STABILIZATION OF SUBGRADE SOIL WITH RICE HUSK ASH FOR USE IN ROAD CONSTRUCTION

Session: 2019

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DEPARTMENT OF CIVIL ENGINEERING
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LAHORE PAKISTAN

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Final year project report submitted in partial fulfillment of the requirements for the Degree of B.Sc. Civil Engineering

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DEDICATION

We dedicate this thesis to our loving family, friends and Esteemed Professors whose unwavering support and encouragement have been the pillars of our academic journey. Their belief in our abilities and their constant motivation have been instrumental in helping us overcome challenges and strive for excellence. We are grateful for their sacrifices, understanding, and belief in the importance of education.

ACKNOWLEDGMENTS

In the name of Allah, who is the Most Beneficent and Merciful, we begin this expression of gratitude and blessings upon the Prophet Muhammad ﷺ, the servant of Allah and the Final Messenger.

Primarily and above all, we express our desire to extend our heartfelt gratitude to our supervisor, Prof. Dr. Hassan Mujtaba. Without his unwavering support, constant motivation, and invaluable guidance, this research project would not have come to fruition. We are truly indebted to him for his dedication and belief in our capabilities.

Our sincere gratitude also goes to the Geotechnical lab staff, whose cooperation and consideration during the laboratory testing phase were immensely helpful. Their support contributed significantly to the successful completion of this research.

Furthermore, we feel incredibly fortunate to have had the presence of our teachers, friends, and family members who have supported and influenced us throughout our academic journey. Their encouragement and guidance have played an instrumental role in shaping us into the individuals we are today.

Lastly, we would like to extend our gratitude to the University of Engineering & Technology (UET), Lahore for providing us with an enriching environment that has enabled us to pursue our dreams and contribute to the betterment of humanity. We are truly grateful for this opportunity.

May Allah bless and guide us all on the path of knowledge and righteousness..

STATEMENT OF ORIGINALITY

Hereby, I declare that this research work presented in this dissertation is a product of my own ideas and research efforts. Any contributions and ideas from external sources have been duly acknowledged and cited in the dissertation. I affirm that this complete dissertation has been written solely by me. I fully understand that if, at any point in the future, it is discovered that the thesis work is not my original creation, the University reserves the right to revoke my degree. I take full responsibility for the integrity and authenticity of this dissertation and assure that it represents my own work and findings..

ABSTRACT

Expansive soils possess a significant risk due to their inherent ability to undergo substantial volume changes in response to moisture variations. These soils, if not properly addressed, can pose a severe natural hazard and cause extensive damage to structures. When saturated, expansive soils expand, and upon drying, they shrink and develop cracks. The expansion of these soils exerts considerable uplift pressure on structures, particularly lightly loaded ones like houses, pavements, floors, and canal linings, resulting in severe damage such as uplift and cracking. Geotechnical investigations in various areas of Pakistan have revealed the extensive presence of such soils, leading to severe damage to various structure types. Early identification of expansive soils during the investigation phase can assist in mitigating their adverse effects. Empirical correlations between swelling parameters and index properties prove valuable for the preliminary identification of expansive soils. Recognizing the challenges associated with local expansive soils, it was crucial to gather comprehensive data on local soils and determine their swelling characteristics to evaluate their swell potential. The rice husk ash's employment for stabilization purposed in the road subgrade was explored as a potential solution.

This literature review examines the contributions of different researchers in the field of stabilizing expansive soil for subgrade road construction. Fentaw (2021) investigated the effectiveness of a mixture containing marble dust, rice husk ash, and cement. Gandhi and Shukla (2021) focused on evaluating the durability of expansive clay after improving it with the addition of cement slag and bagasse ash . Daryati and Ramadhan (2020) studied the usage of rice husk ash, while Bilal and Ahmad (2020) conducted a study conducted under experimental conditions on expansive soil stabilization using stone dust blending. The findings from these studies highlight the potential of specific additive ratios to improve the properties which are related to the engineering of that soil which is expansive, providing valuable insights for effective soil stabilization techniques in road construction.

The primary focus pertaining to this particular research aims to address the stabilization of expansive soil using rice husk ash. The study reveals that the issue of soil swelling predominantly is present in the following five districts of Punjab: Narowal, Dera Ghazi Khan (DG khan), Sialkot, Gujranwala and Chakwal. To conduct a comprehensive investigation, both undisturbed and disturbed soil samples

were collected from the Narowal campus of the University of Engineering and Technology. Geotechnical characterization of these soils involved conducting various tests, including basic classification tests, California bearing ratio tests, unconfined compressive tests, Compaction test and the Atterberg limit tesr. The test results then analyzed and compared with the index properties of normal soils.. Due to the dilation of basic index properties of expansive soil with respect to normal soil, it was a dire need to mitigate its deleterious impacts. For its stabilization, rice husk ash from sapphire chemical industry and Ittehad chemicals was used at different proportions. Again, the soil was brought under same experimentations. After making it least vulnerable for overlying structures, stabilized soil was used as subgrade of road. Results depict that 9% RHA was the optimum content against which CBR was found to be 4.68% and UCS value was found to be 43 kpa against 9% RHA. And OMC increased and max dry unit weight or maximum dry density decreases

Expansive Soil’s stabilization by using Rice Husk Ash (RHA) for Superior Road Construction," manifests a strong correlation with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities). Leveraging rice husk ash as a means to augment soil stabilization for road construction, our innovative endeavor resonates with SDG 9's emphasis on robust infrastructure and ecologically responsible industrialization. Furthermore, our initiative directly addresses SDG 11, as the fortification of road infrastructure facilitates the emergence of safer, more sustainable urban ecosystems. In essence, our project synchronizes with these pivotal global targets, embodying our commitment to pioneer resilient and sustainable infrastructural solutions for an improved urban existence.

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NOMENCLATURE

AASHTO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
ASTM	**A**merican **S**tandard for **T**esting and **M**aterials
CBR	**C**alifornia **B**earing **R**atio
CSH	**C**alcium **S**ilicate **H**ydrate
CaS	**C**alcium **S**ulfide
FTIR	**F**ourier **T**ransform **I**nfrared
GGBFS	**G**round **G**ranulated **B**last **F**urnace **S**lag
GPS	**G**lobal **P**ositioning **S**ystem
LRHA	**L**ime **R**ice **H**usk **A**sh
LL	**L**iquid **L**imit
WGP	**W**aste **G**lass **P**owder
MDD	**M**aximum **D**ry **D**ensity
OMC	**O**ptimum **M**oisture **C**ontent
PI	**P**lasticity **I**ndex
PL	**P**lastic **L**imit
pH	**P**otential of **H**ydrogen
RHA	**R**ice **H**usk **A**sh
SI	**S**ystem **I**nternational
SL	**S**hrinkage **L**imit
SI	**S**well **I**ndex
SEM	**S**canning **E**lectron **M**icroscopy
UCS	**U**nconfined **C**ompressive **S**trength
UET	**U**niversity of **E**ngineering & **T**echnology
SDG	**S**ustainable **D**evelopment **G**oal
SN	**S**tructural **N**umber

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Chapter 1

INTRODUCTION

1.1. GENERAL

The construction of durable, cost-effective, and sustainable roads is a critical aspect of modern infrastructure development. Roads are the lifelines of a region, connecting people, businesses, and communities. The quality and longevity of road infrastructure directly influence economic growth, transportation efficiency, and public safety. As such, finding innovative and sustainable methods for constructing roads is of paramount importance.

Subgrade soil stabilization have a crucial role in construction of road , as it establishes a strong base for the pavement structure. The stability of the underlying soil layer soil directly impacts the road's performance, including its ability to bear loads, resist deformation, and maintain durability. Conventional approaches to soil stabilization rely on the use of cement, lime, and bitumen, which have demonstrated their effectiveness in improving soil characteristics. However, these methods come with notable environmental consequences and financial burdens associated with their production and application.

Expansive soils, characterized by their high clay content and susceptibility to large volume changes upon wetting and drying, pose significant challenges to road construction. These soils often result in pavement distress, such as cracking and heaving, leading to increased maintenance costs and reduced pavement life. Stabilizing expansive soils is essential for ensuring the long-term performance and durability of road infrastructure.

Recently, there has been an increasing fascination with utilizing waste materials for soil stabilization, driven by the potential advantages of cost reduction and environmental sustainability. Waste materials, when applied correctly, have the ability to enhance the engineering related properties of the soil, leading towards the improved subgrade performance while minimizing environmental impact. One such waste material that holds promise is rice husk ash (RHA), which is a residual by-product obtained from the rice milling process.

Rice is a staple food for a significant portion of the global population, resulting in the generation of millions of tons of rice husks each year (approximately 1828 tons annually in Pakistan). These husks are often disposed of by burning them in open fields or boilers to generate energy, leaving behind rice husk ash as residual waste. RHA predominantly contains amorphous silica, which exhibits pozzolanic properties. This means it can chemically react with calcium hydroxide to produce cementitious compounds.. This unique characteristic makes RHA a potential candidate for soil stabilization, particularly in the context of expansive soils.

1.2. BRIEF REVIEW OF PREVIOUS STUDIES

The utilization of byproducts, recycled materials, or discarded substances materials for subgrade soil stabilization has gained considerable attention recently due to its potential for cost reduction and environmental sustainability. Rice husk ash (RHA), a byproduct of rice pondering or milling, shows promise as an effective alternative for stabilizing expansive soils. This section provides an overview of previous studies focusing on RHA and its application in soil stabilization, particularly for expansive soils.

Expansive soils are characterized by their high clay content and their capability to undergo drastic change in volume when subjected to moisture fluctuations. Parameters such as swell index (SI), shrinkage limit (SL),the liquid limit (LL),the plastic limit (PL), and the plasticity index (PI) are commonly used to evaluate the engineering related properties of soils which are expansive.

Various researchers have explored the potential of The implementation of rice husk ash (RHA) as a substance to enhance the stability of the soil which is expansive in nature, capitalizing on its high silica content and pozzolanic properties. Sabat and Panda (2011) demonstrated that the addition of 10% RHA drastically enhanceded the unconfined compressive strength (UCS) of expansive soils, resulting in a 72% increase after 28 days of curing. Nimityongskul and Manivannan (2014) observed that incorporating 15% RHA in soft clay led ultimately to a decrease in the plasticity index and and rising trend in the California Bearing Ratio (CBR).

The RHA’s effectiveness in stabilizing expansive soils can be credited to the pozzolanic type of reaction between silica in RHA and calcium hydroxide in the soil, forming cementitious compounds. Basha et al. (2005) demonstrated that the addition of RHA to clayey soils decreased plasticity index and swelling potential, while increasing the maximum dry density and the unconfined compressive strength.

Despite growing body of research on RHA as a stabilizer for expansive nature soils, there is still a lack of consensus regarding optimal mix proportions and treatment methods. Further investigation is required to establish standardized guidelines for the effective utilization of RHA in soil stabilization practices.

- **SiO_2 (RHA) + $Ca(OH)_2$ (soil) → $CaSiO_3$ (cementitious compound)**

Despite the growing body of research based on RHA as a stabilizer for expansive nature soils, there continues to be a lack of agreement or consensus regarding the optimal mix proportions and treatment methods for different soil types and environmental conditions. For instance, Ramezanianpour et al. (2013) found that adding 15% RHA to clayey soil resulted in the highest UCS, while Srivastava et al. (2017) reported that a 10% RHA addition yielded the best performance in terms of CBR and UCS.

1.3. PURPOSE AND SCOPE OF STUDY

The chief goal and cause of the study is to experimentally evaluate the rice husk ash (RHA)'s effectiveness as a stabilizing type of agent for subgrade soils, specifically focusing on expansive soils commonly encountered in road construction. The investigation aims to determine the optimal mix proportions and treatment methods for utilizing RHA in soil stabilization, with the ultimate target and aimof improving the performance and sustainability of road infrastructure.

The scope of the research includes the following components:

• A comprehensive literature assessment to gather information on the properties of RHA, its potential application in soil stabilization, and previous research on its effectiveness in stabilizing expansive soils. The review will also include an analysis of the advantages and disadvantages of using RHA compared to conventional stabilizers such as cement, lime, and bitumen.

• An experimental program to evaluate the expansive soil's engineering properties samples treated with varying percentages of RHA. The program will involve laboratory testing to measure key geotechnical parameters, such as the Atterberg limits along with the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) along with the swell index (SI), and also shrinkage limit (SL). The experimental end-results will be analyzed to identify trends in the relationship between RHA content and soil properties.

• An assessment of the optimal RHA content and treatment method for stabilizing expansive soils based on the experimental findings. The assessment will consider factors such as cost-effectiveness, environmental impact, and long-term stabilized soil's perfomance.

• A comparison of the performance of RHA-stabilized soil with that of soil treated with conventional stabilizers, based on the experimental data and previous research findings. This comparison will help to determine the potential benefits and limitations of using RHA in construction of road, particularly in the context of expansive soils.

• The detailed research findings underscore the importance of drawing comprehensive conclusions and formulating practical recommendations regarding the future research and application of Rice Husk Ash (RHA) in the realm of soil stabilization for road construction. To expedite the widespread utilization of this environmentally friendly and economically viable soil stabilization method within the construction industry, it is crucial to identify specific areas that require further investigation. These areas should aim to enhance our comprehension of RHA's effectiveness in stabilizing expansive soils and to provide valuable insights for its successful implementation. By addressing these research gaps, we can pave the way for the adoption and integration of RHA as a sustainable and cost-effective technique in soil stabilization practices for road construction projects.

1.4. OBJECTIVES

The main target of this study are:

• Investigation of the parameters related to the geotech and the properties of expansive subgrade soil whose properties are enhanced with rice husk ash (RHA).

• Determination of the optimal RHA content for effective stabilization of expansive soils.

• To determine and examine the impact of RHA on key engineering properties, such as the Atterberg limits, the unconfined compressive test for strength (UCS), the California Bearing Ratio (CBR), swell index (SI), and shrinkage limit (SL).

• To compare the performance of RHA-stabilized soils with that of soils treated with conventional stabilizers like the cement, lime, and bitumen.

• To assess the cost-effectiveness and environmental sustainability of using RHA as a soil stabilizer in road construction.

• To provide recommendations for practical applications of RHA in soil stabilization and identify areas for future research on this topic.

1.5. THESIS OVERVIEW:

• **Introduction**: Discuss subgrade soil stabilization, challenges of expansive soils, introduce RHA as a potential stabilizer, and outline the study's purpose, scope, and objectives.

• **Literature Review:** Review previous studies on RHA, its properties, conventional soil stabilizers, and compare RHA with conventional stabilizers in terms of cost, environmental impact, and performance.

• **Materials and Methods:** Describe expansive soil samples and RHA, explain sample preparation and treatment procedures, detail laboratory testing methods for geotechnical properties, and outline data analysis techniques for optimal RHA content and treatment methods.

• **Results and Discussion:** Present experimental data on RHA-stabilized expansive soils, analyze the relationship between RHA content and soil properties, identify optimal RHA content and treatment method, and compare RHA-stabilized soils with conventionally stabilized soils.

• **Conclusions and Recommendations**: Summarize key findings, assess the cost-effectiveness and environmental sustainability of RHA, provide recommendations for practical applications, and identify areas for future research on RHA as a soil stabilizer.

