

AN EXPERIMENTAL STUDY ON HYBRID STABILIZATION OF EXPANSIVE SOILS USING LIME, COIR FIBER AND POLYPROPYLENE FIBER REINFORCEMENT

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ABSTRACT

Expansive soils exhibit significant volume change due to moisture variation, causing severe damage to pavements, foundations, and light structures. This study investigates the effectiveness of hybrid stabilization using Lime, Coir Fiber, and Polypropylene Fiber in improving the engineering properties of expansive soil. Lime was added in proportions of 4%, 5%, and 6% by dry weight of soil. Coir fiber was added at 0.25%, 0.5%, and 0.75%, while polypropylene fiber was added at 0.1%, 0.25%, and 0.5%. Laboratory tests including Atterberg limits, Standard Proctor Compaction, Sieve Analysis, Specific Gravity, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and Swell Tests were conducted. The study evaluates the improvement in strength, compaction, and swelling characteristics due to chemical and mechanical stabilization. Results indicate significant reduction in plasticity and swell potential, and substantial improvement in strength and bearing capacity. The hybrid combination showed superior performance compared to individual stabilization.

KEY WORDS: Expansive soils, CCF (coconut coir fibres), Lime, Polypropylene fibre, Soil improvement, sustainable construction.

1. INTRODUCTION

Expansive soils are highly plastic clayey soils that undergo significant volume changes due to variations in moisture content. These soils swell during wet conditions and shrink during dry periods. Such behavior creates serious geotechnical problems, including cracking of pavements, differential settlement of foundations, and reduction in bearing capacity. In many parts of India, expansive soils—particularly **black cotton soils**—pose major challenges for construction and infrastructure development. To overcome these problems, soil stabilization techniques are commonly adopted to improve soil strength and reduce swelling characteristics. Among the various stabilization methods, **lime stabilization** is widely used as an effective chemical treatment. Lime reacts with clay minerals through **cation exchange and pozzolanic reactions**, which reduces soil plasticity and increases strength. However, soils treated only with lime may exhibit **brittle behavior**, which can lead to sudden failure under loading conditions. This limitation can be minimized by incorporating **fiber reinforcement** into the soil matrix. Natural fibers such as **coir fiber** improve ductility and contribute to sustainable construction practices, while synthetic fibers like]

polypropylene fiber enhances tensile strength and crack resistance. Therefore, combining lime with both natural and synthetic fibers can create a **hybrid stabilization technique** that improves soil performance more effectively than using individual additives. This study focuses on the hybrid stabilization of expansive soil using varying percentages of **lime, coir fiber, and polypropylene fiber** to evaluate improvements in compaction characteristics, strength properties, and swelling behavior for sustainable and economical ground improvement.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Soil stabilization has been an important area of research in geotechnical engineering due to the widespread problems associated with expansive and weak soils. Expansive soils, characterized by high clay content, exhibit significant swelling and shrinkage with changes in moisture content, which can lead to structural damage, cracking of pavements, and failure of foundations. Over the years, various chemical, mechanical, and hybrid stabilization techniques have been explored to improve the engineering behavior of such soils.

Chemical stabilization, particularly using lime, has been extensively studied for its ability to reduce plasticity, increase strength, and lower swelling potential through cation exchange and pozzolanic reactions. Fiber reinforcement, using natural fibers like coir and synthetic fibers such as polypropylene, has been investigated for enhancing soil ductility, tensile strength, and crack resistance. Recent research has focused on hybrid stabilization, which combines chemical stabilizers with fiber reinforcement to harness the advantages of both methods, resulting in improved strength, durability, and workability. This chapter presents a detailed review of previous studies on lime stabilization, coir fiber and polypropylene fiber reinforcement, and hybrid stabilization techniques, highlighting the key findings and identifying gaps that the present study aims to address.

2.2 Lime Stabilization of Expansive Soils

Lime stabilization is one of the most extensively researched chemical stabilization methods. The addition of lime to clay soils initiates cation exchange, flocculation–agglomeration, and pozzolanic reactions, which reduce plasticity and improve strength characteristics.

