UTILIZATION OF MAIZE HUSK ASH FOR WEAK SOIL STABILIZATION

BY

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BEING A PROJECT PROPOSAL SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, SCHOOL OF ENGINEERING TECHNOLOGY, FEDERAL POLYTECHNIC, MUBI, ADAMAWA STATE.

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DECLARATION

I hereby declare that his project work was written by me and is a record of my own research work.

……………………………………. ……………………..

Name Sign/Date

CERTIFICATION

This is to certify that this project work on "UTILIZATION OF MAIZE HUSK ASH FOR WEAK SOIL STABILIZATION", was approved by the Department of Civil Engineering Technology, Federal Polytechnic Mubi. And was carried out by Okenwa Samuel Tochuckwu (ET/CE/HND/21/005) of the Department of Civil Engineering Technology, Federal Polytechnic Mubi, Adamawa State. Under my supervision.

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DEDICATION

This project/Report work is dedicated to God Almighty the creator of heaven and earth, for his unending love, guidance and protection during this project report work, and also to my beloved parents, my siblings, and entire family at large.

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TABLE OF CONTENTS

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This study investigates the utilization of maize husk ash for the stabilization of weak soils. The research involved a comprehensive analysis of soil properties, including Atterberg limits, Proctor compaction tests, and California Bearing Ratio (CBR) values. The findings revealed that the addition of 5% maize husk ash resulted in notable improvements in soil characteristics. The Atterberg limit decreased, indicating enhanced plasticity, while the Proctor compaction tests showed increased maximum dry density and reduced optimum moisture content. However, beyond 5% maize husk ash content, diminishing returns were observed in terms of CBR values. The highest CBR value was achieved at this percentage, highlighting the potential for maize husk ash to enhance compaction resistance. The results indicate the need for further research to optimize the proportion of maize husk ash for effective soil stabilization. Field trials and quality control standards are recommended to evaluate its practical application and long-term durability. Additionally, environmental considerations and cost-benefit analyses should be addressed to assess the economic and ecological feasibility of this sustainable soil stabilization technique. Raising awareness among construction professionals and collaborating with regulatory authorities are crucial steps towards promoting the adoption of maize husk ash for soil improvement. This research contributes to the ongoing exploration of eco-friendly and cost-effective solutions for soil stabilization in construction, ultimately benefiting both the industry and the environment.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Soil stabilization is an essential aspect of civil engineering and construction projects, aiming to improve the engineering properties of weak or problematic soils. Weak soils pose significant challenges due to their inadequate load-bearing capacity, excessive settlement, and low shear strength, which can compromise the stability and performance of structures (Dash *et al*., 2019). Conventional soil stabilization techniques often involve the use of cement, lime, or other chemical additives, which can be expensive and environmentally detrimental (Tiwari *et al.*, 2020).

Finding further use for biomass wastes will have a salutary effect on the environment, particularly in a developing country like Nigeria, where waste collection tends to be low and these wastes often constitute a menace to the environment. Furthermore, cohesive soils which fall within the band of soils that could be modified abound in Nigeria and are routinely used as sub-base and base course materials in pavement construction, which in some cases do have to be improved or modified with the addition of cement in order to raise the strength parameter to the expected standard (Yinusa & Ahmed, 2014).

These soils typically exhibit low shear strength, high compressibility, and poor load-bearing capacity, which can pose significant challenges for infrastructure development (Choudhary *et al*., 2018; Kavak *et al*., 2019). Traditional methods of soil stabilization involve the use of cement, lime, or chemical additives, which can be costly and may have detrimental environmental impacts (Alawad *et al.*, 2019).

Agricultural waste materials have attracted considerable attention as potential resources for soil stabilization due to their abundance and potential beneficial properties (Nguyen *et al.*, 2019). These waste materials, such as crop residues and byproducts, are generated in large quantities during agricultural processes. The disposal of agricultural waste presents significant environmental challenges and can contribute to pollution and resource depletion. However, many of these waste materials possess inherent characteristics that make them suitable for soil improvement, including high silica and pozzolanic content (Narayanasamy & Santhanam, 2017).

Pozzolanic materials, such as MHA, react with calcium hydroxide in the presence of water to form cementitious compounds, contributing to improved soil strength and stability (Jha *et al.*, 2019). The pozzolanic activity of MHA can enhance the properties of weak soils, including increased shear strength, reduced compressibility, and improved durability (Narayanasamy & Santhanam, 2017).

In recent years, there has been a growing interest in exploring sustainable and eco-friendly alternatives for soil stabilization. One such alternative is the utilization of agricultural waste materials, which not only helps address the waste management issue associated with these materials but also provides a cost-effective and environmentally friendly solution for soil improvement (Azeez *et al.*, 2020; Demirel & Dalkılıç, 2021). Agricultural waste materials are abundantly available, and their utilization in soil stabilization can contribute to a circular economy and reduce the reliance on traditional stabilizing materials.

Maize husk ash (MHA) is an agricultural waste material generated during the processing of maize (*Zea mays*) for food production. It is typically discarded or underutilized, leading to environmental concerns and waste management challenges (Choudhary *et al*., 2020). Maize husk ash is rich in silica and possesses pozzolanic properties, which make it a potential candidate for soil stabilization applications (Nasir *et al*., 2021). Pozzolanic materials, when mixed with calcium hydroxide (lime) and water, react chemically to form cementitious compounds that contribute to the improvement of soil strength and stability (Akinmusuru *et al.,* 2021; Kumar *et al.*, 2022).

Maize husk ash (MHA) is one such agricultural waste material that holds promise for weak soil stabilization. Maize (Zea mays) is one of the most widely cultivated cereal crops globally, and the processing of maize for food production generates substantial amounts of husk waste (Ayinde *et al.*, 2019). Maize husk ash is typically discarded or underutilized, leading to environmental concerns and waste management issues. However, recent studies have revealed the potential of MHA as a soil stabilizer due to its pozzolanic properties and high silica content (Adeoye *et al*., 2018).

Several studies have investigated the use of various agricultural waste materials, such as rice husk ash, sugarcane bagasse ash, and wheat straw ash, for soil stabilization (Choudhary *et al*., 2020; Reddy *et al.*, 2021; Singh *et al*., 2022).

However, the potential utilization of maize husk ash as a soil stabilizer has received relatively less attention. Therefore, further research is necessary to evaluate the geotechnical properties, pozzolanic activity, and long-term performance of stabilized soils using maize husk ash.

1.2 Justification of the Study

Weak or unstable soil poses significant challenges in construction and engineering projects. Weak soils often lack the required strength and stability to support structures, leading to settlement, subsidence, and structural failures. Traditional methods of soil stabilization, such as cement or lime treatment, can be costly and environmentally unfriendly. Therefore, there is a need for sustainable and cost-effective soil stabilization techniques.

Maize (corn) is a widely cultivated crop globally, and its husks are considered agricultural waste after harvesting. The disposal of maize husks can lead to environmental issues and waste management challenges. Utilizing maize husk ash as a soil stabilizer offers an eco-friendly solution by repurposing agricultural waste, reducing landfill burdens, and contributing to a circular economy. Maize husk ash contains silica, which exhibits pozzolanic properties when combined with calcium hydroxide in the presence of water. This reaction results in the formation of cementitious compounds, like calcium silicate hydrate (C-S-H), which contributes to soil stabilization. Pozzolanic reactions enhance soil strength and reduce its susceptibility to volume changes due to moisture variations.

Compared to traditional stabilizers like cement or lime, maize husk ash is a cost-effective alternative. The material is locally available in regions with significant maize production, reducing transportation costs. By utilizing agricultural waste instead of manufactured stabilizers, the overall project cost can be significantly reduced, making it an attractive option, especially for rural or low-budget projects. Improved Soil Engineering Properties: Maize husk ash incorporation improves various soil engineering properties, including increased California Bearing Ratio (CBR), reduced compressibility, and improved shear strength. These enhancements make the stabilized soil suitable for construction purposes, providing a reliable foundation for buildings, roads, and other infrastructure projects.

Using maize husk ash for soil stabilization aligns with sustainable development goals and environmental conservation efforts. By promoting the use of agricultural waste instead of non-renewable resources, this technique reduces the carbon footprint associated with soil stabilization processes, contributing to a greener and more sustainable construction industry. The utilization of maize husk ash for soil stabilization has been subject to extensive research and testing. Several studies have demonstrated its effectiveness in improving soil properties and providing stable foundations. Case studies and successful applications of maize husk ash in weak soil stabilization provide concrete evidence of its viability as a practical and reliable soil stabilization technique.

1.3 Statement of Problem

Weak soils present a significant challenge in the construction industry, requiring effective stabilization methods. Conventional stabilization techniques often involve the use of inexpensive materials and complex procedures. Moreover, these methods may have adverse environmental impacts, such as increased carbon emissions and depletion of natural resources. Therefore, there is a growing need for sustainable and cost-effective alternatives that can improve soil strength and stability while minimizing the environmental footprint.

The disposal of agricultural waste materials, including crop residues and byproducts, presents environmental challenges due to their large-scale production and limited disposal options. These waste materials, if not managed properly, can contribute to pollution, land degradation, and resource depletion. However, many agricultural waste materials possess inherent properties that make them potential for use as soil stabilization agent.

Among these agricultural waste materials, maize husk ash (MHA) is generated in substantial quantities during the processing of maize for food production. Maize husk ash is typically discarded or underutilized, leading to waste management concerns and environmental issues. However, recent studies have shown that MHA exhibits promising properties for soil stabilization due to its high silica content and pozzolanic activity.

Maize husk ash is a waste material generated in large quantities during the processing of maize (*Zea mays*) for food production. It is typically discarded or underutilized, leading to environmental concerns and waste management issues. However, recent studies have shown that MHA possesses promising properties for soil stabilization due to its high silica and pozzolanic content. By harnessing the potential of MHA, it is possible to transform this waste material into a valuable resource for strengthening weak soils.

The problem addressed in this research project is the need for sustainable and cost-effective techniques to stabilize weak soils. By investigating the utilization of maize husk ash for soil stabilization, the study aims to address the following specific issues:

Limited availability of affordable soil stabilization materials: Conventional soil stabilization methods often involve the use of expensive materials, such as cement or lime, which may not be economically viable for all projects. There is a need to explore alternative materials that are readily available, cost-effective, and possess the desired stabilizing properties.

Environmental concerns associated with agricultural waste: Improper disposal of agricultural waste materials, including maize husk, can contribute to environmental pollution and resource depletion. Finding sustainable and beneficial applications for these waste materials, such as soil stabilization, can help alleviate environmental concerns while providing economic benefits.

Inadequate knowledge and guidelines for utilizing maize husk ash for soil stabilization: While there have been studies on the potential of agricultural waste materials for soil stabilization, including MHA, there is a lack of comprehensive guidelines and recommendations for their effective utilization. This research project aims to bridge this knowledge gap by investigating the geotechnical properties and long-term performance of stabilized soils using maize husk ash.

By addressing these issues, this research project seeks to provide a sustainable solution for weak soil stabilization while minimizing the environmental impact associated with the disposal of agricultural waste materials.

1.4 Aim and Objectives of the Study

1.4.1 Aim

The aim of this research is to investigate the effect of maize husk ash in stabilized weak soil in order to improve its physical and engineering properties.

1.4.2 Objectives

The specific objectives of this work are as follows;

i. To obtain adequate maize husk ash under controlled burning of maize husk fiber.
ii. To determine physical properties of the untreated soil samples.
iii. To determine engineering properties of the untreated soil samples.
iv. To investigate the effect of the maize husk ash on soil density and strength characteristics.

1.5 Scope and Limitation of the Study

1.5.1 Scope of the Study

The scope of this research project on the utilization of maize husk ash (MHA) for weak soil stabilization encompasses several key aspects. The study involves conducting laboratory tests to assess the geotechnical properties of weak soil samples and determine their baseline characteristics. This includes tests such as grain size analysis, Atterberg limits, compaction tests, and shear strength tests. This analysis will provide insights into the potential of MHA as a soil stabilizer. The study focuses on the investigation of different techniques for incorporating maize husk ash into weak soils. It explores methods such as direct mixing, pre-soaking, and lime activation to optimize the stabilization process. The research project includes mechanical testing of the stabilized soil samples to evaluate their strength, compressibility, and durability. Tests such as unconfined compression tests, California Bearing Ratio (CBR) tests, and cyclic loading tests may be conducted. Also, the study aims to analyze the long-term performance of the stabilized soils using maize husk ash. This includes evaluating factors such as strength gain over time, resistance to environmental conditions, and durability under different loading conditions.

