THE UTILIZATION OF CRUSHED CONCRETE OBTAINED FROM CONSTRUCTION AND DEMOLITION WASTE AS A SOIL STABILIZER.

BY

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CERTIFICATION

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DEDICATION

This project is humbly dedicated to God, whose grace has sustained me throughout this journey and the many sleepless nights, who is my source of strength, wisdom and purpose. To my dear parents, whose unconditional love, prayers, endless support and sacrifices have made this achievement possible, I thank you. I am forever grateful.

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ABSTRACT

This study examined the use of Crushed Concrete as a soil stabilizer to enhance the geotechnical properties of weak subgrade soils for road construction projects. The growing volume of construction waste and the environmental issues linked to traditional stabilizers such as cement and lime were key motivations for this research. The soil sample was mixed with varying amounts of CC i.e. at 6%, 12% and 18%. Laboratory tests were conducted and they include sieve analysis, Atterberg limits, compaction and CBR tests. The results were analyzed graphically using Microsoft Excel. The particle-size analysis categorized both the natural soil and the crushed concrete as fine sand to fine gravel.

The Atterberg limits indicated that as CC content increased, both the liquid limit and plasticity index decreased, suggesting reduced cohesion and better workability. Compaction results revealed that the maximum dry density (MDD) increased from 1.85 g/cm³ at 0% to 1.92 g/cm³ at 12% CDW, while the optimum moisture content (OMC) decreased from 13.52% to 12.00%, indicating an improvement in compaction efficiency and a reduction in water demand. CBR results also showed significant increases in both soaked and unsoaked values with higher CC concentrations, which met the standards of the Federal Ministry of Works and Housing (FMWH, 2016).

In summary, this study found that crushed concrete is a potent and environmentally sustainable soil stabilizer that can significantly strengthen and stabilize weak subgrade soils. It demonstrated that using CC can serve as a viable alternative to conventional stabilizers, reducing construction costs while promoting waste recycling. Further research is recommended to investigate the long-term durability and field performance of CDW-stabilized soils under traffic loads.

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ACRONYMS

CBR	California Bearing Ratio
C&D	Construction & Demolition
CDW	Construction and Demolition Waste
CC	Crushed Concrete
CO_2	Carbon dioxide
CWC	Crushed Waste Concrete
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
RCA	Recycled Concrete Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

In construction and geotechnical engineering, the condition of the soil plays a vital role in the safety and durability of a structure. Soil stabilization which involves improving the Engineering properties of the soil thereby making it more stable is often employed in cases where the soil requires improvement. It also involves modifying the chemical or physical properties of the soil. It is required when the soil available for construction is not suitable for the intended purpose (Arora, 2003). Generally, soil stabilization is a method of improving soil properties by blending and mixing other materials. Improvements include increasing the dry unit weight, bearing capabilities, volume changes, the performance of in situ subsoils, sands, and other waste materials in order to strengthen road surfaces and other geotechnical applications (Firoozi et al., 2017).

Soils can be stabilized by the addition of cement or lime. Such stabilization processes improve the various engineering properties of the stabilized soil and generate an improved construction material (Firoozi et al., 2017). But the production of these materials (lime and cement) is either energy-intensive or contributes significantly to carbon emissions (Hammond & Jones, 2011). With increasing concerns about environmental sustainability and climate change, researchers are now turning attention to more sustainable alternatives. One of such alternatives is the use of Construction and Demolition Waste (CDW). The construction industry generates a significant amount of waste through demolition, renovation and new construction projects. These wastes commonly referred to as construction and demolition waste, includes materials such as concrete, bricks, wood, metal, glass and plastics. While often considered a disposal challenge, these materials can also impact or even contribute to soil improvement when managed correctly (EPA, 2020). This study seeks to explore how CDW can serve as a sustainable soil stabilizer. The study particularly applies to road subgrade stabilization evaluated using compaction and CBR tests.

1.2 Statement of the Problem

In many urban and developing areas, construction is often carried out on sites with weak or problematic soils that cannot adequately support loads due to their low bearing strength. This poses a major challenge to civil engineers and can result in costly road subgrade solutions or structural failure if not properly addressed. At the same time, the volume of construction and demolition waste being generated is increasing. Most of this waste is either dumped illegally or sent to landfills, posing environmental and space-related problems.

When it comes to soil stabilization, lime and cement are typically the first options considered, but while these stabilizers are effective, they are also expensive and have a substantial environmental impact. This highlights the necessity of investigating alternative materials like construction and demolition waste, which are readily available and environmentally sustainable. Furthermore, there is a need to understand the performance of different proportions of Crushed Concrete (CDW) in weak soils through laboratory testing. This research investigates the effectiveness of crushed concrete in stabilizing weak soil, contributing to both engineering innovation and environmental sustainability.

1.3 Aim and Objectives

The aim of this research is to investigate the use of Crushed Concrete as a stabilizing material to improve the geotechnical properties of a weak soil.

The specific objectives are to:

1. Determine the index and strength properties of the stabilized and un-stabilized soil.
2. Evaluate the improvement in soil properties.
3. Compare the results from stabilized and un-stabilized soil samples to determine the effectiveness of the Crushed Concrete.

1.4 Scope of Study

This study focuses on laboratory scale soil improvement using a selected type of CDW. The study will be conducted using a specific soil type that typically exhibits poor engineering properties. Laboratory testing will assess mechanical performance under varying percentages of CC content.

The parameters to be measured include:

1. The particle size distribution
2. Atterberg limits (used to determine the liquid limit, plastic limit and plasticity index)
3. Moisture content (used to determine the water content of the soil)
4. The MDD and OMC
5. The strength and load-bearing capacity of the soil.

1.5 Justification of Study

This study is both timely and essential due to the increasing challenges of waste management in the construction industry and the growing need for sustainable soil stabilization techniques. CDW is a major component of global solid waste and its improper disposal causes environmental harm and health risks. This research promotes the beneficial reuse of this waste as a resource, helping to reduce landfill burden and its improper disposal leads to serious environmental consequences, including land degradation and pollution. At the same time, many construction projects are delayed or made more expensive due to unsuitable soil conditions that require treatment before construction can begin. This study is justified by the need to address two major challenges in the construction and environmental sectors, the growing volume of construction and demolition waste and the improvement of weak soils before construction. Moreover, using CDW as a type of soil stabilizer can reduce reliance on conventional materials like cement and lime. If proven effective, this approach can offer engineers a more sustainable method for soil improvement, especially in developing regions where budget constraints and environmental policies are critical concerns.

Utilizing CDW as a soil improvement material offers a solution that addresses both waste management and geotechnical challenges. Despite its potential, there is a noticeable gap in data concerning how CDW affects the geotechnical properties of soil in developing countries like Nigeria. This limits the use of CDW for engineering use. Allowing this study to proceed will help bridge this knowledge gap and provide scientific evidence on the feasibility and effectiveness of using CDW, as a stabilizing agent in the local environments of Nigeria. The research findings will support engineers and environmental planners in making informed decisions that align with sustainable development goals. It will also encourage policies that promote recycling and reuse of materials in the construction sector. The study should be supported and allowed to proceed in order to contribute meaningfully to both academic research and real-world engineering applications.

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CHAPTER TWO

LITERATURE REVIEW

This chapter provides a comprehensive review of relevant literature on the utilization of Construction and Demolition Waste (CDW) as a soil stabilizer.

2.1 Concepts and Definitions

1. **Soil Stabilization**

   Soil stabilization involves improving the Engineering properties of the soil and as a result making it more stable. It also involves modifying the chemical or physical properties of the soil. It is required when the soil available for construction is not suitable for the intended purpose (Arora, 2003).

2. **Subgrade Strength**

   Subgrade strength refers to the load-bearing capacity of the soil or material that lies beneath a pavement structure. It plays a critical role in highway and pavement design because it influences how well the pavement can support traffic loads and maintain structural integrity over time. A stronger subgrade can reduce the amount of pavement needed, leading to cost savings and better performance, while a weaker subgrade may require additional support or thicker pavement layers to prevent deformation and failure (Subgrade strength, 2025). The strength of the subgrade is affected by various factors, including the type of soil, its moisture content, the level of compaction, and drainage conditions. To assess subgrade strength, several tests are conducted, such as the California Bearing Ratio (CBR), Resilient Modulus (M_R), Standard Penetration Test (SPT), Dynamic Cone Penetrometer (DCP) and the R-Value test. In this research, the evaluation of subgrade strength will focus on the CBR test.

3. **Construction and Demolition Waste (CDW)**

   Construction and Demolition Waste (CDW) is produced during the construction of and civil engineering structure or demolition project (Poon et al., 2001). The waste generated from construction, renovation, repair and demolition of houses, large building structures, roads, bridges, piers and dams is categorized under construction and demolition waste. It constitutes wood, steel, concrete, gypsum, masonry, plaster, metal, asphalt etc. construction and demolition waste can also contain hazardous materials such as asbestos and lead. About 15 to 20% of solid waste are generated from construction and demolition projects (Gupta et al., 2023).

2.2 Subgrade and Its Importance in Road Construction

Subgrade is defined as the natural soil and chosen particle size aggregate that is compacted to specific levels to support the weight of the courses above, serving as the foundation for road construction. It has the capability of absorbing load stress and may require stabilization through compaction or additives to enhance its strength and reliability, particularly in soils prone to moisture-related instability (Speight, 2016). The subgrade is a crucial component in road construction as it serves as the foundational layer that supports the entire structure, including its own weight and the loads from vehicles. Preparing the subgrade entails modifying the natural soil to create a stable base for the road. It is essential that the subgrade be adequately compacted and graded to effectively handle the road's weight while preventing issues like settlement or deformation.

2.3 Soil Improvement and Stabilization Techniques

Soil improvement and stabilization techniques enhance the engineering properties of the soil making it suitable for construction through traditional methods such as mechanical stabilization, lime stabilization and cement stabilization.

From Arora (2003), Mechanical stabilization is the process of improving the properties of the soil by changing its gradation (i.e. either by the addition of coarse particles or by the removal of fine particles). It includes soil compaction and densification by application of mechanical energy using various sorts of rollers, rammers, vibration techniques and sometimes blasting. Lime is used to stabilize clayey soils and when it reacts with the soil, there is exchange of cations in the adsorbed water layer and thus, there is a decrease in the plasticity of the soil and it induces pozzolanic reactions that enhance strength over time. Lime stabilization is not suitable for sandy soils but when in combination with clay, fly ash or other pozzolanic materials, these soils can be stabilized. Cement, on the other hand, is done by mixing pulverised soil and Portland cement with water and compacting the mix to attain a strong material (soil-cement). It is suitable for granular soils with suitable fines and silty or mixed soils.