Atkinson and Zhang (2009) reported that the addition of 4–6% hydrated lime to high-plasticity clay significantly reduced plasticity index and swelling potential while improving unconfined compressive strength (UCS). They noted that the pozzolanic reaction between lime and silica/alumina phases in clay creates cementitious products that enhance soil cohesion and stiffness. George et al. (2013) investigated the effect of lime on expansive black cotton soil and found that optimum lime content resulted in a considerable increase in California Bearing Ratio (CBR) values and reduced swell pressure. The study concluded that higher lime content accelerated the transformation of clay minerals into stable compounds, yielding long-term strength gains. However, researchers have also observed that lime-treated soils may exhibit brittle failure characteristics under load, which motivates the exploration of fiber reinforcements to improve ductility.

2.3 Coir Fiber Reinforcement in Clay Soil

Natural fibers have gained significant interest due to their environmental compatibility, renewability, and cost-effectiveness. Coir fiber, extracted from coconut husk, possesses high tensile strength and elongation characteristics

when compared to other natural fibers. Kumar and Singh (2015) evaluated the effect of coir fiber reinforcement on clay soils and reported up to a 40% increase in UCS and improved ductile behavior with fiber contents of 0.5–0.75%. The study highlighted that coir fibers bridge micro-cracks and delay crack propagation, leading to enhanced post-peak strength. Similarly, Ramana et al. (2017) observed that inclusion of coir fibers in expansive soil markedly reduced swell potential and improved compaction characteristics. The fiber reinforcement mechanisms were attributed to the tensile load transfer between soil matrix and fibers, which increased resistance to deformation. While coir fibers improve ductility and crack resistance, natural fibers may exhibit slight degradation over long exposure to moisture, which suggests the need to explore combinations with synthetic fibers for balanced performance.

3. MATERIALS USED

3.1 Introduction:

The materials used in the present study include expansive soil, lime, coir fiber, and polypropylene fiber. Each material plays a significant role in improving the soil properties.



Black cotton soil

Fig-1



lime

Fig-2



Coir fiber



Polypropylene fiber

3.2 Expansive Soil

The soil used in this study is an **expansive clay soil collected from the Gooty area**. Expansive soils, also known as swelling clays, exhibit significant volume changes due to variations in moisture content. When water content increases, these soils swell, and when moisture decreases, they shrink. This shrink–swell behavior can cause severe damage to pavements, foundations, and other light structures. The soil sample was collected from a **depth of 0.5–1.0 m below the ground surface**. This depth represents the **active zone**, which experiences considerable moisture variation due to seasonal changes and plays an important role in supporting structures. Before stabilization, the soil was **air-dried, pulverized, and sieved through a 4.75 mm sieve** to remove large particles and ensure uniformity during testing.

Table 3.1 Physical and Mechanical Properties of Expansive Soil

Property	Observed Value
Grain Size Distribution	Clay with silt
Atterberg Limits	LL: 50–60%, PL: 20–40%, PI: 25–60%
Specific Gravity (G)	2.6–2.8
Natural Moisture Content	19%
Swelling Potential	High

3.3 Lime

The stabilizing agent used in this study is **hydrated lime (Ca(OH)₂)**, which is commonly used in soil stabilization. Hydrated lime is produced by adding water to quicklime (CaO) in a process known as slaking, resulting in a fine powder with strong alkaline properties. Lime stabilization improves soil properties through chemical reactions with clay minerals.

Purpose in the Study

- Acts as a chemical stabilizer for expansive soil
- Reacts with clay minerals to form cementitious compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH)
- Improves soil strength, workability, and durability
- Reduces plasticity and swelling potential

Proportions Used

- **4%, 5%, and 6%** by dry weight of soil

The main stabilization reaction occurring in lime-treated soils can be represented as:

These cementitious products bind soil particles together and increase soil strength.

