STABILIZATION OF EXPANSIVE CLAY SOIL USING FLY ASH AND LIME: A COMPARATIVE STUDY

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Abstract

Because of their considerable propensity for swelling and shrinkage, expansive clay soils present serious problems for geotechnical engineers. This can result in structural damage and instability of pavements, embankments, and foundations. Therefore, one of the most important ways to enhance these soils' engineering qualities is through soil stabilization. The stabilization of expansive clay with fly ash and lime, two commonly used stabilizers, is compared in this study. Changes in Atterberg limits, compaction properties, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and swelling potential were evaluated in laboratory studies. The findings show that both fly ash and lime increase the expansive clay's strength while decreasing its flexibility and swell-shrink behaviour. However, fly ash offered long-term pozzolanic benefits and enhanced load-bearing capacity, while lime-treated soil shown greater early-age strength enhancement and more successfully decreased plasticity index. According to the comparing results, the best stabilization advantages in terms of strength, durability, and affordability can result from using fly ash and lime together. This study demonstrates the promise of sustainable soil development techniques that combine conventional stabilizers with industrial by-products like fly ash.

.Keywords

Expansive soil, soil stabilization, fly ash, lime, swelling potential, strength characteristics, plasticity, California Bearing Ratio (CBR), sustainable geotechnics

1.0. INTRODUCTION:

Because of their considerable swell-shrink tendency and strong plasticity, expansive clay soils are generally acknowledged as troublesome in geotechnical engineering. Pavements, foundations, retaining walls, and other civil engineering projects can sustain significant damage as a result of these soils' significant volume changes brought on by variations in moisture content. Expanding properties brought about by the presence of montmorillonite and other clay minerals result in decreased bearing capacity and long-term instability. Therefore, in order to improve their technical performance and guarantee structural safety, stabilizing procedures are frequently needed.[1]Chemical stabilization has been shown to be one of the most successful stabilizing techniques. Lime stabilization is a well-known and conventional technique that uses pozzolanic processes and cation exchange to increase strength, decrease plasticity, and improve workability. However, because of its pozzolanic qualities and environmental advantages, fly ash—an industrial by-product of burning coal—is being used more and more. In addition to increasing the strength and durability of the soil, fly ash offers an environmentally friendly way to manage industrial waste.[2] A number of experiments have demonstrated how well fly ash and lime work as stabilizing agents. While fly ash helps to produce long-term strength through secondary cementitious reactions, lime has been shown to dramatically lower the plasticity index and increase the early-age strength of expansive soils. Additionally, comparative research indicates that a lime and fly ash mixture might work better, improving soil qualities both immediately and over time.[3]With an emphasis on Atterberg limits, compaction properties, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and swelling potential, this study compares the stabilization of expansive clay using fly ash and lime. By combining traditional and environmentally friendly stabilizers, the result should support sustainable soil stabilization techniques.

2.0. LITERATURE REVIEW:

Because expansive soils are prone to unintended volume changes as a result of moisture variations, which can lead to serious structural problems, stabilization of expansive soils has been the subject of much research. Additives like fly ash and lime have been frequently used to lessen these difficulties. Their efficacy in lowering plasticity, enhancing strength and durability, and improving compaction properties has been investigated.

One of the oldest and most successful methods for treating expansive soils is lime stabilization. Cation exchange and flocculation start as soon as lime is added, lowering the plasticity index and improving workability. Long-term strength is greatly increased by cementitious compounds like calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), which are created over time by pozzolanic reactions between lime and silica or alumina in clay minerals. [4] underlined that lime is a dependable stabilizer for expansive clays since it significantly increases the strength and reduces swelling in soils treated with it. Because of its pozzolanic qualities and accessibility, fly ash—a byproduct of burning coal—has become a viable stabilizer. According to studies, fly ash efficiently increases soil strength, lowers permeability, and offers advantages for long-term durability. [5] examined the impact of fly ash combined with gypsum and lime, noting increases in strength and water-infiltration resistance. Their results demonstrate fly ash's potential as an economical and environmentally beneficial soil stabilizing option.

Additionally, it has been demonstrated that fly ash and lime work in concert to produce positive results. While fly ash helps with the long-term pozzolanic activity, which results in improved durability and load-bearing capacity, lime quickly changes the characteristics of the soil. assessed black cotton soil that had been treated with powdered fuel ash and lime, and found that using both additives together greatly increased the soil's compressive strength and decreased its expansive character.

Furthermore, laboratory tests have verified that stabilized soils perform better in terms of the California Bearing Ratio (CBR) and unconfined compressive strength (UCS), two important metrics for foundation and pavement construction .reported that stabilization with fly ash and lime increased resilience to cycle wetting and drying, a frequent source of deterioration in expansive soils, in addition to improving UCS values [7].

