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Experimental Studies On the Effect of Additives On Clayey Soil

Abhishek Pathak[1], Ragini Mishra[2]

[1] M. E. Scholar, Department of Civil Engineering, Babulal Tarabai Institute of Research & Technology, Sagar, Madhya Pradesh, India
[2] Professor, Department of Civil Engineering, Babulal Tarabai Institute of Research & Technology, Sagar, Madhya Pradesh, India

Abstract
The present study investigates the stabilization of clayey soil using marble dust, an industrial by-product, and banana peel powder, an organic agricultural waste, to enhance soil strength and stability for geotechnical applications. Laboratory tests were carried out on natural clayey soil mixed with varying proportions of marble dust (2%, 4%, 6%, 8%, and 10%) and banana peel powder (2%, 4%, 6%, 8%, and 10%), both individually and in combination. Basic characterization included particle size distribution and specific gravity tests, followed by consistency tests (Atterberg limits) to assess the effect of additives on soil plasticity. The Standard Proctor test was performed to determine compaction characteristics, while the California Bearing Ratio (CBR) test was used to evaluate strength and load-bearing capacity. Results revealed that marble dust significantly improved the maximum dry density (MDD) and CBR values, with the highest performance recorded at a 10% replacement level (MDD = 1.795 g/cc; CBR = 9.2% at a 2.5 mm penetration). In contrast, banana peel powder reduced the liquid limit and plasticity index, improving volumetric stability but offering limited gains in CBR. The combined use of both additives showed complementary benefits, with a mix of 6% marble dust and 4% banana peel powder emerging as the optimal blend, balancing strength improvement with reduced plasticity. The findings suggest that the sustainable use of marble dust and banana peel powder not only improves soil performance but also promotes environmental sustainability through waste utilization.

Keywords: Clayey soil; Soil stabilization; Marble dust; Banana peel powder; Atterberg limits; Compaction; California Bearing Ratio (CBR); Sustainable construction

1. Introduction

The development of infrastructure and civil projects demands construction sites and borrow areas of good natural soils. The suitability of a particular site can be evaluated using test data obtained from high-quality soil samples. Often, obtaining high-quality soil samples is time-consuming and requires expertise, primarily when representative samples differ in soil composition over small distances. Moreover, sample disturbance can adversely affect the test results. Additionally, even after a detailed subsurface investigation, the natural soil at a particular location may or may not meet the foundation's design requirements. It is always desirable to have independent means of analysis and assessment based on a scientific framework that involves soil parameters readily determinable from routine investigations. [1] Soils in general are regarded as multi-component, polyphase, and particulate systems with compositional or structural discontinuities. Both the physical and engineering properties of natural soils primarily depend on their mineralogy and the exchangeable cations associated with the clay fraction. For multi–component soil mixtures, soil samples must be obtained to be mixed, and they must be tested in the laboratory under conditions that represent as nearly as possible field conditions. The problem would be significantly simplified if the engineering characteristics of individual cohesive or non-cohesive soils could be used to predict or estimate their behavioral characteristics as a function of the percentage of components. [2] The classical concepts of soil mechanics were developed primarily through investigations of sedimentary deposits. These concepts, if inadvertently applied to residual soils, may result in misleading conclusions. The residual soils are often found to comprise soils of different compositions, encompassing gravels, sand, silt, and clay. Many engineering applications require specific physical properties to be met for use in infrastructure construction. For instance, the soils used in base courses must satisfy the consistency limits specified in definite standards. [3]

2. Objectives of the Research

The primary research of the study is to evaluate the engineering behavior of clayey soil stabilized with marble dust and banana peel powder. The specific objectives are:

- To investigate the effect of marble dust and banana peel powder, both separately and together, on the Atterberg limits (liquid and plastic limits) of clayey soils.
- To examine the impact of these stabilizers on compaction properties such as Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
- To assess the enhancement in California Bearing Ratio (CBR) values for various proportions of marble dust and banana peel powder.
- To determine the optimal mix proportion of marble dust and banana peel powder that provides maximum strength and stability improvements.

3. Scope of Research:

This study focuses on laboratory tests with natural clayey soil samples to assess the impact of stabilizing them using marble dust and banana peel powder. The stabilization process involves adding these materials in varying proportions, both individually and in combination. The experimental program includes sieve analysis and specific gravity tests for soil classification, as well as Atterberg limits (liquid limit, plastic limit, and plasticity index) to observe changes in consistency. Additionally, the Standard Proctor test is conducted to determine the optimal moisture content and maximum dry density. The soil's strength and load-bearing capacity will be tested through the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests. Additionally, the swelling pressure test will examine volumetric stability under moisture variation. The results of stabilized samples will be compared to untreated soil to evaluate improvements and confirm the effectiveness of marble dust and banana peel powder as stabilizing agents

4. Literature Review:

Abdelkader, H. A., Hussein, M. M., & Ye, H. (2021). The marble process industry in Shaq Al--ouban, East Cairo, Egypt, produces significant marble waste daily during cutting and processing. Most waste is dumped openly, causing environmental issues. About 20-25% of processed stone becomes waste. Egypt also faces expansive soil problems, especially in new cities built on such land. This study aims to utilize marble waste for soil stabilization as a low-cost, locally sourced material to mitigate environmental impact. Marble dust was mixed with expansive soil at 5%, 10%, 15%, 20%, and 25% by dry weight. Tests like Atterberg's limits, Proctor compaction, UCS, CBR, swelling, linear shrinkage, and XRF/XRD analyses were performed on natural and stabilized soils. Soil samples were compacted at optimum moisture content and cured for 7 days. Results showed that marble dust improves soil properties: increasing UCS, CBR, calcite content, and decreasing plasticity index, swelling potential, and optimum moisture, while increasing maximum dry density. In summary, higher marble dust content enhances soil strength and stability. [4]

Jain, A. K., & Jha, A. K. (2020). The extensive use of waste materials relies on their geotechnical and mineralogical properties and how they interact with soil. Little research has explored using marble dust, a quarry waste, as a geo-material. This study investigates marble dust's effect on expansive soil and its interactive mechanism. Various tests—Atterberg limits, swell index, compaction, swelling, unconfined strength, pH, electrical conductivity, mineralogical, microstructural, elemental, FTIR, and thermal analyses—were performed with up to 80% marble dust to optimize its use and understand its behavior. Results show marble dust effectively improves soil plasticity and controls swelling, accelerating early strength, with 20% identified as the Optimum Marble Dust Content (OMDC). Microanalyses indicated that changes in gradation, cohesion, mineralogy, microstructure, and chemistry influence the interaction between soil and marble dust. Factors like mineral composition, curing method, temperature, and longevity also affect OMDC and merit further study. [5]