Table 3.2 Physical Properties of Lime

Property	Typical Value / Range
Appearance	White powder
Odor	Mild alkaline smell
Particle Size	< 90 μm
Specific Gravity	2.4
Bulk Density	0.8 g/cm ³
Solubility in Water	Slightly soluble (~1.5 g/L at 20°C)

3.4 Coconut Coir Fiber

Coconut **coir fiber** is a natural fiber obtained from the outer husk of coconuts. It is widely used in soil stabilization due to its **high tensile strength, flexibility, and environmental sustainability**.

Coir fiber is biodegradable and renewable, making it an eco-friendly reinforcement material for geotechnical applications.

Purpose in the Study

- Acts as mechanical reinforcement in expansive soil
- Improves tensile strength and ductility
- Reduces shrinkage cracks
- Enhances soil cohesion and resistance to deformation

Proportions Used

- **0.25%, 0.5%, and 0.75%** by dry weight of soil

3.5 Polypropylene Fiber

Polypropylene (PP) fiber is a **synthetic polymer fiber** commonly used in civil engineering for soil reinforcement. It is chemically inert and resistant to moisture, acids, and alkalis, making it suitable for long-term soil stabilization.

When mixed with soil, polypropylene fibers improve **tensile strength, crack resistance, and durability**.

Purpose in the Study

- Acts as a mechanical stabilizer
- Improves tensile strength and toughness
- Reduces shrinkage cracking
- Enhances structural stability of soil

Proportions Used

- 0.1%, 0.25%, and 0.5% by dry weight of soil

Table 3.5 Physical and Mechanical Properties of Polypropylene Fiber

Property	Typical Value / Range
Fiber Length	6–12 mm
Diameter	18–50 μm
Specific Gravity	0.91–0.93
Tensile Strength	300–500 MPa
Elongation at Break	15–25%
Melting Point	160–170°C
Chemical Resistance	Excellent
Modulus of Elasticity	3.0–5.0 GPa

4.METHODOLOGY

This chapter presents the methodology adopted to study the behavior of expansive soil stabilized using lime, coir fiber, and polypropylene fiber. Laboratory investigations were carried out on both untreated and treated soil samples to evaluate improvements in index properties, compaction characteristics, strength, and swelling behavior. All tests were conducted in accordance with relevant **Indian Standard (IS) Code 2720**

4.1 Methodology Flow:

The sequence of work carried out is as follows:

1. Collection of soil sample
2. Drying, pulverizing, and sieving
3. Determination of properties of untreated soil
4. Preparation of treated soil mixes
5. Laboratory testing of treated soil

4.2 Collection of Soil Sample:

The soil sample was collected from a depth of about 1 m below the ground surface to avoid organic matter and surface impurities. The collected soil was air-dried, pulverized, and sieved through a 4.75 mm sieve before testing.

44.3.1.1 Liquid limit (LL):

To determine the water content at which soil changes from **plastic state to liquid state.**

