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# Experimental Study on use of Bamboo Powder and Ground Granulated Blast Furnace Slag (GGBS) As Admixtures for Improving Strength of An Expansive Subgrade Soil

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**ABSTRACT:** Expansive soil is a type of clay soil that shows high swelling when water is added and shrinkage when it becomes dry. Due to this behavior, expansive soil creates many problems in construction, such as cracks in foundations, roads, and buildings. Therefore, stabilization of expansive soil is necessary to improve its strength and reduce swelling characteristics. In the present study, expansive soil was stabilized using Bamboo Powder and Ground Granulated Blast Furnace Slag (GGBS) as eco-friendly additives. The experimental study was carried out in three stages. Initially, Bamboo Powder was added in proportions of 2%, 4%, 6%, and 8% by dry weight of soil. Among these, 4% Bamboo Powder showed the highest strength and was identified as the optimum dosage. In the second stage, GGBS was incorporated at 5%, 10%, 15%, 20%, and 25%, with the best performance observed at 15% GGBS. In the final stage, the optimum combination of 4% Bamboo Powder and 15% GGBS was applied to the soil. Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests were conducted to evaluate the stabilized soil. The results revealed a significant improvement in strength and load-bearing capacity, with maximum performance achieved after 7 days of curing. The study demonstrates that the combined use of Bamboo Powder and GGBS is an effective, economical, and sustainable approach for stabilizing expansive soil for subgrade and foundation applications.

**KEYWORDS:** Expansive Soil, Bamboo Powder (BP), Ground Granulated Blast Furnace Slag (GGBS), Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR).

## I. INTRODUCTION

Soil is an important component in the construction of roads, pavements, and foundations, as the stability of structures depends on the strength of the underlying soil. Expansive soils create major engineering problems because they swell when wet and shrink when dry, leading to cracks and settlement in structures. To improve such soils, stabilization techniques are used by adding suitable materials that enhance strength and reduce plasticity.

In this paper focuses on use of Bamboo Powder (BP) and Ground Granulated Blast Furnace Slag (GGBS) were used as sustainable stabilizing materials for expansive subgrade soil. Bamboo powder is a natural eco-friendly material, while GGBS is an industrial by-product with cementitious properties. The use of these materials improves soil strength and supports sustainable construction by utilizing waste resources. Laboratory tests were conducted to evaluate the engineering properties of the stabilized soil, and the results showed significant improvement in soil strength and performance.

## II. LITERATURE SURVEY

[1] Shailesh Kumar Yadav et al. (2023) studied bamboo powder-based biochar for clay soil stabilization and found that it improved shear strength, water retention, and bonding between soil particles. The study concluded that bamboo materials enhance soil stability through filler and reinforcement effects.[2] Essizewa Agate et al. (2024) investigated bamboo powder with lime for expansive soil stabilization. The results showed reduced plasticity and swelling with improved CBR values, indicating better subgrade performance.[3] Chakraborty et al. (2023) studied bamboo-based materials for sandy soil and slope stabilization. The study reported improved shear strength and slope stability due to reinforcement and particle interlocking.[4] Shunmei Gong et al. (2024) examined the use of GGBS, fly ash, and lime in silt soil stabilization. The study found that pozzolanic reactions significantly enhanced soil strength and durability with curing time.[5] Zhang et al. (2024) investigated GGBS and fly ash mixtures for soft clay stabilization. The results showed improved early strength and durability due to C-A-S-H gel formation, proving GGBS as an eco-friendly stabilizer.

## III. MATERIALS AND METHODOLGY

The materials used in the present study are discussed in this Part. Material Used are Expansive Soil, Bamboo Powder and Ground Granulated Blast Furnace Slag GGBS.

**EXPANSIVE SOIL:** Expansive soil for this study was collected from Gujala Mandyam, Tirupati, at a depth of 2 m below ground level. The soil was air-dried, pulverized, sieved through a 4.75 mm IS sieve, and tested to determine its engineering properties.