2.3.1 Environmental and Cost Limitations

Mechanical Stabilization

From Fondjo and Ray (2021), below are some of the environmental and cost limitations encountered with the use of mechanical stabilizations.

Environmental Limitations

1. Low Environmental Risk: One advantage is that mechanical stabilization generally does not release harmful compounds into the environment, making it an eco-friendly option.
2. Unreliable in Harsh Conditions: However, it may be unreliable under environmental stress, such as wetting-drying cycles or in conditions involving problematic soils (e.g., expansive or heaving soils), potentially leading to failure or environmental instability over time.

Cost Limitations

1. Supplementary Chemical Use: Mechanical stabilization often requires chemical enhancement to be effective, increasing overall project costs.
2. Implementation Delays: The technique may involve delayed or time-consuming physical processes, especially when in-situ quality control is necessary, which can extend construction schedules.
3. Limited Suitability for Critical Conditions: In cases where soil conditions are severe, mechanical stabilization may not be sufficient, potentially leading to costly redesigns or failures.
4. While the process doesn't require highly trained staff or lab experiments, the time-intensive nature of quality implementation may still result in increased labor and project time costs.

Lime Stabilization

Lime interacts chemically with soil particles, leading to beneficial changes in the soil's engineering properties such as increased soil plasticity index, improved workability, reduced swell potential, enhanced load-bearing capacity and increased resistance to water-induced damage. Due to its numerous advantages and versatile applications, lime's use in soil stabilization has garnered considerable attention and acceptability in the construction industry. While lime stabilization offers several advantages, it is important to consider its potential disadvantages and limitations (Pandey et al., 2024).

Environmental Limitations

1. Lime is an alkaline material and its addition to the soil increases the soil's pH, which may negatively affect nearby vegetation and ecosystems if not properly managed.
2. Factors such as exposure to aggressive chemicals, cyclic wetting and drying and freeze-thaw cycles can affect the performance and stability of lime-stabilized soils over time and reduce its durability and pose environmental risks through material degradation.
3. Lime stabilization can be influenced by temperature variations. Reactions are slowed in cold weather and accelerated in hot conditions, which can lead to rapid drying, shrinkage or delayed curing, potentially impacting local site conditions.

Cost Limitations

1. The success of lime stabilization relies on selecting the appropriate lime type and determining the optimal dosage. The required lime quantity can vary based on soil

characteristics, desired outcomes and project specifications. Limited availability or difficult procurement in some regions can increase costs and cause project delays.

2. Lime stabilization has limited effectiveness on non-cohesive soils**.** It is less effective on granular soils (like sands and gravels), which may require additional treatments or materials, raising overall costs.
3. Lime stabilization requires continuous testing and quality control to ensure effectiveness thereby adding to labor and testing costs.
4. The effectiveness of lime stabilization is time-dependent. It requires adequate curing time, potentially delaying construction and increasing labor and equipment costs due to prolonged schedules.

Cement Stabilization

According to Jawad and Taha (2023), Cement as a soil stabilizer induces a significant increase in soil strength, workability and durability. Permeability and swelling potential are significantly decreased. In addition, a considerable improvement in soil compressibility is achieved for the soil-cement mixture. However, there are many inherent disadvantages in cement stabilized soil.

Environmental Limitations

1. High CO_2 Emissions: The carbon dioxide (CO_2) emission is one of the main greenhouse gases that cause global warming. The increase of CO_2 emission is associated with human activities. One of the activities responsible for CO_2 emission is the cement industry. The production of one ton of cement emits approximately one ton of CO_2, therefore, the cement industry is responsible for about 5% to 10% of the

total CO_2 emission caused by human activities and this is primarily due to the decarbonation of limestone and fossil fuel combustion during clinker production.

2. Impact on Ecosystems: Increased CO_2 levels contribute to rising sea levels, extreme weather events and the extinction of plant and animal species.
3. Resource Depletion: Cement manufacturing consumes significant natural resources such as limestone and fossil fuels, leading to environmental degradation.
4. Growing Demand: With global cement production expected to reach 5 billion tons by 2030, CO_2 emissions are projected to rise substantially unless mitigation measures are adopted.

Cost Limitations

1. High Energy Consumption: Cement production requires temperatures above 1450°C, making it a highly energy-intensive process. It consumes 3% of global energy and 1.5% of global electricity.
2. Rising Fuel Costs: As fossil fuel reserves deplete, energy costs are expected to rise, leading to a projected doubling of cement prices by 2030.
3. Economic Burden on Producing Nations: Major producers like China and India use a significant share of their industrial energy for cement production, which puts pressure on national energy resources and budgets.

2.3.2 The Need for Alternative Improvement Techniques

These limitations have driven interest in alternative, eco-friendly materials like construction and demolition waste (CDW), which offer comparable performance while addressing waste management issues.

While mechanical stabilization offers several practical and environmental benefits such as ease of application, low labor requirements and minimal environmental contamination, it presents notable limitations stated above that justify the need for alternative stabilization methods like the use of construction and demolition (C&D) waste. Mechanical techniques often require enhancement with chemical stabilizers to achieve the desired soil strength, especially in problematic soils such as expansive or heaving soils. This dependency can increase costs and complicate project planning. Moreover, mechanical stabilization may not perform reliably under environmental stresses such as repeated wetting and drying cycles, leading to inconsistent outcomes and potential rework. The process can also be time-consuming when in-situ quality control is critical, which could delay project timelines (Fondjo and Ray, 2021). In contrast, C&D waste materials such as crushed concrete, brick fragments and reclaimed asphalt can enhance both the mechanical and chemical properties of soil, making them effective even in more challenging soil conditions (Sangeetha et al., 2021). The use of C&D waste reduces reliance on chemical additives, minimizes project delays and offers the added benefit of waste reuse, promoting sustainable construction practices. Integrating C&D waste into soil stabilization strategies not only addresses the environmental limitations of mechanical methods but also provides a cost-effective and reliable solution that aligns with modern waste management and circular economy goals.

In light of the environmental and cost-related limitations associated with lime stabilization stated above, there is a growing need to explore sustainable and cost-effective alternatives. One promising approach is the utilization of construction and demolition (C&D) waste as a soil stabilizing agent. C&D waste materials such as crushed concrete, brick fragments, reclaimed asphalt and masonry debris possess inherent mechanical properties that can enhance the bearing capacity and stability of weak soils (Hilal, 2023). Unlike chemical stabilizers, C&D materials do not significantly alter soil pH or introduce harmful substances into the environment due to its inert nature, making them eco-friendlier. By integrating C&D waste into soil improvement practices, the construction industry can move toward more sustainable and resilient infrastructure development while addressing critical environmental and economic challenges.

Given the significant environmental and economic drawbacks associated with cement stabilization, it is essential to explore and adopt alternative soil stabilization methods, such as the use of construction and demolition (C&D) waste. The cement industry is a major contributor to global CO_2 emissions responsible for approximately 5% to 10% of total emissions from human activities mainly due to the decarbonation of limestone and the burning of fossil fuels during production. Furthermore, cement manufacturing is energy-intensive, consuming around 3% of global energy and 1.5% of global electricity, which not only depletes finite natural resources but also escalates production costs. With cement prices projected to double by 2030 due to rising fuel costs and increasing demand, especially in rapidly developing countries, the economic sustainability of cement stabilization is increasingly questionable (Jawad and Taha, 2023). In contrast, C&D waste offers a more environmentally friendly and cost-effective solution. Reusing C&D materials also embodies circular economy principles, reducing landfill usage, conserving virgin resources and lowering greenhouse gas output (Papamichael et al., 2023). Materials such as crushed concrete, bricks and reclaimed asphalt can improve soil properties without generating high carbon emissions or requiring excessive energy inputs. By incorporating C&D waste into soil stabilization practices, the construction industry can significantly reduce its carbon footprint and overall costs, while promoting sustainable development and resource efficiency.

2.4 Use of Construction and Demolition Waste (CDW) as a Stabilization Technique

Several studies have investigated CDW's potential in stabilizing soils for subgrade, pavement and soil improvement. In a study, Alam et al. (2024) mainly investigated the changes in the soil behavior, precisely the strength characteristics on mixing the C&D wastes, by replacing the original soil with 5%, 10%, 15% and 20% of the C&D debris respectively. The results demonstrated that up to a certain extent the strength characteristics improved. From the present study, they concluded that the soil stabilization using C&D debris, in terms of shear strength, compressive strength and subgrade strength, was satisfactory and some of the results they obtained from a few tests were very encouraging. Like the results of the direct shear test and the CBR test, were good enough to encourage the usage of C&D debris for the stabilization of the soil. The C&D debris is a significant contributor to landfill waste. They also recommended that repurposing these materials for soil stabilization, prevents its disposal in landfills, helping to reduce the strain on limited landfill capacity and minimizing the associated environmental hazards. They also stated that the C&D debris usage will be an effective tool for solid waste management, as it leads to proper use of the debris and also help in maintaining cleanliness, in the prevention of land

and water pollution and cater towards the goal of sustainable development for the betterment of the future generation (Alam et al., 2024). Al-Obaydi et al. (2021) conducted a study in Mosul, Iraq, where the city is facing a significant accumulation of demolition materials due to the destruction of much of its infrastructure. They aimed to evaluate the effects of three types of materials dragged asphalt (DA), crushed brick (CB) and crushed concrete (CC) on the performance of low-plasticity clay intended for use as a road subgrade layer. The researchers executed a comprehensive series of both experimental and numerical analyses, incorporating 10% construction and demolition materials and utilizing field California Bearing Ratio (CBR) tests conducted in a large-scale model box. The CBR tests proved reliable for assessing the viability of construction and demolition materials as stabilizers for the subgrade layer. The findings indicated a notable enhancement in CBR values with the addition of these materials to the clay soil. Specifically, the CBR values improved by 12.4% with dragged asphalt, 13.7% with crushed brick, and 49.7% with crushed concrete. As the layer thickness increased from 50 cm to 100 cm, the CBR values improved between 1.1 and 1.7 times. Similarly, further increases in layer thickness from 50 cm to 150 cm led to CBR value enhancements ranging from 1.5 to 1.8 times. It is anticipated that incorporating more than 10% of construction and demolition materials will yield additional improvements in CBR values and other engineering characteristics of the subgrade soil. The use of crushed concrete, which demonstrated higher activity and CBR values, further supports this expectation (Al-Obaydi et al., 2021). In another study conducted by Barisoglu et al. (2023), the authors examined the potential of incorporating recycled construction and demolition (C&D) waste as a partial replacement for cement to improve the mechanical properties of soft soil. They focused on the strength and stiffness characteristics of two types of recycled

