A Study on The Impact of Rice Husk ash on Stabilizing Expansive Soils

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ABSTRACT Soil stabilization using agro-industrial by-products has gained significant attention due to its environmental and economic benefits. This study evaluates the potential of Rice Husk Ash (RHA), a pozzolanic material rich in silica (up to 90%), for stabilizing clayey soil. Laboratory experiments were conducted by blending soil with RHA at varying dosages of 5%, 10%, 15%, and 20% by dry weight. The Atterberg Limits showed a decrease in plasticity index from 24.8% (untreated) to 15.3% at 15% RHA content, indicating improved workability. Standard Proctor Compaction tests revealed a reduction in Maximum Dry Density (MDD) from 1.72 g/cm³ to 1.59 g/cm³ and an increase in Optimum Moisture Content (OMC) from 18.2% to 22.7%, reflecting the lightweight and absorbent nature of RHA. Unconfined Compressive Strength (UCS) increased from 98 kPa for untreated soil to 236 kPa at 10% RHA after 28 days of curing, marking a 141% improvement. Similarly, the Unsoaked California Bearing Ratio (CBR) value increased from 3.4% (untreated) to 9.8% at 15% RHA, a 188% enhancement. These findings suggest that RHA significantly improves the mechanical properties of clayey soil and can be effectively utilized for sustainable ground improvement in geotechnical engineering applications.

Keywords: *Soil stabilization, Rice Husk Ash (RHA), Pozzolanic material, Clayey soil, Atterberg Limits, Plasticity index, Compaction characteristics, Maximum Dry Density (MDD), Optimum Moisture Content (OMC).*

1. INTRODUCTION

In civil engineering, the quality and behaviour of soil significantly influence the durability and stability of infrastructure. Among the various types of soil encountered, expansive soils are especially challenging. These soils, such as black cotton soil, exhibit considerable shrink-swell behaviour depending on moisture content, which can lead to surface cracking, uneven settlement, and structural failures. Covering nearly 20–25% of India's geographical area particularly in regions with fluctuating seasonal moisture expansive soils pose serious complications for construction activities.

To address the limitations posed by such problematic soils, soil stabilization techniques are commonly employed to enhance their engineering properties. Conventional stabilizers like lime and cement are widely used due to their ability to increase soil strength and improve durability. However, these materials are often costly, require significant energy to produce, and contribute substantially to carbon emissions, prompting a growing interest in more sustainable and economically viable alternatives. Rice Husk Ash (RHA) is produced through the controlled burning of rice husk, a major agricultural byproduct obtained during rice milling. Rice husk constitutes about 20% of the weight of harvested rice and is rich in organic content and silica. The production process begins with the collection and possible drying of the rice husk to reduce moisture content, which enhances combustion efficiency. The dried husk is then subjected to controlled combustion at temperatures typically ranging between 500°C and 700°C. This temperature range is critical because it helps preserve the silica in its amorphous form, which is highly reactive and beneficial for applications such as cement and concrete production. Combustion methods include open-field burning, industrial boilers, or specially designed incinerators, with the latter offering better control and higher quality ash. After burning, the ash is allowed to cool before collection. In some cases, the ash is ground into a finer powder to increase its surface area and improve its performance as a pozzolanic material. The final RHA product is light gray to dark in color, with high silica content (up to 85–95%), and its quality largely depends on the combustion process used.

This report focuses on the application of Rice Husk Ash for soil stabilization, evaluating its effectiveness as an eco-friendly, cost-effective alternative to traditional stabilizers. The goal is to not only improve the engineering properties of expansive soils but also to promote sustainable construction practices by reducing reliance on conventional materials and mitigating environmental impacts associated with stone industry waste.

2.MATERIALS AND METHODOLOGY

2.1 MATERIALS

A) Black Cotton Soil

The soil used in this project was collected from Guntur, a region known for its expansive black cotton soil (Regur Soil), which covers about 20% of India's land area, primarily in tropical and subtropical climates. This soil is rich in clay, particularly montmorillonite, and is known for its dark colour. While it is fertile and supports crops like cotton, it poses significant challenges for construction due to its expansive nature. Black cotton soil undergoes considerable volume changes with moisture fluctuations – swelling when wet and shrinking when dry. This shrink-swell behaviour leads to cracking, instability, and poor load-bearing capacity, making it difficult to use for foundations, roads, and other infrastructure. As a result, construction on black cotton soil can lead to foundation failure, surface damage, and overall structural instability. These issues make it essential to apply soil stabilization techniques to improve its properties and ensure the safety and durability of structures built on it.

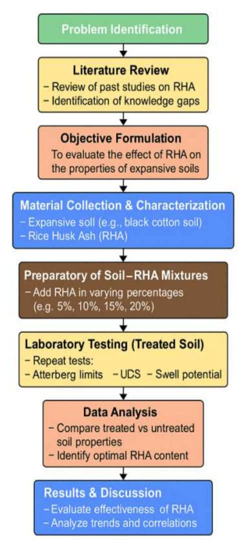
Figure 1. Black Cotton Soil

B) RICE HUSK ASH

Rice Husk Ash (RHA) has gained significant attention as a sustainable and cost-effective material in geotechnical engineering, particularly in soil stabilization. Due to its high silica content and pozzolanic properties, RHA reacts with calcium compounds (like lime or cement) to form cementitious materials that enhance the engineering properties of weak or expansive soils.
When mixed with problematic soils, especially clayey or black cotton soils, RHA improves strength, reduces plasticity, and minimizes swelling and shrinkage. Its fine texture helps fill the voids between soil particles, enhancing soil compaction and reducing permeability. The pozzolanic reaction between RHA and lime or other calcium sources leads to the formation of calcium silicate hydrates (C-S-H), which bind soil particles and improve load-bearing capacity and durability.

