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Performance Assessment of Fly Ash and Cement in Stabilizing Low Strength Soil

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Abstract: The increasing rate of infrastructure development highlights the importance of geotechnical engineering in achieving sustainable and resilient construction. In many regions, particularly in Bangladesh, weak or expansive soils pose significant challenges, leading to structural failures in roads, pavements, embankments, and other critical facilities. This study investigates the potential of fly ash (F.A.) and cement as stabilizing agents to improve the engineering properties of low-strength clayey-silt soils. Laboratory tests were conducted on soil samples mixed with varying proportions of F.A. (5%, 10%, 15%, and 20%) and the same F.A. contents combined with 2% cement. The test results revealed that specific gravity decreased with increasing F.A. content due to its low unit weight but increased slightly compared to corresponding F.A.-only mixtures when cement was added, owing to cement's higher density. The liquid limit, plasticity index, and linear shrinkage decreased progressively with F.A. addition and were further reduced by cement incorporation, while the plastic limit increased, indicating improved workability and a change in soil type from clayey to silty. Direct shear tests showed that cohesion increased with F.A. content up to 15% before declining, whereas the friction angle increased steadily. The highest cohesion (36.36 kPa) was achieved with 15% F.A. + 2% cement, and the maximum friction angle (34.49°) occurred at 20% F.A. + 2% cement. Reactive oxides were found in fly ash and cement, according to XRF analysis, which supported the pozzolanic reactions. These results demonstrate that the combined use of F.A. and cement significantly enhances shear strength and reduces shrinkage, offering a cost-effective and environmentally sustainable solution for stabilizing weak soils. The findings align with the sustainable development goals by promoting resilient infrastructure and safer construction practices in challenging geotechnical environments.

Keywords: ***Stabilization, Additives, Soil modification, Direct shear test.***

Introduction

The rapid expansion of infrastructure worldwide has heightened the importance of geotechnical engineering in ensuring sustainable and resilient development. In developing countries such as Bangladesh, weak or expansive soils often cause failures in roads, embankments, and pavements, causing substantial financial losses and safety risks. Stabilizing such soils is essential to mitigating structural damage and achieving the objectives of the Sustainable Development Goals (SDGs). This study investigates the use of fly ash (F.A.) and cement as stabilizing agents to improve the engineering performance of low-strength clayey-silt soils. The practice of using fly ash, cement and other traditional additives to stabilize challenging materials for construction has been a widely accepted and popular innovation (Ola, 1977; Chen, 1988; Okagbue and Yakubu, 2000; Ikeagwuani and Nwonu, 2021). Fly ash, a byproduct of coal combustion in thermal power plants, has some favorable properties such as low unit weight, high shear strength, low compressibility, insensitive to the moisture variations and pozzolanic properties play an important role in enhancing the engineering properties of soils (Prakash and Sridharan, 2009; Dahale at el., 2016). Additionally, fly ash from power plants poses environmental challenges and creates significant cleanup obstacles.

The research evaluates changes in soil index properties and shear strength parameters through laboratory testing, with the goal of identifying a cost-effective, environmentally friendly stabilization method.

Materials and methods

Low-strength clayey silt soil, fly ash, and cement are the main materials used in this study. The disturbed soil samples were collected from a depth of 1.2-2.0 m, and the basic properties are shown in Table 1.

Table 1, Basic engineering properties of the studied clayey silt soil.

Terminology	Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)	Soil Classification	Grain Size Analysis		
								Clay (%)	Silt (%)	Sand (%)
Values	29.14	2.62	47.85	19.12	28.73	13.93	CI	40.57	41.22	18.21

Nine samples in total, comprising the original soil and soil with different percentages of additives, such as soil + F.A. (5%, 10%, 15%, and 20%) and soil + F.A. (5%, 10%, 15%, and 20%) + Cement (2%) were prepared for laboratory testing. ASTM (1974) method was followed in determining the basic geotechnical characteristics of the treated and untreated soils. To assess the strength variations, direct shear tests were also performed. Lastly, X-ray fluorescence (XRF) was used to assess the elemental composition of the original soil, fly ash, cement, and stabilized soils in order to see how they interact chemically to produce cementitious compounds, also known as pozzolanic compounds.

Results and discussions

The specific gravity of the soil decreased from 2.62 (original) to 2.43 (20% fly ash) due to the lower specific gravity of fly ash (2.1), though it slightly increased with cement addition. Liquid limit and plasticity index decreased with increasing fly ash and 2% cement, while the plastic limit increased. Linear shrinkage also declined, indicating reduced plasticity and deformation potential.

According to the BSCS plasticity chart (BS 5930:1981), all samples plot above the A-line, classifying them as inorganic clays of intermediate plasticity. Fly ash and cement addition made the soil more silty and less plastic due to flocculation, hydration, and pozzolanic reactions, which improved stiffness and bonding.

The obtained strength parameters of the natural and stabilized soils are shown in Table 2. It is found that cohesion (c) increased from 24.65 kPa to 36.36 kPa, while the angle of internal friction (ϕ) rose from 11.22° to 34.49° with the addition of fly ash and cement. Cohesion improved up to 15% fly ash but declined slightly to 20%; however, 2% cement addition consistently enhanced cohesion compared to corresponding fly ash mixtures.

Table 2, Shear strength parameters of original soil and soil with additives.

Samples	Cohesion (c)	Angle of Internal Friction (ϕ)
Original Soil	24.65	11.22
5% FA	**28.09**	**16.03**
10% FA	30.28	20.41
15% FA	**31.77**	**23.31**
20% FA	29.73	26.73
5% FA + 2% C	**32.31**	**21.95**
10% FA + 2% C	35.02	27.44
15% FA + 2% C	**36.36**	**31.76**
20% FA + 2% C	35.52	34.49

The strength gains are attributed to flocculation of clay particles, void filling, and pozzolanic reactions producing Calcium Silicate Hydrate (C.S.H.) and Calcium Aluminate Hydrate (C.A.H.) cementitious compounds, which enhance bonding and soil rigidity. XRF analysis revealed that untreated soil was siliceous with high SiO_2 (63.76%), Al_2O_3 (19.54%), Fe_2O_3 (10.51%), but very low CaO (0.56%). Addition of 5% fly ash slightly increased SiO_2 (64.42%), Al_2O_3 (20.21%), and CaO (0.59%), indicating early pozzolanic potential. Incorporating 2% cement with 5% fly ash raised CaO to 2.24% while SiO_2 and Al_2O_3 declined, reflecting active pozzolanic binding. The key reactions are:

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow C.S.H.$$

$$Al_2O_3 + Ca(OH)_2 + H_2O \rightarrow C.A.H.$$

SiO_2 decreased (63.56%) at 15% fly ash because of reaction consumption. CaO increased to 1.91% and Fe_2O_3 to 17.04% with 15% FA + 2% cement, indicating cementitious gel formation and pozzolanic activity, which are consistent with strength increases in direct shear testing.

Conclusion

This study investigated the stabilization of low-strength soil using fly ash and cement. Fly ash lowered the liquid limit and shrinkage while raising the plastic limit, making the soil less plastic and more stable. Cohesion improved up to 15% fly ash, with maximum strength at 15% fly ash + 2% cement, and friction angle also increased. XRF analysis confirmed reactive oxides in fly ash and cement, validating pozzolanic reactions behind the improvements. The combination proved effective, sustainable, and suitable for geotechnical use.

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