C&D materials. The results indicated that clayey soil exhibited an average strength increase of 2.5 times compared to peat when recycled materials were added, irrespective of the material type. Additionally, while prolonged curing times enhanced the strength of clayey soil, no further strength increase was observed in peat soil after 14 days. This suggests the necessity for further examination of long-term strength development in various mixtures, considering the distinct properties of clayey soil and peat may result in different strength progression over time. The outcomes of this research align with findings from other studies that have affirmed the effectiveness of C&D materials in soil stabilization, contributing to improved mechanical properties. The insights gained from this study could prove beneficial for the soil enhancement sector by highlighting how these recycled materials can be effectively utilized in construction when combined with secondary additives (Barisoglu et al., 2023). In 2023, Hidalgo et al. (2023), reported that a significant portion of solid waste generated annually originates from the demolition and renovation of existing buildings, primarily in the form of construction and demolition (C&D) materials. They identified an alternative application for this waste in road construction; however, the main challenge in utilizing it for structural pavement layers is that it often fails to meet the necessary strength and durability standards for highways. To address this issue, the authors proposed using mixtures of construction and demolition waste in soil improvements for subgrades, which require less additional thickness of pavement structures to comply with highway regulations. Their study examined the performance of mixtures containing silty soil, brick debris, and ceramic tile at various material ratios. Laboratory tests were conducted, including material characterization, compaction assessments, California Bearing Ratio (CBR) evaluations, and resilient modulus measurements, which indicate a material's stiffness. They also performed a parametric evaluation of thicknesses in flexible pavement structures under various traffic conditions and C&D material ratios. The findings indicated that incorporating C&D materials enhances strength and resilient modulus while reducing pavement thickness and costs by more than 7% at ratios of 30%, 40%, and 50%. However, this addition does not ensure long-term durability of the pavement. Hidalgo et al. (2023) recommended that pavements constructed on soils incorporating up to 40% C&D waste are more reliable in maintaining the stability of the interface between the subgrade, base, and asphalt layers (Hidalgo et al., 2023). In this study, Ibrahim et al., (2018) made use of the crushed waste concrete (CWC) (which is considered as one of the biggest components of solid waste), to improve some geotechnical properties of an organic soil. The CWC at the ratios of 5%, 10%, 15% and 20% were added to the organic soil in order to conduct an intensive series of experimental tests. The laboratory tests included the consistency limits by fall cone, modified compaction, unconfined compressive strength (UCS) and swelling percentage. The results they obtained showed that the liquid limits and plasticity index of organic soil decrease as the CWC percentages increase. These decrease are reflected in the soil classification and strength. The increasing of the CWC content increased the maximum dry density of the organic soil and caused an increase in the swelling percentages to a certain limit before it started to decrease. The strength of organic soil, as represented by UCS values, increased with increasing CWC percentages (Ibrahim et al., 2018). Islam et al., (2022) used fine-grained Construction and Demolition Waste to improve the geotechnical behavior of weak soil under study. The main objective of their research was to observe the changes in soil properties after mixing with construction and demolition waste. “Recycled waste mortar powder” was selected as the construction and demolition waste mixed in different percentages in the soil. In addition, the construction and demolition waste powder was inserted into the soil mass as a circular powder column in triangular and square grid patterns as an alternative to the “sand column”. They discovered that the Construction and Demolition Waste in the soil samples improved consolidation settlement and reduced settlement time and compression index. Increments in the pre-consolidation pressure, consolidation rate and permeability of the clay construction and demolition waste mixtures were also remarkable. Islam et al., (2022) recommended that Soil improvement through reusing construction and demolition waste is a sustainable way to solve problems in solid waste management and the soft soil settlement issue under a shallow foundation, ultimately reducing the environmental footprints, saving natural resources and supporting the circular economy concept (Islam et al., 2022). Pauzi et al. (2024) aimed to enhance soil engineering properties and bearing capacity through the use of Recycled Concrete Aggregates (RCA). In their study, they incorporated varying percentages of RCA into soil samples and performed a range of laboratory experiments to analyze the material's performance. The tests included sieve analysis, compaction assessments, and California Bearing Ratio (CBR) measurements. The optimal percentage of RCA was identified using a simulation method. The results indicated a notable increase in bearing capacity as the proportion of RCA rose, with 15% being determined as the optimal amount. The authors found that higher RCA content effectively strengthens soil subgrade structures, highlighting the significant potential of Recycled Concrete Aggregates in engineering applications (Pauzi et al., 2024).

2.4.1 Effects of CDW on Some Soil Properties

1. Compaction Behavior: The incorporation of CDW improves compaction characteristics. Specifically, the maximum dry density (MDD) tends to increase with CDW content, while the optimum moisture content (OMC) decreases. This is due to the coarser and more angular particles of CDW that enhance soil structure and reduce water retention (Hidalgo et al., 2023; Singh et al., 2017). For instance, Hidalgo et al. observed that adding up to 60% ceramic tile or brick CDW increased the MDD to 18.2 kN/m³ while decreasing the OMC from 18% to 10%. The incorporation of Construction and Demolition Waste (CDW) into the soil resulted in a decrease in optimum moisture content (OMC) and an increase in maximum dry density (MDD). As CDW content increased, the OMC reduced due to the lower water absorption capacity of the non-cohesive CDW particles compared to natural clayey soil. Concurrently, the MDD increased because CDW contains more sand-sized particles and exhibits higher specific gravity, thereby improving the soil's packing density (Islam et al., 2022).

2. Strength Properties (CBR, UCS)

i. California Bearing Ratio (CBR): CDW inclusion significantly increases CBR values. A mix with 10–20% CDW can result in CBR increases up to 150% or more, depending on material type and compaction energy. Ceramic tile CDW showed better performance than brick CDW, with CBR values rising to over 100% at 50–60% content (Hidalgo et al., 2023).

ii. Unconfined Compressive Strength (UCS): According to Ibrahim et al. (2018), the unconfined compressive strength (UCS) of organic soil improved consistently with the addition of crushed waste concrete (CWC). As CWC content increased, peak UCS values rose, despite a decrease in optimum moisture content. This strength gain was attributed to the higher density and specific gravity of CWC, which enhanced the overall dry unit weight and compaction of the soil mixture. Barisoglu et al., (2023) showed that the unconfined compressive strength (UCS) of peat soil significantly improved with the addition of recycled materials (RM), derived from construction and demolition waste. The observed differences in performance are likely due to variations in the composition of the recycled materials. Overall, the inclusion of recycled materials enhances the unconfined compressive strength.

3. Permeability and Plasticity

i. Plasticity Index (PI): The PI generally decreases with increasing CDW content. This is attributed to the dilution of clay minerals by the addition of granular, non-cohesive CDW/non-plastic aggregates in CDW (Patil et al., 2021; Alam et al., 2024). According to Islam et al., (2022), the addition of Construction and Demolition Waste (CDW) led to a reduction in the plasticity characteristics of the soil due to the non-cohesive and granular nature of the CDW particles. As CDW content increased from 0% to 40%, the liquid limit decreased from 37.39% to 28.85%, the plastic limit from 22.96% to 14.98% and the plasticity index from 14.43% to 13.87%. Specifically, at 20%, 30%, and 40% CDW content, the PI values were 13.28%, 13.17%, and 13.87%, respectively. Despite these reductions, all soil-CDW mixtures remained within the same classification zone low plasticity clay but with improved (lower) plasticity values, indicating a potential enhancement in soil workability and reduced swelling behavior.

ii. Permeability: while not directly tested, it can be inferred to increase with CDW content due to the reduction in fine clay particles and increase in coarser, free-draining material, leading to improved drainage characteristics (Alam et al., 2024).

4. Bearing Capacity: From Pauzi et al., (2024), The bearing capacity shows a significant increase as the percentage of RCA rises. This indicates that a higher RCA content will lead to improvements in both the engineering properties of the soil and the stability of soil subgrade structures.

2.4.2 Comparison of Construction and Demolition Waste with Lime/Cement Stabilization.

Based on	**Construction & Demolition Waste (CDW)**	**Lime/Cement Stabilization**
Strength Improvement	There is moderate to significant strength gains depending on the type and content of CDW. Optimum improvements at 10–40% CDW. UCS up to 487 kPa observed (Ibrahim et al., 2018; Hidalgo et al., 2023; Singh et al., 2017).	High strength improvements, especially with cement and with lime there is enhanced strength over time (Arora, 2003).
Cost	There is low cost alternative in using recycled materials causing a reduction in construction and disposal costs (Patil et al., 2021; Hidalgo et al., 2023).	High cost due to production and transportation of cement. Costs increase further for large-scale applications (Jawad and Taha, 2023).
Carbon Emissions	Has low embodied energy and emissions and promotes recycling. CDW use helps reduce landfill pressure and supports sustainability (Ibrahim et al., 2018; Hidalgo et al.,	High carbon emissions, the cement industry alone contributes 5% to 10% of global CO_2 emissions. Lime also has several environmental limitations mainly affecting the

	2023).	soil’s properties (Jawad and Taha, 2023; Pandey et al, 2024).
Availability	Widely available in urban and construction areas and composition may vary depending on source (Ibrahim et al., 2018;Gupta et al., 2023; Patil et al., 2021).	Both are readily available commercially, with standardized quality. However, supply may be limited or expensive in rural or remote areas (Jawad and Taha, 2023; Pandey et al, 2024). .

2.5 Summary of Gaps in Literature

Many studies have shown that Construction and Demolition Waste (CDW) can enhance soil strength, compaction and bearing capacity. There is a noticeable geographical gap in research within Nigeria, where areas with weak soils are common and large volumes of CDW are often wasted. Despite their suitability and availability, very few studies have evaluated CDWs' potential for road stabilization under local soil and climatic conditions. This geographical research gap highlights the need for region-specific studies that consider the soil composition, climatic conditions and material availability typical of Nigerian environments. This study also evaluates the soil response at specific percentages, different from the common ones listed in previous works, in order to identify the most effective and economical CDW proportion suitable for road subgrade applications.