CHAPTER 2

LITERATURE REVIEW

2.1. GENERAL

Pakistan being a developing country has increasing rate of construction which require the availability of good soil with satisfactory engineering properties which with each structure built becoming less. Eventually leaving behind the problematic soils for construction among which swelling clay is one of the major types. It swells when it interacts or contacts with water and upon drying it shrinks which leads to heaving and settlement of the structure. The destruction of different structures caused by such soil is in abundance and such case studies can be found. Swelling clay is found in considerable areas of the country like Dera Ismail Khan, Narowal, Dera Ghazi Khan, Sialkot, Gujranwala, Chakwal, Khairpur, and other.

This research focuses on the handlind of swelling type of clay with sustainable use of Rice Husk Ash (RHA). (Wallach, 2022) "Production of rice in the world to be around 755 million tons out of which Pakistan harvested rice crop of 11.1 million tons in 2019 marketing year." (Singh, 2018) "Rice husk, which accounts for approximately 20% of the total weight of rice, can be effectively utilized to produce Rice Husk Ash (RHA). A simple calculation reveals that for every 100 kg of rice husks burned in a boiler, approximately 25 kg of RHA can be obtained as a byproduct. This process involves the combustion of the husks, resulting in the conversion of organic matter into ash. By harnessing this residual material, a substantial amount of RHA can be generated, making it a valuable resource for various applications.." Thus, the average rice husk ash produced per annum is estimated to be 0.55 million tons in Pakistan and overall, 37.75 million tons in the world. Rice Husk is found in abundance in rice producing countries and it either gets dumped or burned as fuel, thus can be found in abundance and used as the stabilizing agent.

RHA as soil stabilizer has proved to be very beneficial and experimental studies have been done in the past for the treatment of different problematic soils with or without other additives. The waste product will be put to better use, lesser dumping sites required and making positive impact on the environment. This research aims to achieve enhancement in the geotechnical properties of the swelling clay after stabilization with RHA and to achieve the suggested limits of the properties. The optimum amount of RHA for the most enhanced properties of the soil.

2.2. SWELLING CLAYS

Swelling clays are a type of soil that undergo significant volumetric changes in response to changes in water content. These changes in volume can can exert a notable influence on the performance of civil engineering infrastructure, particularly in the design and construction of foundations, slopes, earthen dams and embankments. In this essay, we will discuss the properties, behavior, and engineering implications of swelling clays, with reference to some of the key literature in this field. Swelling clays are typically composed of clay minerals such as smectite, illite, and kaolinite, which have a high surface area and a net negative charge that allows them to attract and hold water molecules.

When Soil is exposed withmoisture, the clay kind of minerals can absorb the water and they expand, leading in rise in volume content. Conversely, when the soil dries out, the clay minerals can release water and contract, leading in a decline in the content of volume. This process is also known as shrink-swell behavior and can result in significant cracking, heaving, and settlement of the soil.

The degree of shrinkage and swelling in a clay soil depending on the number of factors, which includes the clay mineralogy, particle size distribution, organic matter content, compaction, and weathering history. Some types of clay minerals, such as smectite, have a greater capacity for swelling and shrinkage than others, while soils exhibiting a broader spectrum of particle dimensions or sizes and a higher organic matter content tend to exhibit less shrink-swell behavior. Compaction and weathering can also affect the degree of swelling and shrinkage, with more compacted and less weathered soils generally exhibiting greater shrinkage.

The swelling and shrinkage behavior of clay soils can have a drastic effect on the performance of civil engineering infrastructure, particularly in the design and construction of foundations. When a foundation is constructed on a swelling clay soil, it is typically designed to accommodate the maximum anticipated vertical and horizontal movements of the soil. This can involve designing the foundation with a greater depth and width, using a more rigid foundation material such as reinforced concrete, or incorporating drainage systems to reduce the water content of soil.

One of the main challenges in dealing with swelling clays is the difficulty in predicting their behavior. Swelling and shrinkage can be affected by factors of wide range, including changes in soil moisture content, temperature, and stress state, as well as the presence of other materials such as salts or organic matter. In addition, swelling clays can exhibit complex and nonlinear behavior, with different rates and degrees of swelling and shrinkage which depends on a magnitude and duration of applied load. As a result, predicting the behavior of swelling clays requires careful consideration of the specific soil and environmental conditions, as well as a comprehensive understanding of the fundamental physics and chemistry of clay mineral-water interactions.

Figure 2.1 Swelling clay (source : uet.edu.pk)

Recent research has focused on developing more accurate and reliable methods for characterizing and predicting the behavior of swelling clays. For example, some studies have used advanced imaging techniques such as the X-Ray Diffraction (XRD) along with the Scanning Electron Microscopy (SEM), and the Fourier Transform Infrared (FTIR) spectral analysis to study the changes in the mineralogy and microstructure of clay soils after the addition of materials such as rice husk ash (RHA). Alam et al. (2019) used XRD and SEM to investigate the changes in the microstructure of a swelling clay after adding the RHA, finding that the RHA filled the voids in the clay microstructure, reducing its porosity and improving its strength.

2.3. RHA

Rice husk ash (RHA) is byproduct of agriculture related field, which has undergone thorough research due to its potential uses in diverse domains., including construction materials, agriculture, and environmental remediation. RHA is produced when rice husks are burned under controlled conditions, resulting in a high-silica ash that can be used as a pozzolanic material or as a source of silicon for other applications. In this essay, we will discuss the properties, applications, and recent research on rice husk ash, with references to some of the key literature in this field.

Rice husk ash is a highly reactive pozzolanic kind of material that can be utilised as a partial replacement of cement in production of concrete. Pozzolanic materials are substances that, when combined with lime and water, form a cementitious compound that can harden and gain strength. RHA has been shown to enhance the strength along with the durability and the workability of concrete, as well as reduce its porosity and permeability [1].

The utilisation of RHA in concrete production can also lead to decrease in the carbon footprint of the construction industry by decreasing the amount of cement used, which is one of the biggest contributor to emissions by green house gas. RHA has also been studied for its applications in environmental remediation, particularly in the removal of those metals which are heavy from contaminated soils and water. RHA has a high surface area and a net negative charge that allows it to adsorb and immobilize heavy metal ions, such as lead and cadmium, in contaminated soils and water. This makes RHA a potentially effective and low-cost material for the remediation of heavy metal-contaminated sites. [2]

In addition to its use in concrete production, RHA has also been studied for its applications in soil improvement and agriculture. RHA contains high levels of silicon, which is an essential nutrient for many crops and can help improve soil fertility and plant growth. RHA has also been shown to have antifungal and insecticidal properties, making it a potential alternative to synthetic pesticides in agricultural settings [3].

Recent research has focused on developing more sustainable and effective and efficient methods for the production and application of RHA. For example, some studies have investigated the use of those energy sources which are alternative, such as the energy which is solar or biomass gasification, for the production of RHA, which can reduce the environmental impact of the production process [4]. Other studies have explored the use of RHA in combination with other materials, such as recycled aggregates or fly ash, to enhance its properties and reduce waste in the industry of construction [5].

Overall, rice husk ash is a versatile and sustainable material that has a wide range of potential applications in various fields, including construction, agriculture, and environmental remediation. Its use can also lead to improvements in performance and sustainability of the materials and systems, as well as contribute to the reduction of greenhouse gas emissions and environmental pollution.

Swelling clay is a type of soil that can expand significantly when it comes into contact with water. This property can cause significant damage to structures built on or near swelling clay, leading to stability issues and even collapse. One potential solution to this problem is to improve the properties related to geotech of swelling clay using sustainable and eco-friendly materials. Rice husk ash (RHA) is one such material that has been explored for this purpose. This literature review will explore the existing research on the sustainable use of RHA for improving the geotechnical properties of swelling clays.

A significant amount of research has been dedicated to enhancing the engineering properties of swelling type of clays found in different regions across the globe. These studies have focused on employing various methods and techniques using a range of abundant and cost-effective materials, such as waste glass powder, Fly Ash along with the Ground Granulated Blast Furnace Slag (GGBFS), Cement Kiln Dust, Rice husk Ash, lime, and gypsum.

In one study, investigated the potential of a mixture comprising marble dust, rice husk ash, and cement to stabilize expansive soil for subgrade road construction. The experimental findings indicated improved engineering properties within certain additive limits, with an optimal mixture ratio of additives determined. [6]

Another study based on evaluated the durability of expansive clay treated with bagasse ash and cement slag. The research demonstrated enhanced engineering properties of the expansive soil within specific additive ranges, suggesting that the soil performed optimally when treated with a certain percentage of these additives. [7]

Based on the exploring the use of rice husk ash for stabilizing expansive soil, varying the ash content from 0% to 9%. The results revealed a reduction in specific gravity and Atterberg limits, indicating improvements in the soil's physical properties. Additionally, the California Bearing Ratio (CBR) exhibited a substantial increase, with an average improvement of approximately 130% after the addition of 6% rice husk ash. [8]

Based on experimental study on expansive soil stabilization using stone dust blending. By incorporating stone dust in different proportions ranging from 5% to 20%, the swell potential of the soil decreased from 8.4% to 4.4% at a 12% stone dust content. Furthermore, the soil transformed from medium expansiveness to non-expansiveness, with the plasticity index and liquid limit values in a trend of decline ehich is gradual like from 20.10% to 8.40% and also 40.65% to 31.89%, respectively, at 18% stone dust content. Moreover, the optimum moisture content (OMC) reduced from 12.34% to 6.22%, and the maximum dry density (MDD) inreases from 1.83 g/cm3 to 2.157 g/cm3 at a 20% stone dust content. [9]

Figure 2.2 Rice husk (Source: Saphire fabrics)

Figure 2.3 Rice Husk Ash after milling process (Source: Saphire fabrics)

Blayia explored the strength enhancement of expansive type of soil through the introduction of Waste Glass Powder (WGP). By incorporating WGP in varying percentages, including 2.5%, 5%, 10%, 15%, and 25% by the dry weight of the soil, significant enhancements were observed in consistency, shear strength, and sub-base thickness reduction. Specifically, adding 15% WGP resulted in a substantial reduction in sub-base thickness, estimated to be approximately 63%. [10]

Mujtaba also investigated behavior of fat clay with the employment of powdered glass. The study showcased improvements in various geotechnical characteristics, such as a decrease in consistency limit, compression characteristics, and swell characteristics, and a relative increase in the maximum dry unit related weight along yield stress and CBR, and also the unconfined compressive strength. The optimum percentage of powdered glass was checked to enhance the tested clay's geotechnical properties was approximately 12%. [11]

Similarly, another study on the application of Ground Granulated Blast Furnace Slag (GGBFS) for enhancing the engineering properties of expansive soils. The research revealed substantial improvements, including an increase in CBR value by approximately 8%, maximum dry unit weight by 10% with a 50% GGBFS mixing ratio, and unconfined compression strength by 35% for remolded samples. [12]

[13] "Conducted a review on stabilization of soil with rice husk ash and also mixed RHA in various proportions with soil (Passing sieve#40) like 5%, 10%, 15% and 20%. Various tests were conducted on these mixes in order to find optimum proportion." The results came out to be:

Table 2.1 Results Concluded from Experiments

Sr No.	Soil + %age of RHA	OMC (%age)	MDD (g/cc)	Liquid Limit (%)	CBR	
					At 2.55 mm penetration (%)	At 5 mm penetration (%)
1	0	16.61	1.766	50.20	1.896	1.814
2	5	18.12	1.633	47.60	2.144	2.129
3	10	20.18	1.573	46.08	2.617	2.445
4	15	22.05	1.45	42.95	2.144	2.033
5	20	24.02	1.36	39.60	-	-

[14] "Experimental study conducted on expansive soil, classified as A-7-5 per AASHTO, underwent stabilization using various additives. These included 3% lime, 15% bagasse ash, and a combination of 15% bagasse ash with 3% lime based on the dry weight of the soil. The results demonstrated positive changes in the soil properties. The addition of these additives led to an increase in the Optimum Moisture Content (OMC) and California Bearing Ratio (CBR) value, indicating improved workability and strength. Conversely, the Maximum Dry Density (MDD) decreased, reducing soil compactness, and the plasticity of the soil decreased as well. Notably, the combination of lime and bagasse ash yielded a significant improvement in CBR compared to individual additives. This suggests the potential of using bagasse ash as an admixture in lime-stabilized expansive soil to enhance stability and load-bearing capacity.."

[15] An investigation was conducted to analyze the compaction related properties, shear strength parameters, California bearing ratio (CBR), compression index, durability, and swelling pressure of expansive soil treated with rice husk ash (RHA) and lime sludge. The RHA content ranged from 5% to 20% in increments of 5%, while the lime sludge content varied from 0% to 15% in increments of 5%. Optimum percentages of 10% RHA and 15% lime sludge were determined. The incorporation of these additives yielded significant improvements in the aforementioned soil properties. The compaction characteristics, CBR values, shear strength, compression index, swelling pressure, and durability all demonstrated positive changes as a result of the treatment. This study highlights the effectiveness of utilizing RHA and lime sludge to enhance the engineering properties of expansive soil.

[16] Conducted an experimental investigation to assess the impact of rice husk ash (RHA), lime, and gypsum on the UCS, Atterberg limits, compaction and free swell index related properties of expansive soil and also California bearing ratio (CBR). The results

demonstrated significant improvement in the strength characteristics of the expansive soil when treated with these additives.

Another study explored the effects of RHA on various geotechnical related properties of a lateritic type soil classified as a A-2-6 (0) or SW for the sub-grade applications. The study examined compaction, consistency limits, and soil strength with RHA contents of 5%, 7.5%, 10%, and 12.5% by weight of the dry soil. The findings indicated that increasing RHA content enhanced the optimum moisture content (OMC), while decreasing the maximum dry density (MDD). Plasticity was reduced, and volume stability and soil strength were improved. The optimal RHA content was determined to be 10%. [17]

Another study concluded experimental analysis that the employment of RHA resulted in a reduction in the plasticity of expansive soil, characterized by decreased liquid limit and increased plastic limit. The plasticity index exhibited a significant decrease, particularly with higher lime content. The swelling pressure of the soil decreased when lime and RHA were added. The study identified that a 6% lime and 6% RHA mixture achieved nearly zero soil swelling. The incorporation of lime and RHA led to the formation of cementitious materials, indicating a pozzolanic reaction in the stabilized soil. A chart was proposed to aid in selecting the appropriate lime-RHA mixture for soil stabilization. The study concluded that lime and RHA, when added in suitable quantities, positively influenced soil strength, significantly increasing the California bearing ratio (CBR) and reducing soil swell over a relatively short period. [18]

[19] conducted an experimental type of study on the behavior of expansive soil mixed with RHA from Yogyakarta, Indonesia. The study involved various laboratory tests and determined that the addition of RHA, particularly in a mixture containing 6% lime and 13% ash, moderately reduced the plasticity index and significantly increase the soil's CBR and shear strength.

[20] Investigated the use of Lime-Rice Husk Ash (LRHA) is to stabilize the expansive type clay soil. The study involved conducting laboratory tests and found that LRHA reduced soil heave and enhanced the geotechnical properties of the diff specimens. The incorporation of LRHA as a soil stabilizer in road pavement construction was deemed beneficial, as it controlled volume compressibility due to moisture variations, leading to reduced maintenance costs.

[21] Carried out an experimental study to evaluate the behavior of clayey soil when treated with lime and RHA. The results depict the drastic improvement in the engineering properties of the soil after treatment, including enhanced consistency limits, reduced swell potential, increased CBR and shear strength, diminished consolidation settlement, and improved rate of consolidation. The utilization of lime and RHA for geotechnical applications was considered cost-effective.

[22] Published a comprehensive study discussing the phenomena related to stabilizing expansive soils, their behavioral patterns, and the initial and remedial stabilization methods that can be employed. The study highlighted the improvement in selected properties of expansive soils through mechanical and chemical stabilization methods.