1.5.2 Limitation of the Study

This study is however limited to only maize husk ash obtained from uncontrolled burning of maize husk fiber available at The Federal Polytechnic, Mubi.

1.6 Significance of the Study

The utilization of maize husk ash for weak soil stabilization offers several potential benefits. Firstly, it provides a sustainable solution to the growing environmental concern of agricultural waste disposal. By converting maize husk ash into a soil stabilizer, it reduces the reliance on traditional stabilizing materials and promotes a circular economy approach.

Secondly, the use of maize husk ash as a soil stabilizer can significantly improve the engineering properties of weak soils. It enhances their shear strength, compressibility, and load-bearing capacity, thereby enabling the construction of more stable and reliable structures. This has implications for a wide range of applications, including road construction, embankments, and foundation engineering.

Lastly, the research project aims to contribute to the existing body of knowledge regarding the utilization of agricultural waste materials for soil stabilization. By investigating the geotechnical properties, pozzolanic activity, and long-term performance of stabilized soils, this study will provide valuable insights and practical recommendations for engineers, researchers, and policymakers involved in sustainable construction practices.

CHAPTER TWO

2.0 LITERATURE REVIEW

Soil quality has been described as the balance between soil degradation and soil resilience (Kennedy & Papendick, 2017). Soil resilience is the ability of soil to return to a dynamic equilibrium after being disturbed (Blum & Santelises, 2019). Soil resilience is controlled by inherent soil properties governed by the factors affecting soil formation (Blum, 2018). Soil degradation is the short to medium term deterioration of soil caused by land use, soil management, and the soil's susceptibility to soil processes that promote loss of function (Blum, 2018). As a soil quality definition is reached, it needs to be flexible to account for the numerous functions that soil may perform.

Soil properties and processes such as moisture retention, water flow, root development, nutrient cycling, and the sustainability of micro and macro organisms are negatively influenced by high bulk density values (Arshad *et al.*, 2016; Arshad & Coen, 2018).

Akinwumi and Aidomojie (2015), studied Effect of Corncob ash on the geotechnical properties of Lateritic soil stabilized with Portland cement. The article aimed at providing experimental insights on the engineering properties of lateritic soil stabilized with cement-corncob ash (CCA) to ascertain its suitability for use as a pavement layer material. Series of specific gravity, consistency limits, compaction, California bearing ratio (CBR) and permeability tests, considering three CCA blends and four CCA contents, varying from 0 to 12%, were carried out. The results showed that the addition of CCA to the soil generally reduced its plasticity, swell potential and permeability; and increased its strength. CCA-stabilization, aside being more economical and environment-friendly than cement stabilization, improved the geotechnical properties of the soil for pavement layer material application. Thus, was recommended for use in pavement layers.

Yinusa and Apampa (2014), did an Evaluation of the Influence of Corn Cob Ash on the Strength Parameters of Lateritic Soils. The soil was mixed with CCA in varying percentages of 0%, 1.5%, 3%, 4.5%, 6% and 7.5% and the influence of CCA on the soil was determined for Liquid Limit, Plastic Limit, Compaction Characteristics, CBR and the Unconfined Compression Test. These tests were repeated on laterite CCA-cement mix and laterite-cement mix respectively in order to detect any pozzolanicity in CCA when it combines with Portland cement and to compare results with a known soil stabilizing agent. The result showed a similarity in the compaction characteristics of soil-cement, soil CCA and soil-CCA-cement, in that with increasing addition of binder from 1.5% to 7.5%, Maximum Dry Density progressively declined while the OMC steadily increased. In terms of the strength parameters, the maximum positive impact was observed at 1.5% CCA addition for soil-CCA with a CBR value of 84% and a UCS value of 1.0MN/m^2, compared with the control values of 65% and 0.4MN/m^2 respectively. For the soil-CCA-cement mix, the strength parameters CBR and UCS continued to increase with increasing binder addition within the tested range for the ratios 1:2 and 1:1 and 2:1 CCA: cement. Significantly, the results from the soil-CCA-cement mix, indicated the pozzolanicity of CCA in that UCS values were higher by at least 14% for the 1:1

ratio, than was attained with the addition of only the corresponding quantity of cement. In the light of the above, it was recommended that CCA can be made commercially available in its pure form or as CCA-cement blends and promoted as a stabilizing agent for soils in pavement construction.

Apampa *et al*., (2015), studied Modelling of Compaction Curves for Corn Cob Ash-Cement Stabilized Lateritic Soils. The study proposed a model for predicting the dry density of lateritic soils stabilized with corn cob ash (CCA) and blended cement – CCA. Lateritic soil was first stabilized with CCA at 1.5, 3.0, 4.5 and 6% of the weight of soil and then stabilized with the same proportions as replacement for cement. Dry density, specific gravity, maximum degree of saturation and moisture content were determined for each stabilized soil specimen, following standard procedure. Polynomial equations containing alpha and beta parameters for CCA and blended CCA-cement were developed. Experimental values were correlated with the values predicted from the Mat lab curve fitting tool, and the Solver function of Microsoft Excel 2010. The correlation coefficient (R2) of 0.86 was obtained indicating that the model could be accepted in predicting the maximum dry density of CCA stabilized soils to facilitate quick decision making in road works.

2.1 Soil

The term ‘Soil’ has different meanings in different scientific fields. It has originated from the Latin word Solum. To an agricultural scientist, it means ‘‘the loose material on the earth’s crust consisting of disintegrated rock with an admixture of organic matter, which supports plant life’’. To a geologist, it means the disintegrated rock material which has not been transported from the place of origin. But, to a civil engineer, the term ‘soil’ means, the loose unconsolidated inorganic material on the earth’s crust produced by the disintegration of rocks, overlying hard rock with or without organic matter. Foundations of all structures have to be placed on or in such soil, which is the primary reason for our interest as Civil Engineers in its engineering behaviour. Soil may remain at the place of its origin or it may be transported by various natural agencies. It is said to be ‘residual’ in the earlier situation and ‘transported’ in the latter. ‘‘Soil mechanics’’ is the study of the engineering behaviour of soil when it is used either as a construction material or as a foundation material. This is a relatively young discipline of civil engineering, systematised in its modern form by Terzaghi (2019), who is rightly regarded as the ‘‘Father of Modern Soil Mechanics’’. An understanding of the principles of mechanics is essential to the study of soil mechanics.

A knowledge and application of the principles of other basic sciences such as physics and chemistry would also be helpful in the understanding of soil behaviour. Further, laboratory and field research have contributed in no small measure to the development of soil mechanics as a discipline. The application of the principles of soil mechanics to the design and construction of foundations for various structures is known as ‘‘Foundation Engineering’’. ‘‘Geotechnical Engineering’’ may be considered to include both soil mechanics and foundation engineering. In fact, according to Terzaghi (2019), it is difficult to draw a distinct line of demarcation between soil mechanics and foundation engineering; the latter starts where the former ends. Until recently, a civil engineer has been using the term ‘soil’ in its broadest sense to include even the underlying bedrock in dealing with foundations.

However, of late, it is well recognised that the sturdy of the engineering behaviour of rock material distinctly falls in the realm of ‘rock mechanics’, research into which is gaining impetus the world over.

2.1.1 Development of Soil Mechanics

The use of soil for engineering purposes dates back to prehistoric times. Soil was used not only for foundations but also as construction material for embankments. The knowledge was empirical in nature and was based on trial and error, and experience. The hanging gardens of Babylon were supported by huge retaining walls, the construction of which should have required some knowledge, though empirical, of earth pressures. The large public buildings, harbours, aqueducts, bridges, roads and sanitary works of Romans certainly indicate some knowledge of the engineering behaviour of soil. This has been evident from the writings of Vitruvius, the Roman Engineer in the first century B.C., Mansar and Viswakarma, in India, wrote books on ‘construction science’ during the medieval period. The Leaning Tower of Pisa, Italy, built between 1174 and 1350 A.D., is a glaring example of a lack of sufficient knowledge of the behaviour of compressible soil, in those days.

Coulomb, a French Engineer, published his wedge theory of earth pressure in 1776, which is the first major contribution to the scientific study of soil behaviour. He was the first to introduce the concept of shearing resistance of the soil as composed of the two components cohesion and internal friction. Poncelet, Culmann and Rebhann were the other men who extended the work of Coulomb.

D' Arcy and Stokes were notable for their laws for the flow of water through soil and settlement of a solid particle in liquid medium, respectively. These laws are still valid and play an important role in soil mechanics.

Rankine gave his theory of earth pressure in 1857; he did not consider cohesion, although he knew of its existence.

Boussinesq, in 1885, gave his theory of stress distribution in an elastic medium under a point load on the surface.

Mohr, in 1871, gave a graphical representation of the state of stress at a point, called 'Mohr's Circle of Stress'. This has an extensive application in the strength theories applicable to soil.

Atterberg, a Swedish soil scientist, gave in 1911 the concept of 'consistency limits' for a soil. This made possible the understanding of the physical properties of soil.

The Swedish method of slices for slope stability analysis was developed by Fellenius in 1926. He was the chairman of the Swedish Geotechnical Commission.

Prandtl gave his theory of plastic equilibrium in 1920 which became the basis for the development of various theories of bearing capacity.

Terzaghi gave his theory of consolidation in 1923 which became an important development in soil mechanics. He also published, in 1925, the first treatise on Soil Mechanics, a term coined by him. (Erd bau mechanik, in German). Thus, he is regarded as the Father of modern soil mechanics. Later on, R.R. Proctor and A. Casagrande and a host of others were responsible for the development of the subject as a full-fledged discipline.

2.1.2 Fields of Application of Soil Mechanics

The knowledge of soil mechanics has application in many fields of Civil Engineering.

2.1.2.1 Foundations

The loads from any structure have to be ultimately transmitted to a soil through the foundation for the structure. Thus, the foundation is an important part of a structure, the type and details of which can be decided upon only with the knowledge and application of the principles of soil mechanics (Craig, 2018).

2.1.2.2 Underground and Earth-retaining Structures

Underground structures such as drainage structures, pipe lines, and tunnels and earth-retaining structures such as retaining walls and bulkheads can be designed and constructed only by using the principles of soil mechanics and the concept of 'soil-structure interaction' (Craig, 2018).

2.1.2.3 Pavement Design

Pavement Design may consist of the design of flexible or rigid pavements. Flexible pavements depend more on the subgrade soil for transmitting the traffic loads. Problems peculiar to the design of pavements are the effect of repetitive loading, swelling and shrinkage of sub-soil and frost action. Consideration of these and other factors in the efficient design of a pavement is a must and one cannot do without the knowledge of soil mechanics (Craig, 2018).

2.1.2.4 Excavations, Embankments and Dams

Excavations require the knowledge of slope stability analysis; deep excavations may need temporary supports 'timbering' or 'bracing', the design of which requires knowledge of soil mechanics. Likewise the construction of embankments and earth dams where soil itself is used as the construction material, requires a thorough knowledge of the engineering behaviour of soil especially in the presence of water. Knowledge of slope stability, effects of seepage, consolidation and consequent settlement as well as compaction characteristics for achieving maximum unit weight of the soil in-situ, is absolutely essential for efficient design and construction of embankments and earth dams. The knowledge of soil mechanics, assuming the soil to be an ideal material elastic, isotropic, and homogeneous material coupled with the experimental determination of soil properties, is helpful in predicting the behaviour of soil in the field. Soil being a particulate and heterogeneous material, does not lend itself to simple analysis. Further, the difficulty is enhanced by the fact that soil strata vary in extent as well as in depth even in a small area. Although knowledge of soil mechanics is a prerequisite to be a successful foundation engineer. It is difficult to draw a distinguishing line between Soil Mechanics and Foundation Engineering; the later starts where the former ends (Craig, 2018).

