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Sustainable Utilization of Fly Ash and Lime for Peat Soil Improvement: A Comprehensive Laboratory Investigation

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Abstract - This study investigates the sustainable stabilization of highly organic peat from Kodaikanal, India, using a blended binder comprising Class C fly ash and hydrated lime. Due to its high compressibility, low shear strength, and acidic environment, peat is challenging to stabilize using cement alone. Therefore, the effectiveness of fly ash–lime treatment was examined by varying the dosages of fly ash (0–20%) and lime (6–10%). The influence of stabilization on consistency limits, compaction behavior, unconfined compressive strength (UCS) at 7, 28, and 56 days, and soaked California Bearing Ratio (CBR) was evaluated, along with SEM–EDAX analyses performed on untreated and optimum stabilized specimens (F20L10). The results indicate that fly ash–lime addition reduces liquid limit, increases maximum dry density, and lowers optimum moisture content, highlighting improved flocculation and densification of the organic fabric. A significant increase in strength and bearing capacity was observed, with UCS and CBR values improving by three to five times compared to virgin peat at 56 days, particularly for mixes containing ≥10% fly ash with 8–10% lime. SEM observations reveal a transformation from a loose, porous peat structure to a denser, cemented matrix with reaction products forming around and between particles, while EDAX confirms enhanced Ca–Si–Al composition indicative of C–S–H/C–A–H formation. Overall, Class C fly ash activated with lime provides a technically effective and potentially lower-carbon approach for improving peat subgrades in transportation and geotechnical applications.

Keywords: ***Peat soil; Fly ash; Lime stabilization; Pozzolanic reaction; Microstructural analysis; Sustainable ground improvement***

1. INTRODUCTION

In contemporary geotechnical engineering practice, the scarcity of stable, competent ground for infrastructure development has emerged as a pervasive challenge. Consequently, constructing structures on unsuitable soils is frequently unavoidable, rendering the pre-construction enhancement of ground conditions a critical and technically demanding task for geotechnical engineers. In numerous scenarios, the improvement of problematic soil characteristics constitutes an indispensable preliminary step to ensure the safety, serviceability, and longevity of new constructions.

A diverse array of ground improvement techniques is employed to enhance the geotechnical properties of such soils, encompassing densification methods (e.g., shallow compaction, dynamic deep compaction, and pre-loading), drainage enhancement strategies, inclusion-based approaches (e.g., geosynthetics and stone columns), and stabilization techniques. Among these, chemical stabilization holds particular prominence in addressing the unique challenges posed by expansive clays, collapsible loess deposits, and soft, fine-grained soils, such as peat.

Peat is an extremely soft, highly compressible, and organic-rich soil formed by the partial decomposition of plant remains under persistently waterlogged, anaerobic conditions. With organic contents frequently exceeding 75%, peat is commonly classified as an extreme form of problematic soil, exhibiting very high natural water contents, large void ratios, low bulk density, and negligible undrained shear strength in its natural state (Saberian et al., 2016; Radwan et al., 2021). These characteristics lead to excessive primary consolidation and significant long-term creep, making peat highly unsuitable as a natural foundation medium for conventional civil engineering works (Islam & Hashim, 2008; Islam et al., 2008). From a geotechnical perspective, peat deposits are associated with low bearing capacity, high compressibility, pronounced time-dependent settlement, high permeability in the macro-void structure, and strong heterogeneity in both vertical and lateral directions (Kazemian et al., 2012; Saberian et al., 2016). The creep component of settlement often dominates the long-term behaviour, and small to moderate surcharge loads may induce substantial delayed deformations. Field observations have reported instability phenomena, such as local sinking, slip failure, and excessive deformation, beneath embankments and road structures founded on peat (Islam et al., 2008; Azam et al., 2024). As a result, construction on peat typically requires either deep foundations (e.g., piles) that bypass the weak layer or ground improvement techniques to modify the in situ peat properties.

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Chemical and mass stabilization have become widely adopted approaches for improving the engineering properties of peat and other organic soils. In mass stabilization, binders are mixed in situ with the peat to form a more homogeneous, cemented matrix that behaves like a load-bearing crust, thereby reducing settlement and improving stability (Islam et al., 2008; Pallav et al., 2023). Conventional binders such as ordinary Portland cement (OPC) and lime have long been used; however, the high organic content, acidity, and presence of humic substances in peat can inhibit cement hydration and limit the effectiveness of pure cement-based systems (Tastan et al., 2011; Yulianto et al., 2022). This has prompted growing interest in blended and alternative binders that incorporate industrial by-products and pozzolanic materials, particularly fly ash.

Fly ash is a siliceous–aluminous by-product capable of reacting with calcium hydroxide from lime or cement in the presence of moisture to form secondary cementitious products such as calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H). When combined with lime, fly ash can initiate pozzolanic reactions, refine the pore structure, and develop a stiffer skeletal framework in organic soils, resulting in enhanced strength and reduced compressibility (Tastan et al., 2011; Wong et al., 2015; Tastan & Edil, 2011). Lime, on the other hand, contributes to immediate modification through cation exchange and flocculation–agglomeration of the organic–mineral matrix, reducing plasticity and improving workability prior to longer-term pozzolanic hardening. Several studies have directly investigated the stabilization of peat with combinations of fly ash and lime, or closely related blended systems. Physico–geotechnical investigations on tropical peat treated with fly ash (FA), quicklime (QL) and OPC at varying dosages (FA: 5–20%, QL: 2–8%, OPC: 5–20%) have shown substantial increases in unconfined compressive strength (UCS), improved density and modified index properties, along with useful empirical correlations between physical parameters and UCS for design purposes (Bujang et al., 2005; Huat et al., 2005).