**BAMBOO POWDER:** The material used in this study was obtained from Mrida Green & Development Pvt. Ltd.. It contained a high silica content of about 75% SiO<sub>2</sub>, which helped improve pozzolanic reactions and bonding in stabilized soil. The material consisted of fine white granules, with all particles passing through a 150 $\mu$  sieve. Before use, the material was air-dried and sieved through a 150  $\mu$ m sieve to ensure uniformity. It was then mixed with soil at proportions of 0%, 2%, 4%, 6%, and 8% by dry weight of soil. The chemical properties of the material are shown in Table 1.

Table 1: The Chemical Properties of Bamboo Powder

S. No	Property	Value
1	Ph (1% solution)	10.83
2	Total Silica Content	76.52%
3	Lead (Pb)	0.42 ppm
4	Arsenic (As)	0.18 ppm
5	Cadmium (Cd)	0.06 ppm
6	Mercury (Hg)	0.02 ppm

**GROUND GRANULATED BLAST FURNACE SLAG (GGBS):** Ground Granulated Blast Furnace Slag (GGBS) used in this study was collected from the RO plants supply area near Achyutham Block. GGBS contains Calcium, Silica, Alumina, and Magnesium Compounds, which contribute to the formation of Cementitious products that enhance soil strength and stability. Before mixing, the material was air-dried and passed through a 75  $\mu$ m sieve to obtain uniform particle size. It was then added to the soil in proportions of 0%, 5%, 10%, 15%, and 20% by dry weight of soil. The chemical properties of the material are shown in Table 2.

Table 2: The Chemical Composition of Ground Granulated Blast Furnace Slag

S. No	Minerals	Percentages
1	Calcium Oxide	30-50%
2	Silica	28-38%
3	Alumina	8-24%
4	Magnesia	1-18%
5	Iron	0.2-16%
6	Manganese	0.15-0.76%
7	Sulphur	1.0-1.9%

### III. METHODOLOGY

The experimental program conducted to evaluate the effectiveness in stabilizing selected expansive soil using BP and GGBS. Different proportions of each additive, along with varying curing periods, were considered to study their effect on compaction, strength, and CBR.

Table 3 Methodology of the Study

S.NO	Sample	% of Bamboo Powder	% of GGBS	Curing time (days)	Test Conducted
1	Soil	0	0	0	<ul style="list-style-type: none"> <li>• Atterberg limits</li> <li>• Compaction Characteristics</li> <li>• Unconfined Compressive Strength</li> <li>• CBR</li> </ul>
2	Soil+ Bamboo powder	0,2,4,6,8	0	0,3,7,14	<ul style="list-style-type: none"> <li>• Compaction Characteristics</li> <li>• Unconfined Compressive Strength</li> <li>• CBR</li> </ul>
3	Soil+ GGBS	0	0,5,10,15,20	0,3,7,14	<ul style="list-style-type: none"> <li>• Compaction Characteristics</li> <li>• Unconfined Compressive Strength</li> <li>• CBR</li> </ul>
4	Soil + Bamboo Powder + GGBS	4 (Optimum)	15 (Optimum)	0,3,7,14	<ul style="list-style-type: none"> <li>• Compaction Characteristics</li> <li>• Unconfined Compressive Strength</li> <li>• CBR</li> </ul>

Different soil mixtures were prepared with varying percentages of BP and GGBS to evaluate their effect on the stabilization characteristics of expansive soil. Bamboo powder was added at 0–8%, while GGBS was added at 0–20% by dry weight of soil. The mix designations and mix proportions used in this study are presented in Table 5 and Table 6.

