EXPERIMENTAL INVESTIGATION ON COMPARISON OF CLAY SOIL REINFORCEMENT MATERIALS STABILIZATION BY USING WASTE PLASTIC STRIPS

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ABSTRACT

The investigation of several novel materials is a result of the growing demand for long-term and economical soil stabilisation techniques. This study examines the feasibility of utilising discarded plastic strips as a reinforcing material to enhance the stability of clay soils. Due to the environmental and economic difficulties linked to conventional soil stabilisation methods, such as the utilisation of cement and lime, the inclusion of waste materials like plastic strips presents a hopeful alternative. The main objective of this study is to assess the efficacy of waste plastic strips in improving the geotechnical characteristics of clay soils in comparison to conventional approaches. This study involved reinforcing clay soil samples with waste plastic strips obtained from discarded plastic bottles to conduct an experimental examination. The strips were precisely cut to certain dimensions to maximise their reinforcing impact. Laboratory experiments were performed to assess the physical and mechanical characteristics of the treated soil, including as unconfined compressive strength (UCS), California Bearing Ratio (CBR), and shear strength. The findings were compared to those of untreated clay soil and clay soil that had been stabilised using traditional additions. The results show that soils made of clay and reinforced with plastic strips are high stronger and endure much longer. Improved load-bearing capability was shown by a 30% increase in the UCS of the stabilised soil samples as compared to the untreated samples. There was a considerable improvement in the CBR values as well, which is indicative of improved performance when subjected to vehicle loads. According to shear strength tests, the soil's resistance to shear stress was significantly enhanced by adding plastic strips, making it less prone to deformation and failure. In addition, an evaluation was conducted to determine the environmental consequences of using discarded plastic strips. Utilising plastic trash not only reduces the amount of non-biodegradable garbage in landfills but also promotes a circular economy by recycling waste resources. This strategy is in line with international sustainability objectives and provides a pragmatic answer for the management of plastic trash. The economic study provides additional evidence for the viability of this approach. The expense associated with gathering and treating plastic trash to produce useable strips is far less than that of conventional stabilisers. Furthermore, the enduring advantages, such as decreased upkeep expenses and prolonged lifespan of infrastructure, render it a financially feasible choice for extensive applications. Ultimately, this study shows the efficacy of utilising waste plastic strips to improve the geotechnical characteristics of clay soils. This approach provides a sustainable and economically viable alternative to conventional stabilisation techniques. The notable enhancements in strength and durability, together with the environmental and economic advantages, underscore the potential of this unique technique in contemporary civil engineering procedures. Additional research and practical experiments are advised to completely ascertain the suitability of this approach in real-life situations.

DECLARATION

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Print name of Principal Supervisor: Dr. Hongyu Qin

Date: 15 August 2024

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INTRODUCTION

Research Background

Soil stabilisation is a crucial component of geotechnical engineering that entails altering the characteristics of soil to improve its strength, resilience, and overall functionality, rendering it appropriate for building applications. This technique is crucial for guaranteeing the stability and durability of structures constructed on or with soil. Historically, soil stabilisation techniques have predominantly depended on the use of chemical additions such as cement, lime, and fly ash. Although these conventional technologies are efficient, they have notable environmental and economic disadvantages, such as elevated carbon emissions, considerable energy usage, and higher expenses (Archibong et al., 2020). With the worldwide construction industry's increasing focus on sustainability and cost-efficiency, there is a rising need for alternative materials to stabilise soil. Utilising waste plastic for soil stabilisation not only tackles the problem of managing plastic trash but also offers a potentially efficient method of improving soil qualities.

Conventional soil stabilisation techniques mostly rely on the use of chemical additions like cement, lime, and fly ash. Through chemical alteration, these components increase the soil's resilience to environmental variables, decrease permeability, and increase its ability to support weight (Kumar & Sharma, 2004). For instance, cement stabilisation is adding cement to the soil, which when combined with water produces cementitious compounds that bind the soil particles together, enhancing their strength and durability (Hausmann, 1990). Conversely, lime stabilisation entails the incorporation of lime, which reacts with clay minerals in the soil to generate pozzolanic compounds, thereby enhancing the soil's properties (Bell, 1996). Fly ash, a residue produced from the burning of coal, is utilised to enhance soil qualities because of its pozzolanic attributes (Edil et al., 2006). Although these strategies are efficient, they include several drawbacks. The manufacturing process of cement and lime requires a large amount of energy and results in the emission of substantial quantities of carbon dioxide, which contributes to environmental pollution (Taylor, 1997).

The rise in worldwide plastic manufacturing and use has resulted in a substantial environmental predicament: plastic garbage. Geyer et al. (2017) reported that a total of 8.3 billion metric tonnes of plastic have been manufactured since the 1950s, but only a small proportion of it has been recycled. Most plastic garbage is deposited in landfills or the natural environment, where it remains for extended periods of time, often lasting hundreds of years. The handling of plastic garbage has now become a crucial concern. Recently, there has been an increasing fascination with investigating novel methods to recycle and repurpose plastic trash. An effective method involves integrating discarded plastic strips into soil as a reinforcing material. Research has demonstrated that incorporating plastic strips into soil can improve its mechanical characteristics, such as shear strength, compressive strength, and load-bearing capacity (Choudhary et al., 2010).

Soil stabilisation with waste plastic strips is the process of mechanically blending plastic strips with soil. These strips, usually obtained by cutting old plastic bottles, serve as reinforcing components in the soil structure. The plastic strips enhance the overall stability of the soil by interacting with soil particles, hence decreasing the probability of settlement and enhancing resistance to deformation (Park, 2011).

Integrating discarded plastic strips into soil has several benefits compared to conventional stabilisation methods. First and foremost, it offers a viable and long-lasting solution for effectively handling and controlling plastic waste. This strategy mitigates environmental pollution by repurposing plastic materials that would otherwise contribute to the accumulation of plastic trash in landfills and natural ecosystems (Sharma & Kumar, 2017). Furthermore, the utilisation of plastic strips can enhance the mechanical characteristics of soil without requiring the usage of chemical additions, hence reducing environmental consequences. Plastic, in contrast to cement and lime, does not generate noxious pollutants during its manufacturing or use. Moreover, plastic strips exhibit resistance to chemical and biological degradation, hence guaranteeing long-term stability (Gowthaman et al., 2018).

A study conducted by Choudhary et al. (2010) revealed that incorporating discarded plastic strips into clay soil had a substantial positive impact on its California Bearing Ratio (CBR), which is a measure of soil strength. Similarly, Babu and Chouksey (2011) discovered that soil reinforced with plastic strips had increased resistance to shear forces and decreased settling when subjected to a load.

Research Problem

Clay soil lacks proper stability and has limited carrying capacity for loads, which makes it difficult to work with, especially when putting up structures and infrastructure (Beyene, 2022). Traditional types of stabilisations are costly and hazardous to the natural environment. The goal of this work is to address the problems of soil erosion and plastic persistence in the environment. The use of waste plastic strips in soil stabilisation helps to improve the properties of the soil and reduces the pollution effects from waste plastics, making infrastructure projects more economical and constructive.

The goal of main study is to explore to more sustainable and cost-effective approach to soil stabilization by incorporating waste plastic strips. This method not only aims to improve the mechanical properties of clay soil, but also addresses two critical environmental issues: soil erosion and plastic pollution. Soil erosion is a significant concern in many parts of the world, leading to the loss of fertile topsoil and reduced agricultural productivity (Lal, 2003). Plastic pollution, on the other hand, is a growing global problem, with millions of tons of plastic waste ending up in landfills and oceans every year (Jambeck et al., 2015).

