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A THEORETICAL STUDY ON EXPANSIVE SOIL STABILIZATION BY THE ADDITION OF FLY ASH, LIME AND CEMENT

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Abstract
Soil stabilization plays a crucial role in enhancing the engineering properties of problematic soils for various construction applications. This theoretical study examines how fly ash, lime, and cement stabilise soil. The goal is to examine this stabilising technique's benefits and mechanisms. The theoretical study reviews fly ash, lime, and cement soil stabilisation literature, research articles, and technical reports. The study examines stabilised soil system chemical processes, physical interactions, and mechanical behaviour. The findings show that fly ash, a coal combustion byproduct, behaves as a pozzolan and forms cementitious compounds with lime and cement. This combination increases compressive strength, lowers permeability, and strengthens stabilised soil. Lime reduces expansive soil flexibility and stabilises them through its pozzolanic reaction. Cement binds soil, enhancing cohesion and shear strength. Fly ash, lime, and cement synergistically improve soil engineering features like swelling potential, load-bearing capacity, and erosion and moisture resistance, according to the theoretical research. However, soil properties, stabilising agent dosage, and engineering and quality control methods must be considered for successful deployment. Fly ash, lime, and cement can stabilise soil, and this theoretical analysis provides a foundation for further experimental and field research. The findings advance knowledge and enable sustainable and cost-effective soil stabilisation options in construction projects.

Keywords— Expansive soil, Admixture, Black Cotton Soil, Fly ash, Cement, Lime, unconfined compressive strength, compaction, swelling.

Introduction

Soil Stabilization

According to Unsever Y. S. and Diallo M. L. [1], "soil stabilisation" is the process of increasing the soil's bearing capacity or stability through proportioning, controlled compaction, and/or the addition of appropriate admixtures or stabilisers. It involves assessing the soil's qualities, determining which of its qualities are lacking, selecting an efficient and cost-effective way of stabilising the soil, and creating a stabilised soil mix with the desired stability and durability values. According to Vijayakumar, A., Kumar, S. N., & Tejareddy, P. A. [2], the primary goal of soil stabilisation is to raise the soil's carrying capacity. By controlling the shrink-swell characteristics of a soil and enhancing its shear strength, stabilisation can improve a subgrade's ability to sustain foundations and pavements by increasing its load bearing capacity. Expanding clays and granular materials are just two examples of the many sub-grade materials that can be treated with stabilisation. Better soil gradation, a decrease in the flexibility index or swelling potential, and an increase in strength and durability are the most frequently attained advantages by stabilisation, according to Bukhary, A., & Azam, S. [3]. Stabilisation can also be utilised to give construction workers a working platform during rainy weather. We refer to these kinds of improved soil quality as "soil modification." Higher resistance values, decreased flexibility, decreased permeability, thinner pavement, no need for excavation, material transportation and processing, or foundation importation are some advantages of stabilising soil [4]. It also helps with compaction and offers all-weather access to project sites [5]. The current moisture content, the intended use of the soil structure, and the eventual financial reward could all be deciding factors in soil stabilisation. In order

to stabilise soil, common admixtures include fly ash, cement, and lime. According to Unsever y. s. and Diallo M. L. [1], the necessity to use soil stabilisation to improve soil quality is growing as good soil becomes scarcer and their location becomes more challenging and expensive.
It happened for a number of reasons, some of which are as follows:
• Using aggregates with superior engineering qualities to replace low-grade soils.
• Improvement of the soil's bearing capacity and strength.
• Buildings, whether natural or man-made, can be preserved by waterproofing.
• To promote the use of leftover geomaterials in the construction of buildings.
• To enhance the properties of permeability.
• To improve undesirable characteristics of the soil, such as high plasticity, excessive swelling or shrinkage, etc.
• To utilize locally produced materials of lower quality.
• Lastly, improving the local soil's characteristics.

Materials Used in Soil Stabilization
The methods employed in soil stabilisation determine the materials that are utilised. They are listed below:
• Soils of different grades.
• Fly ash, lime, and cement.
• Grade-based aggregates.
• Both natural and synthetic polymers.
• Geogrids and geoblankets are examples of geomaterials.
• Solid waste products from mines, cities, and industries.