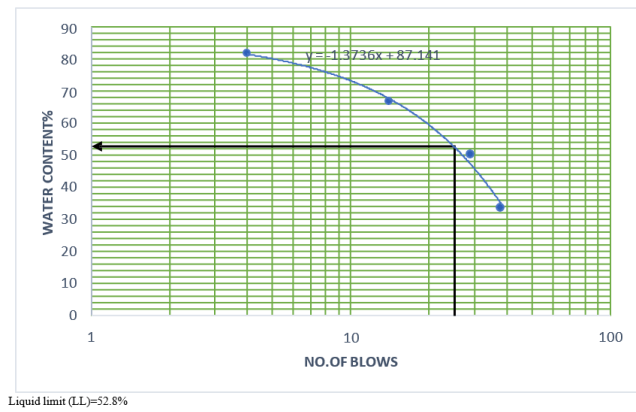


The soil sample passing through a 425 micron IS sieve is taken and mixed thoroughly with distilled water to form a uniform, smooth paste. A portion of this prepared soil paste is placed in the cup of the Casagrande liquid limit apparatus and spread evenly to a uniform thickness using a spatula. A standard grooving tool is then used to cut a clean groove along the center line of the soil mass in the cup. The handle of the apparatus is rotated at a uniform speed of about two revolutions per second, causing the cup to rise and fall freely. The number of blows required to bring the two sides of the soil groove together along a length of about 12 mm is carefully counted and recorded. Immediately after this, a small representative sample of the soil is taken from near the closed groove to determine its moisture content. The test is repeated for at least three to four trials by adjusting the water content of the soil to obtain different numbers of blows, typically ranging between 10 and 40. A graph is then plotted between the water content and the logarithm of the corresponding number of blows. The liquid limit of the soil is determined as the water content corresponding to 25 blows from the plotted flow curve.

Table-6: Liquid limit values

Description	Sample-1	Sample-2	Sample-3	Sample-4
Container no	6	9	7	2
No of blows	38	29	14	4
Empty weight of container (w1)	25g	25g	25g	25g
Empty weight of container + wet soil (W2)	45g	41g	40g	45g
Empty weight of (W3) container + oven dry soil	40g	35g	34g	36g
Weight of water W4=((W2-W3)-W1)	5g	5g	6g	9g
Weight of oven dry soil W5=(W3-W1)	15g	10g	9g	11g
Water Content W=W4/w5 x100	33.33%	50%	66.67%	81.81%

Graph-1: Flow Curve



4.3.7 CBR test:

To determine the bearing capacity of soil and its suitability for use as a subgrade material in pavements and road construction.

4.3.4 Standard Proctor Test:

To determine the optimum moisture content (OMC) at which a given soil attains its maximum dry density (MDD) under a specified compaction effort. Take a representative air-dried soil sample passing the 4.75 mm sieve and mix it thoroughly with a known amount of water to bring it to a desired moisture content, then assemble the standard Proctor mould (1000 cc capacity) with its base plate and collar, and apply a light coat of oil to the inside; place the moist soil into the mould in three equal layers, compacting each layer by giving 25 blows with a 2.6 kg rammer falling freely from a height of 310 mm, ensuring uniform distribution of blows over the surface; after compacting the top layer, remove the collar, trim off the excess soil to make the surface flush with the top of the mould, clean the exterior, and weigh the mould with the compacted soil to determine its bulk density; then take a representative sample from the mould to determine its moisture content; subsequently, break the soil, add more water to increase the moisture content, and repeat the compaction process for different moisture contents (at least 4–5 trials); finally, calculate the dry density for each trial and plot a graph between moisture content and dry density to determine the optimum moisture content (OMC) and maximum dry density (MDD).



Fig-21



Fig-22

Take a representative soil sample, air-dried and passing the 20 mm sieve, and mix it thoroughly with water to achieve the desired moisture content; compact the soil into a CBR mould in three layers using a standard compaction rammer, giving 56 blows per layer for the standard CBR test (or 25 blows per layer for the **modified test**), ensuring uniform compaction and levelled surface; carefully remove the collar and insert a perforated metal base plate at the bottom, then place the mould with the compacted sample into the CBR testing machine and apply a surcharge weight if required; immerse the mould in water (soaked CBR) or keep it at natural moisture (unsoaked CBR) for the specified soaking period, usually 4 days for soaked conditions; after soaking, attach the penetration piston (usually 50 mm diameter) to the proving ring and lower it onto the soil surface; apply load at a uniform penetration rate of 1.25 mm/min and record the corresponding load readings at penetration depths of 0.625 mm, 1.25 mm, 1.875 mm, 3.125 mm, 5 mm, 7.5 mm, and 10 mm; finally, calculate the CBR value using the formula $CBR (\%) = \frac{\text{Load on soil}}{\text{Standard load}}$ at 2.5 mm and 5 mm penetrations, and report the higher of the two as the CBR of the soil.