Aminur et al. (2009) reported that peat stabilised with OPC, QL, and FA exhibited significant strength gains with increasing stabilizer content and curing time, and that mixtures of QL and FA could achieve up to ~70% of the UCS obtained with 20% OPC, indicating the efficiency of lime–fly ash blends in reducing cement dependency. Similar trends of increasing UCS and maximum dry density, and decreasing optimum moisture content, were observed when Class F pond ash (a fly-ash–rich material) was used to stabilize tropical peat at replacement levels of 5–20% (Kolay et al., 2011). Yulianto et al. (2019, 2022) modelled crystal growth and strength development in peat stabilized with a mixture of lime ($CaCO_3$) and fly ash, demonstrating that lime–fly ash mixtures can significantly increase load-carrying capacity and reduce compression, and highlighting the importance of curing time, moisture movement, and water filtration effects on stabilized peat performance. Taib et al. (2023) investigated chemical stabilization of amorphous peat from Sarawak using cement, fly ash, and lime at different water–additive ratios and reported notable improvements in strength and consistency limits, underscoring the contribution of fly ash to long-term strength accumulation in lime/cement-treated peat.

At a larger scale, Pallav et al. (2023) proposed an in situ mass stabilization method for road embankments on peat using calcareous fly ash and silica fume, achieving substantial increases in stiffness and bearing capacity and demonstrating the feasibility of ash-based binders for peat improvement in field applications. Related work on organic soils and peat-like materials further supports the use of fly ash–lime or fly ash–calcium systems. Tastan et al. (2011) showed that fly ash can be highly effective in stabilizing organic soils, with performance strongly influenced by ash type, organic content, and curing conditions. Wong et al. (2015) utilized fly ash as a pozzolan to enhance long-term strength in stabilized peat columns, while Radwan et al. (2021) demonstrated that partial replacement of cement with fly ash and polypropylene fibres in peat stabilization can limit cement usage without compromising strength. Broader reviews of organic soil stabilization confirm that combinations of lime, cement, fly ash, and other industrial by-products can successfully improve the mechanical and consolidation behaviour of organic soils when binder composition and dosage are appropriately optimized (Amiri et al., 2023; Ahmad et al., 2024; AIP Geotechnical Review, 2024; Tastan et al., 2011).

More recently, the focus has shifted toward sustainable and low-carbon binder systems, seeking to reduce clinker-based cement and high-lime usage while maintaining or improving performance. Studies have explored palm oil fuel ash (POFA), calcareous fly ash, rice husk ash, bottom ash, and other industrial residues as components in blended binders for peat and organic soil stabilization (Ahmad et al., 2024; Pallav et al., 2023; Macías-Párraga et al., 2025). These works collectively indicate that fly ash–based blends, activated by lime or other calcium sources, can offer a technically viable and environmentally favourable alternative to traditional cement-only systems in peat stabilization.

Despite this substantial body of research, the behaviour of peat stabilized with fly ash–lime systems remains highly dependent on peat type (fibrous vs. amorphous), organic content, pH, ash chemistry, binder ratio, and curing environment. Variability in field conditions and the strong influence of long-term creep and microstructural evolution mean that there is still a need for systematic studies that: (i) quantify strength and stiffness development in peat treated with controlled fly ash–lime proportions; (ii) examine the influence of curing time and moisture regime; and (iii) relate macroscopic mechanical response to underlying microstructural

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changes. Addressing these aspects is essential to developing reliable mix-design frameworks and performance-based design criteria for the sustainable stabilization of peat deposits using fly ash and lime.

2. MATERIALS

2.1 Peat Soil

The peat soil used in this study was collected from the Kodaikanal region in Tamil Nadu, India. An initial reconnaissance survey was conducted at the site to understand the geological and environmental setting associated with peat formation. Observations during the visit indicated that climatic factors, such as temperature, humidity, and high annual rainfall, play a dominant role in the formation, accumulation, and decomposition processes governing peat development in the region. These climatic conditions promote waterlogging and anaerobic decomposition of plant residues, resulting in the formation of highly organic peat with distinctive engineering and microstructural characteristics.

Bulk peat samples were excavated from shallow depths and transported in airtight containers to prevent moisture loss and disturbance. The collected material exhibited the typical features of tropical peat, including dark brown coloration, high organic content, and spongy texture. The collected sample was tested in accordance with the relevant Indian Standards to determine the basic properties, as listed in Table 1. The grain size distribution of the peat is shown in Fig. 1.

Table 1 Basic Properties of Virgin Peat Soil

Description	Values	Reference
Specific Gravity, G	2.26	IS 2720 (Part 3/Sec 1)-1980
Fines (< 75μ)	37.04%	IS: 2720 (Part 4)-1985
Gravel	1.57%	IS: 2720 (Part 4)-1985
Liquid Limit, W_L	53.1%	IS: 2720 (Part 5)-1985
Plastic Limit, W_p	NA	IS: 2720 (Part 5)-1985
Max. Dry density (g/cc)	1.22	IS: 2720 (Part 7)-1980
Optimum Moisture Content (%)	33	IS: 2720 (Part 7)-1980
Unconfined Compressive Strength (kPa)	32 (28 Days)	IS: 2720 (Part 10)-1973
CBR (Soaked) (%)	2	IS: 2720 (Part 16)-1987
Organic content	30.4%	IS: 2720 (Part 22)-1972
Degree of humification	H3	IS: 2720 (Part 22)-1972
Free Swell Index	No Volume Change	IS: 2720 (Part 40)-1977
pH	4.1	IS 2720 (Part 26)-1987