2.1.3 Soil Formation

Soil is formed by the process of ‘Weathering’ of rocks, that is, disintegration and decomposition of rocks and minerals at or near the earth’s surface through the actions of natural or mechanical and chemical agents into smaller and smaller grains. The factors of weathering may be atmospheric, such as changes in temperature and pressure; erosion and transportation by wind, water and glaciers; chemical action such as crystal growth, oxidation, hydration, carbonation and leaching by water, especially rainwater, with time. Obviously, soils formed by mechanical weathering (that is, disintegration of rocks by the action of wind, water and glaciers) bear a similarity in certain properties to the minerals in the parent rock, since chemical changes which could destroy their identity do not take place. It is to be noted that 95% of the earth's crust consists of igneous rocks, and only the remaining 5% consists of sedimentary and metamorphic rocks. However, sedimentary rocks are present on 80% of the earth's surface area. Feldspars are the minerals abundantly present (60%) in igneous rocks. Amphiboles and pyroxenes, quartz and micas come next in that order. Rocks are altered more by the process of chemical weathering than by mechanical weathering. In chemical weathering some minerals disappear partially or fully, and new compounds are formed. The intensity of weathering depends upon the presence of water and temperature and the dissolved materials in water. Carbonic acid and oxygen are the most effective dissolved materials found in water which cause the weathering of rocks. Chemical weathering has the maximum intensity in humid and tropical climates (Smith & Ian, 2018).

A deposit of soil material, resulting from one or more of the geological processes described earlier, is subjected to further physical and chemical changes which are brought about by the climate and other factors prevalent subsequently. Vegetation starts to develop and rainfall begins the processes of leaching and eluviation of the surface of the soil material. Gradually, with the passage of geological time profound changes take place in the character of the soil. These changes bring about the development of 'soil profile'. Thus, the soil profile is a natural succession of zones or strata below the ground surface and represents the alterations in the original soil material which have been brought about by weathering processes. It may extend to different depths at different places and each stratum may have varying thickness. Generally, three distinct strata or horizons occur in a natural soil-profile; this number may increase to five or more in soils which are very old or in which the weathering processes have been unusually intense. From top to bottom these horizons are designated as the A-horizon, the B-horizon and the C-horizon. The A-horizon is rich in humus and organic plant residue. This is usually eluviated and leached; that is, the ultrafine colloidal material and the soluble mineral salts are washed out of this horizon by percolating water. It is dark in colour and its thickness may range from a few centimetres to half a metre. This horizon often exhibits many undesirable engineering characteristics and is of value only to agricultural soil scientists. The B-horizon is sometimes referred to as the zone of accumulation. The material which has migrated from the A-horizon by leaching and eluviation gets deposited in this zone. There is a distinct difference of colour between this zone and the dark top soil of the A-horizon. This soil is very much chemically active at the surface and contains unstable fine-grained material. Thus, this is important in highway and airfield construction work and light structures such as single storey residential buildings, in which the foundations are located near the ground surface. The thickness of B-horizon may range from 0.50 to 0.75m. The material in the C-horizon is in the same physical and chemical state as it was first deposited by water, wind or ice in the geological cycle. The thickness of this horizon may range from a few centimetres to more than 30 m. The upper region of this horizon is often oxidized to a considerable extent. It is from this horizon that the bulk of the material is often borrowed for the construction of large soil structures such as earth dams. Each of these horizons may consist of sub-horizons with distinctive physical and chemical characteristics and may be designated as A1, A2, B1, B2, etc. The transition between horizons and sub-horizons may not be sharp but gradual. At a certain place, one or more horizons may be missing in the soil profile for special reasons (Smith & Ian, 2018).

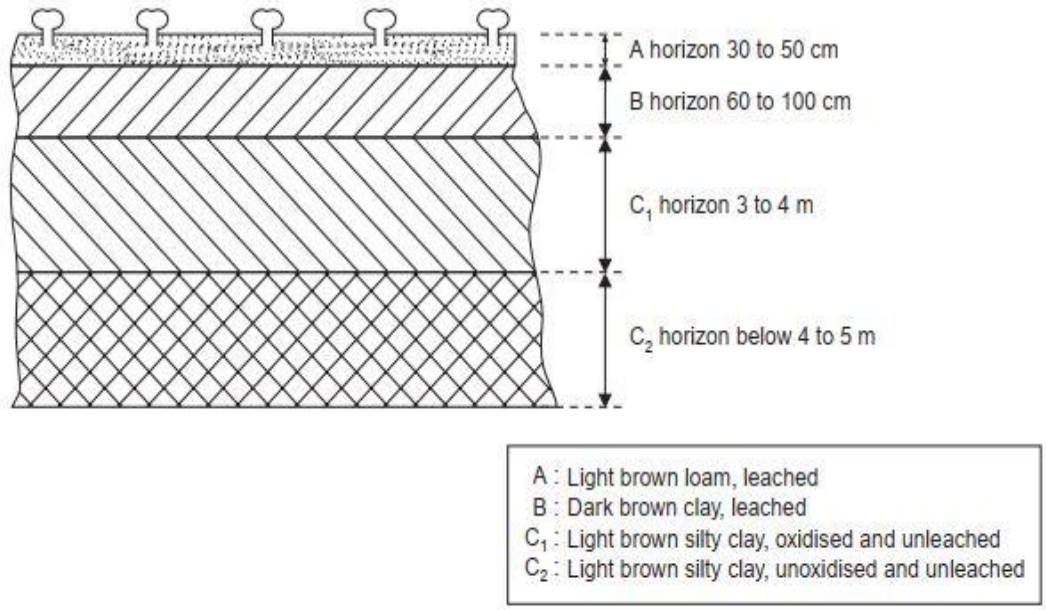

Figure 2.1: Typical Soil Profile

2.1.4 Residual and Transported Soils

Soils which are formed by weathering of rocks may remain in position at the place of region. In that case these are 'Residual Soils'. These may get transported from the place of origin by various agencies such as wind, water, ice, gravity, etc. In this case these are termed ''Transported soil''. Residual soils differ very much from transported soils in their characteristics and engineering behaviour. The degree of disintegration may vary greatly throughout a residual soil mass and hence, only a gradual transition into rock is to be expected. An important characteristic of these soils is that the sizes of grains are not definite because of the partially disintegrated condition. The grains may break into smaller grains with the application of a little pressure (Smith & Ian, 2018).

The residual soil profile may be divided into three zones: (i) the upper zone in which there is a high degree of weathering and removal of material; (ii) the intermediate zone in which there is some degree of weathering in the top portion and some deposition in the bottom portion; and (iii) the partially weathered zone where there is the transition from the weathered material to the unweathered parent rock. Residual soils tend to be more abundant in humid and warm zones where conditions are favourable to chemical weathering of rocks and have sufficient vegetation to keep the products of weathering from being easily transported as sediments. Residual soils have not received much attention from geotechnical engineers because these are located primarily in undeveloped areas. In some zones in South India, sedimentary soil deposits range from 8 to 15 m in thickness. Transported soils may also be referred to as 'Sedimentary' soils since the sediments, formed by weathering of rocks, will be transported by agencies such as wind and water to places far away from the place of origin and get deposited when favourable conditions like a decrease of velocity occur. A high degree of alteration of particle shape, size, and texture as also sorting of the grains occurs during transportation and deposition. A large range of grain sizes and a high degree of smoothness and fineness of individual grains are the typical characteristics of such soils. Transported soils may be further subdivided, depending upon the transporting agency and the place of deposition, as under:

i. Alluvial soils. Soils transported by rivers and streams: Sedimentary clays.

ii. Aeoline soils. Soils transported by wind: loess.

iii. Glacial soils. Soils transported by glaciers: Glacial till.

iv. Lacustrine soils. Soils deposited in lake beds: Lacustrine silts and lacustrine clays.

v. Marine soils. Soils deposited in sea beds: Marine silts and marine clays.

Broad classification of soils may be:

1. Coarse-grained soils, with average grain-size greater than 0.075 mm, e.g., gravels and sands.
2. Fine-grained soils, with average grain-size less than 0.075 mm, e.g., silts and clays.

These exhibit different properties and behaviour but certain general conclusions are possible even with this categorization. For example, fine-grained soils exhibit the property of 'cohesion' bonding caused by inter molecular attraction while coarse-grained soils do not; thus, the former may be said to be cohesive and the latter non-cohesive or cohesionless (Smith & Ian, 2018).

2.1.5 Some Commonly Used Soil Designations

The following are some commonly used soil designations, their definitions and basic properties:

i. Bentonite. Decomposed volcanic ash containing a high percentage of clay mineral

montmorillonite. It exhibits high degree of shrinkage and swelling.

ii. Black cotton soil. Black soil containing a high percentage of montmorillonite and colloidal material; exhibits high degree of shrinkage and swelling. The name is derived from the fact that cotton grows well in the black soil.

iii. Boulder clay. Glacial clay containing all sizes of rock fragments from boulders down to finely pulverized clay materials. It is also known as ‘Glacial till’.

iv. Caliche. Soil conglomerate of gravel, sand and clay cemented by calcium carbonate.

v. Hard pan. Densely cemented soil which remains hard when wet. Boulder clays or glacial tills may also be called hard-pan— very difficult to penetrate or excavate.

vi. Laterite. Deep brown soil of cellular structure, easy to excavate but gets hardened on exposure to air owing to the formation of hydrated iron oxides.

vii. Loam. Mixture of sand, silt and clay size particles approximately in equal proportions; sometimes contains organic matter.

viii. Loess. Uniform wind-blown yellowish brown silt or silty clay; exhibits cohesion in the dry condition, which is lost on wetting. Near vertical cuts can be made in the dry condition.

ix. Marl. Mixtures of calcareous sands or clays or loam; clay content not more than 75% and lime content not less than 15%.

x. Moorum. Gravel mixed with red clay.

xi. Top-soil. Surface material which supports plant life.

xii. Varved clay. Clay and silt of glacial origin, essentially a lacustrine deposit; varve is a term of Swedish origin meaning thin layer. Thicker silt varves of summer alternate with thinner clay varves of winter (Verruijt, 2018).

2.1.6 Structure of Soils

The ‘structure’ of a soil may be defined as the manner of arrangement and state of aggregation of soil grains. In a broader sense, consideration of mineralogical composition, electrical properties, orientation and shape of soil grains, nature and properties of soil water and the interaction of soil water and soil grains, also may be included in the study of soil structure, which is typical for transported or sediments soils. Structural composition of sedimented soils influences, many of their important engineering properties such as permeability, compressibility and shear strength. Hence, a study of the structure of soils is important. The following types of structure are commonly studied:

(a) Single-grained structure

(b) Honey-comb structure

(c) Flocculent structure (Venkatramaiah, 2016).

2.1.6.1 Single-grained Structure

Single-grained structure is characteristic of coarse grained soils, with a particle size greater than 0.02mm. Gravitational forces predominate the surface forces and hence grain to grain contact results. The deposition may occur in a loose state, with large voids or in a sense state, with less of voids (Venkatramaiah, 2016).

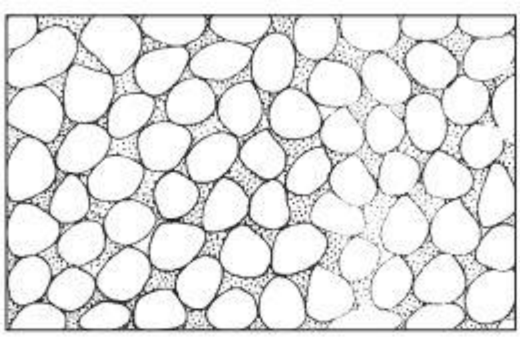

Figure 2.2: Single-Grained Structure

2.1.6.2 Honey-comb Structure

This structure can occur only in fine-grained soils, especially in silt and rock flour. Due to the relatively smaller size of grains, besides gravitational forces, inter-particle surface forces also play an important role in the process of settling down. Miniature arches are formed, which bridge over relatively large void spaces. This results in the formation of a honey-comb structure, each cell of a honey-comb being made up of numerous individual soil grains. The structure has a large void space and may carry high loads without a significant volume change. The structure can be broken down by external disturbances (Venkatramaiah, 2016).