Therefore, this study is designed to fill these gaps by focusing on road subgrade stabilization using CDW, evaluating improvements through compaction and CBR tests and providing relevant data that can guide sustainable road construction practices in Edo State (study area) and other parts of Nigeria.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The study was conducted in Iguosa Housing Estate, a suburban community situated in Ovia North-East, Edo State, Nigeria. Iguosa community is situated nearby to Idunmwowina community, as well as near the town Oluku. It is located at approximately 6°21'21" North latitude and 5°36'31" East longitude.

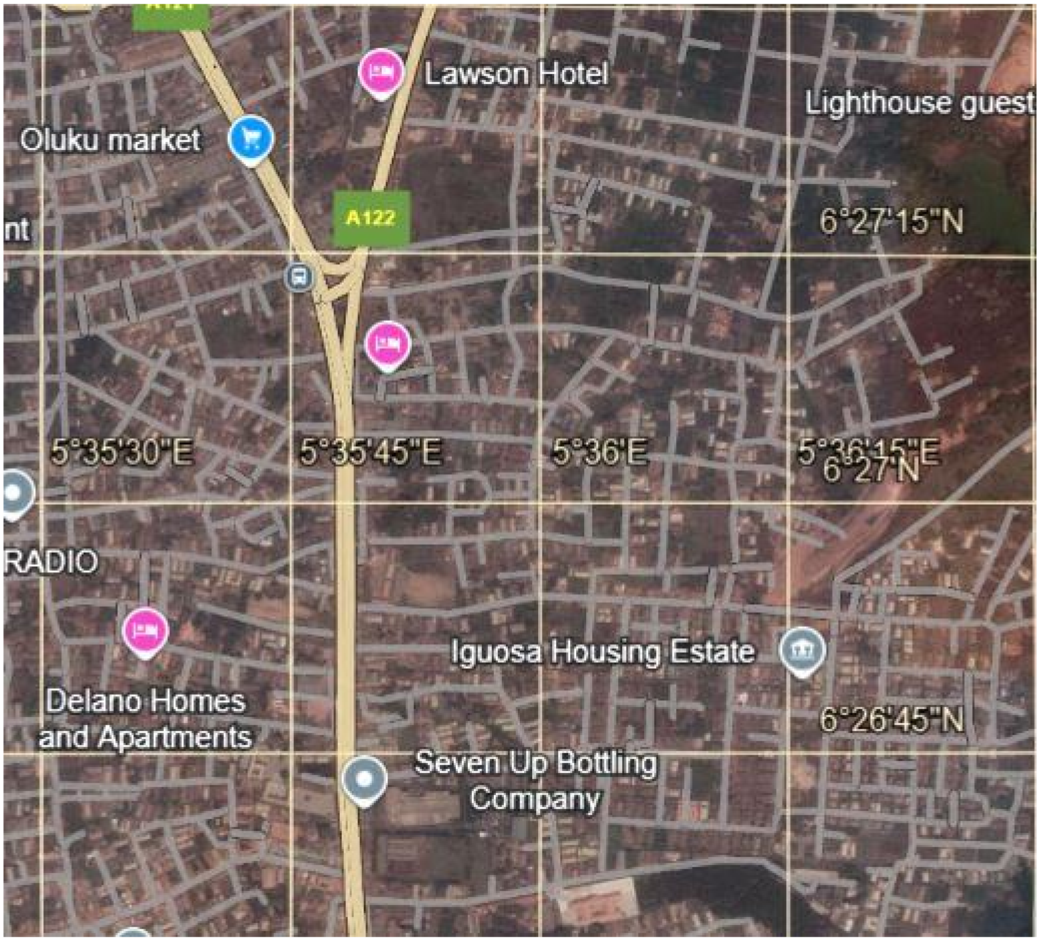


Figure 3.1: Map of Benin City showing Iguosa Community (Source: Google Earth Pro)

This region lies to the west of Benin City and can be reached via the Benin–Lagos expressway. The geology in the area is mainly characterized by the Benin Formation, which comprises primarily unconsolidated sands, silts and clayey laterites, all of which are vulnerable to volume fluctuations and differential settlement which pose significant challenges in the field of foundation engineering. The terrain of Iguosa is characterized by sandy soil, gentle to steep slopes and is prone to erosion and landslides. The soils found in Iguosa display moderate to high plasticity and have a low bearing capacity in their natural form, which makes them suitable for further improvement studies.

3.2 Materials and Equipment

The following materials were used

i. The soil sample was collected from the designated site (the Iguosa Housing Estate) and preliminary classification of its index properties done to confirm its soil type.
ii. The construction and demolition waste (CDW) was obtained from the structural laboratory of the Civil Engineering Department of the University of Benin, in the form of molded blocks. The blocks were crushed to give the crushed concrete (CC) that was then sieved and categorized.
iii. Testing Equipment used; Standard proctor test apparatus, CBR machine, Sieves, oven, weighing balance, moisture cans etc.

3.3 Collection and Preparation of Sample

The soil samples were collected using a hand auger, in a disturbed manner at a depth of 0 - 1.0m and were placed in airtight polythene bags. They were then transported to the geotechnical laboratory, where the soil sample was air-dried and pulverized to break down clumps before various tests were conducted. The construction and demolition waste material (crushed concrete) was crushed and cleaned of debris before being sieved through a 4.75 mm sieve.

3.4 Experimental Procedures

The following experimental procedures are extracted from the Laboratory Manual for Civil and Structural Engineering Students, made by the Department of Civil Engineering, Faculty of Engineering, University of Benin.

3.4.1 Sieve Analysis (From the 300 level manual, ELA 301)

Sieve analysis or particle size distribution of soil is used to separate soil into a range of sizes and determine relative properties by dry weight of each size range. It usually consists of two sieving methods, namely; dry sieving and wet sieving analysis methods. The wet sieving method was employed in this experiment.

Apparatus: This would include a set of sieves, brush for cleaning the sieves, drying oven, weighing balance and a large receiving pan.

Procedure:

1. Select and prepare the measured soil sample (100g) by soaking for 24hours.
2. Oven dry the sample and weigh.
3. Arrange the sieves in order (i.e. from large to small) to make a set and place the receiving pan below the set.
4. Pass the weighed soil sample through the set of sieves.
5. Manually shake the set of sieves for 10-20 minutes.
6. Record the weight of each sieve and receiving pan separately.
7. Calculate the cumulative percentages passing each sieve size to determine the particle size distribution.

3.4.2 Atterberg Limit (From the 300 level manual, ELA 302)

The atterberg limit consists of three tests namely Liquid Limit, Plastic Limit and Shrinkage Limit. The experimental procedures for Liquid Limit and Plastic Limit follows what has been stated in the laboratory manual.

Apparatus: liquid limit or casagrade device and grooving tool, large glass plate for plastic limit, distilled water, weighing balance, drying oven, spatula and weighing cans

3.4.3 Moisture Content (From the 300 level manual, ELA 301)

The moisture content of a soil is the percentage of water present, expressed as a percentage of the dry weight of the soil and it is used in soil classification. The oven method would be employed for this experiment.

Apparatus: This would include moisture cans, a sensitive weighing balance and an oven.

Procedure:

1. Weigh the empty moisture cans (take as W_1)
2. Place some quantity of the moist soil sample into the weighed cans and weigh and note as W_2
3. Place the weighed moisture cans + soil sample into the oven to dry for 24 hours at 105°C-110°C.
4. After drying for 24 hours, remove from the oven and leave to cool before weighing the cans + dry soil as W_3.
5. Calculate the moisture content using the formula in the manual.

3.4.4 Proctor Compaction Test (From the 400 level manual, ELA 401)

It is used in the determination of the moisture content/dry density relationship of a soil. The standard proctor compaction test would be used for this experiment.

Apparatus: a standard proctor mould (with base and collar), a 2.5kg rammer with a drop of 300mm, a weighing balance, a measuring cylinder and a mixing tray.

Procedure:

1. Weigh 3kg of the soil sample and pour into the mixing tray.
2. Measure about 5% of the sample's weight of water using the measuring cylinder and pour into the soil sample. Mix thoroughly to ensure the water runs through the sample.
3. Share the mixed soil into three equal parts and compact in 3 layers, in the mould of known weight (with collar attached). Each layer being compacted with 25 blows of the 2.5kg rammer with a drop of 300mm.
4. Remove the collar and base and use a straight edge to level the soil and then weigh.
5. Extrude the soil from the mould and determine its moisture content.
6. Break up the compacted soil into parts and mix with the remaining air dried sample.
7. Add more water to the sample (about 2%) and mix thoroughly.
8. Repeat (3) to (6) four times until the weight of the compacted soil reaches its maximum and decreases.

3.4.5 California Bearing Ratio (CBR) Test (From the 500 level manual, ELA 501)

This is used to determine the penetration resistance of a compacted soil specimen and the result is compared to a standard resistance for crushed stone.

Apparatus: The CBR test machine, CBR mould, 2.5kg rammer, weighing balance, straight edge, filter papers, surcharges, curing tank and cans.

Procedure:

1. Prepare the soil specimen for the CBR test by compacting it (see procedure for compaction test).

2. Place the mould holding or containing the compacted soil specimen with one base plate in position, having the upper face exposed on the plated load frame of the testing machine.
3. Place surcharge weights on the specimen as required.
4. Ensure that the proving ring, its guide brackets, the extension plunger, load dial gauge, and penetration dial gauge are properly positioned.
5. Seat the plunger under a load of 4.5 kg for a bearing ratio of up to 30%, or 22.5 kg for a bearing ratio above 30%.
6. Switch on the machine or wind the handle until the plunger just comes to rest on the soil specimen. Movement should be stopped before any displacement occurs, and both the proving ring dial gauge and penetration dial gauge should then be set to zero.
7. Using the stop clock and switching on the machine (or winding the handle), the plunger should be moved down into the specimen at a uniform rate of 1.27 mm per minute.
8. Readings on the dial gauge pointer on the proving ring should be taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, 9.0, 11.0, 12.0, and 12.5 mm.
9. Raise the plunger from the sample and level it by filling the depression left on its surface by the plunger and trimming any excess material with a straight edge.
10. To test the other end (bottom) of the soil specimen in the mould, remove the base plate from the lower end and attach it to the upper end of the mould. Invert the

mould while maintaining the soil intact, and repeat the testing procedure as previously described.