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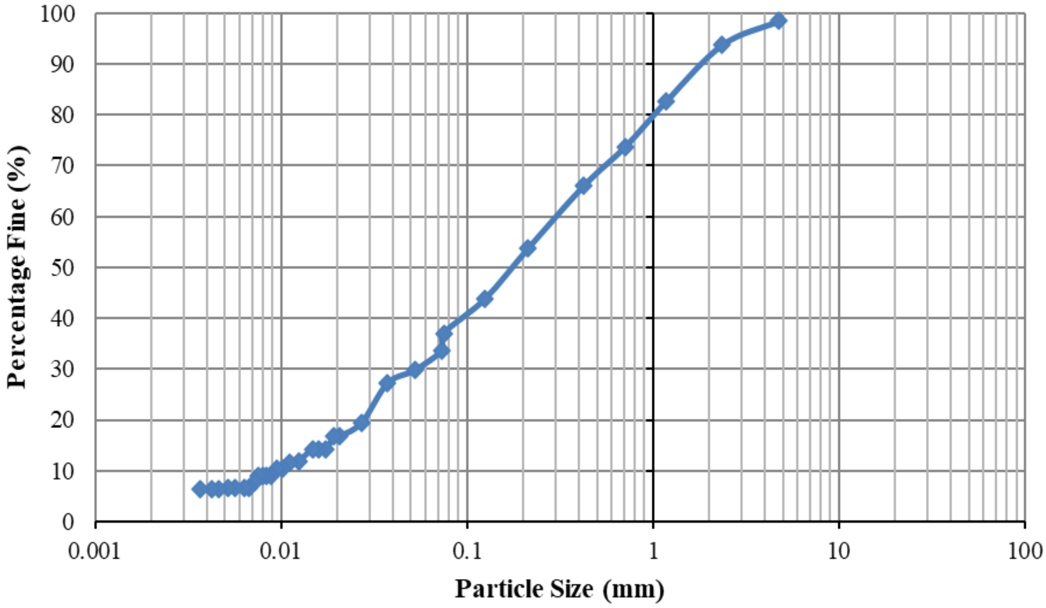

Fig. 1 Grain Size Distribution of Peat Soil

2.2 Fly Ash

Fly ash was procured from the North Chennai Thermal Power Plant, Tamil Nadu. Based on the oxide composition provided by the plant and verified through laboratory testing, the material was classified as Class C fly ash, characterized by a relatively high calcium content and self-cementing properties. Class C fly ash offers the advantage of contributing both pozzolanic and hydraulic reactions, making it suitable for stabilizing organic soils such as peat. The ash was oven-dried, sieved through a 425-µm sieve, and stored in airtight containers before use. The specific gravity was found to be 2.06, and the fines content was 94%, with no clay particles present.

2.3 Lime

Commercially available hydrated lime, chemically identified as calcium hydroxide [$Ca(OH)_2$], was used as the secondary stabilizing agent. Lime was selected due to its ability to modify soil behavior through cation exchange, flocculation–agglomeration, and pozzolanic reactions when combined with siliceous–aluminous materials, such as fly ash. The lime was stored in sealed containers to avoid carbonation during handling. As IRC recommends high purity of hydrated lime (≥85% $CA(OH)_2$) for peat soils, the lime purity test was performed as per IS 1514-1990 and found to be 87% of CaO.

3. EXPERIMENTAL INVESTIGATION

Although Class C fly ash possesses inherent self-cementing properties, its reactivity is significantly inhibited when mixed with highly organic peat. The acidic environment and presence of humic substances in peat suppress pozzolanic reactions, necessitating the use of an alkaline activating agent to initiate and sustain cementitious bonding. Therefore, the addition of lime becomes essential to activate Class C fly ash and achieve effective stabilization of peat.

3.1 Lime Demand Test

The lime demand of the Kodaikanal peat was determined to identify the minimum alkali required to neutralize its high acidity and enable effective pozzolanic reactions. The test followed the pH-based procedure recommended in ASTM D6276 (Eades–Grim) and IRC: SP 89. Peat–lime mixtures were prepared with lime contents ranging from 0% to 12% (on a dry weight basis), sealed in airtight containers, and maintained at 25 ± 2 °C. The pH of each mixture was measured after 24 h, 7 days, and 28 days using a calibrated pH meter. The lime content at which the mixture consistently achieved a pH of ≥ 12.4 was identified as the chemical lime demand essential for activating pozzolanic reactions in the peat, and the results are furnished in Table 2. Figure 2 shows the pH test for the Peat+lime sample performed in the laboratory.

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Table 2. Lime Demand Test Results For Kodaikanal Peat (Lime Added On Dry-Weight Basis)

Lime content (% dry wt)	pH (24 h) mean ± SD	pH (7 days) mean ± SD	pH (28 days) mean ± SD	Activation status (pH ≥ 12.4)
0 (control)	4.12 ± 0.06	4.05 ± 0.04	4.01 ± 0.05	No
2	6.82 ± 0.10	6.45 ± 0.12	6.30 ± 0.09	No
4	9.48 ± 0.14	9.10 ± 0.18	8.95 ± 0.16	No
6	11.81 ± 0.12	11.55 ± 0.10	11.40 ± 0.11	No (near)
8	**12.62 ± 0.07**	**12.58 ± 0.06**	**12.52 ± 0.05**	**Yes**
10	12.78 ± 0.05	12.74 ± 0.04	12.70 ± 0.04	Yes
12	12.88 ± 0.03	12.85 ± 0.03	12.82 ± 0.02	Yes

Fig. 2 pH Test Performed for Peat+Lime Mixing

Table 2 summarizes the lime-demand results for Kodaikanal peat. The untreated peat exhibited a strongly acidic pH of ~4.1. The incremental addition of hydrated lime progressively increased the pH; mixtures containing ≥ 8% lime (dry weight) achieved and maintained the activation threshold (pH ≥ 12.4) at 24 hours, 7 days, and 28 days. Based on these chemical demand tests, 8% lime was considered the minimum chemical activator dosage for subsequent fly ash–lime mix trials.

3.2 Mix Design Matrix for Peat Stabilised with Class C Fly Ash and Lime

A systematic mix-design matrix was developed to evaluate the stabilisation behaviour of peat using Class C fly ash and hydrated lime. The chemical lime demand of the peat, determined from the pH-based lime-demand test, was found to be 8% (dry-weight basis). Fly ash contents of 0%, 5%, 10%, 15%, and 20% were selected to capture a wide range of pozzolanic contributions, while lime contents of 6%, 8%, and 10% were used to investigate the performance below, at, and above the lime demand. Since fly ash acts as a pozzolanic material rather than the primary alkali source, varying its content does not influence the fundamental chemical lime requirement. The test matrix is given in Table 3.