In summary, the studies indicate that incorporating RHA, lime, and other additives can lead to substantial improvements in the geotechnical properties of expansive soils, including reduced swell potential, enhanced strength, and altered mineralogy and microstructure. The optimal dosage of RHA for improving the properties of swelling clays appears to be around 10% by weight.

CHAPTER 3

METHODOLOGY

3.1. GENERAL

To gain insights into the behavior of expansive soils, a literature survey was conducted, focusing specifically on Punjab. Geotechnical organizations were consulted to gather information on swelling soils in Punjab and identify the districts prone to swelling. Subsequently, both that is the disturbed and undisturbed type of soil samples were gathered from the UET Narowal campus, located in a potential swelling district.A comprehensive laboratory investigation program was undertaken, encompassing sieve analysis, classification tests along with the compaction tests, California bearing ratio (CBR) tests and unconfined compression strength (UCS) tests. The samples which were disturbed, used for classification tests to determine the soils' index properties, while block samples taken as undisturbed kind of samples were employed to assess the in-situ characteristics of the soils. The subsequent phase involved the stabilization of these soils using various proportions of Rice Husk Ash (RHA). The stabilized soils were then utilized as subgrade material for road pavement. The study integrated all the collected data on expansive type of soils in the study area, along with correlations which is proposed between index properties and swelling parameters. Through this comprehensive approach, the study aimed to gain a deeper understanding of expansive soils in Punjab, evaluate their properties through laboratory tests, and propose the use of RHA as a stabilizing agent for subgrade improvement in road construction. The study also aimed to establish correlations between index properties and swelling behavior to enhance the design and performance of road pavements in areas affected by expansive soils.

3.2. COLLECTION OF AVAILABLE INFORMATION/DATA

Results computed regarding Geotechnical Aspects of soils in Punjab region were thoroughly checked to get the desired sample in local vicinity. Following are the departments reached in this regard.

- Soil Survey of Pakistan.
- Geological Survey of Pakistan.
- Geotechnical Engineering Laboratories, Civil Engineering Department, U.E.T., Lahore

The gathered data includes the plasticity index, particle size distribution and liquid limit. This information proves valuable for identifying expansive soils during the initial stages. Table 3.1 presents the ranges of liquid limit, clay fraction percentage, and plasticity index for all districts in Punjab. Based on the collected information, it has been determined that the potential swelling districts in Punjab are Narowal, Gujranwala, Chakwal, Dera Ghazi Khan and sialkot These districts exhibit high values of clay related fraction percentage, liquid limit, and plasticity index, indicating the presence of expansive soils. Our primary focus for soil sampling was specifically on the district of "Narowal".

Table 3.1 Degree of Expansiveness with respect to District

Sr. No.	**District**	**Number of Sites**	**Range of Clay Fraction**	**Range of LL**	**Range of PI**	**Degree of Expansiveness (based on PI)**
1	Dera Ghazi Khan	**29**	**20-26**	**37-57**	**16-28**	**Moderate to High**
2	Gujranwala	**27**	**14-25**	**32-57**	**11-27**	**Low to High**
3	Narowal	**28**	**18-23**	**34-51**	**12-24**	**Low to Moderate**
4	Sialkot	**26**	**18-26**	**32-57**	**12-27**	**Low to High**
5	Chakwal	**28**	**15-25**	**33-53**	**14-27**	**Low to High**

(Source: ResearchGate)

Further Rice Husk Ash was arranged from two sources

- Ittehad Chemicals
- Sapphire Fabric Industry.

3.3. SOIL SAMPLING

For the investigation of swelling potential in the Narowal district, both disturbed and undisturbed soil samples were gathered from various sites. Undisturbed samples were obtained in the form of block samples directly from the field. At each site, adjacent soil was carefully excavated to expose a block of soil, which was then collected from a depth of 1 meter at the UET Narowal site. To preserve the field moisture content, the collected block samples were immediately sealed in cans using candle wax.

These undisturbed block samples played a crucial role in determining the in-situ density of the soil and natural moisture content. Additionally, they were utilized to evaluate the swelling parameters corresponding to the soil's natural condition. The transportation of both the undisturbed block samples and disturbed soil samples was carried out with utmost care to ensure their integrity during characterization and analysis.

Figure 3.1 Undisturbed sample collection (UET NWL)

Figure 3.2 Sampling from 3 feet depth (UET NWL)

Figure 3.3 Preparing Undisturbed Sample (UET NWL)

3.4. LABORATORY TESTING AND PROCEDURES

Different tyoe of tests that are usually performed on the soils are

- Classification Tests (ASTM-D 4643, ASTM-D 422, ASTM-D 4318)
- Chemical Composition (ASTM-D 4972)
- Compaction Test (ASTM D-698, ASTM D-1557)
- Unconfined Compression Test (ASTM-D2166)
- California Bearing Test (ASTM-D1883)

3.4.1. Classification tests:

In the laboratory investigation, several tests for classification were conducted to characterize the soil samples. These tests included:

3.4.1.1. Moisture content: The undisturbed block samples, which were safeguarded with wax during fieldwork, were utilized for determining the natural moisture content. Samples were extracted from the inner core of the blocks and subsequently subjected to oven drying to obtain an accurate measure of moisture content in their natural condition.

3.4.1.2. Specific gravity of soil solids: This test is employed to determine the specific gravity of soil particles. It provides valuable information about the soil's density and composition**.**

3.4.1.3. Sieve analysis: The distribution of the soil samples based on the size of particle was determined using the ASTM D422 standard procedure. This analysis helps classify the soils collected from different sites based on their particle size fractions.

3.4.1.4. Hydrometer analysis: Following the ASTM D422 procedure, this test is performed on such a soil fraction passing through sieve No. 200. It determines the percentage of silt and clay in the soil, providing additional information about its composition.

3.4.1.5. Atterberg limits: The Atterberg limits related tests were carried out following the standard procedure outlined in ASTM D4318.. These tests determine the plasticity limit and liquid limit of the soil. These parameters are useful for identifying swelling soils, as soils with high swelling potential typically exhibit a liquid limit which is greater than 50.0% and a plasticity index which is also greater than 25%.

By performing these classification tests, the laboratory investigation aimed to gain a comprehensive understanding of the soil properties and characteristics in order to evaluate their swelling potential accurately.

3.4.2. Chemical composition:

The chemical composition of expansive soils can be analyzed using various methods, including ASTM standards. The specific ASTM standards depend on the specific chemical properties of interest. Here are some commonly used ASTM standards for analyzing the chemical composition of expansive soils:

3.4.2.1. Determination of pH (ASTM D4972)

This standard explains the determination of the pH value of a sample of soil. pH measurement provides information about the acidity or alkalinity of the soil, which can affect its behavior and reactivity.

3.4.2.2. Determination of carbonate content (ASTM D4373)

This standard explains a method for determination of the carbonate content in a soil sample. Carbonates, such as calcium carbonate, can affect the swell-shrink kind of behavior and trend of expansive type of soils.

3.4.2.3.Determination of sulfate content (ASTM D4972)

This standard describes the determination of the sulfate content in a soil sample. Sulfates can cause detrimental effects on the soil, such as increasing its expansiveness.

3.4.2.4 Determination of chloride content (ASTM D512)

This standard covers the determination of chloride content in a soil sample. Chlorides can have adverse effects on soil stability and contribute to the corrosion of structures in contact with the soil.

3.4.2.5.Determination of organic matter content (ASTM D2974)

This standard provides a approach for ascertaining the organic matter content in a soil sample. Organic matter can significantly influence the engineering properties and behavior of soils.

3.4.2.6. Determination of the Hydrgen, Total Carbon, and the Content of Nitrogen (ASTM D5373)

This standard constitutes of ascertaination of the total carbon, hydrogen, and nitrogen content in a soil sample. It provides information about the organic composition of the soil.

3.4.3. Compaction test

To assess the compaction characteristics of the swelling soils, both the Standard Proctor Test and the Modified Proctor Test were conducted. These tests provide valuable information about the soil's ability to be compacted and its resulting density. The test procedures followed were in accordance with ASTM standards.

- **Standard Proctor test (ASTM D-698)**: This test determines the dry density which is maximum and optimum moisture content of the soil under standard compaction conditions. The soil is usually compacted in the layers using a specified compaction energy and moisture content range. The test helps in determining the compaction parameters for designing the subgrade or fill materials.

- **Modified proctor test (ASTM D-1557, Procedure A):** Like the conventional Proctor Test, the Proctor Test which is modified establishes the max. value dry density and moisture content's optimum of the soil. However, it utilizes a higher compaction energy than the Standard one Proctor Test. The Proctor Test which is Modified is often used for heavy-duty applications or situations where higher compaction efforts are required.

By conducting these compaction tests according to the relevant ASTM standards, the laboratory investigation aimed to assess the compaction characteristics of the swelling soils and obtain the necessary parameters for designing stable and compacted subgrades or fill materials.The relevant ASTM standard for compaction testing is ASTM D698, titled "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lb./ft3 (600 $kN - m/m3$))."

Here is a general overview of the compaction test procedure using ASTM D698:

3.4.3.1. Sample preparation

Obtain a representative soil sample from the field. Remove any organic materials, rocks, or debris from the sample. Take a sufficient quantity of the soil to perform multiple tests and ensure statistical significance. Air-dry the sample and break down any aggregates**.**

3.4.3.2. Moisture content's determination

Determine the soil's moisture content by following the ASTM D2216 standard titled "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of the Soil and the Rock by Mass."

3.4.3.3. Compaction mold preparation:

Prepare the compaction molds according to the specifications provided in ASTM D698. The molds are typically cylindrical with a standard volume and diameter. Ensure the molds are clean and free from any debris.

3.4.3.4. Compaction procedure:

Place a known amount of soil in the compaction mold in the layers. Each layer is compacted using a specified number of blows. The standard effort for compaction in ASTM D698 is 12,400.0 ft-lb./ft3 (599.9 kN-m/m3), which can be achieved using a specific compaction hammer or equipment. Compact each layer evenly and uniformly.

3.4.3.5. Moisture content adjustment

Repeat the compaction procedure for different moisture contents by adding or subtracting water from the soil sample. Ensure proper mixing and uniform distribution of water throughout the soil.

3.4.3.6. Determination of dry density

After compaction, empty the soil sample from the mold carefully. Determine the weight and volume of the compacted soil to calculate the dry density. Measure the dimensions of the compacted specimen, and calculate its volume. Then, determine the dry weight of the specimen by oven-drying it to constant weight.

3.4.3.7. Calculation of compaction parameters

Calculate the dry density and the moisture content for each compaction point. Plot the results by using curve of compaction and then determine the dry density which is maximum and the optimum moisture content's value.

3.4.3.8. Test replication

Perform multiple tests at different moisture contents to obtain representative data. This helps to establish a more accurate compaction curve and identify the optimum moisture content. It's important to note that this is a general outline of the compaction test procedure using ASTM standards. Always refer to the specific ASTM standard (ASTM D698) for detailed instructions, equipment requirements, and any additional specifications or modifications to the test method.

3.4.4. Unconfined compression test:

The Unconfined Compression Test, alternatively referred to as the Unconfined Compressive Strength (UCS) test, is employed to assess the strength properties of a soil sample without applying any external confinement. The applicable ASTM standard for performing this test is ASTM D2166, titled "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil." This test is valuable in evaluating or get to know the strength related characteristics of the soil under investigation when it is subjected to axial loading without any surrounding support or confining pressure. By following the guidelines outlined in ASTM D2166, engineers and researchers can accurately evaluate the compressive strength of cohesive soils.Here is a general overview of the Unconfined Compression Test procedure using ASTM D2166:

3.4.4.1. Sample preparation

Prepare a representative soil sample by removing any organic materials, rocks, or debris. Ensure the sample is adequately air-dried or saturated, depending on the testing requirements. Take a sufficient quantity of the soil to perform multiple tests for statistical significance.

3.4.4.2. Sample trimming

Trim the soil sample to obtain a regular cylindrical shape with smooth and parallel top and bottom surfaces. The sample dimensions should conform to the specifications mentioned in ASTM D2166, considering the specific sample size and testing requirements.

3.4.4.3. Test setup

Place the trimmed soil sample on the loading platen of the testing apparatus, ensuring that it is centered and aligned properly. Apply a light initial axial load to maintain contact between the sample and platen.

3.4.4.4. Loading

Apply vertical axial load to the soil sample at a constant rate specified in the ASTM standard (typically around 0.2 in/min or 5 mm/min). Continuously monitor the axial load and the corresponding axial deformation (strain) of the sample during the test.

3.4.4.5. Test termination:

Continue applying the axial load until the soil sample fails or reaches a predetermined axial deformation criterion. The test can be terminated either when the sample undergoes a specified amount of axial strain or when it reaches a failure point.

3.4.4.6. Data collection

Record the maximum axial load applied to the soil sample at failure, as well as any relevant deformation or strain data during the test. This data is used to calculate the unconfined compressive strength and other parameters.

3.4.4.7. Calculation of unconfined compressive strength

Calculate the compressive strength which is unconfined using the maximum axial load of failure and the cross-sectional area of the soil sample. The unconfined compressive strength is typically expressed in units of stress (e.g., pounds per square inch or kilopascals).

3.4.4.8. Test replication:

Perform multiple tests on different soil samples to obtain representative data and ensure the reliability of the results. This helps to establish the variability and average strength characteristics of the soil.

3.4.5. California Bearing Test:

The California Bearing Ratio (CBR) test is utilized to assess the load-bearing capacity and strength base materials and of that subgrade soil. It provides valuable information about the soil's resistance to penetration under controlled conditions. The applicable ASTM standard for conducting the CBR test is ASTM D1883, titled "Standard Test Method for CBR's (California Bearing Ratio) of Laboratory-Compacted Soils." By following the guidelines outlined in ASTM D1883, engineers and researchers can accurately determine the CBR value of laboratory-compacted soils, which is an vital parameter for designing and evaluating pavement structures and other geotechnical applications.."

Here is a general overview of the California Bearing Ratio (CBR) test procedure using ASTM D-1883:

3.4.5.1. Sample preparation

Prepare a representative soil sample by removing any organic materials, rocks, or debris. The sample can be obtained from the field or prepared in the laboratory using compaction methods specified by ASTM D1883. Take a sufficient quantity of the soil to perform multiple tests for statistical significance.

3.4.5.2. Compaction of specimen

Compact the soil sample in a cylindrical mold with specified compaction effort and moisture content. The compaction effort depends on the specific testing requirements and is typically provided as a standard effort level (e.g., 56,000 ft-lb/ft^3 or 2700 kN-m/m^3). Follow the compaction procedure outlined in ASTM D1883.

3.4.5.3. Sample trimming

After compaction, trim the soil specimen to obtain a regular shape with smooth and parallel top and bottom surfaces. The sample dimensions should conform to the specifications mentioned in ASTM D1883, considering the specific sample size and testing requirements.

3.4.5.4. Soaking

Soak the compacted soil specimen in water for a specified period, typically 96 hours (4 days). Ensure the specimen remains fully submerged during the soaking period. This process allows for saturation and consolidation of the soil.

3.4.5.5. Test Setup

Place the soaked soil specimen in the CBR test apparatus, positioning it on the loading platen. The specimen should be centered and aligned properly. Apply a restraining load to prevent lateral movement during the test.

3.4.5.6. Loading

Apply a vertical load to soil specimen at a constant rate specified in the ASTM standard (typically 0.05 inches per minute or 1.3 mm per minute). Continuously measure and record the load and corresponding deformation (strain) of the specimen during the test.