11. Remove samples of about 350 g each of the soil immediately below the surfaces of both ends and determine their respective moisture contents.
12. Record all the results of the test in the table provided.

3.5 Mix Proportion

Four distinct mixtures of soil and Crushed Concrete (CC) were evaluated: a control mixture of 0%, as well as soil mixtures containing 6%, 12% and 18% CC.

These mix ratios were selected to fall within a moderate range (0–20%), commonly used in previous studies, while ensuring sufficient variation to evaluate the progressive effects of CC on compaction and CBR behavior.

i. The 0% mix served as the control sample to establish a baseline for soil characteristics.
ii. The 6% mix represented the lower addition level, to observe minor modifications in compaction and strength.
iii. The 12% mix was chosen as a medium level where noticeable improvements are expected based on similar stabilization studies.
iv. The 18% mix tested the upper range, to determine whether excessive CC would lead to failure or reduced compaction efficiency.

This process helps identify the best percentage at which road subgrade stabilization would be most effective.

3.6 Data Collection and Analysis

Laboratory test results were examined to assess how Crushed Concrete (CC) would influence the engineering characteristics of soil. The analysis involved the following procedures:

1. Index property analysis**:** Sieve analysis and Atterberg limits tests were utilized to classify the soil and assess how adding CC affected its plasticity and composition.
2. Compaction test analysis: The plots illustrating the relationship between dry density and moisture content were created for each mix. From these graphs, the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were identified, and the variations in MDD and OMC were analyzed across different percentages of CC. This analysis aimed to explore the effect of CC on the compaction characteristics of the soil.
3. CBR test analysis: The CBR values were computed from the load penetration curves at 2.5 mm and 5.0 mm penetrations. The higher of the two values was selected as the representative CBR for each mix. The CBR values at 0%, 6%, 12% and 18% were also compared like in the case of compaction, to identify the trend of improvement and determine the optimal CC percentage for subgrade stabilization.
4. Graphical and Comparative Evaluation: Graphs were plotted using Excel spreadsheet to show variations in MDD, OMC and CBR with respect to CC content. These graphs helped visualize the performance improvement and identify the stabilization level where the soil achieved maximum strength.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Particle Size Distribution (sieve analysis)

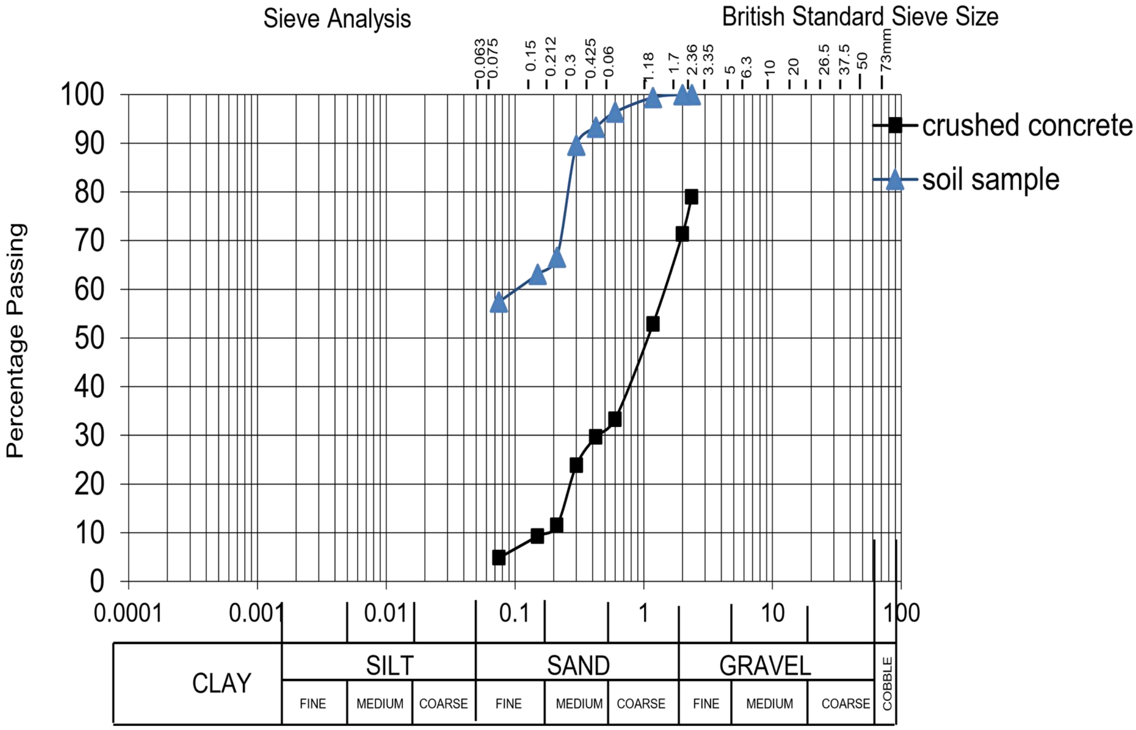


Figure 4.1 Particle Size Distribution Curve for Soil and Crushed Concrete

The particle size distribution curve in figure 4.1 show that the soil sample and the crushed concrete are graded between fine sand to fine gravel. The particle size distribution curve indicates that the soil sample consists predominantly of fine sand and fine gravel fractions. The CC on the other hand, contains well-graded fine to medium gravel with some coarse sand particles. They are predominantly coarse-grained materials with fine fractions that contribute to plasticity. The CC exhibits a slightly higher percentage of finer particles, which aids in filling soil voids and enhances gradation.

4.2 Atterberg Limit

Table 4.1: Atterberg Limits of Soil–CC Mixtures

Sample ID (%)	LL (%)	PL (%)	PI (%)	PLASTICITY
0	40.00	19.49	20.51	CI
6	25.70	20.09	5.61	CL
12	25.8	20.53	5.27	CL
18	25.01	20.70	4.31	ML

Based on the AASHTO Soil Classification System (AASHTO M145), the natural soil is classified as A-7-6**.** This is due to 57.5% of the material passing the No. 200 sieve, a Liquid Limit of 40% and a Plasticity Index of 20.5%. The A-7-6 group typically represents clayey soils of low to medium plasticity, which have poor drainage**,** high compressibility and significant shrink-swell potential. Such soils are unsuitable for subgrade construction in their natural state, therefore, stabilization using Crushed Concrete (CC) is necessary (AASHTO, 2012).

Table 4.1 presents the test results for the atterberg limits. An increase in CC content in the soil mass, caused a reduction in the LL due to the fact that the soil has minimal plasticity and an increase in PL due to the coarser and more granular nature of the crushed concrete. The soil sample exhibited the highest LL (40.00%) and PI (20.51%) and the lowest PL (19.49%), thus lying in the range of intermediate clay (CI). This shows clayey behavior with moderate plasticity, indicating that the soil is cohesive, can hold water and deform, which are not ideal properties for subgrade performance. Upon the addition of 6%CC, the Liquid Limit dropped sharply from 40 to 25.70% and is increased slightly on 12%CC addition and it is decreased again on the addition of 18%CC. The Plastic Limit increased slightly from 19.49% for the natural soil to about 20.70% at 18%CC content. This slight increase indicates that the inclusion of the crushed concrete reduces soil cohesion and allows the soil to be rolled at slightly higher moisture contents without cracking. In contrast, the Liquid Limit decreased significantly, leading to a sharp drop in Plasticity Index from 20.51% to about 4.31%. Addition of 6%CC, showed a transition from intermediate clay to clay of low plasticity (CL), indicating that the addition of CC began to replace the clay particles, thereby reducing plasticity and improving workability. This transition was also seen for 12%CC content. Also, the addition of 18%CC content showed that the CC-soil lies in the range of low elasticity silty soils (ML), indicating that the soil is non-plastic and a silty sand material with very low cohesion, good drainage and high stability which are suitable for road subgrade use. This implies that the stabilized soil transitions from a medium plastic to a nearly non-plastic behavior, characteristic of granular materials. Figure 4.2 shows the LL graph showing the various LL for the mix proportions.

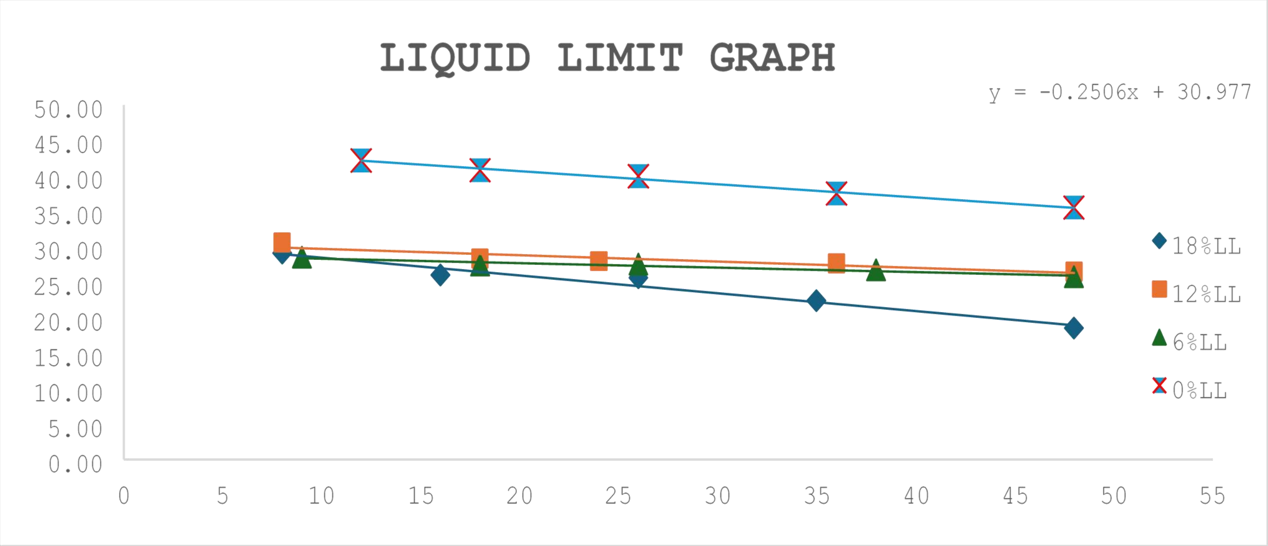


Figure 4.2 Liquid Limit Graph.

