducible; optimised and retrialled where deficiencies appear correctable through dosage, mixing, moisture or compaction control; and rejected where weak zones or moisture sensitivity persist despite adequate construction control. Field validation thus provides the final OTMS treatability test: whether chemically conditioned, structurally adequate and moisture-resistant behaviour can be reproduced across the treated road section, not merely demonstrated in selected specimens.

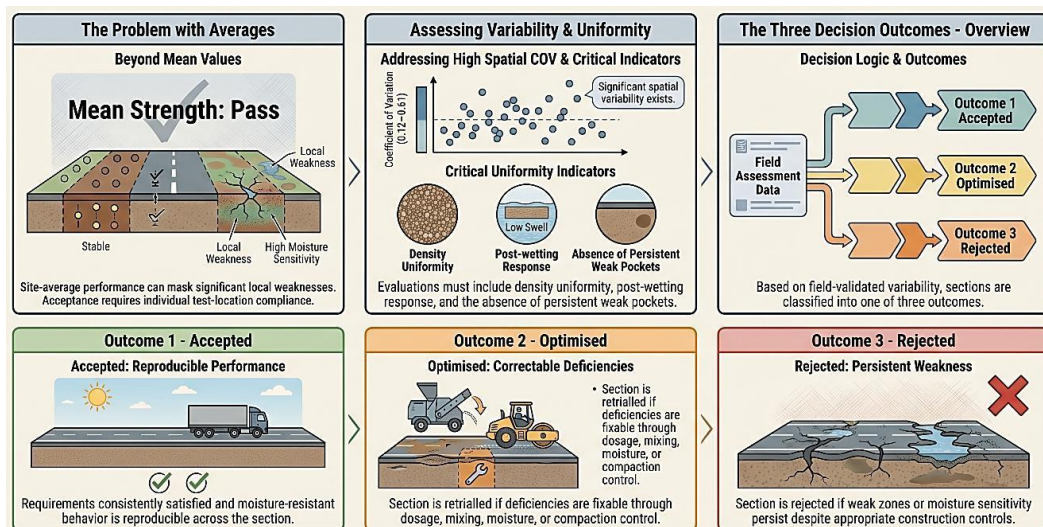


Figure 1. Field acceptance logic for OTMS treatment: Shift from simple average values to a variability-based decision framework for stabilised road subgrades.

Performance-based treatability and implementation framework

The laboratory and field procedures developed in Sections 3 and 4 ultimately require a clear engineering decision: Whether OTMS can be treated reliably, requires advanced conditioning, or should be excluded from shallow stabilisation. The proposed framework therefore classifies treatability by demonstrated response rather than by a universal organic-content or binder threshold.

Treatment categories and decision variables

Four treatment categories are proposed (*Table 3*). OTMS-A represents mineral-dominated soil with limited chemical interference, for which conventional binder screening may remain adequate. OTMS-B defines the principal neutralisation-first domain, where interference is measurable but controllable at a practicable conditioning dosage. OTMS-C represents severe but shallow interference requiring advanced conditioning assessment. Materials governed by peat fabric, deep compressibility or excessive moisture are excluded because their dominant behaviour cannot be resolved through shallow chemical stabilisation. The boundaries are intentionally performance-based. Zri et al. (2025) showed that comparable binder systems can produce markedly different road-performance outcomes where material composition differs, supporting the need for a treatment envelope rather than unrestricted binder escalation. On a similar note, Abdul Azam et al. (2024) showed that peat-type materials remain strongly governed by compressibility and settlement despite strength improvement. Classification should therefore integrate neutralisation demand, sustained alkalinity, soaked CBR, retained strength, compressibility, treatment depth and construction feasibility.

Table 3. Proposed performance-based OTMS treatability categories.

Category	Indicative condition	Treatment pathway
OTMS-A	Low organic interference	Conventional binder screening
OTMS-B	Moderate, controllable interference	Neutralisation-first treatment
OTMS-C	Severe but shallow interference	Advanced conditioning assessment
Excluded	Peat fabric, deep compression or excessive moisture	Replacement or deeper ground improvement

Acceptance and rejection boundaries

Acceptance for neutralisation-first treatment requires convergence of chemical compatibility, retained geotechnical performance and field reproducibility. Conditioning should improve structural-binder efficiency at equivalent dosage, while soaked and cyclic performance, volumetric stability, density and mixing uniformity remain satisfactory. Dosage should therefore be selected from treatment response rather than maximum additive content. This is in line with findings by Razali et al. (2026), that lime-treated residual soil exhibits an optimum rather than continuously improving response; for OTMS, the preferred neutralisation dosage is similarly the minimum practical level that sustains compatible chemistry and produces measurable structural benefit. Shallow treatment should be rejected where neutralisation demand becomes excessive, alkalinity or calcium availability cannot be sustained, wetting causes unacceptable deterioration, field variability remains uncontrolled, or compressibility and settlement govern behaviour. The acceptance boundary is therefore not a single numerical threshold, but a performance envelope within which chemical conditioning, structural response and construction reproducibility collectively justify shallow stabilisation.