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Table 3 Test Matrix and Mix Design

Mix ID	Fly Ash (%)	Lime (%)	Mix ID	Fly Ash (%)	Lime (%)	Mix ID	Fly Ash (%)	Lime (%)
F_0L_6	0	6	$F_{10}L_6$	10	6	$F_{20}L_6$	20	6
F_0L_8	0	8	$F_{10}L_8$	10	8	$F_{20}L_8$	20	8
F_0L_{10}	0	10	$F_{10}L_{10}$	10	10	$F_{20}L_{10}$	20	10
F_5L_6	5	6	$F_{15}L_6$	15	6			
F_5L_8	5	8	$F_{15}L_8$	15	8			
F_5L_{10}	5	10	$F_{15}L_{10}$	15	10			

3.3 Sample Preparation

The peat used in this study was air-dried, lightly pulverized without damaging the fibrous matrix, and sieved through a 4.75 mm mesh to remove coarse roots and debris. Class C fly ash and hydrated lime were oven-dried and stored in airtight containers to prevent moisture absorption and carbonation. Binder proportions were calculated on a dry-weight basis for the peat, and the required quantities of peat, fly ash, and lime were initially blended in a dry form until a uniform mixture was achieved. Deionized water was then added to facilitate workability and initiate the early chemical reactions between lime, fly ash, and the organic components of peat. The mixture was sealed in airtight containers and stored at 25 ± 2 °C for a 24-hour malleable reaction period to allow sufficient interaction before specimen preparation. Following this conditioning period, samples were obtained for consistency tests and then molded and compacted for further geotechnical and strength evaluations in accordance with the respective Indian Standards. Figure 3 shows the sample preparation and storage for the reaction.

Fig. 3 Sample Preparation and Storage

4. RESULTS AND DISCUSSIONS

The outcomes of the laboratory investigation on peat soil stabilized with varying proportions of fly ash and lime are presented and interpreted in this section. Test results are analyzed to assess the influence of binder combination on the engineering performance and behavioral improvement of the treated peat.

4.1 Effect on Consistency Limit

The variation in liquid limit for peat stabilized with different proportions of fly ash and lime is shown in Figure 4, illustrating the influence of binder dosage on the consistency behavior of the treated soil.

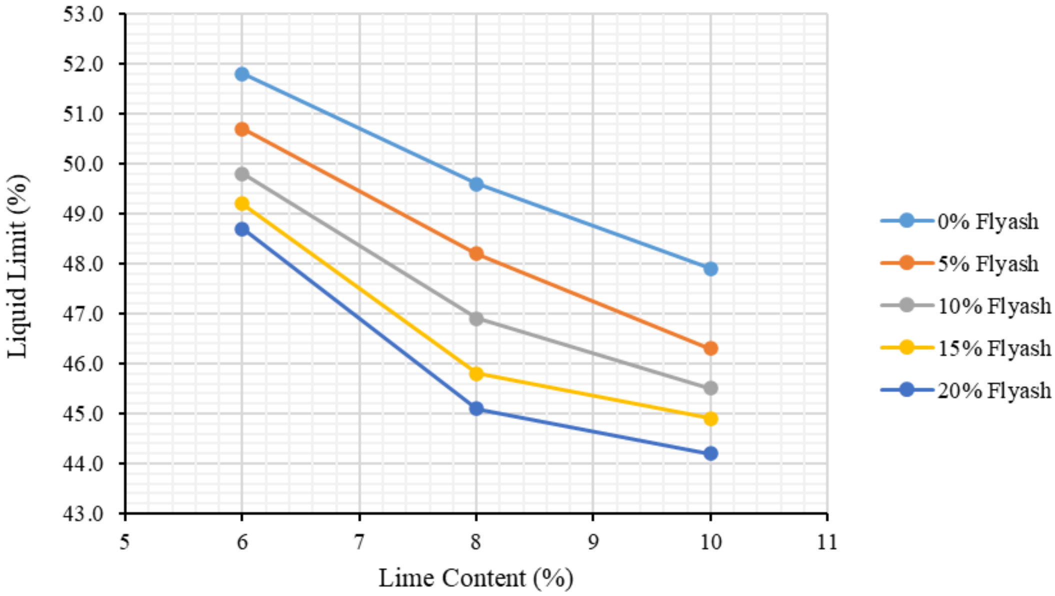

Fig. 4 Liquid Limit Variation based on Flyash and Lime Proportions

A general reduction in liquid limit is observed with increasing lime and fly ash contents, indicating reduced water-holding capacity and improved flocculation of the organic matrix. The changes are more pronounced in mixes containing ≥10% fly ash combined with 8–10% lime, reflecting enhanced pozzolanic reactions that contribute to reduced plasticity.

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4.2 Effect on Compaction Properties

The compaction characteristics of untreated and stabilized peat were determined to obtain the optimum moisture content (OMC) and maximum dry density (MDD), which are necessary for preparing molded specimens for UCS and CBR testing. The variation in MDD and OMC with binder dosage is presented in Figure 5.