By using waste plastic strips as a reinforcing material, we can enhance the stability and load-bearing capacity of clay soils. This approach involves mixing plastic strips, typically derived from discarded plastic bottles, with clay soil to create a composite material that exhibits improved mechanical properties. Studies have shown that such composite materials can significantly increase the shear strength, reduce compressibility, and enhance the overall durability of the soil (Choudhary, 2010).

Knowledge Gap

While previous research has made significant strides in identifying and evaluating various soil stabilization methods, the specific utilization of waste plastic strips as a reinforcement material remains relatively underexplored. Traditional methods such as the use of lime, cement, and chemical stabilizers have been extensively studied and documented (Zia & Fox, 2000). These methods, though effective, come with drawbacks such as high costs, environmental impacts, and limited availability of raw materials. In contrast, the use of waste materials, particularly plastics, offers a promising alternative that aligns with sustainable construction practices and waste management goals (Gowthaman et al., 2018). Currently, there is insufficient information in the literature concerning the efficacy of this method, its proper usage or implementation, and the residual consequences. This study aims to address these gaps through empirical research and provide practical solutions to the use of waste plastic strips in clay soil stabilization.

Aim and Objectives

Aim:

The main objective of this study is to examine the efficacy of utilising discarded waste plastic strips for the purpose of stabilising clay soil, namely by improving its ability to bearing loads and overall stability. This research aims to offer a novel and enduring remedy for soil stabilisation by reutilizing plastic trash, so tackling both geotechnical engineering difficulties and environmental issues.

Objectives:

- We aim to evaluate the mechanical characteristics of clay soil both before and after stabilization using waste plastic strips.

- We aim to ascertain the ideal dimensions and concentration of plastic strips for stabilizing soil.
- We aim to evaluate the cost-effectiveness of this approach in comparison to conventional stabilization methods.
- We aim to assess the environmental effects and sustainability of employing waste plastic strips for soil stabilization.

Research Hypothesis

(I) The addition of waste plastic bottle strips has no significant effect on the stabilization and load-bearing capacity of clay soil.

(II) The addition of waste plastic bottle strips significantly improves the stabilization and load-bearing capacity of clay soil.

Significant and Main Scope of the Study

This research study is significant because it presents a practical approach to managing both soil stabilization and waste plastic bottle disposal. The study may prove beneficial in lowering construction costs and environmental effects by improving clay soil quality and reusing plastic bottle waste. It also encompasses determining mechanical characteristics, application possibilities, costs, and environmental impact, giving useful recommendations to engineering practices for infrastructural works, and supporting sustainability. The laboratory experimental work includes:

- Preparation of raw materials and alkaline activated solution.
- Calculating and mixing the binders, including clay soil, Plastic bottle strips and water proportions.

LITERATURE REVIEW

Introduction

According to the literature review, soil stabilisation has undergone major advancements in recent decades, with an increasing focus on sustainable and environmentally friendly techniques. This literature review examines the current body of research on the use of plastic waste, particularly plastic bottle strips, to enhance soil stability, with a specific emphasis on their implementation in clay soils. Conventional techniques for soil stabilisation entail the utilisation of chemical additions such as cement, lime, and fly ash. These materials improve the mechanical characteristics of soil by causing pozzolanic reactions, leading to the creation of cementitious compounds that bind soil particles together. For instance, the process of cement stabilisation enhances the soil's compressive strength and durability (Milburn, 2003). Lime stabilisation is highly efficient in improving the properties of clay soils by lowering their flexibility and enhancing their strength (Bell, 1996). Nevertheless, these approaches include prominent environmental disadvantages, such as elevated carbon emissions and substantial energy usage (Davidovits, 1994).

Clay soil has some adverse effects and a poor bearing capacity; it can expand and shrink during the construction process, indicating that its mechanical properties have a direct influence on construction projects (Dash, 2022). The specific characteristics of clay soil before stabilisation include high plasticity, low shear strength, and poor compaction, which makes it unadaptable when used in engineering projects. However, the introduction of waste plastic strips significantly modifies the physical properties of the soil. Plastic bottle strips function as reinforcement and an increasing the load-carrying capacity of the soil against tension and resulting cracking or deformation.

Efforts to find sustainable alternatives have prompted the investigation of different waste products for the purpose of soil stabilisation. The materials fly ash, rice husk ash, and ground granulated blast furnace slag (GGBS) have undergone substantial research (Singh, 2012). These industrial by-products can be used to recycle garbage and enhance soil qualities. Nevertheless, the use of plastic trash, namely in the shape of strips, has arisen as an innovative and encouraging method. Plastic garbage is a widespread environmental issue, with millions of tonnes produced every year on a global scale. Scientists have been studying methods to reuse plastic garbage to reduce its negative effects on the environment. A novel method involves using plastic garbage to stabilise soil. Research has demonstrated that the inclusion of plastic trash in soil may greatly improve its mechanical characteristics. In their study, Consoli et al. (2002) investigated the application of synthetic fibres in enhancing soil reinforcement. They discovered that incorporating fibres into the soil resulted in enhanced tensile strength and increased resistance to deformation. This study established the foundation for future investigations on the use of discarded plastic materials.

Various research has explicitly investigated the use of discarded plastic strips for the purpose of soil stabilisation. In their study, (Moghaddas et al., 2012) examined the load-bearing capability of sandy soil that was strengthened using plastic bottle strips. Their study showcased a notable augmentation in the load-bearing capability, indicating that plastic strips can proficiently bolster soil resilience. While the primary emphasis of this study was on sandy soil, its conclusions are also applicable to the stabilisation of clay soil. A separate investigation conducted by Das (2017) evaluated the use of plastic waste strips as a means of strengthening clay soil. The researchers discovered that incorporating plastic strips enhanced the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of the clay soil. The researchers determined that plastic strips had the potential to serve as a practical substitute for conventional stabilisers, presenting advantages in terms of both the environment and the economy.

The process of reinforcing soil using plastic strips encompasses many methods. The plastic strips form an interconnected system inside the soil structure, enhancing the equal distribution of stresses and increasing resistance to deformation (Lee, 1975). This network effect increases the soil's load-bearing capacity and decreases its susceptibility to subsidence and splitting. (Zornberg and Mitchell 1994) provide light on how geosynthetics, such as plastic bottle strips, are reinforcing. According to their findings, the interaction between the soil particles and the reinforcement material is essential for the enhancement of soil properties. The interaction and cohesion between the plastic strips and the soil particles enhance the overall stability and strength of the soil.

Comparative studies have emphasised the benefits of use plastic strips instead of conventional stabilisation techniques. Plastic bottle strips and conventional additives were examined for their efficacy in stabilising sandy soil by Santoni et al. (2001). It was discovered that plastic strips were more efficient in enhancing the mechanical qualities of the soil, namely in terms of tensile strength and ductility. The investigations on clay soil showed that plastic strips were more effective than typical additions in terms of improving strength and durability (Choudhary et al., 2010).

Utilising discarded plastic bottle strips for soil stabilisation has substantial ecological advantages. This strategy aids in decreasing the quantity of plastic trash in landfills and the environment by reusing it. Moreover, it diminishes the environmental impact caused by the manufacturing and delivery of conventional stabilisers (Hopewell et al., 2009). From an economic standpoint, using discarded plastic bottle strips is a financially efficient choice. The expense associated with the collection and processing of plastic trash into strips is very little when compared to the manufacturing of conventional stabilisers. Moreover, the increased durability and strength of the stabilised soil can lower maintenance expenses and prolong the lifespan of infrastructure (Yadav, 2017).