4.3 Compaction Characteristics

Table 4.1: Compaction Results for Soil–CC Mixtures

Sample ID (%)	MDD (g/cm^3)	OMC (%)
0	1.85	13.52
6	1.83	12.85
12	1.92	12.50
18	1.85	12.00

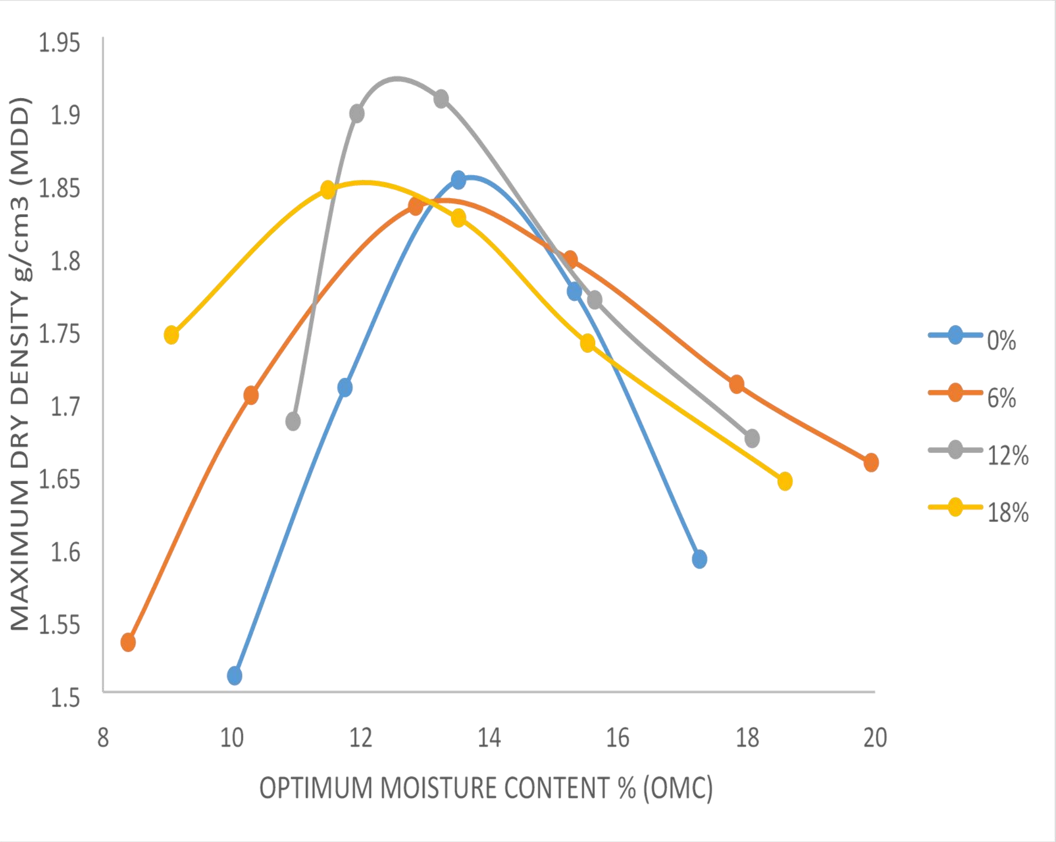


Figure 4.3 MDD vs. OMC Graph.

Figure 4.3 shows the dry density vs moisture content graph of the compaction test for the soil sample and the soil-CC mixtures in Table 4.2. The Maximum Dry Density (MDD) increased from 1.85 g/cm^3 for the natural soil to a peak value of 1.92 g/cm^3 at 12% Cc, followed by a slight reduction at 18% CC. The increase in MDD at 12% CC indicates improved packing efficiency and particle interlocking between the soil and CC particles, leading to a denser mixture. Conversely, the Optimum Moisture Content (OMC) decreased steadily from 13.52% for the natural soil to 12.00% at 18% CC. This reduction suggests that the inclusion of the crushed concrete lowers the soil's affinity for water, resulting in better drainage and less moisture sensitivity. Overall, the results indicate that the 12% CC mix yields the most favorable compaction characteristics, producing a dense, well-packed subgrade material with reduced water demand, both of which are desirable properties for road construction.

4.4 California Bearing Ratio

Table 4.2: CBR results for Soil-CC Mixtures

Sample ID (%)	Soaking Condition	CBR at 2.5mm (Top)	CBR at 5.0 mm (Top)	CBR at 2.5mm (Bottom)	CBR at 5.0 mm (Bottom)
0	Unsoaked	7.646	8.347	8.879	10.147
	Soaked	2.395	2.521	9.866	8.510
6	Unsoaked	14.798	16.039	21.704	22.095
	Soaked	4.047	3.069	18.991	12.929
12	Unsoaked	17.018	19.312	18.991	25.531
	Soaked	2.560	2.466	11.592	16.694
18	Unsoaked	21.951	21.440	26.390	28.641
	Soaked	4.047	8.604	13.318	24.713

According to BS 1377 (1990) and AASHTO T193, the higher of the two penetrations (2.5 mm or 5.0 mm) is recorded only if it does not exceed the other by more than 25% and if otherwise, use the CBR at 2.5 mm as the official value

Table 4.3: Unsoaked CBR Percentage Values

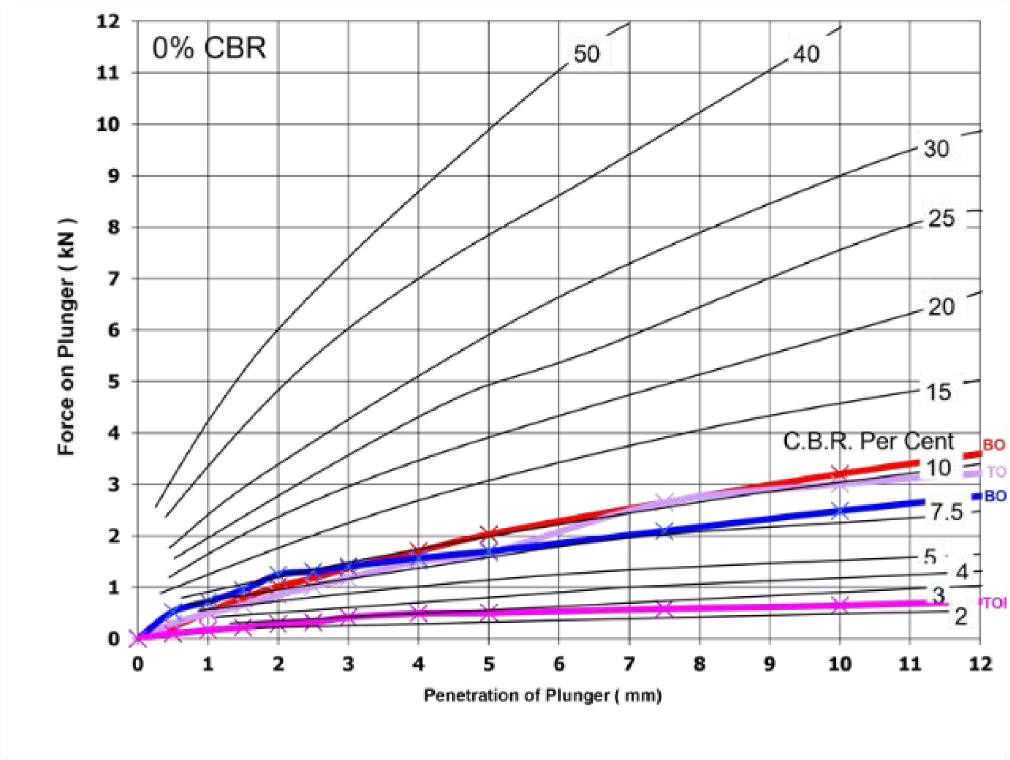
Sample ID (%)	0	6	12	18

Top (%)	8.347	16.039	19.312	21.951
Bottom (%)	10.15	22.10	25.53	28.64

Table 4.4: Soaked CBR Percentage Values

Sample ID (%)	0	6	12	18
Top (%)	2.521	4.047	2.560	8.604
Bottom (%)	9.87	18.99	16.69	24.71

The California Bearing Ratio (CBR) test was conducted under both soaked and unsoaked conditions for the natural soil and for soils stabilized with varying percentages of crushed concrete. The results are summarized in Table 4.3. The bottom CBR values were used to ensure more accurate and reliable assessment of the soil's bearing capacity, due to its representation of actual field conditions, where the load from the pavement is transmitted from the top surface and dissipates through the lower portion of the specimen. According to the Federal Ministry of Works and Housing (FMWH), (2016), a minimum CBR value of 10% (soaked) is required for subgrade materials, while higher CBR values (typically above 15%) are preferred for unsoaked subgrades used in pavement design. The soil sample (i.e. at 0%), with soaked and unsoaked CBR values of 9.87% and 10.15% respectively, barely meets the minimum requirement, confirming that it would perform poorly as a subgrade material in its natural state. The stabilized samples (6%–18% CC), however, all exceed the FMWH minimum soaked and unsoaked requirements, with values ranging between 18.99%–24.71% (soaked) and 22.10%–28.64% (unsoaked), indicating that they possess adequate bearing strength and moisture stability for use as road subgrade materials. The best performance was observed at 18% CC, showing the highest bearing capacity and water resistance, making it most suitable for road subgrade applications.


