INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

Stabilization of Puducherry Inland Clay with Lime and Quarry Dust: Geotechnical Evaluation

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OPEN ACCESS

Received: 20/08/2025

Accepted: 15/09/2025

Published: 08/10/2025

Citation: Ramesh NJL, Natarajan K, Eswari S (2025) Stabilization of Puducherry Inland Clay with Lime and Quarry Dust: Geotechnical Evaluation. Indian Journal of Science and Technology 18(37): 3024-3039. https://doi.org/10.17485/IJST/v18i37.1467

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Background/Objectives: The expansive clay soils of the Puducherry inland region exhibit high plasticity, excessive swelling, and low shear strength, making them unsuitable for direct use in construction without stabilization. Despite the proven effectiveness of lime and quarry dust as soil stabilizers, limited research exists on Puducherry inland clay, especially regarding long-term curing, durability, and the mechanistic interactions between these stabilizers and the clay. This study investigates the effect of lime and quarry dust as stabilizing agents on the geotechnical characteristics of Puducherry inland clay. **Methods:** Soil samples were treated separately with varying proportions of lime and quarry dust (7%, 14%, 21%, and 28% by dry weight) to assess improvements in geotechnical behaviour. Laboratory tests, including Atterberg limits, Free Swell Index (FSI), compaction characteristics, direct shear test, and Unconfined Compressive Strength (UCS) were conducted to evaluate changes in soil properties. **Findings:** The plasticity index of lime-stabilized clay decreased by approximately 25%, while quarry dust-stabilized clay showed a decrease of approximately 37%. The optimum moisture content of lime-stabilized clay and quarry dust-stabilized clay decreased by about 20% and 35%, respectively. The maximum dry density of lime- and quarry dust-stabilized clay increased by about 10% and 35%, respectively. Cohesion values for both lime- and quarry dust-stabilized clay were reduced by about 28%. The UCS of lime-stabilized clay showed a significant increase up to 21% additive content, beyond which the strength dropped drastically, whereas quarry dust-stabilized clay exhibited a continuous strength increase even beyond 21% addition. The FSI of lime- and quarry dust-stabilized clay decreased by about 35% and 28%, respectively. **Novelty:** Utilizing quarry dust for the stabilization of clay improves soil properties, making it suitable for construction. Compared to lime, quarry dust is abundantly available and is usually disposed of in landfills, contributing to environmental pollution. Stabilizing clay with quarry dust offers two key advantages: it enhances the engineering properties of clay and helps mitigate pollution by effectively utilizing a waste material.

Keywords: Clay; Soil Stabilization; Cohesion; Lime; Quarry Dust; Geotechnical Properties

1 Introduction

In India, expansive soils constitute about 15–20% of the total land area, posing significant challenges for construction and infrastructure development. Their tendency to undergo substantial heave and settlement requires careful geotechnical assessment and stabilization before use in engineering applications. Expansive soils are characterized by their swelling and shrinkage behaviour, which generates higher upward pressure on overlying structures. This volume change is primarily due to the presence of clay minerals with a high affinity for water [(1)]. In India, expansive soils cover about 800,000 km^2 across several states. When such soils cannot provide adequate stability for construction, designers usually avoid the site, alter foundation design, replace the soil, or improve it through ground improvement techniques such as soil stabilization. Stabilization is often preferred due to its cost-effectiveness compared to replacing problematic soils with better-quality soils such as murrum [(2)].

Non-cohesive soils are generally preferred for the construction of subgrades for roads. In cohesive soils, the major issues are their swelling and shrinking nature, which leads to differential settlement, making them unsuitable for construction. To reduce differential settlement, deep foundations or pile foundations are often preferred; however, these make construction far more expensive than the superstructure itself. For low-cost construction, stabilizing cohesive soils is far more economical than adopting deep foundations [(3)]. To stabilize clay, materials often used include molasses, waste foundry sand, construction demolition waste, lime, polyurethane resin, and glass waste. Among these, lime is the most widely used worldwide as the oldest traditional stabilizer [(4)]. Soil stabilization is carried out to improve the poor geotechnical properties of existing soil, especially where site space is limited, offering a more economical alternative to deep foundations. The aim is to prevent future settlement and enhance shear strength and bearing capacity [(5)].