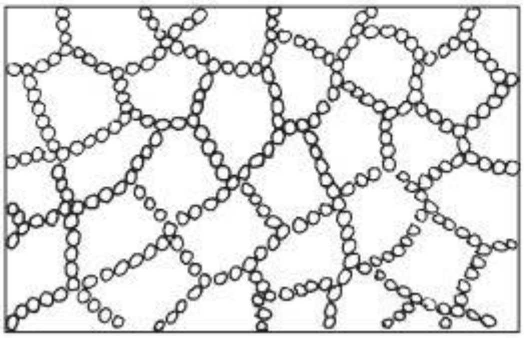

Figure 2.3: Honey-Comb Structure

2.1.6.3 Flocculent Structure

This structure is characteristic of fine-grained soils such as clays. Inter-particle forces play a predominant role in the deposition. Mutual repulsion of the particles may be eliminated by means of an appropriate chemical; this will result in grains coming closer together to form a ‘floc’. Formation of flocs is ‘flocculation’. But the flocs tend to settle in a honeycomb structure, in which in place of each grain, a floc occurs. (Venkatramaiah, 2016).

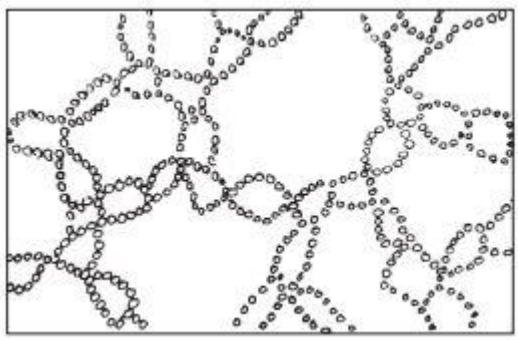

Figure 2.4: Flocculent Structure

Thus, grains grouping around void spaces larger than the grain-size are flocs and flocs grouping around void spaces larger than even the flocs result in the formation of a ‘flocculent’ structure. Very fine particles or particles of colloidal size (< 0.001 mm) may be in a flocculated or dispersed state. The flaky particles are oriented edge-to-edge or edge-to-face with respect to one another in the case of a flocculated structure. Flaky particles of clay minerals tend to from a card house structure when flocculated (Venkatramaiah, 2016).

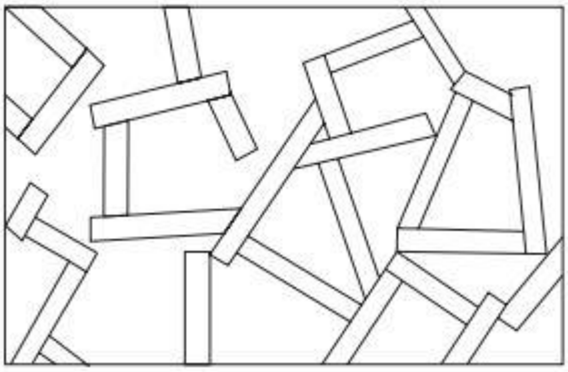

Figure 2.5: Card-House Structure of Flaky Particles

When inter-particle repulsive forces are brought back into play either by remoulding or by the transportation process, a more parallel arrangement or reorientation of the particles occurs. This means more face-to-face contacts occur for the flaky particles when these are in a dispersed state. In practice, mixed structures occur, especially in typical marine soils (Venkatramaiah, 2016).

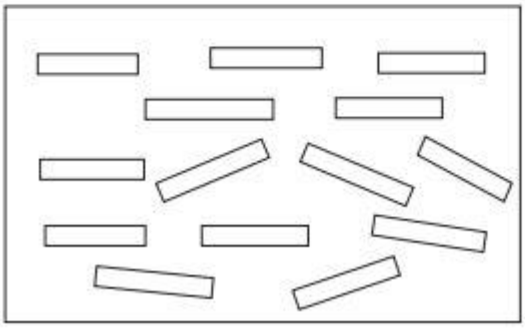

Figure 2.6: Dispersed Structure

2.2.7 Texture of Soils

The term 'Texture' refers to the appearance of the surface of a material, such as a fabric. It is used in a similar sense with regard to soils. Texture of a soil is reflected largely by the particle size, shape, and gradation. The concept of texture of a soil has found some use in the classification of soils to be dealt with later (Venkatramaiah, 2016).

2.2 Soil Stabilization

Soil Stabilisation in the broadest sense, refers to the procedures employed with a view to altering one or more properties of a soil so as to improve its engineering performance. Soil Stabilisation is only one of several techniques available to the geotechnical engineer and its choice for any situation should be made only after a comparison with other techniques indicates it to be the best solution to the problem. It is a well-known fact that, every structure must rest upon soil or be made of soil. It would be ideal to find a soil at a particular site to be satisfactory for the intended use as it exists in nature, but unfortunately, such a thing is of rare occurrence (Budhu, 2019).

Although certain techniques of stabilisation are of a relatively recent origin, the art itself is very old. The original objective of soil stabilisation, was, as the name implies, to increase the strength or stability of soil. However, techniques have now been developed to alter almost every engineering property of soil. The primary aim may be to alter the strength and/or to reduce its sensitivity to moisture changes. The most common application of soil stabilisation is the strengthening of the soil components of highway and airfield pavements (Craig, 2018).

2.2.1 Classification of the Methods of Stabilisation

A completely consistent classification of soil stabilisation techniques is difficult. Classifications may be based on the treatment given to soil, on additives used, or on the process involved. Broadly speaking, soil stabilisation procedures may be brought under the following two heads:

i. Stabilization without additives

ii. Stabilisation with additives

Stabilization without additives may be ‘mechanical’ rearrangement of particles through compaction or addition or removal of soil particles. It may be by ‘drainage’ drainage may be achieved by the addition of external load, by pumping, by electro-osmosis, or by application of a thermal gradient heating or cooling. Stabilisation with additives may be cement stabilisation (that is, soil cement), bitumen stabilisation, or chemical stabilisation (with fly ash, lime, calcium or sodium chloride, sodium silicate, dispersants, physico-chemical alteration involving ion-exchange in clay-minerals or injection stabilisation by grouting with soil, cement or chemicals). The appropriate method for a given situation must be chosen by the geotechincal engineer based on his experience and knowledge. Comparative laboratory tests followed by limited field tests, should be used to select the most economical method that will serve the particular problem on hand. Field-performance data may help in solving similar problems which arise in future. It must be remembered, however, that soil stabilisation is not always the best solution to a problem (Craig, 2018).

2.2.1.1 Stabilization of Soil without Additives

Some kind of treatment is given to the soil in this approach; no additives are used. The treatment may involve a mechanical process like compaction and a change of gradation by addition or removal of soil particles or processes for drainage of soil (Craig, 2018).

2.2.1.1.1 Mechanical Stabilization

'Mechanical stabilisation' means improving the soil properties by rearrangement of particles and densification by compaction, or by changing the gradation through addition or removal of soil particles (Craig, 2018).

i. **Rearrangement of Particles (Compaction):** The process of densification of a soil or 'compaction', as it is called, is the oldest and most important method. In addition to being used alone, compaction constitutes an essential part of a number of other methods of soil stabilisation. The important variables involved in compaction are the moisture content, compactive effort or energy and the type of compaction. The most desirable combination of the placement variables depends upon the nature of the soil and the desired properties. Fine-grained soils are more sensitive to placement conditions than coarse-grained soils (Craig, 2018).

ii. **Change of Gradation (Addition or Removal of Soil Particles):** The engineering behaviour of a soil depends upon (among other things) the grain-size distribution and the composition of the particles. The properties may be significantly altered by adding soil of some selected grain-sizes, and, or by removing some selected fraction of the soil. In other words, this approach consists in manipulating the soil fractions to obtain a suitable grading, which involves mixing coarse material or gravel (called 'aggregate'), sand, silt and clay in proper proportions so that the mixture when compacted attains maximum density and strength. It may involve blending of two or more naturally available soils in suitable proportions to achieve the desired engineering properties for the mixture after necessary compaction. Soil materials can be divided into two fractions, the granular fraction or the ‘aggregate’, retained on a 75-micron I.S. Sieve, and the fine soil fraction or the ‘binder’, passing this sieve. The aggregate provides strength by internal friction and hardness or incompressibility, white the binder provides cohesion or binding property, water-retention capacity or imperviousness and also acts as a filler for the voids of the aggregate. The relative amounts of aggregate and binder determine the physical properties of the compacted stabilized soil. The optimum amount of binder is reached when the compacted binder fills the voids without destroying all the grain-to-grain contacts of coarse particles. Increase in the binder beyond this limit results in a reduction of internal friction, a slight increase in cohesion and greater compressibility. Determination of the optimum amount of binder is an important component of the design of the mechanically stabilized mixture. Mechanical stabilisation of this type has been largely used in the construction of lowcost roads. Guide specifications have been developed based on past experience, separately for base courses and surface courses (Craig, 2018).

2.2.1.1.2 Stabilization by Drainage

Generally speaking, the strength of a soil generally decreases with an increase in pore water and in the pore water pressure. Addition of water to a clay causes a reduction of cohesion by increasing the electric repulsion between particles. The strength of a saturated soil depends directly on the effective or intergranular stress.

For a given total stress, an increase in pore water pressure results in a decrease of effective stress and consequent decrease in strength. Thus, drainage of a soil is likely to result in an increase in strength which is one of the primary objectives of soil stabilisation. The methods used for drainage for this purpose are:

1. Application of external load to the soil mass,
2. Drainage of pore water by gravity and/ or pumping, using well-points, sand-drains, etc.,
3. Application of an electrical gradient or electro-osmosis; and,
4. Application of a thermal gradient (Craig, 2018).

2.2.1.2 Stabilization of Soil with Additives

Stabilisation of soil with some kind of additive is very common. The mode and degree of alternation necessary depend on the nature of the soil and its deficiencies. If additional strength is required in the case of cohesionless soil, a cementing or a binding agent may be added and if the soil is cohesive, the strength can be increased by making it moisture-resistant, altering the absorbed water films, increasing cohesion with a cement agent and adding internal friction. Compressibility of a clay soil can be reduced by cementing the grains with a rigid material or by altering the forces of the adsorbed water films on the clay minerals. Swelling and shrinkage may also be reduced by cementing, altering the water adsorbing capacity of the clay mineral and by making it moisture-resistant. Permeability of a cohessionless soil may be reduced by filling the voids with an impervious material or by preventing flocculation by altering the structure of the adsorbed water on the clay mineral; it may be increased by removing the fines or modifying the structure to an aggregated one. A satisfactory additive for soil stabilisation must provide the desired qualities and, in addition, must meet the following requirements: Compactibility with the soil material, permanency, easy handling and processing, and low cost. Many additives have been employed but with varying degrees of success. No material has been found to meet all the requirements, and most of the materials are expensive (Smith & Ian, 2018).

2.2.1.2.1 Additives Stabilization

The various additives used fall under the following categories:

(i) **Cementing Materials**: Increase in strength of the soil is achieved by the cementing

action of the additive. Portland cement, line, fly-ash and sodium silicate are examples of such additives.

(ii) **Water-Proofers**: Bituminous materials prevent absorption of moisture. These may be used if the natural moisture content of the soil is adequate for providing the necessary strength. Some resins also fall in this category, but are very expensive.

(iii) **Water-Retainers**: Calcium chloride and sodium chloride are examples of this category.

(iv) **Water-Repellents or Retarders**: Certain organic compounds such as stearates and silicones tend to get absorbed by the clay particles in preference to water. Thus, they tend to keep off water from the soil.

(v) Modifiers and other miscellaneous agents: Certain additives tend to decrease the plasticity index and modify the plasticity characteristics. Lignin and lignin-derivatives are used as dispersing agents for clays (Smith & Ian, 2018).

2.2.1.2.2 Cement Stabilization

Portland cement is one of the most widely used additives for soil stabilisation. A mixture of soil and cement is called ‘‘soil-cement’’. If a small percentage of cement is added primarily to reduce the plasticity of fat soils, the mixture is said to be a ‘‘cement-modified soil’’. If the soil cement has enough water which facilitates pouring it as mortar, it is said to be a ‘plastic soil cement’’. It is used in canal linings. The chemical reactions of cement with the silicious soil in the presence of water are believed to be responsible for the cementing action. Many of the grains of the coarse fraction get cemented together, but the proportion of clay particles cemented is small. Almost any inorganic soil can be successfully stabilized with cement; organic matter may interfere with the cement hydration. Soil-cement has been widely used for low-cost pavements for highways and airfields, and as bases for heavy traffic. Generally, it is not recommended as a wearing coarse in view of its low resistance to abrasion (Craig, 2018).