Types of Soil Stabilization
The three basic types of soil stabilization techniques are
(a) Mechanical (b) Chemical (c) biological soil stabilisation

Expansive Soil
Expansive soils, commonly referred to as swell-shrink soils, have a propensity to swell and shrink in responding to the variations in the moisture content. This difference in the soil causes a great deal of anguish in the soil, which is followed by harm to the structures that are above it [6]. These soils absorb the water and swell during wetter times, such as monsoons; as a result, they become softer and can hold less water [7]. On the other hand, these soils become harder during drier seasons, such as summers, when evaporation causes them to lose the moisture they have stored. These sorts of soils, which are typically found in arid and semi-arid parts of the world, are seen to be potential natural hazards because, if left untreated, they might seriously harm-built structures and result in fatalities. These kinds of characteristics are generally seen in soils containing montmorillonite. These soils have severely harmed civil engineering structures, with annual costs measured in billions of dollars worldwide.


Fig 1.1. Black cotton soil

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Why Black Cotton Soil

- The high swelling and shrinking of the soil cause fissures in the structures built on it, rendering it unsuitable for use as a foundation [8].
- Therefore, in order to use black cotton soil as a foundation material, it must be improved. By decreasing permeability and boosting overall strength, the stabilization process guarantees soil stability [9].
- It is quite difficult to manage the soil because of its tendency to swell and dry up. It also loses its bearing ability when it becomes wet.
- This soil expands from 20% to 30% of its initial volume, which leads to foundation cracks, making building constructed on it unsafe.
- Due to its unique properties, any construction should undergo high stabilization.

Fig.1.3. Shrinkage crack

Fig. 1.4. Floor crack

Fly Ash

The byproduct of the combustion of coal in furnaces, fly ash is typically found in thermal power plants [10]. Similar to the volcanic ashes in the past utilised in hydraulic cements, fly ash has a similar composition. These volcanic ashes were also used for other purposes. It was thought that these ashes were among the best pozzolans (binding agents) available anywhere in the world. Fly ashes are tiny particles that are mostly made of alumina, silica, and iron. Because the majority of fly ash particles are spherical in shape, it is simple for them to flow and blend together to create an appropriate mixture. The minerals found in fly ash are both crystalline and amorphous in form. Its composition varies according to how the coal is burned, but in general, it is a non-plastic silt. Fly ash is a possible material that can be used for waste liners. In addition, it can be used as a barrier material in combination with bentonite and lime. Fly ash is a waste substance that is being generated at a rate significantly higher than its current use. Stated differently, we are creating more fly ash than we can use.

Fly ash has been reported in a few cases to have the ability to strengthen expansive soil after addition, however the strength is not very high by Li M. et al.[1].

Table 1.1 : Physical properties of fly ash

Physical Properties	Value of physical properties
Grain size distribution	Gravel size 4%
	Sand size 72%
	Silt size 24%
	Uniformity coefficient, C_u = 7.70
	Coefficient of curvature, C_c = 1.46
	D_{50} = 0.170mm
Specific gravity	2.16
Liquid limit & plastic limit	Non plastic
Optimum moisture content at proctor energy (OMC)	37%
Maximum dry at density proctor energy (MDD)	10.40 kn/m^3
Cohesion at OMC & MDD	32 kn/m^3
Angle of internal friction at OMC & MDD	36^0
Permeability, k at MDD	3.7 x 10^{-5} (cm/s)

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Table 1.2: Chemical composition of Fly ash

Constituents	Percentage by weight
SiO2	50.5
Al2O3	25.01
Fe2O3	0.71
CaO	9.73
MgO	4.18
Loss on ignition	9.8
Other	0.07

Why Fly Ash

Many highway embankment building projects around the nation have used fly ash with success.It has also been demonstrated that incorporating fly ash into the building materials lowers PM emissions at the construction site[11]. Even though the advantages of fly ash as a sustainable building material are now well known, there is still more room to be explored considering the amount of fly ash produced and the advancements in technology in the construction sector. Fly ash is a versatile substance that may be used for a variety of tasks. How it is utilised will depend on the specifics of the area in which it is used.