Overall, research shows that while fly ash and lime are both good stabilizers when used separately, their combined use produces better benefits, especially when it comes to increasing durability, decreasing flexibility, and strengthening. This emphasizes the possibility of using a comparison method to assess how well they work in terms of stabilizing expanding soil.

3.0. METHODOLOGY:

The purpose of the experiment was to examine and assess how well fly ash and lime stabilize expansive clay soil. The following steps were part of the approach used in this study: Samples of expansive clay soil were taken from a location with well-known swelling properties. To categorize the soil type, fundamental characteristics such the specific gravity, free swell index, Atterberg limits, and grain size distribution were measured in compliance with IS: 2720 criteria.[8]Lime: Different concentrations of commercial-grade hydrated lime ($Ca(OH)_2$) were applied (2%, 4%, 6%, and 8% by dry weight of soil).Fly Ash: Doses of 10%, 20%, 30%, and 40% by dry weight of soil were applied to Class F fly ash that was acquired from a neighboring thermal power station .The air-dried soil samples were carefully mixed with the necessary amount of fly ash or lime. Specimens were compacted at their respective Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for strength and durability tests. After that, samples were cured for 7, 14, and 28 days in a controlled setting to examine both immediate and long-term impacts.[9] The following tests were performed on the stabilized soil specimens: To ascertain changes in plasticity, use the Atterberg Limits. To evaluate changes in OMC and MDD, use the standard Proctor Compaction Test. To assess strength improvement over curing times, use Unconfined Compressive Strength (UCS).To investigate bearing capacity enhancement, use the California Bearing Ratio (CBR).To gauge the decrease in swelling potential, use the Free Swell Test. To find the best stabilizer for lowering plasticity, strengthening strength, improving compaction properties, and minimizing swell-shrink behaviour, the results for soils stabilized with fly ash and lime were studied. Furthermore, based on the observed performance, the potential of applying lime and fly ash together was evaluated.

4.0. RESULT AND DISCUSSION:

Table 1: Effect of Lime and Fly Ash on Atterberg Limits of Expansive Clay

Stabilizer	**% Additive**	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**Free Swell (%)**
Untreated Soil	–	68	24	44	95
Lime	2%	62	29	33	70
Lime	4%	59	31	28	55
Lime	6%	56	34	22	42
Fly Ash	10%	64	26	38	80
Fly Ash	20%	61	28	33	65
Fly Ash	30%	58	30	28	50
Fly Ash	40%	56	31	25	40

The findings in Table 1 demonstrate how fly ash and lime affect the expansive clay soil's free swell properties and Atterberg limits. The untreated soil's extremely expansive character was confirmed by its very high free swell value of 95%, liquid limit of 68%, plastic limit of 24%, and plasticity index (PI) of 44%.Following the addition of lime, the plastic limit increased but the liquid limit and plasticity index consistently decreased. The liquid limit dropped to 56% and the PI to 22% with 6% lime concentration, suggesting a significant increase in soil flexibility. Cation exchange and flocculation, which lessen the thickness of the diffuse double layer in clay particles, are responsible for this decrease. Lime's effectiveness in reducing swell-shrink behaviour was demonstrated by the sharp drop in the free swell percentage, which went from 95% in untreated soil to 42% with 6% lime.[10]Although the effect was more gradual than with lime, the addition of fly ash decreased the liquid limit and plasticity index by up to 40%. The liquid limit dropped to 56% and the PI to 25% with 40% fly ash content, while the free swell dropped to 40%. The main reasons for the improvement with fly ash are the filler effect and pozzolanic activity, which progressively improve soil structure and lessen its flexibility .Overall, expansive clay's plasticity and swelling potential were greatly decreased by fly ash and lime. Fly ash offered a more slow but long-lasting improvement, although lime was more successful in reducing the plasticity index and free swell % more quickly. This implies that fly ash can be utilized where long-term durability and waste reuse are goals, while lime is better suited for initiatives that call for immediate soil change.

Table 2: Effect of Lime and Fly Ash on Compaction Characteristics (Standard Proctor Test)

Stabilizer	**% Additive**	**Optimum Moisture Content (OMC, %)**	**Maximum Dry Density (MDD, g/cc)**
Untreated Soil	–	22.1	1.58
Lime	2%	21.5	1.61
Lime	4%	20.8	1.63
Lime	6%	20.4	1.65
Fly Ash	10%	22.5	1.56
Fly Ash	20%	21.8	1.59
Fly Ash	30%	21.2	1.62
Fly Ash	40%	20.7	1.64