Figure 2. Rice Husk Ash

2.2 METHODOLOGY



A Syudy' onThe Effect of Rice Husk Ash in *Expansive Sols* Soils

3. RESULTS AND DISCUSSION

3.1 WET SIEVE ANALYSIS

Total Soil = 2000 g

Total sand retained on 75µ sieve = 580 g (after 24 hours' oven dried) (29.5%)

Total silt + clay passed through 75µ sieve = 1420 g (71.5%)

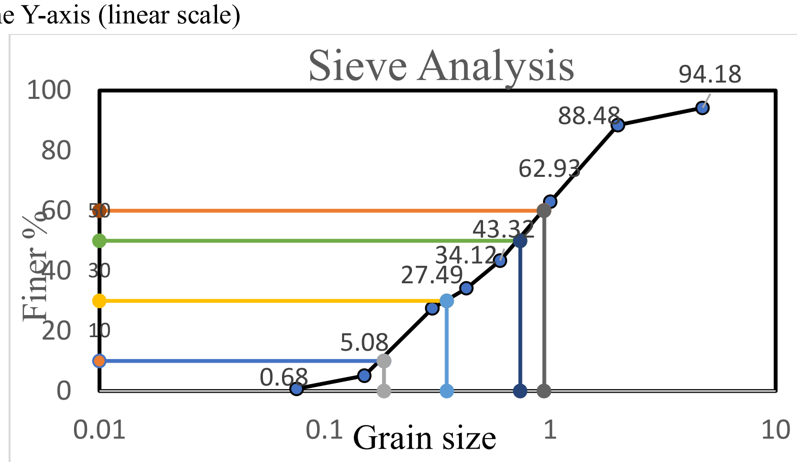
Table 4.3. Wet Sieve Analysis for Black Cotton Soil

Sieve	Weight of sand retained in grams	% weight retained	Cumulative % weight retained	% finer
4.75	23.29	5.82	5.82	94.18
2	22.83	5.70	11.52	88.48
1	102.19	25.55	37.07	62.93
600µ	78.44	19.61	56.68	43.32
425µ	36.81	9.20	65.88	34.12
300µ	26.55	6.63	72.51	27.49
150µ	89.67	22.41	94.92	5.08
75µ	17.50	4.4	99.32	0.68
Pan	2.72	0.68	100	0
	Total =400 g			

Graphical Representation:

Plot a grain size distribution curve on a semi-log graph with:

- Particle size (mm) on the X-axis (logarithmic scale)
- % Finer on the Y-axis (linear scale)



D10=0.18, D30=0.37, D50=0.65, D60=0.77, Cu=4.27mm, Cc=0.987mm

Figure 3 Graphical representation of Wet Sieve Analysis.

This graph represents the results of a sieve analysis, illustrating the grain size distribution of a soil or sediment sample. The x-axis (logarithmic scale) shows grain size in millimetres, while the y-axis indicates the percentage of material finer than each size. The curve demonstrates a progressive increase in finer material, reaching about 94.18% at the largest grain size shown. Horizontal coloured lines represent key percentiles (e.g., D10, D30, D50, D60), useful for calculating uniformity and gradation. The graph helps in classifying soil types and understanding their engineering behaviour.

3.2 EFFECT ON ATTERBERG LIMITS WITH VARYING RICE HUSK ASHPERCENTAGES

A) Liquid Limit

Table 1. Liquid Limit Table for BCS

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	61	43	18.38	24.62	22.24	42	61.65
2	63	42	16.48	19.53	18.34	32	63.97
3	65	18	18.72	23.71	21.71	20	66.88
4	67	15	17.42	22.9	20.67	18	68.61
5	69	39	18.72	28.28	24.34	12	70.10

Table 2. Liquid Limit Table for BCS+4%RHA

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	57	26	16.93	21.65	19.93	50	57.33
2	59	24	19.75	23.35	22.01	39	59.29
3	61	5	20.13	23.32	22.11	23	61.11
4	63	6	19	21.32	20.42	17	63.38
5	65	17	19	26.25	23.38	9	65.52

Table 3 Liquid Limit Table for BCS+8%RHA

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	57	36	18.92	22.6	21.24	36	58.62
2	59	27	18.12	23.18	21.29	27	59.62
3	61	29	18.44	21.66	20.41	19	63.45
4	63	9	19.32	22.25	21.07	9	67.42

Table 4 Liquid Limit Table for BCS+12%RHA

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	55	31	19.03	24.41	22.47	43	56.39
2	56	1	19.36	24.75	22.8	39	56.68
3	57	2	19.08	21.78	20.78	27	58.82
4	58	34	16.55	20.16	18.81	20	59.73
5	59	19	18.54	22.3	20.89	14	60

Table 5 Liquid Limit Table for BCS+16%RHA

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	57	14	17.6	23.08	21.11	47	56.12
2	58	45	16.53	19.02	18.1	35	58.59
3	59	35	17.06	20.5	19.21	24	60
4	60	20	18.6	21.23	20.22	16	62.34

Table 6 Liquid Limit Table for BCS+20%RHA

S.no	Water content	Can no	Empty weight (w_1)	Wet weight (w_2)	Dry weight(W_3)	No. of blows	Moisture content
1	58	3	18.17	21.87	20.51	45	58.11
2	59	28	17.18	20.17	19.06	39	59.04
3	60	16	17.53	20.47	19.36	25	60.65
4	61	30	18.64	20.45	19.76	12	61.60

Flow curve Graph plotting:

- Plot a graph of moisture content (%) vs. number of blows (log scale).
- Draw a best-fit straight line (flow curve).
- The moisture content corresponding to 25 blows is the Liquid Limit (LL).

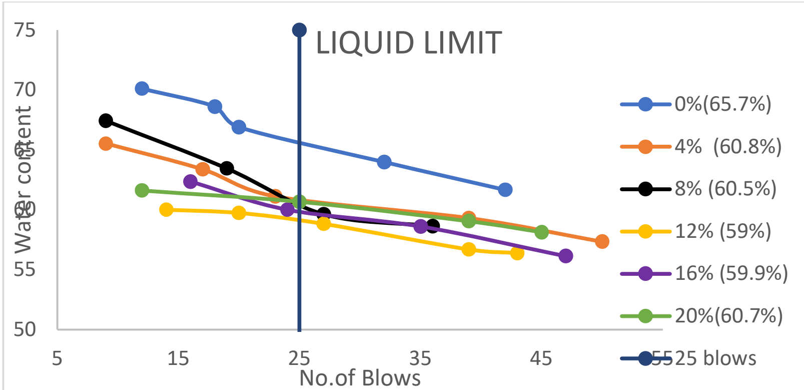


Figure 4 Graphical representation of Liquid Limit.

