A LABORATORY STUDY ON THE EFFICACY OF RICEHUSK ASH AND MAGNESIUM CHLORIDE IN ENHANCING STRENGTH CHARACTERISTICS OF EXPANSIVE SOIL AS A SUBGRADE FOR FLEXIBLE PAVEMENTS

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Abstract - Expansive soils, covering nearly one-sixth of India's land area, are locally known as Black Cotton Soils or Regur. These shrink-swell soils undergo significant volume changes up to 30% due to variations in moisture content, leading to heaving or settlement that can severely damage structures and pavements. In particular, expansive subgrades contribute substantially to road failures. Traditional remedies such as soil replacement and moisture control often face limitations due to high costs or impractical implementation.

This study investigation the stabilization of expansive soils using Rice Husk Ash (RHA), an industrial waste, combined with Magnesium Chloride ($MgCl_2$), a chemical stabilizer. RHA, a by-product of rice milling, is produced in vast quantities in India approximately 20 million tonnes annually. Due to its siliceous nature and impurities, RHA is seldom used in industry and is typically dumped, causing environmental pollution. Utilizing RHA in soil stabilization not only addresses waste disposal challenges but also offers economic and environmental benefits.

Chemical stabilization using electrolytes like $MgCl_2$ provides a promising alternative to conventional lime treatment. These chemicals readily dissolve in water, offering a convenient method for soil treatment via ponding or borehole injection, facilitating cation exchange without the need for extensive mixing. This investigation aims to assess the impact of RHA and $MgCl_2$ on the strength and performance of expansive soils, contributing to more sustainable and cost-effective geotechnical practices.

Keywords: Expansive Soil (ES), Rice Husk Ash (RHA), Magnesium Chloride ($MgCl_2$), Stabilization, CBR, Plasticity index

1.Introduction

Expansive soils are a category of problematic soils characterized by their tendency to undergo considerable volumetric changes in response to moisture fluctuations expanding when saturated and shrinking upon drying. These soil movements can induce substantial structural distress in civil engineering infrastructure, including pavements, foundations, embankments, and utility lines. Found predominantly in arid and semi-arid climatic zones, expansive soils pose significant engineering challenges across the globe.

In India, these soils are commonly known as Black Cotton (BC) soils, named for their distinctive dark color and historical suitability for cotton cultivation. BC soils cover approximately 20% of the nation's land area, with major occurrences in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, and Tamil Nadu. They are especially prevalent throughout the Deccan Plateau, particularly south of the Vindhya Hill range, spanning an estimated 200,000 square miles.

The highly plastic nature of expansive soils leads to differential heaving and settlement, which severely affects the performance and durability of structures built upon them. These deformations often exceed those predicted by conventional elastic or plastic soil models, rendering traditional geotechnical design approaches inadequate. As a result, infrastructure constructed on expansive soils is prone to cracking, distortion, and premature failure, contributing to substantial maintenance and repair costs.

Over the years, several mitigation strategies have been developed to address the problematic behaviour of expansive soils. Techniques such as soil replacement, moisture control, pre-wetting, and chemical stabilization with lime or cement have been employed with varying degrees of success. However, each method presents certain limitations, including high cost, implementation complexity, and limited long-term effectiveness.

In recent times, the use of industrial and agricultural waste materials such as fly ash, rice husk ash, and other pozzolanic by-products indyhas emerged as a promising and sustainable alternative for soil stabilization. These materials not only improve the engineering properties of expansive soils but also offer an environmentally friendly solution to industrial waste management. This study focuses on the geotechnical behaviour of black cotton soils in India and evaluates existing and emerging stabilization techniques, with particular emphasis on the use of industrial waste for enhancing soil performance.

