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Siddhesh Kumbhalkar, Kashish Choudhary, Yash Khaparde, Shubham Shahu, & Prof. Atul Gautam. (2026). Stabilization Of Expansive Soil Using Fly Ash. *International Journal of Multidisciplinary Academic Studies and Research (IJMASR)*, 1(9), 1–8. <https://doi.org/10.5281/zenodo.22814183>

Article Info

Received: 14th September 2026, Accepted: 15th September 2026, Published: 17th September 2026.

Stabilization Of Expansive Soil Using Fly Ash

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Abstract: Expansive soil is a major problem in civil engineering because its volume changes with changes in moisture content. Black cotton soil, which is commonly found in many parts of India, expands during the rainy season and shrinks during the dry season. This behaviour can cause cracks, uneven settlement and damage to roads and foundations. The present research work investigates the stabilization of expansive soil using fly ash as a waste-based stabilizing material. In this study, expansive soil collected from Kalmeshwar, Nagpur, Maharashtra, is mixed with fly ash obtained from Koradi Thermal Power Station, Nagpur. Fly ash is added in different proportions of 5%, 10%, 15% and 20% by dry weight of soil. The untreated soil is used as the control sample. Laboratory tests are carried out to study the changes in Liquid Limit, Plastic Limit, Plasticity Index, Free Swell Index, Optimum Moisture Content, Maximum Dry Density, California Bearing Ratio and Unconfined Compressive Strength. The results show that the addition of fly ash reduces the plasticity and swelling behaviour of expansive soil and improves its compaction and strength characteristics. Based on the considered experimental values, the 15% fly ash mixture gives better overall improvement in CBR and UCS, while higher fly ash content gives further reduction in plasticity and free swelling. The study indicates that fly ash can be effectively used to improve the engineering performance of expansive soil. Its use also provides a useful method for utilizing industrial waste and reducing the requirement for conventional stabilizing materials. The developed treatment can be considered for economical and sustainable pavement subgrade applications.

Keywords: Expansive soil, Black cotton soil, Fly ash, Soil stabilization, Swelling, CBR, UCS, Sustainable construction.

I. Introduction

Soil is one of the most important natural materials used in civil engineering construction. Roads, buildings, foundations, embankments and other infrastructure are generally constructed over or with the support of soil. However, all types of soil do not have suitable engineering properties for construction. Expansive soil is one of the major problematic soils because it undergoes significant volume changes with changes in moisture content. Black cotton soil is a common type of expansive soil found in many parts of India. It contains a high proportion of active clay minerals and shows considerable swelling when water enters the soil mass. During the rainy season, the soil absorbs water and expands, while during the dry season it loses moisture and shrinks. The repeated swelling and shrinkage may result in cracks, uneven settlement, loss of bearing capacity and damage to pavements and foundations [3], [9], [12]. The engineering behaviour of expansive soil creates serious difficulties in pavement and foundation construction. Changes in moisture content can cause changes in soil volume and strength, which may affect the long-term performance of structures constructed over such soils. Therefore, improvement of the engineering properties of expansive soil is necessary before its use in important civil engineering applications. Conventional soil stabilization methods generally include mechanical compaction and the addition of materials such as lime, cement and other chemical stabilizers.

These methods can improve strength and reduce the undesirable properties of soil; however, their cost and environmental impact have encouraged researchers to investigate alternative and waste-based stabilizing materials [6], [8], [11]. In recent years, the utilization of industrial and construction waste materials for soil stabilization has received considerable attention. Construction and demolition waste has been investigated for improving the strength, bearing capacity and compaction characteristics of problematic soils [7], [11], [13]–[16]. Studies have reported that suitable quantities of recycled construction materials can improve California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and other engineering properties while reducing swelling behaviour [5], [13], [14]. The use of waste materials for soil improvement also provides an opportunity for waste management and reduces the dependence on conventional stabilizing materials.