This chart presents the effect of varying stabilizer percentages on the liquid limit of Black Cotton Soil. As stabilizer content increases from 0% to 20%, the liquid limit consistently decreases, improving soil properties. The most significant drop is observed up to 12%, beyond which the reduction is minimal. At 12% stabilizer content, the liquid limit reaches its lowest value (59%), indicating it as the optimum dosage. This reduction signifies lower plasticity and swelling, making the soil more stable and suitable for construction.

C) PLASTIC LIMIT:

Table 7 Plastic Limit for all replacement of Rice Husk Ash

Soil replacement (%)	Can no	Can weight	Wet sample+ can	Dry sample+ can	Plastic limit
0	29	18.44	21.41	20.75	28.75
4	43	18.41	21.62	20.93	27.26
8	23	18.21	23.51	22.4	26.45
12	38	18.94	23.58	22.66	24.65
16	26	18.93	19.57	19.44	26.25
20	7	18.78	21.41	20.86	26.55

4.3.3 PLASTICITY INDEX:

Table 8 Plasticity Index for all replacement of Rice Husk Ash

Replacement (%)	Liquid Limit	Plastic Limit	Plasticity Index
0	65.7	28.75	36.95
4	60.8	27.26	33.54
8	60.5	26.45	34.05
12	59	24.65	34.35
16	59.9	26.25	33.65
20	60.7	26.55	34.15

As the Rice Husk Ash content increased, a decrease in both the Liquid Limit and Plasticity Index was observed, while the Plastic Limit increased. This trend suggests that Rice Husk Ash, being a non-plastic organic material, reduces the soil's cohesive properties and water retention capacity. The reduction in LL and PI indicates a lower plasticity and improved workability of the soil.

Plasticity chart for only Black Cotton Soil.

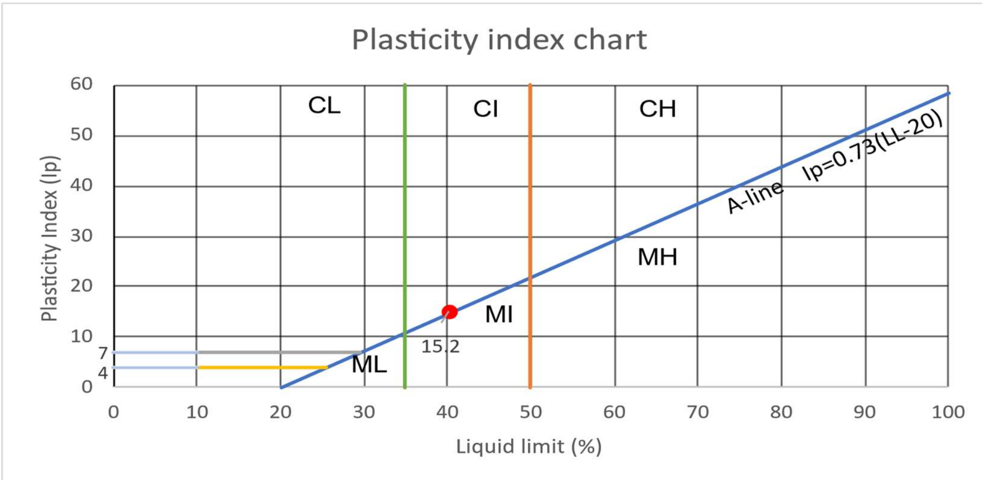


Figure 5 Graphical representation of Plasticity Index (BCS).

Plasticity chart for all replacements of Rice Husk Ash.

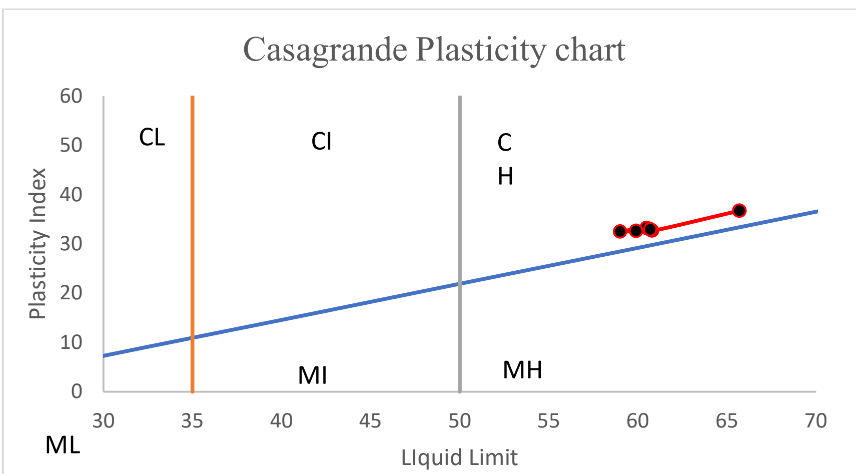


Figure 6 Plasticity chart for all replacements of Rice Husk Ash.

Soil Classification Using Casagrande Plasticity Chart

1. The plotted points fall in the region above the A-line.
2. The liquid limit (LL) values range approximately from 58 to 66.
3. The plasticity index (PI) values range from around 30 to 38.
4. These data points indicate high plasticity behaviour.

5. Therefore, this soil is classified as CH (inorganic clays) according to the Unified Soil Classification System (USCS).

Comparison between Atterberg Limits and Plasticity Index

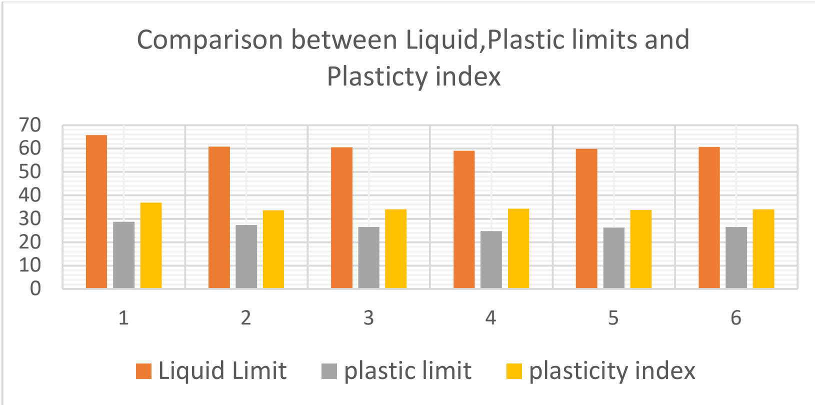


Figure 7 Graphical representation of Comparison between Atterberg Limits and Plasticity Index

