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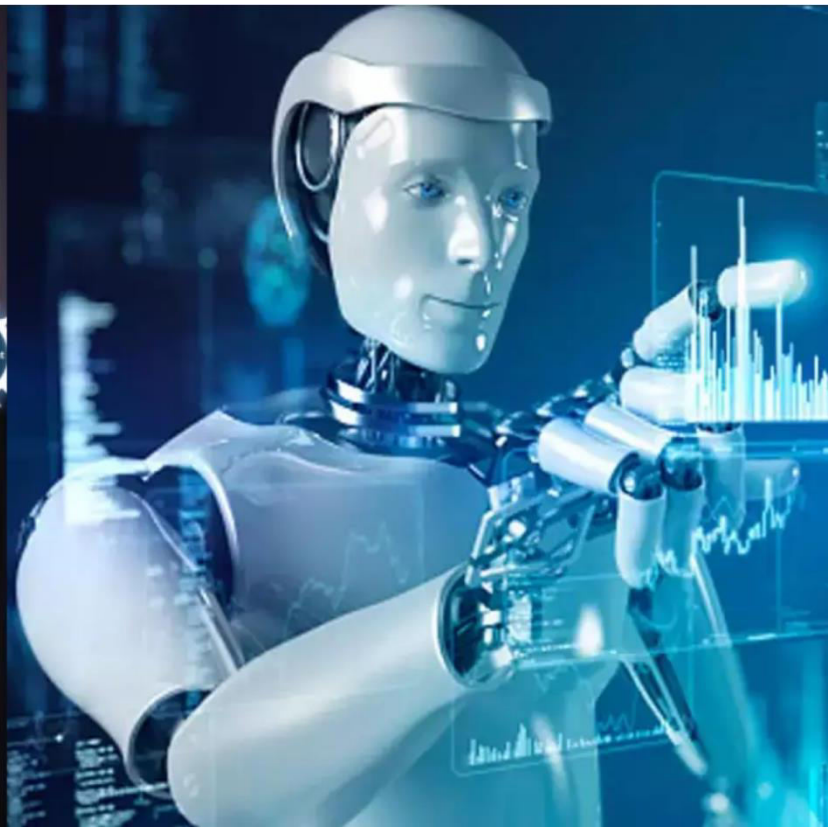

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Effect of Rice Husk Biochar and GGBS on the Engineering Behaviour of an Expansive Soil

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ABSTRACT: The results of enhancing expansive soil's geotechnical behaviour using a mix of Biochar and GGBS are detailed in this article. On a selected expansive soil, involving tests for Atterberg limits, IS Light Compaction, Unconfined Compressive Strength and California Bearing Ratio as per Indian Standard code demonstrated the effectiveness of chemical stabilization techniques using Rice Husk BIOCHAR (RHB) and GGBS. The research revealed that the addition of RHB and GGBS both individually and in combination at varying percentages, resulted in improved engineering properties of the soil over different curing periods (0,7,14, and 28 days). Specifically, the unconfined compressive strength (UCS) test results showed enhanced soil strength with prolonged curing periods for samples treated with RHB and GGBS. The combination of RHB at percentages of (5-15%) and GGBS at percentages of (5-20%) proved to be particularly effective in enhancing the strength and the soil's California Bearing Ratio. It was discovered that this novel stabilizing technique was economical, non-destructive, energy-efficient, and environmentally benign. The results suggest that the optimum combination of RHB and GGBS can serve as a viable solution for stabilizing expansive soils offering improved engineering properties and sustainability benefits.

KEYWORDS: Expansive Soil, Geotechnical Engineering, Soil Stabilization, GGBS, RHB.

I. INTRODUCTION

The role of soil in civil engineering is indeed fundamental, as it serves as the foundation for all structures and also used as construction material. Geotechnical engineering, a specialized branch of civil engineering, focuses on studying characteristics of the soil to ascertain its ability to support loads and appropriateness for building endeavours.

Soil classification based on physical and engineering characteristics is crucial in assessing the feasibility of site development and foundation support. The weathering of rocks leaves behind residual soils, which are known as expansive soils. The country's most troublesome soils are these. More than 20% of India's total land area is covered with expansive soils. In addition to Madhya Pradesh, Maharashtra, Andhra Pradesh, Gujarat, Tamil Nadu, and Karnataka, it extends to other regions of India. These soils affect the roads, buildings, embankments and engineering structure. Regur, or black cotton soil, is a special kind of soil distinguished by its deep black hue and expanding characteristics.

Soil samples were taken two meters below ground level to guarantee uniform characteristics and prevent contamination from the surface. Rice husk is the rice residue which can cause Environmental problems. Pyrolysis of Rice husk yields RHB. Given below are the sustainable approaches for utilizing RHB so as to avoid Environmental problems. Reapplying RHB to paddy fields as a Soil amendment. Enhance the soil quality of problematic soils such as Expansive soils by mixing the soil with Optimum RHB and further modify with self-cementing industrial waste such as GGBS.