Table-13: CBR observation table

Penetration (mm)	Penetration Load (kg)	Standard Load (kg)	CBR Calculation	CBR (%)
0	0	1370	$(0/1370) \times 100$	0
0.5	20	1370	$(20/1370) \times 100$	1.46
1	35	1370	$(35/1370) \times 100$	2.55
1.5	50	1370	$(50/1370) \times 100$	3.65
2	60	1370	$(60/1370) \times 100$	4.38
2.5	68	1370	$(68/1370) \times 100$	4.96
3	75	2055	$(75/2055) \times 100$	3.65
4	90	2055	$(90/2055) \times 100$	4.38
5	102	2055	$(102/2055) \times 100$	4.96

CBR at 2.5 mm penetration is 4.96%.

Curing process for UCS and CBR Tests:

Curing Procedure for UCS and CBR Tests: For both the Unconfined Compressive Strength (UCS) test and the California Bearing Ratio (CBR) test, the soil sample is first prepared at its optimum moisture content and compacted into the mould in layers using a standard compaction method. For UCS, the compacted cylindrical specimen is placed in a moist curing environment, typically wrapped in wet cloth or kept in a humidity- controlled chamber at room temperature, for a specified period (commonly 1, 3, 7, or 28 days) to allow the soil or stabilized mix to develop strength uniformly before testing.

For CBR, after compaction in the CBR mould, the sample is soaked in water for 4 days (96 hours) to simulate worst-case field moisture conditions, ensuring the soil reaches full saturation and equilibrium prior to penetration testing. Both curing processes are crucial to replicate field conditions and obtain reliable strength and bearing values.

Table-14: long term UCS values

Days Cured	UCS (kPa)	Load (N)
0	59.5	480
7	83.3	671
14	95.2	768
28	113.1	912



Fig-23

Table-15: Long Term CBR values

Days Cured	CBR (%)
0	4.965
7	6.95
14	7.94
28	9.43



Fig-24

4.4.3 Standard Proctor Test:

To determine the optimum moisture content (OMC) at which a given soil attains its maximum dry density (MDD) under a specified compaction effort.

A representative sample of soil mixed with the required percentages of lime, coir fiber, and polypropylene fiber was air-dried and pulverized. The calculated amount of water was added to the mix and thoroughly blended to achieve uniform moisture distribution, taking care to ensure even dispersion of fibers.

The moist soil was then compacted in a standard Proctor mould of 1000 cm³ capacity in three equal layers, each layer receiving 25 blows from a 2.6 kg rammer falling from a height of 310 mm. After compaction, the collar was removed and the excess soil was trimmed to level the surface. The weight of the mould with compacted soil was recorded, and a sample was taken to determine moisture content. This procedure was repeated for different moisture contents to obtain a range of dry densities. The dry density corresponding to each moisture content was calculated and plotted to obtain the compaction curve, from which the OMC and MDD were determined. Special care was taken to ensure uniform mixing and proper compaction, as the presence of fibers can affect density and compaction behavior.

Table-19: Proctor Compaction values for (4% lime:0.25% coir fiber:0.1% polypropylene fiber)

Description	Sample-1	Sample-2	Sample-3	Sample-4
Empty weight of mould(w1)	5515g	5515g	5515g	5515g
Weight of mould + soil(w2)	7238g	7268g	7338g	7240g
Volume of cylinder D=10.16cm, H=11.6cm	940.44 cc	940.44 cc	940.44 cc	940.44 cc
Weight of soil in the mould(W)	1723g	1753g	1823g	1725g
Water content(w)	8%	11%	14%	17%
Bulk density				
$\rho_b = \frac{M}{V}$	1.83 g/cc	1.89 g/cc	1.908 g/cc	1.88 g/cc
Dry density				
$\rho_d = \frac{w}{1+w} \rho_b$	1.10 g/cc	1.6 g/cc	1.69 g/cc	1.56 g/cc

Table-20: Proctor compaction values after adding of additives

Lime (%)	Coir fiber (%)	Polypropylene fiber (%)	Dry density(g/cc)	Moisture content (%)
4	0.25	0.1	1.69	14
5	0.5	0.25	1.77	12
6	0.75	0.75	1.38	14