2.2.1.2.3 Bitumen Stabilization

Bituminous materials such as asphalts and tars have been used for soil stabilisation. This method is better suited to granular soils and dry climates. ‘Bitumens’ are nonaqueous system of hydrocarbons which are completely soluble in ‘Carbon disulphide’. ‘Asphalts’ are natural materials or refined petroleum products, which are bitumens. ‘Tars’ are bituminous condensates produced by the destructive distillation of organic materials such as coal, oil, lignite and wood. Most bitumen stabilisation has been with asphalt. Asphalt is usually too viscous to be incorporated directly with soil. Hence, it is either heated or emulsified or cut back with a solvent like gasoline, to make it adequately fluid. Tars are not emulsified but are heated or cut back prior to application. Soil-asphalt is used mostly for base courses of roads with light traffic. Bitumen stabilises soil by one or both of two mechanisms: (i) binding soil particles together, and (ii) making the soil water-proof and thus protecting it from the deleterious effects of water. Obviously, the first mechanism occurs in cohesionless soils, and the second in cohesive soils, which are sensitive to water. Asphalt coats the surfaces of soil particles and protects them from water. If also plugs the voids in the soil, inhibiting a flow of pore water. Bitumen stabilisation may produce one of the following:

(i) Sand-bitumen

(ii) Soil-bitumen

(iii) Water-proof mechanical stabilization

(iv) Oiled earth (Craig, 2018).

2.2.1.3 Chemical Stabilization

Chemical stabilisation refers to that in which the primary additive is a chemical. The use of chemicals as secondary additives to increase the effectiveness of cement and of asphalt has been mentioned earlier. Lime and salt have found wide use in the field. Some chemicals are used for stabilizing the moisture in the soil and some for cementation of particles. Certain aggregates and dispersants have also been used (Craig, 2018).

2.2.1.3.1 Lime Stabilization

Lime is produced from natural limestone. The hydrated limes, called 'slaked lines', are the commonly used form for stabilisation. In addition to being used alone, lime is also used in the following admixtures, for soil stabilisation:

(i) Lime-fly ash (4 to 8% of hydrated lime and 8 to 20% of fly-ash)

(ii) Lime-Portland cement

(iii) Lime-bitumen

The use of lime as a soil stabilizer dates back to Romans, who used it in the construction of the 'Appian way' in Rome. This road has given excellent service and is maintained as a traffic artery even today. There are two types of chemical reactions that occur when lime is added to wet soil. The first is the alteration of the nature of the adsorbed layer through ion exchange of calcium for the ion naturally carried by the soil, or a change in the double layer on the soil colloids. The second is the cementing action or pozzolanic action which requires a much longer time. This is considered to be a reaction between the calcium with the available reactive alumina or silica from the soil (Craig, 2018).

Lime has the following effects on soil properties: Lime generally increases the plasticity index of low-plasticity soil and decreases that of highly plastic soils; in the latter case, lime tends to make the soil friable and more easily handled in the field. It increases the optimum moisture content and decreases the maximum compacted density; however, there will be an increase in strength. About 2 to 8% of lime may be required for coarse-grained soils, and 5 to 10% for cohesive soils. Certain sodium compounds (e.g., sodium hydroxide and sodium sulphate), as secondary additives, improve the strength of soil stabilized with lime. Lime may be applied in the dry or as a slurry. Better penetration is obtained when it is used as a slurry. The construction of lime-stabilized soil is very much similar to that of soil cement. The important difference is that, in this case, no time limitation may be placed on the operations, since the lime-soil reactions are slow. Care should be taken, however, to prevent the carbonation of lime. Lime stabilisation has been used for bases of pavements (Craig, 2018).

2.2.1.3.2 Salt Stabilization

Calcium chloride and sodium chloride have been used for soil stabilisation. Calcium chloride is hygroscopic and deliquescent. It absorbs moisture from the atmosphere and retains it. It also acts as a soil flocculant. The action of sodium chloride is similar. The effect of salt on soil arises from colloidal reactions and the alteration of the characteristics of soil water. Salt lowers the vapour pressure of pore water and also the freezing point; the frost heave will be reduced because of the latter phenomenon. The main disadvantage is that the beneficial effects of salt are lost, if the soil gets leached (Craig, 2018).

2.2.1.3.3 Lignin and Chrome-Lignin Stabilization

Lignin is one of the major constituents of wood and is obtained as a by-product during the manufacture of paper from wood. Lignin, both in powder form and in the form of sulphite liquor, has been used as an additive to soil for many years. A concentrated solution, partly neutralized with calcium base, known as Lignosol, has also been used. The stabilizing effects of lignin are not permanent since it is soluble in water; hence periodic applications may be required. In an attempt to improve the action of lignin, the ‘Chromelignin process’’ was developed. The addition of sodium bichromate or potassium bichromate to the sulphite waste results in the formation of an insoluble gel. If the lignin is not neutralized, it is acid and acts as a soil aggregate; when neutralized as with Lignisol, it acts as a dispersant. Chrome lignin imparts considerable strength to soils as a cementing agent (Craig, 2018).

2.2.1.3.4 Stabilizers with Water-Proofers

It is well known that cohesive soils possess considerable strength when they are dry. When they have access to water, they imbibe it and lose strength. Water-proofers, i.e., chemicals which prevent the deleterious effects of water on soils, are useful in such cases. Siliconates, amines and quaternary ammonium salts fall in this category. Water-proofers do not increase the strength, but help the soil retain its strength even in the presence of water (Verruijtm, 2018).

2.2.1.3.5 Stabilisation with Natural and Synthetic Resins

Certain natural as well as synthetic resins, which are obtained by polymerization of organic monomers, have also been used for soil stabilisation. They act primarily as water-proofers. Vinol resin and Rosin, both of which are obtained from pinetrees, are the commonly used natural resins. Aniline-furfural, polyvinyl alcohol (PVA), and calcium acrylate are commonly used synthetic resins. Asphalt and lignin, which are also resinous materials, have already been discussed separately (Verruijtm, 2018).

2.2.1.3.6 Aggregants and Dispersants

Aggregants and dispersants are chemicals which bring about modest changes in the properties of soil containing fine grains. These materials function by altering the electrical forces between the soil particles of colloidal size, but provide no cementing action. They affect the plasticity, permeability and strength of the soil treated. Low treatment levels are adequate for the purpose. Aggregants increase the net electrical attraction between adjacent fine-grained soil particles and tend to flocculate the soil mass. Inorganic salts such as calcium chloride and ferric chloride, and polymers such as Krilium are important examples. Change in adsorbed water layers, ion-exchange phenomena and increase in ion concentration are the possible mechanisms by which the aggregants work. Dispersants are chemicals which increase the electrical repulsion between adjacent fine grained soil particles, reduce the cohesion between them, and tend to cause them to disperse. Phosphates, sulphonates and versanates are the most common dispersants, which tend to decrease the permeability. Ion exchange and anion adsorption are the possible mechanisms by which the dispersants work (Verruijtm, 2018).

2.3.1.3.7 Miscellaneous Chemical Stabilizers

Sodium silicate can be used as a primary stabilizer as well as a secondary additive to conventional stabilizers such as cement. Injection is the usual process by which this is used. Phosphoric acid also has been used to some extent. Molasses, tung oil, sodium carbonate, paraffin and hydrofluoric acid are some miscellaneous chemicals which have been considered but have not received any extensive application (Verruijtm, 2018).

2.2.1.4 Injection Stabilization

Injection of the stabilizing agent into the soil is called ‘Grouting’. This process makes it possible to improve the properties of natural soil and rock formations, without excavation, processing, and recompaction. Grouting may have one of the two objectives; to improve strength properties or to reduce permeability. This is achieved by filling cracks, fissures and cavities in the rock and the voids in soil with a stabilizer this is initially in a liquid state or in suspension and which subsequently solidifies or precipitates. Injection is a very common technique in the oil industry; petroleum engineers frequently use this method for sealing or operating wells. Injection techniques, unfortunately, are rather complex. The selection of proper grout material and appropriate technique can normally be made best only after field exploration and testing. The results of the injection process are rather difficult to assess. Grouting must be called an art rather than a science (Verruijtm, 2018).

2.3 Maize Husk Ash

This is obtained from uncontrolled burning of maize husk. The husks of maize were sun dried to make them easily combustible and then burnt inside the iron drum at 700°C for90 minutes inside a galvanized drum to prevent contamination with soil materials. The maize husk ash wassieved through sieve No. 200 to obtain a material of fineness similar to cement. The presence and compositions of the following major and minor compounds such as silica (SiO) 64.90%,aluminum oxide (ALO) 10.79%, ferric oxide (FeO) 4.75%, calcium oxide (CaO) 10.24%, magnesium oxide (MgO) 2.08%, Sulphur trioxide(SO) 2.53%, sodium oxide (NaO) 0.43%, potassium oxide (KO) 4.23% and phosphorus oxide (P,O,) 0.05% were determined in study conducted by (Oluremi *et al*., 2018).

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The study area for this research work is Federal Polytechnic, Mubi, Adamawa State.

3.2 Materials

The materials used for this study are:

i. Weak Laterite Soil
ii. Maize Hush Ash
iii. Water

3.2.1 Weak Laterite Soil

The soil sample used for the study was a weak laterite soil obtained after removing top a depth of 0.5m before the soil sample was collected by disturbed sampling method and sealed in bags to avoid loss of moisture during transportation.

3.2.2 Water

Clean water from the tap at the Civil Engineering Laboratory of Federal Polytechnic, Mubi was used for conducting all laboratory tests.

3.2 Methods

The geotechnical properties of the natural soil and the soil with maize husk at a varying percentage of coir were determined in accordance with BS 1377 (1990) to ascertain the degree of alteration involved.

Table 3.1: Test conducted

Test	Description	BS 1377 Part
Natural Moisture Content Test	Determines water content as a percentage of total weight in a soil sample.	Part 2
Specific Gravity Test	Measures ratio of soil solids' density to water density.	Part 2
Particle Size Distribution	Separates soil particles into size fractions using sieves with varying mesh sizes.	Part 2
(Sieve Analysis)	Provides information about particle size distribution within the soil sample.	
Atterberg's Limits Test	Determines plastic and liquid limits, aiding soil behavior classification.	Part 2, Part 3
Compaction Test	Evaluates moisture-density relationship, determining maximum dry density and optimum moisture content.	Part 4
CBR (California Bearing Ratio)	Measures soil's load-bearing capacity by evaluating penetration resistance under controlled conditions.	Part 4, Part 9

3.2.1 Natural Moisture Content Determination

Two moisture cans were weighed empty and recorded. A representative specimen of the soil sample was collected to the cans. The cans with the sample were weighed and kept inside an oven for 24 hours at a temperature of 100°C after which the weight of the oven dried sample was noted and recorded. The weights of the dried soil and the water in the soil were obtained by difference in weight.

Natural moisture content = $\frac{\text{weight of water}}{\text{weight of dried soil}} \times 100\ \% = \frac{M_2 - M_3}{M_3 - M_1} \times 100$ - (3.1)

Where; M_1 = Weight of empty can

M_2 = Weight of can + wet soil

M_3 = Weight of can + dry soil

3.2.2 Specific Gravity

A clean dry pychometer (density bottle) of 250ml was weighed (164g) after which it was filled with distilled water. The pychometer with the water was weighed again. The bottle was then emptied and dried. 120g of the oven dried sample of soil was introduced into the bottle. Distilled water was then carefully poured into the bottle and stirred with a glass rod during the process to allow trapped air to be released. Finally, the bottle was filled to the rim with water after which the outside was dried and then weighed.