Blast furnace slag is an industrial by-product which is produced in large quantity from iron industries after extraction of iron from iron ores in a blast furnace and poses serious disposal problems and creating environmental hazards. Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

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II. LITERATURE SURVEY

Lu *et al.* [3] compared how different dosages (0–10%) and particle sizes (fine, medium, and coarse) of biochar influence soil cracking behaviour under drying conditions. The primary testing methods included desiccation cracking tests using image analysis software (CIAS), scanning electron microscopy (SEM) for microstructural analysis, and mercury intrusion porosimetry (MIP) to assess pore structure. **Garg *et al.* [4]** This study investigates Biochar derived from pyrolyzed peach pit biomass was applied to kaolin and bentonite soils at 0%, 5%, and 10% by weight and subjected to controlled dispersion and sedimentation testing using distilled and saline water containing NaCl concentrations of 0%, 1%, 5%, and 10%. **Chen *et al.* [5]** Saturation was enhanced in soils treated with biochar, which yielded 8% biochar for fine-grained soils, 6% for medium-grained soils, and 2% for coarse-grained soils. However, the impact on coarse soils was minimal. **Kamdar and Solanki [6]** research into the effects of varying biochar contents on soil properties revealed that plasticity index, specific gravity, maximum dry density, and liquid/plastic limits all dropped; free swell index went from 54% in virgin soil to 38% after adding 10% biochar.

Nepal *et al.* [7] said it is a tool for achieving sustainable soil management and environmental protection, advocating for interdisciplinary research to fully realize its global potential. The optimal moisture content, maximum dry density, liquid limit, plastic limit, and plasticity index all drop as the GGBS % rises, according to research by Ashish Kumar Pathak, Dr. V. Pandey, Krishna Murari, and J.P. Singh [11]. Soft soil was combined with GGBS at several percentages (0, 3, 6, 9, and 12%), according to Ruqayah Al-khafaji, Hassnen M. Jafer, Anmar Dulaim, W. Atherton, and ZahraaJwaida [12]. Utilization of GGBS enhanced the soil's physical and strength properties, according to the findings. Incorporating GGBS into soil reduced the Plasticity Index while increasing MDD and decreasing OMC.In order to enhance the soil's qualities, Sravanthi et al. [13] reported using2%,4%, and 6% on black cotton soil. Soil tests like Atterberg's limit, compaction test, CBR, and UCS are used to learn about soil characteristics. This study confirms that RBI Grade-81 is an effective material for improving subgrade soil. According to Chandan Kumar Behera and Satyapriya Senapati [14], the expansive soil had a liquid limit of 52.33%, a plastic limit of 22.45%, and a specific gravity of 2.6. Adding varying percentages of GGBS and stone dust decreased the OMC and increased the MDD. Adding varying proportions of GGBS and stone dust also increased the UCS value.

Biochar and GGBS both work as soil stabilizers, but they do so in different ways, according to the research we looked at. As a sustainable substance, biochar improves soil microstructure and water retention. GGBS has a profound effect on cementitious reactions, making them stronger and less plastic. Combining expansive soil with RHB and GGBS has only been examined in a small number of research. The combination of RHB and GGBS enhances compaction behavior, increases gel formation, and decreases cracks.

III. MATERIALS USED

The materials used in this study are An Expansive soil, Rice Husk Biochar, GGBS

Table 1: Biochar Made from Rice Husks: Its Physical and Chemical Characteristics

PHYSICAL PROPERTIES	**RESULTS**
PHYSICAL STATE	Micronised Powder
ODOUR	Odourless
APPEARANCE	Black Colour Powder
COLOUR	Black
PACK DENSITY	0.77 gm/cc
pH of 5% SOLUTION	6.91
SPECIFIC GFRAVITY	2.64
OIL ABSORPTION	54 ml / 100 gms
CHEMICAL PROPERTIES	
SILICA (SIO_2)	21.42%
FERRIC OXIDE (Fe_2O_3)	8.83%

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TITANIUM OXIDE (TiO_2)	47.22%
CALCIUM OXIDE (CaO)	2.88%
MAGNESIUM OXIDE (MgO)	5.12%
POTTASIUM OXIDE (K_2O)	4.96%
SODIUM OXIDE (Na_2O)	9.01%
LOSS ON IGNITION	0.001%
HEAVY METALS: LEAD (Pb) ARSENIC (As)	 0.550% 0.000%

Table 2 Chemical properties of GGBS

S.No	Characteristics	Test Protocol	Range (%)	Typical Result (%)
1	SiO_2	IS: 4032:1985 Reaff 2009	32.00 to 38.00	35.20
2	Al_2O_3	IS: 4032:1985 Reaff 2009	14.00 to 20.00	18.80
3	CaO	IS: 4032:1985 Reaff 2009	32.00 to 38.00	35.38
4	MgO	IS: 4032:1985 Reaff 2009	6.00 to 10.00	6.93
5	Fe_2O_3	IS: 4032:1985 Reaff 2009	0.70 to 1.50	1.30
6	MnO	IS: 4032:1985 Reaff 2009	0.30 to 0.90	0.37
7	Chloride	IS: 11224:1985 Reaff 2010	0.02 to 0.07	0.022
8	Total Alkalis	IS: 4032:1985 Reaff 2009	0.50 to 1.00	0.58
9	Sulphide Sulphur	IS: 4032:1985 Reaff 2009	0.20 to 0.50	0.28
10	Insoluble Residue	IS: 4032:1985 Reaff 2009	1.00 to 3.00	1.90
11	Loss on Ignition	IS: 4032:1985 Reaff 2009	0.10 to 0.70	0.20
12	Glass Content	IS: 12089:1987 Reaff 2004	86.00 to 94.00	93.25
13	Free Moisture	IS: 12089:1987 Reaff 2004	10.00 to 20.00	12.00