0% CBR
Force on Plunger (kN)
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8
9
10
11
12
50
40
30
25
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C.B.R. Per Cent
10
7.5
5
4
3
2
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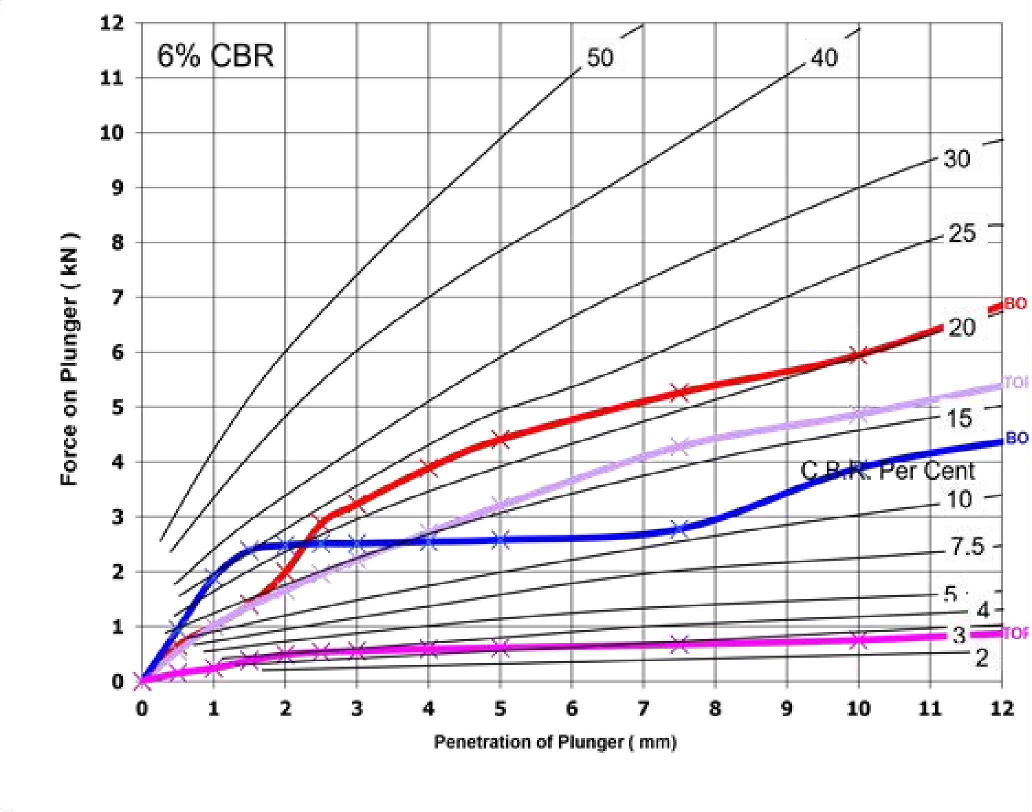
6% CBR
Force on Plunger (kN)
Penetration of Plunger (mm)
0
1
2
3
4
5
6
7
8
9
10
11
12
50
40
30
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20
15
C.B.R. Per Cent
10
7.5
5
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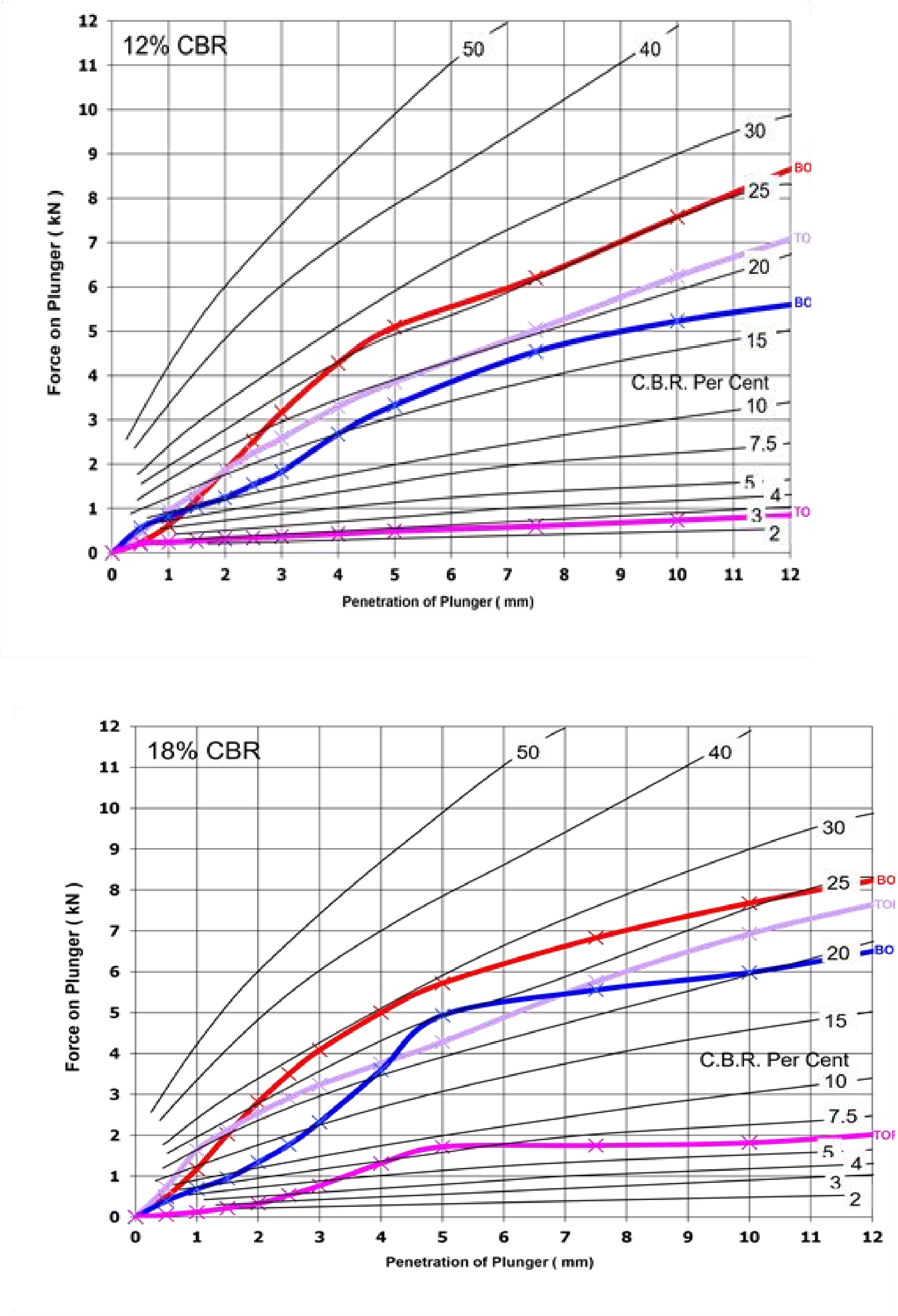

Figure 4.4: Showing the Various CBR Graphs

4.5 Comparison with Previous Studies

1. Atterberg limits

In the present study, the PI dropped sharply with CC addition (i.e. from 20.51% to 4.31% across 6-18% CC), indicating a transition from intermediate/medium-plastic clay toward low-plasticity/silty behavior as CC replaced fines. In comparison with previous studies; Ibrahim et al. (2018) reported decreases in liquid limit and PI with progressive addition of crushed waste concrete (CWC) and attributed this to dilution of clay by non-plastic CDW (Ibrahim et al., 2018). Likewise, Islam et al. (2022) found reductions in LL and PI when fine CDW (mortar powder) was mixed with clay indicating that CDW reduces plasticity and improves workability (Islam et al., 2022). Patil et al. (2021**)** also observed improved workability and lowered plasticity when black cotton soil was mixed with CDW at 10% (Patil et al., 2021). This shows a clear trend between the observations in this work and the observations in the previous studies. The CDW dilutes the clay fraction and reduces water absorption, indicating that the results agree qualitatively and quantitatively with these previous studies.

2. Compaction Behaviour (MDD and OMC)

The present study showed that the MDD increased from 1.85 to 1.92 g/cm³ (peak at 12% CC) and the OMC decreased from 13.52% to 12.00% (18% CC). In comparison with previous studies; Hidalgo et al. (2023) and Islam et al. (2022) reported that CDW increases MDD and reduces OMC because CDW particles are denser and absorb less water than clay (Hidalgo et al., 2023; Islam et al., 2022). Alam et al. (2024) and Pauzi et al. (2024) also reported higher dry densities with CDW/RCA inclusion and identified an optimum range where MDD peaks (often between 10–20% depending on source and gradation), (Alam et al., 2024; Pauzi et al., 2024).

The peak at 12% in this work is consistent with these studies that find a moderate CDW content gives the best packing and beyond the optimum, coarsening or gradation imbalance can reduce packing efficiency. In the present study, 18% showed a slight MDD drop and this matches the optimum content pattern reported in Hidalgo and Alam.

3. CBR (soaked and unsoaked)

In the present study, the bottom CBR (unsoaked) increased from 10.15% to 28.64% at 18% CC (nearly a 2.8times improvement), while the soaked bottom CBR similarly improved to 24.71% at 18% CC. In comparison with previous studies; Al-Obaydi et al. (2022) found a significant CBR increase as the crushed concrete produced a 49.7% CBR gain at 10% in their field model tests. This present study shows even larger percentage increases at higher mix contents. The differences are likely due to: CDW type, gradation, compactive effort and whether tests were field or lab (Al-Obaydi et al., 2022). Patil et al. (2021) reported maximum improvement near 10% replacement for black cotton soil. This present study shows progressive improvement to 18% suggesting that this particular CDW + soil combination responds well up to higher contents; this is similar to Pauzi (2024) who found optimum RCA 15% but noted material-dependent optima (Patil et al., 2021; Pauzi et al., 2024). Alam et al. (2024) and Hidalgo et al. (2023) also report substantial CBR and resilient modulus gains with CDW; the observed values of the present study, fall inside the range reported by these authors, confirming that CDW consistently improves subgrade bearing capacity (Alam et al., 2024; Hidalgo et al., 2023).

In the present study, the larger gain at 18% (versus many studies that peak at 10–15%) can be explained by the specific CDW gradation and the way CDW filled the voids and improved interlocking in the soil sample. Conversely, some studies warn of diminishing returns or durability issues at very high CDW contents, a warning to consider field verification and durability testing (Hidalgo et al., 2023).

The experimental results from this study are consistent with the body of literature that supports CDW as an effective soil stabilizer (Ibrahim, 2018; Islam, 2022; Al-Obaydi, 2022; Hidalgo, 2023; Alam, 2024). While many studies identify an optimum in the 10–15% range, the specific CDW grading and the lateritic/clayey nature of the soil sample explain why this investigation recorded peak density at 12% and continuing CBR improvement to 18% and even beyond. The findings therefore corroborate previous research while emphasizing the need for local mix trials and long-term durability testing before field implementation (Barisoglu et al., 2023; Hidalgo et al., 2023).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research investigated the utilization of crushed concrete, a type of construction and demolition waste, as a stabilizing material for improving the engineering properties of weak subgrade soil. Laboratory analyses including Atterberg limits, compaction and CBR tests, were conducted to assess the effects of varying percentages of crushed concrete on the soil's performance.

The study identified and analyzed the basic index and strength properties of both stabilized and un-stabilized soils. Laboratory tests such as sieve analysis and Atterberg limits showed that adding crushed concrete reduced the soil's plasticity and improved its texture, confirming that crushed concrete alters the soil's physical characteristics. In alignment with the first objective, the index and strength properties of both the stabilized and un-stabilized soils were determined. The un-stabilized soil exhibited high plasticity, moderate density and low bearing capacity, while the stabilized soil (i.e. The addition of CC at 6%, 12% and 18%), the Plasticity Index (PI) reduced drastically, indicating improved workability and reduced clay activity, thereby demonstrating that CC modifies the fundamental engineering properties of the soil.