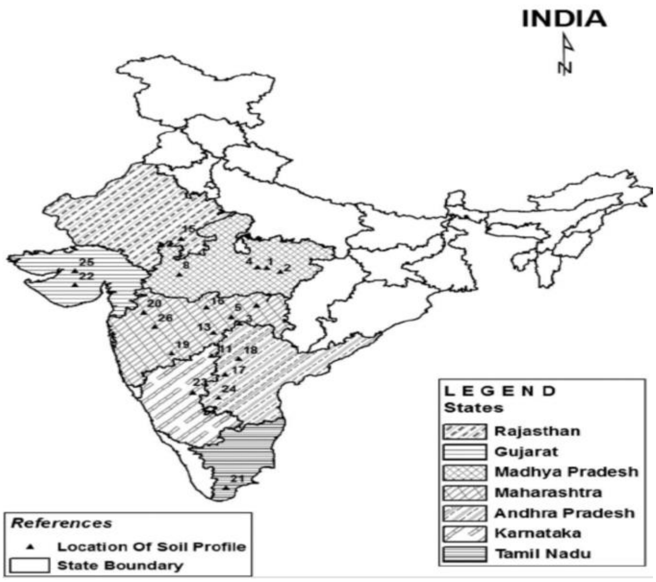


Figure 1.1 Map showing black cotton soil regions of India

1.1 Rice Husk

Rice husk is an abundantly available waste material in all rice producing countries, and it contains about 30%–50% of organic carbon. Rice husk ash (RHA) is an abundantly available and renewable agriculture by-product from rice milling in the rice-producing countries. It has the highest proportion of silica content among all plant residues. In the course of a typical milling process, the husks are removed from the raw grain to reveal whole brown rice which upon further milling to remove the bran layer will yield white rice. RHA is the product of incineration of rice husk. RHA is grayish-black in color due to unburned carbon. At burning temperatures of 550–800 °C, amorphous silica is formed, while crystalline silica is produced at higher temperatures. The specific gravity of RHA varies from 2.01 to 2.27; it is highly porous and light weight, with a very high specific surface area.

For present study, the RHA was Sourced from the captive power plant of Lalitha Rice mill, Peddapuram, East Godavari district, Andhra Pradesh, India.

The high percentage of siliceous materials in rice husk ash indicates it has potential pozzolanic properties. RHA has been classified into high carbon char, low carbon ash and carbon free ash. It is chemically stable and its physical properties are similar to that of natural sand. The high angularity and friction angle of rice husk contribute to excellent stability and load bearing capacity.

Rice husk ash contain a large amount of iron oxide and silicate. It has higher density, stay in the top layer and then transported to a water basin with a low temperature for solidification. Rice husk aggregate tend to free drying and are not frost susceptible. It is highly resistant to moisture penetration and fungal decomposition. Husk therefore makes a good insulation material. Rice husk ash has a high silica contents which means that it decomposes slowly when brought back to the field.

1.2 Expensive Soil

The soil used was a typical black cotton soil collected from Toorpulanka near Amalapuram, in East Godavari District, Andhra Pradesh State, India. This expansive soil was collected at a depth of 1.0m from the ground level. The tests were carried out on the soil as per IS Codes of practice.

1.3 Objective of Study

The objectives of the present experimental study are

- To determine the Engineering properties of the Expansive Soil.
- To assess the performance of Expansive Soil when treated with Rice Husk Ash and Magnesium Chloride.
- To evaluate the optimal proportion of RHA and Magnesium Chloride at which soil provides the maximum strength.

- To perform the California bearing ratio (CBR) and cyclic plate load test on both treated and untreated expansive soil combination.