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III. METHODOLOGY

Soil qualities may be altered by adding self-cementing materials, which cause pozzolanic materials to react with water to produce cementitious materials. Pozzolanic characteristics are shown by the main and secondary binders that are often used for stabilization. Primary binders include cement and lime, whereas secondary binders include gypsum, fly ash, rice husk biochar, and blast furnace slag. Any or all of the binders may be used. This research looks at how RHB and GGBS may be utilized to make Expansive soil stronger. Soil strength qualities may be better understood with the use of tests like the California Bearing Ratio and Unconfined Compressive Strength. At first, soil combined with RHB was subjected to compaction experiments to ascertain its compaction properties. The Unconfined Compressive Strength tests were carried out at different OMC and MDD concentrations of 5%, 10%, and 15% RHB, and then left to cure for 7, 14, and 28 days, respectively. At the optimal RHB level, GGBS was applied to the soil in several percentages:5%,10%,15%, and 20%. We measured the treated materials' Unconfined Compressive Strength (UCS) after 0, 7, 14, and 28 days of curing, as well as their California Bearing Ratio (CBR). According to the results of the comparison, the different therapies' efficacy varied with the duration of the healing process.

IV. EXPERIMENTAL RESULTS

Properties of untreated soil:
Expansive soil for this study came from Gajulamandyam in Andhra Pradesh's Tirupati area. Soil samples were taken two meters below ground level to guarantee uniform characteristics and prevent contamination from the surface. The findings showed that the soil was classified as expansive soil based on its plasticity index (57.13%), free swell index (245%), and liquid limit (72.21%).

Table 3: Properties of Untreated soil:

S.No	Property	Method adopted	value
1	Gravel **(%)**	IS: 2720 (Part 4)- 1985	1.00
2	Sand (%)	IS: 2720 (Part 4)-1985	43.00
3	Silt (%)	IS: 2720 (Part 4)-1985	16.00
4	Clay (%)	IS: 2720 (Part 4)-1985	40.00
5	Specific Gravity (G)	IS: 2720 (Part 3); Sec 1:1980	2.68
6	Liquid Limit (%)	IS: 2720 (Part 5)-1985	72.21
7	Plastic Limit (%)	IS: 2720 (Part 5)-1986	15.08
8	Plasticity index	IS: 2720 (Part 5)-1986	57.13
9	Free Swell Index (%)	IS: 2720 (Part 40)- 1977	235.00
10	Maximum Dry Density (MDD) (kN/m^3)	IS: 2720 (Part 7)-1980	18.05
11	Optimum Moisture Content (OMC) (%)	IS: 2720 (Part 7)-1980	14.00
12	Unconfined Compression Strength (kPa)	IS: 2720 (Part 10)-1991	67.49
13	IS Classification	IS: 1498	CH

Evaluation of Treated Soil:
1.The Revised Proctor Test
2. Unconfined Compression Strength Experiment
3. Atterberg limits
4. California Bearing Ratio test.

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Mix Designations for Rice husk biochar mixed sample are shown in Table 4:

Table 4 Mix Designations for Rice husk biochar mixed sample

S.No.	Mix designations	%RHB	Details about mix
1	M_0	0	100% Soil
2	M_1	5	95% Soil+5% RHB
3	M_2	10	90% Soil+10% RHB
4	M_3	15	85% Soil+15% RHB

Table 5: Assigning Mixtures to RHB and GGBS

S.No.	Mix designations	% RHB	%GGBS	Details about mix
1	M_{21}	Optimum Obtained from Table 4	5	85% Soil+10% RHB+5%GGBS
2	M_{22}	Optimum Obtained from Table 4	10	80%Soil+10% RHB+10% GGBS
3	M_{23}	Optimum Obtained from Table 4	15	75% Soil+10% RHB+15% GGBS
4	M_{24}	Optimum Obtained from Table 4	20	70% Soil+10% RHB+20% GGBS

1. COMPACTION CHARACTERISTICS:

The requirements of IS 2720: Part 7: 1980 were met throughout the test. We used the relationship between dry density and water content to build a compaction curve. Maximum Dry Density (MDD) was used to determine the Optimum Moisture Content (OMC). To find the soil's strength, tests are conducted at7,14, and 28 days. After 28 days of cure, the results of OMC and MDD are shown in Figures 1 and 2.

Table 6: OMC & MDD of (Soil-RHB) Mixes:

Mix Designations	RHB (%)	OMC (%)	MDD(g/cc)
M_0	0	15.60	1.512
M_5	5	16.34	1.662
M_{10}	10	17.72	1.614
M_{15}	15	20.15	1.510

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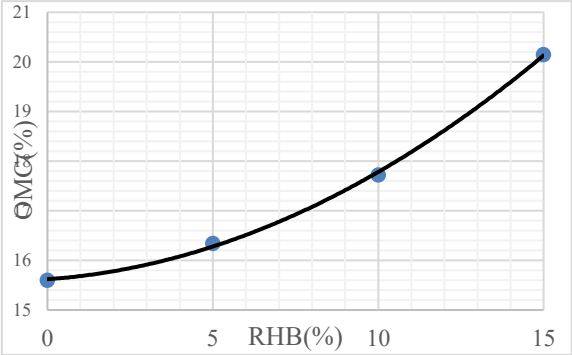
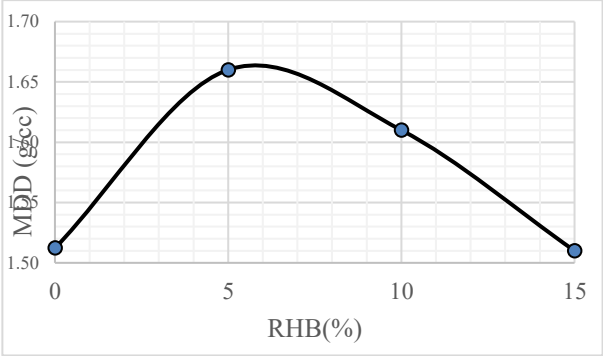