Table 4: Mix Designations of GGBS Mixed Sample

S. No	Mix Designations	% of Bamboo Powder	Proportions
1	B1	0	100% Soil
2	B2	2	100% Soil+2%BP
3	B3	4	100% Soil+4%BP
4	B4	6	100% Soil+6% BP
5	B5	8	100% Soil+8% BP

Table 5: Mix Designations of GGBS Mixed Sample

S. No	Mix Designations	% of GGBS	Proportions
1	G1	0	100% Soil
2	G2	5	100% Soil+5%GGBS
3	G3	10	100% Soil+10%GGBS
4	G4	15	100% Soil+15% GGBS
5	G5	20	100% Soil+20% GGBS

#### IV. EXPERIMENTAL RESULTS

**Properties of Untreated Soil:** Expansive soil for this study was collected from Gujala Mandyam, Tirupati, at a depth of 2 m below ground level. The soil was air-dried, pulverized, sieved through a 4.75 mm IS sieve, and tested to determine its engineering properties. Based on the test results of selected soil is given table 6 Liquid Limit (68.5%), Plastic Limit (43.05%), Plasticity Index (25.5%), and Free swell Index (170%) the soil was identified as Expansive Soil.

Table 6 Properties of Tested Expansive Soil

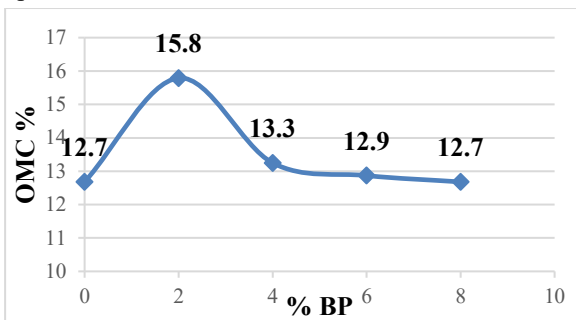
S. No	Property	Reference	Value
1A	Gravel (%)	IS: 2720(Part 4), 1985	0
B	Sand (%)	IS: 2720(Part 4), 1985	40.6%
C	Silt+ Clay (%)	IS: 2720(Part 4), 1985	59.4%
2	Specific Gravity of Coarse Fraction (G)	IS: 2720(Part3) sec 1,1980	2.6
	Specific Gravity of Fine Fraction (G)	IS: 2720(Part3) sec 1,1980	2.7
	Specific Gravity of Total Soil (G)	IS: 2720(Part3) sec 1,1980	2.65
3	Liquid Limit (%)	IS: 2720(Part5),1985	68.6%
4	Plastic Limit (%)	IS: 2720(Part5),1986	43.1 %
5	Plasticity Index	IS: 2720(Part5),1986	25.5 %

6	Free Swell Index (%)	IS: 2720(Part40),1977	170.0%
7	Maximum Dry Density (MDD)	IS: 2720(Part8),1980	19.10(kN/m <sup>3</sup> )
8	Optimum Moisture Content (OMC) (%)	IS: 2720(Part8),1980	12.7%
9	Unconfined Compression Strength (kPa)	IS: 2720(Part10),1991	195.55
10	Californian Bearing Ratio (Unsoaked) (%)	IS: 2720(Part16),1987	12.8
	Californian Bearing Ratio (Soaked) (%)	IS: 2720(Part16),1987	9.1
11	IS Classification	IS: 1498	CH SOIL

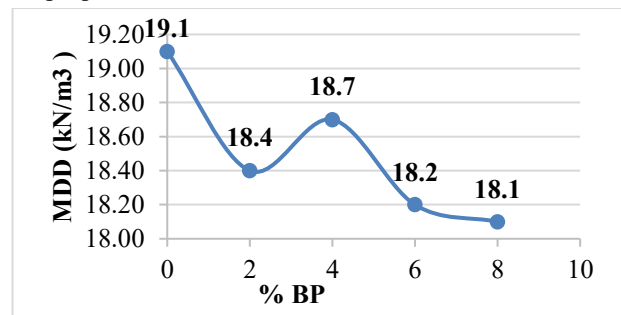
**Tests Conducted on Treated Soil:**

1. Modified Proctor Test
2. Unconfined Compressive Strength (UCS)
3. California Bearing Ratio test (CBR)

**Modified Proctor Test:** The Proctor Compaction Test, also known as the Heavy Compaction Test, is conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil. The test identifies the moisture content at which the soil achieves maximum compaction by reducing air voids. In this study, the test was performed on both untreated soil and soil mixed with different proportions of Bamboo Powder and GGBS to evaluate