Fig.1.5. Fly ash

Cement

Ordinary Portland Cement is mixed with pozzolanic minerals to create Portland Pozzolana Cement (PPC). Portland cement and fine pozzolana can be blended to create Portland pozzolana cement, or clinker and pozzolana can be ground together. Pozzolana makes up 10–25% of the cement's weight. Pozzolanic elements included in PPC contribute to the reinforcement of concrete's strength. Portland cement can be used to either change and enhance the soil's characteristics or turn it into a stronger, more durable cemented mass[12]. if or if the soil needs to be stabilised or amended will determine how much cement is required.

Why Cement

Cement stabilization is a building method that involves combining subgrade dirt with cement and water to strengthen it[13]. Water hydrates the cement in this soil stabilization technique, causing reactions that provide the soil strength by forming a matrix between the soil particles. Greasy soils benefit greatly from cement stabilization.

Table 1.3: Properties of cement

Physical properties	Value
Standard Consistency (%)	33
Specific Gravity	2.90
Initial setting time (minute)	30(min)
Final setting time (minute)	600(max)
Fineness (m^2/kg)	300
Soundness (mm)	10 (max)
Compressive strength (MPa)	22.2 (3 days)
	28.5 (7 days)
	33.6 (28 days)
% of fly ash addition	34.8 (15.0 (min), 35.0 (max))

Fig.1.6. Cement

Lime

Lime-Adding lime to the soil to enhance its characteristics, such as density and bearing ability, is known as soil stabilisation. The following is a brief discussion of the several parameters that effect lime-soil stabilisation: soil type, lime type, lime content used, compaction, curing period, and additions. According to Eades and Grim, the lime stabilisation procedure is basically a two-stage procedure[14]. The reactions between clay and lime were identified using differential thermal analysis (DTA) and X-ray diffraction[15]. Depending on the mineralogical makeup of the soil, Cation Exchange, Flocculation, Carbonation, and certain short-term pozzolanic reactions also take place during the early stage of modification, which might take many hours or days to complete. At this point, the soil's workability and plasticity have mostly altered. The pozzolanic processes that contribute to the gains in strength and durability occur during the second stage, which is also referred to as long-term treatment.

Why Lime

There is some variation in the usage of the term "lime." The term "lime" must refer to either hydrated lime or quicklime for the purposes of stabilizing soil.

In terms of chemistry, hydrated lime is calcium hydroxide (Ca(OH)2), and quicklime is calcium oxide (CaO).

Lime stabilization utilizes pozzolans, inherent in clay soils, to create cementitious relationships that effectively reinforce and stabilize clay soil in a lasting manner. Lime stabilization utilizes pozzolans, which naturally occur in clay soils, to create cementitious linkages that permanently enhance the strength of the soil. Lime stabilization is employed to enhance the long-term durability of fine-grained soils with high silt and clay composition.

Table 1.4: Properties of lime

Component	**Percentage (%) composition**
CaO	82
MgO	5.3
H_2O	0.87
$Ca(OH)_2$	86.47
SiO_2	2.54
PH	9.03
Al_2O_3	4.85
Others	3.52
Loss of ignition	0.23
Property	**Description**
Colour	White
Solubility	Partially soluble in H_2O & HCI
Texture	Smooth

Fig. 1.7. Lime

Objective

There are different objectives for this, which include:

• Replacing aggregates with superior engineering qualities with low-quality soils.
• Improvement of the soil's bearing capacity and strength.
• Buildings, whether natural or man-made, can be preserved by waterproofing.
• To promote the use of leftover geomaterials in the construction of buildings.
• To enhance the properties of permeability.
• To improve undesirable characteristics of the soil, such as high plasticity, excessive swelling or shrinkage, etc.

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• To utilise locally produced materials of lower quality.

Literature

The study by Mengmeng et al. [16] found that adding fly ash and bio cement to expansive soil increased its ultimate consolidation strength (UCS) by 142.6 kPa. The study also found that fly ash, when combined with bio cement, could improve the functional properties of expanding soil for generations to come. Other studies have used fly ash and lime in soil-dried soil, cement and fly ash in building materials, and bitumen emulsions in gravel soil and highway shoulder areas. The study suggests that using fly ash and bio cement in conjunction with bio cement can improve soil stability and functional properties for generations to come.