Graph 1



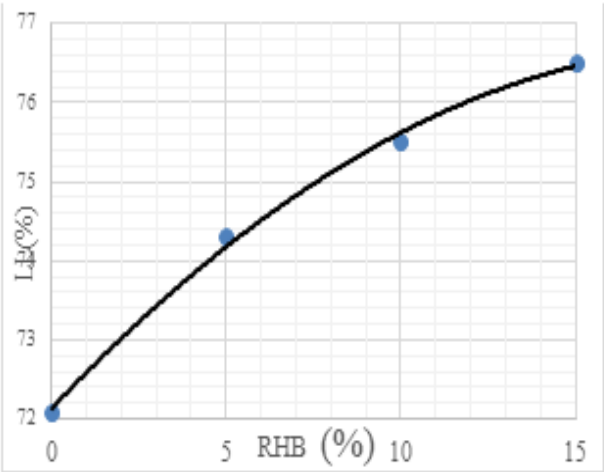
Graph 2

Graph 1 Variation of OMC with addition of different % RHB, Graph 2 Variation of MDD with addition of different % RHB.

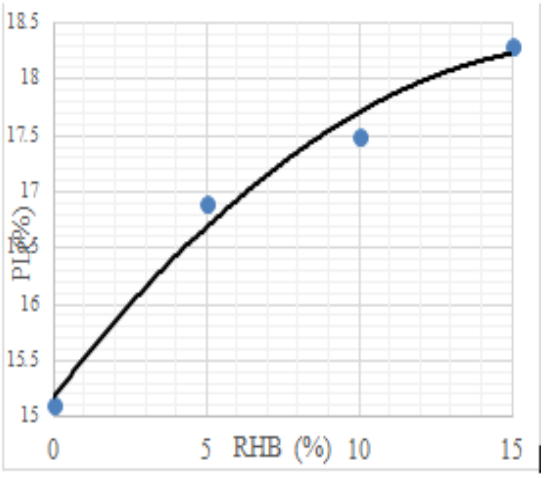
Graph 1&2 represents RHB fills the voids density increases & OMC also increased. Soil particles replaced by RHB density decreases.

Table 7: OMC & MDD of (Soil-Optimum RHB-GGBS) Mixes:

Mix Designations	Optimum RHB (%)	GGBS (%)	Compaction value	
			OMC (%)	MDD (%)
M_{21}	10	5	17.99	1.636
M_{22}	10	10	17.28	1.621
M_{23}	10	15	17.52	1.631
M_{24}	10	20	16.69	1.622



Graph 3



Graph 4

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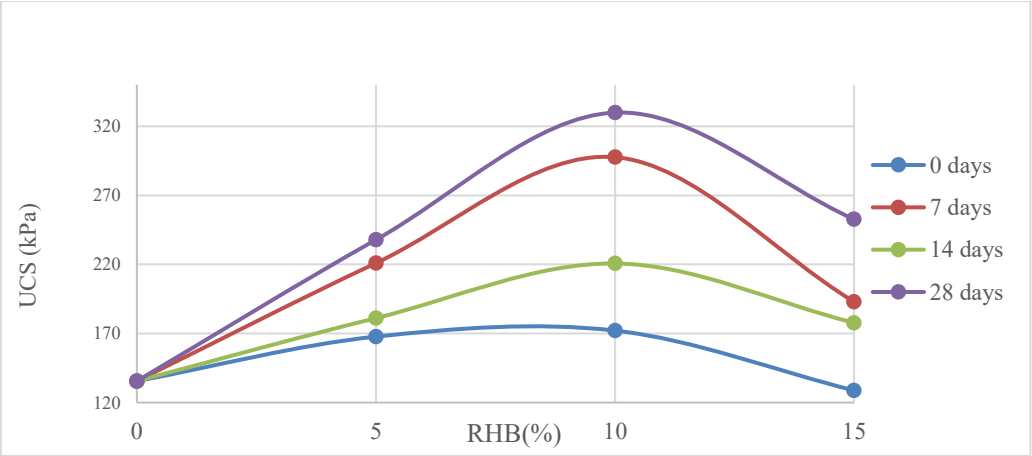
Graph 3 Variation of OMC with addition of 10%optimum RHB & Graph 4 Variation of MDD with addition of 10% Graph 3&4 represents OMC increases due to water requirement for hydration and pozzolanic reactions along with water absorption by biochar, while MDD decreases due to the low density of biochar and flocculated soil structure caused by calcium ions."