3.4.5.7. Calculation of CBR

Calculate the CBR value using the maximum value of load sustained by such specimen and the standard reference load. The CBR value is expressed as a percentage, representing the load's ratio sustained by the specimen to the load required to achieve the same deformation in a standard crushed rock material.

3.4.5.8. Test replication

Perform multiple tests on different soil specimens to obtain representative data and ensure the reliability of the results. This helps to establish the variability and average CBR values of the soil.

It's important to note that this is a general outline of the California Bearing Ratio (CBR) test procedure using ASTM standards. Always refer to the specific ASTM standard (ASTM D1883) for detailed instructions, apparatus requirements, and any additional specifications or modifications to the test method.

3.4.6. Design of pavement using Structural Number (SN)

The structural number method is a widely used approach for flexible pavements' design. It involves assigning a structural number to each layer of the pavement structure, including the subgrade, base course, and surface course. The structural number represents the cumulative structural contribution of each layer to distribute the traffic loads and ensure the pavement's structural integrity. Here's a general procedure for subgrade design using the structural number method:

3.4.6.1. Determine design traffic

Identify the design traffic loading that the pavement will be subjected to. This includes factors such as the anticipated number and type of vehicles, their axle loads, and repetitions over the design life of the pavement.

3.4.6.2. Determine required structural number

Determine the needed structural number for a pavement based on the design traffic and desired performance criteria. This can be done using pavement design methods such as the AASHTO (American Association of State Highway and Transportation Officials) design guidelines or other relevant standards. The required structural number considers factors such as traffic loading, climate conditions, and expected service life.

3.4.6.3. Allocate structural number to layers

Allocate the structural number to each layer of the pavement structure. This typically includes the surface course, base course, and subgrade. The structural number allocation is based on the layer's load-carrying capacity, stiffness, and resilience.

3.4.6.4. Determine subgrade structural number

Assign a portion of the overall structural number to the subgrade layer. This is based on the subgrade's strength and stiffness characteristics, often represented by the California Bearing Ratio (CBR) value. The specific allocation of the structural number to the subgrade depends on the design methodology and equations used in the selected design method.

3.4.6.5. Verify subgrade strength

Conduct field or laboratory tests to determine the subgrade's CBR value or other relevant strength parameters. This helps validate the initial assumptions made during the allocation of the subgrade structural number. Adjustments may be necessary if the actual subgrade strength deviates significantly from the assumed values.

3.4.6.6. Determine subgrade thickness

Calculate the required subgrade thickness based on the allocated subgrade structural number and the design method being used. This calculation considers the subgrade's strength, the CBR value, and the desired performance criteria. The thickness of that layer which is a subgrade can be adjusted based on the available CBR values or by incorporating soil stabilization techniques if required.

3.4.6.7. Design other pavement layers

Once the subgrade thickness is determined, proceed with designing the other pavement layers, such as the base course layer and the other layer of the surface course. This involves allocating the remaining structural number to these layers based on their characteristics and their contribution to the overall pavement structure.

3.4.6.8. Validate design

Perform structural and functional analysis of the pavement design to ensure that it meets the desired performance criteria. This may involve using design software, finite element analysis, or other engineering methods to evaluate the pavement's structural capacity, deflections, and stress distribution under the design traffic loading.

CHAPTER 4

RESULTS & DISCUSSIONS

4.1. GENERAL

This discussion of results provides a detailed analysis and the discussion of the results recieved from the stabilization of expansive soil in the Narowal district using rice husk ash as an additive. The experimental findings clearly demonstrate the significant improvement in the properties related to swell of the expansive soil due to the incorporation of rice husk ash. The effectiveness of rice husk ash as a agent which is stabilizing, is evident from the considerable enhancements observed in various geotechnical parameters. The optimal dosage of rice husk ash was determined by conducting tests on unconfined compressive strength and California bearing ratio. These tests played a crucial role in assessing the performance and load-bearing capacity of the stabilized soil. The results of the California bearing ratio tests provided valuable insights into the suitability of the stabilized soil for subgrade applications in road construction. By considering the CBR values obtained, it was determined that the stabilized soil meets the required standards and can be confidently used as a subgrade material. Overall, the research findings indicate that the inclusion of rice husk ash significantly enhances the engineering related properties and performance of expansive soil. The successful stabilization of the soil using rice husk ash offers a promising solution for mitigating the challenges associated with expansive soils in the Narowal district. The detection of this study leads to the growing knowledge’s body on sustainable and effective soil stabilization techniques, providing valuable insights for geotechnical engineers and practitioners involved in infrastructure development projects.

4.1.1. Grain size distribution and clay characterization

Following chart depicts the results for the seive analysis of the virgin soil. soil sample analyzed has a relatively high proportion of fine particles, as indicated by the soil’s high percentage passing through the #200 sieve (91.44%). The soil’s percentage passing through the 4 sieve (0%) indicates that the soil sample does not contain any large particles. Additionally, the data shows that the soil sample contains a relatively that percentage which is a high, of particles in the size range of 0.075-0.15 mm, as indicated by the relatively low percentage of that soil passing through the #100 sieve (94.1%).

As percent passing through sieve number 200 was more than 12%, which is justified as our sample is clay. So hydrometer test was performed. Based on the hydrometer analysis, the soil sample has a particle size distribution ranging from the clayey to coarser sand. But its mostly clayey.The percentage of finer soil than 0.075 mm is 75.0%, which depicts that the soil sample is mostly composed of fine-grained particles. The effective diameter of the soil particles ranges from 0.075 mm to 0.0750 mm.

Based one the results, our soil sample falls into A-7-6 soil type according to AASHTO classifiaction for soil.

Seive analysis for RHA was also performed. Based on the sieve analysis table, the Rice Husk Ash (RHA) sample did not retain any weight on the 4.75 mm sieve and only 0.75 g of RHA passed through the finest sieve (pan), indicating that it is mostly composed of fine particles. The majority of the RHA (89.46%) retain on 0.425 mm sieve, indicating that it is a coarse-grained material.

The RHA sample can be classified as poorly grade material or gap graded, according to the Unified Soil Classification System (USCS). The percentage passing through the 0.075 mm sieve is less than 50%, which suggests that the RHA may have a low plasticity index and be classified as a Group A-2-4 material in accordance with the AASHTO classification system.

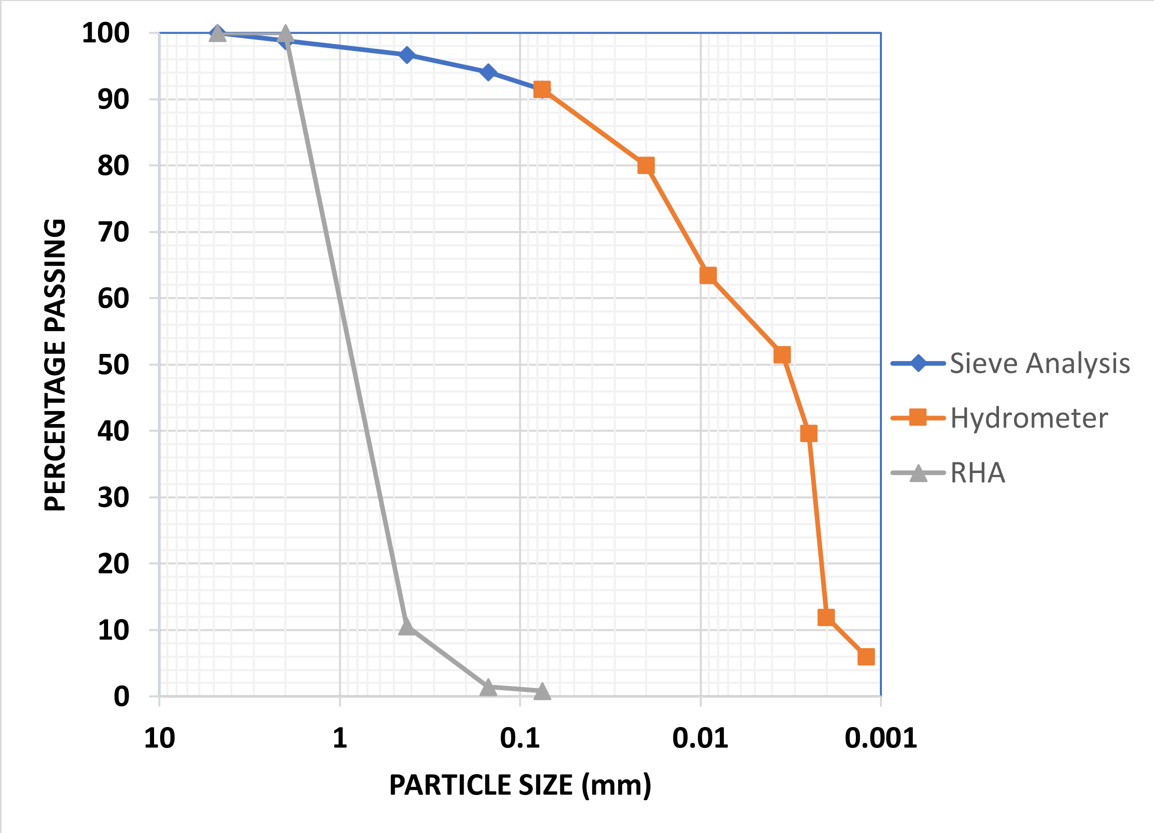

Figure 4.1 Sieve Analysis and hydrometer of virgin soil and RHA

4.1.2. Atterberg limits:

From the table, soil sample's LL was determined to be 49. Then PL was found to be 28.328, and the PI was calculated to be 20.672. These results indicate that the soil has moderate plasticity and can be molded within a range of 20.672% content of moisture, which is the difference between the PL and LL. Figure 4.2, Shows the moisture content against 25 blows, which is our liquid limit for sample.

Figure 4.3 and 4.4 also shows that according to the results of Atterberg Limit, our soil is A-7-6 and CL.

A-7-6 is a USCS classification for soils that have a plasticity index which is larger than 7, and a liquid limit greater than or equal to 50. These soils are considered to be in the "CH" or "MH" groups, which represent clay soils with high and medium plasticity, respectively. The A-7-6 classification indicates that the soil has moderate to high plasticity and may require special considerations in construction and engineering applications.

Table 4.1 (Atterberg Limits' test results)

Liquid Limit(graph)	49
Plastic limit	28.328
Plasticity index	20.672

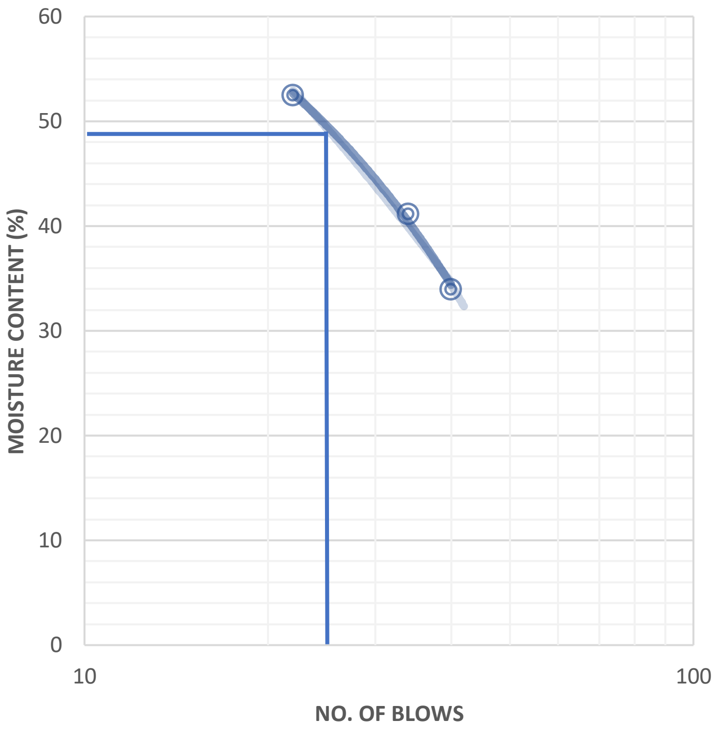

Figure 4.2 No. of blows vs Moisture Content (%)

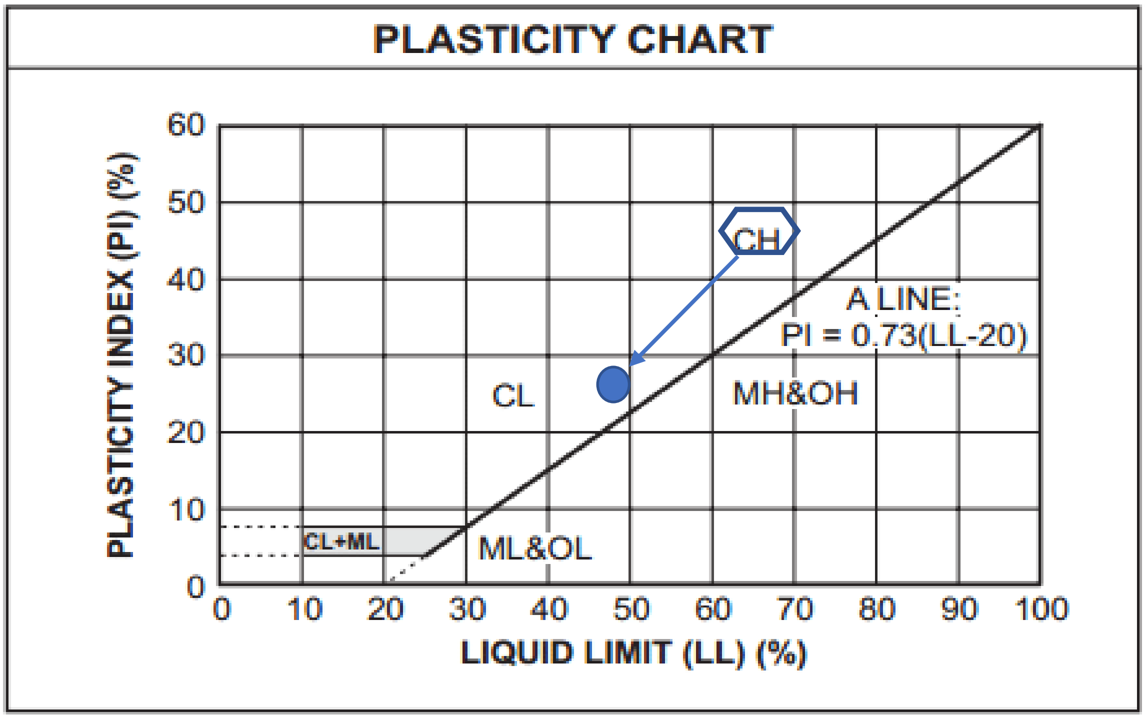

Figure 4.3 USCS classification Line chart

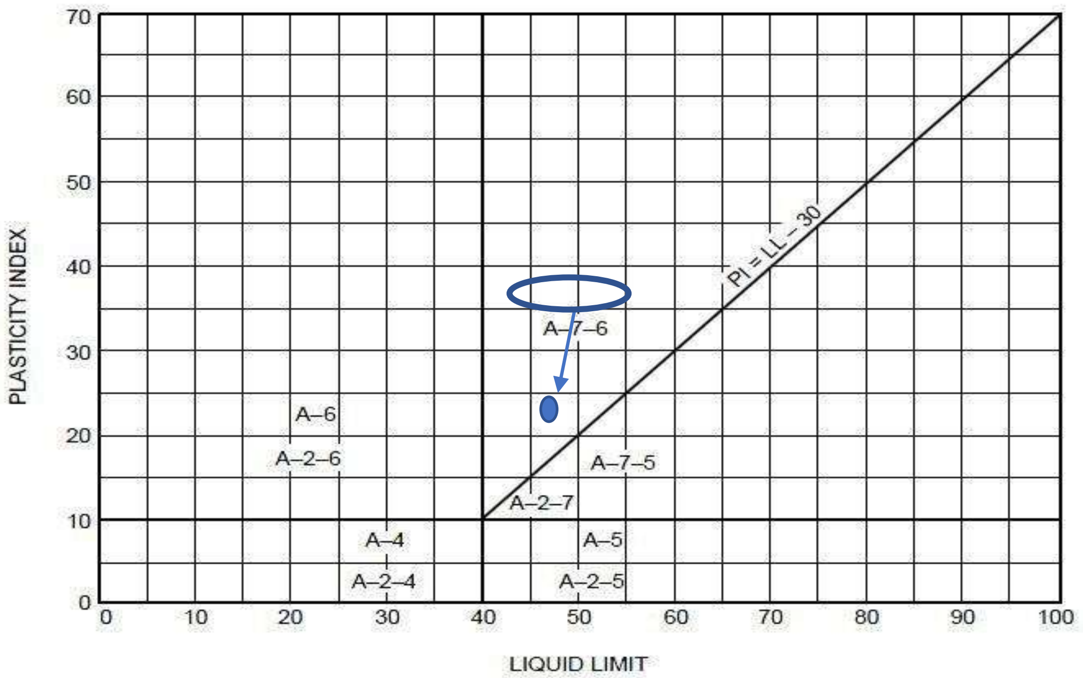

Figure 4.4 AASHTO Classification Chart

4.1.3. Compaction:

The obtained wet density values of the soil ranged from 1.640 g/cm^3 to 1.99 g/cm^3, with a corresponding dry density range of 1.53 g/cm3 to 1.75 g/cm^3. These dry density values, when converted to kilonewtons per cubic meter (KN/m^3), ranged from 15.05 KN/m^3 to 17.15 KN/m^3.