The bar chart compares the Liquid Limit, Plastic Limit, and Plasticity Index of six soil samples treated with varying stabilizer percentages. All samples exhibit high Liquid Limits (above 58%) and Plasticity Indices (above 30%), indicating the presence of high-plasticity clay soils. Stabilization is commonly used to reduce the Plasticity Index in order to enhance soil strength and workability. The second sample, which corresponds to a stabilizer content of 12%, demonstrates the most effective reduction in Plasticity Index, achieving a value of approximately 32%, the lowest among all samples. This indicates that the 12% dosage results in the most favourable improvement in soil properties. Additionally, the relatively small difference between Liquid Limit and Plastic Limit in this sample suggests improved consistency and reduced plasticity. In contrast, the higher PI values in other samples suggest either insufficient or excessive stabilization. At 12%, optimal chemical interaction likely occurs between the stabilizer and clay minerals, promoting flocculation and minimizing plasticity. From both technical and economic perspectives, 12% stabilizer content is identified as the optimum percentage for effective soil stabilization in this study.

Can No	Empty weight (W_1) in g	Wet weight (W_2) in g	Dry weight (W_3) in g	Water content (W_2-W_3/W_3-W_1) *100
17	18.94	41.60	39.68	9.26
32	20.49	45.50	42.97	11.25
20	18.16	48.19	44.94	12.13
24	19.63	42.71	39.86	14.08
11	19.10	44.69	41.37	14.90
37	18.75	41.95	38.51	17.40
15	17.15	39.02	35.54	18.92
44	18.93	51.16	45.75	20.17
30	18.64	42.05	37.65	23.14
22	18.33	46.62	41.17	23.86
2	19.06	39.42	35.20	23.99
45	16.46	33.46	30.17	26.14
5	20.35	34.56	31.30	29.77

Graph plotting:

- Plot moisture content (%) vs. dry density (g/cm³).
- The peak point gives Maximum Dry Density (MDD) and the corresponding moisture content is the Optimum Moisture Content (OMC).

- **3.2 LIGHT COMPACTION TEST**
- **A) Light Compaction Test for Untreated Black Cotton Soil**
- Dry weight of soil =3000 g, Weight of cutter =2058 g, Volume of cutter = 1000cc
  - **Table 9 Light Compaction only for Untreated Black cotton soil**

Light Compaction curve for Black cotton soil

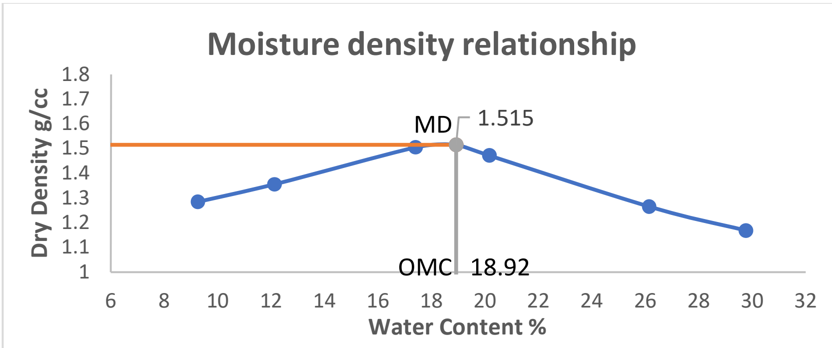


Figure 8 Light Compaction Curve (BCS)

Table 10 Light Compaction for BCS + 4% RHA

s.no	water content	can no	empty weight(w_1)	wet weight(w_2)	dry weight(w_3)	bulk density	dry density	moisture content
1	5	17	18.92	33	32.09	1.489	1.418	6.90
2	7	18	18.63	31.88	31	1.521	1.421	7.11
3	9	24	19.62	35.98	34.59	1.552	1.433	9.28
4	11	39	19.33	42.86	40.55	1.569	1.44	10.88
5	13	42	16.4	34.47	32.28	1.669	1.476	13.79
6	15	43	18.3	39.58	36.73	1.754	1.525	15.46
7	17	5	20.05	32.07	30.29	1.784	1.524	17.38
8	19	26	16.78	35.78	32.66	1.759	1.478	19.64
9	21	15	17.13	27.43	25.59	1.749	1.445	21.74
10	23	9	18.83	28.38	26.61	1.727	1.404	22.75

Table 11 Light Compaction for BCS + 8% RHA

s.no	water content	can no	empty weight(w_1)	wet weight(w_2)	dry weight(w_3)	bulk density	dry density	moisture content
1	11	30	18.63	24.14	23.48	1.66	1.497	13.60
2	13	29	18.36	32.4	30.54	1.73	1.53	15.27
3	15	16	17.49	30.23	28.44	1.77	1.55	16.34
4	17	35	17.01	31.67	29.42	1.832	1.595	18.13
5	19	19	18.39	30.81	28.8	1.932	1.623	19.30
6	21	20	18.46	32.5	30.08	1.928	1.593	20.82
7	23	45	16.39	25.77	24.1	1.871	1.521	21.66
8	25	1	19.48	30.51	28.52	1.793	1.434	22.01

Table 12 Light Compaction for BCS + 12% RHA

s.no	water content	can no	empty weight(w_1)	wet weight(w_2)	dry weight(w_3)	bulk density	dry density	moisture content
1	0.11	15	17.14	27.88	26.75	1.687	1.51	11.75
2	0.13	24	19.62	31.91	30.45	1.716	1.51	13.48
3	0.15	43	18.34	31.29	29.57	1.759	1.52	15.31
4	0.17	17	18.42	34.15	31.84	1.793	1.53	17.21
5	0.19	42	16.37	33.45	30.71	1.86	1.56	19.10
6	0.21	6	18.82	28.63	26.89	1.939	1.60	21.56
7	0.23	18	18.6	30.09	27.94	1.884	1.53	23.01
8	0.25	26	16.79	30.59	27.83	1.824	1.45	25
9	0.27	16	17.45	31.43	28.43	1.759	1.38	27.32