2.Unconfined Compressive Strength:

Table 8: UCS values for soil mixed with addition of varying percentages of RHB

Mix designations	RHB (%)	Unconfined Compressive Strength(kPa)			
		0 days	7 days	14 days	28 days
M_0	0	135.580	135.580	135.580	135.580
M_5	5	167.741	220.937	181.128	183.327
M_{10}	10	172..125	297.630	220.686	329.890
M_{15}	15	128.765	192.969	177.780	252.700



Graph 5 Variation of UCS of soil mixed with addition of RHB in different Percentages at different Curing Period (0,7,14,28) days

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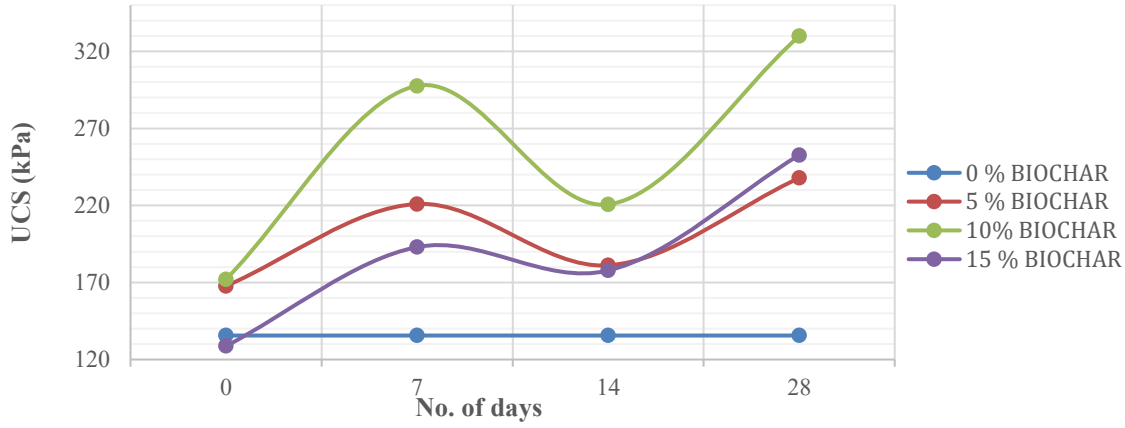
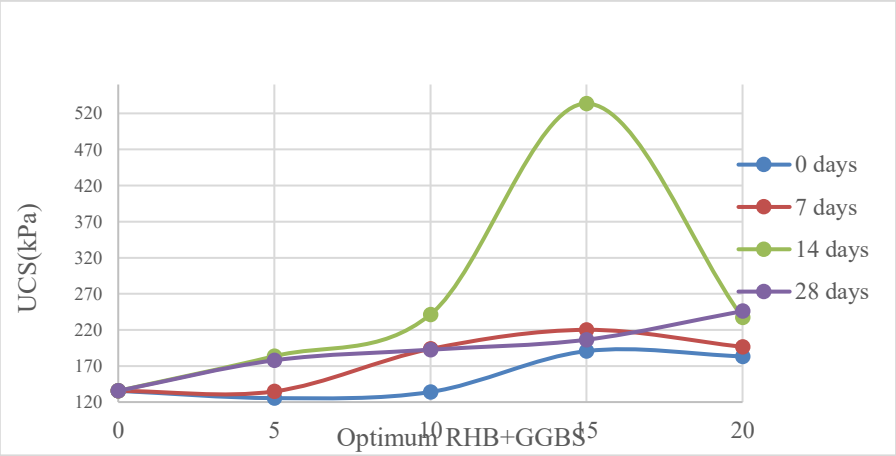


Table 9: Unconfined compressive strength values for soil mixed with optimum RHB (10%) with varying

Mix designations	Optimum RHB (%)	GGBS (%)	Unconfined Compressive Strength(kPa)			
			0 days	7 days	14 days	28 days
M_{21}	10	5	125.49	134.80	183.60	177.86
M_{22}	10	10	133.96	193.63	241.32	192.56
M_{23}	10	15	190.60	220.11	533.60	206.42
M_{24}	10	20	183.30	196.50	237.21	245.99



Graph 6: Changes in UCS over time for soil mixes treated with 10% optimal RHB and varied GGBS at 0, 7, 14, and 28 days of curing

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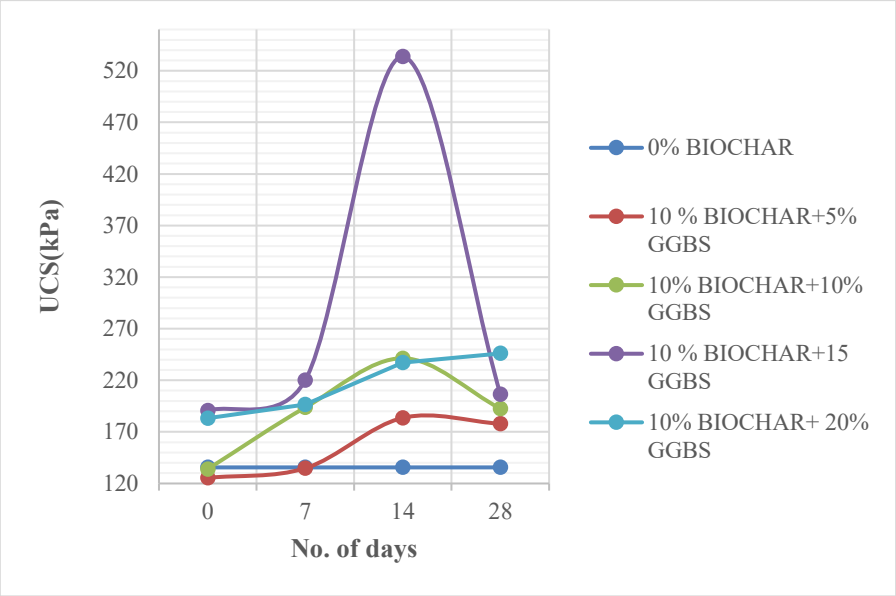