S.No	Property	Properties
1.	**Grain size distribution** Sand (%) Silt (%) Clay (%)	 6 25.2 68.8
2.	**Atterberg limits** Liquid limit (%) Plastic limit (%) Plasticity index (%)	 78.921 37.25 41.66
3.	**Compaction properties** Optimum Moisture Content (O.M.C) (%) Maximum Dry Density (MDD) (g/cc)	 27.01 1.41
4.	Specific Gravity (G)	2.53
5.	IS Classification	CH
6.	C.B.R (%)	1.321
7.	Differential free swell (%)	120
8.	Cohesion (C) (Kg/cm^2)	0.36
9.	Angle of internal friction (ø)	0º

Table-1: Properties of Expansive Soils

2. REVIEW OF LITERATURE

2.1 Dr. D. Koteswara Rao et al. (2011) Kakinada, stated that the RHA is manufactured in the amount of 20 million tons per year, poses a significant environmental risk, inflicting damage to the land and the ecosystem in which it is disposed. There are numerous options for disposing it through the commercial use of RHA. The UCS increased by 548 percent after 28 days curing for an optimum percent of RHA with lime and gypsum, and the CBR increased by 1350 percent after 14 days curing for an optimum percent of RHA with lime and gypsum.

2.2 Katti et al. (1966) attempted to stabilize the in-situ soil using KOH solution, and they discovered that treating black cotton soils in place with an aqueous solution of KOH can change their properties.

2.3 Sivanna et al. (1976) investigated the effects of $CaCl_2$ and KOH on the strength and consolidation properties of black cotton soil and found that these chemicals boosted strength while decreasing settling and swelling. Field studies were thought to be necessary to determine their applicability under in-situ settings.

2.4 Muntohar et al. (2000) to stabilize expansive soil, a mixture of rice husk ash and lime was utilized. RHA was used as a replacement for expansive soil at 7.5 percent, 10%, and 12.5%, and lime at 2%, 4%, 6%, 8%, 10%, and 12%. Their Ip (plasticity index) plummeted from 41.25% to 0.96 % with a 12-12.5%RHA-lime combination, and their swell potential declined from 19.23% to minimal. CBR value increased from 3% to 16%, internal friction angle increased from 50 to 240, and cohesion increased from $54.32kN/m^2$ to $157.19kN/m^2$, raising bearing capacity from $391.12kN/m^2$ to $4131kN/m^2$.

2.5 Radhey S. Sharma et al (2008) the engineering features of a reconfigured soft soils combined with lime, calcium (CaCl2) and RHA were examined. By dry weight of soil, the quantities of RHA, lime, and calcium chloride were increased from 0% to 16%, 0% to 5%, and 0% to 2%, respectively. The effect of additives on UCS and CBR has been discovered. The stress-strain behavior of expansive clay was improved by adding up to 5% calcium or 1% CaCl2. The greatest improvement in breakdown load was 225 and 328 % at 4% lime and 1% calcium chloride, respectively. A RHA level of 12% was discovered to be ideal in terms of both UCS and CBR in the presence of either lime or calcium chloride.

2.6 Vishnu T.C et al. (2016) work on "Stabilization Using Rice Husk Ash, Lime, and Jute," that at 6% RHA, 6% Lime, and 2% Jute gradually increased OMC, decreased MDD, increased UCS, and increased CBR.

3. EXPERIMENTATION

3.1 DIFFERENTIAL FREE SWELL (DFS)

To determine the Free Swell Index of soil as per **IS: 2720 (Part XL) – 1977**. Free swell or differential free swell, also termed as Free Swell Index, and is the increase in volume of soil without any external constraint when subjected to submergence in water.

$$\textbf{Free Swell Index} = ([V_d - V_k] / V_k) \times 100\%$$

Where,

V_k = Volume of soil specimen read from the graduated cylinder containing kerosene.

V_d = Volume of soil specimen read from the graduated cylinder containing distilled water.

Fig 3.1 : Differential Free Swell Test

3.2 ATTERBERG LIMITS

3.2.1 LIQUID LIMIT

Virgin soil and optimum percentage of RHA (i.e. 9% by dry weight) are mixed with the soil and the liquid limit was determined as per **IS: 2720 (part-5)-1985**.