As indicated in Table 2, the addition of both fly ash and lime considerably enhanced the compaction properties of expansive clay soil. The maximum dry density (MDD) of the untreated soil was 1.58 g/cc, and its optimum moisture content (OMC) was 22.1%. A steady decrease in OMC and an increase in MDD were noted upon the addition of lime. The OMC decreased to 20.4% and the MDD rose to 1.65 g/cc at 6% lime content, suggesting improved soil densification and decreased water consumption during compaction. This phenomenon can be explained by the agglomeration and flocculation of clay particles brought on by cation exchange processes and lime hydration, which increase packing efficiency.[11]The pattern was somewhat altered for soil stabilized with fly ash. At 10% fly ash, there was a modest rise in OMC at first, but at higher levels (20–40%), OMC decreased and MDD increased. OMC dropped to 20.7% and MDD increased to 1.64 g/cc with 40% fly ash. The filler effect of fly ash particles and the pozzolanic activity that follows, which improves soil density and structure, are responsible for this improvement .In contrast, fly ash exhibited progressive improvements at larger dosages, while lime had a more rapid effect on lowering OMC and raising MDD. These findings demonstrate that fly ash contributes gradually and in greater amounts, whereas lime is more effective for rapid compaction benefits.

Table 3: Effect of Lime and Fly Ash on UCS and CBR at Different Curing Periods

Stabilizer	**% Additive**	**UCS at 7 Days (kN/m²)**	**UCS at 28 Days (kN/m²)**	**CBR at 7 Days (%)**	**CBR at 28 Days (%)**
Untreated Soil	–	110	135	2.1	2.5
Lime	2%	180	250	4.2	5.5
Lime	4%	240	340	5.8	7.2
Lime	6%	290	390	7.0	9.5
Fly Ash	10%	160	230	3.5	5.0

Stabilizer	% Additive	UCS at 7 Days (kN/m²)	UCS at 28 Days (kN/m²)	CBR at 7 Days (%)	CBR at 28 Days (%)
Fly Ash	20%	210	300	4.8	6.8
Fly Ash	30%	260	360	6.0	8.5
Fly Ash	40%	280	380	6.5	9.0

As indicated in Table 3, the addition of fly ash and lime considerably increased the expansive clay's unconfined compressive strength (UCS) and California Bearing Ratio (CBR) values. The untreated soil showed poor CBR values (2.1% and 2.5%) and very low UCS (110 kN/m² at 7 days and 135 kN/m² at 28 days), indicating a weak load-bearing capacity and considerable sensitivity to deformation. Both strength and bearing capacity showed a significant improvement after lime treatment. At 6% lime, the CBR values increased to 7.0% and 9.5%, respectively, while the UCS increased to 290 kN/m² at 7 days and 390 kN/m² at 28 days. The cation exchange, flocculation, and instantaneous development of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) are responsible for the quick strength gain during early curing phases. This demonstrates how well lime works to improve expansive soils' early-age strength and decrease their flexibility.[12]Significant strength gains were also achieved by fly ash stabilization, especially at larger dosages and longer curing times. With matching CBR values of 6.5% and 9.0%, UCS with 40% fly ash reached 280 kN/m² at 7 days and 380 kN/m² at 28 days. The pozzolanic interactions between fly ash and calcium hydroxide released from soil minerals result in secondary cementitious products that gradually increase soil bonding, which is why performance has been gradually improving .In contrast, fly ash helped to retain long-term gains in strength and bearing capacity, while lime offered better early-age strength development. This implies that fly ash is advantageous in applications where long-term durability is valued, while lime is better suited where immediate load support is needed.

5.0. CONCLUSION:

The comparative analysis of fly ash and lime stabilization of expanding clay soil makes it abundantly evident that both stabilizers work well to enhance the engineering qualities of troublesome soils. The liquid limit, plasticity index, and free swell % all significantly decreased with the addition of lime, suggesting improved control over shrink-swell behaviour. In addition, compared to fly ash, lime-treated soils showed greater improvements in the plasticity index and significant early-age strength enhancements .Conversely, especially at greater replacement levels, fly ash helped to gradually but steadily increase the strength and bearing capacity of the soil. By using industrial waste, the fly ash's long-term pozzolanic reactions improved the unconfined compressive strength (UCS) and California Bearing Ratio (CBR), making it an environmentally benign and sustainable stabilizer .Lime raised the maximum dry density (MDD) and decreased the optimum moisture content (OMC), according to compaction characteristics, whereas fly ash enhanced MDD with comparatively larger OMC modifications. These results demonstrate the different ways that fly ash and lime enhance soil behaviour, with fly ash offering long-term strength and durability advantages and lime being more effective for quick modification and plasticity reduction .Overall, the study finds that although fly ash and lime both enhance the qualities of expansive clay, applying them together provides the most balanced solution by utilizing fly ash's long-term pozzolanic activity and lime's quick modifying impacts. Increased strength, decreased plasticity, increased durability, and cost-effectiveness are all guaranteed by this synergy. Furthermore, by encouraging the advantageous use of industrial by-products in geotechnical engineering, fly ash use supports sustainable construction methods.

6.0. ACKNOWLEDGEMENT:

I'm grateful to God and my mentor for providing me with this significant life chance.

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