In Graph 5 UCS ↑ up to 10% due to better particle arrangement. Due Weak chemical effect there is limited silica reaction so UCS ↓ after 10% no bonding taken place. In Graph 6 "In initial percentages no much change is observed but there is increase in strain at 15% and at 14 days is addition of GGBS and is due to the combined effect of compressible biochar and partially cemented structure from C-S-H gel, which delays crack propagation and allows higher deformation.

3.LIQUID LIMIT: IS: 2720 (Part 5) 1985
The Liquid Limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes for 10 mm on being given 25 blows in a standard manner. This is the Limiting moisture content at which the cohesive soil passes from liquid state to plastic state.

PLASTIC LIMIT: IS: 2720 (Part 5) 1986
Soil starts to act like a plastic substance at a certain moisture concentration, which is called the Plastic Limit. Soil spun into threads with a diameter of 3.2 mm (1/8 inch) may collapse at this water concentration, which is also known as the Plastic Limit.

Table 10 Atterberg limits of soil mixed with RHB

Mix designations	RHB (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
M_0	0	72.1	15.1	57.0
M_5	5	74.3	16.9	57.4
M_{10}	10	75.5	17.5	58.0
M_{15}	15	76.5	18.3	58.2

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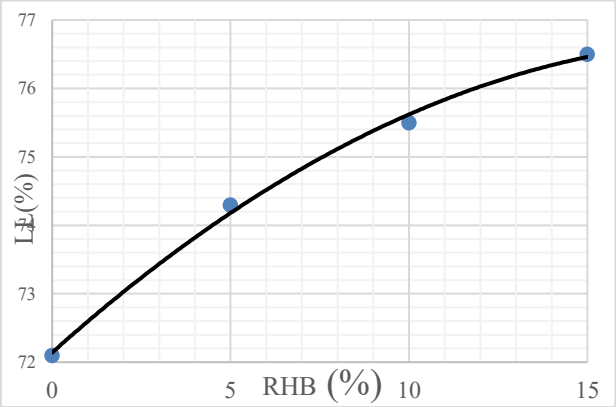
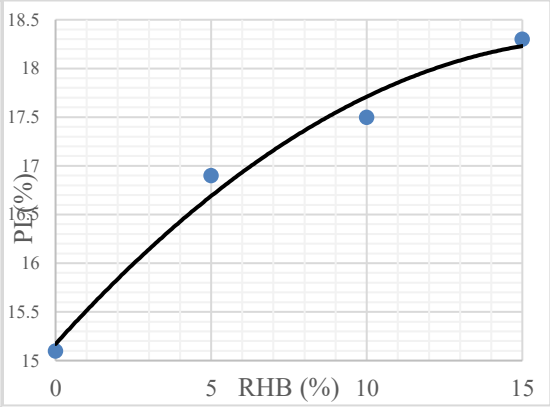
The Atterberg boundaries of soils amended with varying percentages of RHB

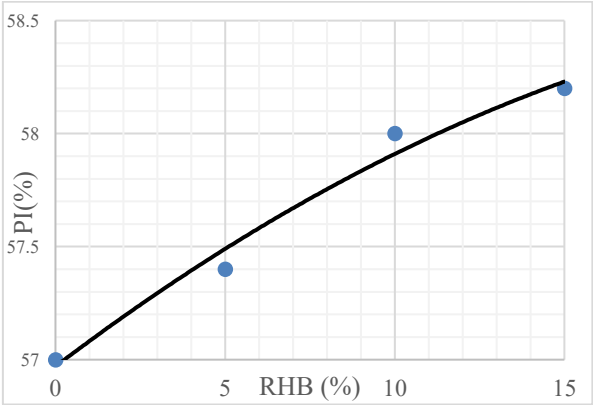


Graph 7



Graph 8

Graph 7 shows the change in liquid limit as a function of RHB percentage, and Graph 8 shows the change in plastic limit as a function of RHB percentage.



Graph 9: Plasticity Index Variation with % RHB Addition

- From Graph 7,8 & 9 Rice husk biochar (RHB) has: High porosity, High surface area so it absorbs more water, so soil needs more water to reach liquid state. Due to: RHB contains SiO_2 + porous carbon Functional groups (–OH) attract water. Biochar improves water holding + particle bonding Soil becomes workable at higher moisture content hence Soil needs more water to become plastic. Since LL increases more than PL
- $PI = LL - PL$. Increased adsorption → more plastic behavior.