After analyzing the compaction test results, it was determined that the optimum moisture content (OMC) for achieving maximum dry density was found to be 13.566%. At this moisture content, the corresponding optimum dry density (MDD) was measured to be 1.749 g/cm^3 or 17.147 KN/m^3.

These values are crucial in constructing a compaction curve, which depicts the relationship between dry density and the moisture content of the soil. The compaction curve aids in understanding the compaction behavior of the soil sample, particularly in identifying the moisture content that results in the highest degree of compaction.

It is essential to note that these values and percentages are specific to the tested soil sample from the Narowal district and may not be directly applicable to other soil types or locations. Site-specific testing and analysis are recommended in determining the optimal dry density and moisture content for a particular soil composition and project requirement.

The optimum dry density (ODD) is the dry density which is maximum achieved during compaction of a soil at that moisture content which is optimum. It is the density at which the soil particles are most closely packed, leading to the highest strength, stiffness and stability of the soil. The MDD value in this case was found to be 1.749 g/cm^3 or 17.147 KN/m^3. (Figure 4.5).

These values provide useful information for soil engineers in designing and constructing engineering structures on or with the soil. For instance, knowing the OMC and MDD of the soil can help engineers determine the appropriate moisture content and compaction effort required to achieve the desired degree of soil compaction for a given project. Additionally, the MDD can be used to estimate the soil’s load-bearing capacity, which is important in regulating the suitability of the soil for supporting different types of structures.

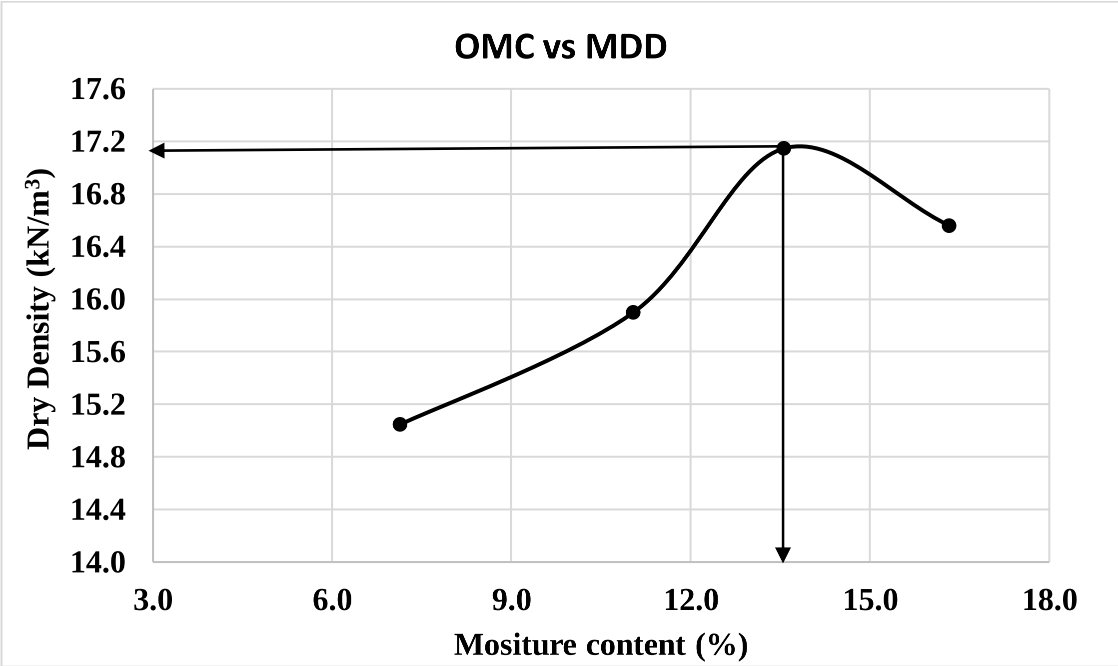

Figure 4.5 Optimum moisture content vs Modified Dry density

Table 4.2 (Compaction test results)

Optimum moisture content (%)	13.566
Optimum Dry Density (g/cm3)	1.749
Optimum Dry Density (kN/m3)	17.147

4.1.4. Unconfined Compaction test

At the beginning of the experiment, stress values were zero, and the percentage strain was also zero, as shown in the Figure 4.6. As the axial load increased, the stress values increased, indicating that the sample was undergoing compression. The percentage strain values also increased, indicating that the sample was undergoing deformation. The rate of increase of stress reduced as the axial load increased, and the sample approached its peak strength.

Beyond the peak strength, the rate of increase of strain increased again until the sample failed.

From an unconfined compression test, the cohesion value can be estimated as half of the UCS value, as in eq.1, since the unconfined compression test assumes a homogeneous and isotropic material, and the failure occurs on a plane perpendicular to the axis of loading. Therefore, the shear strength is solely ascribed to the cohesion of the material.

Cohesion value = $UCS\ value\ /\ 2\ =\ 30.0507\ /\ 2\ =\ 15.02535\ kPa$ (4.1)

The secant modulus, a parameter used to assess the severity or stiffness of the soil, is derived from the curve of stress-strain obtained during the test. It is computed by

determining the slope of a line drawn from the origin to a predefined strain level on the curve. Generally, the strain level selected for this calculation falls within the range of 50% to 75% of the maximum strain achieved during the test. The modulus of secant serves as a measurement of the soil's resistance to deformation and provides insights into its structural behavior under applied loads.
Assuming that the secant modulus was calculated using a strain level of 50%, the secant modulus can be estimated as the stress at 50% strain divided by 50%.
Secant Modulus = Stress at 50% Strain / 50% Strain.

Using the provided data, the stress at 50% strain is approximately 15.54 KPA. Therefore, the secant modulus can be estimated as:

Secant Modulus = $1554\ kPa\ x\ 50\% \ = \ 751.2677446\ kPa$

Table 4.3 (UCS results)

UCS Value (kPa)	30.05
Cohesion value (kPa)	15.02
Secant Modulus (kPa)	751.26

The unconfined compressive strength (UCS) is 30.0 kilo-Pascals, as shown in (Figure 4.6), which represents the maximum compressive stress that the material can withstand without failure when loaded in an unconfined condition.

The cohesion value is 15.02 kPa, which represents the shear strength which material possess and is the intercept of the failure envelop of the Mohr-Coulomb failure envelope.

The *secant modulus* is 751.2677446 kPa, which is a measure of the stiffness of the material and is determination by division the change in stress by the corresponding change in strain over a certain range of values.

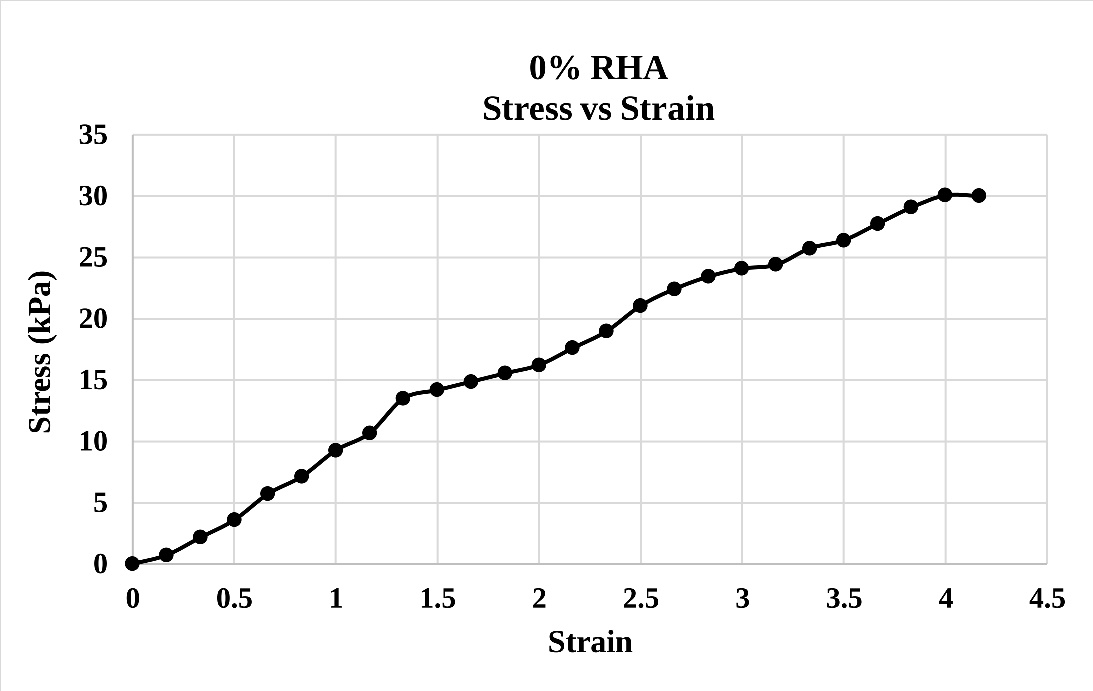

Figure 4.6 Stress vs Strain for UCS

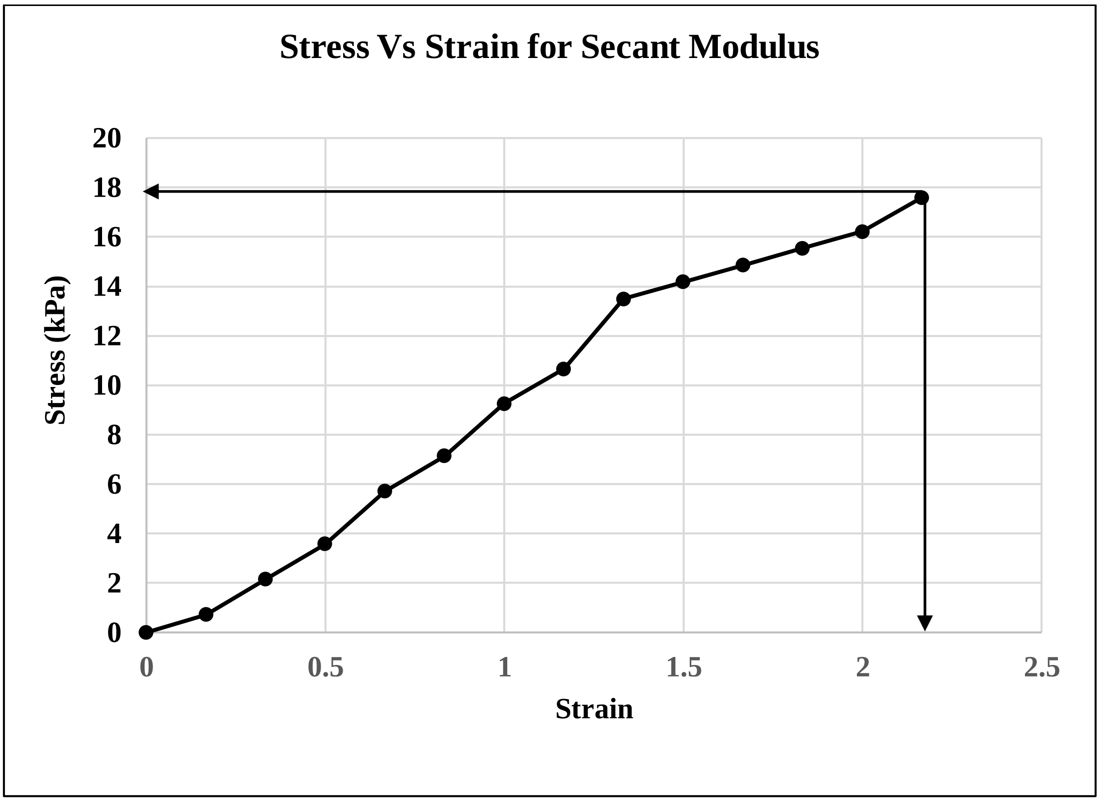

Figure 4.7 Stress vs Strain curve for Secant Modulus

4.1.5. California Bearing Ratio test

California Bearing Ratio **(CBR**) test on a soil sample compacted at different numbers of blows. The CBR test is a determination of the strength of the soil, specifically under standardized conditions, its resistance to penetration by a plunger. The results are reported as a percentage of the resistance of a standard material, such as crushed limestone.

Table 4.4 shows the results for three different compaction levels: 10, 30, and 65 blows. For each compaction level, the table lists the results for different amounts of penetration by the plunger, in terms of both the dial reading (DDR) and the load (LDR). The table also includes the product of DDR and the load column in inches, as well as the load calculated as three times the LDR.

Based on the table, it appears that the CBR of the soil's sample increases as the number of blows used for compaction increases. Additionally, the CBR tends to be higher for shallower penetration depths, as expected.