4.4.4 UCS Test:

To determine the unconfined compressive strength of cohesive soil. For the Unconfined Compressive Strength (UCS) test on soil treated with lime, coir fiber, and polypropylene fiber, first air-dry the soil, pulverize it, and pass it through a 4.75 mm sieve to remove coarse particles; then add the required percentage of lime to the dry soil and mix thoroughly, followed by the uniform distribution of randomly oriented coir fibers and polypropylene fibers in the desired proportions to avoid balling, after which water is added to bring the मिश्रण to the optimum moisture content determined from compaction tests; the prepared mix is then compacted into cylindrical molds (commonly 38 mm diameter and 76 mm height) in layers to achieve maximum dry density, and the specimens are carefully extruded and sealed to prevent moisture loss before being cured for specified periods (such as 7, 14, or 28 days) under controlled conditions to allow proper pozzolanic reactions and bonding; after curing, the specimens' dimensions and weight are measured, and they are placed in the UCS testing machine where axial load is applied मिना lateral confinement at a constant strain rate (around 0.5–2% per minute) until failure, and the maximum load is recorded to calculate the unconfined compressive strength as the peak load divided by the corrected cross-sectional area.

Table-21: UCS Values for Treated Soil of different curing daya (kPa)

Mix (Lime % : Coir % : PP %)	0 Days	7 Days	14 Days	28 Days
(4 : 0.25 : 0.1)	85	145	185	240
(5 : 0.5 : 0.25)	115	205	260	340
(6 : 0.75 : 0.5)	110	195	250	325

4.4.5 CBR Test:

To determine the bearing capacity of soil and its suitability for use as a subgrade material in pavements and road construction.

For conducting the California Bearing Ratio (CBR) test on soil treated with lime, coir fiber, and polypropylene fiber, the soil is first air-dried, pulverized, and sieved through a 4.75 mm sieve to remove coarse particles; the required percentage of lime is then added and mixed thoroughly with the dry soil, followed by the uniform addition of coir fiber and polypropylene fiber in specified proportions to ensure proper distribution without clustering; water is then added to bring the mixture to the optimum moisture content obtained from compaction tests; the prepared mix is compacted into the CBR mold in layers using standard compaction to achieve maximum dry density, and surcharge weights are placed on top to simulate field conditions; for soaked CBR, the specimen is immersed in water for 4 days while maintaining the surcharge load; after soaking, the mold is placed in the CBR testing machine, and a plunger is penetrated into the specimen at a constant rate of 1.25 mm per minute, recording the load at penetrations of 2.5 mm and 5 mm, and the CBR value is calculated as the ratio of the measured load to the standard load expressed as a percentage, with the higher value generally reported as the CBR of the treated soil.

Table-22: CBR Values (%) for Treated Soil of different curing days

Mix (Lime % : Coir % : PP %)	0 Days	7 Days	14 Days	28 Days
(4 : 0.25 : 0.1)	7.5	11.2	13.5	16.8
(5 : 0.5 : 0.25)	9.2	14.8	18.6	23.5
(6 : 0.75 : 0.5)	8.8	13.9	17.2	21.8

RESULTS & DISCUSSIONS

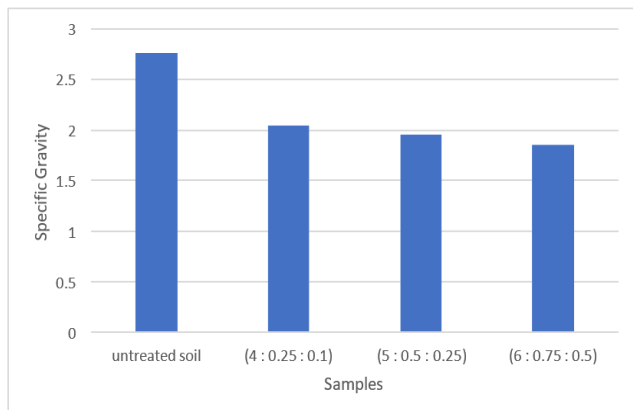
In this chapter, we present and interpret the data we obtained from our experiments.