The specific gravity (Gs) was thus calculated from the following

Specific gravity,

(Gs) = $\frac{\text{weight of dired sample}}{\text{weight of equal volume of water}}$ $Gs = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$ - - (3.2)

Where; W_1 = Weight of empty pycnometer

W_2 = Weight of pycnometer + dry soil

W_3 = Weight of pycnometer + soil + water

W_4 =Weight of pycnometer + water

3.2.3 Particle Size Distribution (Sieve Analysis)

The method employed for determination of particle size distribution is the dry sieve analysis. A process known as sieve washing was carried out on about 300g of the black cotton soil sample. This process involves soaking and washing out the clay content from the soil then oven-drying the remaining soil sample for 24 hours. The dried soil was weighed again before poring it through a stack of sieves already arranged in descending order of the aperture size (i.e. 5.00mm, 3.35mm, 2.0mm, 1.18mm, 850µm, 600µm, 425µm, 300µm, 150µm, 75µm and the base pan) and vibrated for 5 minutes. After shaking, each sieve together with its content was then weighed. The weight of empty sieve which had earlier been weighed was then subtracted from the combined weights of soils retained and the sieve, which gave the actual weight of the soil sample retained in each of the sieves. The sum of these retained weights was checked against the original soil.

3.2.4 Atterberg's Limit Determination

Albert Atterberg developed a series of tests to evaluate the relationship between moisture content and soil consistency. This series include three separate tests namely: liquid limit test, plastic limit test and the shrinkage limit test.

3.2.4.1 Liquid Limit Test (Cone Penetrometer Method)

About 200g of air dried soil passing through the 425µm sieve was mixed with distilled water to a putty-like consistency on a flat surface, filled in a cup and levelled with spatula. The height of the penetrometer cone was adjusted to 0.00mm reading, then the penetrometer brass cup well compacted with the soil sample was placed under the cone. The knob was adjusted until there was a slight contact between the tip of the penetrometer cone and the surface of the soil sample in the brass cup. The knob was pressed so as to allow the penetrometer penetrate into the soil sample.

The penetrometer reading was taken and noted. A representative specimen of the soil sample from the brass cup was taken and placed in a labelled moisture can. The weight of the can and the wet sample was also noted and recorded. It was then kept in an oven for 24 hours in order to determine its moisture content. The test was repeated five times but each time with increasing water content at varied proportion. The liquid test was carried out for the natural soil and then on maize husk ash with laterite soil.

3.2.4.2 Plastic Limit

About 150g of the soil sample passing through sieve 425µm was prepared in the same manner as in liquid limit. It was thoroughly mixed with distilled water on a glass plate until it was plastic enough to be rolled into a ball. The ball of the soil was then rolled between the hand and glass plate. The rolling continues until a thread of about 3mm in diameter was obtained, a stage at which the thread crumbled.

The portion of the crumbled soil were then gathered and placed in a moisture can which was kept in the oven for 24 hours for moisture content determination.

Plasticity index is given by:

Plasticity index = Liquid limit - plastic limit - - - - (3.3)

3.2.5 Compaction Test

An empty mould of diameter 10.2cm and volume 940cm^3 was weighed with the base but without the collar. 3000g representative sample of the soil to be compacted was weighed and poured into the tray with the lumps broken so as to be reduced to smaller sizes. Water was added to the soil (1st trial) and mixed thoroughly after which it was packed into the mould in three layers. Using the British Standard Light compactive effort, each layer was given an evenly distributed 25blows from a 2.5kg rammer. After the compaction of the last layer, the surface of the compacted soil was ensured to be slightly above the top rim of the mould then the collar was removed and the excess soil trimmed off to be even with the top of the mould. The mould with the compacted soil was weighed and soil sample was taken from the top and bottom into the moisture cans for moisture content determination after 24 hours of drying in the oven. The entire procedure was repeated until the weight of the compacted soil and the mould began to drop (i.e. the soil has failed) with each trial having additional quantity of water mixed thoroughly with the soil.

The procedure was followed in like manner when the soil was stabilized with varying quantity of maize husk ash at a predetermined optimum amount maize husk ash in order to obtain the optimum moisture content.

3.2.6 California Bearing Ratio

A ¾ in (19 mm) sieve is used to sieve the soil specimen. If all material passes through the sieve, we can use all of it for the test. But some of the material might be retained in the sieve. In that situation have to replace the retained amount with an equal amount of the materials which pass ¾ in the sieve and retained on the #4 sieve. After sieving, make 3 sample specimens each containing 6.8 kg (15 lb). Specimen 1, 2, 3 will be compacted with about 10, 30 & 56 blows respectively. This will provide variations in the percentage of maximum dry density. Sufficient amounts of water shall be mixed with specimens to maintain optimum water content. The mould shall be attached to the base plate with the extension collar. Then the weight shall be measured. Then a spacer disk shall be placed into the mould with a filter paper on top of the spacer disk. The mould shall be filled with soil in 3 layers. For example: for specimen 1, we have to provide 10 blows per layer with the rammer for the compaction. The water content of the material shall be determined before and after the compaction procedure. Then the extension collar shall be removed and the top of the mold shall be trimmed with a straightedge to smoothen the surface. The other two specimens shall be compacted following the same procedures mentioned above. Remove spacer disk, base plate. Then, the weight of Mould plus compacted soil shall be measured. Then invert the mould and soil and attach the base plate to the mould with a coarse filter paper. Provide numbering of all your equations, e.g. (3.1), (3.2) etc.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

This chapter presents the results of the tests conducted and the discussion of the results. The experiment carried out in this research work are Moisture Content Determination, Sieve Analysis, Atterberg limit, Specific Gravity, Compaction Analysis and California Bearing Ratio (CBR).

4.1.1 Natural Moisture Content

Table 4.1: Natural Moisture Content of Weak Soil

Observation and Calculation	**0%**	**5%**	**10%**
The water content W = $\frac{M_2-M_3}{M_3-M_1} \times 100$	21.17	17.69	17.61

Results obtained from the experiment shows that the average moisture content of the weak soil in its natural state is 18.82%.

4.1.2 Specific Gravity

Table 4.2: Specific Gravity of Weak Soil

Soil Specimen number	**0%**	**5%**	**10%**	15%
Specific gravity of soil particles $\frac{m2-m1}{(m4-m1)-(m3-m2)}$	2.62	2.72	2.58	2.53

The results obtained from the experiment shows that the average specific gravity is 2.61.

4.1.3 Sieve Analysis

The results of the sieve analysis is presented in figure 4.1 below.

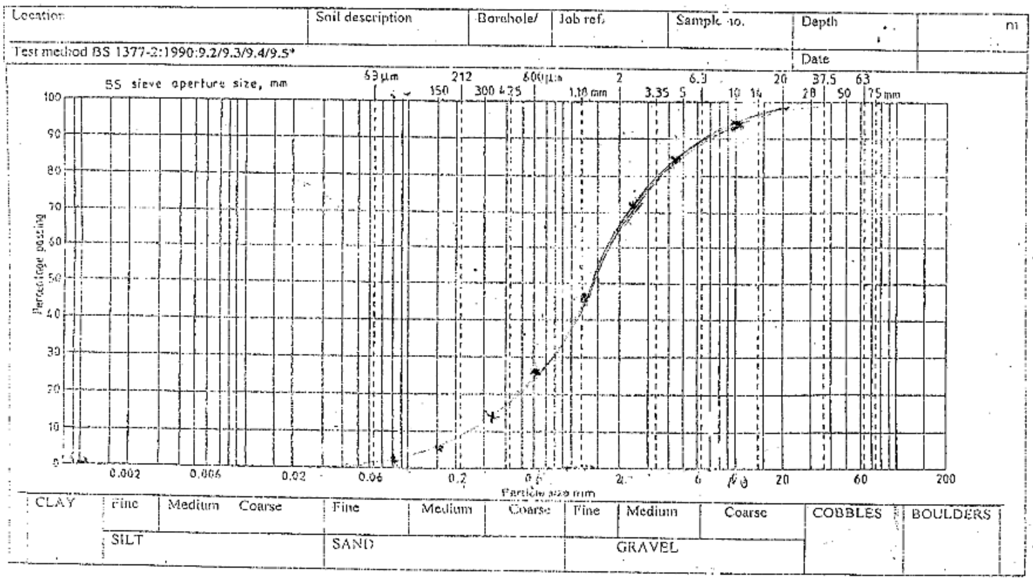

Figure 4.1: Sieve Analysis of Unstabilized Weak Soil

4.1.4 Atterberg Limits

This is as a result of the decrease of the clay sized fractions in the soil, thereby decreasing the ability of the soil to attract and absorb water as shown in figure 4.2.