Lime addition improves the strength of expansive clays. The presence of calcium chloride can absorb atmospheric moisture and retain slight dampness in the clay, ultimately reducing shrinkage cracks. The presence of calcium chloride may therefore be responsible for the improvement in strength [(6)]. Utilizing waste materials as an alternative to stabilize clay is an effective approach to promoting environmental sustainability. Many waste materials possess favourable qualities, making them suitable for use in foundations, stabilization, construction, and highway development [(7)]. Lime addition to clay triggers two stages of reactions, providing both immediate and long-term benefits. In the short term, cation exchange occurs between clay particle ions and calcium ions from lime, reducing the excess water around the particles and creating stronger particle bonds. In the long term, a pozzolanic reaction takes place, where SiO^2 and Al^2O^3 combine to form gel-like structures such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), leading to further soil strengthening [(8)]. The addition of quarry dust significantly enhances the quality of Korattur clay soil, making it more suitable for use in pavement construction [(9)]. Economic analysis shows that using a 1:2 mix of fly ash and quarry dust, up to 45% replacement, can significantly reduce construction costs while improving expansive soil subgrades for flexible pavement construction [(10)].

Although lime and quarry dust have been shown to be excellent soil stabilisers, there has been little research, notably on the Puducherry inland clay, which has unique geotechnical properties. Previous research has mostly concentrated on short-term strength increases, with little emphasis on long-term cures, durability, and a mechanistic understanding of lime and quarry dust interactions with clay. The majority of recent studies on soil stabilisation have looked at lime or quarry dust, frequently just assessing short-term strength. These approaches do not address the long-term viability and sustainable use of industrial byproducts. In contrast, the suggested model compares the use of lime and quarry dust in terms of availability, economic effectiveness, and environmental sustainability as stabilisation methods. Furthermore, the potential for quarry dust to minimise lime usage and provide a more sustainable stabilisation technique has not been fully investigated. This work fills these gaps by doing a thorough geotechnical examination of Puducherry inland clay stabilised with variable quantities of lime and quarry dust over a variety of curing times.

2 Methodology

2.1 Materials

The soil samples were taken from the Sudhagar Nagar (Latitude: 11°92'48.10" N; longitude: 79°79'91.0) Reddiyarpalayam, Puducherry from depth of 1.5 m to 5 m for the study. Figure 1 representing the location map of the study area. The samples from the selected location were collected using Auger boring method as per IS 1892-1979. After sample collection in airtight bags, samples were shifted to the laboratory. The soil samples were pulverized in the pulverizing machine after drying. Dried samples were sealed again in the airtight bags, which prevents further moisture loss. The soil was classified as High compressible silty clay as per plasticity chart IS 1498-1970. Figure 2 representing the Plasticity chart for the collected sample. Table 1 gives the geotechnical characteristics of the Puducherry clay investigated in the research.