The improvements in soil properties were evaluated, as the inclusion of crushed concrete caused a marked reduction in the liquid limit and plasticity index of the soil, showing that CC reduced the cohesive and swelling potential of the natural soil. The compaction results revealed that the maximum dry density increased up to 1.92 g/cm³ at 12% CC, while the optimum moisture content decreased, implying improved packing efficiency and reduced water absorption. The CBR results showed that both soaked and unsoaked values improved significantly with higher CC percentages, achieving peak values of 24.71% and 28.64% respectively at 18% CC. When compared with the FMWH (2016) standards, the untreated soil failed to meet the required subgrade strength, whereas stabilized soils from 6% CC upward exceeded the minimum requirements for both soaked and unsoaked conditions.

The comparison between stabilized and un-stabilized soils revealed that CC addition enhances the geotechnical behavior of weak soils and strength parameters confirmed that optimal performance was achieved at moderate CC percentages.

Significant observations include:

i. The strength improvement was progressive up to 18% CC, indicating that CC content within this range is optimal for subgrade stabilization.
ii. The 12% mix achieved the highest dry density, while 18% provided the highest bearing strength, demonstrating that the ideal percentage depends on the design requirement.
iii. Crushed concrete improved the moisture resistance of the soil, suggesting better field performance under Nigerian climatic conditions.

In conclusion, the addition of crushed concrete to weak soil significantly enhanced its geotechnical properties, validating its suitability as an alternative stabilizing material. The findings support the use of CDW in sustainable road subgrade construction and waste management practices in Nigeria.

5.2 Recommendations

Based on the results of this study, the following recommendations are made:

i. Engineers and contractors should adopt the use of CDW, particularly crushed concrete, as a cost-effective stabilizer in subgrade improvement, especially in areas with weak soils.

ii. The Federal and State Governments should develop and enforce policies encouraging the reuse of construction and demolition waste to reduce environmental pollution.

iii. Construction companies should establish waste-recycling facilities to process CDW for engineering applications rather than disposing of it in landfills causing land pollution.

iv. Future studies should investigate the long-term durability, permeability and performance of CDW-stabilized soils and also improve on the mix proportions.

v. Environmental and professional bodies such as the FMWH should consider including CDW-based stabilization guidelines in its national road-construction specifications and also sensitize stakeholders about the economic and environmental benefits of using CDW as a stabilizing agent.

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APPENDIX A

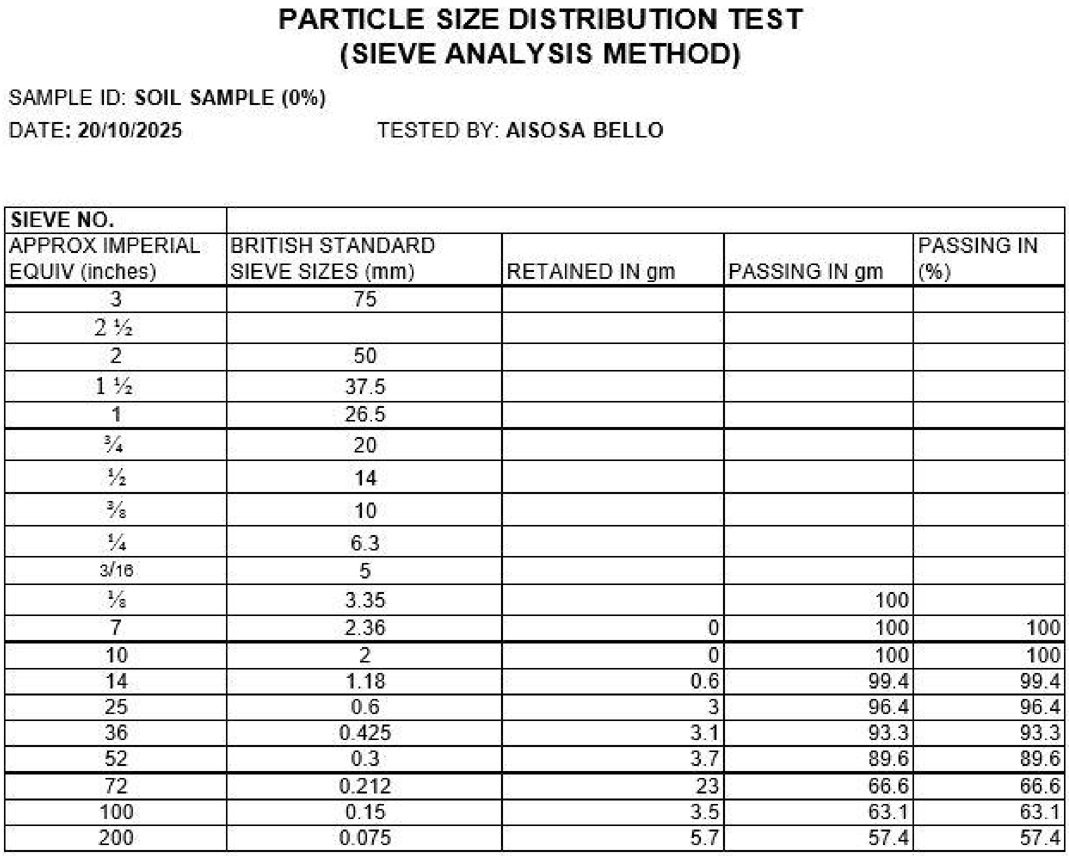
PLATE A-1 Showing the Collection of the Soil Sample from Iguosa Housing Estate.

PLATE A-2 Showing the first Stage of Preparation after bringing the Sample from the Site.

PLATE A-3: Soil Sample.

PLATE A-4: Crushed Concrete.

APPENDIX B



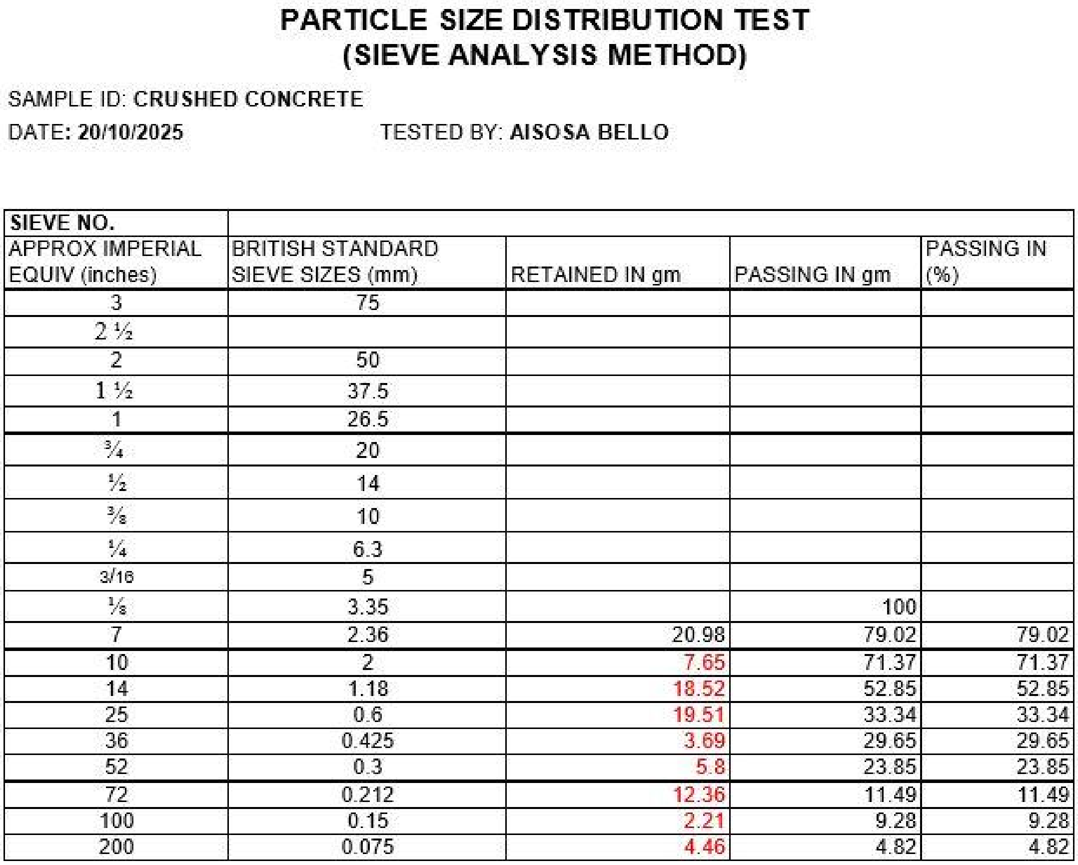
PARTICLE SIZE DISTRIBUTION TEST
(SIEVE ANALYSIS METHOD)

SAMPLE ID: **SOIL SAMPLE (0%)**

DATE: **20/10/2025** TESTED BY: **AISOSA BELLO**

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2 ½				
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	0	100	100
10	2	0	100	100
14	1.18	0.6	99.4	99.4
25	0.6	3	96.4	96.4
36	0.425	3.1	93.3	93.3
52	0.3	3.7	89.6	89.6
72	0.212	23	66.6	66.6
100	0.15	3.5	63.1	63.1
200	0.075	5.7	57.4	57.4

Figure B-1: Showing % Passing for the Soil Sample.



PARTICLE SIZE DISTRIBUTION TEST
(SIEVE ANALYSIS METHOD)

SAMPLE ID: **CRUSHED CONCRETE**

DATE: **20/10/2025** TESTED BY: **AISOSA BELLO**

SIEVE NO.				
APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3	75			
2 ½				
2	50			
1 ½	37.5			
1	26.5			
¾	20			
½	14			
⅜	10			
¼	6.3			
3/16	5			
⅛	3.35		100	
7	2.36	20.98	79.02	79.02
10	2	7.65	71.37	71.37
14	1.18	18.52	52.85	52.85
25	0.6	19.51	33.34	33.34
36	0.425	3.69	29.65	29.65
52	0.3	5.8	23.85	23.85
72	0.212	12.36	11.49	11.49
100	0.15	2.21	9.28	9.28
200	0.075	4.46	4.82	4.82

Figure B-2: Showing %Passing for the Crushed Concrete (CDW).