5.1 Atterberg Limits:

- Untreated soil is highly plastic clay.
 - Fibers prevent direct Atterberg testing on treated soil, but lime treatment is expected to improve soil consistency and stability.

5.2 Specific Gravity:

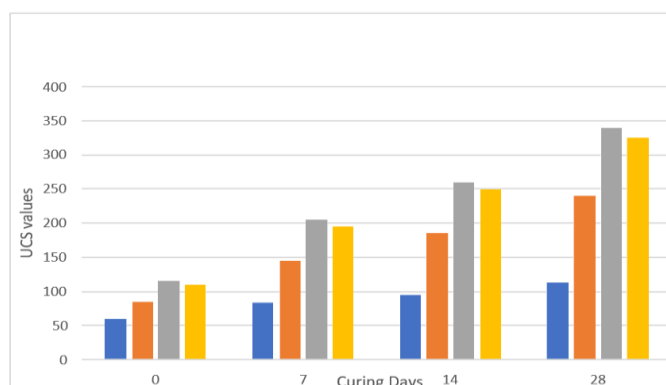
Graph-5: Specific Gravity Vs Samples



- The specific gravity of untreated soil is **2.76**, typical for clayey soils.
- The specific gravity decreases progressively with the addition of lime, coir fiber, and polypropylene fiber.
- The reduction is due to the lower specific gravity of fibers (coir and polypropylene) compared to soil minerals.
- Higher fiber and lime content in the treated mixes results in lower bulk density and specific gravity, indicating increased porosity and lighter soil structure.

5.3 UCS Test:

Graph-6: UCS Values Vs Curing days



- The UCS values for all soil samples **increase progressively with curing time** from 0 to 28 days, indicating ongoing pozzolanic reactions and improved soil strength over time.

- The **lowest UCS values** (blue bars) correspond to the untreated soil, starting around 60 kPa at day 0 and increasing to about 110 kPa at 28 days.

- The **treated soil mixes** (represented by orange, grey, and yellow bars) show significantly higher UCS values at all curing stages compared to untreated soil, confirming the effectiveness of lime, coir fiber, and polypropylene fiber in soil stabilization.

- Among the treated mixes:

- The **grey bars** represent the mix with 5% lime, 0.5% coir fiber, and 0.25% polypropylene fiber, showing the **highest UCS values** at all curing periods, reaching approximately 340 kPa at 28 days, indicating this as the optimum mix proportion for maximum strength gain.

- The **yellow bars** (likely 6% lime, 0.75% coir fiber, 0.5% polypropylene fiber) also show high UCS values but slightly less than the grey bars, possibly due to excess fiber content reducing bonding efficiency.

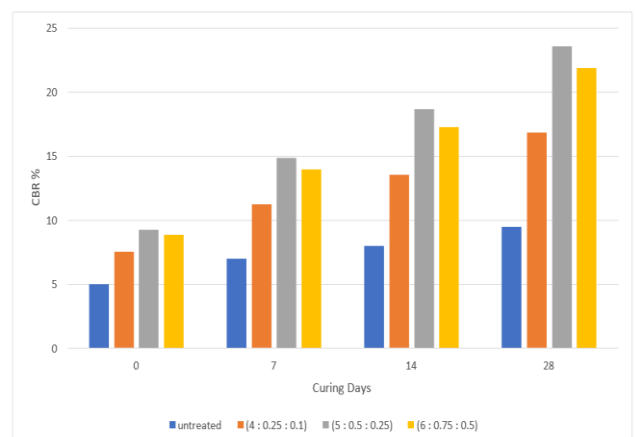
- The **orange bars** (4% lime, 0.25% coir fiber, 0.1% polypropylene fiber) exhibit moderate strength improvement compared to untreated soil but less than higher lime and fiber mixes.

- The consistent increase in UCS with curing time highlights the importance of adequate curing to allow lime-soil chemical reactions and fiber-matrix bonding to develop fully.

- Overall, the graph demonstrates that lime stabilization combined with fiber reinforcement significantly enhances soil strength, with the mix containing 5% lime and moderate fiber content providing the best performance.