Debnath, A., Saha, S., Chattaraj, R. (2021). In this study, the effectiveness of marble dust to improve the mechanical properties of clayey soil has been studied. Marble has high lime content, which acts as the main factor for soil stabilization. 25–30% marble dust (MD) is generated during marble quarries, and stones are cut as a block. In this study, marble dust was added in the range of 0–30% to the virgin soil by weight. Various tests, including Atterberg's limits, compaction tests, and strength tests, were performed on both untreated and treated soils. The results obtained for the treated soil were compared with those from the untreated soil. Unconfined compressive strength (UCS) tests were performed at different curing intervals. It was found that the soil strength increased with the increase in marble powder content and curing periods. [6]

Soğancı, A. S., Yenginar, Y., & Orman, A. (2023). Stabilizing clayey soils is challenging in geotechnical engineering. Lime and cement are common materials for shallow and deep stabilization. However, marble dust (MD) and granulated blast furnace slag (GBFS), which are more economical and eco-friendlier, are less used. This study investigates the effects of MD and GBFS on improving both low- and high-plasticity clays. Different percentages (5-20%) of MD or GBFS were added to soils. Experiments, including compaction and unconfined compression tests, measured geotechnical properties. Results showed that adding MD or GBFS reduced optimum moisture content but increased bulk density, dry density, and strength over time. The optimal additive amounts were 15% MD or 10% GBFS for CL soils and 10% MD or 15% GBFS for CH soils. The highest improvement ratios were with 15% MD on CL soils and 15% GBFS on CH soils. Overall, MD and GBFS effectively improve clay soils. [7]

Jarjusey, A., Hayano, K., Kassa (2024) introduce a new method for managing surplus soil in urban construction using banana leaf powder (BLP), an eco-friendly stabilizer derived from agricultural waste. Unlike traditional cement or lime, which raise environmental concerns, BLP from dried banana leaves was tested against orange peel biopolymer (OBP) and fly ash (FA). Results show that BLP's water absorption (Wab) is higher than that of FA but lower than OBP, helping to improve soil compaction and strength. The water absorption mechanism of BLP affects the effectiveness of soil treatment. Analysis of cone index (qc) revealed a material-independent relationship between a parameter (β = Wab × A) and qc for BLP and FA, influenced by their water absorption behaviour. A hybrid stabilizer combining BLP and FA was developed, and experiments showed that FA can slow BLP decay caused by fungal mycelia, thereby enhancing long-term durability. The findings demonstrate that agricultural waste can be effectively used for soil stabilization, addressing issues like high alkalinity and carbon emissions associated with cement and lime stabilizers. [8]

Sweya, L. N., Chacha, N. T., & Saitoti, J. (2024). The study evaluated briquettes made from bagasse (B), corn husk (CH), and cassava roots (CR) using banana peels (BP), wastepaper (WP), and clay soil (CS) as binders. Mixing ratios were based on carbonized materials, and their physical and combustion properties were measured. WP showed weak shatter resistance, CS had the best tumbling resistance, and WP had better water penetration. CS briquettes at 3:1:1 had low moisture (2.7%), while 1:3:1 had low volatile matter (28%), and 2:2:1 had 41%. The ash content was highest (41%) at a 2:2:1 ratio, which also had the highest heating value (HV). BP briquettes at 0:4:1 had the lowest moisture (4.9%), and 2:2:1 had the highest volatile matter (41.5%). Ash was highest (15.5%) at 1:3:1, and 2:2:1 had the highest HV. WP briquettes at a 1:3:1 ratio had the lowest moisture content (2%), while those at a 3:1:1 ratio had the highest volatile matter content (35%). The highest ash was in the ratio 4:0:1. The briquette at 2:2:1 had the highest HV of 25.5 MJ/Kg. All materials were suitable for briquetting, though the weather affected the quality. WP at 2:2:1 showed the best overall results, especially with CR and CH feedstocks. [9]

Matthew and Morgan (2018) reported that the use of Mt. Mazama volcanic ash as a natural pozzolan for sustainable soil and unpaved road improvement. Chemical analyses reveal that Mt. Mazama volcanic ash exhibits a chemistry similar to that found in many Pozzolanic materials. Additionally, Sustainability studies indicate that replacing Portland cement with volcanic ash reduces carbon dioxide emissions and embodied energy. [10]

Rifa'i and Yasufuku (2014) studied the effect of utilizing volcanic ash as a substitute material for soil stabilization from a geo-environmental perspective. They observed that the Utilization of Volcanic Ash with a grain size passing sieve number 270 is more effective. The effect of Volcanic Ash content on soil stabilization can improve the engineering properties of soft soil, alter the grain size distribution curve by decreasing the fine fraction, reduce consistency limits, render the soil non-plastic, increase bearing capacity, and decrease swelling potential. The addition of 35% volcanic ash and 9% lime has the most significant effect on soil improvement. [11]

Cheng & Huang (2019). A clay soil, which was classified under clay of low plasticity (CL) according to USCS, was treated with 4% volcanic ash and a varied composition of sugarcane bagasse ash. The UCS increased from 1.38 to 5.1 kg/cm2 at an optimal mixture of 4% volcanic ash and 10% sugarcane bagasse ash. The maximum CBR value of 13.91% was recorded at an optimal mixture of 4% volcanic ash and 4% sugarcane bagasse ash. [12]

Roesyanto et al, 2017. A clay soil, which is classified as clay of low plasticity (CL) according to the unified soil classification (USCS) system and A-7-6 according to the American Association of State Highway and Transportation Officers (AASHTO) classification system, was treated with a mixture of 2% gypsum and a varied composition of volcanic ash. [13]

Rifa'i et al., 2013. A deposit of volcanic ash was characterized, classified, and utilized as a soil stabilization material in Indonesia. It was observed that the addition of volcanic ash and curing of the specimen for 14 days increased the engineering properties of the soft clay, decreased the liquid limit, and increased the bearing capacity of the clay. A mixture of 35% volcanic ash and 5% lime was found to be the optimum mixture for achieving maximum strength. A volcanic ash resulting from a volcanic eruption on Mount Merapi, when admixed with lime, was used to treat clay soil. [14]