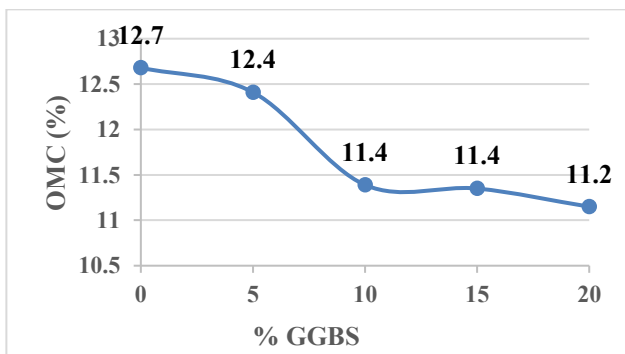
Graph 1 Variation of OMC of (Soil- BP) Mixes



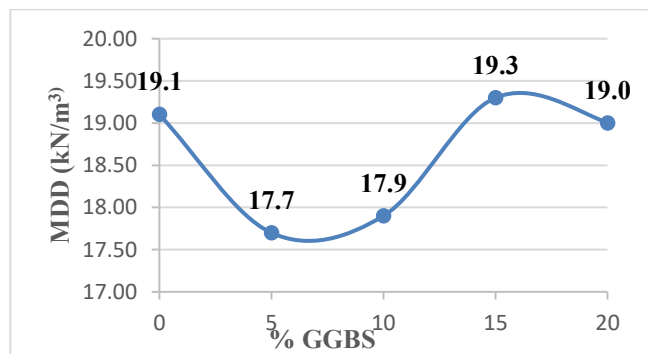
Graph 2 Variation of MDD of (Soil- BP) Mixes

the effect of stabilization on compaction characteristics.

The Heavy Compaction Test showed that BP affects the compaction properties of expansive soil. The addition of BP increased the OMC and decreased the MDD due to its water absorption and lightweight nature. Among all mixes, 4% BP showed the best compaction performance.



Graph 3 : Variation of OMC of (Soil-GGBS) Mixes



Graph 4 :Variation of MDD of (Soil- GGBS) Mixes

The addition of GGBS reduced the OMC and increased the MDD of expansive soil. The maximum dry density was achieved at 15% GGBS, showing improved compaction characteristics. Beyond 15% GGBS, the MDD decreased due to excess slag reducing particle bonding.

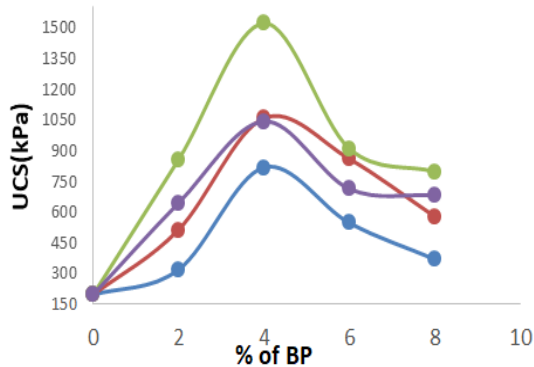
V. UNCONFINED COMPRESSIVE STRENGTH TEST

Unconfined compressive strength test was conducted on pure soil and soil mixed Bamboo powder in different proportions at different curing periods of 0,3,7,14 days. Samples were prepared at optimum moisture content obtained from heavy compaction test and stress strain graphs were plotted.