5.4 CBR Test:

Graph-7: CBR Vs Curing days



1. The graph shows a steady increase in CBR values with increasing curing days for both untreated and treated soils, reflecting strength gain over time due to lime stabilization and fiber reinforcement.
2. The **untreated soil** (blue bars) has the lowest CBR values throughout, starting at about 5% on day 0 and reaching just under 10% at 28 days, indicating relatively poor bearing capacity without treatment.
3. All **treated soil mixes** exhibit significantly higher CBR values compared to untreated soil at all curing periods, demonstrating the effectiveness of the combined lime and fiber treatment in improving soil strength and load-bearing capacity.
4. Among the treated mixes:
 - The mix with **5% lime, 0.5% coir fiber, and 0.25% polypropylene fiber** (grey bars) consistently shows the highest CBR values, reaching approximately 24% at 28 days, indicating this combination provides the best reinforcement and stabilization effect.
 - The mix with **6% lime, 0.75% coir fiber, and 0.5% polypropylene fiber** (yellow bars) shows slightly lower CBR values than the 5% lime mix, possibly due to excessive fiber content causing reduced compaction or bonding efficiency.
 - The mix with **4% lime, 0.25% coir fiber, and 0.1% polypropylene fiber** (orange bars) shows moderate improvement over untreated soil, with CBR values increasing up to around 17% at 28 days.
5. The increasing trend of CBR with curing days highlights the importance of allowing sufficient curing time for the pozzolanic reactions and fiber-soil interactions to fully develop strength.
6. Overall, the results confirm that the optimal mix ratio is 5% lime with moderate fiber content, which yields the highest CBR values and thus the best improvement in soil bearing capacity.

CONCLUSION

- The untreated soil was identified as poorly graded clay with a liquid limit of 52.8%, plastic limit of 27.3%, and plasticity index of 25.5%, indicating medium to high plasticity and poor engineering properties.
- The specific gravity of untreated soil was found to be 2.76, which decreased with the addition of lime, coir fiber, and polypropylene fiber due to the lower density of stabilizing

materials.

- The Unconfined Compressive Strength (UCS) of untreated soil increased from 59.5 kPa to 113.1 kPa over 28 days, whereas treated soil showed significant improvement. The maximum UCS of 340 kPa was obtained for the mix containing 5% lime, 0.5% coir fiber, and 0.25% polypropylene fiber, indicating it as the optimum mix.
- Similarly, the California Bearing Ratio (CBR) of untreated soil increased from 4.965% to 9.43%, while treated soil showed substantial improvement. The highest CBR value of 23.5% was observed for the same optimum mix, making it highly suitable for subgrade applications.
- The results indicate that the addition of lime improves soil strength through pozzolanic reactions, while coir and polypropylene fibers enhance ductility and resistance to cracking.
- Among all mixes, the combination of 5% lime, 0.5% coir fiber, and 0.25% polypropylene fiber was found to be the most effective in improving both strength and bearing capacity.
- Based on the improved UCS and CBR values, the treated soil can be effectively used in road subgrades, embankments, and foundation layers, making it a sustainable and economical solution for weak soil stabilization.

Recommended:

- The study shows that soil stabilized with 5% lime, 0.5% coir fiber, and 0.25% polypropylene fiber gives the best performance; hence, this mix is recommended as the optimum proportion for improving weak clayey soils.
- The stabilized soil can be effectively used in road subgrade construction, especially for rural roads and low-volume traffic roads, where improvement in CBR is essential.
- It is recommended to adopt this stabilization technique in embankments and earth fills, as the addition of fibers enhances ductility and reduces cracking.
- Proper curing time (at least 14 to 28 days) should be ensured in field applications to achieve maximum strength due to lime's pozzolanic reactions.
- Uniform mixing of lime and fibers is essential in field conditions to avoid clustering of fibers, which may reduce strength.

- The use of natural coir fiber makes the method environmentally friendly and cost-effective; however, durability of coir in long-term applications should be considered.

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