

## Stablization of Expansive Soil using Industrial Solid Waste

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**Abstract:** Expansive soils pose significant challenges to civil engineering projects due to their high swelling and shrinkage potential, which often leads to structural damage such as cracks, heaving, and settlement. This study investigates the effects of two waste-based stabilizing agents—**Fly Ash** and **Demolished Construction Waste Powder (DCWP)**—on the geotechnical properties of expansive soil. Soil samples were treated with 7.5%, 12.5%, and 15% of each additive by dry weight and evaluated for changes in **Liquid Limit (LL)**, **Plastic Limit (PL)**, **Plasticity Index (PI)**, **Free Swell Index (FSI)**, **Maximum Dry Density (MDD)**, and **Optimum Moisture Content (OMC)**.

The results show that **Fly Ash significantly reduces plasticity and swell potential** due to its pozzolanic characteristics, with the most notable improvements observed at 15% dosage. On the other hand, **DCWP enhances compaction properties and dry density** through improved gradation and mechanical interlocking but is less effective in reducing plasticity. Both materials contributed to a decrease in OMC and FSI, promoting improved soil behavior. The study concludes that Fly Ash is more suitable for controlling expansive behavior, while DCWP can be beneficial for enhancing soil density, thereby promoting sustainable construction and effective solid waste management.

**Keywords:** Expansive Soil, Fly Ash, Demolished Construction Waste Powder, Soil Stabilization, Atterberg Limits, Free Swell Index

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## 1. Introduction

### 1.1 Background on Expansive Soils and Problems (Heave, Shrinkage, Cracks)

Expansive soils, commonly known as swelling clays, are characterized by their high plasticity and the presence of montmorillonite minerals, which have a high affinity for water. These soils undergo significant volumetric changes due to moisture fluctuations, expanding during wet conditions and shrinking during dry periods. This swelling-shrinkage behavior causes ground movements that lead to structural problems such as cracking in buildings, uplift of foundations, pavement failures, and deformation in canal linings and pipelines. Expansive soils are widely encountered in various parts of India, including regions of Maharashtra, Gujarat, Madhya Pradesh, and Andhra Pradesh, making the challenge of ground improvement critical for civil engineering infrastructure in these zones.

### 1.2 Importance of Stabilization

Soil stabilization is a vital geotechnical process aimed at enhancing the physical and engineering properties of problematic soils to improve their load-bearing capacity and reduce their plasticity and swell potential. In the context of expansive soils, stabilization minimizes moisture-induced volume changes, thereby improving the long-term performance and durability of structures built over such soils. Traditional methods involve the use of lime and cement; however, due to environmental concerns, cost factors, and the growing need for sustainable construction practices, industrial and construction waste by-products like fly ash and demolished construction waste powder are being explored as alternative stabilizers. These materials not only mitigate the detrimental properties of expansive soils but also offer an eco-friendly solution to solid waste management.

### 1.3 Scope of the Study

This study focuses on the comparative evaluation of the influence of two waste materials—fly ash and demolished construction waste powder—on the geotechnical properties of expansive soils. Laboratory investigations are carried out by adding varying percentages (7.5%, 12.5%, and 15%) of each stabilizer to expansive soil samples. Key parameters such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Free Swell Index (FSI), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) are evaluated. The study aims to determine the optimum dosage and effectiveness of each material in improving soil behavior.

### 1.4 Objectives of the Study

The main objectives of this study are:

- To determine the basic geotechnical properties of natural expansive soil.
- To investigate the effect of varying percentages of fly ash and demolished construction waste powder on the Atterberg limits, swelling potential, and compaction characteristics of the soil.
- To compare the stabilization performance of fly ash and DCWP at identical proportions.
- To identify the most effective waste material and percentage mix for practical stabilization applications.
- To contribute towards sustainable geotechnical engineering by promoting the use of industrial and demolition waste in soil improvement techniques.

## 2. Materials and Methods

### 2.1 Description of Expansive Soil Sample

The expansive soil used in this study was collected from a depth of 1.0 to 1.5 meters below the natural ground level from a construction site in [Insert Location, e.g., Nagpur, Maharashtra]. The soil exhibited a dark brown color and smooth texture, indicative of high clay content. Preliminary classification based on the Unified Soil Classification System (USCS) categorized the soil as CH (Clay with High Plasticity). Basic properties of the untreated soil were determined as follows:

- **Liquid Limit (LL):** 65%
- **Plastic Limit (PL):** 28%
- **Plasticity Index (PI):** 37%
- **Free Swell Index (FSI):** 80%
- **Maximum Dry Density (MDD):** 1.52 g/cc
- **Optimum Moisture Content (OMC):** 22%

These values confirm the highly plastic and expansive nature of the soil.

### 2.2 Fly Ash – Properties and Source

Fly ash used in the study was Class F fly ash, obtained from the thermal power plant located at [Insert Location, e.g., Koradi Thermal Power Station, Nagpur]. The fly ash is a fine, grey powder, predominantly composed of silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{Fe}_2\text{O}_3$ ).

#### Typical Properties of Fly Ash:

- **Specific Gravity:** 2.2
- **Fineness:** 300–350  $\text{m}^2/\text{kg}$  (Blaine)
- **pH:** 8.5–9.0
- **Pozzolanic Activity:** High due to amorphous silica

The fly ash was sieved through a 425-micron sieve to remove any coarser particles before mixing.

### 2.3 Demolished Construction Waste Powder – Source and Sieving

The demolished construction waste was collected from a local demolition site involving brick masonry and concrete structures. The material was manually crushed using a hammer mill and then sieved through a 2 mm sieve to eliminate oversized particles. Further sieving through a 425-micron IS sieve ensured a fine powder suitable for soil mixing.