Hossain et al., 2006: Clay soil has been stabilized with a varied composition of cement, lime, volcanic ash, and a combination of these chemicals. Compaction, unconfined compressive strength, split tensile strength, modulus of elasticity, and California bearing ratio tests were used as evaluation criteria to determine the effect of these chemicals on the strength and durability of the clay soil. It was concluded that the stabilized clay using these chemicals can be employed in various constructions, including road pavements and low-cost ones. [15]

Sahu and Rajesh Jain (2016) utilized NaOH in their research to stabilize black cotton soil collected from the Jabalpur region. They aimed to find the effects of NaOH on mixing with black cotton soil, which serves as a stabilizing agent. The percentage of NaOH used ranged from 0 to 16% with soil, and properties such as shrinkage limit, swelling percentage, and consistency limit were observed as the concentration of NaOH increased. Ultimately, it is concluded that some properties of the soil improved, while others deteriorated. [16]

5. Experimental Investigation on Clay – Marble Dust – Banana Peel Powder Mixture

- Over the last years, environmental issues have prompted humans to use industrial wastes as alternatives to some construction materials. Both earthwork researchers and engineers have given considerable attention to utilizing wastes in soil stabilization and enhancing the physical and mechanical properties of soils. This may help both remove environmental problems and contribute to the economy. Industrial wastes, such as fly ash, iron slag, wood ash, plastic waste, and iron filings, show considerable potential to stabilize soils, which are occasionally used to improve the properties of poor soils. Expansive soils shrink when they lose their moisture, but swell when they absorb water. Moisture absorption may occur as a result of rain, torrential downpours, leaking pipes carrying water or sewage, and impeded surface water evaporation due to the built structures adjacent to water reservoirs. Clay soils are highly vulnerable to swelling. [17]
- Soil is one of the most critical materials used in various construction works. Especially for earthworks, dams, bridges, and other similar projects. The expansive soil exhibits high strength in dry conditions but exhibits low strength in wet conditions. Thus, variations in the characteristic behavior of expansive soil result in significant problems in the engineering properties during construction. Numerous laboratory investigations have been conducted to enhance the physical and mechanical properties of soil. To utilize the waste product as a corrected material for construction works, without affecting the environmental aspect. Stabilization of soil with lime, cement, and bitumen is expensive and therefore requires an economically viable alternative. We are using soil mixed with various marble dust and banana peel powder, which exhibits high shear strength, benefiting the Geotechnical material. [18]
- In situ improvement of soil properties using additives is commonly referred to as soil stabilization, which is often used with fine soils. Indeed, soil stabilization is a process in which natural or synthetic materials are added to soil, thereby improving its properties. It is typically used to modify and enhance low-quality materials, which brings about changes in soil properties including decreased rate

of subsidence, decreased adhesion coefficient in soils with high cohesion (clay), increased adhesion coefficient in soils with low cohesion (sand), reduced percentage of water absorption and prevention of soil expansion, reduced cost of earth structures (transport), speed road construction operations, resistance to frost and defrost, improved ductility, reduced rigidity of earth structures, lack of weed growth in the surface of earth structures such as roads and reduced thickness of bearing layer. [19]

- The combination of marble dust and banana peel powder in soil stabilization presents a novel approach with the potential for synergistic effects. The inorganic nature of marble dust complements the organic properties of banana peel powder, resulting in a balanced modification of the soil's properties. This combination can provide a more comprehensive improvement in the soil's strength, plasticity, and durability compared to using each material individually. Experimental studies have demonstrated that this combination not only enhances the mechanical properties of clayey soils but also contributes to more sustainable and environmentally friendly construction practices. [20]

6. Materials:

6.1. Clay:

Clay soil is a type of soil characterized by its fine particles and distinctive physical and chemical properties. These features influence its behavior in agricultural, construction, and environmental contexts. [21]

6.2. Marble Dust

Marble dust is defined as a finely powdered byproduct produced during the cutting, grinding, and polishing of marble. When used in soil stabilization, marble dust serves as a stabilizing agent, enhancing the engineering properties of the soil. It increases soil strength, decreases plasticity, and improves the soil's load-bearing capacity, making it more suitable for construction purposes. The calcium carbonate in marble dust can also help chemically stabilize soils by reacting with clay particles, thereby improving the soil's overall stability and performance in construction projects. [22]

6.3. Banana Peel Powder

Banana peel powder is a finely ground product made from dried banana peels. It is rich in essential nutrients like potassium, phosphorus, calcium, and magnesium, as well as organic compounds such as polyphenols and dietary fiber. Banana peel powder is utilized in various applications, including as a natural fertilizer, a component in animal feed, a bio-adsorbent for water purification, and as an ingredient in skincare and food products due to its antioxidant properties. Its high nutrient content makes it beneficial for soil health and plant growth when used as an organic amendment. [23]

7. Mix Proportions

Natural clayey soils obtained at **Babulal Tarabai Institute of Research & Technology, Sagar**, were stabilized by adding Marble Dust by weight at intervals of 2%, 4%, 6%, 8% and 10% by dry weight of clay. In comparison, Banana peel powder was added at intervals of 2%, 4%, 6%, 8% and 10% by dry weight of the clay sample. The clayey soil was additionally stabilized with a blend of Marble Dust and Banana peel powder at varying percentages, used in earlier individual combinations, totaling five (5) mix combinations. The relative cost of the materials justified the choice of percentages for lime and bamboo ash powder. The specimen (natural clay samples stabilized with lime and bamboo ash powder) will be subjected to compaction and the California bearing ratio test. Tables 1 &2 present the percentage replacement of natural clay samples using Marble Dust and Banana peel powder.

Table 1: Mix proportion of Natural Clay and Marble Dust

Mix No.	Mix Proportions
M1	100% Clay + 0% MD
M2	98% Clay + 2% MD
M3	96% Clay + 4% MD
M4	94% Clay + 6% MD
M5	92% Clay + 8% MD
M6	98% Clay + 10% MD

Table 2: Mix proportion of Natural Clay and Banana Peel Powder

Mix No.	Mix Proportions
B1	100% Clay + 0% BPP
B2	98% Clay + 2% BPP
B3	96% Clay + 4% BPP
B4	94% Clay + 6% BPP
B5	92% Clay + 8% BPP
B6	98% Clay + 10% BPP

In the given table, no.1 represents the mix proportion of clay with some different percentages of marble dust. In the given table, clay has been replaced by marble dust at various percentages. As shown in Table 2, clay is replaced with banana peel powder at multiple percentages.