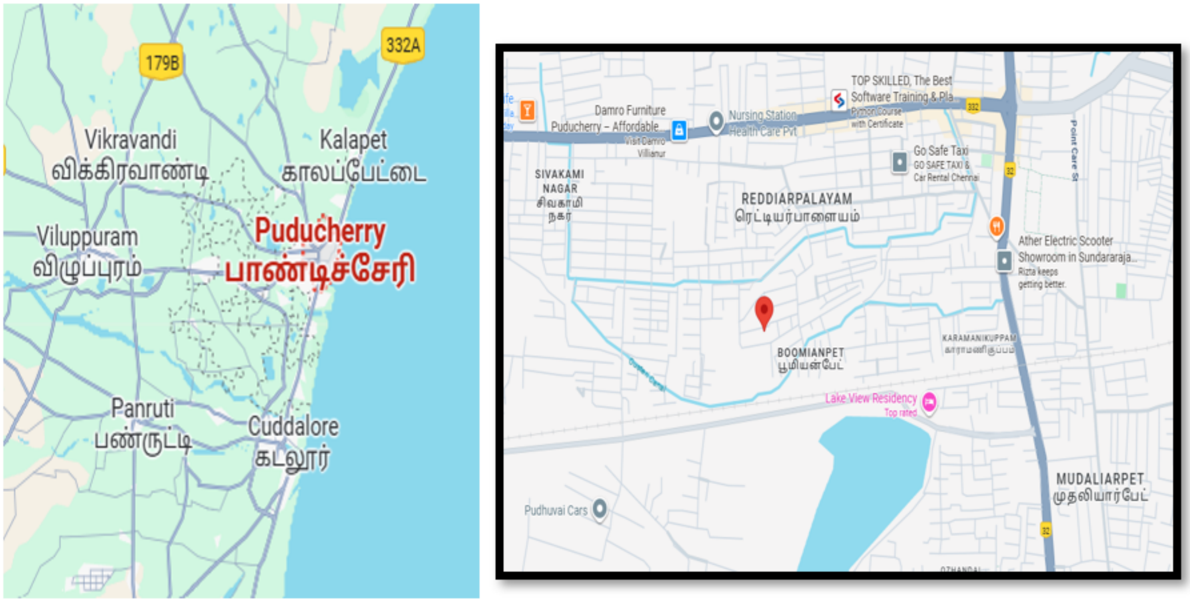


Fig 1. Location Map of the Study Area

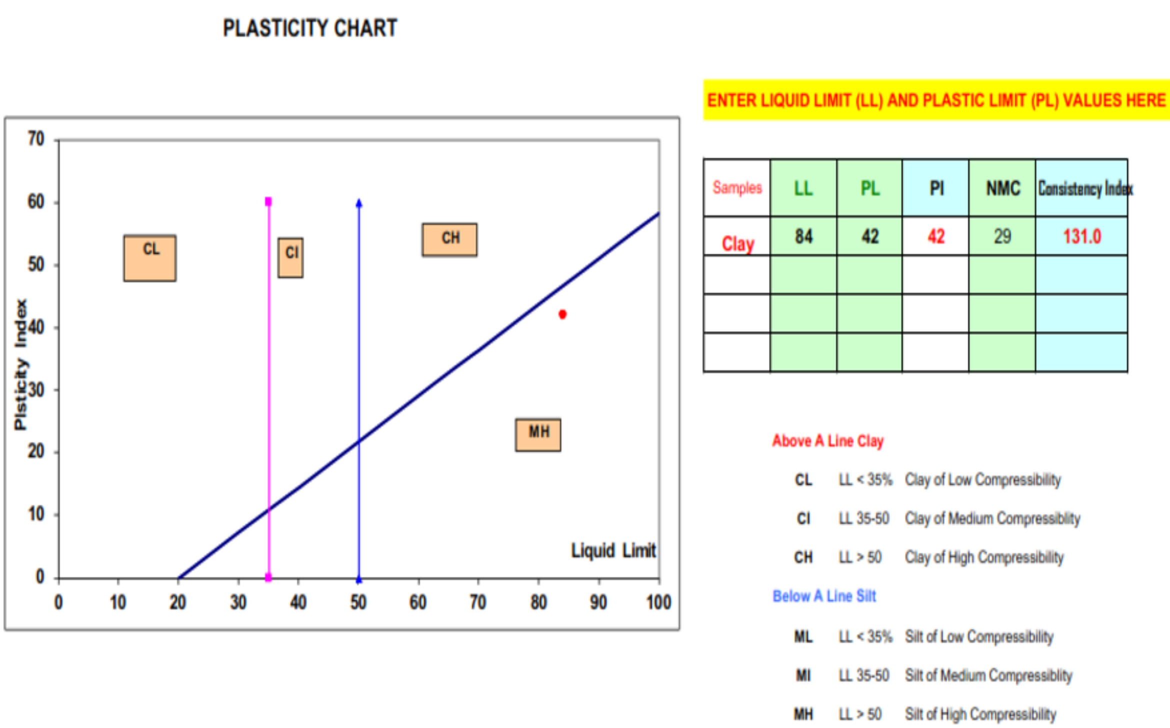


Fig 2. Plasticity Chart of Collected Sample

Table 1. Geotechnical Characteristics of Puducherry Inland Clay

PropertiesTested	Result Values		Values as per IS Code		IS Codes
Natural Moisture Content (NMC) %	32		30 – 50%		IS 2720 (Part 2): 1973
Wet Density (kN/m^3)	15.1		14 - 18		IS: 2720 (Part 28) – 1974
Free Swell Index (FSI) %	100		50-100%		IS: 2720 (Part 40) – 1977
Direct Shear	C (kN/m^2)	ϕ (Degree)	C (kN/m^2)	ϕ (Degree)	IS: 2720 (Part 13) – 1986
	3.81	8°55'	0 - 20	0° - 10°	
Liquid Limit	84		50 – 100		IS: 2720 (Part 5) – 1985
Plastic Limit	42		35 – 50		
Optimum Moisture Content (OMC) %	23.53		16 – 22		IS: 2720 (Part 7) – 1980
Maximum Dry Density (MDD) kN/m^3	16.4		16 - 19		
Grain Size Analysis (%)	Silt (%)	Clay (%)	Silt (%)	Clay (%)	IS: 2720 (Part 4) – 1985
	71.11	28.89	50 - 85	15 - 50	