Table 13 Light Compaction for BCS + 16% RHA

s.no	water content	can no	empty weight(w_1)	wet weight(w_2)	dry weight(w_3)	bulk density	dry density	moisture content
1	0.11	39	19.29	35.52	33.89	1.636	1.746	11.16
2	0.13	15	17.14	36.73	34.4	1.661	1.791	13.49
3	0.15	24	19.62	35.2	33.13	1.674	1.824	15.32
4	0.17	43	18.3	31.51	29.55	1.714	1.884	17.42
5	0.19	17	18.92	27.13	25.79	1.771	1.961	19.50
6	0.21	42	16.37	29.77	27.39	1.824	2.034	21.59
7	0.23	6	18.82	30.22	28.07	1.789	2.019	23.24
8	0.25	18	18.6	29.22	27.09	1.733	1.983	25.08
9	0.27	26	16.79	25.21	23.45	1.667	1.937	26.42

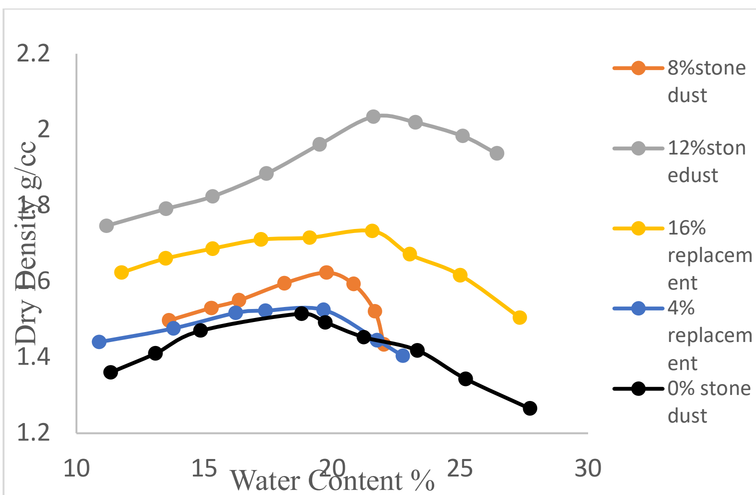


Figure 9 Comparison between compaction curves of all replacements.

The graph presents light compaction curves showing the relationship between dry density (g/cc) and water content (%) for soil mixtures with varying percentages of Rice Husk Ash and replacement materials. Each curve shows a peak dry density, indicating the optimum moisture content (OMC) for compaction. As the percentage of Rice Husk Ash increases, the peak dry density also increases, reaching a maximum at 12% Rice Husk Ash with a dry density of approximately 2.03 g/cc around 21% water content. This indicates that 12% Rice Husk Ash is the optimum content, as it results in the densest and most compacted soil. Beyond 12%, dry density begins to decline, likely due to excess fines hindering proper particle arrangement. Lower percentages, such as 0%, 4%, and 8%, yield lower dry densities, showing that the inclusion of Rice Husk Ash improves compaction properties up to an optimum point. Therefore, 12% Rice Husk Ash content is considered optimal based on maximum dry density achieved under light compaction.

Table 14 OMC, MDD Values Obtained

Replacement (%)	Optimum moisture content (g/cm3)	Maximum dry density(g/cc)
0%	18.79	1.515
4%	19.64	1.525
8%	19.76	1.623
12%	21.59	2.034
16%	21.56	1.73

Replacement on Optimum Moisture Content and Maximum Dry Density under Light Compaction

The compaction characteristics of soil with varying percentages of Rice Husk Ash replacement were evaluated under light compaction conditions. The data shows that the optimum moisture content (OMC) increases progressively from 18.79% at 0% replacement to a peak of 21.59% at 12% replacement. Correspondingly, the maximum dry density also increases from 1.515 g/cc to a maximum of 2.034 g/cc at 12% replacement. This trend indicates improved compaction efficiency due to better particle gradation and packing up to this point. Beyond 12%, at 16% replacement, the dry density decreases to 1.730 g/cc, despite a comparable OMC (21.56%), suggesting that excess fines from Rice Husk Ash may hinder compaction by reducing interparticle friction and increasing moisture sensitivity. Therefore, 12% Rice Husk Ash replacement is identified as the optimum level, providing the highest dry density and optimal moisture conditions for compaction.

3.5. UNCONFINED COMPRESSIVE STRENGTH FOR 7 DAYS:

Table 15 UCS for Black cotton soil:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	0.6	0.53
50	0.5	0.006578947	1.2	1.06
75	0.75	0.009868421	5.6	4.94
100	1	0.013157895	11	9.70
125	1.25	0.016447368	16.2	14.28
150	1.5	0.019736842	20.2	17.81
175	1.75	0.023026316	23.4	20.63
200	2	0.026315789	25.6	22.57
225	2.25	0.029605263	27.4	24.16
250	2.5	0.032894737	28.8	25.39
275	2.75	0.036184211	30	26.45
300	3	0.039473684	31.4	27.69
325	3.25	0.042763158	32	28.22
350	3.5	0.046052632	32.8	28.92
375	3.75	0.049342105	33.6	29.63
400	4	0.052631579	33.8	29.80
425	4.25	0.055921053	34	29.98

450	4.5	0.059210526	34	29.98
475	4.75	0.0625	33	29.10
500	5	0.065789474	32	28.22
		qu	29.98 kN/m^2	
		su	14.99 kN/m^2	

Table 16 UCS for Black cotton soil + 4% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e=dl/Lo)	Force (N)	Stress (N/mm2)	Stress (KN/m2)
0	0	0	0	0.00	0.00
25	0.25	0.003289474	2	1763.51	1.76
50	0.5	0.006578947	3	2645.26	2.65
75	0.75	0.009868421	4	3527.02	3.53
100	1	0.013157895	7	6172.28	6.17
125	1.25	0.016447368	11.2	9875.64	9.88
150	1.5	0.019736842	16.4	14460.77	14.46
175	1.75	0.023026316	20.8	18340.48	18.34
200	2	0.026315789	24	21162.10	21.16
225	2.25	0.029605263	26	22925.60	22.93
250	2.5	0.032894737	27.4	24160.06	24.16
275	2.75	0.036184211	28.4	25041.81	25.04
300	3	0.039473684	29.2	25747.22	25.75
325	3.25	0.042763158	30	26452.62	26.45
350	3.5	0.046052632	31.2	27510.72	27.51
375	3.75	0.049342105	32.4	28568.83	28.57
400	4	0.052631579	31.4	27687.08	27.69
425	4.25	0.055921053	30	26452.62	26.45
UCS		qu	28.57	KN/m2	
Undrained shear strength		su	14.28	KN/m2	