Ash-based materials have also been investigated for improving expansive soil properties. The use of lime and wood ash has shown improvement in the engineering behaviour of black cotton soil [9], while natural lime and pozzolanic materials have been reported to reduce plasticity and swelling and improve the bearing performance of expansive soil [10]. These findings indicate that ash and pozzolanic materials have potential for stabilizing problematic soils. However, the effectiveness of a stabilizing material depends on the characteristics of the soil, the type of additive and its percentage in the soil mixture. Therefore, determining a suitable or optimum stabilizer content is an important part of soil stabilization studies [13], [25], [27].

Different waste materials have been studied for expansive soil stabilization in recent years. Fibres such as bamboo and other natural or synthetic fibres have been used to improve strength, ductility and crack resistance of subgrade soils [18], [20], [26], [27]. Ceramic powder has also been investigated for reducing plasticity and improving the CBR of subgrade soil [19]. Similarly, recycled plastic materials have been studied for improving shear strength and load-bearing behaviour of expansive black cotton soil [29], [30]. Waste paper sludge has been reported to reduce volume change characteristics of expansive road subgrades [22], [24]. These studies demonstrate the growing interest in sustainable waste-based soil stabilization.

The performance of stabilized soil is not dependent only on the quantity of stabilizing material. The interaction between soil particles and the added material, moisture condition, curing period and environmental exposure can also affect the final engineering properties. Studies on construction and demolition waste and geopolymer-based stabilization have reported significant improvements in strength and stiffness [23], [25]. At the same time, research involving wetting–drying cycles has shown that stabilized expansive soil may experience changes in stiffness and strength under repeated moisture variations [31]. Therefore, proper selection of stabilizer content and evaluation of multiple engineering properties are necessary before recommending a stabilization method for practical applications.

Fly ash is a fine industrial by-product mainly generated from coal-based thermal power plants. Due to its fine particle size and pozzolanic nature, fly ash has potential for use in soil improvement. Its use as a stabilizing material can help in modifying the physical and engineering properties of expansive soil while also providing a useful application for an industrial waste material. The use of fly ash can therefore provide both geotechnical and environmental benefits. However, the effectiveness of fly ash stabilization depends on the properties of the original soil and the quantity of fly ash added. Hence, experimental determination of the suitable fly ash content is necessary for a particular expansive soil.

The use of locally available materials is particularly important for developing an economical and practical stabilization technique. In the present study, expansive soil was collected from the Kalmeshwar region of Nagpur, Maharashtra, while fly ash was obtained from Koradi Thermal Power Station, Nagpur. The collected soil was investigated in its untreated condition and after adding different percentages of fly ash. The study considers fly ash contents of 5%, 10%, 15% and 20% by dry weight of soil, with untreated soil considered as the control sample.

The present research focuses on evaluating the effect of fly ash on important engineering properties of expansive soil. Laboratory investigations include Liquid Limit, Plastic Limit, Plasticity Index, Free Swell Index, Optimum Moisture Content, Maximum Dry Density, California Bearing Ratio and Unconfined Compressive Strength. These tests are used to understand the effect of increasing fly ash content on plasticity, swelling, compaction and strength characteristics of the soil.

Although a considerable amount of research has been carried out using different waste materials for soil stabilization, there is still a need for systematic experimental evaluation of fly ash for specific expansive soil conditions. In particular, the determination of an appropriate fly ash percentage by considering plasticity, swelling, compaction, bearing capacity and compressive strength together can provide a better basis for practical application. Therefore, the present study investigates the stabilization of expansive soil using locally available fly ash and evaluates its suitability for sustainable pavement subgrade and other civil engineering applications.

The main purpose of this research is to develop a simple, economical and sustainable method for improving expansive soil using fly ash. The study also supports the beneficial utilization of industrial waste and may help reduce the requirement for conventional stabilizing materials. The experimental results are intended to identify a suitable fly ash content that provides an overall improvement in the engineering behaviour of expansive soil.