Lime used in this study collected from Thondamanathham in Villianoor District. Lime, due to its high alkalinity and reactivity with clay minerals, is an efficient soil stabiliser that reduces flexibility and swelling while increasing soil strength through cation exchange and pozzolanic reactions. However, insufficient lime or poor drying might limit its function, making the use of quarry dust a more sustainable and effective stabilisation technique. Figure 3 is representing grain size distribution curve for the lime used in this study. Table 2 gives the geotechnical properties of lime used in this study.

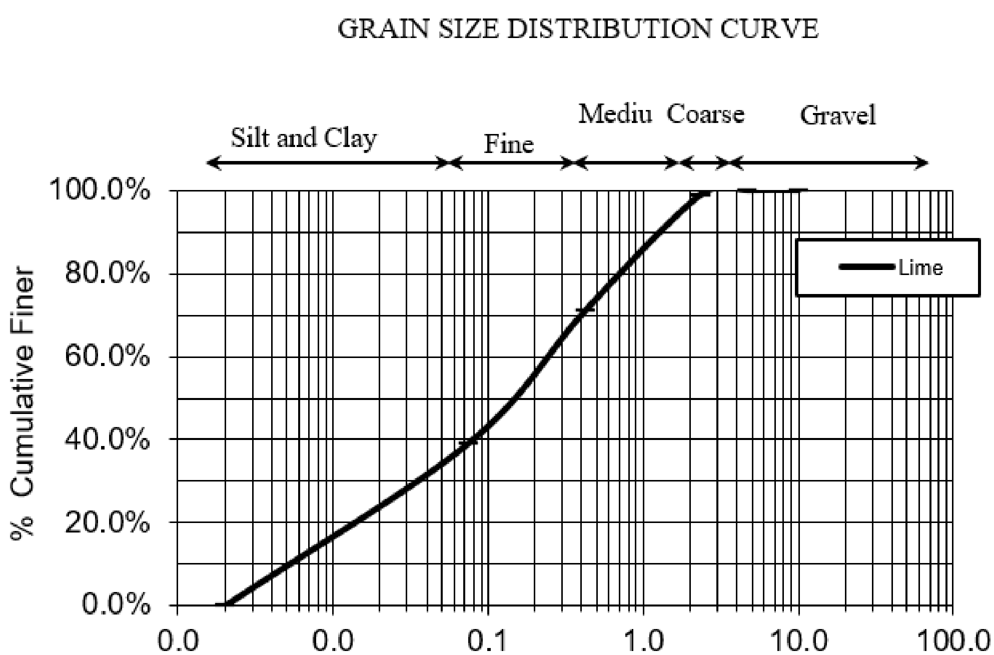


Fig 3. Grain Size Distribution Curve for Lime

Quarry dust used in this study collected from Thiruvakkarai, Villupuram district, Tamil Nadu. It is a by-product generated during the mechanical crushing of rocks in quarries. It consists of fine, angular particles rich in silica and alumina. In soil stabilization, quarry dust acts as a filler, reduces voids, enhances compaction, and improves strength and durability. Figure 4 is representing grain size distribution curve for the quarry dust used in this study. Table 3 gives the geotechnical properties of quarry dust used in this study.