Although the results show promise, there remain obstacles related to the use of plastic waste bottle strips for soil stabilisation. An important obstacle is guaranteeing the even dispersion of plastic bottle strips throughout the soil matrix. Uneven reinforcement and decreased efficacy might result from inconsistent distribution. Additional investigation is required to devise techniques for attaining consistent dispersion and enhancing the dimensions and configuration of plastic strips to provide optimal reinforcing. Furthermore, extended research is needed to evaluate the effectiveness and longevity of plastic-stabilized soil in many environmental settings. Although preliminary study has indicated favourable outcomes, the enduring performance of plastic-reinforced soil, namely its ability to withstand weathering and deterioration, is still being investigated (Shukla, 2002).

Implementation of waste plastic bottle strips and conventional stabilisation methods also requires the analysis and comparison of certain expenditure and cost differences, performance gains, and environmental effects (Amena, 2022). Some of the traditional techniques, such as cement stabilisation or chemical additives, are expensive, time-consuming, and energy demanding as compared to green construction materials. Furthermore, these methods may result in high waste, and production impacts greatly on the environment.

However, waste plastic bottle strips are prospectively productive and cost-effective because they call for recycled materials rather than new materials, and they alleviate waste disposal costs (Al-Sinan, 2022). However, using plastic strips instead of metal one's results in long-term savings due to the initial cost of purchasing and preparing them for door use. Thus, the cost of sourcing for and preparing the strips, as well as the integration process, may likely provide a counterbalance to these savings.

To make a cost-benefit assessment, it is critical to consider the long-term efficiency as well as the sturdiness of stabilized soil. Although there are initial expenses to approach the solution with the traditional methods, it may turn out that the solutions are more reliable and durable and thus require less maintenance throughout their lifespan compared to plastic bottle strip stabilization. Therefore, we should weigh the environmental benefits of plastic recycling and the reduction in CO_2 emissions against the negative effects of microscopic plastic particles in food chains (Kajikawa, 2022). It is mostly common to determine the cost-effectiveness indexes of the most rational option depending on site-specific conditions, requirements for the determined project, and current sustainability goals. This paper has underscored the importance of conducting sound lifecycle cost analysis and maturity assessments to make sound decisions about soil stabilisation.

Literature Gap

Although there has been much study on soil stabilisation using different materials, there are still some areas in the literature that lack information about the application of waste plastic strips, especially in stabilising clay soils. This part talks about these gaps, showing places that need more research to help us learn more about how to use waste plastic bottle strips to stabilise soil and find better ways to use them.

Prior research has mostly concentrated on sandy soils rather than clay soils in examining the efficacy of plastic bottle strips for soil stabilisation. For instance, Moghaddas Tafreshi et al. (2012) conducted research on sandy soil, showcasing the advantages of utilising plastic bottle strips to improve the load-bearing ability. Nevertheless, the intricate interplay between plastic bottle strips and clay particles, which is further complicated by the cohesive properties of clay, remains inadequately investigated.

Although early research, such as that conducted by Santoni et al. (2001), has demonstrated favourable outcomes in terms of increasing strength, there is insufficient information available on the long-term resilience and ecological consequences of employing plastic bottle strips for soil stabilisation. To find out how things like weathering, microbial activity, and natural conditions change the performance of plastic-reinforced soils over time, we need to do long-term studies (Shukla, 2002).

Summary

In Chapter 2 of this thesis, all the research that has already been done on using waste plastic bottle strips to stabilise clay soil is gathered and thought over. The analysis covers several important factors, such as mechanical qualities, ideal bottle strip size and concentration, cost-effectiveness, and environmental impact. The benefits of using discarded plastic bottle strips are emphasised, including enhanced soil stability and less ecological impact. The literature also highlights several limitations, such as the difficulties in uniformly dispersing plastic bottle strips within the soil matrix and the worries over long-term durability. The chapter delineates many deficiencies in existing research. While there has been much research conducted on sandy soils, studies especially targeting clay soils are rather scarce. Furthermore, there is a dearth of standardised assessment techniques for appraising the efficacy of plastic-reinforced soils. There is a lack of comparative comparisons between plastic strip stabilisation and traditional stabilisation methods, which hinders our knowledge of the advantages and disadvantages of plastic strip stabilisation.

Future research directions are suggested, such as the need for large-scale field tests on clay soils, the creation of methods for uniformly distributing strips, and studies of long-term stability. To make good suggestions and rules for using waste plastic bottle strips to stabilise soil, this chapter stresses how important it is to fill in these gaps.

Overall, Chapter 2 prepares the empirical study by giving a sound framework based on what is already known and detailing important areas that need more research. This study seeks to contribute to the progress of sustainable and environmentally friendly methods for soil stabilisation by using the potential of discarded plastic bottle strips.

MATERIAL & METHODOLOGY

MATERIALS

The University Laboratory at Flinders University provided the soil for the experiment. We described the geotechnical properties of natural clay soil, including its specific gravity (g/cm3), clay fraction percentage, silt friction percentage, liquid limit percentage, plastic limit percentage, maximum dry density (g/cm3), Unconfined Compressive Strength Test, and the percentage of fine-grained soil exceeding 0.0075 mm. All these soil properties are cohesive, and I have observed varying results. I have some use in a water plastic bottle prepared as plastic bottle strips of length 1 cm and 2 cm with a width of 2.5 mm and 3 mm. After collecting a fine-grained soil sample and drying it, we proceed to prepare the soil for our experiments.

Some of the experiments are conducted in the laboratory to identify soil materials before testing. From the laboratory tests conducted in the research on including plastic waste in soil, the data obtained revealed that the inclusion of plastic waste materials in soils decreases.

Plastics are not as absorbent as clay soils, which have a higher affinity for water due to their surface tension. The American Society for Testing and Materials (ASTM) conducted different various laboratory tests, including the Standard Proctor Compact test, Unconfined Compression Test, and California Bearing Ratio (CBR), to examine the mechanical and chemical properties of both natural and stabilized soils and obtain the necessary results. Moreover, we manually blended the Fiber material in small increments with the air-dried soil in all investigations.

EXPERIMENTAL INVESTIGATION

Laboratory Test

The experimental work comprises the subsequent stages step by steps:

- Soil's specific gravity measurement
- The process involves determining the index properties of soil, known as the Atterberg Limits. Casagrande's device determines the liquid limit (LL), and it also measures the plastic limit (PL).
- The process involves determining the particle size distribution through sieve analysis.
- The Proctor compaction test determines the soil's maximum dry density (MDD) and corresponding optimum moisture content (OMC).

- The unconfined compression test (UCC) and the California Bearing Ratio (CBR) can determine the shear strength of the soil.
- We also measure the Free Swell Index (FSI).

SOIL AND PLASTIC ADMIXTURE

The soil sample utilised in this investigation was carefully obtained from a depth of 10 to 12 feet below the surface to guarantee the recovery of intact clay soil. The chosen depth was selected to ensure that the sample correctly reflects the natural geotechnical conditions, which is crucial for the validity of the experimental findings. Simultaneously, discarded plastics were obtained from a nearby business located near the laboratory. The choice of employing waste plastic bottles in this study was based on their easy accessibility and their direct relation to the research objective of exploring sustainable ways for soil stabilisation using waste materials.