8. Methodology:

The experimental program aimed to assess the influence of marble dust and banana peel powder on the engineering properties of clayey soil. Natural clay samples were collected, dried, and sieved before being prepared into mixes. Marble dust was added at incremental percentages of 2%, 4%, 6%, 8%, and 10% by dry weight, with banana peel powder added in similar proportions. Selected combinations of both materials were also prepared to study their combined stabilization effects. Standard laboratory tests adhering to IS: 2720 standards were performed. The soil's particle size distribution was determined via sieve analysis, and specific gravity was measured using a pycnometer. Consistency characteristics were evaluated through Atterberg limits tests (liquid limit, plastic limit, and plasticity index) on both untreated and treated samples. The compaction properties were examined using the Standard Proctor test to determine the optimum moisture content (OMC) and maximum dry density (MDD). Strength testing was conducted using the California Bearing Ratio (CBR) test at penetration depths of 2.5 mm and 5.0 mm to evaluate the load-bearing capacity. The results of the stabilized samples were compared with those of the untreated soil to identify trends, assess improvements, and determine the optimal mix proportion for maximum strength and stability.

9. Particle Size Distribution:

The particle size distribution of the soil was determined by sieve analysis, and the results are presented in Table 3. The test was conducted on a soil sample by passing it through a set of standard sieves, ranging from 4.75 mm to 0.075 mm, to measure the percentage retained and the finer fraction at each step. It has been observed that there is no retention of soil particles on the 4.75 mm sieve, indicating the absence of coarser gravel fractions. Most of the soil mass is retained on sieves between 2.36 mm and 0.15 mm, with higher percentages being found at 0.6 mm (17.96%), 0.3 mm (21.18%), and 0.15 mm (21.66%). The cumulative distribution indicates that approximately 85% of the soil is finer than the 0.15 mm sieve and is therefore more likely to be in the range of fine sand to silt-sized. This grading illustrates the finer character of the soil, with only about 3% finer than the 0.075 mm sieve, and is more indicative of the presence of limited clay-sized particles. Table 3 represents the Particle size distribution of clay soil.

Table 3: Particle Size Distribution of Clayey Soil

S. No.	Sieve (mm)	Wt. of retained soil (gm)	%age retained	Cumulative %age	Finer Percentage
1.	4.75	0	0	0	100
2.	2.36	41.20	9	9	91
3.	1.18	84.50	16.87	24.87	75.14
4.	0.6	91.20	17.96	43.81	56.18
5	0.3	105.40	21.18	65	37.17
6	0.15	108.80	21.66	85	14.33
7	0.075	59.40	11.83	97.49	3

According to sieve analysis results, the soil contains only about 3% fines, which are minor particles smaller than the 0.075 mm sieve, indicating it is essentially clean sand. The particle size characteristics were calculated as D10 ≈ 0.115 mm, D30 ≈ 0.241 mm, and D60 ≈ 0.688 mm, resulting in a coefficient of uniformity (Cu) of 5.97 and a coefficient of curvature (Cc) of 0.74. Based on the Unified Soil Classification System (USCS) and IS: 1498, a clean sand is classified as well-graded (SW) if $Cu \geq 6$ and $1 \leq Cc \leq 3$. Since the calculated values are slightly outside these ranges, the soil is classified as poorly graded sand (SP). This indicates that the soil consists of particles within a limited size range, which reduces its compactness and interlocking strength but increases permeability.

10. Specific gravity:

The specific gravity of normal expansive soil is determined in accordance with IS code standards. However, we are accustomed to deciding gravity using the pyrometer test. Therefore, for determining the specific gravity of the mixtures, a standard test method is functional, which is outlined in Chapter 3 of the methodology. It can be considered by using the dry mass of each component and its specific gravity value.

Table 4: specific gravity of soil

Sample No.	Sample 1	Sample 2	Sample 3
Empty pycnometer (M1)	633 gm	633 gm	633 gm
Pycnometer with dry soil (M2)	833 gm	833 gm	833 gm
Pycnometer filled with water (M4)	1476 gm	1475 gm	1476 gm
Pycnometer with soil and water (M3)	1579gm	1585 gm	1587 gm
Specific Gravity	2.06	2.22	2.24

The specific gravity of the soil samples was determined using a pycnometer in accordance with IS: 2720 (Part III) – 1980. The experimental observations for three representative soil samples are summarized in Table 4. The weight of the empty pycnometer (M1) was recorded as 633 g for all trials. In contrast, the weight of dry soil (M2) was 833 g. The pycnometer filled with water alone (M4) weighed approximately 1475–1476 g, whereas with soil and water (M3), the recorded values ranged from 1579 g to 1587 g. Using the standard relation, the specific gravity of the soil solids was computed as 2.06, 2.22, and 2.24 for Samples 1, 2, and 3, respectively. The results indicate that the specific gravity of the soil falls within the typical range for fine-grained soils (2.0–2.7), suggesting a predominance of quartz and feldspar minerals, with a limited presence of heavy minerals or organic matter.

11. Atterberg Limit:

11.1. Liquid Limit and Plastic Limit of Soil

The Atterberg limit indicates the transition state of the soil sample from a liquid to a semi-solid and then to a solid state. The liquid, plastic, and plasticity index are indices of the number of fines present within a soil sample—results obtained from a mixture of clay, marble dust, and banana peel powder. Table no. 10 represents the Atterberg limit of clay. Tables no. 5 & 6 represent the liquid and plastic limits of clayey soil.

Table 5: Liquid limit of clay

Determination No.	Sample no.1	Sample No.2	Sample No.3
No. of blows	34	28	17
Weight of dry soil	120gm	120gm	120gm
Weight of water	65gm	73gm	74.2 gm
Water content	54.16	60.83	61.83

The liquid limit of the expensive soil is 58.66%.