Table 2. Geotechnical Characteristics of Lime

PropertiesTested	Result Values		Values as per IS Code	
Natural Moisture Content (NMC) %	Nil		Nil	
Wet Density (kN/m^3)	9.4		9 - 13	
Free Swell Index (FSI) %	Nil		Nil	
Direct Shear	C (kN/m^2)	ϕ (Degree)	C (kN/m^2)	ϕ (Degree)
	2.01	25°91’	0 - 20	0° - 30°
Liquid Limit	Nil		Nil	
Plastic Limit	Nil		Nil	
Optimum Moisture Content (OMC) %	26.92		18 – 28	
Maximum Dry Density (MDD) kN/m^3	15.85		15 - 18	

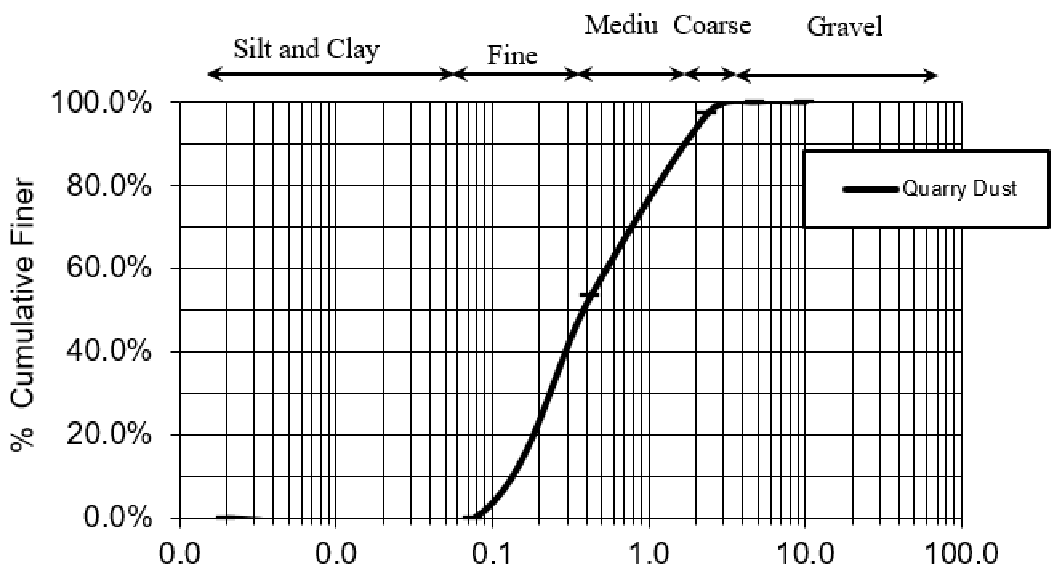


Fig 4. Grain Size Distribution Curve for Lime

Table 3. Geotechnical Characteristics of Quarry Dust

PropertiesTested	Result Values		Values as per IS Code	
Natural Moisture Content (NMC) %	Nil		Nil	
Wet Density (kN/m^3)	18.9		16 - 19	
Free Swell Index (FSI) %	Nil		Nil	
Direct Shear	C (kN/m^2)	ϕ (Degree)	C (kN/m^2)	ϕ (Degree)
	4.36	26°33’	0 - 20	0° - 30°
Liquid Limit	Nil		Nil	
Plastic Limit	Nil		Nil	
Optimum Moisture Content (OMC) %	11.36		8 - 12	
Maximum Dry Density (MDD) kN/m^3	21.27		17 - 22	

2.2 Mix ID Details for Stabilization

Table 4 shows various mix ID for the stabilization. CC represents clay collected from the site needs to be stabilization. To stabilize the clay, lime and quarry dust has been added at the rate of 7%, 14%, 21% and 28% by the weight of clay respectively and cured for 0, 7, 14, 21, 28 and 56 days.