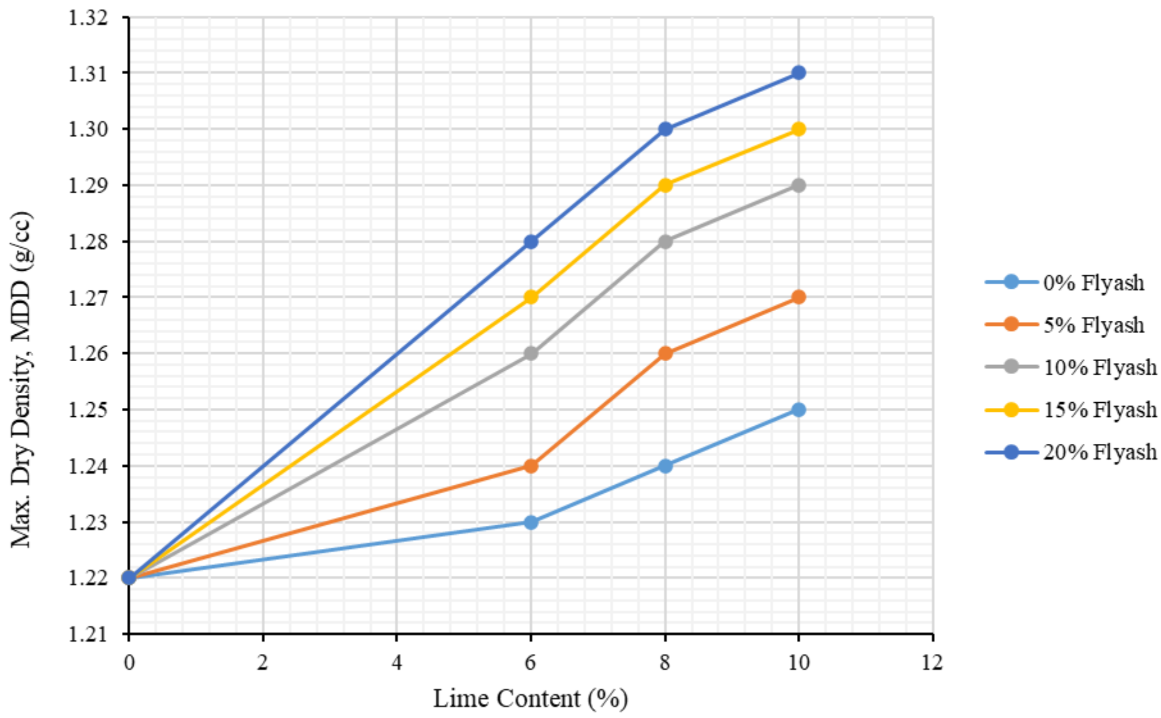

Fig. 5 Maximum Dry Density Variation Based on Flyash and Lime Proportions

A steady increase in MDD and a reduction in OMC are observed with the addition of fly ash and lime, reflecting improved packing and reduced dependence on pore water due to flocculation and cementitious reaction products. Mixes containing 10–20% fly ash with 8–10% lime exhibited the most favorable compaction response, suggesting enhanced structural densification and suitability for strength and durability performance.

4.3 Effect on Unconfined Compressive Strength (UCS)

The unconfined compressive strength (UCS) of untreated and stabilized peat was determined at 7, 28, and 56 days of curing to evaluate the influence of fly ash–lime stabilization on the time-dependent strength improvement of peat. Figure 6 illustrates the variation in UCS with different binder combinations across the curing periods.

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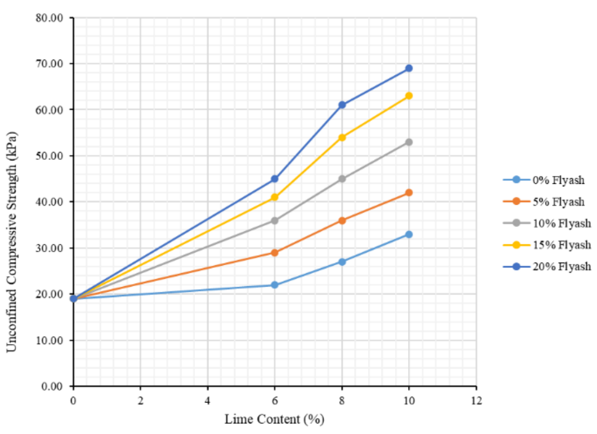
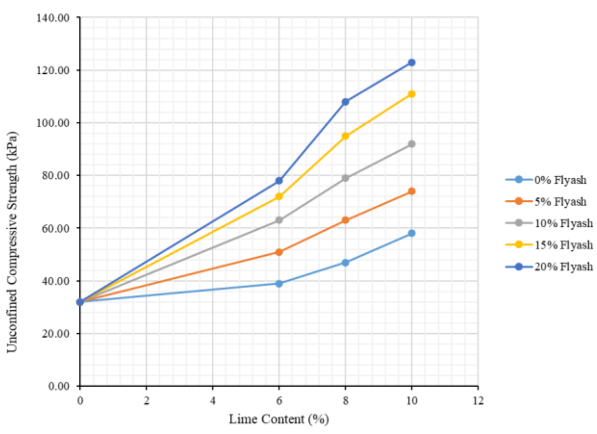
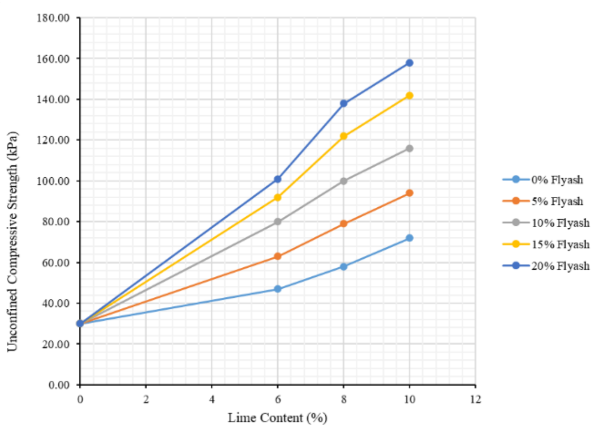




7 Days **28 Days**



56 Days

Fig. 6 UCS Variation Based on Flyash and Lime Proportions after Different Curing Period

A substantial improvement in UCS is observed in the stabilized specimens compared to the virgin peat. Strength gain increases with both higher binder contents and longer curing durations, confirming the progressive development of cementitious reaction products through pozzolanic activity. The mixes containing 10–20% fly ash, in combination with 8–10% lime, show the greatest improvement, with UCS values reaching more than three to five times those of untreated peat by 56 days, indicating effective stabilization and enhanced bonding within the organic matrix.

4.4 Effect on California Bearing Ratio (CBR)

The soaked California Bearing Ratio (CBR) test was carried out on untreated and stabilized peat specimens to evaluate improvements in load-bearing capacity under fully saturated ground conditions. The influence of fly ash–lime dosage on soaked CBR is presented in Figure 7.