Liquid limit is the moisture content at which 25 blows in standard liquid limit apparatus will just close a groove of standard dimensions cut in the sample by the grooving tool by specified amount. The flow curve is plotted in the log-scale on the x-axis, and the water content in the arithmetic scale on y-axis. The flow curve is straight line drawn on the semi-logarithmic plot, a nearly as possible through three or more plotted points. The moisture content corresponding to 25 blows is read from this curve rounded off to the nearest whole number and is reported as the liquid limit of the soil.

Fig 3.2.1: Liquid limit

Virgin soil and optimum percentage of RHA (i.e., 9% by dry weight) is mixed with the soil and the plastic limit was determined as per **IS: 2720 (part-6)-1972**.

3.2.2 Plastic Limit

Plastic limit is the moisture content at which a soil when rolled into thread of smallest diameter possible, starts crumbling and has a diameter of 3mm.

The Plastic limit (W_p) is reported as the average moisture content at which the soil begins to crumble when rolled into 3mm threads.

Fig 3.2.2: Liquid limit

3.3 Modified Proctor Compaction Test

The maximum dry density (MDD) and Optimum Moisture Content (OMC) of the soil are determined through compaction tests, following the procedure outlined in the Indian standard codes of practice IS: 2720 (Part VIII)-1983.

3.4 California Bearing Ratio (CBR)

Test The California Bearing Ratio (CBR) serves as a measure of the shearing resistance of a material under controlled density and moisture conditions. A load penetration curve is plotted for each specimen on a natural scale. From these curves, the CBR values are calculated for 2.5 mm and 5.0 mm depths of penetration.

Table-2: Mix Proportions for testing Soil

S.NO	Stabilizing Agent	% content
1	Rice Husk Ash	0,3,6,9,12,15
2	Magnesium Chloride	0,0.5,1,1.5,2

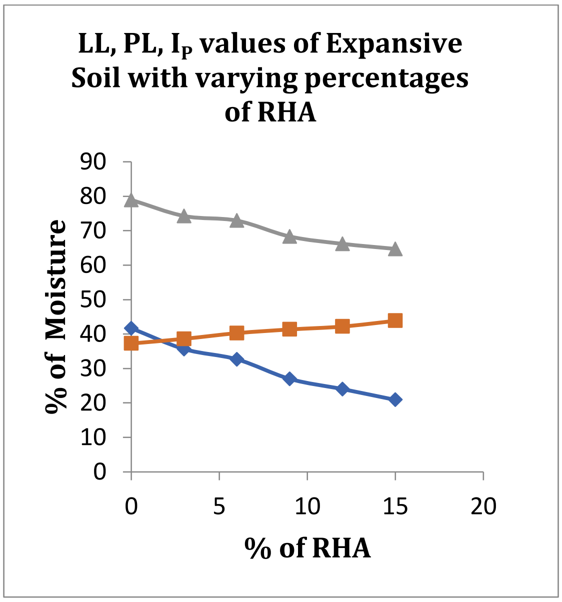
4. RESULTS AND DISCUSSION

4.1 Differential Free Swell Test

S.NO	MIX PROPRTIONS	DFS (%)
1	91%ES+9%RHA+0% $MgCl_2$	99
2	90.5%ES+9%RHA+0.5% $MgCl_2$	85
3	90%ES+9%RHA+1% $MgCl_2$	78
4	**89.5%ES+9%RHA+1.5% $MgCl_2$**	**65**
5	89%ES+9%RHA+2% $MgCl_2$	55