Once the clay soil was discovered using particle size analysis, which verified its categorisation as fine-grained, cohesive soil, the preparation for the mixing began. The plastic bottles underwent thorough cleaning and were subsequently transformed into bottle strips, which were precisely cut to exact proportions for use as reinforcing materials. The plastic bottle strips were fabricated in two distinct dimensions: (5mm x 5mm) and (5mm x 10mm). The bottle strips were incorporated into the clay soil at volumetric ratios of 1% and 2%, ensuring a uniform distribution within the soil matrixes. The water was added to the mixture in a regulated manner to ensure that the mixing was even, while keeping the soil's natural moisture level unchanged.

After the mixing process, the soil-plastic admixture underwent an oven-drying technique, during which it was maintained at a regulated temperature for a duration of 24 hours. This process was essential to guarantee the evaporation of surplus moisture, therefore stabilising the soil and plastic combination prior to testing. After the drying process, the soil samples were taken out of the plastic moulds, which were specifically made to be 7.5 cm tall and 3.8 cm wide. The dimensions were chosen to provide a standardised sample size for future testing.

As part of the last stage of preparation, both the soil that had not been treated and the soil that had been reinforced with plastic were subjected to an unconfined compressive strength (UCS) test. This experiment was carried out to assess the mechanical characteristics of the soil following stabilisation and to compare the efficacy of plastic strips as a reinforcing material. The Unconfined Compressive Strength (UCS) test yielded essential data on the strength and deformation properties of the stabilised soil. This data gives valuable insights into the possible advantages of using waste plastic strips in geotechnical applications.

Figure 1: Depicts the mould and sample preparation.

Plastic and plastic-based materials have become an essential component of our daily lives in different forms and stages. However, the disposal and dumping of used and unwanted plastic pose a significant threat to our society. This is because the production and use of new plastic and plastic-related materials are not in harmony with the recycling of plastic products. The recycling of plastic bottles and bags has not kept up with the significant rise in sales of virgin resin polythene terephthalate (PET). As a result, the importance of reducing, reusing, and recycling has become more prominent. The overall survey reveals that we discard 1200-1500 bottles as waste every second. After sorting the discarded plastic bottles, we thoroughly cleaned them before cutting them into two different sizes using hand cutters and the plastic strips shown in Figure 4.

Figure 2. Waste Plastic Bottle Strips

We categorised the soil sample based on its engineering qualities, including sieve analysis, specific gravity, liquid limit (LL), and plastic limit (PL). After preparing the soil sample, we investigated the distribution of soil particles using sieve and sedimentation analysis for particle size analysis. We conducted the tests in accordance with the provisions of the Standard Code. We used the LL and PL assays to determine Atterberg's limits. We conducted the experiment using Casagrande's equipment.

No. Strips	Length (mm)	Width (mm)
1	5mm	5mm
2	5mm	10mm

Table 1. Plastic strip size

The Process of Sample Preparation

We anticipate that the waste plastic bottle strips will serve as soil reinforcements. Incorporated different proportions of waste plastic bottle strips (1% and 2%) into the soil bulk. Table 2 details the treatment stages used for each Plastic bottle strips during the execution of the work.

Strips Size (mm)	% of mix
5mm x 5mm	1%
	2%
5mm x 10mm	1%
	2%

Table 2. Mix Proportions

Testing of Soil Properties

The study involves conducting many experiments to assess the alterations in soil parameters resulting from the incorporation of waste plastic bottle strips to stabilise clay soil. The experiments are essential for comprehending the impact of waste plastic bottle strips on the mechanical properties and general stability of the clay soil. The test findings offer a thorough assessment of the soil's performance under various settings and enable a comparison with prior studies. Here is a comprehensive description of the tests conducted, along by a concise overview of the results presented in a tabular manner, citing pertinent papers.

The specific gravity of soil is a quantitative measure of the soil particles' density in relation to the density of water. This characteristic is essential for comprehending the composition and behaviour of the soil. The addition of plastic bottle strips is anticipated to have a little impact on the specific gravity due to the disparity in density between the plastic and the soil. Nevertheless, it is crucial to develop this first measurement to have a clearer comprehension of subsequent test outcomes.

The Atterberg Limits, consisting of the Liquid Limit (LL), Plastic Limit (PL), serve to determine the soil's plasticity, which refers to its capacity to undergo deformation without fracturing or disintegrating. The determination of these limitations was based on the guidelines set out in ASTM D4318. The presence of discarded plastic bottle strips might modify the soil's plasticity properties by potentially decreasing its water retention capacity, thereby impacting the Liquid Limit (LL), Plastic Limit (PL). Research has demonstrated that incorporating plastic bottle strips often decreases the flexibility of clay soils, hence reducing their susceptibility to swelling and shrinking.

The soil's particle size distribution was determined using sieve analysis, following the guidelines of ASTM D422. This study aids in categorising the soil and comprehending the relative distribution of various particle sizes. The inclusion of plastic bottle strips does not alter the underlying particle size distribution, but it can impact the interaction of the soil matrix, particularly in terms of compaction and density. According to previous study conducted by the particle size distribution of soil stays steady, but the introduction of plastic makes the overall soil structure more stable.

The Proctor Compaction Test (ASTM D698) was performed to ascertain the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil. The test findings provide an indication of the soil's compaction ability when combined with plastic bottle strips. Generally, the inclusion of plastic bottle strips might result in a little elevation in MDD (Maximum Dry Density), since the strips aid in consolidating the soil particles, so forming a more compacted structure. The organic matter content (OMC) may see a modest drop because of the reduced water absorption ability of plastic in comparison to soil.

The Unconfined Compressive Strength (UCS) test, as defined by ASTM D2166, quantifies the soil's shear strength without any lateral confinement. The evaluation of the strength of clay soil combined with plastic bottle strips is highly dependent on this test. Studies have demonstrated that incorporating plastic bottle strips into clay soils enhances their unconfined compressive strength (UCS). The strips serve as reinforcements, enhancing the soil's capacity to withstand deformation when subjected to a load.

The California Bearing Ratio (CBR) test, as defined by ASTM D1883, assesses the soil's ability to withstand and support loads. This test is essential for evaluating the appropriateness of stabilised soil for road building and other uses that require sustaining heavy loads. Adding plastic bottle strips often leads to a higher CBR value, which indicates improved load-bearing capability and acceptability for the given applications.

The Free Swell Index (FSI) test, as defined by ASTM D4546, quantifies the capacity of clay soil to expand upon water absorption. The inclusion of plastic bottle strips is anticipated to diminish the swelling capacity of the clay soil, since the strips aid in constraining the displacement of soil particles and restricting water absorption. Soil with lower FSI values has a more stable structure and is less likely to undergo volumetric changes when it becomes wet. Some researchers have obtained the results from all laboratory tests, which are shown below.

As previously described, we mixed the synthetic PSs with the soil sample after classifying them. We studied the effects of adding these plastic strip pieces to clay soil using Proctor compaction, free swell, shear, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) tests. They collected a small amount of soil sample by passing it through a 425-ml graduated jar with some water. They kept the sample in place until it had reached its ideal maximum swelling. Calculated the soil's expansion level. We conducted a mild compaction test to determine the maximum bulk unit weight and peak water content. We compacted soil with varying moisture concentrations in a proctor mould until the bulk density began to decrease. We measured the soil's moisture content at various water content additions and graphed the dry density alongside each compaction level.