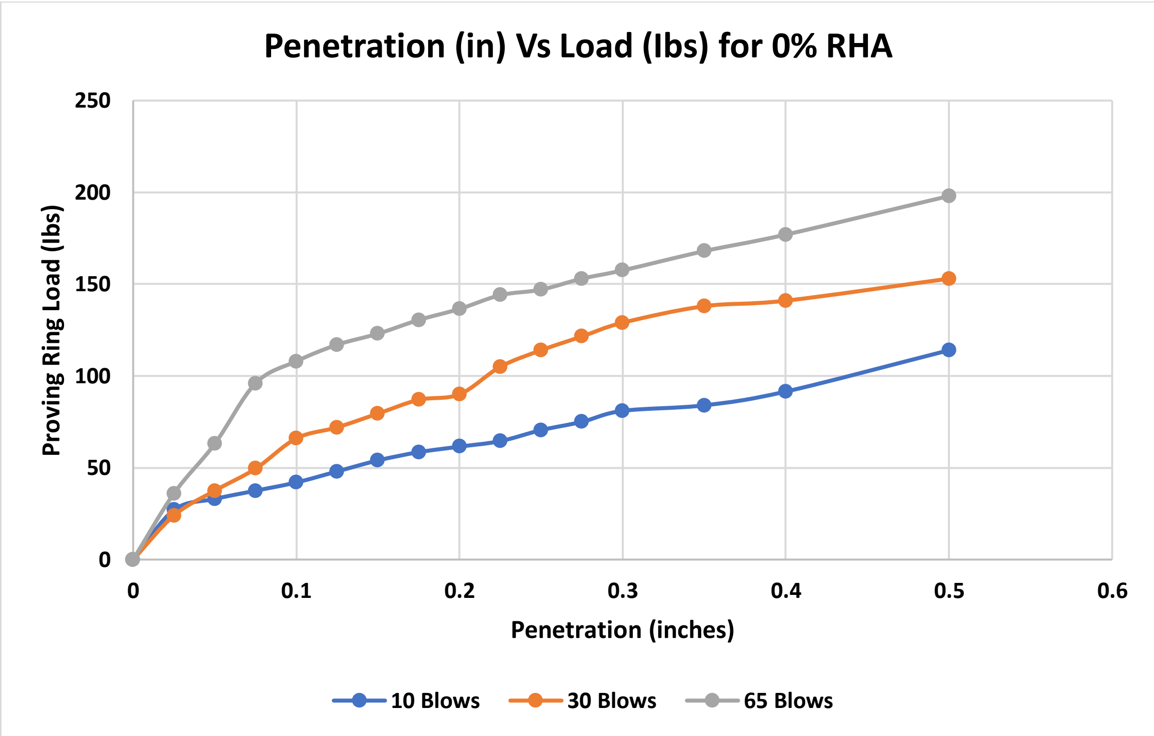

Figure 4.8 CBR test

Table 4.4 (CBR test results)

Standard Load (Ib)		Sample 1 (Ibs)		Sample 2 (Ibs)		Sample 3 (Ibs)	
at 1"	at 2"	at 1"	at 2"	at 1"	at 2"	at 1"	at 2"
3000	4500	42	61.5	108	136.5	66	90

With 0% RHA	
CBR at 1"	2.4
CBR at 2"	2.13

The CBR (California Bearing Ratio) values provided in the given scenario serve as indicators of the relative strength of a material when utilized as a subgrade for roads or pavements. These values are determined by comparing the force which is required to pierce a soil sample with a standard circular piston at a specific rate to the force needed to penetrate a standard material, typically crushed stone. CBR values range from 0 percent to 100 percent, with higher values promises greater and morestrength.

Based on the given information, the sample with 0% RHA exhibited CBR values of 2.4% at 1" and 2.133% at 2". These values suggest that the material has relatively low strength and may not be suitable for high-traffic areas as a subgrade material. However, the suitability of the material would depend on the specific requirements of the project and other relevant properties of the material, such as maximum dry density, optimum moisture content, and shear strength.

In terms of determining the design CBR value, the typical approach involves selecting the lower of the two CBR values measured at different depths. In this case, the CBR value at 2" is lower than the CBR value at 1", resulting in a design CBR of 2.133%. This indicates that the soil is exhibiting elastic deformation behavior..

4.2. RESULTS OF STABILIZED SOIL USING RHA

4.2.1. Atterberg Limits by using RHA

LL, PL, and PI are interconnected soil properties that find common use in soil classification and geotechnical engineering.

LL, or **Liquid Limit**, refers to water content at which transition of soil takes place from a state to a liquid state. It gauges the soil's susceptibility to deformation under stress. A higher LL signifies a greater water content needed for the soil to flow and deform.

PL, or **Plastic Limit**, denotes that content of water at which there is exhibition of plastic properties of soil. It represents the minimum moisture content required for the soil to demonstrate plastic behavior. A higher PL indicates a higher clay content in the soil.

PI, or **Plasticity Index**, is calculated by the difference between PL and LL. It provides a measure of such range of content of water over which the soil displays plastic properties. A higher PI signifies greater soil plasticity.

According to the provided table, as the percentage of RHA inc. from 0% to 9%, the LL decrease from 49% to 43%. This decline implies that the soil requires less water content to transition from a state of plastic to a state of liquid. This effect can also be accredited to the high water-holding capability of RHA, which leads to a decline in the water content necessary for the soil to reach its liquid limit, as shown in Figure 4.10.

Similarly, as the RHA percentage increases, the PL also decreases from 28.328% to 25.817%, as in Figure 4.10, indicating that the min water content required for the soil to exhibit plastic properties decreases. This is because RHA acts as a binder and reduces the soil's plasticity.

As a result of the decrease in both LL and PL, the PI also decreases from 20.672 to 17.182, as in Figure 4.10. This indicates that the range of content of water at which the soil exhibits plastic properties decreases as the RHA content increases.

Test was stopped at 9 percent RHA, as the trend was not changing. The liquid limit, plastic limit and plasticity index was decreasing continuously, as the reasons behind these trends is explained above. All the values have been shown in tabular form, as shown in Table 4.5.

Table 4.5 Results by using RHA

RHA (%)	**LL**	**PL**	**PI**
0	49	28.3	20.7
5	46.1	27.0	19.1
7	44.9	26.7	18.2
9	43	25.8	17.2

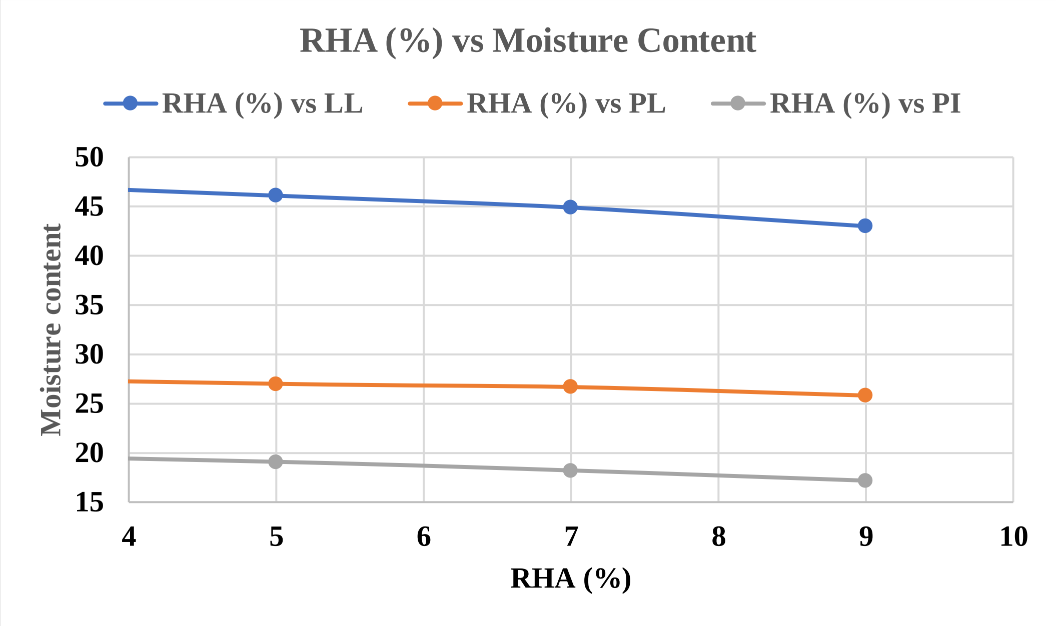

Figure 4.9 RHA (%) vs LL, PL, PI

4.2.2. Compaction by using RHA

As the RHA content is increased from 0% to 13%, the OMC value shows an increasing trend from 13.566% to 21.67%, as shown in Figure 4.11. It is due to fact that RHA is a that material which is pozzolanic, and its addition to soil increases the water demand for cementation of particles. Hence, the soil requires a higher moisture content to reach maximum compaction.

The rise in Moisture Content which is optimum (OMC) with the progressive employment of RHA to the soil primarily stems from the alteration in soil structure induced by RHA particles. RHA exhibits a high level of porosity and has a tendency to absorb more water compared to soil particles. Consequently, when RHA is incorporated into the soil, it enhances the water-holding capacity of the soil, leading to challenges in achieving maximum compaction. Consequently, the OMC increases with higher RHA content to offset the heightened water requirement of the soil.

In addition, RHA is a highly pozzolanic material, which means it reacts with water and calcium hydroxide to generate cementitious compounds. This reaction consumes water, leading to a decrease in the available water in the soil and an increase in the OMC. Moreover, the pozzolanic reaction can also lead to an increase in the soil density, which may offset the decrease in density caused by the increased water content.

Overall, The intricate rise in OMC associated with the rise in RHA’s content is influenced by multiple factors, including the water retention capacity of RHA, the occurrence of the pozzolanic type of reaction, and the structure of the soil.

The table clearly demonstrates that the inclusion of RHA content results in a decline in the dry density of the soil. At 0% RHA, the max dry density (MDD) of the soil is 1.749 g/cm3, while at 13% RHA, the MDD decreases to 1.568 g/cm3.

This trend can be **explained** by the fact that RHA particles are lighter than soil particles and have a lower density. The introduction of RHA into the soil leads to the occupation of certain pore spaces that would've otherwise been filled by soil particles. As a result, the overall density of the soil decreases. Additionally, the RHA particles have a smooth surface that reduces interlocking with soil particles, thus reducing the soil's ability to achieve high compaction densities.

Moreover, the RHA particles absorb water and expand, leading to the formation of large voids in the soil matrix, which decreases the soil's dry density. As the RHA content increases, the amount of water absorbed by the RHA particles also increases, leading to more voids in the soil and lower dry densities.

To summarize, the decline in the compacted density of the soil as the RHA content increases can be ascribed to several factors: the decreased density of RHA particles, diminished interlocking between RHA and soil particles, and the creation of significant gaps caused by the expansion of RHA particles.

In general, the incorporation of RHA into soil lead to a rise in soil moisture content (OMC) and a reduction in the max compacted density. These effects can be observed in the data, as shown in the Figure 4.11 and the Table 4.6

Table 4.6 (Results of OMC vs MDD by using RHA)

RHA (%)	**OMC (%)**	**MDD g/cm^3)**	**MDD kN/m^3)**
0	13.5	1.74	17.1
5	17.7	1.6	16.5
7	18.4	1.6	16.1
9	19.5	1.6	15.9
11	20.6	1.5	15.6
13	21.6	1.5	15.3

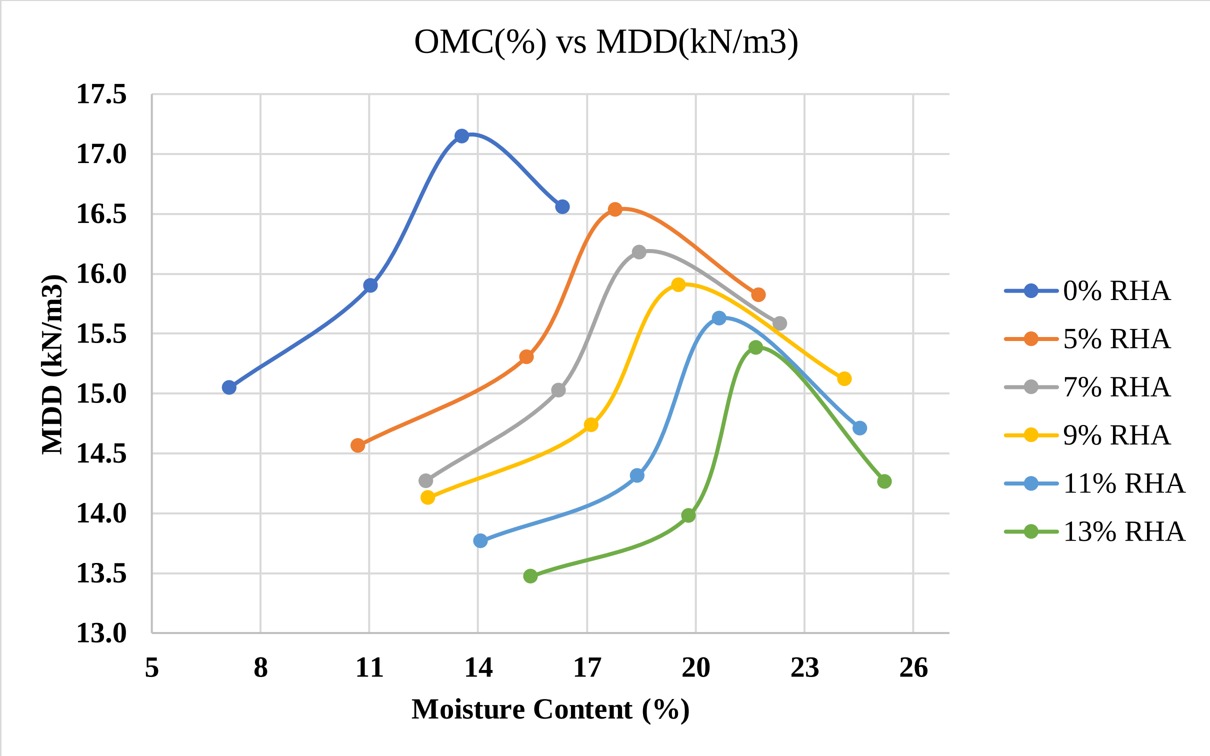

Figure 4.10 OMC vs MDD by using RHA

4.2.3. Unconfined compression test by using RHA

The trend in the UCS values with increasing RHA content shows an initial increase up to a certain RHA content (in this case, 9%), followed by a decrease in strength with further RHA additions, as in Figure 4.12 and 4.13 and Table 4.7. This initial rise can be accredited to the pozzolanic interaction occurring between the RHA. and calcium hydroxide in the company of water, which can lead to the development of additional cementitious compounds and subsequently, higher strength. However, beyond a certain limit, the excessive amount of RHA can lead to the formation of weak spots within the matrix, leading to a decrease in strength. Moreover, it should be noted that excessive rice husk ash (RHA) content can have an effect on the strength characteristics of such problematic soil. The presence of RHA may act as a filler material, occupying voids that would otherwise be filled with stronger matrix particles. This can result in lower strength values for the soil. The following observations were made regarding the unconfined compressive strength (UCS) of the soil with varying percentages of RHA:

- Initially, as the percentage of RHA increases, the UCS of the soil shows an increasing trend. For example, at 0% RHA, the UCS is measured to be 30.05 kPa, and it reaches a maximum value of 43.86 kPa at 9% RHA (as depicted in Figure 4.13).
- However, beyond the optimum percentage of 9% RHA, the UCS starts to decrease. At 13% RHA, the UCS reaches a minimum value of 38.27 kPa.

- The highest UCS value is observed at the optimal RHA content of 9%. This indicates that 9% is the optimum value of percentage of RHA for improving the soil's strength.
- The rise in UCS with increasing RHA content can be accredited to the such pozzolanic type of reaction between the RHA and the soil. This reaction produces cementitious compounds that fill the voids in the soil, thereby increasing its strength.
- Nevertheless, when the RHA content exceeds the optimum value of 9%, the excess RHA particles may interfere with the pozzolanic reaction, leading to a decrease in soil strength. This interference could be a result of the excess RHA particles acting as inert fillers, reducing the effectiveness of the pozzolanic reaction.

It is important to highlight that the UCS values presented in the table are specific to the soil type and the RHA used in the study. These values may vary for different soil types and types of RHAs. Therefore, caution is necessary when extrapolating these results to other scenarios.