Table 6: Plastic limit of clay

Determination No.	Sample no.1	Sample No.2	Sample No.3
Weight of dry soil	20gm	20gm	20gm
Weight of water	10 gm	9.5gm	9.3 gm
Water content	50	47.5	46.5

Plastic Limit of expensive soil is 48%

Plasticity Index = Liquid Limit- Plastic Limit = 58.66- 48 = 10.66

We are now determining the Atterberg limit using marble dust and banana peel powder at varying percentages. Tables 6 & 7 represent the Atterberg limits of clay with marble dust and clay with banana peel powder at different percentages.

Table 7: Atterberg limits of clay with marble dust

S. No.	Liquid Limit	Plastic Limit
100% Clay	58.66	48
98% Clay + 2% Marble Dust	65.45	53.45
96% Clay + 4% Marble Dust	64.31	52.65
94% Clay + 6% Marble Dust	62.14	51.19
92% Clay + 8% Marble Dust	61.33	50.16
90% Clay + 10% Marble Dust	59.44	48.41

The Atterberg limits of clay mixed with varying amounts of marble dust were measured to evaluate the impact of marble dust on soil consistency. The results, shown in Table X, indicate that the liquid limit of pure clay was 58.66% with a plastic limit of 48%. As marble dust was added, both limits increased initially, reaching their highest values at 2% marble dust (LL = 65.45%, PL = 53.45%) and 4% marble dust (LL = 64.31%, PL = 52.65%). Furthermore, the addition of marble dust caused both limits to decrease gradually, with the liquid and plastic limits dropping to 59.44% and 48.41%, respectively, at a 10% concentration of marble dust. This pattern indicates that small amounts of marble dust enhance the soil's water-holding capacity and plasticity, whereas larger amounts dilute the clay minerals, thereby reducing the consistency limits. Figure 1 shows the Atterberg limits of clay with marble dust.

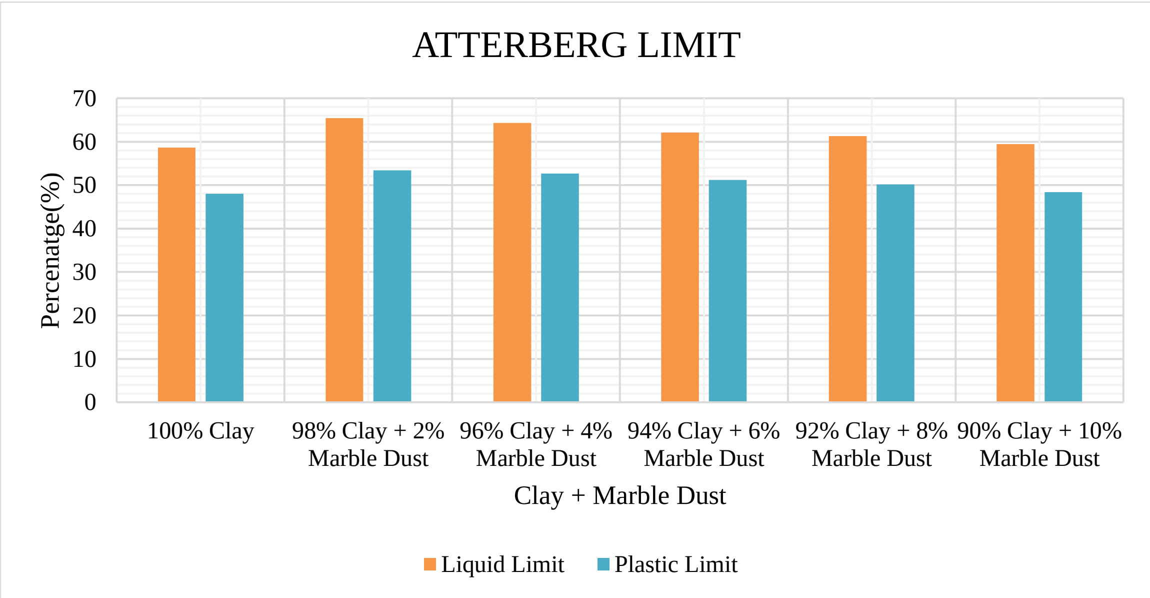

Figure 1: Atterberg limits of clay with marble dust.

Table 8: Atterberg limits of clay with banana peel powder

S. No.	Liquid Limit	Plastic Limit
100% Clay	58.66	48
98% Clay + 2% Banana Peel Powder	57.15	49.16
96% Clay + 4% Banana Peel Powder	56.05	50.51
94% Clay + 6% Banana Peel Powder	54.13	52.64
92% Clay + 8% Banana Peel Powder	52.61	53.65
90% Clay + 10% Banana Peel Powder	51.10	55

The Atterberg limit results of clay mixed with banana peel powder are shown in Table X. For pure clay, the liquid limit and plastic limit were 58.66% and 48%, respectively. As banana peel powder was added, a decreasing trend in the liquid limit was observed, dropping from 57.15% at 2% replacement to 51.10% at 10% replacement. Conversely, the plastic limit gradually increased, rising from 49.16% at a 2% replacement rate to 55% at a 10% replacement rate. This inverse relationship between the liquid and plastic limits indicates that adding banana peel powder reduces the clay's ability to absorb and hold water, while also enhancing its workability by increasing the plastic limit. This behavior suggests that banana peel powder acts as a stabilizer by reducing excessive plasticity, making the soil more suitable for engineering uses. Figure 2 shows the Atterberg limits of clay with Banana peel Powder.

