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(RESEARCH ARTICLE)

Stabilization of expansive soil using different combinations of glass powder and rice husk ash

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Abstract

The global issue of expansive soil is the root cause of significant harm to structures designed for civil engineering. The difficulty with expansive soils is that they expand when water is absorbed and contract when it evaporates because of clay minerals including kaolinite, montmorillonite. Because of its poor shear resistance and load-bearing capacity, it makes it difficult to build foundations for Infra Construct. The expansive soil is widely distributed worldwide, especially in certain regions of Pakistan including Sindh, Punjab, and KPK. The soil was gathered for this study from Kohat KPK's Shindand region. For such soils to be acceptable for construction, they must be stabilized. The soil was stabilized using different combinations of leftover glass powder and rice husk ash (RHA). Expansive soil samples mixed with various combinations of Glass Powder and Rice Husk Ash (RHA) were subjected to various geotechnical tests, including Sieve Analysis, Hydrometer analysis, Atterberg limit, Free Swell Index (FSI), Standard Proctor Test (SPT), Unconfined Compression Strength (UCS), and California Bearing Ratio (CBR). According to Atterberg's limit, adding 3% GP and 6% RHA results in a significant reduction of the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), providing the ideal dose level. Additionally, adding 3% GP and 6% RHA resulted in a drop of 10.8% in the optimal moisture content (OMC) and an increase of 1.42% in the treated soil's maximum dry density (MDD). Adding 3% GP and 6% RHA reduces the Free Swell index by 27.2%. After treating the untreated soils with 3% GP and 6% RHA, the UCS significantly increased by 160.6%.

Keywords: Expansive soil; Soil stabilization; Glass powder; Rice husk ash (RHA); Geotechnical properties; Sustainable construction

1. Introduction

Expansive soils, widely encountered in various regions across the globe which present substantial challenges in construction and infrastructure development. Characterized by their high shrink-swell potential, these soils undergo significant volume changes with moisture variations. During wet conditions, expansive soils absorb water and expand, whereas in dry conditions, they lose moisture and contract. This cyclical swelling and shrinking can cause severe structural damage, such as cracks in foundations, pavements, and walls, leading to increased maintenance costs and reduced lifespan of structures [1]. Traditional soil stabilization methods often involve the use of lime, cement, or other chemical stabilizers to improve the engineering properties of expansive soils. While effective, these methods may not always be sustainable or economically viable, especially in regions where access to these materials is limited or their environmental impact is a concern [2]. The application of glass powder and rice husk ash in soil stabilization involves mixing these materials with expansive soil in various proportions. This combination aims to improve the soil's engineering properties, such as shear strength, compressibility, and bearing capacity. using glass powder and rice husk ash in soil stabilization are manifold. Firstly, these materials are cost-effective and readily available, especially in regions

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with a thriving glass manufacturing industry and rice cultivation. Secondly, their use in soil stabilization helps mitigate the disposal issues associated with industrial and agricultural waste, thus contributing to environmental sustainability. Thirdly, the combination of glass powder and rice husk ash has been shown to improve the soil's mechanical properties, enhancing the durability and performance of structures built on expansive soils [3]. but the variability in the quality and properties of glass powder and rice husk ash can affect the consistency and predictability of the stabilization results. Additionally, the long-term effects of these materials on soil properties and the environment need further investigation to ensure their safe and effective use in large-scale applications [4]. The problematic clayey soil known as expansive soil swells when water meets it and contracts when the water evaporates [5]. The amount of water that interacts with the soil directly correlates to a change in volume. The expansive soil's volume change behavior puts pressure on civil engineering structures, particularly lightly loaded ones that are resting on the soil, the shrinking of the soil eliminates support from buildings or other structures that are resting on the soil [6]. Such soil moisture content changes are linked to sewage line leaks, floods, and rainfall. Therefore, it is crucial to research how expansive soils swell and the factors influencing their resulting expansions and contractions. Hydrophilic minerals like smectite, kaolinite, montmorillonite, etc. make up expansive soils [7].

The amount of clayey soil that swells depends on several factors, including the amount of cations utilized, the mineralogical structure, the percentage of volume of these mineral substances, and the physical and chemical conditions that the soil is subjected to. The types and concentrations of absorbing cations and clay elements are the main factors that determine how clayey soils swell. The stability of broad soil is further influenced by the mineral content, grain shape, and size distribution, despite the percentages of sand and fine clay fractions.

Table 1 Burmister's Consistency Limits [37]

Degree of Expansion	L.L	P.L	S.L	F.S.I
Low	<25%	<20%	>17%	<20%
Medium	40-60%	25-50%	8-18%	25-50%
High	>60%	>35%	6-12%	>35%

Montmorillonite has the highest water-holding capacity among these clay minerals. The three-layered lattice structure of montmorillonite, which is hydrated aluminum silicate, expands when water seeps into the soil's interior layer [8]. These minerals may absorb more water, which also extracts swelling pressure. Water molecules and exchangeable cations occupy the area between the joined sheets. These ions cause a very weak connection to form between the joined sheets. We refer to the resulting arrangement of particles as swelling or shrinkage. In expansive soils, swelling has always been associated with shrinkage. The upward vertical deformation is called swelling, and the downward vertical deformation is called shrinking. Soil shrinkage causes the soil's top layers to sink and, as a result, causes cracks that compromise the structure [9]. The greater values of the plasticity index and liquid limit are related to the soil's shifts in size. By adding right amount of stabilizer, the PI and LL values can be reduced to desired levels [10]. Many issues of expansive soils manifest as breaks and fractures in pavements pipes for gas, water, and sewage, roadways, slab-on-grade elements, drainage systems, and canal linings. It has been determined that these damages exceed 14 by a factor of two the combined damages resulting from earthquakes, tornadoes, hurricanes, and floods. Substantial portions of the globe, such as the United States, South Africa, Saudi Arabia, Pakistan, India, and so on, are covered by expansive soils. These soils are found in Sindh (Khairpur), Khyber Pakhtunkhwa (DI Khan, Kohat, Bannu, etc.), and Punjab (Kalar Kahar, Chakwal, Nandipur, etc.) in Pakistan. To simulate field conditions during the experimentation process, soil samples were taken from the Shindand area of Kohat KPK at a depth of 2.5 feet. After that, the samples were placed in sealed bags to keep the moisture inside. Kohat is located in the northern parts of KPK, which experiences arid weather with an average rainfall of roughly 15 cm [11]. Stabilization is used to enhance expansive soil properties. Expansive soils inflict enormous harm, hence various industrial and agricultural waste materials are used to stabilize these soils. Compaction procedures (i.e., Mechanical Stabilization) are used to stabilize expansive soils, although the results are less successful. Therefore, to advance high strength and better qualities, chemical stabilizer agents are utilized; consequently, to reduce project costs, various waste products are used. Expansive soils have better stiffness and strength when garbage and fibers are added in addition to chemical agents. Common stabilizers include marble dust, bagasse ash, lime, Portland cement, rice husk ash, glass powder, etc. One of the first developed building materials, lime (CaO), is a burnt by-product of limestone that has been used by humans for over 2,000 years [12,13]. These days, stabilizing highly flexible soils using lime is a widespread practice in many earthworks, including embankments, foundation bases, railways, airports, canal linings, and slope protection. In this study, stabilizers made of rice husk ash (RHA) and glass powder are used. The glass industry discards a significant amount of glass, which could have an effect on the environment and ecology [14].

Rice husk has a significant ash concentration, with 20% to 25% of the material consisting of silica (80–90%). RHA is categorized as carbon-free (pink or white), low carbon (grey), and high-carbon char (black) [15]. By keeping its initial moisture content below permissible bounds (less than 50%), the RHA seems to be a very helpful material for lightweight filling that would not cause any problems with compaction [16]. Zamin et al. (2021) study found that expansive soils supplemented with waste glass powder were less likely to inflate. Each of the studies that were referenced showed how, in the countries where it was utilized, well-recycled glass powder was used as a soil stabilizer. However, whether leftover glass powder can be utilized to stabilize troublesome soils has not been evaluated in the field [17].