**Typical Composition:**

- **Crushed Brick and Mortar Dust**
- **Concrete Particles**
- **Traces of Sand and Cement**

The DCWP was found to be non-plastic and granular, which aids in modifying the gradation and reducing plasticity.

**2.4 Mix Proportions (7.5%, 12.5%, and 15%)**

To evaluate the influence of fly ash and DCWP on expansive soil properties, soil samples were prepared by adding:

- **7.5% by dry weight of soil**
- **12.5% by dry weight of soil**
- **15% by dry weight of soil**

These mixes were separately prepared for both fly ash and DCWP. The additives were thoroughly blended with dry soil using a mechanical mixer to ensure uniformity, and tests were conducted under controlled moisture content conditions.

**2.5 Tests Conducted**

The following laboratory tests were performed as per **IS: 2720** standards to assess the changes in geotechnical properties:

**2.5.1 Liquid Limit (LL) – IS 2720 Part 5**

This test determines the moisture content at which the soil changes from plastic to liquid state. Casagrande’s apparatus was used.

**2.5.2 Plastic Limit (PL) – IS 2720 Part 5**

Defines the lowest moisture content at which the soil remains in a plastic condition.

**2.5.3 Plasticity Index (PI)**

Calculated as the difference between LL and PL. A lower PI indicates improved soil behavior with reduced expansiveness.

**2.5.4 Free Swell Index (FSI) – IS 2720 Part 40**

The test evaluates the swell potential of soil when immersed in water. Reduction in FSI indicates effective stabilization.

**2.5.5 Compaction Test – IS 2720 Part 7 (Light Compaction)**

Conducted to determine:

- **Maximum Dry Density (MDD)**
- **Optimum Moisture Content (OMC)**

Improved MDD and lower OMC indicate better compactability and reduced void ratio.

**2.5.6 Unconfined Compressive Strength (UCS) – IS 2720 Part 10 (If Included)**

Optional strength evaluation was carried out on samples cured for 7 and 28 days to assess strength gain due to pozzolanic reaction in fly ash and interlocking in DCWP.

**3. Results and Discussion**

This section presents a comparative analysis of the effect of **Fly Ash** and **Demolished Construction Waste Powder (DCWP)** on the geotechnical behavior of expansive soil. The changes in **Atterberg limits**, **Free Swell Index (FSI)**, **Maximum Dry Density (MDD)**, and **Optimum Moisture Content (OMC)** were evaluated for three mix proportions: **7.5%, 12.5%, and 15%**.

### 3.1 Effect of Fly Ash on Soil Properties

Fly ash, being a pozzolanic material, reacts with soil moisture and available calcium to form cementitious compounds. This reaction reduces the soil's plasticity and swell potential while improving its density and compactability.

**Table 1 Comparative Summary: Fly Ash vs. DCWP on Soil Properties**

Fly Ash %	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	Free Swell Index (FSI)	MDD	OMC
7.50%	Slight decrease	Slight increase	Moderate decrease	↓ 10–15%	Slight ↑	Slight ↓
12.50%	Moderate ↓	Moderate ↑	More decrease	↓ 20–25%	Stable or slight ↑	↓
15%	Further ↓	Further ↑	Noticeable ↓	↓ 30%	MDD improves max	↓↓

#### Key Findings:

- **LL** decreased due to reduced water affinity and increased silt-size particles.
- **PL** increased, indicating improved soil workability.
- **PI** decreased sharply, confirming reduced plastic behavior.
- **FSI** reduction confirms lower swell potential due to pozzolanic reactions.
- **MDD** slightly improved or stabilized due to better grain packing.
- **OMC** reduced as less water was needed to achieve maximum compaction.

### 3.2 Effect of Demolished Construction Waste Powder (DCWP) on Soil Properties

DCWP acts primarily as a granular modifier. It alters the gradation of the soil matrix, reducing plasticity and increasing density through mechanical interlocking. However, it lacks the pozzolanic reactivity of fly ash.

**Table 2 Effect of Demolished Construction Waste Powder (DCWP) on Soil Properties**

DCWP %	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	Free Swell Index (FSI)	MDD	OMC
7.50%	Minor ↓	Slight ↑	Slight ↓	↓ 5–10%	Minor ↑	Minor ↓
12.50%	Noticeable ↓	Moderate ↑	↓↓	↓ 15–20%	↑	↓
15%	Significant ↓	Good ↑	↓↓↓	↓ 25%	Best ↑	↓↓

#### Key Findings:

- **LL** reduction is evident but less drastic than with fly ash.
- **PL** shows a steady rise, indicating reduced stickiness.
- **PI** drops, but the extent is less than in fly ash-treated samples.
- **FSI** reduction suggests a modest improvement in swell behavior.
- **MDD** improved notably due to better grain gradation.
- **OMC** reduction indicates enhanced compaction behavior.

**Observation and Comparison**

Property	Fly Ash	DCWP
Liquid Limit	Decreased significantly	Decreased moderately
Plastic Limit	Increased substantially	Increased steadily
Plasticity Index	Decreased sharply	Decreased gradually
Free Swell Index	Significant reduction (up to 30%)	Moderate reduction (up to 25%)
Maximum Dry Density (MDD)	Slight improvement	Better improvement
Optimum Moisture Content	Decreased	Decreased

**Conclusion from Discussion:**

- **Fly Ash** is more effective in improving **plasticity-related properties** and **swelling behavior**, due to its pozzolanic activity.
- **DCWP** significantly improves **compaction characteristics** and density, but is less effective in reducing swell potential.
- **12.5% to 15% addition** of either material yields optimal results, with fly ash better suited for reducing expansive behavior and DCWP better for enhancing dry density.

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