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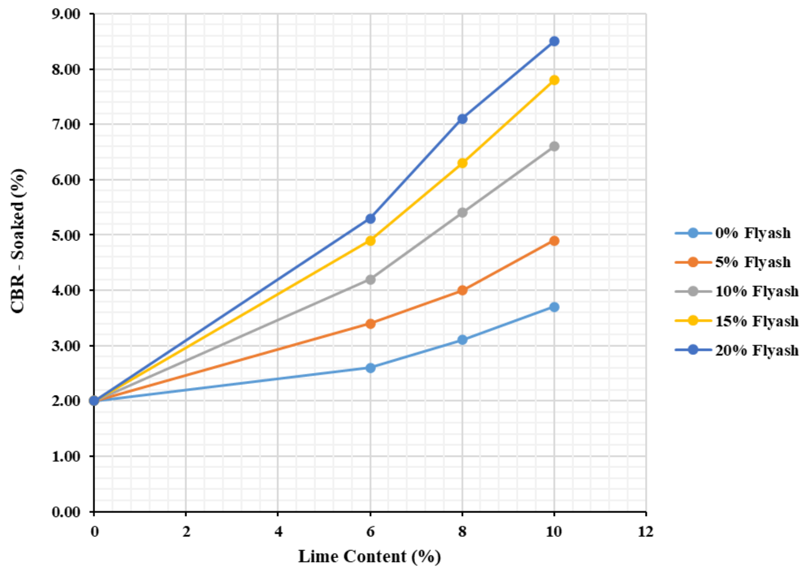
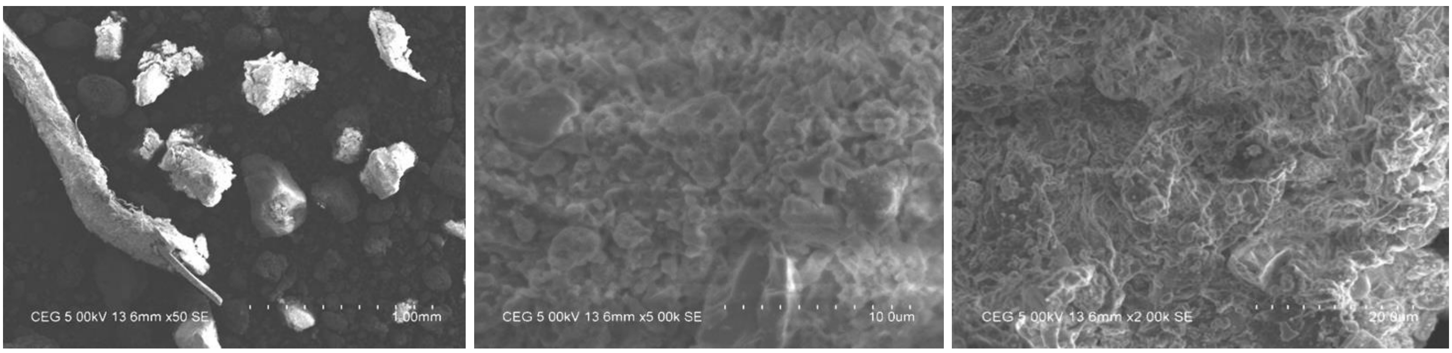


Fig. 7 Soaked CBR Value Variation Based on Flyash and Lime Proportions

The soaked CBR values show a remarkable improvement upon stabilization compared to virgin peat, which exhibits extremely poor bearing capacity in saturated conditions. Increasing fly ash content along with lime enhances strength due to pozzolanic reactions forming cementitious compounds that bind the organic particles together and reduce susceptibility to water softening. The mixes containing 10–20% fly ash with 8–10% lime provide the most significant improvement, achieving soaked CBR values more than three to four times that of untreated peat. This demonstrates the ability of the binder combination to effectively upgrade peat subgrade performance under wet field environments.

5. MICROSTRUCTURAL ANALYSIS

To elucidate the mechanisms behind the observed improvement in strength and stiffness, microstructural characterization was performed using Scanning Electron Microscopy (SEM) coupled with Energy-Dispersive X-ray Analysis (EDAX). SEM was utilized to examine changes in soil fabric, pore structure, and interparticle bonding, whereas EDAX provided insights into elemental composition and the formation of cementitious reaction products. Based on the scope of the study, the analysis was conducted on virgin peat and the stabilized mix that exhibited the highest strength gain (F20L10), enabling a direct comparison of the microstructural transformation induced by fly ash–lime treatment. The SEM analysis results of untreated and treated peat are given in Figures 8 and 9.



(a) (b) (c)

Fig. 8 SEM Analysis Results of Untreated Peat (a) 1mm (b) 20µ (c) 10µ Magnifications

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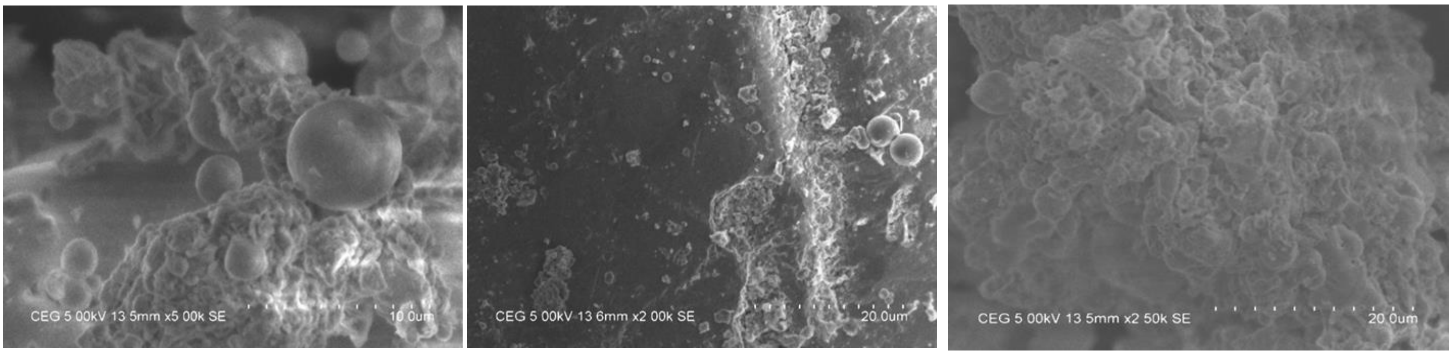
The SEM images of the virgin peat clearly reveal a highly heterogeneous, porous, and weakly bonded microstructure. At lower magnification, large plant-fiber fragments and irregular organic particles are observed within a loose skeletal framework characterized by prominent voids. The fibrous elements show limited mineral infilling or bonding, consistent with the high compressibility and low shear strength of the soil. At intermediate and higher magnifications, the matrix appears as a wrinkled and convoluted organic surface containing numerous interconnected micro-pores, with particle contacts occurring only at isolated points. The absence of crystalline or gel-like phases confirms that the peat fabric lacks significant cementation, and interparticle interactions are primarily governed by weak organic matter and entrapped water rather than rigid mineral bonding.