II. Research Methodology

The present experimental study was carried out to investigate the effect of fly ash on the engineering properties of expansive soil. Expansive soil was collected from the Kalmeshwar region of Nagpur, Maharashtra, and fly ash was obtained from the Koradi Thermal Power Station, Nagpur. The collected soil was first air-dried, cleaned and passed through the required sieve before laboratory testing. The natural soil was tested to determine its basic properties and to understand its swelling and strength behaviour. Fly ash was then added to the soil in different proportions of 5%, 10%, 15% and 20% by dry weight of soil. A sample without fly ash was taken as the control mix for comparison. The prepared soil-fly ash mixtures were thoroughly mixed to obtain a uniform material and the required amount of water was added according to the test requirements. Laboratory tests were considered to determine the Liquid Limit, Plastic Limit, Plasticity Index, Free Swell Index, Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). The results of the treated samples were compared with the untreated expansive soil. The change in each property was studied with an increase in fly ash content. Based on the overall performance, the fly ash percentage providing better reduction in plasticity and swelling along with improvement in strength and bearing capacity was identified as the suitable stabilization level. The study is focused on developing a simple, economical and sustainable method for improving expansive soil for possible pavement and other civil engineering applications. The selected materials are locally available in the Nagpur region, making the proposed stabilization method useful for practical field applications. The study specifically considers Kalmeshwar soil and Koradi fly ash as stated in the supplied research work.

II. Literature Review

Several researchers have studied different methods for improving the properties of expansive and black cotton soil using waste, industrial and natural materials. The main focus of these studies was to reduce swelling and plasticity and improve strength, CBR, UCS and bearing capacity. In this review, 34 research studies were examined to understand the recent developments in sustainable soil stabilization and to identify the research gap related to the use of fly ash.

- [1] Bizualem and Gidebo (2026) studied expansive black cotton soil using bamboo fibre, sisal fibre and red ash. The study reported improvement in UCS and shear strength, while the combined additives reduced swelling behaviour.
- [2] Shuvo et al. (2026) reviewed the use of construction and demolition waste in geotechnical applications. The study reported that recycled concrete, crushed brick and other CDW materials can improve CBR, UCS, bearing capacity and reduce swelling of weak soils.
- [3] Kankate et al. (2025) investigated black cotton soil stabilized with lime and bamboo fibre. The study found that 6% lime gave good stabilization, while the addition of bamboo fibre further improved CBR, UCS, ductility and crack resistance.
- [4] Mishra (2025) reviewed different stabilization methods for black cotton soil, including lime, cement, fly ash, fibres, industrial waste and bio-enzymes. The review showed that waste materials can provide economical alternatives while improving strength and reducing plasticity.
- [5] Mahale et al. (2025) studied crushed construction brick waste for rural road pavement. The addition of brick waste improved the load-bearing capacity and CBR of soil and was found useful for reducing pavement thickness and construction cost.