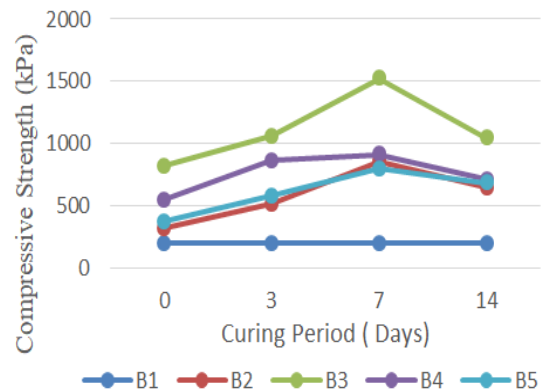
**(SOIL – BP) Mixes:** In this study, the Unconfined Compressive Strength (UCS) test was conducted on soil stabilized with BP. BP was added in proportions of 0%, 2%, 4%, 6%, and 8% by dry weight of soil. The specimens were prepared at OMC and cured for 0, 3, 7, and 14 days before testing.

Table 7: UCS values of (Soil- BP) Mixes

% Mixes	BP	UCS (kPa) Curing days			
		0 Days	3 Days	7 Days	14 days
0 %	(B1)	195.55	195.55	195.55	195.55
2 %	(B2)	317.83	512.98	855.44	643.50
4 %	(B3)	<b>817.84</b>	<b>1058.33</b>	<b>1522.11</b>	<b>1043.11</b>
6 %	(B4)	546.55	859.49	910.13	712.58
8 %	(B5)	369.14	577.59	797.15	711.13



Graph 5: Variation of UCS of (Soil- BP) Mixes



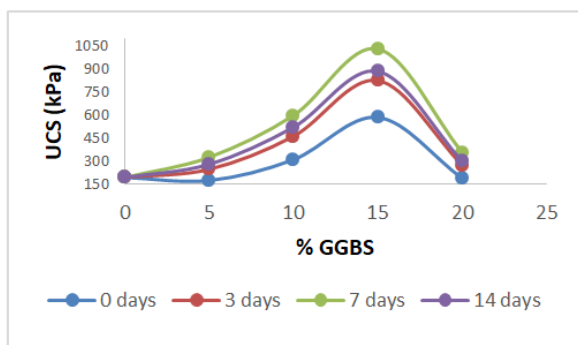
Graph 6: Variation of UCS of (Soil- BP) Mixes with curing days

The UCS results showed that BP improved the strength of expansive soil up to an optimum level. The maximum UCS value was obtained at 4% BP with 7 days of curing, indicating the best performance. Beyond 4%, the strength decreased due to reduced bonding and compaction efficiency.

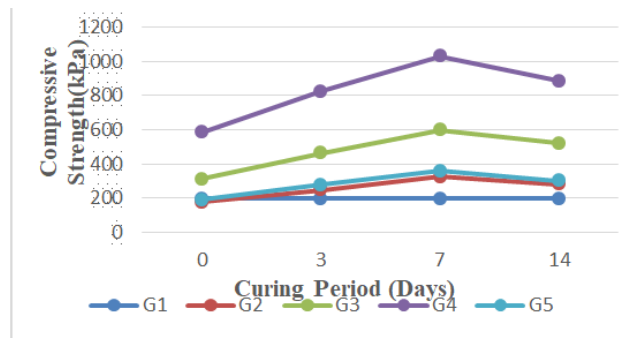
**(SOIL - GGBS) Mixes:** In this study, the Unconfined Compressive Strength (UCS) test was conducted on soil stabilized with GGBS. GGBS was added in proportions of 0%, 5%, 10%, 15%, and 20% by dry weight of soil. The specimens were prepared at OMC and cured for 0, 3, 7, and 14 days before testing.