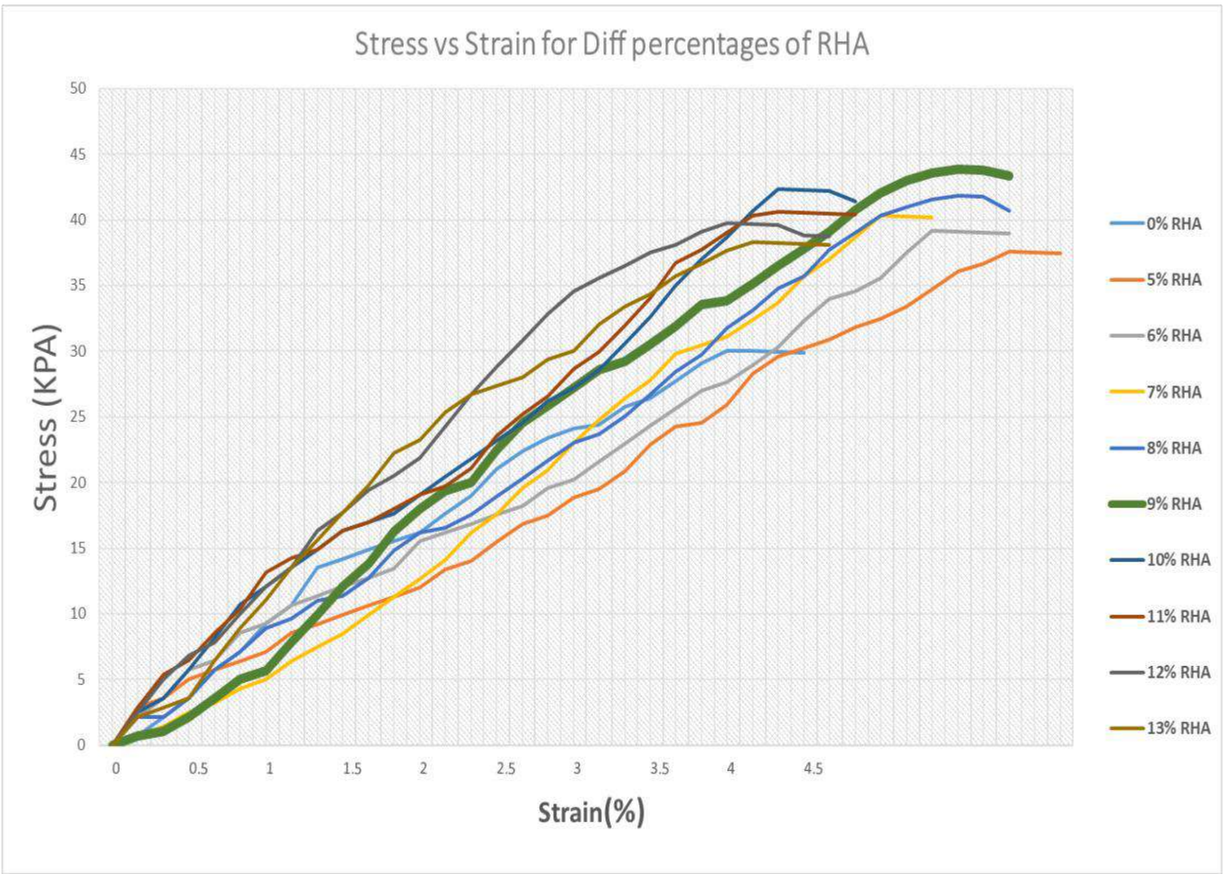

Figure 4.11 UCS with % of RHA

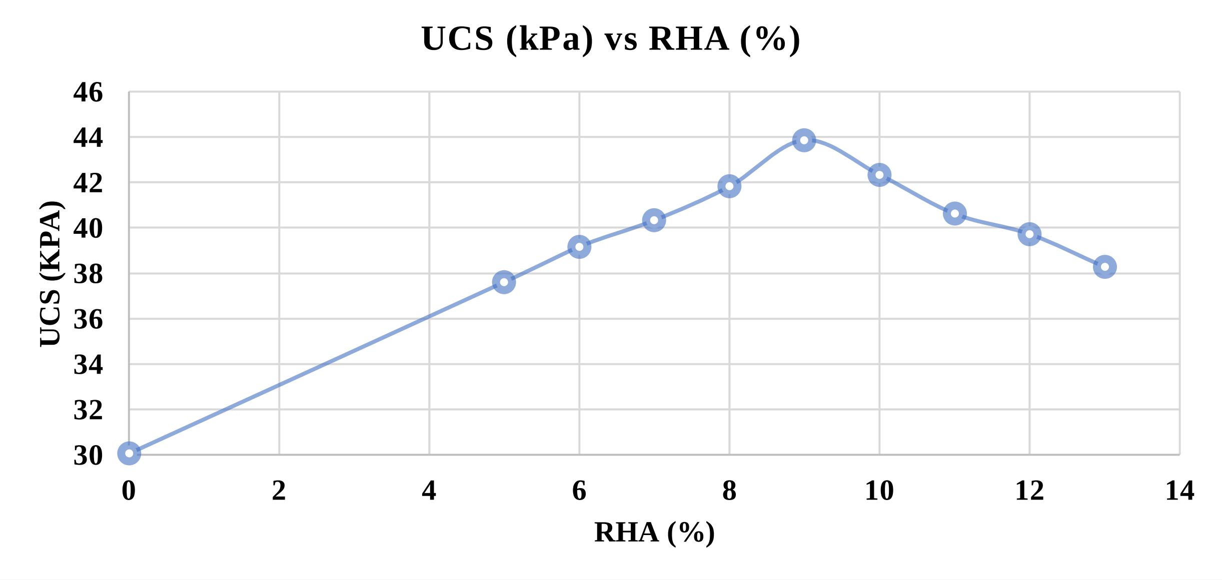

Figure 4.12 UCS vs RHA

Table 4.7 (UCS vs RHA)

RHA (%)	**UCS (kPa)**
0	30.05
5	37.60
6	39.17
7	40.33
8	41.82
9	43.86
10	42.33
11	40.61
12	39.72
13	38.27

4.2.4. California Bearing Ratio with different percentages of RHA (%)

The table shows the impact of Rice Husk Ash (RHA) on Design California Bearing Ratio (CBR) of a soil sample. Here are some points to explain the trend:

1. The Design CBR of the soil sample increases with the employment of RHA up to a certain point, beyond which it starts to decrease.
2. At 5% RHA content, the Design CBR is higher than that of the soil sample with 0% RHA content, indicating that RHA shows a increasing impact on the strength of the soil.
3. The maximum Design CBR is observed at 9% RHA content, which is 4.68, as shown in Table 4.8. This indicates that there is an optimum amount of RHA that can be added to the soil to improve its strength.

4. Beyond the optimum RHA content, the Design CBR starts to decrease, indicating that adding too much RHA may have negative impact on the soil strength.
5. The decline in the value of Design CBR at higher RHA contents may be due to the fact that RHA has a lower specific gravity than the soil particles, which can reduce the overall density of the soil.
6. Then the increase in Design CBR up to the optimum RHA content may be due to the pozzolanic type of reactions of RHA with the sych soil particles, which can lead to the formation of such cementitious compounds and improve the strength of the soil.
7. The decrease in Design CBR beyond the optimum RHA content may be due to the excessive pozzolanic type of reaction, as which can lead to such formation of the weak compounds and reduce the strength of the soil, as in Figure 4.14.

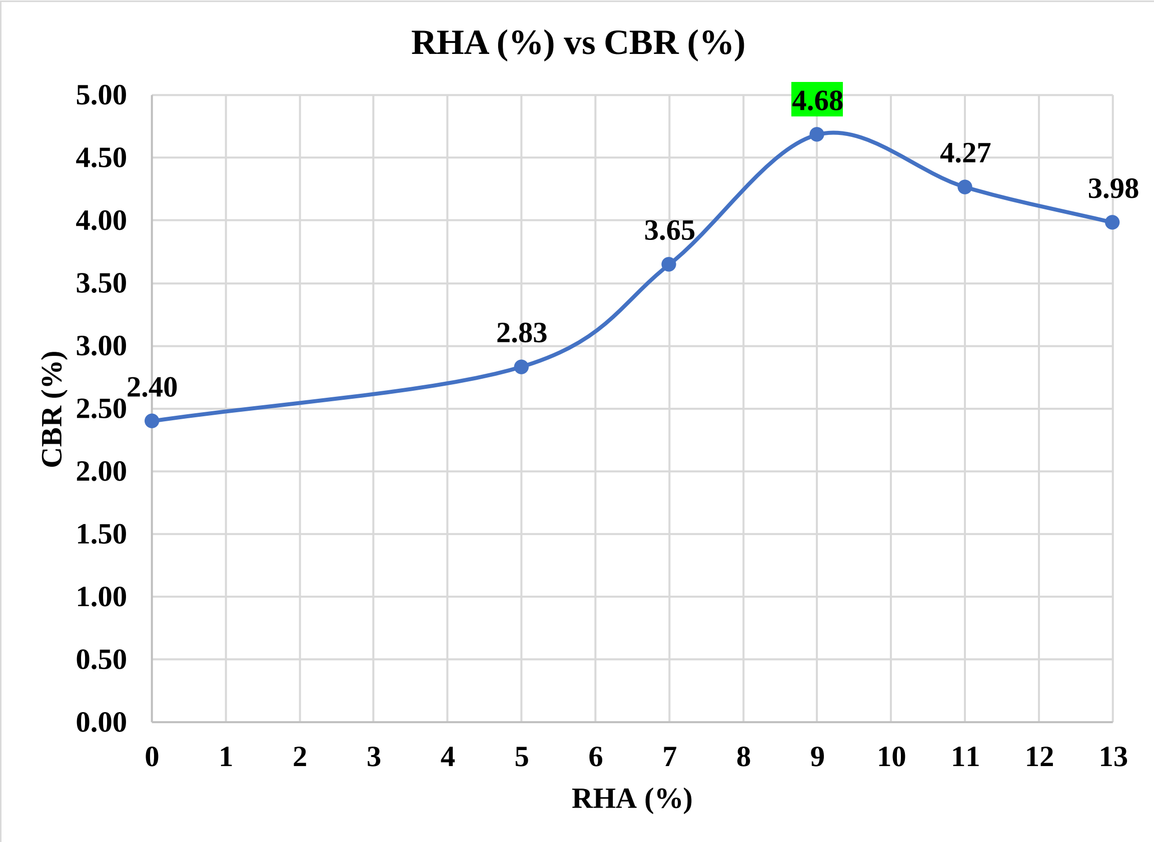

Figure 4.13 RHA (%) vs CBR (%)

Table 4.8 Design CBR

RHA (%)	**Design CBR (i.e., at 1")**
0	2.40
5	2.83
7	3.65
9	4.68
11	4.27
13	3.98

The comparison between a design CBR of 2.4 and 4.68 for use in subgrade soil can be made in the following ways:

1. **Load-bearing capacity:** The subgrade soil with a design CBR of 4.68 would exhibit a greater load-bearing capacity in comparison to the soil with a design CBR of 2.4. This means it can withstand more load and provide better support to the overlying pavement structure.
2. **Stability:** The subgrade soil with a design CBR of 4.68 would also be more stable compared to the soil with a design CBR of 2.4. This means it would be less susceptible to deformation and settlement under traffic loads and various environmental parameters or factors such as the moisture and temperature changes.
3. **Durability:** The subgrade soil with a design CBR of 4.68 would also be more durable compared to the soil with a design CBR of 2.4. This means it would have a longer service life and require less maintenance and repairs.
4. **Cost-effectiveness:** While the subgrade soil with a design CBR of 4.68 may provide better performance compared to the soil with a design CBR of 2.4, it may also be more expensive to achieve. The cost-benefit analysis should be considered while deciding CBR.

Overall, a subgrade soil with a design CBR of 4.68 would be preferable for use in pavements as it provides better load-bearing capacity, stability, and durability. However, the decision should also consider the cost-effectiveness and specific project requirements.

4.2.5. Design of subgrade using CBR

In our thesis on the stabilization or reinforcement of subgrade soil using Rice Husk Ash (RHA) for road construction, we focused on designing pavement using the AASHTO flexible pavement design method. This widely utilized method considers various factors such as traffic loads, climate conditions, materials properties, and subgrade soil characteristics.

For the design of the pavement structure, we adopted a layered approach as per the AASHTO method. The pavement structure consists of multiple layers, each playing a role in load distribution and overall performance. The subgrade layer, being the foundation of the pavement, requires particular attention to ensure stability and prevent failure.

To enhance and better the subgrade soil's properties, we incorporated RHA as a stabilizing agent. RHA, a byproduct of rice husk combustion, contains high amounts of amorphous silica, which can enhance soil stability, reduce plasticity, and increase strength characteristics. Our aim was to increase the capacity of the subgrade soil in terms of bearing of load. and address potential issues like differential settlement and rutting.

During the design process, we utilized California Bearing Ratio (CBR) values obtained from testing as a means to evaluate the strength of the subgrade soil. However, we assumed CBR values for the sub-base and base layers, as well as the corresponding resilient modulus values. These assumptions allowed us to estimate the behavior of these layers under traffic loading.

Our thesis primarily focused on the AASHTO design method for flexible pavement, specifically emphasizing RHA's role and use for subgrade soil stabilization. Through the incorporation of RHA, Our objective was to enhance the strength and overall performance of the subgrade. contributing to the longevity and sustainability of road infrastructure.
It's important to note that the specific results and subgrade thicknesses obtained using the structural number method will vary depending on the design traffic, subgrade conditions, and the design methodology employed.