Liquid Limit = *36%* Plastic Limit = *21.2* Plasticity Index = 15*%*

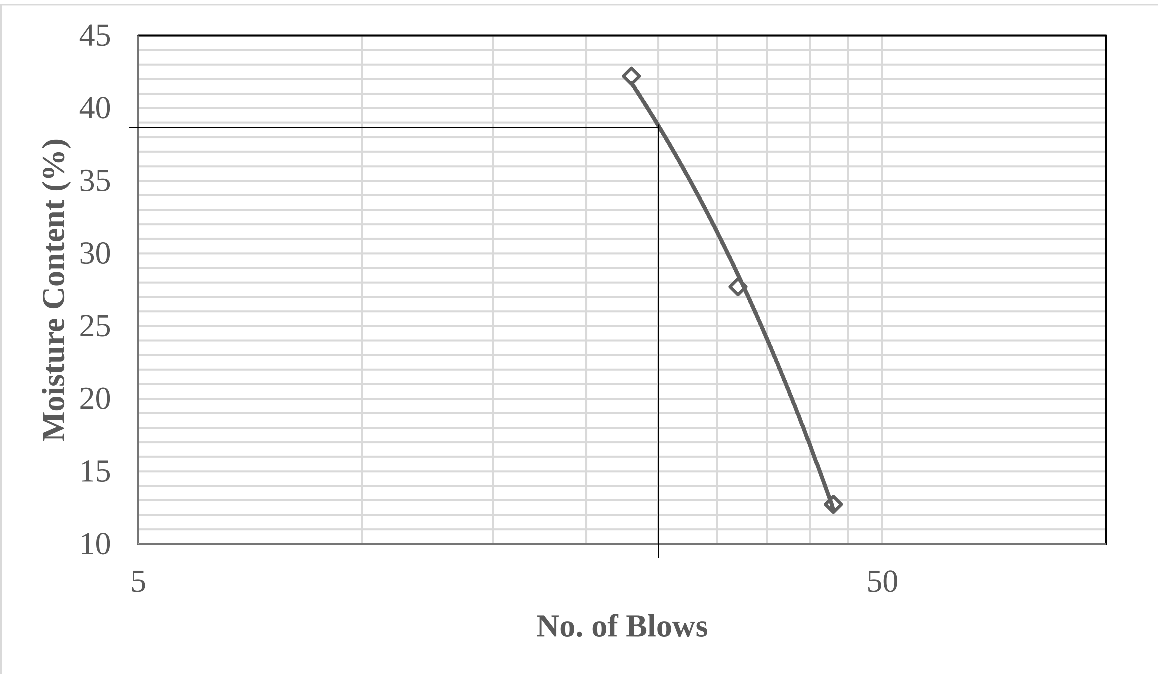

Figure 4.2: Atterberg Limit for Soft Soil with 0% Maize Husk Ash

Liquid Limit = *32%* Plastic Limit = *19%* Plasticity Index = 13*%*

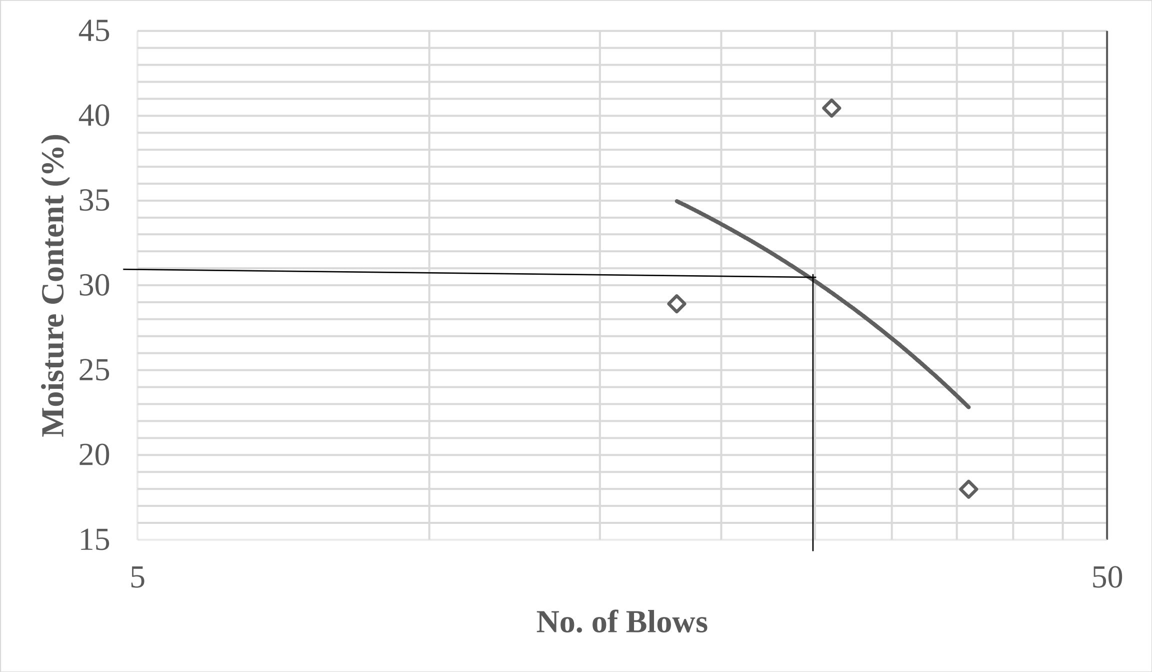

Figure 4.3: Atterberg Limit for Soft Soil with 5% Maize Husk Ash

Liquid Limit = *29%* Plastic Limit = *16.20* Plasticity Index = *12.8%*

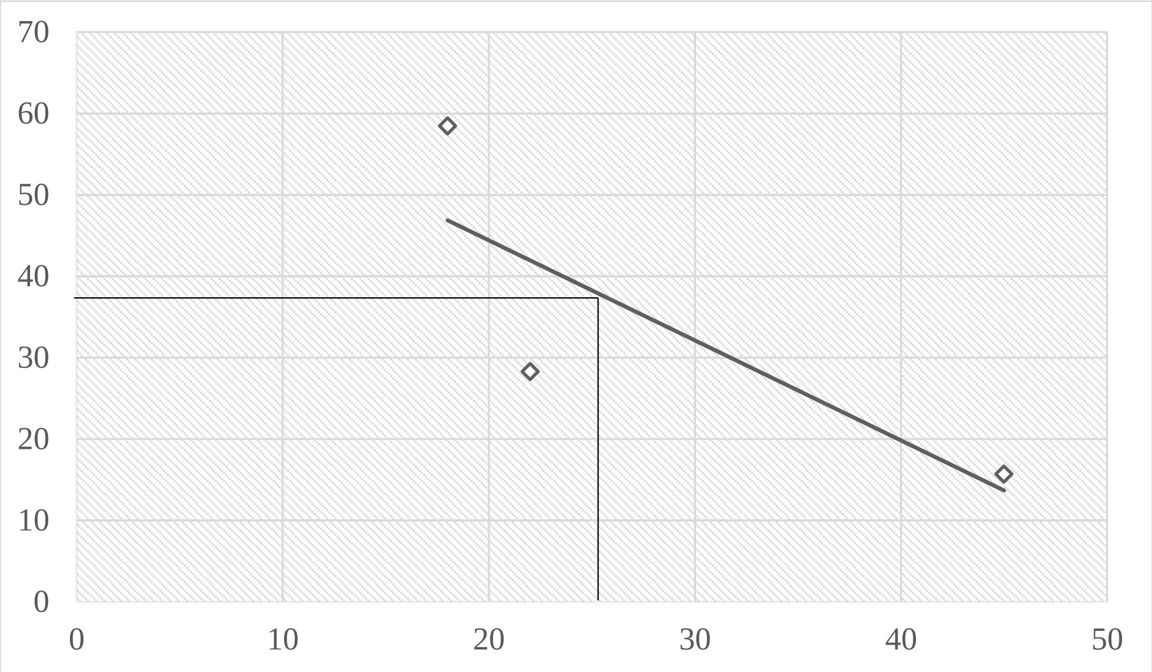

Figure 4.4: Atterberg Limit for Soft Soil with 10% Maize Husk Ash

4.1.5 Compaction Characteristics

Table 4.3: Compaction Data for Unstablized Weak Soil

PERCENTAGE OF MAIZE HUSK ASH	0%	5%	10%	15%
Dry Density (g/cm^3)	1.83	1.88	1.75	1.62