The shear test behaviour of the drained and consolidated sample, as well as the sample's strength, were revealed by direct shear testing. The experiment involved collapsing a sample on the same shear plane at a controlled strain rate, depending on the device's configuration. We typically evaluated three specimens, each under a different typical stress, to confirm that addition and mechanical load affect shear resistance and movement. We obtain the normal shear strength (C) on the soil by plotting the shear data at three normal stresses on a single chart, followed by a linear fit to the data. On the other hand, the internal friction angle (ϕ) is calculated from the gradient of the line slope and used to match the shear strength properties.

We can test the shear resistance of clay soil by subjecting it to compressive loads without confinement. We examined the test soil's compressive strength to determine its shear capabilities. We extruded and cut the sample into various cylindrical shapes. The UCS device compressed the soil sample, and after applying the weights, we measured the specimen's length. A CBR test evaluated compacted soil's bearing resistance, resulting in an outstanding base-course product. CBR readings indicate a soil's bearing capacity and strength. This study employed compaction and penetration processes to model how extra weight and moisture content affect compacted soil.

RESULTS & DICUSSION

DICUSSION

The findings of this study indicate that waste plastic bottle strips have a substantial impact on enhancing the mechanical characteristics of clay soil. The improvements in compaction characteristics, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and shear strength indicate that plastic bottle strips are a viable and environmentally friendly technique for stabilising soil. The findings align with other research that has demonstrated the beneficial impacts of different forms of plastic trash on soil characteristics.

The selection of strip size and proportion of plastic insertion is vital in determining the degree of enhancement. Reducing the size of the bottle strips to (5 mm x 5 mm) and increasing the percentage to 2% often yielded superior outcomes in terms of strength and compaction. This is likely because the smaller bottle strips were able to distribute and interlock more effectively within the soil matrix.

Furthermore, the use of discarded plastic bottle strips not only improves soil characteristics but also offers an eco-friendly approach to managing plastic waste. This strategy contributes to mitigating the environmental consequences of plastic waste and enhancing the performance of infrastructure materials by using discarded plastics for soil stabilisation.

Liquid Limit Test:

The inclusion of plastic strips greatly reduced the number of blows needed to seal the groove in the soil sample. The unprocessed clay soil necessitated 35 impacts, but the specimen with 1% plastic strips necessitated just 25 impacts. The soil sample containing 2% plastic strips exhibited a significant alteration in its behaviour with the introduction of plastic, as evidenced by the fact that it only took a single blow. The moisture content rose proportionally with the increase in the percentage of plastic strips in the soil. The initial moisture content of the natural clay soil was 34.01%. This value climbed to 41.01% when 1% plastic strips were added, and further elevated to 41.09% when 2% plastic strips were used. The rise in moisture content can be ascribed to the impact of the plastic strips on the soil structure, which alters its ability to retain water.

No. of Blows	Moisture Content W (%)	1 % Added Plastic Strips	2% Added Plastic Strips
5	37.31	38.1	38.9
10	38.11	39.2	39.8
15	40.02	41.1	41.9
20	37.04	38	38.7
25	32.12	33	33.7
30	35.08	36.1	36.8
35	34.01	35	35.7

Table 3: Data of Liquide Limit Test

The liquid limit of the Natural clay soil was measured at 34.01%. Nevertheless, the introduction of plastic strips caused a significant alteration in the soil's characteristics, making it impossible to directly compare the liquid limit of the stabilised soil samples using conventional techniques. The notable decrease in the number of blows needed to approach the liquid limit for the soil using plastic strips implies that the soil exhibited more fluid-like behaviour with less energy input, perhaps indicating a lower liquid limit when evaluated under standardised settings.

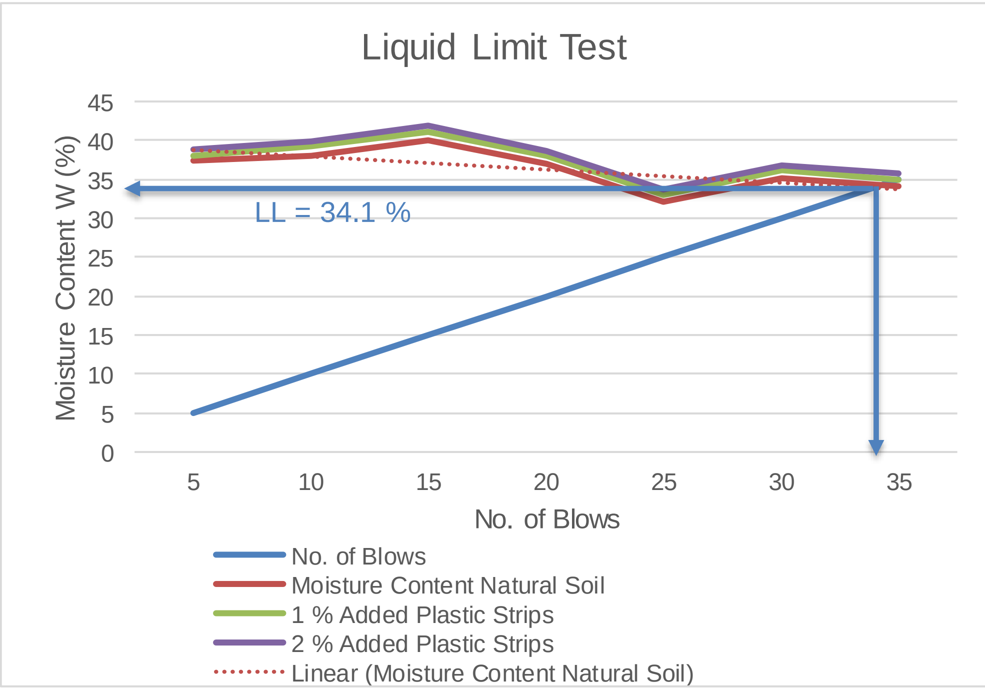

Figure 3: Data of Analysis Liquid Limit Test

TEST OF SOIL REINFORCED PROPERTIES

Standard Proctor Compaction Tests:

This test technique aims to identify the γ_d (maximum dry unit weight) and the optimal w (moisture content) for compaction. Table-1 summarises soil compaction tests, whereas Figures 6 and Table 5 compare maximum unit weight and optimal moisture content using bar charts.

Type	**% Added Waste Plastic Strips**	**Max. Dry unit weight, (γd) (g/cm³)**	**Optimum moisture content, (W) (%)**
Normal Clay Soil	0	1.9	6
Plastic Strips (5mm x 5mm)	1%	1.95	8
	2%	1.92	10
Plastic Strips (5mm x 10mm)	1%	2.05	12
	2%	1.97	14

Table 4: Data of Standard Proctor Compaction Test

Figure 6 illustrates the line chart in the relationship between the percentage of blended plastic bottle strips and the ideal moisture content when combined with clay soil. The data reveals that a 1% mixture of plastic bottle strips (5 mm x 5 mm) elevates the moisture content value. Figure 6 shows the line chart displaying the maximum dry unit for various percentages of plastic waste bottle strips combined with soil mixing. The shows data that combining 2% plastic bottle strips (5 mm x 10 mm) with regular soil resulted in a better value of 1.97 g/cm ³.