Table 4. Mix ID details for stabilization

Sl. No	Mix ID	Description
1.	CC	Puducherry Inland Clay
2.	CC+7%L	Puducherry Inland Clay + 7% of Lime by the weight of Clay
3.	CC+14%L	Puducherry Inland Clay + 14% of Lime by the weight of Clay
4.	CC+21%L	Puducherry Inland Clay + 21% of Lime by the weight of Clay
5.	CC+28%L	Puducherry Inland Clay + 28% of Lime by the weight of Clay
6.	CC+7%QD	Puducherry Inland Clay + 7% of QD by the weight of Clay
7.	CC+14% QD	Puducherry Inland Clay + 14% of QD by the weight of Clay
8.	CC+21% QD	Puducherry Inland Clay + 21% of QD by the weight of Clay
9.	CC+28% QD	Puducherry Inland Clay + 28% of QD by the weight of Clay

2.3 Testing Methods

2.3.1. Atterberg Limits

The Atterberg limits of the soil, such as Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI), were found based on IS: 2720 (Part 5) – 1985. These tests were conducted on the soil samples passing through a 425 μm sieve to get exact results. Casagrande apparatus was used to determine the liquid limit of the soil sample. A uniform paste of oven dried soil mixed with a distilled water was placed in the brass cup of the device and a standard groove was cut through its centre using grooving tool. The cup was repeatedly dropped from a height of 10 mm at a rate of two revolutions per second and No. of blows required to close the grove over a distance of 12 mm was recorded. Plastic Limit was found by rolling the soil sample on a glass plate. About 20 g of soil mass was mixed with distilled water to form a cohesive mass and small portions were rolled into threads of uniform diameter by hand till the thread reached 3mm in diameter. The rolled threads were collected and oven dried to determine their moisture content. The same procedure repeated for three trials, and the average value was reported as PL. Plasticity index represents the range of water content over which the soil sample exhibits plastic behaviour, which provides an indication of its cohesiveness. Plasticity index can be calculated as difference between liquid limit and plastic limit. Figure 5 shows the Casagrande Apparatus.

2.3.2. Free Swell Index (FSI)

The free swell index test was used to find the swelling behaviour of the soil samples based on IS: 2720 (Part 40) – 1977. This test determines the increase in volume of a soil sample when immersed in water compared to immersion in a non – polar fluid (Kerosene). The same procedure repeated for three trials, and the average value was reported. Figure 6 shows free swell index experiment. The free swell index is determined using the below formula,

$$\text{FSI }(\%) = \frac{V_d - V_k}{V_k} \times 100$$

Where, V_d = Volume of soil in distilled water (ml)

V_k = Volume of soil in Kerosene (ml)

Fig 5. Casagrande Apparatus

Fig 6. Free Swell Index Test

2.3.3. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

OMC and MDD were found using the proctor compaction test based on IS: 2720 (Part 7) – 1980. Oven dried soil passing through 4.75 mm sieve was taken and mixed thoroughly with a known quantity of water. The mould with base plate attached was weighed and assembled with the extension collar. The soil was compacted in the mould in three layers and 25 blows in each layer. The mould with the compacted soil was weighed to determine the bulk density. A soil sample from the mould to determine its moisture content by oven drying at 105 - 110°C. The test was repeated, and average value was tabulated. Figure 7 shows the Proctor Compaction Test Apparatus.