When the moisture content varies, expansive soils may experience a volume change. Because of their capacity to rise, these soils have the potential to create differential settlements, which could harm infrastructure. Any building built on these soils would eventually crack and crumble due to differential settlement, which is the result of significant mass displacement brought on by moisture changes in expansive soil. For instance, when precipitation seeped into the broad soil beneath a road in Sudan, the road displayed a differential settlement of up to 15% [18]. Expansive soils experience significant volumetric changes, such as swelling and shrinking, which are correlated with variations in the water content [19]. These soils contain clay minerals with a high shrink-swell capability, such as montmorillonite, kaolinite etc. These soils absorb water during the monsoon season, swell, and become softer. As a result, their ability to support weight is diminished. During dry seasons, the evaporation of water leads these soils to shrink or lose volume, hardening them and creating fractures [20]. Shrink-swell behavior is more likely to occur below the surface of the earth, where seasonal and environmental changes directly affect it. The distant soils are well on their way to having clay minerals with Vander Waals forces called montmorillonite. The measurement of monovalent cations held to the minerals in the soil is crucial for determining a significant amount of serious damage in expansive soils [21].

Table 2 Overview of Soil Stabilization Techniques, Their Descriptions, and Limitations

Ref	Soil stabilization with different material	Description	Limitation
[22]	Expansive soil stabilization using soda lime glass powder (SLGP)	the stabilization of expansive soils using soda lime glass powder (SLGP) as a pozzolanic stabilizer, examining its effects on soil properties, while addressing recycling of non-biodegradable glass waste.	It does not explore the long-term durability or environmental impact of stabilized soils under real-world field conditions.
[23]	Expansion Soil Stabilization with agricultural waste	the use of agricultural waste such as coffee husk ash, cornhusk fiber, coir fiber, and others for improving the geotechnical properties of expansive soil, emphasizing their potential in enhancing strength, reducing cracking, and promoting sustainable soil stabilization practices.	the insufficient detailed and broad study on the long-term durability of plant-based agricultural waste additives in expansive soil stabilization.
[24]	Expansion Soil Stabilization using Mechanical and Chemical Methods:	explores the stabilization of expansive soils using mechanical and chemical methods, with a focus on improving soil characteristics.	A limitation identified is the environmental impact, particularly the potential for groundwater contamination from toxic additives in chemical stabilization, which may lead to restrictions in application based on sustainability concerns.
[25]	Soil stabilization with glass granules	the effects of expanded glass granules on the shear modulus, damping ratio, and modulus reduction values of clay-based mixed specimens, demonstrating the influence of high friction angles and material composition on their dynamic mechanical behavior.	The limited range of effective cell pressures tested, which may affect the generalizability of the results across broader geotechnical conditions.

[26]	expansive soil Stabilization using industrial waste	The use of Sugarcane Bagasse Ash (SBA), Glass Fiber (GF), and Ceramic Dust (CD) to improve the engineering properties of expansive black cotton soil, focusing on reducing swelling, enhancing strength, and stabilizing soil through waste reuse.	The use of higher percentages of Glass Fiber (GF) beyond 3% led to oozing out of GF from soil, which can impact the overall performance and may require further optimization.
[27]	Expansive Soil Stabilized with Waste Granite Dust	The geotechnical properties of expansive soil treated with granite dust (GD) at varying percentages, highlighting its influence on unconfined compressive strength (UCS), failure strain, California Bearing Ratio (CBR), swelling potential, and linear shrinkage, supported by regression models and microstructural analyses.	While the influence of GD on geotechnical properties was explored for different curing periods and GD percentages, the long-term durability and performance beyond 30% GD addition were not thoroughly investigated, potentially limiting the generalizability of findings for higher GD contents.
[28]	Stabilization of expansive soil using alkali-activated fly ash	The stabilization of expansive soil using alkali-activated fly ash with varying NaOH content, emphasizing improvements in compressive strength, cohesion, and reduction in soil expansiveness.	The excessive NaOH content beyond 8% leads to soil brittleness and a decline in strength, suggesting a narrow optimal range for NaOH concentration.

The geotechnical characteristics of expansive soil before and after using Rice Husk Ash (RHP) as a stabilizer. It focuses on changes in plasticity index (PI), liquid limit (LL), plastic limit (PL), swelling potential (S), and swelling pressure (SP) with varying percentages of RHP. The results show significant improvements in reducing these properties with optimal RHP ratios, specifically 15%, which effectively reduces soil expansion and enhances stability but the study is the reliance on laboratory tests for evaluating soil characteristics, which may not fully represent field conditions, potentially limiting the applicability of findings in practical construction scenarios [29]. It has been established that the expansive soil found in some parts of Saudi Arabia has an impact on the quality of asphalt-paved roads. As a result, several of these roads have been replaced or abandoned. Road users experience severe pain, safety risks, and vehicle damage because of the settlement or heave formation caused by the limited bearing capacity of expansive soil on asphalt-paved roadways [30]. Expansive soils have a degrading effect that requires enhancing their bearing capacity through chemical and mechanical stabilization. In comparison to mechanical stabilizing methods including compaction of expansive soils and ground treatments, chemical stabilization with basic stabilizers like lime and Portland cement is more efficient and cost effective [31]

Water presence has a significant effect on how fine-grained soils behave structurally. Due to each soil's unique ability to absorb water, different soils exhibit varying Atterberg limitations. Essential characteristics for estimating activity are the plastic and liquid limitations. The liquid limit and the plastic limit are crucial factors in classifying the behavior of soil.

Table 3 Classification of Fine-grained soils with liquid Limit [38]

Soil Type	**Liquid limit**
High plastic clay	LL > 50
Medium plastic clay	30<LL>50
Low plastic clay	LL<30

A paper claims that the soil stabilization technique also reduces lead and copper leakage to as much as 98–100%, lowering the risk to human health as a result of the metals' intrusion into groundwater [32]. The practice of adding chemicals to soil to stabilize clay subgrade beneath foundations was first introduced by Blacklock et al. Following his outstanding accomplishment, a range of chemical agents were applied by surface treatment, subgrade injection, and close mixing with soil [33]. There were multiple stages of Indiramma et al.'s experimental inquiry. Initially, different proportions of lime (4% and 8%) were combined with expansive soil. Then, two distinct fly ash and lime mixtures—10% fly ash plus 4% lime and 10% fly ash plus 8% lime were investigated. Adding lime, either alone or in combination with fly ash, resulted in significant decreases in critical metrics such as liquid limit, plastic limit, plasticity index, ideal moisture content, and differential free swell index. These declines suggest that the soil is more suitable for use in engineering projects because it is less likely to exhibit shrink-swell phenomena. The treated soils also had higher maximum dry unit weight and strength, demonstrating increased bearing capacity and durability [34]. N. Tiwari et al. investigated strengthening loose soil with reused bagasse ash (BA) and fibers of coir (CF) to increase its durability and strength. They discovered that whereas CF strengthened against cracking and increased durability during freeze-thaw cycles, BA decreased swelling and enhanced soil characteristics. This environmentally friendly method has the potential to stabilize soil in road pavements at a reasonable cost [35]. The use of locally obtained calcined clay-based geopolymers (GPs) as a sustainable and economical method of stabilizing expansive soils was successfully investigated by Sopharith Chou et al. Significant increases in soil stiffness, strength, and durability were shown by their research, along with a decrease in strains caused by swelling and shrinking. The importance of locally produced GPs in improving expansive soil qualities for long-lasting highway infrastructure is highlighted by these studies [36].

This research article aims to determine the ideal quantity of additives required to raise the bearing capacity, lower lateral deformation, and settlement, and improve other soil properties. It also examines using agricultural and industrial waste materials to enhance the quality of soil. The amount of waste that needs to be disposed of responsibly is growing daily. This pollutes the environment and poses serious risks to it. Waste goods like glass powder and rice husk ash (RHA) are employed as soil stabilizers in expansive soils to eliminate these industrial wastes.