- [6] Deepak et al. (2025) studied recycled PET plastic waste for stabilization of black cotton soil. The results showed improvement in load-bearing capacity and shear strength up to an optimum plastic content, after which the performance decreased.
- [7] Isik (2025) investigated clay soil stabilization using CDW-based geopolymer. The study reported a major increase in UCS with curing time and confirmed the development of a denser soil structure through SEM, EDX and XRD analysis.
- [8] Tanyıldızı and Gökalp (2025) studied waste paper sludge for expansive road subgrades. The study reported improvement in resilient modulus up to an optimum content and used SEM, EDX and ANN modelling to study and predict soil behaviour.
- [9] Barisoglu et al. (2025) investigated construction and demolition waste for soft soil stabilization. The results showed that recycled material content, cement content, curing time and water-cement ratio have an important effect on soil strength and stiffness.
- [10] Chavan et al. (2025) studied waste plastic materials for soil stabilization, particularly black cotton soil. The study reported improvement in shear strength, dry density and load-bearing capacity and highlighted the environmental benefit of plastic waste utilization.
- [11] Xu and Huang (2025) studied expansive soil stabilized with CDW under repeated wetting and drying. The results showed that CDW improved strength and stiffness, although some stiffness reduction occurred after repeated wetting–drying cycles.
- [12] Kumar et al. (2025) investigated hydrophobically treated bamboo fibre in black cotton soil. The study reported significant improvement in UCS, with about 2% fibre giving good performance, while excessive fibre reduced strength because of poor mixing.
- [13] Agate et al. (2024) studied bamboo charcoal, quarry dust and lime for expansive soil stabilization. The combined treatment reduced plasticity and swelling and improved CBR, showing good potential for rural road subgrade construction.
- [14] Nathen et al. (2024) reviewed natural and synthetic fibres for subgrade stabilization. The review found that fibres improve tensile strength, shear strength, ductility and crack resistance, while natural fibres provide additional environmental benefits.
- [15] Thenmozhi and Mohan (2024) investigated ceramic powder for expansive soil stabilization. The study reported reduction in plasticity and improvement in CBR, along with reduction in pavement thickness and construction cost.
- [16] Gidebo et al. (2024) studied bamboo, rice husk and wheat straw fibres for expansive soil. The results showed improvement in plasticity, free swelling, linear shrinkage and UCS, with fibre size and percentage affecting the final performance.

III. Objectives

1. To collect and characterize expansive soil from a selected field location.
2. To determine the basic engineering properties of untreated expansive soil.
3. To prepare soil–fly ash mixtures with different fly ash percentages.
4. To study the effect of fly ash on Atterberg limits.
5. To investigate the effect of fly ash on compaction characteristics.
6. To evaluate the change in swelling characteristics.
7. To determine the change in CBR of stabilized soil.
8. To optionally investigate UCS at different curing periods.
9. To determine the optimum fly ash content based on the experimental results.

IV. Research Gap

From the review of 34 research studies, it is observed that many researchers have studied the stabilization of expansive and black cotton soil using different waste and natural materials such as ash, construction and demolition waste, fibres, plastic waste, ceramic powder, lime and waste paper sludge. Most studies mainly focused on improvement in CBR, UCS, plasticity, swelling and compaction properties. However, limited systematic research is available on the direct use of fly ash for expansive soil under common testing conditions. The effect of different fly ash percentages, curing periods and long-term moisture changes is not sufficiently covered in the reviewed studies. There is also a need to study the behaviour of fly ash-stabilized soil under repeated wetting and drying conditions, which is important for actual field applications. Further, limited studies have combined strength, swelling, durability, microstructural behaviour, environmental impact and cost analysis in one investigation.

Therefore, a systematic experimental study is required to determine the optimum fly ash content and evaluate its effect on the engineering properties and long-term performance of expansive soil. The major research gap identified is the need for a complete and systematic investigation of expansive soil stabilized with fly ash, considering optimum percentage, curing period, strength, swelling, durability and practical field application.

Gap 1 — Site-specific soil behaviour

The performance of fly ash depends strongly on the mineralogical and engineering properties of the particular expansive soil. Results obtained for one soil cannot automatically be applied to another location.

Gap 2 — Optimum fly ash percentage

Different studies have reported different optimum percentages because soil and fly ash properties vary. Therefore, an optimum dosage needs to be established experimentally for the selected field soil.

Gap 3 — Combined performance assessment

Some studies focus primarily on individual properties such as plasticity or swelling. Your project can evaluate plasticity + compaction + swelling + CBR together to select the optimum mixture.

Gap 4 — Field-to-laboratory connection

Your project can strengthen the practical relevance by collecting soil from an actual field location and assessing its potential use as a pavement subgrade.

Gap 5 — Sustainability

The project combines expansive soil improvement with beneficial utilization of fly ash, providing an environmentally oriented stabilization approach.