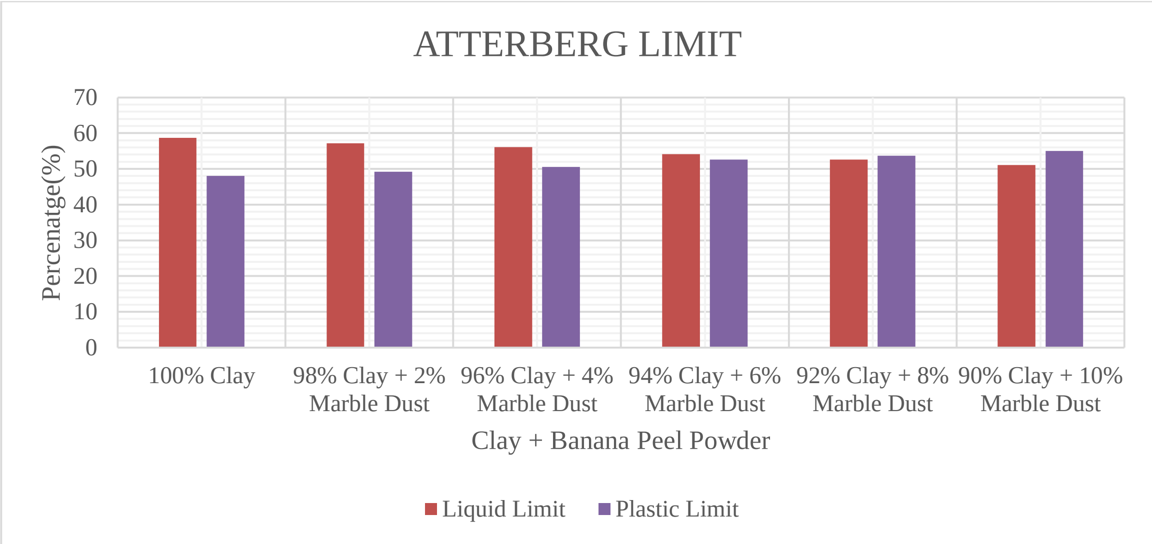

Figure 2: Atterberg limits of clay with Banana peel Powder

12. Standard Proctor Test

The relationship between the maximum dry unit weight and optimum moisture content of natural clayey soils stabilized with Marble dust and Banana peel powder

Table 9: Standard Proctor Test

Proctor compaction test for Clayey Soil	
Optimum Moisture content (%)	Maximum Dry Density (g/cc)
16	1.545
18	1.617
20	1.632
22	1.629
24	1.588
Proctor compaction test for Clayey Soil (98%) + Marble Dust (2%)	
16	1.585
18	1.619
20	1.635
22	1.658
24	1.639
26	1.623
Proctor compaction test for Clayey Soil (96%) + Marble Dust (4%)	
12	1.634
14	1.653
16	1.665
18	1.625
Proctor compaction test for Clayey Soil (94%) + Marble Dust (6%)	

12	1.627
14	1.663
16	1.675
18	1.665
20	1.629
Proctor compaction test for Clayey Soil (92%) + Marble Dust (8%)	
12	1.663
14	1.678
16	1.785
18	1.665
20	1.629
Proctor compaction test for Clayey Soil (90%) + Marble Dust (10%)	
12	1.695
14	1.784
16	1.795
18	1.765
20	1.729
Proctor compaction test for Clayey Soil (98%) + Banana Peel Powder (2%)	
17	1.58
19	1.59
21	1.62
23	1.61
25	1.58
Proctor compaction test for Clayey Soil (96%) + Banana Peel Powder (4%)	
15	1.58
17	1.60
19	1.62
21	1.62
23	1.59
Proctor compaction test for Clayey Soil (94%) + Banana Peel Powder (6%)	
15	1.59
17	1.63
19	1.69
21	1.64
23	1.57
Proctor compaction test for Clayey Soil (92%) + Banana Peel Powder (8%)	
15	1.59
17	1.65
19	1.73
21	1.69
23	1.55
Proctor compaction test for Clayey Soil (90%) + Banana Peel Powder (10%)	

15	1.64
17	1.70
19	1.73
21	1.69
23	1.65

A proctor compaction test was conducted to investigate the impact of marble dust and banana peel powder on the compaction characteristics of clayey soil. For the natural clay, the maximum dry density (MDD) was 1.632 g/cc at an optimum moisture content (OMC) of 20%. Adding marble dust significantly improved compaction behavior. With 2% marble dust, the MDD slightly increased to 1.658 g/cc at a 22% OMC. Higher additions of 4% and 6% marble dust reduced the moisture content to 14–16%, with MDD values ranging from 1.665 to 1.675 g/cm³. The most notable improvements occurred at 8% and 10% marble dust, where the dry density increased sharply to 1.785 g/cc and 1.795 g/cc at 16% OMC, indicating better packing and a lower void ratio due to the filler effect of marble dust. In contrast, banana peel powder showed moderate gains in compaction. At lower percentages (2%–4%), the MDD values were similar to natural clay (around 1.62 g/cc), rising to 1.73 g/cc at 6%–8% banana peel powder. The peak improvement was observed at 10% banana peel powder, with an MDD of 1.73 g/cc at 19% OMC, and a slight decrease was noted at higher moisture levels. Overall, marble dust proved more effective in enhancing the compaction properties of clayey soil than banana peel powder, indicating its greater potential as a stabilizing and densification agent.

13. Results:

13.1. California Bearing Ratio:

The California Bearing Ratio (CBR) test was conducted on clayey soil with incremental additions of marble dust to assess the improvement in load-bearing capacity. The results, presented in Table 10, show the variation of CBR values at standard penetrations of 2.5 mm and 5.0 mm for pure clay and for mixes containing 2% to 10% marble dust.

Table 10: California Bearing Ratio (CBR) for Clay +Marble Dust

Penetration (mm)	**CBR% of Different Percentage of Marble Dust + Clay**					
	100% Clay	98% Clay + 2% Marble Dust	96% Clay + 4% Marble Dust	94% Clay + 6% Marble Dust	92% Clay + 8% Marble Dust	90% Clay + 10% Marble Dust
2.5	6.3	7.4	8.2	8.5	8.7	9.2
5.0	7.0	8.0	8.6	9.0	9.4	9.8

The results of the CBR test clearly indicate that the addition of marble dust enhances the strength characteristics of clayey soil. For pure clay, the CBR values at 2.5 mm and 5.0 mm penetration were 6.3% and 7.0%, respectively. With the inclusion of marble dust, a progressive increase in CBR values was observed, reaching 7.4% and 8.0% at 2% addition, and further improving to 9.2% and 9.8% at 10% addition. The consistent increase in CBR values with higher marble dust content can be attributed to the filler effect of marble dust particles, which reduces void spaces and improves soil densification under load. This results in better load-distribution capability and higher resistance to penetration. The findings suggest that marble dust significantly improves the subgrade strength of clayey soil, making it more suitable for use in pavement layers and other geotechnical applications where higher bearing capacity is essential. Figure 3 shows the California Bearing Ratio (CBR) for Clay +Marble Dust.