Table 17 UCS for Black cotton soil+ 12% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	1.6	1.41
50	0.5	0.006578947	4.8	4.23
75	0.75	0.009868421	7.2	6.35
100	1	0.013157895	11.8	10.40
125	1.25	0.016447368	15	13.23
150	1.5	0.019736842	19.8	17.46
175	1.75	0.023026316	25	22.04
200	2	0.026315789	29.4	25.92
225	2.25	0.029605263	32	28.22
250	2.5	0.032894737	34.6	30.51
275	2.75	0.036184211	36	31.74
300	3	0.039473684	37.4	32.98
325	3.25	0.042763158	38.8	34.21
350	3.5	0.046052632	41.2	36.33
375	3.75	0.049342105	42.6	37.56
400	4	0.052631579	44.4	39.15
425	4.25	0.055921053	43.2	38.09
450	4.5	0.059210526	42.4	37.39
475	4.75	0.0625	41.2	36.33
500	5	0.065789474	39	34.39
		qu	39.15 kN/m^2	
		su	19.57 kN/m^2	

Table 18 UCS for Black cotton soil + 16% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	2.6	2.29
50	0.5	0.006578947	4.6	4.06
75	0.75	0.009868421	9.2	8.11
100	1	0.013157895	13.4	11.82
125	1.25	0.016447368	17.4	15.34
150	1.5	0.019736842	21	18.52
175	1.75	0.023026316	24	21.16
200	2	0.026315789	26	22.93
225	2.25	0.029605263	27.2	23.98
250	2.5	0.032894737	29	25.57
275	2.75	0.036184211	30.2	26.63
300	3	0.039473684	32	28.22
325	3.25	0.042763158	33.4	29.45
350	3.5	0.046052632	34.6	30.51
375	3.75	0.049342105	35.2	31.04
400	4	0.052631579	36	31.74
425	4.25	0.055921053	36.4	32.10
450	4.5	0.059210526	38.2	33.68
475	4.75	0.0625	39.8	35.09
500	5	0.065789474	42.2	37.21
525	5.25	0.069078947	40.2	35.45
550	5.5	0.072368421	38.4	33.86

575	5.75	0.075657895	37.2	32.80
		qu	37.21 kN/m^2	
		su	18.61 kN/m^2	

Graphical representation of UCS after 7 days:

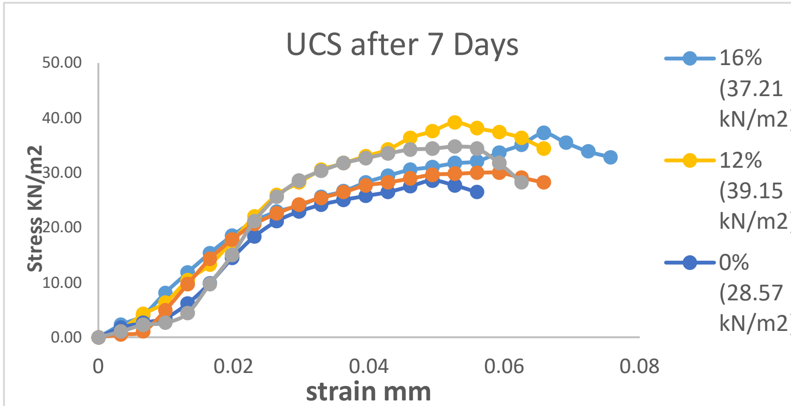


Figure 10 Unconfined compressive strength for 7 days Comparison for all replacements

0% = 28.57 KN/m^2, 4% = 29.98 KN/m^2, 8% = 34.74 KN/m^2, 12% =39.15 kN/m^2, 16% =37.21 kN/m^2

4.6. UNCONFINED COMPRESSIVE STRENGTH FOR 28 DAYS:

Table 19 UCS for Black cotton soil:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	2.2	1.94
50	0.5	0.006578947	2.8	2.47
75	0.75	0.009868421	3.6	3.17
100	1	0.013157895	7.2	6.35
125	1.25	0.016447368	13.2	11.64
150	1.5	0.019736842	20.2	17.81
175	1.75	0.023026316	25.2	22.22
200	2	0.026315789	31.2	27.51
225	2.25	0.029605263	35	30.86
250	2.5	0.032894737	37.8	33.33
275	2.75	0.036184211	39.4	34.74
300	3	0.039473684	40.6	35.80
325	3.25	0.042763158	41	36.15
350	3.5	0.046052632	41.2	36.33
375	3.75	0.049342105	40.8	35.98
400	4	0.052631579	40	35.27
425	4.25	0.055921053	39	34.39
			qu	36.33 kN/m2
			su	18.16 kN/m2

Table 20 UCS for Black cotton soil + 4% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	2.4	2.12
50	0.5	0.006578947	3.4	3.00
75	0.75	0.009868421	4.4	3.88
100	1	0.013157895	9	7.94
125	1.25	0.016447368	14.4	12.70
150	1.5	0.019736842	21.4	18.87
175	1.75	0.023026316	28.4	25.04
200	2	0.026315789	35	30.86
225	2.25	0.029605263	39.4	34.74
250	2.5	0.032894737	42	37.03
275	2.75	0.036184211	42.8	37.74
300	3	0.039473684	42.4	37.39
325	3.25	0.042763158	41.2	36.33
350	3.5	0.046052632	38	33.51
			qu	37.74kN/m2
			su	18.86kN/m2

Table 21 UCS for Black Cotton soil + 8% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain(e=dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	3.2	2.82
50	0.5	0.006578947	8.6	7.58
75	0.75	0.009868421	17.4	15.34
100	1	0.013157895	25	22.04
125	1.25	0.016447368	32.8	28.92
150	1.5	0.019736842	38	33.51
175	1.75	0.023026316	42	37.03
200	2	0.026315789	44.4	39.15
225	2.25	0.029605263	45.4	40.03
250	2.5	0.032894737	45.4	40.03
275	2.75	0.036184211	44.2	38.97
300	3	0.039473684	41.4	36.50
325	3.25	0.042763158	37.8	33.33
			qu	40.03
			su	20.02