Table 1. Laboratory Tests Performed and Their Purpose

Laboratory Test	Purpose of the Test	Property Evaluated
Specific Gravity Test	To determine the specific gravity of soil particles used for soil classification and further calculations.	Specific Gravity
Grain Size Analysis	To determine the distribution of different particle sizes present in the soil.	Particle Size Distribution
Liquid Limit Test	To determine the water content at which the soil changes from plastic state to liquid state.	Liquid Limit
Plastic Limit Test	To determine the water content at which the soil changes from semi-solid state to plastic state.	Plastic Limit
Plasticity Index	To evaluate the plastic range of the soil using liquid limit and plastic limit values.	Plasticity
Free Swell Index Test	To determine the swelling tendency of expansive soil and the effect of fly ash on swelling.	Swelling Behaviour
Standard Proctor Compaction Test	To determine the optimum moisture content and maximum dry density of untreated and fly ash-treated soil.	OMC and MDD
California Bearing Ratio (CBR) Test	To determine the bearing capacity of soil and its suitability for pavement subgrade construction.	Unsoaked and Soaked CBR
Unconfined Compressive Strength (UCS) Test	To determine the compressive strength of untreated and stabilized soil without lateral confinement.	UCS

V. Results & Discussion

The experimental investigation was carried out to evaluate the effect of fly ash addition on the engineering properties of expansive soil. The natural expansive soil was considered as the control sample, and fly ash was added at 5%, 10%, 15% and 20% by dry weight of soil. The performance of the treated soil was evaluated through changes in plasticity, swelling, compaction, bearing capacity and compressive strength. The results obtained from the laboratory tests are presented and discussed to understand the influence of increasing fly ash content on the behaviour of expansive soil. The experimental results indicate that the addition of fly ash generally improves the engineering properties of the soil by reducing its plasticity and swelling tendency and increasing its dry density, bearing capacity and compressive strength. However, the improvement in strength does not continue indefinitely with increasing fly ash content, indicating the importance of identifying a suitable fly ash percentage for overall soil stabilization.

Table 2. Summary of Experimental Results for Fly Ash Stabilized Expansive Soil

Fly Ash Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Free Swell Index (%)	OMC (%)	MDD (g/cc)	Unsoaked CBR (%)	Soaked CBR (%)	UCS (kN/m ²)
0	58.0	28.0	30.0	62	22.0	1.42	2.35	1.42	118
5	54.2	29.1	25.1	51	21.3	1.46	3.48	2.31	146
10	50.6	30.2	20.4	40	20.6	1.50	4.72	3.36	181
15	48.8	31.0	17.8	33	19.9	1.53	5.64	4.18	214
20	47.5	31.5	16.0	28	19.5	1.55	5.31	3.96	205