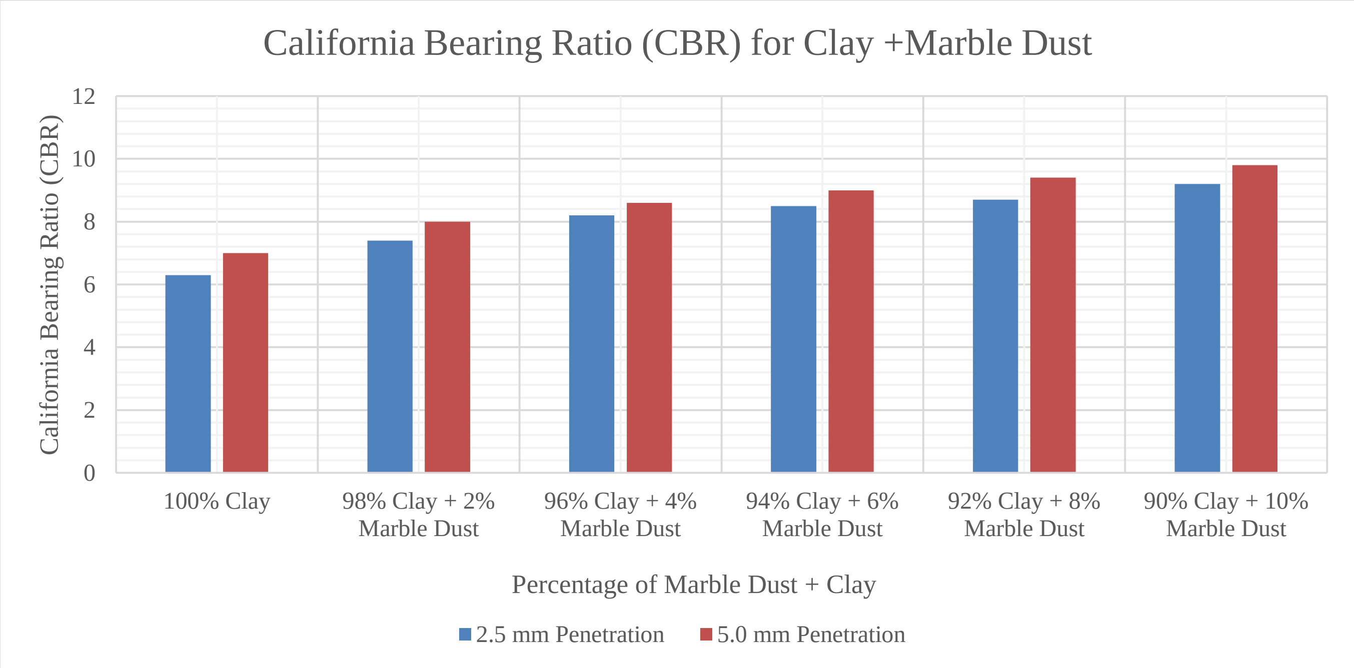

Figure 3: California Bearing Ratio (CBR) for Clay +Marble Dust.

Table 11: California Bearing Ratio (CBR) for Clay +Banana Peel Powder

Penetration (mm)	**CBR% of Different Percentage of Banana peel powder + Clay**					
	100% Clay	98% Clay + 2% Banana peel powder	96% Clay + 4% Banana peel powder	94% Clay + 6% Banana peel powder	92% Clay + 8% Banana peel powder	90% Clay + 10% Banana peel powder
2.5	6.3	6.2	6.2	7.3	7.2	6.7
5.0	7.0	7.6	7.7	6.6	7.5	7.5

The California Bearing Ratio (CBR) results for clay mixed with banana peel powder are shown in Table 11. For pure clay, the CBR values were 6.3% at a 2.5 mm penetration and 7.0% at a 5.0 mm penetration. Adding banana peel powder did not show a consistent improvement trend, unlike marble dust. At lower percentages (2–4%), the CBR values remained nearly the same, with values of around 6.2% at 2.5 mm and 7.6–7.7% at 5.0 mm penetration. At 6% banana peel powder, the CBR at 2.5 mm increased to 7.3%, showing a temporary increase in load-bearing capacity. However, further addition (8–10%) caused fluctuating results, with values ranging from 6.7% to 7.2% at 2.5 mm and 7.5% at 5.0 mm. This inconsistent behavior suggests that banana peel powder may slightly affect soil structure and reduce plasticity, but it does not reliably improve the strength of clayey soil. Therefore, banana peel powder is less effective than marble dust in enhancing the CBR and overall bearing capacity of clay subgrades. Figure 4 displays the California Bearing Ratio (CBR) for clay and banana peel powder.