- Safe disposal of agricultural and industrial leftovers helps reduce environmental pollution.
- It is a cost-effective method of altering the geotechnical properties of expansive soils Study Area and Data

The Shindand neighborhood of Kohat, which is situated in the FATA at coordinates thirty-three*33'0N, 71*38'0E, is where a soil sample for this study was collected. The region is dry due to the intense heat and little rainfall.

2. Materials and Methodology

2.1. Identification of expansive soil

Assessing water quality holds paramount importance due to its multifaceted implications for human health, ecological integrity, and socio-economic well-being. Several studies underscore the critical role of water quality assessment in safeguarding public health and environmental sustainability, providing empirical evidence and theoretical frameworks to support this assertion. Water quality assessment plays a pivotal role in protecting public health by identifying and mitigating risks associated with waterborne diseases and contaminants. According to Li., (2020), poor water quality is a significant contributor to waterborne illnesses, with microbial pathogens, chemical pollutants, and toxic substances posing considerable health risks to exposed populations. The timely detection and management of water quality issues are essential for preventing outbreaks of waterborne diseases and ensuring the safety of drinking water supplies (Li et al., 2020). Poor water quality can impair the ability of ecosystems to provide essential services, such as water purification, nutrient cycling, and habitat provisioning, leading to cascading impacts on biodiversity and ecosystem functioning (Carpenter, 2018) and (Dudgeon, 2006).

Figure 1 Indication of Expansive Soil

The Differential settlement in and around the building because of recurring cycles of swelling and shrinking is a significant issue in expansive soils. Direct observation of expansive soil features, such as polygonal soil cracking, heaving, and diagonal cracking resulting from differential settlement, can identify its presence in each location. The presence of clay minerals like kaolinite and montmorillonite is what causes expansive soil to swell. These minerals are very attracted to water that has been absorbed. The misalignment of doors and windows might be the first indication of expansive soil beneath a building.

2.2. Material and soil sample collection

To prevent plants and organic compounds from being present in the upper layer of the soil, the top layer of the soil is first removed during the sample-collecting process. Next, a trench measuring three by three feet is dug, depending on the state of the ground. The soil sample was taken from the Shindand area of Kohat, and samples acquired in the field were securely packaged in plastic bags to prevent moisture content loss before being transferred to the laboratory. The following supplies needed for the sample collection were Plastic bags, Shovel, Hoe.

Figure 2 Google Map of the Shindand area of Kohat

There are multiple strategies employed to stabilize the expansive soil. In our investigation, we employed chemical stabilizers, such as GP and RHA, to enhance the characteristics of expansive soil. Glass was obtained from a glass industry in Swabi which was then crushed and converted to powder form, while RHA was obtained from a supplier.

Figure 3 Sample Collection

3. Methodology

The soil sample was subjected to a range of laboratory procedures to quantify several aspects of expansive soil. While some soil properties are dependent on both the form and composition of the soil and can only be accurately assessed on unaltered samples, other properties are absorbed into the nature of the soil matrix and are not impacted by disturbed soil. While "index properties" provide valuable information about the soil without directly measuring the required value, certain soil tests assess the actual qualities of the soil. The replacement of GP and RHA mixtures for stabilizing expansive soil removed from the Shindand area of Kohat (KPK) was determined by geotechnical testing. Numerous tests were run, some of which are briefly discussed here.

3.1. Sieve analysis

This test was performed under ASTM D6913-04(09). The sieve analysis test was performed for the gradation of the soil sample. Sieve analysis is comprised of a column of sieves. For 8 to 10 minutes the sample was shaken by a sieve shaker. The remaining weight was divided by the soil's total weight to calculate the percentage maintained on each sieve after shaking. Based on the obtained data, a graph was plotted between the percentage passing, noted on ordinate from selected sieves, and particle size (mm), noted on the abscissa.

Figure 4 Sieve Analysis of Sample

3.2. Hydrometer analysis

The test was performed under ASTM D421-22. For calculating the activity of the soil sample 50g of soil sample was passed from sieve no. two hundred. A solution of sodium hexametaphosphate with the soil sample was prepared. The sample was mixed for 5 minutes with the mixer. The solution was then transferred to the hydrometer jar and the jar was filled up to 1000cc by adding water. The readings were taken after 15 sec, 30 sec, 1, 2, 4, 8, 16, 16, 30 minutes, 1 hour, 2 hours, 4 hours, and 24 hours using a hydrometer.

If V is the cylindrical particle's end velocity of descending, then it may be found using:

$$1\ V = \left(\frac{1}{8}\right) * [Gs - 8\ Gw] * D2 \text{ (Eq-1) [39]}$$

- V is the soil particle's final speed (cm/s). D is the Soil particle dimension (cm)
- Gs is the soil particle's specific gravity or G.
- Gw is the Fluid's specific gravity.
- n is the Liquid viscosity (g-s/cm2).

The dimension of the soil grains was determined using the following equation if the test's temperature remained constant.

$$D = k * (\frac{HR}{T})$$ (Eq-2) [40]

Where:

- T is the time in minutes.
- D is the soil particle dimensions (mm)

The formula for calculating the percentage finer N is.

- $G*V$

$$N\% = \frac{G*V}{((G-1)*W)*(r-rw)} * 100$$ (Eq-3) [41]

Where:

- Where V is the soil solution volume (in centiliters).
- W is the dry soil's test mass; r is the hydrometer value in water. RW = The soil suspension's hydrometer value
- G is the soil particle's specific gravity.

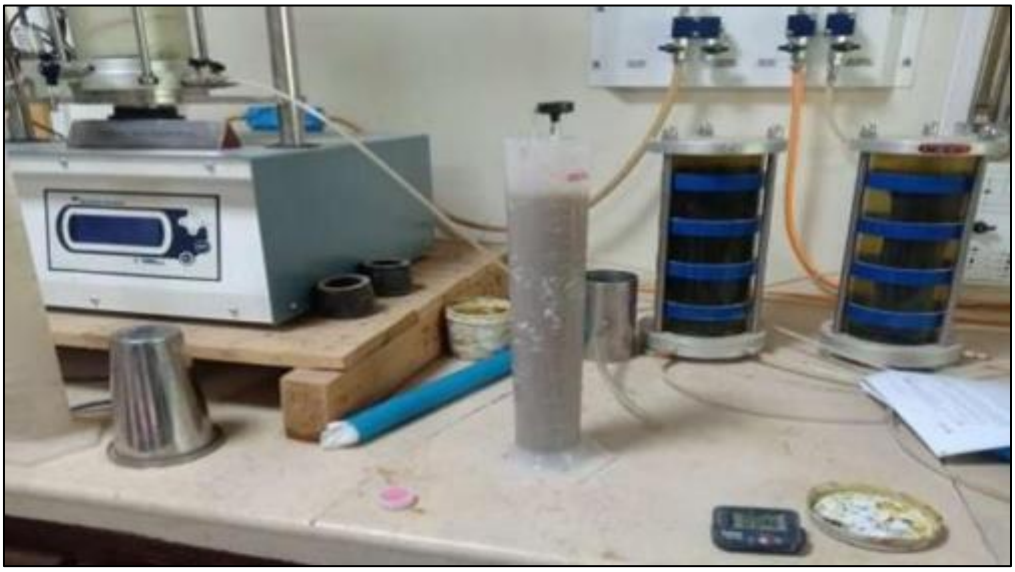

Figure 5 Hydrometer Analysis on Natural Soil

The Atterberg limits i.e., Liquid limit and Plastic limit are the basic measures of critical water in soil. This test was performed for untreated soil and on the following combinations of GP and RHA with expansive soil (1%+3%, 1%+6%, 1%+9%, 2%+3%, 2%+6%, 2%+9%, 3%+3%, 3%+6%, 3%+9%) respectively.

This test was performed under ASTM D4318-10. Soil samples required for the test were passed from Sieve No 40. 100g of the soil sample was taken. The sample was then mixed with water in a dish and substitution with RHA and GP. The soil sample was placed in Casagrande's apparatus, and the surface was leveled with the help of a grooving tool, the soil sample was cut down into two portions, symmetrically. The number of blows was noted when the bottom of the soil sample touched each other. The sample was, then, taken and put in the oven to find moisture content for each test. The experiment was repeated three times, with different water contents. Water content was displayed on the y-axis of the graph, and the quantity of blows was plotted on the x-axis. The tested soil specimen's water content was equal to 25 blows; this was its liquid limit.