Sharma et al. [17] found that adding lime and Fly Ash to clay soil improves its strength. The ideal proportion for fortifying poor clay soil is 73% to 25% to 2%. Mohammed Shukri Al-Zoubi [18] found that cement concentration increases undrained strength, with the fastest rate occurring at 6-10% cement content. Aldaood Abdulrahman, Khalil Amina, and M. Bouasker [19] found that straw fiber inclusions and cement can improve axial strain at failure and soil strength. Munirwan et al. [20] found that coffee husk ashes and soil can improve soil's physical qualities and plasticity. Ajaz Ahmad Hurrah, Er. Abhishek, and Rubel [21] used bagasse ash as a substitute for virgin expansive soil, revealing significant changes in soil parameters.

B. R. Phanikumar's [22] study examined the impact of lime and fly ash on swelling capacity, consolidation pattern, and shear strength of expansive clays. The study found that both lime and fly ash improved the geotechnical properties of clay samples, but lime performed better. Ghaffoori et al. [23] research examined the effects of fine ground granulated blast furnace slag and fly ash on the compaction and unconfined compressive strength of stabilized clayey soil. Bagasse ash and lime were used to stabilize expansive soil in 2014. The plasticity index and maximum dry density of uncured soil samples decreased after 7 days of air curing, and the CBR values increased with age of curing. The combination of lime and bagasse ash reduced the stabilized soil's maximum dry density, and soil CBR increased after lime or lime and bagasse ash were added.

Rachmad et al. [24] studied the stabilization of loose soil using Lime, FlyAsh, and cement. They found that soil properties, such as water content, grain size distribution, Atterberg limits, proctor, compressive strength (CBR), and consolidation tests, increased after combining the soil with a mixture of 6% Lime, 2% fly ash, and 8% cement. A study by J.M. Raut et al. [25] found that a mixture of 7.5% murrum and 5% fly ash had the highest MDD and unconfined compressive strength. Abhraneel Sengupta [26] explored the feasibility of using fly ash and ground granulated blast furnace slag (GGBFS) as stabilizing agents. However, only 58% of flyash and 55% of blast furnace slag are used, highlighting the need for more research on the effects of stabilization on expansive soil properties.

Azmi et al. [27] and Santosh et al. [28] conducted experiments on soil stabilization using fly ash at various percentages. They found that fly ash can enhance soil's engineering properties, lower its liquid limit, and increase its plastic limit. The optimal content for proctor compaction tests is 7%, and the maximum dry density value drops precipitously after adding 5% and 10% fly ash.

Dar et al [29] found similar results using plastic clay and fly ash for soil stabilization. They found that as the percentage of fly ash in the soil increased, the L.L. and P.I. of the soils declined. The most significant reduction was observed at a 30% fly ash content.

A series of tests by A.Karthik et al [30] found that adding fly ash to expansive soil reduces swelling and makes the soil more robust. The effectiveness of fly ash as a stabilizing additive in expansive soils was also investigated.

Conclusion

the addition of fly ash, lime, and cement has proven to be an effective method for soil stabilization. The combination of these materials offers numerous benefits, including improved engineering properties and enhanced durability of the stabilized soil.

Fly ash, a byproduct of coal combustion, acts as a pozzolan and provides supplementary cementitious properties when mixed with lime and cement. It enhances the compressive strength, reduces permeability, and improves the chemical stability of the soil. Lime, on the other hand, contributes to the formation of pozzolanic compounds and aids in reducing the plasticity of expansive soils. Cement acts as a binder, increasing the cohesion and shear strength of the stabilized soil.

The synergistic effect of fly ash, lime, and cement results in reduced swelling potential, increased load-bearing capacity, and improved resistance to erosion and moisture-induced damage. The stabilized soil becomes more suitable for construction purposes, such as foundation design, road construction, and embankment stabilization.

However, it is important to consider the specific characteristics of the soil and the appropriate dosage of each stabilizing agent to achieve optimal results. Proper engineering and quality control measures should be implemented during the soil stabilization process to ensure long-term performance and sustainability.

In summary, the addition of fly ash, lime, and cement offers a cost-effective and environmentally friendly solution for soil stabilization, providing improved properties and enabling the utilization of problematic soils in various engineering applications.

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