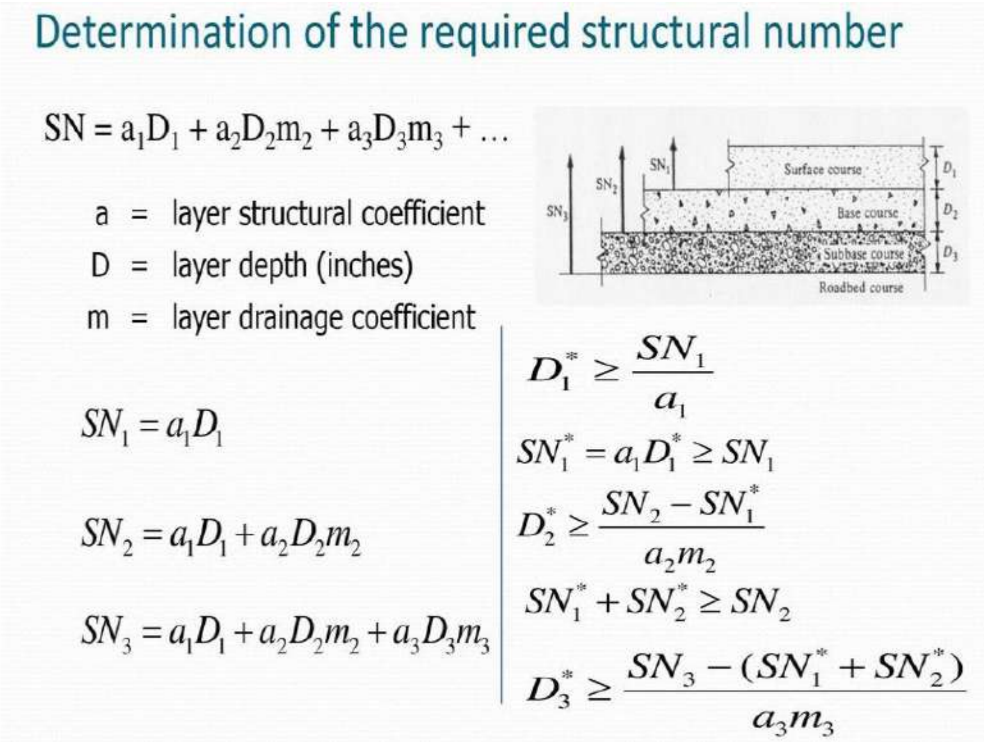

Figure 4.14 Structural number formulae (source: research gate)

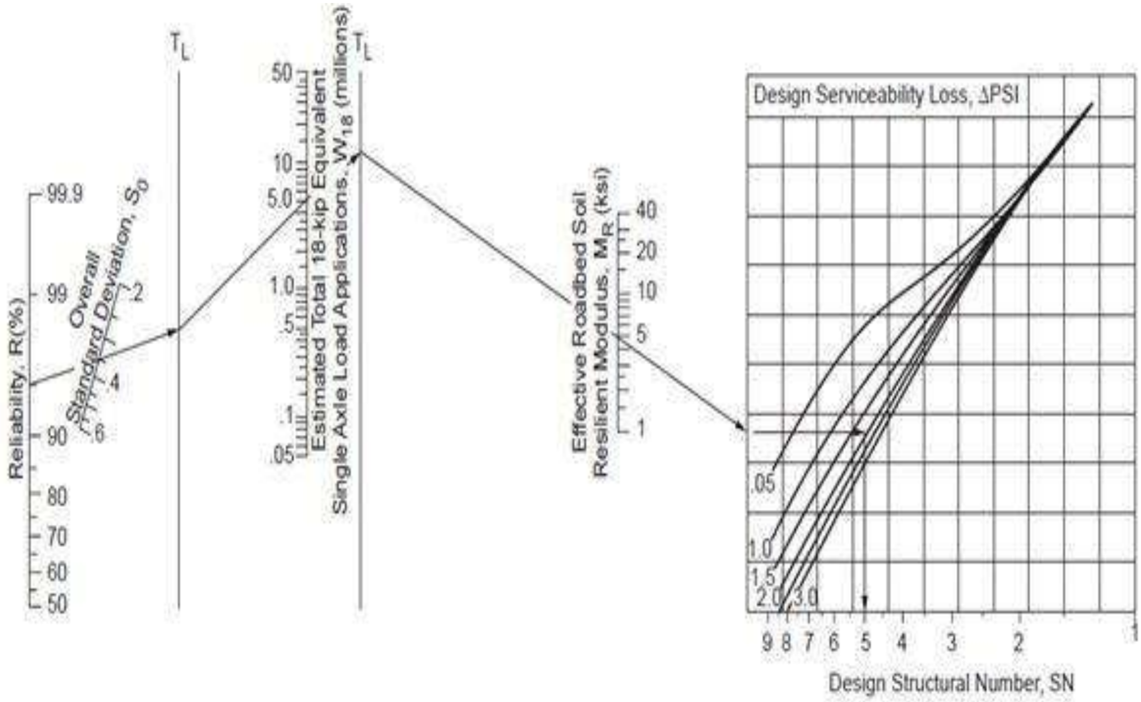

Figure 4.15 AASHTO flexible pavement design chart (source: research gate)

The use of local design guidelines and consulting with a qualified pavement engineer is recommended to obtain accurate and site-specific results for subgrade thickness design. Procedure is simple and basic. Firstly, you have the design CBR value. On the basis of that you calculate the resilient modulus based on CBR and r values by following expressions:

For soils which are fine-grained with a soaked CBR of 10 or less, as in eq. 3:

$$M_r\ (lb/in^2) = 1500 \times CBR \quad (4.3)$$

For R-values which are less than or equal to 20, as in er. 4:

$$M_r\ (lb/in^2) = 1000 + 555 \times R \quad (4.4)$$

And then by assuming or having field based resilient modulus values of sub-base and base, you calculate the structure numbers. Structural numbers depend on the sub-base, base and wearing surface structure co-efficient (i.e., a_1,a_2,a_3) and by assuming drainage coefficient "m" like in our case we did .8 based on fair quality of drainage. Then using the structural co-efficients the thickness of all three layers is calculated. Based upon our values for CBR, the thickness of subgrade, base course and surface courses are the following:

Table 4.9 Thickness of subgrade using Structural Number

RHA (%)	Subgrade Design CBR (%) (i.e., at 1")	Subgrade Resilient modulus	Sub-base Resilient modulus (Ib/in2)	Base Resilient modulus(ib/in2)	SN_3	SN_2	SN_1	a_3 (CBR=22% of sub-base)	a_2 (CBR=100% of base
0	2.40	3600	13500	31000	5.5	3.8	2.6	0.1	0.14
5	2.83	4245	13500	31000	5.1	3.8	2.6	0.1	0.14
7	3.65	5475	13500	31000	4.8	3.8	2.6	0.1	0.14
9	4.68	7020	13500	31000	4.6	3.8	2.6	0.1	0.14
11	4.27	6405	13500	31000	4.74	3.8	2.6	0.1	0.14
13	3.98	5970	13500	31000	4.66	3.8	2.6	0.1	0.14

a_1 (Mr =45000 Ib/in_2, AC)	D_1 (inches)	D_1* (inches)	SN_1*	D_2	D_2*	SN_2*	D_3	D_3*	SN_{3*}
0.44	5.91	6	2.64	10.36	10.5	3.82	21.05	21.5	5.54
0.44	5.91	6	2.64	10.36	10.5	3.82	16.05	16.5	5.14
0.44	5.91	6	2.64	10.36	10.5	3.82	12.3	12.5	4.82
0.44	5.91	6	2.64	10.36	10.5	3.82	9.8	10	4.62
0.44	5.91	6	2.64	10.36	10.5	3.82	11.55	12	4.78
0.44	5.91	6	2.64	10.36	10.5	3.82	10.55	11	4.70

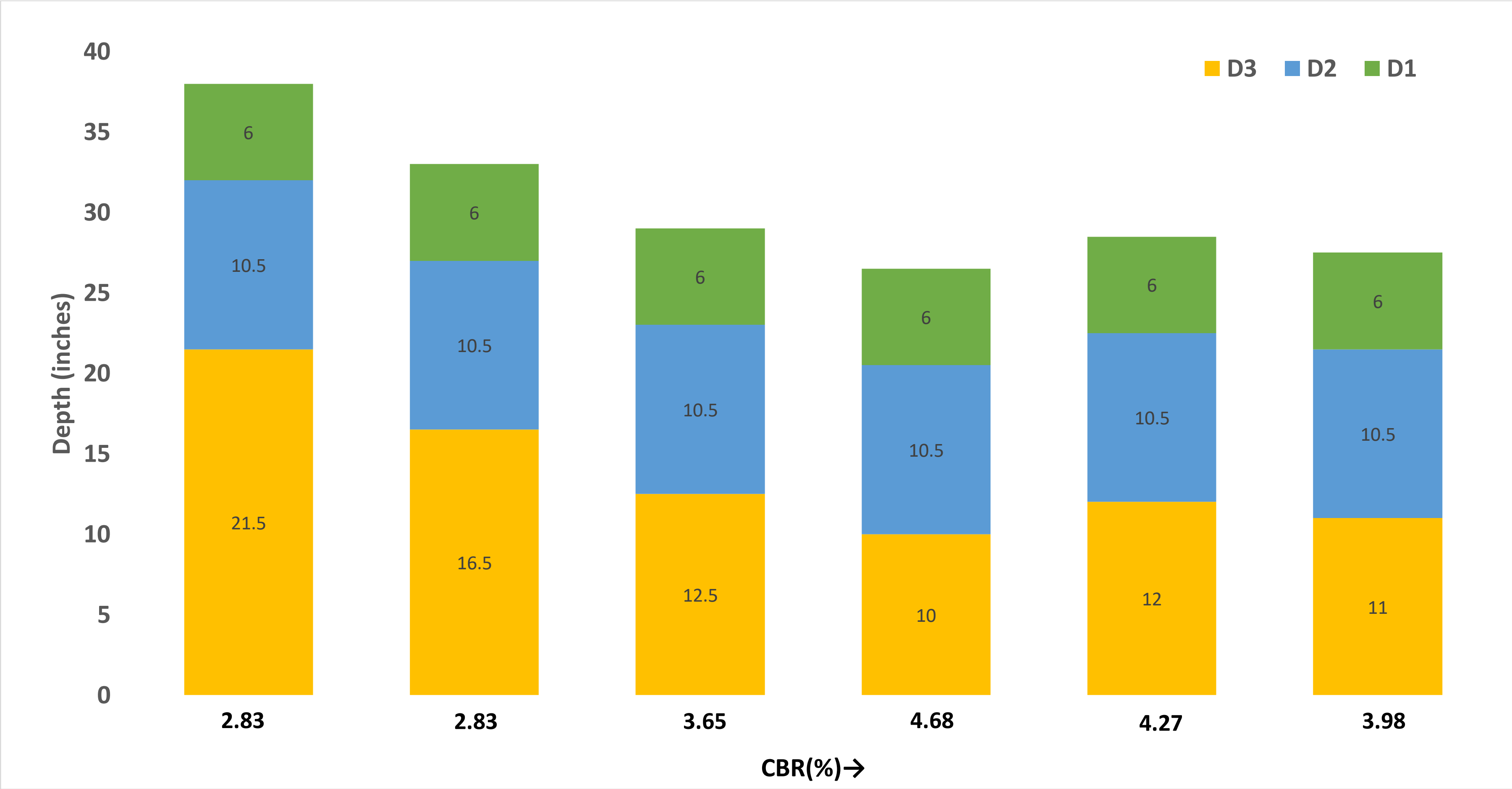

Figure 4.1 Thickness of subgrade for varying CBR (%)

CONCLUSION & RECOMMENDATIONS

5.1. GENERAL

This research aimed to address the challenges posed by expansive soils in major areas of Pakistan by implementing soil stabilization techniques. The study focused on Punjab, specifically Dera Ghazi Khan, Chakwal, Sialkot, Gujranwala, and Narowal, is characterized by five distinct areas prone to potential swelling.Among these districts, detailed investigations were carried out at the Narowal site. Thorough extensive type of the laboratory related testing was carried to analyze the fundamental characteristics and properties and swelling behavior of expansive soils. The identification of these soils was based on various parameters, including plasticity index, expansion index, and swell potential. Additionally, the study examined various factors that influence the swelling properties of soils, including the initial dry unit weight, the initial moisture content plasticity index, and the addition of non-swelling kind of soil. In order to establish correlations between swelling parameters (swell potential and swell pressure) and key soil properties (such as initial moisture content along with plasticity index and initial dry unit weight), a series of tests were conducted using varying proportions of rice husk ash (RHA). The aim was to find the optimal content of RHA that effectively mitigates soil swelling. Based on the obtained test data, the expansive soils were treated with the determined optimum content of RHA. The stabilized soil was then utilized as a subgrade material for road construction. This approach ensures that the collected data on expansive soils and the correlations between soil properties and swelling parameters were incorporated in the design of the road subgrade. Overall, the research focused on identifying potential swelling districts, characterizing the expansive soils, investigating factors affecting their swelling properties, determining the optimal RHA content for stabilization, and utilizing the stabilized soil in road subgrade construction.

5.2. CONCLUSIONS

The following findings are derived from the conducted experimental investigations.

1. The subgrade soil in Narowal district is classified as Highly Plastic Clays (CH) with swelling potential, characterized by a liquid limit of approximately 49%, plasticity index of 20.67, and plastic limit of 28.33% (A-7-6 and CL soil classification).
2. Incorporating Rice Husk Ash (RHA) in the subgrade soil improved its engineering properties. The addition of RHA led to a reduction in the limit of liquid (LL), plastic limit, and index of plasticity, while simultaneously increasing the optimum moisture content.

3. The employment of RHA enhanced the unconfined compressive strength (UCS) of the soil, reaching a maximum value at 9% RHA content. The inclusion of RHA also resulted in an enhancement of the design California Bearing Ratio (CBR)., peaking at 4.68 at 9% RHA content.
4. A subgrade soil with an improved design CBR of 4.68 provides enhanced load-bearing capacity, stability, and durability, making it suitable for pavement applications. However, cost-effectiveness and specific project requirements should be considered when deciding on the optimal RHA content for subgrade stabilization.

5.3. RECOMMENDATIONS FOR FUTURE WORK

1. **Experimental Models**: In order to better simulate field conditions and accurately represent the behavior of soil samples, the development of models that incorporate lateral moisture movement is necessary. Currently, laboratory swell tests involve vertically confined soil samples, allowing swelling to occur only in the vertical direction. However, it is important to recognize that in the field, soil is not laterally confined, and moisture can move laterally. To address this discrepancy between laboratory testing and field conditions, it is crucial to design experimental setups that incorporate the provision for lateral moisture movement. By allowing for lateral moisture migration, the testing conditions can better reflect the behavior of soil in real-world scenarios. This enhancement in experimental setup will help researchers and engineers to obtain more realistic and representative results, leading to improved understanding and accurate predictions of soil behavior under field conditions. Therefore, the development of models and experimental setups that consider lateral moisture movement is essential to bridge the gap between laboratory testing and actual field conditions, enabling a more comprehensive and reliable analysis of soil behavior and performance.
2. **GPS:** It is strongly recommended to incorporate GPS (Global Positioning System) technology in geotechnical investigation reports to identify and report the locations of expansive soils accurately. By utilizing GPS, the precise coordinates of soil sample collection sites can be recorded, allowing for the mapping and spatial analysis of different soil types using Geographic Information System (GIS) software. The integration of GPS technology provides several benefits in the field of geotechnical engineering. Firstly, it enables geotechnical professionals to establish a comprehensive database of expansive soil locations, aiding in the identification of high-risk areas and facilitating future research and analysis. Secondly, the spatial information obtained through GPS can be integrated with other geotechnical data, such as soil properties and geological features, to create detailed geotechnical maps and models. By using GIS software, the collected GPS data can be visualized,

analyzed, and overlaid with other relevant information, such as infrastructure projects, land use patterns, and environmental factors. This spatial analysis provides valuable insights into the distribution and characteristics of expansive soils, assisting in decision-making processes related to construction, land management, and risk assessment. In summary, incorporating GPS technology in geotechnical investigation reports allows for accurate mapping of expansive soils and their spatial distribution. This integration with GIS software enhances the understanding of soil behavior, aids in risk assessment, and supports informed decision-making in geotechnical engineering projects.**Further research on long-term performance:** Conduct long-term field studies to evaluate the performance and durability of pavements constructed with RHA-stabilized subgrade soil. This will help assess the long-term effectiveness of RHA in improving the stability and strength of the subgrade.

3. **Optimization of RHA content:** Explore the potential for optimizing the RHA content in subgrade stabilization. Conduct additional laboratory tests with varying RHA percentages to ascertain the optimal composition or content that provides the highest strength and stability while considering cost-effectiveness.
4. **Investigation of other additives:** Explore the possibility of combining RHA with other additives or stabilizers to enhance the engineering characteristics of subgrade soil. Also Investigate synergistic effects of different additives and their potential to improve strength, reduce plasticity, and enhancing subgrade soil's capacity in terms of load baering.
5. **Field implementation and performance monitoring:** Implement pilot projects to assess the practical application of RHA-stabilized subgrade in real-world road construction. Monitor the performance of these pavements over time, including factors such as settlement, rutting, and overall durability, to validate the laboratory findings and gain practical insights.

By addressing these future recommendations, further advancements can be made in the field of subgrade soil stabilization, contributing to the development of sustainable and resilient road infrastructure.

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