Figure 6 Liquid Limit test in Progress

The ASTM D4318-00 was followed in performing this test. Sieve number 40 was used to filter the soil sample. Using a stirrer, stabilizers (RHA and GP) and an appropriate volume of water were added to the soil sample and thoroughly mixed. After a period in the open, the soil was then rolled with fingers on a glass plate using a 3 mm diameter stainless steel rod. The sample's diameter must be smaller than 3 mm to be checked. The sample was kneaded once again and rolled into the thread to determine whether there were any cracks on the thread, which would indicate a higher water content. The dirt sample was repeatedly processed until it broke. To determine the moisture content, the soil sample was subsequently put in the oven. The plastic limit was the soil sample's moisture content at which cracks started to form.

Figure 7 Plastic Limit Test in progress

This test was performed under the ASTM D422-63. The soil passing sieve no 40 was taken in a graduated glass cylinder up to 10ml. Then water was poured in graduated cylinder upto 100ml. left it for 24 hours and read the final volume of soil after 24 hours. At the end, the Free Swell Index was calculated using the following formula.

FSI = [1] *100 [42]

This soil test was conducted at varying percentages of RHA and GP for both treated and untreated soil.

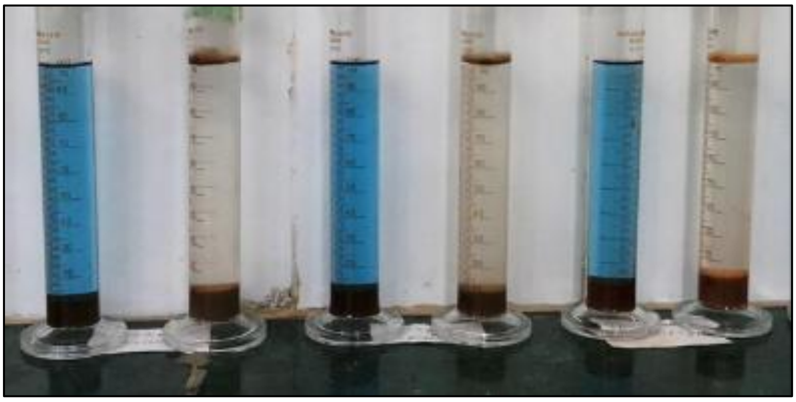

Figure 8 Free Swell Index Test

3.3. Standard proctor test

ASTM D698 is followed when conducting this test. A laboratory compaction test protocol was devised by Proctor (1993) to estimate the optimum moisture content (OMC) at which a particular type of soil will become denser and reach its maximum dry density (MDD) in the field.

By progressively adding more water to the spaces and forcing out the air, the compaction process aids in raising the bulk density. After passing through sieve number 4, a 2.5-kilogram sample of dirt was obtained and thoroughly ground. The finely ground dirt was completely combined with varying amounts of water to fill the compaction mold in three layers.

Each layer was then compacted using a conventional proctor hammer, which was struck twenty-five times from a 12-inch height. To find the maximum dry density, an experiment was conducted four or five times with a 2% increase in the proportion of water each time. We can then determine the OMC and MDD by graphing the test data with the dry density on the Y axis and the water content on the X axis.

Figure 9 Standard Proctor Test of Natural Soil

3.4. Unconfined compression strength test (UCS)

The ASTM D2166-06 was used for the UCS test. Sieve number 40 was used to filter the dirt. A sampler (mold) measuring 37 mm in diameter and 72 mm in height was used to prepare the sample. The mass of the sample was noted on the datasheet after it was weighed. The specimen was centered on the bottom plate and carefully inserted into the compression apparatus.

The load and deformation dials were set to zero, and the apparatus was adjusted so that the upper plate barely contacted the specimen. A data sheet was utilized for recording both load and displacement dial readings at each of the five divisions on the dial's deformation. The load was applied so that the device created an axial strain at a rate of 0.5% to 2% per minute. The load was applied until the specimen's load (load dial) drastically dropped.

When the deformation exceeded the calculated 10% strain, or when the load was held constant for at least four deformation dial readings, the load was reduced. After the sample was taken out of the compression apparatus, its water content was measured.

Figure 10 UCS Test Apparatus

3.5. California bearing ratio test (CBR)

According to ASTM D1883 / D1883M - 16e1 Standard Test Method, the first step in performing the CBR test is to prepare a representative soil sample by air-drying and screening it to eliminate big particles. Next, grease is applied to the cylindrical CBR mold, which has a base plate and collar, making it simple to remove the compacted soil. To reach the required moisture content, the soil is combined with water and then compacted in layers using a mechanical compactor.

The ASTM recommends utilizing a maximum of twenty-five blows per layer. Following compaction, the specimen is submerged in water for four days to achieve complete saturation. The saturated specimen is evaluated by applying a vertical load at a steady rate until it fails or reaches a predetermined deformation, recording the applied load at various deformations. Next, the test load to standard load ratio is computed and multiplied by one hundred to get the CBR as a percentage.

Figure 11 CBR Test Apparatus

Material and Methodology of the research was discussed in this chapter. It includes the location of places from where materials are collected and also the laboratory tests which were performed are briefly described. Procedure of all the tests are stated briefly according to the ASTM standards.

4. Results and Discussions

4.1. General

This research article analyzes and discusses the soil investigations conducted using geotechnical methods. It discusses engineering properties as well as the soil properties index. Specific gravity, liquid limit, plastic limit, shrinkage limit, relative density, dry density, initial water content, grain size distribution, free swell index, hydrometer analysis, and other characteristics are included in the index properties. In contrast, the engineering properties are compaction and compressibility. The test results are addressed with an emphasis on highlighting the stabilizing effect of MD and RHA.

4.2. Gradation curve

4.2.1. Sieve analysis

Both the AASHTO and the Unified Soil Classification System use sieve analysis to classify soil. The original strength and permeability of the soil can be estimated via sieve analysis. Determining the sizes and forms of the particles is crucial since it affects numerous other laboratory tests. Untreated expansive soil samples were subjected to sieve analysis tests in a laboratory setting. The test's outcomes are displayed in Figure 12.

According to the graph, 87% of the soil passes via sieve #200 (0.075 mm), indicating that the material has been uniformly graded. This suggests that the soil is problematic and clayey.

4.2.2. Hydrometer analysis

The figure illustrates the results of a hydrometer analysis conducted on untreated expansive soil to determine its grain size distribution, particularly focusing on particles smaller than 0.075 mm, which include silt and clay. The analysis reveals that the soil consists of 50% clay and 36% silt, with the remaining portion likely comprising sand or coarser particles. This high clay content classifies the soil as clayey, indicating significant potential for swelling and shrinking due to changes in moisture levels. The soil's activity, calculated as 0.78, reflects the ratio of its plasticity index to the clay fraction, suggesting moderate activity. This value is typical for soils dominated by kaolinite, a less expansive clay mineral, though the soil's classification as "expansive" implies the presence of more active minerals like montmorillonite or environmental factors that enhance its swelling behavior.

The gradation curve, which plots particle size against the percentage of particles finer than that size, shows a steep slope in the fine-grained range, indicating a uniform particle distribution. This uniformity can exacerbate the soil's instability under load, making it challenging for construction purposes. High clay content leads to low permeability and high plasticity, causing the soil to swell when wet and crack when dry. These characteristics pose significant challenges for foundations, pavements, and other civil engineering structures, necessitating stabilization to improve the soil's load-bearing capacity and reduce its expansive nature.

Understanding the gradation and activity of the soil is crucial for predicting its behavior in construction projects. The results from this analysis provide a baseline for evaluating the effectiveness of stabilization methods, such as the use of glass powder (GP) and rice husk ash (RHA), in mitigating the problematic properties of expansive soils. By addressing these issues, the soil can be made more suitable for engineering applications, reducing the risk of structural damage and improving overall project durability.