Atterberg limits for soil mixed with addition of optimum RHB (10 %) & varying % of GGBS:

Table 11 Atterberg limits for soil mixed with addition of optimum RHB (10 %) with varying GGBS

Mix Designations	Optimum RHB (10%)	GGBS (%)	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)
M_0	0	0	72.1	15.1	57.0
M_{21}	10	5	69.6	16.5	53.1

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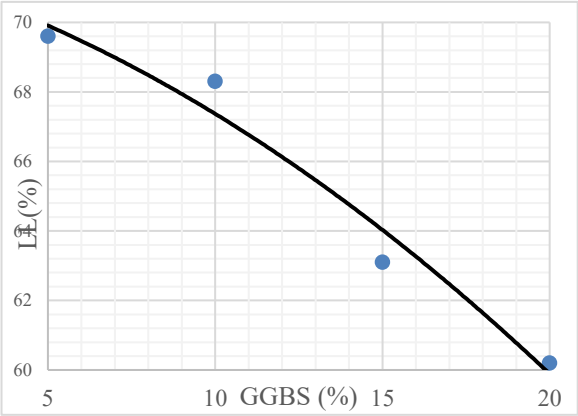
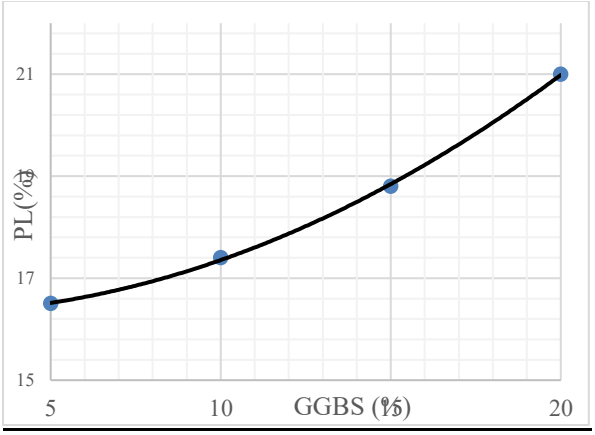
M_{22}	10	10	68.3	17.4	50.9
M_{23}	10	15	63.1	18.8	44.3
M_{24}	10	20	60.2	21.0	39.2

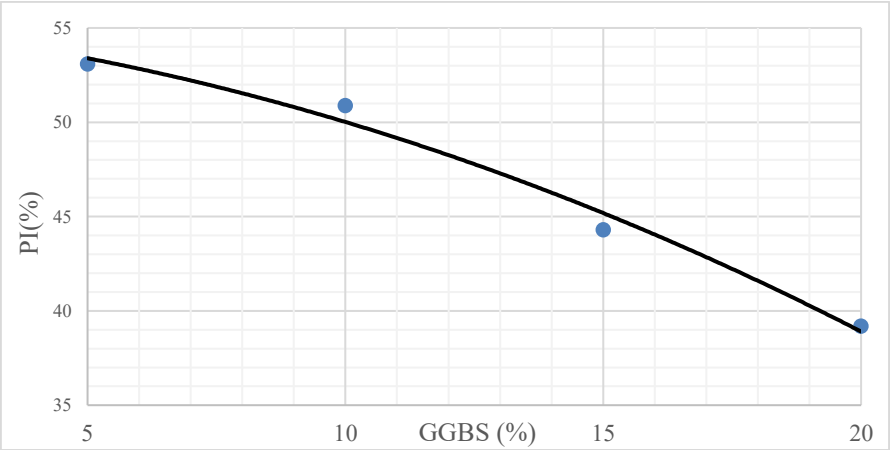


Graph 10



Graph 11

Graphs 10 and 11 show the changes in the liquid and plastic limits as a function of the 10% ideal RHB and the different values of GGBS (5, 10, 15, and 20).



Graph 12 Variation of plasticity Index with addition of 10% optimum RHB and varying GGBS (5,10,15,20)

From Graph10,11 & 12 Cation exchange reduces water affinity in Liquid Limit test and in Plastic Limit (PL) can increase due to combined effects of RHB + early chemical reactions. Soil becomes Less plastic & more stable in Plasticity Index.

4. CALIFORNIA BEARING RATIO TEST: IS: 2720 (Part 16)- 1980

Consolidated Breakthrough Rate (CBR) is the ratio, in percentage terms, of the force per unit area needed to break through a standard material at the same rate as a 50 mm diameter circular plunger penetrating a mass of dirt at a rate of 1.25 mm/min. Typically, 2.5 and 5 mm penetrations are used to calculate the Ratio. Consistently higher values for the Ratio at 5 mm than the Ratio at 2.5 mm warrant its usage.