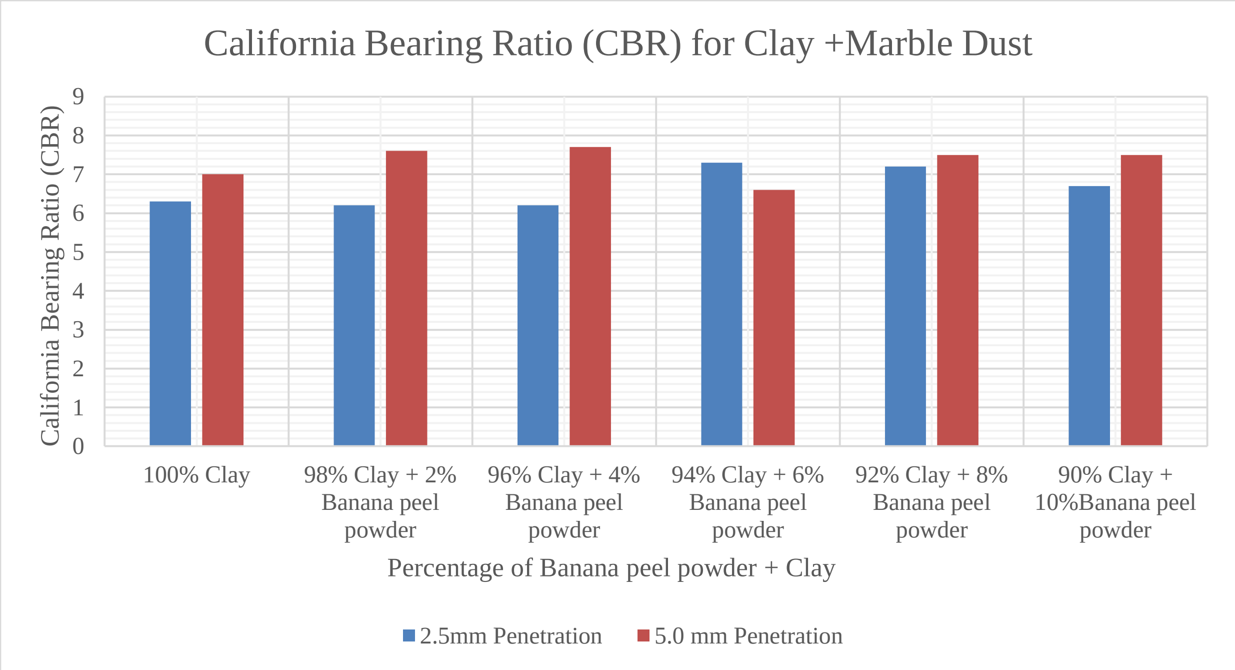

Figure 4: California Bearing Ratio (CBR) for clay and banana peel powder

Analysis of compaction and CBR test results indicates that marble dust and banana peel powder affect the strength and stability of clay differently. Marble dust primarily serves as a mineral filler, enhancing particle packing and reducing voids, which results in a higher maximum dry density (MDD) and California Bearing Ratio (CBR). The best results were obtained at a 10% marble dust concentration, with an MDD of 1.795 g/cc and CBR values of 9.2% at 2.5 mm and 9.8% at 5.0 mm penetration, indicating an improved load-bearing capacity. Conversely, banana peel powder primarily reduces soil plasticity and swelling potential rather than significantly increasing CBR. The optimal range for banana peel powder was 4–6%, where the plasticity index decreased notably, while the strength remained moderate. Overall, a mix of 6% marble dust and 4% banana peel powder is recommended, balancing the benefits of marble dust in compaction and strength with the ability of banana peel powder to reduce plasticity and improve volumetric stability, thereby providing a sustainable and effective soil stabilization approach.

14. Discussion:

The experimental study demonstrates the differing effects of marble dust and banana peel powder in stabilizing clayey soil. Marble dust, an inorganic mineral high in calcium carbonate, mainly enhances soil compaction and bearing capacity. This is demonstrated by a notable rise in maximum dry density (MDD), reaching 1.795 g/cm³ at a 10% replacement, and a steady increase in California Bearing Ratio (CBR) values up to 9.9% at 2% replacement, as measured at 2.5 mm penetration. The filler property of marble dust reduces voids and promotes particle interlocking, leading to improved densification and enhanced load resistance.

Conversely, banana peel powder, an organic additive, had a more pronounced effect on soil consistency than on its strength. The liquid limit decreased steadily, while the plastic limit increased with higher percentages of banana peel powder, resulting in a sharp drop in the plasticity index. This suggests improved volumetric stability and reduced susceptibility to swelling and shrinkage, common issues in expansive clay soils. However, CBR values did not show a consistent upward trend, with only moderate gains of 4–6% at addition before fluctuating to higher levels.

When comparing the two, marble dust was more effective in enhancing strength and density, whereas banana peel powder was better at reducing plasticity and moisture sensitivity. This complementary behavior indicates that a combined mix offers more benefits than using either additive alone. Based on the results, a blend of 6% marble dust and 4% banana peel powder appears to be optimal, as it balances the enhancement of strength and reduction of plasticity. This mixture ensures higher density and CBR values through the addition of marble dust, while the banana peel powder helps control the shrink–swell behavior.

Overall, the study demonstrates that industrial by-products, such as marble dust, and agricultural waste, including banana peel powder, can be efficiently utilized in soil stabilization, offering both environmental and engineering advantages. The combined approach provides a sustainable solution, enhancing soil strength, reducing plasticity, and promoting waste reuse, thereby supporting eco-friendly construction practices.

15. Conclusion:

The experimental study investigated the stabilization of clayey soil using marble dust (2–10%) and banana peel powder (2–10%) as individual and combined additives.

Soil classification tests (sieve analysis and specific gravity) revealed that the natural soil was a poorly graded sand (SP) with limited fines (≈approximately 3% < 0.075 mm) and a specific gravity of 2.06–2.24, indicating a dominance of quartz and feldspar minerals.

Atterberg limits:

- Pure clay showed a liquid limit of 58.66% and plastic limit of 48%, with a plasticity index (PI) of 10.66.
- Addition of marble dust initially increased both LL and PL up to 2–4% replacement, but higher percentages caused a gradual decrease, indicating dilution of clay minerals.
- Addition of banana peel powder caused a steady decrease in LL and an increase in PL, resulting in a significant reduction in PI, thereby lowering soil plasticity and improving volumetric stability.

Compaction characteristics (Proctor test):

- Pure clay had an MDD of 1.632 g/cc at an OMC of 20%.
- Marble dust considerably improved compaction, with the highest MDD of 1.795 g/cc achieved at 10% marble dust (OMC ≈ 16%).
- Banana peel powder gave moderate improvement, with a peak MDD of 1.73 g/cc at 8–10% addition (OMC ≈ 19%), showing it is less effective than marble dust in densification.

California Bearing Ratio (CBR):

- Pure clay exhibited CBR values of 6.3% at 2.5 mm and 7.0% at 5.0 mm penetration.
- Marble dust consistently improved CBR, with maximum values of 9.2% (2.5 mm) and 9.8% (5.0 mm) at 10% addition.
- Banana peel powder did not show consistent improvement; only moderate gains were seen at 4–6% addition, with CBR fluctuating at higher percentages.

Performance comparison:

- Marble dust is more effective in enhancing strength, compaction, and load-bearing capacity due to its filler effect and calcium carbonate content.
- Banana peel powder primarily reduces soil plasticity and swelling potential, improving workability and long-term stability, but has a limited effect on strength parameters.

Optimal mix proportion:

- For maximum strength and density: 0% marble dust is the best single additive.
- For reduced plasticity and moderate strength, 4–6% banana peel powder is effective.
- For balanced improvement in strength and stability 6**% marble dust + 4% banana peel powder** is recommended as the optimal mix.

Sustainability aspect:

- The use of marble dust (an industrial waste) and banana peel powder (an agricultural waste) provides an eco-friendly soil stabilization method, promoting waste utilization, reducing environmental impact, and lowering the cost of soil improvement in civil engineering projects

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