Table 8: UCS values of (Soil- GGBS) Mixes

% GGBS Mixes	UCS (kPa)			
	0 Days	3Days	7 Days	14 Days
0 % (G1)	195.55	195.55	195.55	195.55
5% (G2)	175.93	248.61	326.48	281.34
10% (G3)	310.95	462.73	598.26	521.90
15% (G4)	585.70	825.31	1030.47	884.81
20% (G5)	189.23	276.41	358.79	301.65



Graph 7: Variation of UCS of (Soil- GGBS) Mixes



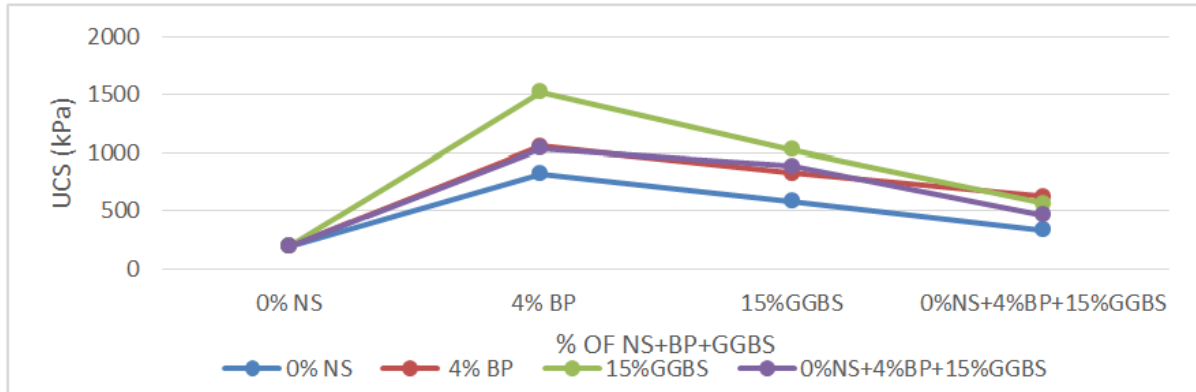
Graph 8: Variation of UCS of (Soil- GGBS) Mixes with Curing Days

The UCS results indicate that the addition of GGBS improves the strength of expansive soil up to an optimum level. The maximum UCS value of 1030.474 kPa was obtained at 15% GGBS with 7 days curing, showing the best performance. Beyond 15% GGBS, the strength decreased due to excess slag reducing effective bonding between soil particles.

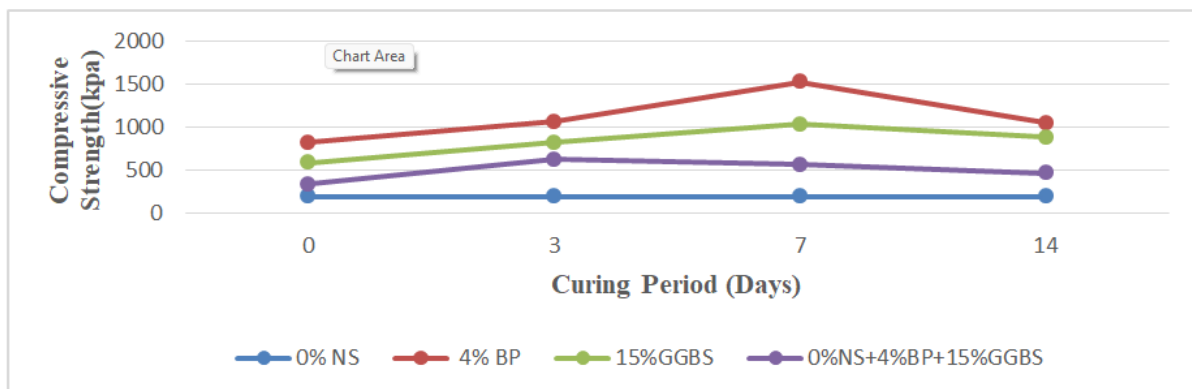
**(SOIL-BP-GGBS) Mixes:** In this study, the Unconfined Compressive Strength (UCS) test was conducted on soil mixed with 4% BP, 15% GGBS, and their combined mix. The specimens were prepared at Optimum Moisture Content (OMC). All samples were cured for 0, 3, 7, and 14 days before testing.