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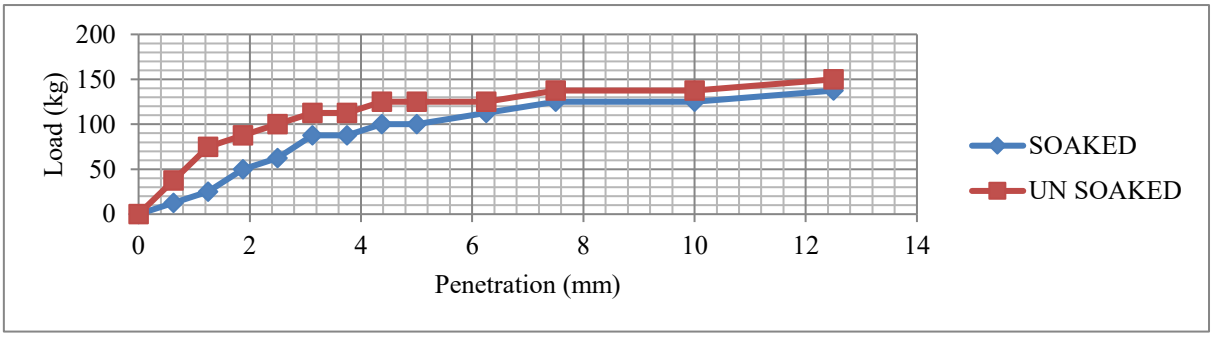
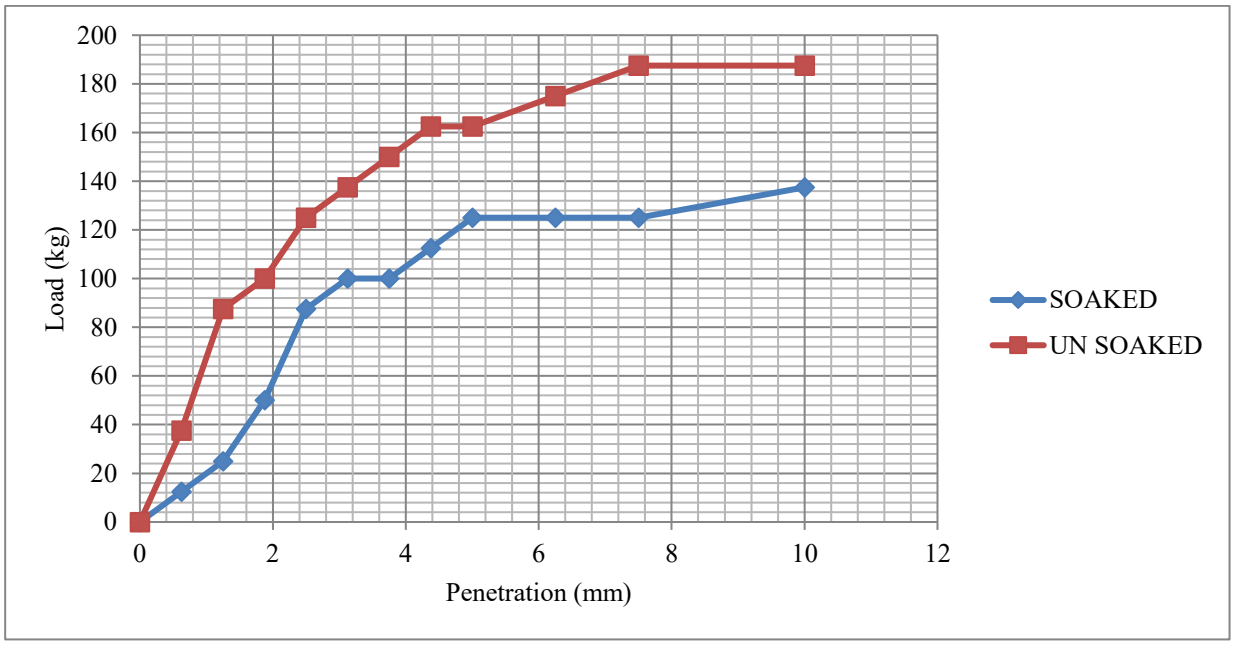
Table 12 CBR values for soil mixed with addition of optimum RHB (10%) and GGBS (15%)

Mix Designations	Optimum RHB (%)	Optimum GGBS (%)	Unsoaked CBR (%)	Soaked (%)
M_0	0	0	7.30	4.87
M_{10}, M_{15}	10	15	9.12	6.39





Graph 13 CBR (Unsoaked, Soaked) for soil mixed with addition of 10% optimum RHB and 15% optimum GGBS
From Graph 13 **CBR** ↑Due to Cementation, and Reduced plasticity so the Soil will become as a strong subgrade.

V. CONCLUSION

Soils treated with Rice husk biochar:

- When RHB is added, the liquid limit and plasticity index are shown to get up.
- As the proportion of RHB increases, the plastic limit is shown to rise.

- When RHB is added, the Optimal moisture content (OMC) rises and the Maximum dry density (MDD) falls.
- It was discovered that adding RHB content up to 10% increased the unconfined compressive strength, while adding more RHB content causes the UCS value of soil to fall.
- According to UCS, 10% RHB is the sweet spot. The UCS value is doubled compared to untreated soil after 0,7, 14, or 28 days of curing when 10% RHB is added.
- Up to 28 days into the curing period, the UCS value increases dramatically; however, beyond that point, there is little to no noticeable gain in strength.
- According to the data shown above, expanding soils may be stabilized by adding RHB, which increases the soil's strength. The ideal amount of RHB to use is 10%.

Soils treated with Rice husk biochar and GGBS:

- The inclusion of GGBS causes an increase in the liquid limit and a reduction in the plasticity index, respectively.
- As the amount of GGBS increases, a drop in the plastic limit is seen.
- The inclusion of GGBS and RHB up to 15% causes a reduction in maximum dry density (MDD) and an increase in optimal moisture content (OMC).
- The Unconfined compressive strength was found to increase with the addition of GGBS content up to15% and with further increase in GGBS content the UCS value of soil decreases. The Optimum content of RHB+GGBS from view of UCS is 15%. With the addition of 10% RHB+15% GGBS the UCS value is increased by two times that of untreated soil after 0,7,14,28 days curing.
- The UCS value is increasing significantly with the curing period up to 14 days, after that not much significance in improvement of strength is observed.
- Based on the data shown above, it can be inferred that by adding RHB and GGBS to expansive soils for stabilization, the soil's strength is increased. The ideal ratio of RHB to GGBS is 10% to 15%.

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