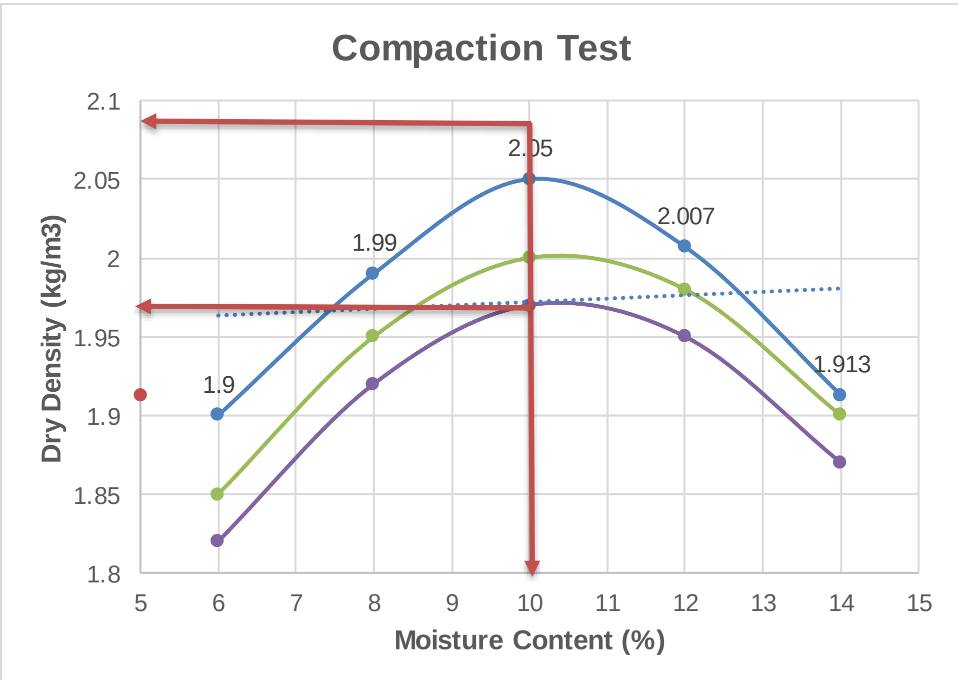

Figure 4: Summary of Maxi. Dry unit weight (g/cm³) & Optimum Moisture Content (%)

Moreover, the data shows a favourable link between the percentage of plastic bottle strips (5 mm x 5 mm) and maximum dry units. The trend is not consistent across all plastic bottle strip mixes, since increasing the plastic strip mix (5 mm x 10 mm) results in a lower maximum dry unit. The size of the plastic strips significantly affects the maximum dry unit, with the (5mm x 5mm) variety increasing and the (5 mm x 10mm) variant decreasing.

Unconfined Compressive Strength (UCS) Test:

We conducted unconfined compressive strength tests to ascertain the unconfined shearing strength. Table 6 displays the summary of the unconfined compressive test results, while Figure 7 presents a bar chart illustrating the comparisons.

Type	**% Added Waste Plastic Strips**	**Unconfined Compressive Strength (MPa)**	**Average UCS (MPa)**
Normal Clay Soil	0	0.1645	0.1982
Plastic Strips (5mm x 5mm)	1%	0.1893	0.1933
	2%	0.2267	0.2341
Plastic Strips (5mm x 10mm)	1%	0.1061	0.1215
	2%	0.1419	0.1532

Table 5: Data of Unconfined Compressive Strength Tests

Figure 7 illustrates the relationship between the unconfined compressive strength and different proportions of plastic bottle strips combined with soil. After carefully examining the given data, the combination containing 2% plastic bottle strips (measured at 5 mm x 5 mm) mixed with ordinary dirt showed a significantly main higher value of 0.2256 MPa. This signifies a significant rise of 22.45% as compared to the original composition consisting of 0% plastic bottle strips or only natural soil.

The results indicate a positive relationship between the proportion of plastic bottle strips measuring (5 mm x 5 mm) and the unconfined compressive strength. Essentially, the findings demonstrate constant improvement in strength as the ratio of main plastic bottle strips in the combination increases to decrease.

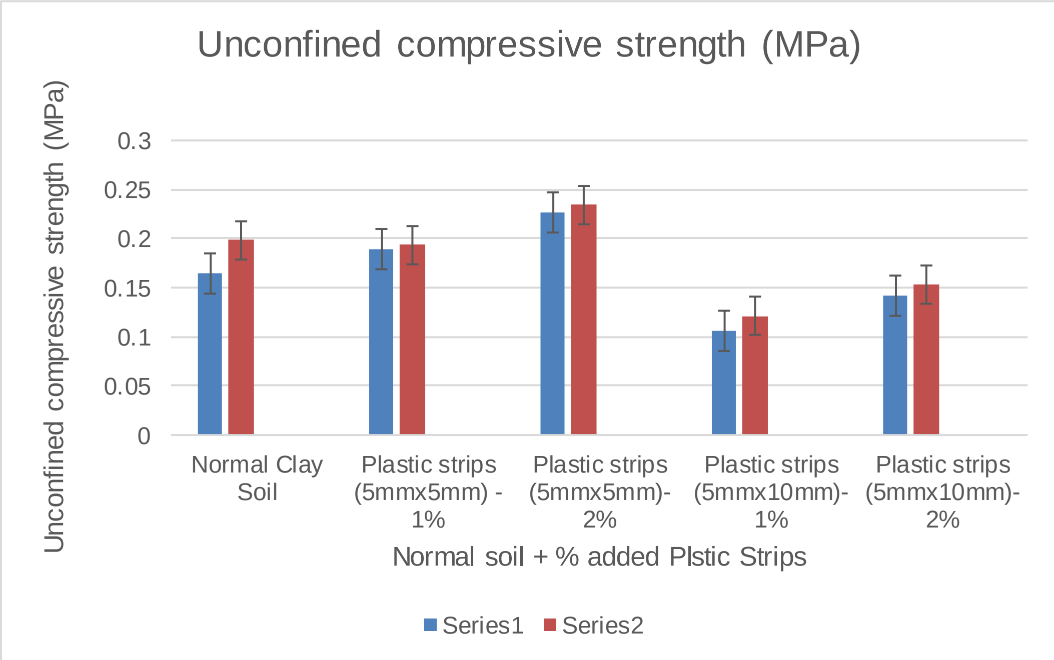

Figure 5: Unconfined compressive strength

California Bearing Ratio (CBR)

The CBR test was employed to evaluate the soil samples' ability to sustain loads. This test is specifically pertinent for assessing the feasibility of utilising stabilised soil in road building and other infrastructure applications.

Soil Sample	CBR (%)
Normal Clay Soil	4.5
Soil + 1% 5 mm x 5 mm Strips	7.0
Soil + 2% 5 mm x 5 mm Strips	8.2
Soil + 1% 5 mm x 10 mm Strips	6.8
Soil + 2% 5 mm x 10 mm Strips	7.5

Table 6: Data of California Bearing Ratio (CBR)

Althouse Table 7 indicate Soil containing plastic strips measuring (5 mm x5 mm), with concentrations of 1% and 2%: The addition of 1% plastic strips measuring (5 mm x 5 mm) resulted in an increase in the CBR value to 7.0%. The treated soil shows a considerable enhancement in bearing capacity compared to the untreated soil, suggesting that even a tiny quantity of plastic reinforcement may greatly increase the soil's ability to bear weight. By increasing the amount of (5 mm x 5 mm) plastic strips to 2%, the CBR value reached 8.2%, which was the highest recorded in this testing. The rise in

CBR can be attributed to the plastic strips' improved load distribution, which minimises soil deformation and enhances stability.