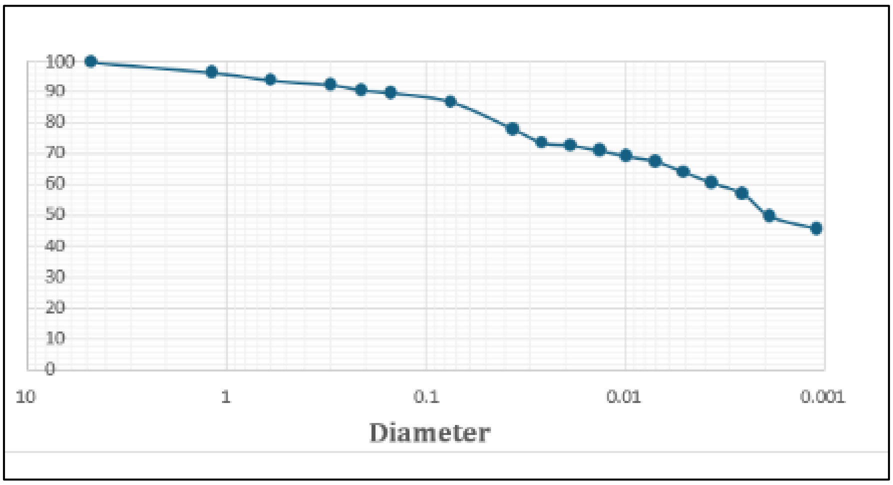

Figure 12 Gradation Curve of Untreated Soil

4.3. Atterberg limits

The liquid and plastic limits, among other various ranges of moisture levels, make up the Atterberg limits. Atterberg limits tests were conducted on untreated soil and treated soil combined with GP and RHA at the specified percentages (1%+3%, 1%+6%, 1%+9%, 2%+3%, 2%+6%, 2%+9%, 3%+3%, 3%+6%, 3%+9%) to ascertain the cohesive soil consistency. The consistency of soil is highly influenced by its water content.

4.3.1. Atterberg limits

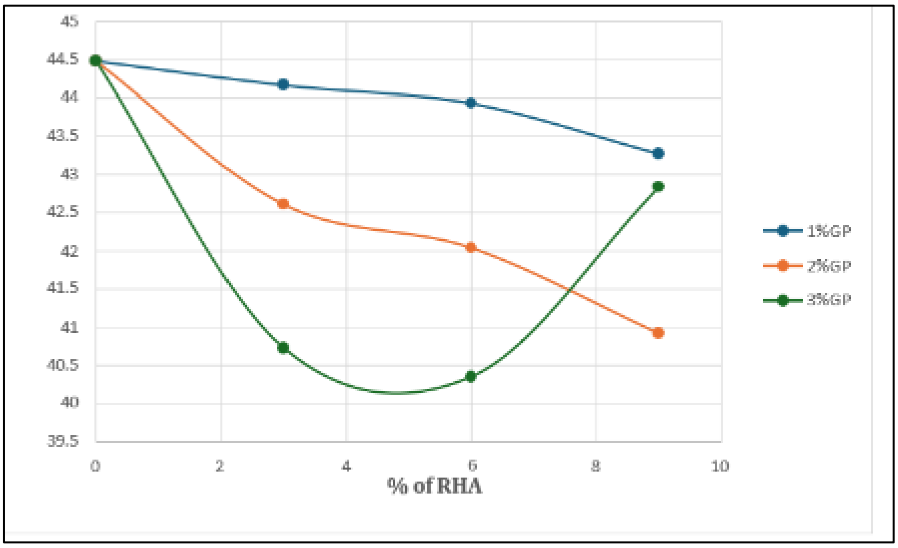

Figure 13 Liquid Limit of Soil + GP + RHA

Figure 13 depicts the liquid limit variations of both untreated and treated soil samples with varying percentages of GP and RHA. The liquid limit is a fundamental indicator of the soil's consistency and its susceptibility to volumetric changes due to moisture content alterations

The Figure 13 illustrates the variation in the liquid limit of soil samples treated with different combinations of Glass Powder (GP) and Rice Husk Ash (RHA) compared to the untreated soil. The liquid limit (L.L.) is a crucial parameter representing the moisture content at which soil transitions from a liquid state to a plastic state. Soils with a liquid limit exceeding 35% are considered expansive and are prone to significant volume changes due to moisture fluctuations, leading to geotechnical challenges such as settlement and heaving. In this study, the untreated soil exhibited a liquid limit of 44.5%, indicating a medium degree of expansion according to Burmister's classification. Upon treating the soil with varying percentages of GP and RHA—specifically combinations of 1% GP with 3%, 6%, and 9% RHA; 2% GP with 3%, 6%, and 9% RHA; and 3% GP with 3%, 6%, and 9% RHA—notable changes in the liquid limit were observed. The addition of GP and RHA generally led to a decrease in the liquid limit up to a certain point. The most significant reduction was achieved at the 3% GP + 6% RHA combination, where the liquid limit decreased by 10.3% compared to the untreated soil. This reduction can be attributed to the agglomeration and flocculation of clay particles facilitated by the pozzolanic reaction of GP and RHA with the soil. The additives enhance particle bonding, reduce plasticity, and decrease the soil's ability to absorb water.

However, beyond this optimal combination, an increase in the liquid limit was observed with higher percentages of GP and RHA. The rise in liquid limit at higher additive concentrations may be due to the increased presence of pozzolanic materials, which require more water to achieve full hydration during the Atterberg limit testing. The higher water demand reflects the formation of additional cementitious compounds that enhance soil cohesion. These findings suggest that the appropriate proportions of GP and RHA effectively reduce the liquid limit, contributing to soil stabilization. According to Burmister's criteria, a soil with a liquid limit less than 25% is classified as stabilized with low expansion potential. While the treated samples did not reach this threshold, the reduction in liquid limit indicates improved soil behavior and reduced expansiveness.

4.3.2. Plastic limit

The moisture level, expressed as a percentage, at which cohesive soil transitions from a plastic to a semisolid state is known as the plastic limit. Illustrates the low degree of expansion in soil with a plastic limit of less than 20. Because it diffuses the double layer of clay particles and raises coarser particles by replacing finer soil particles with coarser particles, the values of plastic limit drop as the percentage of FA increases. Flocculation is caused by cations' ion exchange.

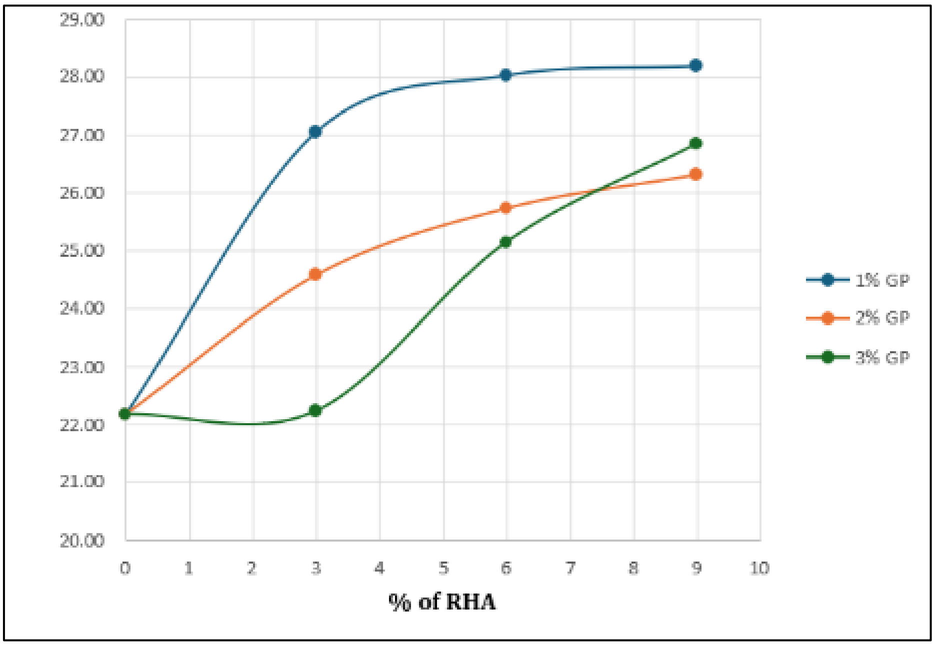

Figure 14 Plastic Limit of Soil + GP + RHA

The P.L. increases by 13.3% at 3%GP+6%RHA and by 25.8% at 3%GP+9%RHA. Subsequently, as GP and RHA percentages increase, the plastic limit also rises because of their finer particle sizes, which are greater than those of soil. The graph showed that as GP and RHA increased, the plastic limit also increased. Comparing the plastic limit value at 3%GP+6%RHA and 3%GP+9%RHA% to the untreated P.L value of 22.51%, the values increased to 13.3 percent and 25.8%, respectively. This demonstrates how the soil qualities were enhanced by GP and RHA.