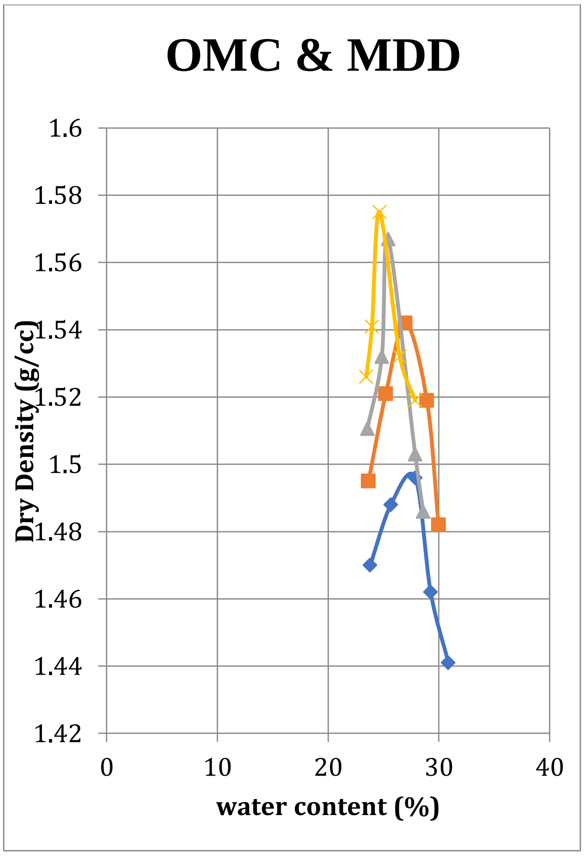
4.2 Atterberg Limits Test

S.NO	MIX PROPRTIONS	LL (%)	PL (%)	I_P (%)
1	91%ES+9%RHA+0 % $MgCl_2$	68.3	41.33	26.97
2	90.5%ES+9%RHA+0 .5% $MgCl_2$	63. 58	41. 98	21.6
3	90%ES+9%RHA+1 % $MgCl_2$	59.68	42.58	17.1
4	**89.5%ES+9%RHA+ 1.5% $MgCl_2$**	**56.34**	**42.79**	**13.55**
5	89%ES+9%RHA+2 % $MgCl_2$	50.31	43.26	7.05



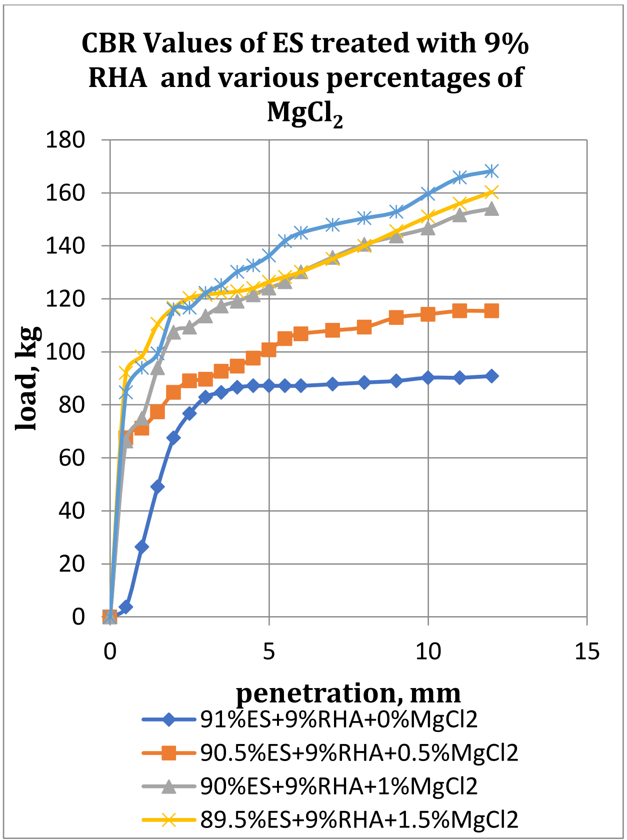
4.3 Compaction Properties

S.NO	MIX PROPRTIONS	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
1	91%ES+9%RHA+0% $MgCl_2$	26.02	1.472
2	90.5%ES+9%RHA+0.5% $MgCl_2$	25.99	1.496
3	90%ES+9%RHA+1% $MgCl_2$	25.42	1.542
4	**89.5%ES+9%RHA+1.5% $MgCl_2$**	24.12	1.567
5	89%ES+9%RHA+2% $MgCl_2$	23.67	1.575