(a) (b) (c)

Fig. 9 SEM Analysis Results of Peat Tretaed with F20L10 (a) 20µ (b) 20µ (c) 10µ Magnifications

The SEM images of the treated peat–fly ash–lime mixture (F20L10) demonstrate a distinct transformation from the loose and highly porous organic fabric of virgin peat to a denser and cemented microstructure. The formerly discrete peat fibers and mineral fragments are now agglomerated into compact clusters, indicating the formation of hydration and pozzolanic reaction products that bind the particles together and partially fill the voids. The coated surfaces and reaction rims observed along the organic interfaces suggest diffusion-controlled pozzolanic activity, leading to enhanced interparticle bonding and improved structural continuity. Embedded spherical fly ash particles function as nucleation sites, with some appearing partially dissolved and enveloped by gel-like C–S–H/C–A–H phases, confirming ongoing chemical reactions and strong mechanical interlock.

The SEM observations clearly validate the macroscopic strength improvements observed in UCS and CBR tests, as the formation of cementitious products enhances particle bonding and reduces the porous, fibrous nature of virgin peat. The denser and more continuous load-transfer skeleton observed in the treated mix (F20L10) explains the significant increase in shear strength and bearing resistance with curing. Thus, the microstructural transformation directly supports the effectiveness of fly ash–lime stabilization in improving the engineering performance of peat.

Figures 10 and 11 present the EDAX spectra for the untreated and stabilized peat samples, respectively, illustrating the changes in elemental composition resulting from fly ash–lime treatment.

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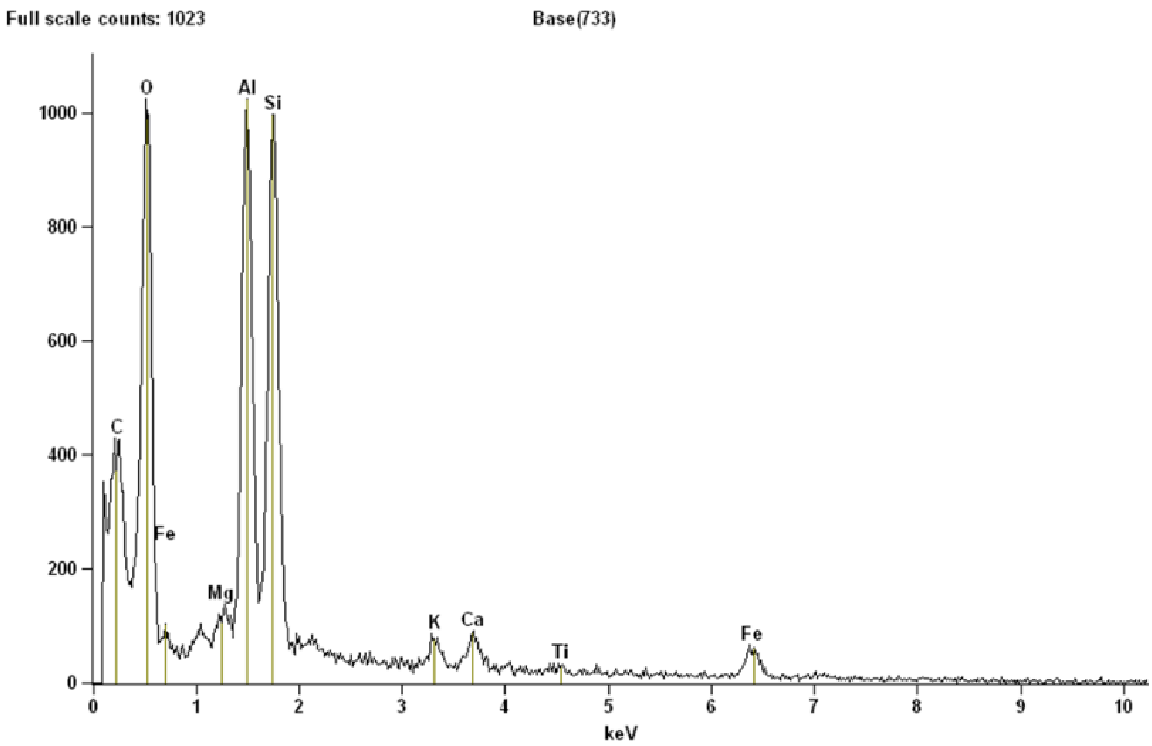
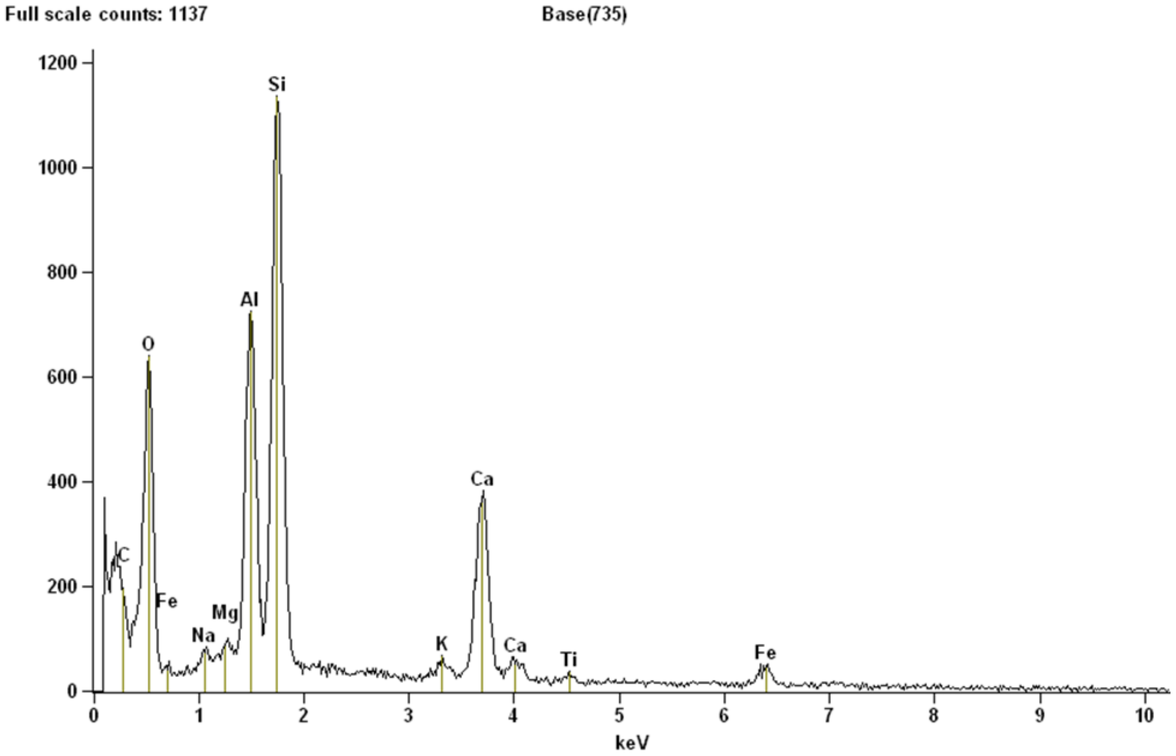