Implementation relevance to road agencies

For road agencies, the framework addresses two opposing risks: unnecessary removal of potentially treatable mineral soil and acceptance of chemically incompatible treatment based on satisfactory dry strength. The former increases excavation, imported fill, haulage and disposal, while the latter transfers moisture sensitivity and weak treatment zones into pavement service. Implementation should therefore integrate mechanical performance, constructability and resource efficiency. Yu et al. (2024)

demonstrated this broader approach by validating a calcium-carbide-residue-based stabiliser through laboratory strength and bearing tests, environmental assessment and full-scale highway application, confirming that treatment viability must extend beyond specimen-scale strength. Ghimire and Bheemasetti (2025) similarly showed that reduced-cement pavement mixtures can retain wetting-drying performance while lowering environmental and economic burdens. For JKR and comparable road authorities, the proposed framework adds a treatability decision layer to specification-based acceptance by distinguishing when OTMS should undergo conventional treatment, neutralisation-first stabilisation, advanced conditioning or removal. Its purpose is not to broaden acceptance of organic-bearing soils, but to improve discrimination between reusable OTMS and material whose chemical or geotechnical limitations make shallow stabilisation unreliable. In this context, neutralisation demand becomes a practical risk-management parameter linking material characterisation, binder efficiency, field quality and pavement performance.

Conclusion

This companion paper completes the OTMS treatability framework introduced in Part I by translating the concepts of organic interference and neutralisation demand into an experimentally testable, performance-based and field-verifiable treatment system for road applications. Whereas Part I established organic-tainted mineral soil (OTMS) as a distinct geotechnical treatability category and identified neutralisation demand as a governing variable, Part II provides an operational pathway for determining whether such material can be treated reliably, requires more advanced conditioning or should be excluded from shallow stabilisation. The proposed framework demonstrates that neutralisation demand should not be determined from immediate pH response alone, but through sustained chemical compatibility and measurable improvement in structural-binder efficiency, because an alkaline condition does not necessarily confirm that sufficient chemical capacity remains available for effective cementitious strengthening. Accordingly, the neutralisation-first approach separates chemical conditioning from structural cementation so that the contribution of each treatment function can be evaluated independently, while equivalent-binder controls enable genuine conditioning benefits to be distinguished from improvements caused simply by increasing binder dosage. The laboratory validation programme consequently progresses from baseline material characterisation and determination of neutralisation demand to controlled treatment comparisons and road-relevant performance verification. For road applications, successful OTMS treatment cannot be defined solely by peak dry UCS because satisfactory initial strength may conceal persistent moisture sensitivity, incomplete chemical conditioning or deterioration under environmental exposure. Treatment suitability must therefore be demonstrated through soaked CBR, retained strength, durability, moisture resistance, volumetric stability, compactability, achievable density and stiffness, with particular emphasis placed on the ability of the treated material to retain acceptable performance after wetting. Laboratory qualification alone, however, does not establish practical treatability, because treatment effectiveness must also survive construction variability and scale effects. Field validation therefore provides an essential final stage for verifying treatment uniformity, moisture condition, achieved density, mixing effectiveness, spatial variability and post-wetting behaviour under representative roadwork conditions. This laboratory-to-field progression provides

a more defensible basis for determining whether treatment is sufficiently robust for implementation rather than merely successful under controlled laboratory conditions. The principal contribution of this study is therefore not the prescription of a universal neutraliser, binder type or dosage, but the establishment of a performance-based treatability boundary that supports engineering decisions among conventional stabilisation, neutralisation-first treatment, advanced conditioning and exclusion from shallow stabilisation. Such an approach can reduce the risk of unnecessarily removing potentially reusable mineral soil while also preventing chemically incompatible material from being accepted solely because satisfactory dry strength has been achieved. Ultimately, OTMS should be considered treatable only when organic interference can be controlled sufficiently for durable cementation to develop, when the resulting geotechnical performance can be retained under moisture exposure, and when that performance can be reproduced consistently under field conditions. Neutralisation demand therefore provides the critical link between material characterisation, chemical compatibility, binder efficiency, engineering performance and field implementation, establishing a practical foundation for performance-based decision-making in the treatment and responsible reuse of organic-tainted mineral soils.

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Conflict of interest

The authors declare that they have no commercial, financial, or personal relationships that could be perceived as having influenced the research or its publication.

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