4.4 CBR Value of Expansive Soil

S.NO	MIX PROPRTIONS	Soaked CBR %
1	91%ES+9%RHA+0% $MgCl_2$	5.602
2	90.5%ES+9%RHA+0.5% $MgCl_2$	6.498
3	90%ES+9%RHA+1% $MgCl_2$	7.977
4	**89.5%ES+9%RHA+1.5% $MgCl_2$**	**8.784**
5	89%ES+9%RHA+2% $MgCl_2$	8.190



5. CONCLUSIONS

Optimum percentages of Rice Husk Ash and Magnesium Chloride were observed during laboratory investigations are summarized in following table.

S.NO	Additives	Optimum Percentage
1	Rice Husk Ash	9%
2	Magnesium Chloride	1.5%

Conclusions of the various laboratory test results were presented.

i) It is observed from the laboratory test results that the Liquid Limit of the Expansive Soil has decreased from 78.92% to 56.34% by 28.61% on treating Expansive Soil with 9% RHA and 1.5% $MgCl_2$.

ii) It is noticed that the Plastic Limit of the Expansive soil has increased from 37.25% to 42.79% by 14.89% on treating Expansive Soil with 9% RHA and 1.5% $MgCl_2$.

iii) The Plasticity Index of the Expansive Soil has decreased from 41.66% to 13.55% by 67.47% on treating Expansive soil with 9% RHA and 1.5%$MgCl_2$

iv) By the addition of 9% RHA and 1.5% Magnesium Chloride, the DFS value has decreased from 120% to 65% by 45.83%.

v) It is observed from the results that the C.B.R value of the Expansive Soil has increased from 1.321% to 8.784% by 564.95% on treating Expansive soil with 9% RHA and 1.5% $MgCl_2$.

vi) It is noticed that the O.M.C of the Expansive Soil has decreased from 27.08% to 24.12% by 10.93% on the addition of 9% RHA and 1.5% $MgCl_2$.

vii) It is observed from the results that the MDD of the Expansive Soil has been increased by 11.13% on the addition of 9% RHA and 1.5% $MgCl_2$

viii) The CBR value of the Expansive Soil on treating with 9% RHA and 1.5% $MgCl_2$ is found to be 8.19% and it is satisfying standard specifications.

ix) It is observed from the laboratory investigations of the cyclic plate load test results, the ultimate cyclic pressure of treated Expansive Soil sub grade flexible pavement with 9% RHA has been improved from 630kPa to 1000kPa by 58.7% and further improved to 1400kPa by 122.2% on treating Expansive Soil Sub-grade with 9% RHA and 1.5% $MgCl_2$.

x) It is observed from the laboratory test results of cyclic plate load test that the total deformations of treated Expansive Soil sub-grade flexible pavement with an optimum of 9% RHA and 1.5% $MgCl_2$ has been reduced from 2.73mm to 2.33mm by 14.65% at OMC.

xi) So finally, it is concluded from the above test results that the expansive soil treated with 9% RHA and 1.5% $MgCl_2$ is suitable to use as sub grade material for the pavement construction.

5.1 DISCUSSIONS

Hence, from the present laboratory investigations, it was included that the Expansive Soil treated with 9% of Rice husk ash and 1.5% Magnesium Chloride as an optimum exhibits satisfactory result as per IRC 37-2001 and 2012 code of practice.

5.2 FURTHER SCOPE OF WORK

The following areas are identified as the scope of further research in this direction, based on the experience of the present work.

- Further laboratory investigations can be carried out with the addition of various chemicals with the expansive soil along with RHA to improve strength characteristics.
- Field tests are to be conducted to confirm the laboratory test results in the field.
- Further laboratory Cyclic Plate Load tests can be conducted by using Geo-textile as Reinforcement and Separator.

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