Table 9: UCS values of (Soil-4%BP-15%GGBS) Mixes with Curing

% of NS+BP+GGBS	UCS (kPa)			
	0	3	7	14
0% NS	195.55	195.55	195.55	195.55
Soil+4% BP	817.84	1058.33	1522.11	1043.11
Soil+15%GGBS	585.71	825.31	1030.47	884.81
0%NS+4%BP+15%GGBS	335.50	625.32	565.39	464.80



Graph 9: Variation of UCS of (Soil- 4%BP -15%GGBS) Mixes

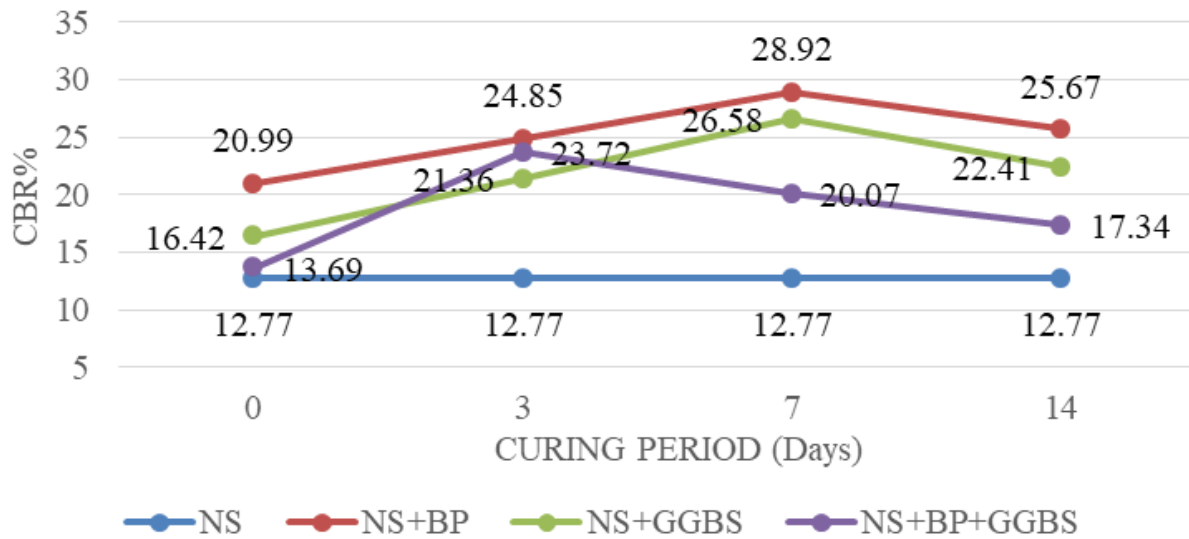


Graph 10: Variation of UCS of (Soil-4%BP -15%GGBS) Mixes with curing day

The UCS results showed that both BP and GGBS improved the strength of expansive soil compared to untreated soil. The highest UCS value of 1522.114 kPa was obtained with 4% bamboo powder after 7 days of curing, indicating optimum performance. Soil treated with 15% GGBS also showed significant strength improvement, with a maximum UCS of 1030.474 kPa at 7 days curing. Overall, BP performed better than GGBS, while the combined mix showed comparatively lower strength.

**3. CALIFORNIA BEARING RATIO TEST:** California bearing test was conducted at Optimum Percentages based on Unconfined Compressive Strength test, which is 4% BP alone with treated soil and 15% GGBS alone treated soil.