Element	*Net Counts*	*Weight %*	*Atom %*
C	431	10.92	17.57
O	10444	46.29	55.89
Mg	508	0.67	0.53
Al	10576	14.29	10.23
Si	11233	16.20	11.15
K	698	1.70	0.84
K	0	---	---
Ca	838	2.35	1.13
Ca	0	---	---
Ti	171	0.72	0.29
Ti	0	---	---
Fe	879	6.87	2.38
Fe	554	---	---
Total		100.00	100.00

Fig. 10 Chemical Composition of Virgin Peat Obtained from EDAX



Element	*Net Counts*	*Weight %*	*Atom %*
C	0	0.00	0.00
O	5935	39.48	56.94
Na	281	0.77	0.77
Mg	249	0.39	0.37
Al	7522	11.88	10.16
Si	13314	22.10	18.16
K	328	0.91	0.54
K	0	---	---
Ca	5413	17.69	10.19
Ca	0	---	---
Ti	214	1.07	0.51
Ti	0	---	---
Fe	626	5.71	2.36
Fe	0	---	---
Total		100.00	100.00

Fig. 11 Chemical Composition of Treated Peat Obtained from EDAX

The EDAX spectra confirm a distinct chemical transformation from an organic-dominated surface in the virgin peat to a mineral-rich and cementitious matrix in the stabilized mix. The untreated sample exhibits a strong carbon peak, reflecting the high organic content typical of peat, along with only minor amounts of silicon, aluminum, and calcium, which is consistent with the absence of bonding phases observed in the SEM images. In contrast, the F20L10-treated specimen exhibits significantly increased contents of calcium, silicon, and aluminum, accompanied by high oxygen levels, indicating the formation of calcium–silicate–hydrate and calcium–aluminate–hydrate products due to pozzolanic reactions between fly ash and lime. This compositional shift supports the microstructural observations of pore infilling, particle coating, and agglomeration, thereby providing direct chemical evidence for the enhanced strength and reduced compressibility measured in the UCS and CBR tests.

6. CONCLUSION

The experimental program confirms that blended Class C fly ash and lime can successfully convert a weak, highly compressible peat into a denser, cemented material with improved strength and bearing capacity suitable for subgrade applications. The combined macro- and micro-scale evidence highlights the importance of both mix proportion and curing in mobilizing pozzolanic reactions and achieving durable stabilization.

- Fly ash–lime addition resulted in a systematic reduction in liquid limit and optimum moisture content, accompanied by an increase in maximum dry density, reflecting improved particle packing and flocculation of the peat matrix.
- Unconfined compressive strength increased substantially with higher binder contents and longer curing periods; mixtures with 10–20% fly ash and 8–10% lime reached more than three to five times the UCS of virgin peat at 56 days.
- Soaked CBR values of the stabilized mixes showed comparable trends, with F20L10 and similar combinations achieving several-fold improvements over untreated peat, indicating enhanced subgrade performance under saturated conditions.
- SEM observations revealed a clear transition from a loose, fibrous, highly porous fabric in the virgin peat to a denser, agglomerated, and cemented microstructure with evident particle coatings and pore infilling in the treated mix.
- EDAX analyses confirmed a shift from an organic-dominated, low-calcium surface to a Ca–Si–Al–O-rich composition, consistent with the formation of C–S–H and C–A–H gels, validating the pozzolanic mechanism inferred from mechanical behavior.
- Overall, the study demonstrates that Class C fly ash activated by lime offers a technically effective and potentially more sustainable alternative to cement-intensive binders for peat stabilization, particularly at fly ash contents of 15–20% with lime dosages at or slightly above the lime demand.

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