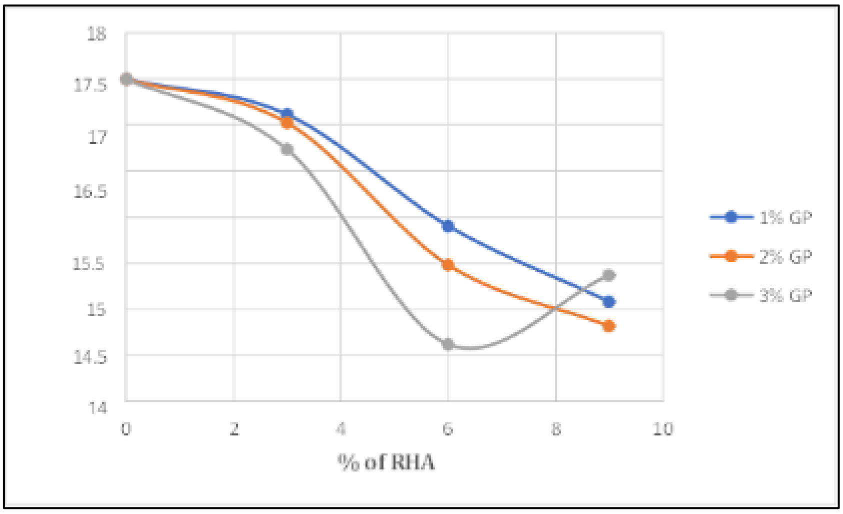

Figure 15 Plasticity index values of Treated soil

4.4. Compaction tests

Figure 16 and Figure 17 present the results of the maximum dry density and optimal moisture content, illustrating the link between MDD and OMC at various percentages of GP and RHA. The MDD is initially affected by GP and RHA up to 3%GP+6%RHA, after which it begins to decrease.

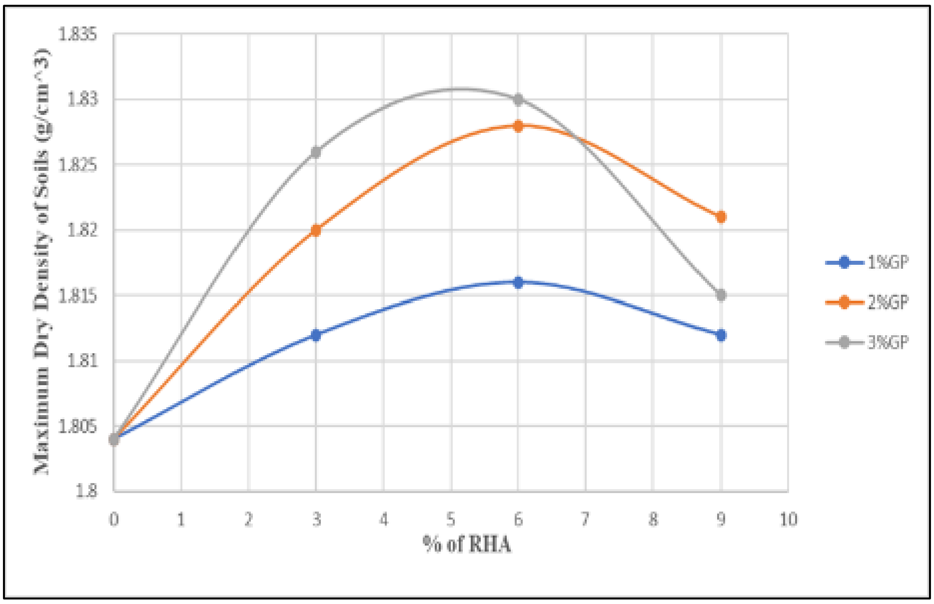

Figure 16 Maximum Dry Density results of soil at different percentages of GP and RHA

The treated soil sample's GP and RHA particle content is the cause of the rise in flocculation. The soil particles clumped together because of flocculation, increasing MDD. Since the specific gravities of GP and RHA are lower than that of soil, the resulting mix will have a lower specific gravity, which will reduce MDD. Higher percentages of stabilizers are used.

The reduction in MDD is caused by unreacted GP and RHA particles. Filler materials, such as GP and RHA, are added to the mixture to fill in air spaces and enhance density. The dry density dropped as more GP and RHA were added because all the air gaps were filled with water, GP, and RHA.

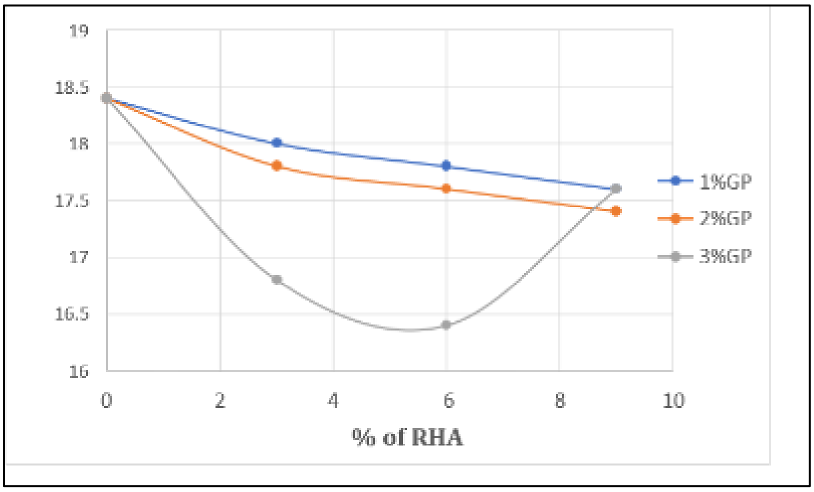

Figure 17 Optimum Moisture Content of Treated Soil

Additionally, there are no longer any holes or spaces to replace it, thus solid soil particles begin to replace it, reducing density. It may also be related to flocculation, which is characterized by an increase in the repulsive forces of the soil that oppose compaction forces and cause the mix's density to start falling. The justification for raising the ideal moisture level is that additional water is needed for the cementitious reaction to be completed by the soil additive. And the interchange of cations between additives is what causes the decrease in OMC.

4.5. Free swell index test(FSI)

The volume of soil that increases when submerged in water is known as the Free Swell Index. This technique is employed to ascertain the overall swelling properties of clay soil. Table 3 illustrates the concept of expansive soil, which is defined as soil with a degree of expansion greater than 35% indicated by the free swell index. Figure 18 displays the free swell index results for both treated and untreated soil samples at the recommended amounts of GP and RHA. By adding 3%GP and 6%RHA, the FSI decreases by 27.2%. The absence of swelling and cohesiveness in GP is the cause of the decrease in FSI.

The deflocculating effect, which stops water from penetrating clay particles as the particles lose their affinity for water and their surface area decreases, could potentially be the cause of the FSI decrease. Since GP is a non-expansive material, the addition of 3% results in a 27.2% reduction in the soil Free Swell Index.