Table 22 UCS for Black cotton soil+ 12% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e= dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	0	0.00
25	0.25	0.003289474	3.2	2.82
50	0.5	0.006578947	7.4	6.52
75	0.75	0.009868421	8.8	7.76
100	1	0.013157895	11.8	10.40
125	1.25	0.016447368	14.8	13.05
150	1.5	0.019736842	19.2	16.93
175	1.75	0.023026316	22	19.40
200	2	0.026315789	26.4	23.28
225	2.25	0.029605263	28.2	24.87
250	2.5	0.032894737	29.8	26.28
275	2.75	0.036184211	32.4	28.57
300	3	0.039473684	34.8	30.69
325	3.25	0.042763158	37.2	32.80
350	3.5	0.046052632	39.4	34.74
375	3.75	0.049342105	42.6	37.56
400	4	0.052631579	44.8	39.50
425	4.25	0.055921053	47.8	42.15
475	4.75	0.0625	49.8	43.91
500	5	0.065789474	51.4	45.32
525	5.25	0.069078947	50.2	44.26
550	5.5	0.072368421	49.2	43.38
575	5.75	0.075657895	48.2	42.5005429
			qu	45.32
			su	22.66107785

0%=36.33 KN/m^2, 4% =37.74 KN/m^2, 8% =40.03 KN/m^2, 12% =45.32 KN/m^2,
16% = 43.38 KN/m^2

The Stress-Strain Curve graph presents the mechanical behaviour of samples with varying stabilizer contents (0%, 4%, 8%, 12%, and 16%) under compressive loading. As observed, the peak stress increases with increasing stabilizer content up to 12%, reaching a maximum of 39.15 kN/m². Beyond this point, a slight reduction is seen, with the 16% sample attaining 37.21 kN/m². The 0%, 4%, and 8% samples showed progressively increasing peak strengths of 28.57, 29.98, and 34.74 kN/m², respectively. This trend suggests that up to 12% content, the additive significantly enhances material strength and stiffness, but further addition may introduce diminishing returns or brittleness.

The UCS after 28 days graph shows the unconfined compressive strength behaviour of the same compositions after curing. The sample with 12% stabilizer content again yielded the highest UCS of 45.32 kN/m², demonstrating the most effective long-term strength development. The 16% sample followed with a UCS of 43.38 kN/m², while 8%, 4%, and 0% contents recorded values of 40.03, 37.74, and 36.33 kN/m², respectively. This confirms the earlier trend observed in the stress-strain response. Additionally, strain-softening was apparent in all samples after reaching peak strength.

Table 23 UCS for Black cotton soil+ 16% Rice Husk Ash:

Dial Reading	Deformation (mm)	Strain (e=dl/Lo)	Force (N)	Stress (KN/m2)
0	0	0	1	0.88
25	0.25	0.003289474	2.6	2.29
50	0.5	0.006578947	3.6	3.17
75	0.75	0.009868421	5.6	4.94
100	1	0.013157895	9.6	8.46
125	1.25	0.016447368	13.6	11.99
150	1.5	0.019736842	17.2	15.17
175	1.75	0.023026316	20.8	18.34
200	2	0.026315789	23.6	20.81
225	2.25	0.029605263	26.2	23.10
250	2.5	0.032894737	28.4	25.04
275	2.75	0.036184211	30.2	26.63
300	3	0.039473684	31.8	28.04
325	3.25	0.042763158	33.2	29.27
350	3.5	0.046052632	34.8	30.69
375	3.75	0.049342105	36.6	32.27
400	4	0.052631579	38.6	34.04
425	4.25	0.055921053	42.2	37.21
450	4.5	0.059210526	44.8	39.50
475	4.75	0.0625	47.8	42.15
500	5	0.065789474	49.2	43.38
525	5.25	0.069078947	48.2	42.50
550	5.5	0.072368421	47.2	41.62
575	5.75	0.075657895	45.8	40.38
			qu	43.38
			su	21.69114845

UCS Test for 28 days:

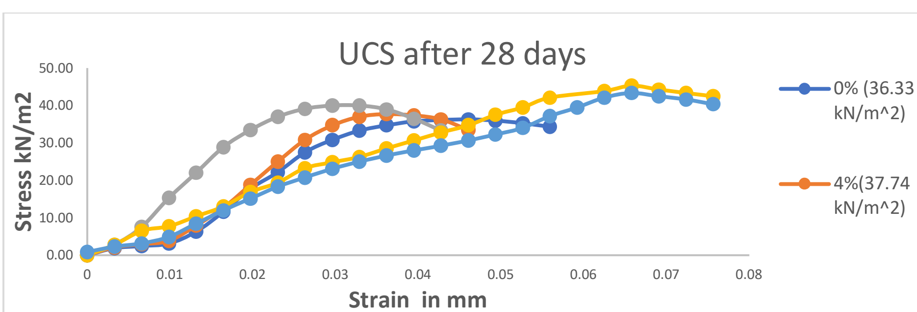


Figure 11 Unconfined compressive strength for 7 days Comparison for all replacements

3.7. CALIFORNIA BEARING RATIO FOR 28 DAYS:

Table 24 CBR for Black cotton soil:

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	1	102
1	2	204
1.5	2.6	265.2
2	2.8	285.6
2.5	3.6	367.2
4	4.2	428.4
5	4.8	489.6
7.5	5.2	530.4
10	5.6	571.2
12.5	5.8	591.6

Table 25 CBR for BCS+ 2%RHA:

penetration (mm)	**Load Readings**	**(KGF)**
0	0	0
0.5	1	102
1	2	204
1.5	2.6	265.2
2	2.8	285.6
2.5	3.4	346.8
4	3.8	387.6
5	4.4	448.8
7.5	5.2	530.4
10	5.6	571.2
12.5	5.8	591.6

Table 26 CBR for BCS+ 4%RHA:

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0	0
1	1.2	122.4
1.5	2.4	244.8
2	3.2	326.4
2.5	4.2	428.4
4	5.2	530.4
5	6	612
7.5	6.8	693.6
10	7.2	734.4
12.5	7.6	775.2

Table 27 CBR for BCS+ 4%RHA:

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0	0
1	0.2	20.4
1.5	0.8	81.6
2	2.8	285.6
2.5	4	408
4	5.2	530.4
5	5.6	571.2
7.5	6.8	693.6
10	7.2	734.4
12.5	7.6	775.2

Table 28 CBR for BCS+ 8%RHA

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0.6	61.2
1	2.6	265.2
1.5	3	306
2	4.2	428.4
2.5	4.4	448.8
4	6.2	632.4
5	7	714
7.5	7.8	795.6
10	8.6	877.2
12.5	9.6	979.2

Table 29 CBR for BCS+10%RHA

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0.6	61.2
1	2.6	265.2
1.5	3	306
2	4.2	428.4
2.5	4.8	489.6
4	6.2	632.4
5	7.2	734.4
7.5	7.8	795.6
10	8.6	877.2
12.5	9.6	979.2

Table 30 CBR for BCS+ 16%RHA

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0.6	61.2
1	1.6	163.2
1.5	2.4	244.8
2	3.6	367.2
2.5	4.8	489.6
4	5.8	591.6
5	6.8	693.6
7.5	7.6	775.2
10	8.4	856.8
12.5	9.6	979.2

Table 31 CBR for BCS+ 18%RHA

penetration (mm)	Load Readings	(KGF)
0	0	0
0.5	0.6	61.2
1	1.6	163.2
1.5	2.4	244.8
2	3.6	367.2
2.5	4.6	469.2
4	5.8	591.6
5	6.4	652.8
7.5	7.6	775.2
10	8.4	856.8
12.5	9.6	979.2

3.7. CALIFORNIA BEARING RATIO (28 DAYS)

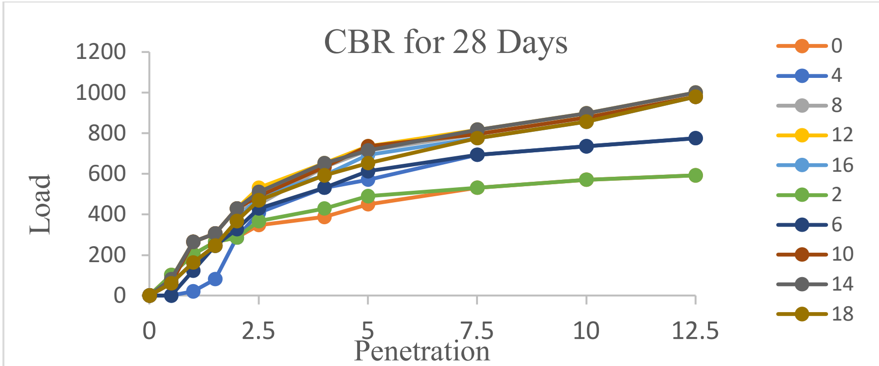


Figure 12 California Bearing Ratio Comparison for all replacements and BCS

The graph presents the California Bearing Ratio (CBR) results after 28 days for various stabilizer percentages. The x-axis denotes the penetration in millimetres, while the y-axis indicates the applied load. Among the tested samples, those stabilized with 8%, 10%, 12%, 14%, and 18% exhibit substantially higher load-bearing capacities compared to the untreated sample (0%) and lower percentages like 2% and 4%. The 12% stabilizer content achieves one of the highest peak loads, reaching approximately 1000 units at 12.5 mm penetration, closely matching the performance of 10%, 14%, and 18%. This indicates that performance gains beyond 12% are marginal and not cost-effective. Samples with 2% and 4% stabilization show limited improvement over the untreated condition, while 6% and 8% transitional increases. Given its strong performance and efficiency, 12% is identified as the most suitable stabilizer percentage, balancing strength enhancement and material economy. This dosage optimally improves subgrade strength without unnecessary material usage or cost.

3.8 ULTRA SONIC PULSE VELOCITY:

Table 32 UPV for all replacements.

percentage (%)	UPV m/s
0	273
2	308
4	328
6	370
8	425
10	515
12	625
14	578
16	567
18	535

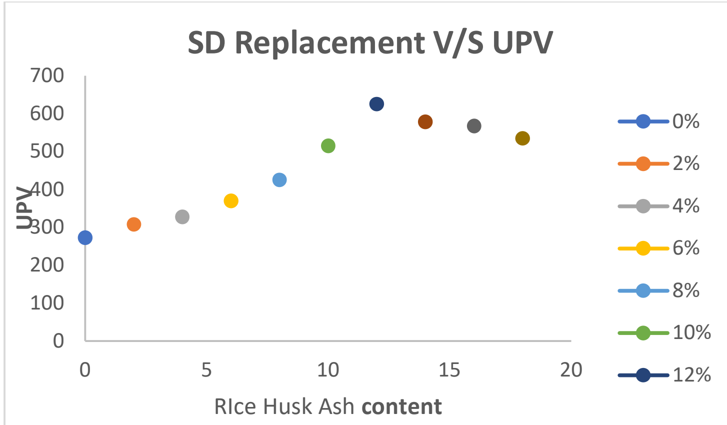


Figure 13 Graph for percentage of replacement and UPV

The graph illustrates the relationship between Rice Husk Ash (RHA) content and Ultrasonic Pulse Velocity (UPV), indicating material density and uniformity. UPV increases with RHA content, peaking at 12%, suggesting enhanced compaction and internal structure. Beyond 12%, a slight decline in UPV is observed, making 12% RHA replacement the optimum for improving material integrity.

4. CONCLUSION

This study demonstrates that the addition of Rice Husk Ash (RHA) significantly enhances the engineering properties of black cotton soil. The results indicate a substantial reduction in Liquid Limit and Plasticity Index, with the most effective stabilization achieved at 12% RHA content. This optimal dosage also resulted in improved workability, increased Plastic Limit, and enhanced strength parameters as evidenced by Unconfined Compressive Strength and California Bearing Ratio tests. While Maximum Dry Density decreased, Optimum Moisture Content increased, reflecting better compaction characteristics. Ultrasonic Pulse Velocity results confirmed uniformity and improved compaction. Overall, 12% RHA proved to be the ideal stabilizer percentage, effectively reducing swelling potential and improving structural integrity, offering a sustainable, cost-effective solution for stabilizing problematic black cotton soils in geotechnical applications.

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