The inclusion of 1% plastic bottle strips measuring (5 mm x 10 mm) in the soil led to a CBR value of 6.8%, which was somewhat lower compared to the CBR value obtained with (5 mm x 5mm) strips at the same percentage. Nevertheless, when the proportion was elevated to 2%, the CBR value saw a rise to 7.5%. While the readings are significantly lower in comparison to the (5 mm x 5 mm) strips, they nonetheless indicate a noteworthy enhancement over the untreated soil.

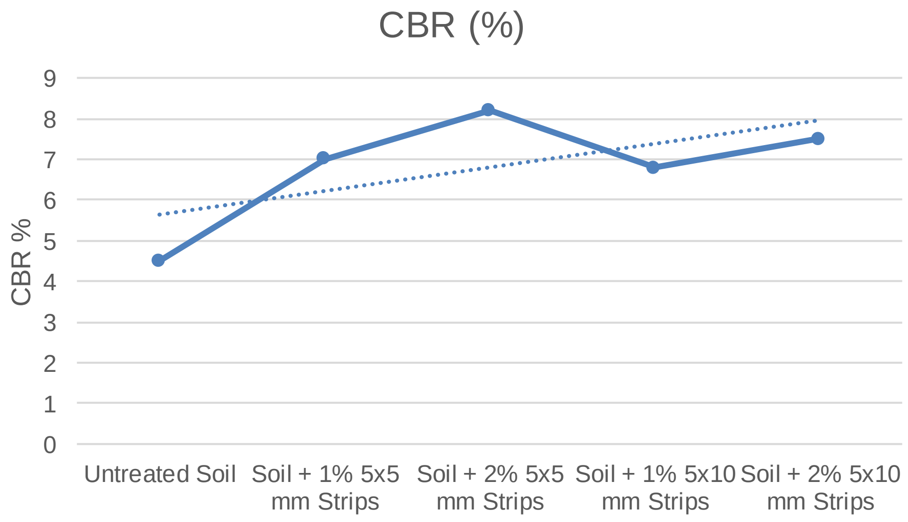

Figure 6: California Bearing Ratio (CBR)

The CBR values demonstrate a significant enhancement in the soil's ability to sustain loads when plastic bottle strips are included. The soil sample comprising 2% of (5 mm x 5 mm) strips had the highest CBR value of 8.2%. The increase in bearing capacity may be ascribed to the enhanced compaction and strength offered by the plastic bottle strips, which render the soil more resilient to deformation when subjected to a load.

Shear Strength

The soil samples were subjected to direct shear testing to evaluate their shear strength characteristics, namely the cohesion (C) and internal friction angle (φ).

Untreated Soil: The cohesiveness of the untreated soil was measured to be 30 kPa, and the internal friction angle was determined to be 26°. The given values describe the inherent shear strength properties of the clay soil. This type of soil usually has a considerable level of cohesiveness owing to the small size of its particles. However, it has a lower internal friction angle, indicating a relatively restricted ability to resist sliding along a shear plane.

Soil Sample	Cohesion (C) (kpa)	Internal Friction Angle (φ) (°)
Normal Clay Soil	30	26
Soil + 1% 5x5 mm Strips	40	28
Soil + 2% 5x5 mm Strips	45	30
Soil + 1% 5x10 mm Strips	38	27
Soil + 2% 5x10 mm Strips	43	29

Table 7: Data of Shear Strength Soil

Here, Table 8 the Shear Soil containing plastic strips measuring (5 mm x 5 mm) at concentrations of 1% and 2%: The addition of 1% plastic strips measuring (5 mm x 5 mm) to the soil resulted in a rise in cohesion to 40 kPa, and an increase in the internal friction angle to 28°. This rise demonstrates that the addition of even a tiny quantity of plastic reinforcement may greatly raise the shear strength of the soil by enhancing the interlocking of soil particles. Incorporating 2% of (5 mm x 5 mm) strips resulted in an increase in cohesion to 45 kPa and the internal friction angle to 30°. This indicates that larger concentrations of plastic strips offer even stronger resistance to shear forces, possibly owing to the improved interaction between the soil and plastic fibres.

Soil containing plastic strips of (5 mm x 10 mm) with concentrations of 1% and 2%: When 1% plastic strips were added, the soil exhibited a cohesiveness value of 38 kPa and an internal friction angle of 27°. Although the readings are lower compared to the (5 mm x 5 mm) strips, they nevertheless indicate a substantial enhancement compared to the untreated soil. By including 2% of (5 mm x 10 mm) strips, the cohesiveness was enhanced to 43 kPa, while the internal friction angle rose to 29°. The somewhat reduced performance seen in the (5 mm x 10 mm) strips may be attributed to their greater dimensions, which might result in a less homogeneous dispersion and interaction within the soil matrix.

Determine Cohesion and Friction Angle

Derive the equation for the failure envelope: The failure envelope in a plot of shear stress vs normal stress is often described by the equation:

$$\tau = C + \sigma n \cdot \tan(\phi)$$

where:

τ = Shear stress at failure

C = Cohesion

σn = Normal stress

ϕ = Angle of internal friction

- **Find Cohesion (C)**: The y-intercept of the failure envelope line (when normal stress $\sigma n=0$) represents the cohesion C.
- **Find Friction Angle (φ)**: The slope of the failure envelope line represents $\tan(\phi)$. You can calculate ϕ by:

$$\phi=\arctan(\text{slope})$$

Example Calculation Using Your Data

Let's use the data for the untreated soil as an example:

- **Shear Strength Data** (from your data):
  - Cohesion (C) = 30 kPa
  - Internal Friction Angle (φ) = 26°

For this soil sample:

- Plot the shear stress (τ) versus normal stress (σ_n).

The line equation obtained from the plot will be:

$$\boldsymbol{\tau=30+\sigma n\cdot \tan(26^\circ)}$$

In my data, for different soil samples with added plastic strips, I would repeat the process, but utilise the given data points to plot the shear strength vs normal stress for each sample, and then compute the cohesion and friction angle as specified. This method allows us to assess how the addition of plastic strips alters the soil's shear strength properties, as evidenced by changes in cohesion and internal friction angle.

CONCLUSION

The primary objective of this study was to conduct experiments to investigate the process of clay soil stabilisation by the utilisation of waste plastic bottle strips. The study sought to assess the efficacy of integrating waste plastic bottle strips as a reinforcement material to enhance the engineering properties of clay soils, specifically in relation to compaction characteristics, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and shear strength parameters.

The results suggest that incorporating discarded plastic bottle strips into clay soils greatly improves their mechanical qualities. The experimental findings demonstrated that the addition of plastic strips, measuring (5 mm x 5 mm) and (5 mm x 10 mm), at concentrations of 1% and 2% respectively, resulted in enhanced Maximum Dry Density (MDD) and reduced Optimum Moisture Content (OMC) in the soil. The unconfined compressive strength (UCS) significantly enhanced when plastic bottle strips were added, reaching its peak in samples containing 2% of (5 mm x 5 mm) plastic bottle strips. The inclusion of plastic strips enhances the load-bearing capacity and structural integrity of the soil.

Moreover, the CBR values of the treated soils exhibited substantial enhancement, indicating that the inclusion of plastic bottle strips enhances the soil's resistance to penetration, rendering it more appropriate for road and pavement construction. The increase in shear strength indices, such as cohesion and internal friction angle, provides additional evidence of the usefulness of plastic bottle strips in strengthening clay soils.