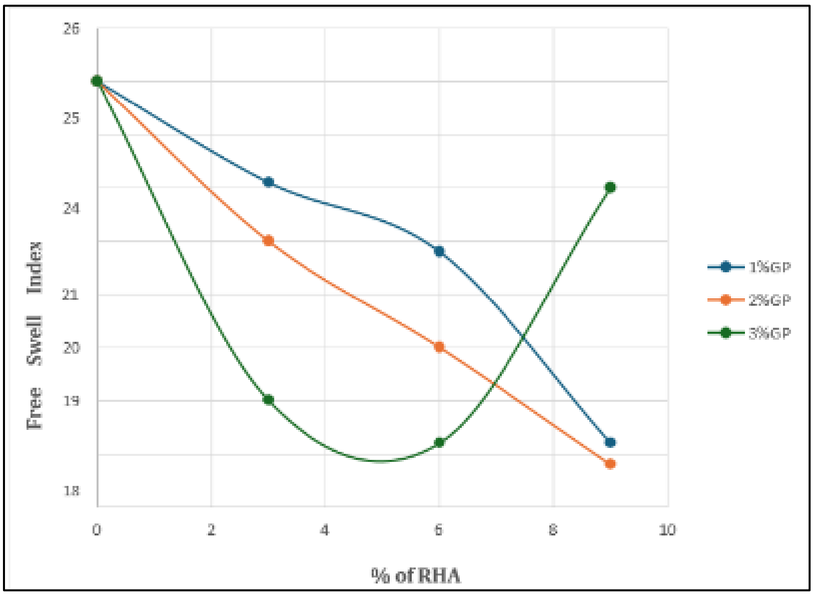

Figure 18 Free Swell Index Results of Treated Soil

The addition of RHA as a non-expansive material to soft clay may lessen the diffuse double layers because the main ingredients of RHA are spherical non-crystal silicate, iron, and aluminum oxides combined with some unburned carbon and microcrystal material, which decreases the water affinity of clayey particles. As GP and RHA grow, the FSI decreases, according to the data reduced to 27.2%, and then by adding 3%GP+9%RHA the FSI value increases.

Table 4 Degree of expansion w.r.t Free Swell Index (Burmeister)

Degree of Expansion	Free Swell Index
Low	<20%
Medium	20-35%
High	>35%

4.6. Unconfined compression test (UCS)

The maximum axial compressive stress that a right-cylinder sample of material can bear in an unconfined environment is known as the unconfined compressive strength (UCS). The cohesive soils' undrained shear strength is identified by engineering properties. The value of UCS for stabilized soil specimens is influenced by the type, quantity, curing period, and curing process. Compaction energy and moisture content both affect UCS. Despite the trash concentration in the soil, a rise in qu is observed when sample moisture content increases. The findings indicated that compression strength is positively impacted by moisture content.

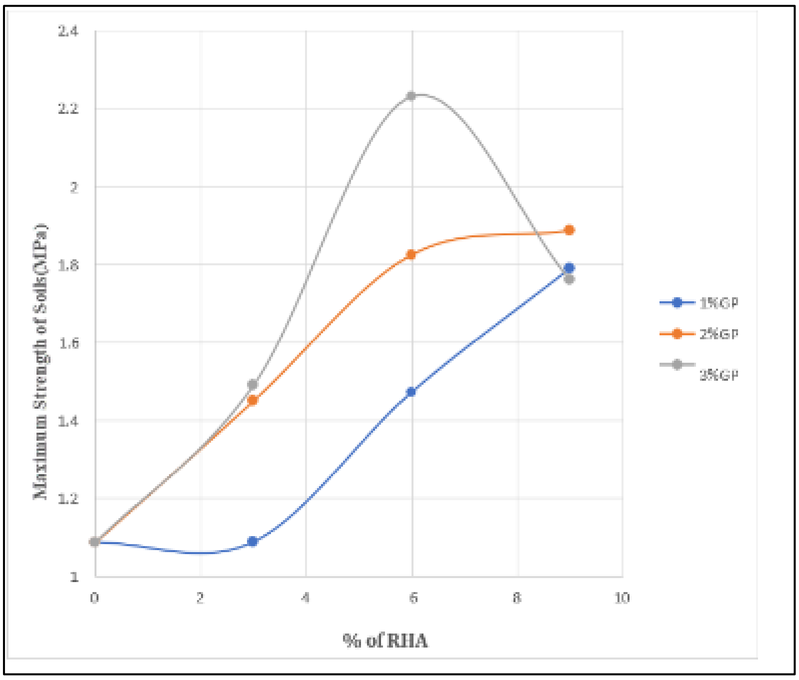

Figure 19 UCS Test Results of Treated Soil

Figure 19 presents the results of the Unconfined Compressive Strength (UCS) tests conducted on treated soil samples with varying percentages of Glass Powder (GP) and Rice Husk Ash (RHA). The UCS test measures the maximum axial compressive stress that a cylindrical soil specimen can withstand under unconfined conditions, providing a critical parameter for assessing the load-bearing capacity and stability of soils in geotechnical engineering applications. In this study, the soil samples were treated with different combinations of GP and RHA to evaluate the enhancement in strength characteristics due to stabilization. The specific combinations tested were 1% GP with 3%, 6%, and 9% RHA; 2% GP with 3%, 6%, and 9% RHA; and 3% GP with 3%, 6%, and 9% RHA. The untreated soil sample served as the control specimen to compare the effects of the additives. The maximum improvement in UCS was achieved at the 3% GP + 6% RHA combination, where the UCS value increased by 160.6% compared to the untreated soil. This remarkable enhancement indicates that the 3% GP + 6% RHA mixture is the optimal content for soil stabilization in this context, as it demonstrates greater strength than any other sample.

The significant increase in unconfined compressive strength can be attributed to the pozzolanic tendencies of rice husk ash. RHA, rich in silica, reacts with calcium hydroxide present in the soil to form additional cementitious compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H). These compounds enhance the bonding between soil particles, resulting in a denser and more cohesive soil matrix with greater strength. The glass powder also contributes to this pozzolanic activity, further improving the mechanical properties of the soil. However, beyond this optimal additive content, a slight decrease in UCS was noted at higher percentages of GP and RHA. This reduction may be due to the excess pozzolanic material leading to an imbalance in the soil-additive mixture, causing weak zones or inadequate hydration. It suggests that there is an optimal range of GP and RHA content that maximizes the strength benefits without compromising the integrity of the soil structure. These findings demonstrate that the appropriate proportions of GP and RHA significantly improve the mechanical properties of expansive soils, making them more suitable for construction purposes. The increase in UCS implies enhanced load-bearing capacity, reduced settlement potential, and overall better performance of the soil as a foundation material.

4.7. California bearing ratio (CBR)

When the water content is at its ideal level, soil stabilization with additional materials is conducted at concentrations of three% GP and 6% RHA and 3%GP and 9% RHA, so that the total mixture is 10% dry weight of the soil.

Table 5 Unsoaked and Soaked CBR of Soil + GP + RHA

Composition	Unsoaked CBR	Soaked CBR
Soil	3.56	2.14
Soil+3%GP+6%RHA	6.63	2.94
Soil+3%GP+9%RHA	5.82	2.73

Table 4 presents the California Bearing Ratio (CBR) test results for both unsoaked and soaked conditions of untreated soil and soil treated with specific percentages of Glass Powder (GP) and Rice Husk Ash (RHA). The CBR test is a crucial measure of the strength and load-bearing capacity of subgrade soil, subbase, and base course materials for use in road and pavement construction. Higher CBR values indicate greater resistance to penetration and improved performance under load. In the unsoaked condition, the untreated soil exhibited a CBR value of 3.56, reflecting its initial load-bearing capacity. Upon treatment with 3% GP and 6% RHA, the unsoaked CBR value increased significantly to 6.63, representing an 86.2% improvement over the untreated soil. This substantial increase can be attributed to the pozzolanic reactions between the additives and the soil particles, leading to the formation of cementitious compounds that enhance particle bonding and reduce voids within the soil matrix. When the RHA content was increased to 9% while maintaining GP at 3%, the unsoaked CBR value was 5.82. Although this value is higher than that of the untreated soil, it is slightly lower than the CBR value obtained with 6% RHA. This observation suggests that there is an optimal percentage of RHA beyond which the benefits on CBR start to diminish. Excessive RHA might lead to an imbalance in the soil-additive mixture or insufficient binder content to effectively enhance the soil structure.