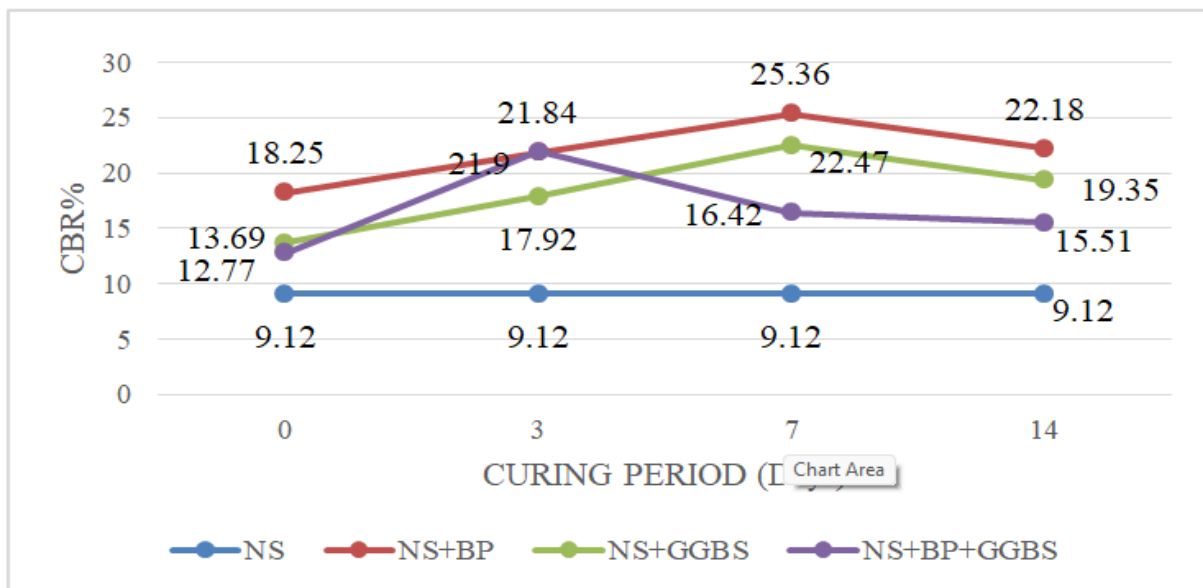
**UNSOAKED CBR:** The unsoaked CBR test results show that the addition of BP and GGBS significantly improved the strength of expansive soil compared to natural soil. The maximum CBR values were observed at 7 days curing, indicating effective soil stabilization and strength enhancement.



Graph 11: Variation of Unsoaked CBR of (Soil-Admixtures) Mixes with Curing Period (Days)

The unsoaked CBR results showed that untreated soil maintained a low and constant CBR value throughout all curing periods. Soil treated with 4% BP exhibited significant improvement, achieving the highest CBR value at 7 days of curing. Similarly, soil stabilized with 15% GGBS also showed considerable improvement due to cementitious reactions. Overall, the stabilized soils demonstrated enhanced strength, with optimum performance observed after 7 days curing.

**SOAKED CBR:** The soaked CBR test results show that natural soil has low strength under saturated conditions, while the addition of BP and GGBS significantly improves the CBR values. The maximum strength was observed around 7 days curing, indicating effective stabilization of expansive soil under soaked conditions.



Graph 12: Variation of Soaked CBR of (Soil-admixture) Mixes with Curing Period

The soaked CBR results showed that untreated soil had a low CBR value under saturated conditions. Soil treated with 4% BP and 15% GGBS showed significant improvement, with maximum strength observed at 7 days curing. The increase in CBR was due to improved particle bonding and cementitious reactions in the stabilized soil. Overall, soil stabilization effectively enhanced the soaked strength characteristics of expansive soil.

## VI. CONCLUSION

1. The Atterberg limits and free swell index tests confirmed that the collected soil possesses high plasticity.
2. The Modified Proctor test showed that the addition of BP and GGBS changed the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil.
3. The UCS test results indicated significant strength improvement, with maximum values obtained at 4% BP and 15% GGBS after 7 days of curing.
4. The soaked and unsoaked CBR test results showed considerable improvement in load-bearing capacity for stabilized soil compared to untreated soil.
5. Overall, the study proved that BP and GGBS are effective and sustainable materials for enhancing the engineering properties of expansive soil.

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