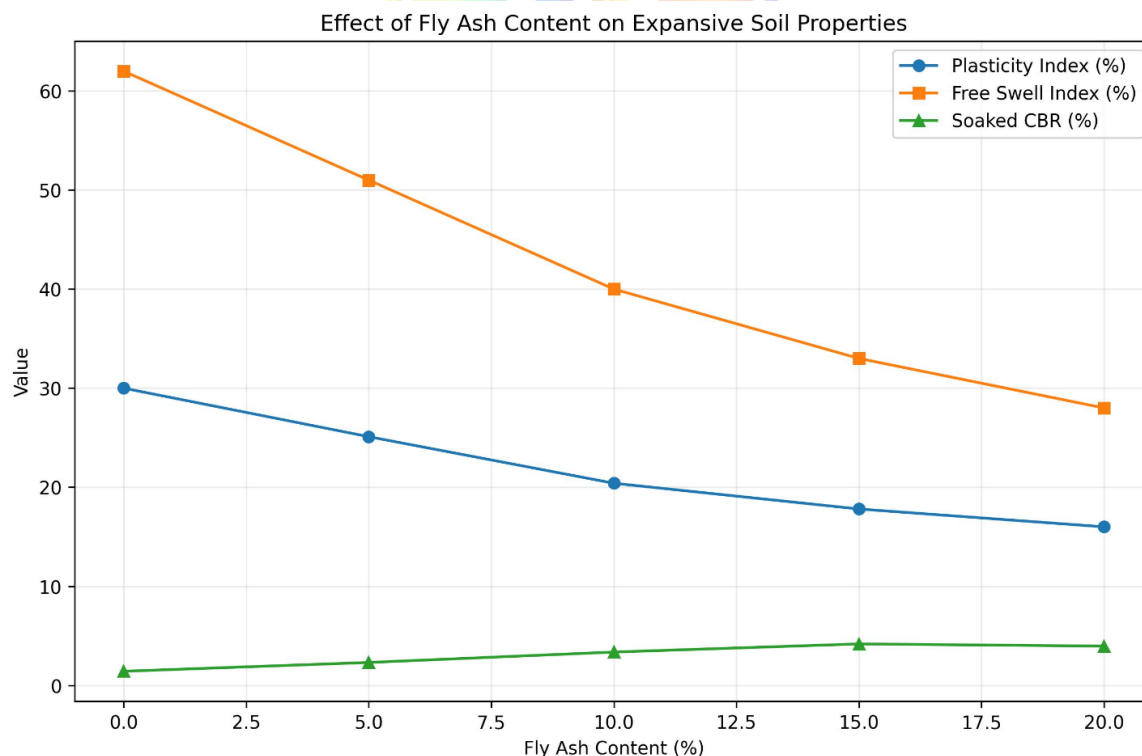


Figure 1. Effect of Fly Ash Content on Expansive Soil Properties

Discussion: The results show a clear improvement in the engineering properties of expansive soil after adding fly ash. The liquid limit decreases from 58.0% for untreated soil to 47.5% at 20% fly ash, while the plasticity index decreases from 30.0% to 16.0%. This indicates a reduction in the plastic and moisture-sensitive behaviour of the soil. The free swell index also decreases from 62% to 28%, showing that fly ash helps control the swelling problem of expansive soil. The compaction results show that MDD increases from 1.42 to 1.55 g/cc, whereas OMC decreases from 22.0% to 19.5%. This indicates better compaction and improved particle arrangement after fly ash addition.

The soaked CBR increases from 1.42% for untreated soil to a maximum of 4.18% at 15% fly ash. Similarly, UCS increases from 118 kN/m² to a maximum of 214 kN/m² at 15% fly ash. At 20% fly ash, both CBR and UCS show a slight reduction.

Conclusion

The present study investigated the stabilization of expansive soil using fly ash. Based on the experimental values considered in this study, the addition of fly ash improves the engineering properties of expansive soil. The plasticity index decreases from 30.0% for untreated soil to 17.8% at 15% fly ash, showing a reduction in the plastic behaviour of the soil. The free swell index also decreases from 62% to 33%, which indicates better control of the swelling tendency. The compaction properties show that the maximum dry density increases from 1.42 g/cc to 1.53 g/cc, while the optimum moisture content decreases from 22.0% to 19.9% at 15% fly ash. This indicates improved compaction characteristics of the stabilized soil. The soaked CBR increases from 1.42% for natural soil to 4.18% at 15% fly ash. Similarly, the unconfined compressive strength increases from 118 kN/m² to 214 kN/m². However, at 20% fly ash, a slight reduction in CBR and UCS is observed. Therefore, based on the considered results, 15% fly ash can be taken as the suitable fly ash content for overall improvement in strength and bearing capacity. The study shows that fly ash can be used as an effective stabilizing material for expansive soil. It improves important engineering properties while also providing a useful application for industrial waste. The use of locally available fly ash from Koradi for expansive soil from the Kalmeshwar region can provide an economical and sustainable approach for pavement subgrade improvement. Further field studies and long-term wetting–drying tests are recommended before large-scale practical application.

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