In the soaked condition, which simulates the worst-case scenario where the soil is fully saturated with water, the untreated soil displayed a CBR value of 2.14. The addition of 3% GP and 6% RHA increased the soaked CBR to 2.94, marking a 37.4% improvement over the untreated soil. Similarly, the 3% GP and 9% RHA mixture yielded a soaked CBR of 2.73, which is a 27.6% increase compared to the untreated soil. The improvements in soaked CBR values indicate that the additives not only enhance the soil's dry strength but also improve its resistance to water-induced weakening. The enhanced performance in both unsoaked and soaked conditions can be attributed to the pozzolanic activity of RHA and the filler effect of GP. The RHA, rich in amorphous silica, reacts with calcium hydroxide in the soil to form additional cementitious compounds like calcium silicate hydrate (C-S-H), which contribute to strength gain. GP, with its fine particle size, fills the voids between soil particles, leading to a denser and more cohesive soil structure. This combined effect reduces the soil's susceptibility to moisture ingress and swell-shrink behaviors, thereby enhancing its overall stability and strength. These findings demonstrate that the optimal combination of 3% GP and 6% RHA provides the most significant improvement in CBR values under both unsoaked and soaked conditions. The results suggest that this combination is effective in stabilizing expansive soils and improving their suitability for use in subgrade layers of pavements and roads.

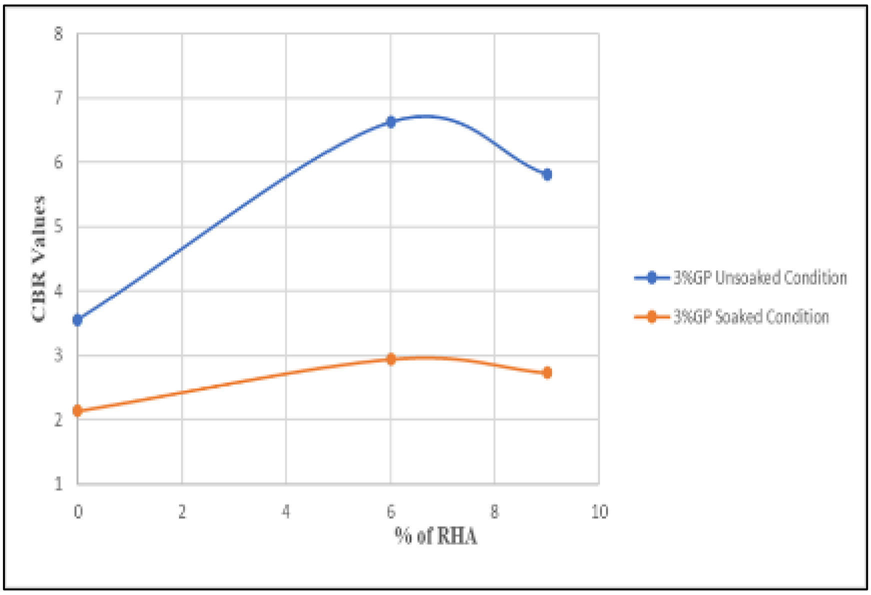

Figure 20 CBR values at different percentages of RHA

Figure 20 illustrates the California Bearing Ratio (CBR) values obtained from soil samples treated with varying percentages of Rice Husk Ash (RHA) in combination with a constant percentage of Glass Powder (GP). Specifically, the soil stabilization was conducted using 3% GP with 6% RHA and 3% GP with 9% RHA, resulting in total additive contents of 9% and 12% of the dry weight of the soil, respectively. The tests were performed at the soil's optimum water content to evaluate the impact of the additives on the soil's bearing capacity under ideal moisture conditions. The CBR test measures the strength and load-bearing capacity of soils used in the subgrade and subbase layers of road and pavement construction. Higher CBR values indicate a greater ability of the soil to withstand loads without significant deformation, reflecting improved stability and suitability for construction purposes. In Figure 20, the untreated soil serves as the baseline, exhibiting an unsoaked CBR value of 3.56% and a soaked CBR value of 2.14%. Upon the addition of GP and RHA, there is a significant increase in the CBR values.

These results indicate that the 3% GP and 6% RHA combination yields the most significant improvement in both unsoaked and soaked CBR values. The higher percentage increases in CBR values with this combination suggest that it is the optimal proportion for enhancing the soil's load-bearing capacity under the tested conditions.

The substantial increase in CBR values can be attributed to several factors:

- Pozzolanic Reaction: RHA, rich in amorphous silica, reacts with calcium hydroxide in the soil to form additional cementitious compounds like calcium silicate hydrate (C-S-H). This reaction improves soil particle bonding and reduces void spaces, leading to a denser and stronger soil matrix.
- Filler Effect of GP: The fine particles of GP act as fillers, occupying voids between soil particles and contributing to a more compacted structure. This enhances mechanical interlocking and friction between particles, further increasing the soil's strength.
- Reduction in Plasticity: The additives reduce the plasticity of the soil, decreasing its susceptibility to deformation under load and improving its load-bearing capacity.

The decrease in CBR values observed with the higher RHA content (9% RHA) compared to the 6% RHA treatment suggests that there is an optimal RHA proportion beyond which the benefits start to diminish. Excessive RHA may lead to an imbalance in the soil-additive mixture or hinder proper compaction, resulting in less effective stabilization.

These findings demonstrate that the optimal combination of 3% GP and 6% RHA effectively enhances the mechanical properties of the expansive soil, making it more suitable for subgrade applications in road and pavement constructions. The improved CBR values imply that the treated soil can support higher loads, potentially allowing for thinner pavement designs and reducing construction costs.

5. Conclusion

To enhance the expansive soils, GP and RHA were added in this study, and the mechanical behavior of the reinforced expansive soil was evaluated. Standard Proctor, unconfined compressive strength, and California Bearing Ratio were used in the lab to examine the effects of additions on the expansive soil's performance metrics. These are the main conclusions that the study deduces from the experimental test data:

The percentage of GP and RHA in the soil grew along with the limits of its plastic and liquid contents. By adding reinforcements, the soil's high plastic clay content was also reduced to low plastic clay content. The soil's plasticity index decreased as the fraction of additions rose, indicating a decrease in the percentage of clay in the soil and a consequent reduction in the soil's capacity to swell.

As the amount of GP and RHA rose, the maximum dry density of the soil increased up to 3%GP and 6%RHA after which it started to decrease . Because GP and RHA particles are finer than soil particles, the optimal moisture content decreased from

18.4 to 16.43 percent at 3%GP and 6%RHA and after that point OMC started to increase. An increase in the surface area of the soil particles was the reason for this, which was linked to the rise in surface area. It indicates that wetting soil particles with a bigger surface area requires more water.

The amount of GP and RHA in the soil rose, causing its unconfined compressive strength to rise from 1.086 MPa to 2.231 MPa. The unconfined compressive strength was found to be enhanced by the cementitious effects of pozzolanic activities of soil, rice husk ash, and glass powder. This was observed to be maximum at 3% GP and 6% RHA, 1.6 times greater than the natural soil.

The addition of GP and RHA caused a decrease in the FSI of treated soil with the minimum FSI value of 18.4% at 3%GP and 6%RHA, while after the addition of additives after this point the FSI value started to increase.

Based on the results, 3%GP and 6%RHA was selected as the optimal ratio because of minimum liquid limit value and maximum unconfined compressive strength.

CBR test was performed only for optimal ratio in both soaked and unsoaked conditions, which showed that the CBR value of 3%GP and 6%RHA was greater than 3%GP and 9%RHA in both soaked and unsoaked conditions.

Recommendations

Based on the findings, the following recommendations are submitted:

- It is recommended to perform SEM analysis on stabilized & un-stabilized samples to observe the bond between various elements.
- It is also recommended that a cost analysis of the stabilized samples be performed to evaluate the financial cost of stabilization on bigger projects.
- GP and RHA should be employed for other types of problematic soil and their performance should be analyzed.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of ethical approval

This article meets with the ethical required standard.

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