Utilising waste plastic bottle strips for soil stabilisation enhances the soil's engineering characteristics and offers an environmentally friendly approach to plastic waste management. This method of transforming discarded plastic bottles into building materials helps to mitigate environmental pollution and advance the use of sustainable construction techniques.

Nevertheless, it is crucial to acknowledge that the ideal proportion and dimensions of plastic bottle strips must be meticulously calculated according to the soil conditions and intended use. Excessive or improper usage of plastic bottle strips may have negative impacts on the soil's functionality. Hence, it is advisable to conduct more investigations to examine the extended resilience and characteristics of plastic-reinforced soils in various environmental and loading scenarios.

Ultimately, this study shows the successful use of waste plastic bottle strips as a material for soil stabilisation, providing significant engineering benefits and environmental advantages. The results affirm the possibility of using plastic-reinforced soils in a wider range of building endeavours, especially in areas where there is an abundance of plastic trash and clay-rich soils. Future study should prioritise the optimisation of plastic bottle strip usage and investigate their effectiveness in various soil types and climatic situations to create complete guidance for their practical application.

FUTURE WORK

The results of this study on the stabilisation of clay soils using waste plastic bottle strips have shown several opportunities for more investigation. The present work has shown that plastic bottle strips may effectively improve the mechanical characteristics of clay soils. However, further exploration is needed to fully exploit the potential of this technology.

1. **Long-term Durability Studies:** The long-term durability of plastic-reinforced soils is a critical area for future research. The behaviour of plastic bottle strips over protracted periods under varying environmental conditions (e.g., temperature fluctuations, moisture variations, freeze-thaw cycles) must be examined, even though the short-term benefits have been thoroughly established. It is essential to comprehend the long-term performance to accurately predict the lifespan and maintenance needs of infrastructure constructed on or with plastic-reinforced soils.
2. **Impact of Strip Size and Shape**: The current study employed plastic bottle strips of specific dimensions (5mmx5mm & 5mmx10mm) to determine the impact of strip size and shape. To ascertain the most suitable configurations for a variety of soil types and load-bearing applications, future research could investigate a broader spectrum of sizes and shapes, such as lengthier segments, varying widths, or plastic particles with distinct geometries. This could facilitate the creation of solutions that are more specifically designed to address various geotechnical challenges.
3. **Field Trials and Large-scale Applications**: The validation of these findings under real-world conditions is contingent upon the completion of field trials, even though laboratory tests have provided valuable insights. Large-scale experiments on construction sites, such as roads, embankments, or foundations, would offer a more comprehensive comprehension of the practical challenges and advantages associated with the utilisation of waste plastic bottle strips in soil stabilisation.
4. **Environmental Impact Assessment**: Although the utilisation of waste plastic bottle strips in soil stabilisation is a step towards sustainable construction practices, a comprehensive environmental impact assessment is necessary to assess any potential ecological repercussions. The leaching of chemicals from plastic materials into the soil, the impact on soil microbiota, and the overall environmental footprint of the use of such materials in large quantities should be the primary focus of future studies.

5. **Optimization of Mixing Techniques:** The uniformity and efficacy of stabilisation are significantly influenced by the method of incorporating plastic bottle strips into the soil mixture. To optimise the advantages of reinforcement, future research should investigate a variety of combining techniques and apparatus that can guarantee the uniform distribution of plastic bottle strips throughout the soil matrix.

6. **Economic Analysis and Feasibility Studies**: To encourage the widespread implementation of this technique, it is imperative to perform thorough economic analyses that compare the cost-effectiveness of plastic strip stabilisation with other conventional methods. In addition to the material and labour costs, such studies should estimate the potential savings from enhanced infrastructure longevity and reduced environmental impact.

7. **Exploration of Other Waste Materials**: Expanding upon the achievements of utilising waste plastic bottle strips, further investigation might examine the possibilities of employing additional discarded materials, such as plastic fibres, shredded rubber, or recovered composites, for the purpose of enhancing soil stability. This has the potential to expand the range of sustainable construction techniques and make a positive contribution to the circular economy.
8. **Regulatory and Standardization Efforts**: With the increasing prevalence of plastic-reinforced soils, it is necessary to establish industry standards and regulatory guidelines to guarantee the secure and efficient use of these materials. Future endeavours should entail partnering with regulatory entities to create testing processes, safety precautions, and quality assurance benchmarks.

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APPENDICES

Figure 7: Sample of Clay Soil

Figure 8: Prepared Soil Samples for Testing

Figure 9: Soil Samples Drying in an Oven

Figure 10: Clay Soil Samples with Admixture Plastic Strips

Figure 11: Soil with 1% Add Plastic Strips with Compaction Test

Figure 12: Failure of 1s Sample in Compaction Test

Figure 13: Liquid Limit Cup Method

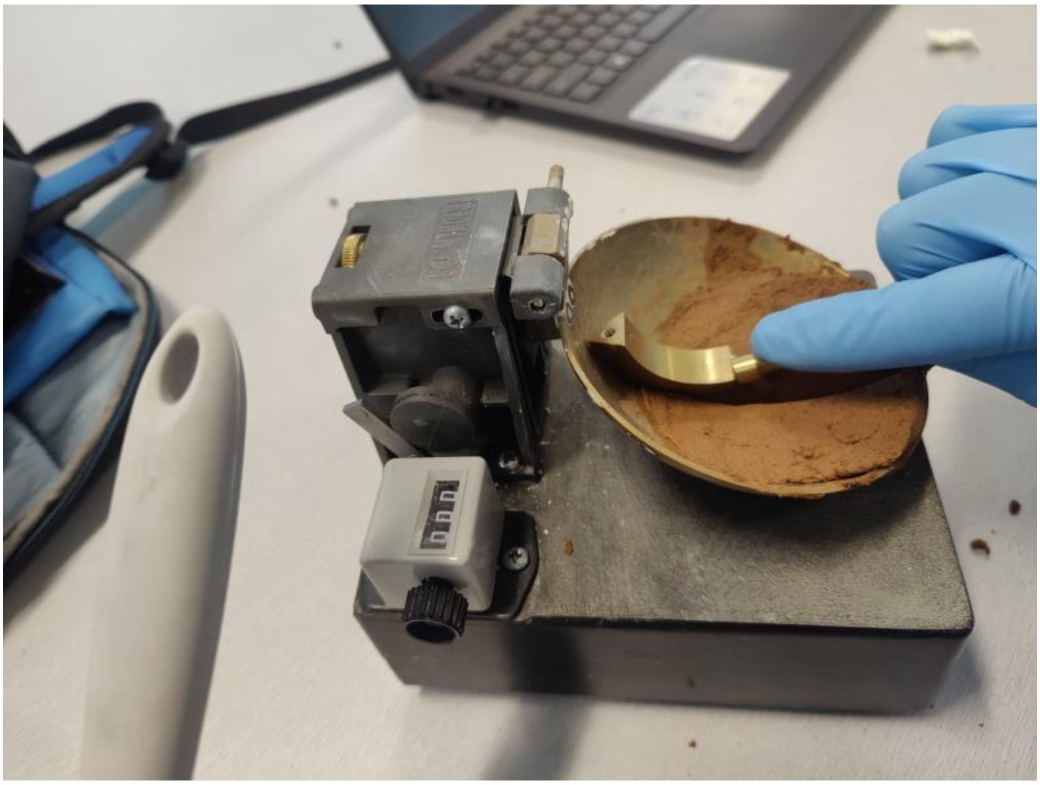

Figure 14: Casagrande apparatus being used the liquid limit of a soil sample.