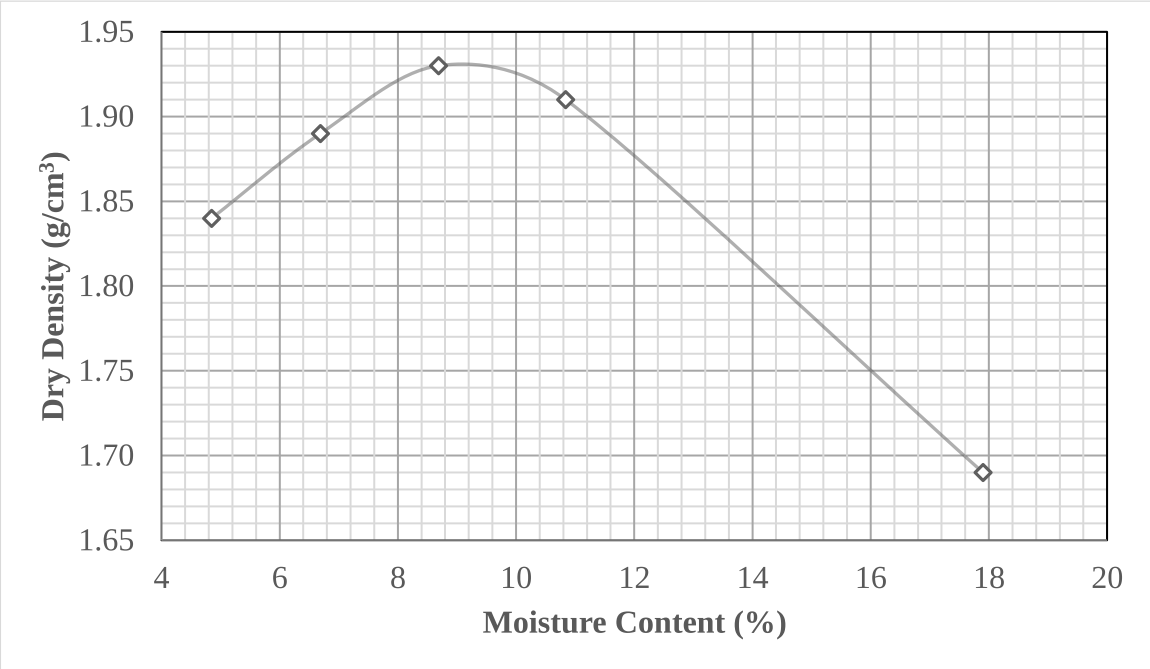

Figure 4.5: Dry Density and Moisture Content Curve for 0%

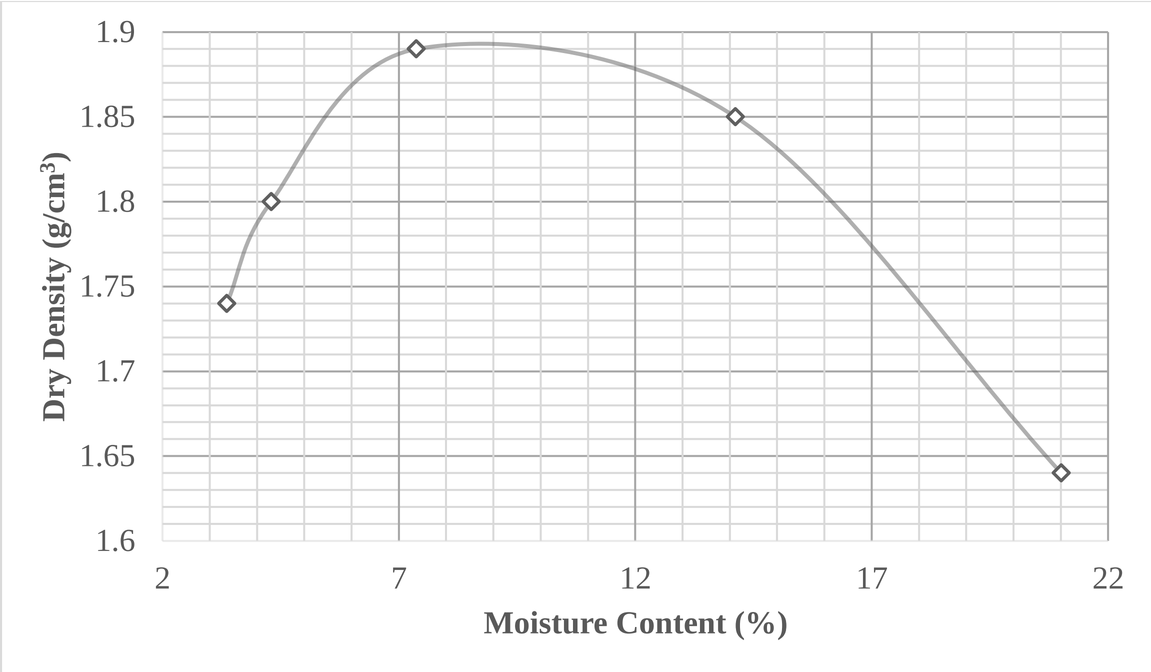

Figure 4.6: Dry Density and Moisture Content Curve for 5%

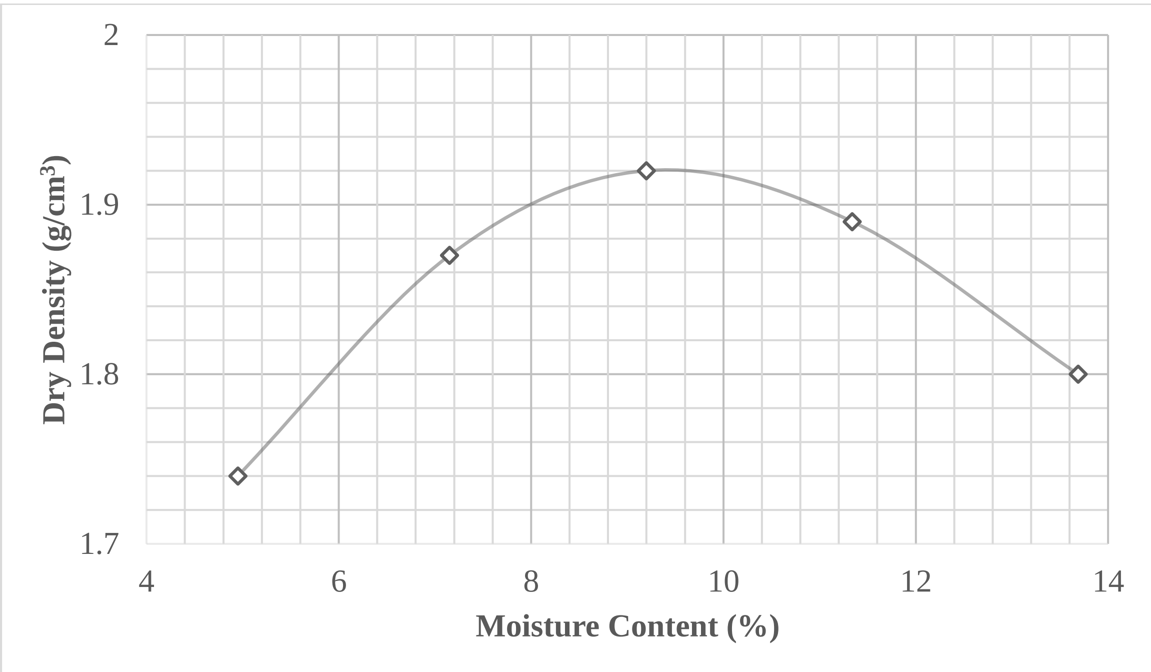

Figure 4.7: Dry Density and Moisture Content Curve for 10%

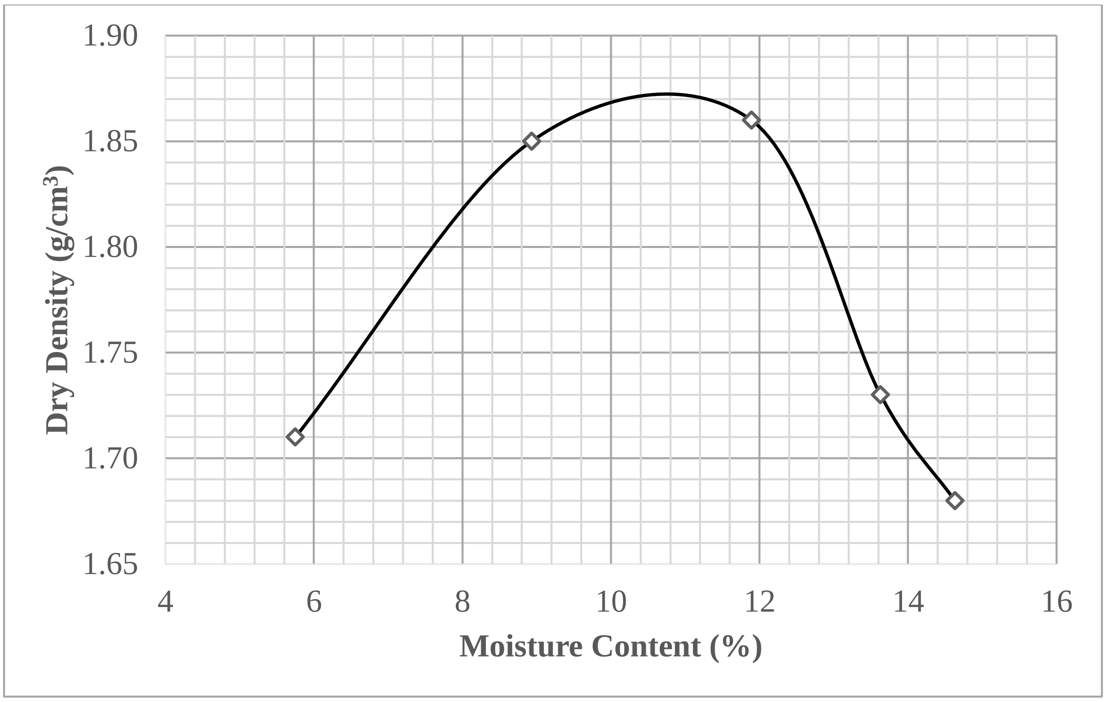

Figure 4.8: Dry Density and Moisture Content Curve for 15%

4.1.6 California Bearing Ratio

Table 4.4: California Bearing Ratio

Percentage of Maize Husk Ash	**0%**	**5%**	**10%**	**10%**
California Bearing Ratio	27.45	27.21	18.53	14.15

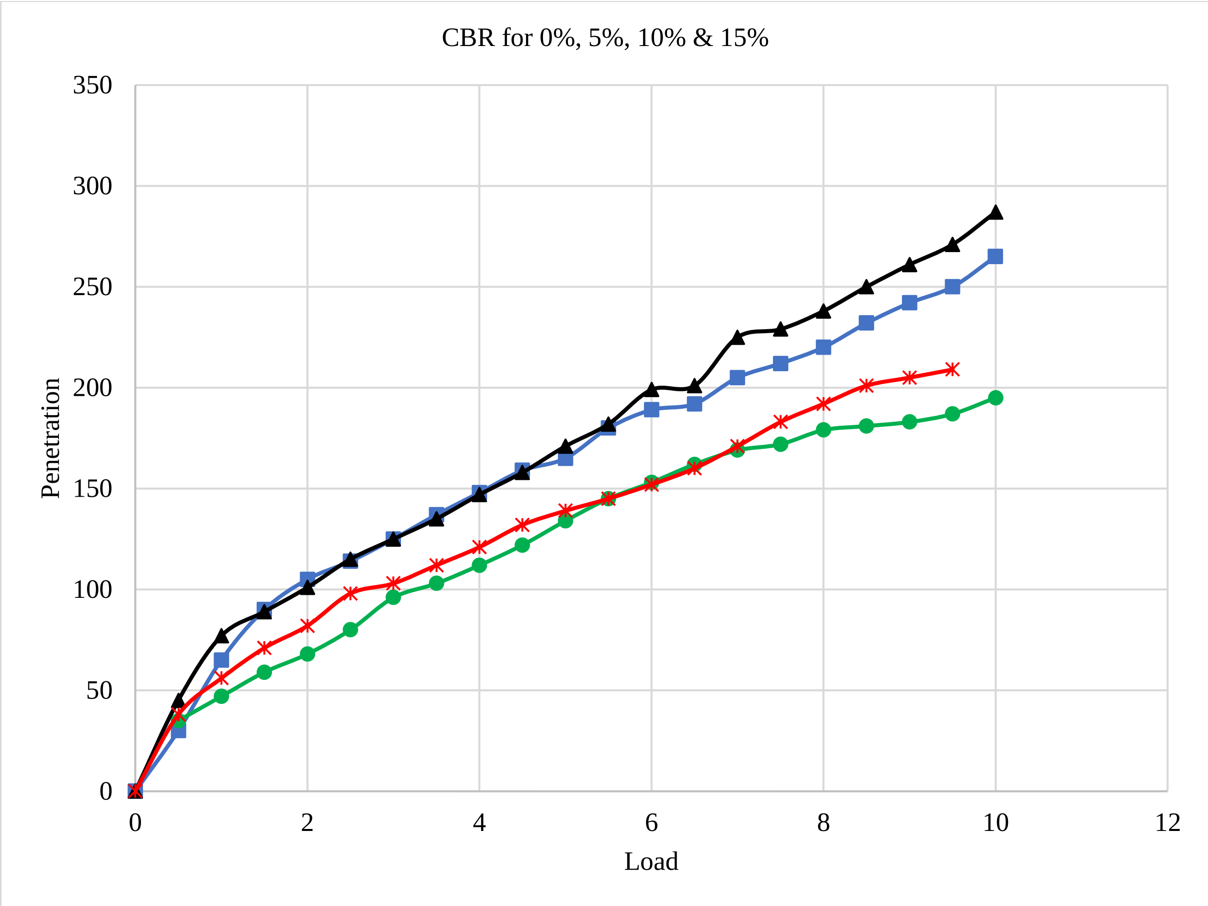

Figure 4.9: CBR @ 0%, 5%, 10% & 15%

4.2 Discussion

The BS1377 part 2:1990 for soil grading, in the appendix of this work, the classification of the soil falls under A-7-6 ASSHTO from the sieve analysis in result as shown in figure 4.1.

According a research conducted by Hamisu (2022) the result average Atterberg limit was 23.4%, which is higher than 15%% this signifies that the soil used in this research is a weak soil.

Hamisu's research (2022) showed an average atterberg limit of 23.4%, which is much lower than 36%. This is an improvement, and it also indicates that adding 5% maize husk ash improved the soil.

The average atterberg limit for the soil, reported by Hamisu (2022), was 23.4%, which is low compared to 32%, depicting that the 10% maize husk ash added helped improve the soil.

Hamisu (2022) determined that the average atterberg limit for the soil to be 23.4%, which is lower than 29%, indicating that the weak soil had been improved with 15% maize husk ash.

According to research conducted by Enzenwa *et al*., (2022) which indicated that the average MDD and OMC to 11.2Mg/cm^3 and 1.9% respectively when compared to the result obtained above it can be deduced that the soil is not suitable for construction.

In accordance with the findings of Enzenwa *et al*., (2022), the average MDD and OMC were 1.89Mg/cm^3 and 8.52% respectively, indicating that the stabilized soil is not suitable for construction.

The MDD and OMC averages were 1.79Mg/cm^3 and 10.5%, respectively, according to Enzenwa *et al*., (2022), indicating that the stabilized weak soil in this research cannot be used for construction.

When compared to the results obtained above it can be concluded that the stabilized soil is not suitable for construction based on the MDD and OMC results 1.60 and 16% respectively obtained by Enzenwa *et al*., (2022).

The compaction test results shown in table 4.3 and Figure 4.5. The optimum moisture content (OMC) was observed to have decreased from 1.9% at 0% to 8.52% at 5%, 10.5% at 10% and a decrease to 9.79% at 15%. The decrease and increase in optimum moisture content with in maize husk ash content could have been as a result of decreasing and increasing demand for water by various soil and maize husk ash mineral particles to undergo hydration reaction. On the other hand, the maximum dry density (MDD) increased from 0%, 5%, 10% and decreased at 15% with maize husk ash content. This increase in MDD agrees with Moses (2008) report relating that cementitious stabilizers generally increase the maximum dry density of soils at optimal amount between 0 – 15%.

Figure 4.9 shows the California Bearing Ration (CBR) value in relation to unstabilized i.e. 0% and stabilized specimens. However, the unstabilized weak soil had the highest California Bearing Ration value of 27.45, when treated with 0% Maize Husk Ash there was a decrease as seen in the figure above, the weak soil shows an increase with the highest California Bearing Ration value of 27.21 when 5% of Maize Husk Ash, and thereafter the California Bearing Ration decreased with the further addition of 10% and 15% maize husk ash to 18.53 and 14.15 respectively.

The highest California Bearing Ration value is 27.45%, which is obtained at an inclusion of 5% Maize Husk Ash into the weak soil, but further additional Maize Husk Ash tends to decrease the California Bearing Ration value. This behavior may be attributed to the compaction resistance of the Maize Husk Ash and the fact that the Maize Husk Ash had a lower specific gravity than soils. Nataraj and McManis (1997) noted that the interaction between the soil and the fiber reinforcement controlled the response of the soil/fiber mixture to compaction.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, the findings of this study provide valuable insights into the utilization of maize husk ash for weak soil stabilization. The soil used in this research falls under A-7-6 ASSHTO classification based on the BS1377 part 2:1990 grading, signifying its weak nature. The average Atterberg limit of 23.4%, as reported by Hamisu (2022), indicates the inherent weakness of the soil. However, it is noteworthy that the addition of 5% maize husk ash led to an improvement in the Atterberg limit, demonstrating the potential for soil enhancement.

Further analysis by Enzenwa *et al.* (2022) revealed that the modified Proctor compaction test results showed a decrease in the optimum moisture content (OMC) as maize husk ash content increased, along with an increase in maximum dry density (MDD) up to 10%. This aligns with previous findings that cementitious stabilizers generally increase MDD within this range.

The California Bearing Ratio (CBR) values indicated that the addition of 5% maize husk ash led to the highest CBR value of 27.45%, suggesting improved compaction resistance. However, beyond this point, the CBR values decreased with further additions of maize husk ash, likely due to the interaction between the soil and the ash, along with the lower specific gravity of the ash compared to the soil.

In light of these results, it can be concluded that maize husk ash has the potential to improve the properties of weak soil up to a certain limit, particularly in terms of

Atterberg limits and CBR values. However, the stabilized soil may still not be suitable for construction based on the MDD and OMC values. Further research and experimentation may be needed to optimize the proportions of maize husk ash for effective soil stabilization in practical engineering applications. This study contributes to the understanding of sustainable solutions for soil improvement in the context of weak soils.

5.2 Recommendations

Based on the findings of the study on the utilization of maize husk ash for weak soil stabilization, the following recommendations are made:

i. Further research is needed to determine the optimal proportion of maize husk ash for effective soil stabilization. The study showed that 5% of ash led to improvements in soil properties, but beyond this point, diminishing returns were observed. Experimentation with various percentages may help identify the most cost-effective and performance-enhancing ratio.

ii. It is essential to conduct field trials to assess the practical application of maize husk ash for soil stabilization in real construction projects. Field-scale studies can help evaluate the long-term effectiveness and durability of the stabilized soil, considering factors like traffic loads and environmental conditions.

iii. Consider the environmental impact of maize husk ash production and its long-term effects on soil and groundwater. Assess the potential leaching of harmful substances from the ash and implement mitigation strategies to ensure minimal environmental harm.

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APPENDIX