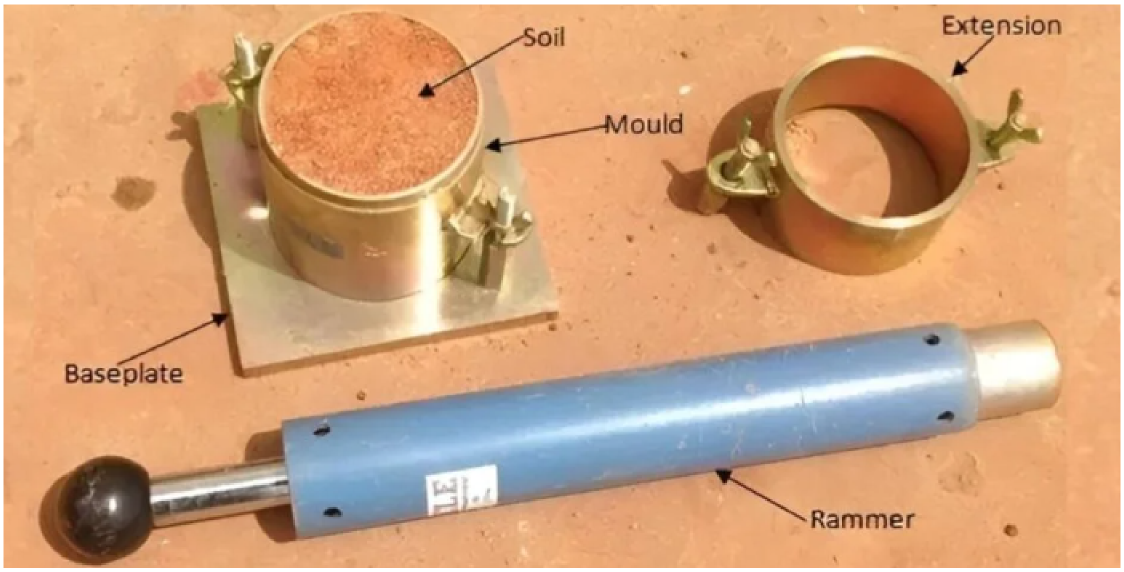


Fig 7. Proctor Compaction Test

2.3.4. Direct Shear Strength

Shear strength of the soil sample were determined using Direct Shear Test as per IS: 2720 (Part 13) – 1986. To find cohesion (c) and angle of internal friction (ϕ) of the soil, the test was conducted under consolidated drained conditions. Oven dried soil sample was compacted into a shear box in three layers to achieve the desired density. A normal load was applied vertically on the specimen using the loading frame. The load and corresponding horizontal displacement were recorded until the specimen failed, indicated by a peak in the shear force or large displacement and the same procedure repeated for at least three different normal stresses. Figure 8 Shows the Direct Shear Test Apparatus.

2.3.5. Unconfined Compressive Strength (UCS)

Unconfined compressive strength of the soil sample was determined in accordance with IS: 2720 (Part 10) – 1991. Oven dried soil sample is taken for the preparation of cylindrical specimens of 38mm diameter and 76 mm height were carefully prepared using respective moulds from a larger sample. Specimens were placed vertically between the platens of the compression machine. Axial load was applied gradually at a strain rate of 0.5 – 2% per minute. The test was repeated for at least three specimens to obtain significance results. Figure 9 shows the unconfined compressive strength Apparatus.

3 Results and Discussion

3.1 Atterberg Limits

As shown in Figures 10(a) and 10(b), both lime-treated and quarry dust-treated clay exhibit a marked reduction in liquid limit and plasticity index compared to untreated inland clay across all curing stages. For lime-treated clay, the plasticity index decreased by approximately 3–38%, with higher lime contents (21% and 28%) consistently showing the greatest improvement, particularly at longer curing periods. Similarly, quarry dust-treated clay showed reductions in plasticity index ranging from 2–37%, with the most significant decreases observed at higher quarry dust contents. These results indicate that both lime and

Fig 8. Direct Shear Strength Test

quarry dust effectively lower the plasticity of Puducherry inland clay, thereby improving its workability and reducing its swelling potential.

From the above graphs, curing time had a consistent influence on PI reduction, with longer curing periods yielding greater improvements. Lime stabilization alone showed a steady and progressive reduction in PI, while the combination with quarry dust exhibited an initial fluctuation followed by a sharp drop beyond the mid-level replacement ratio. These results confirm that higher stabilizer content and longer curing periods are key factors in minimizing soil plasticity, making the treated clay more suitable for construction applications such as subgrade layers. Furthermore, the inclusion of quarry dust not only enhances the pozzolanic reaction but also promotes the sustainable utilization of industrial by-products.

Bharadwaj et al. suggested that a maximum of 9% lime along with molasses and waste foundry sand improved the geotechnical characteristics of soft clayey soil[4]. Phanikumar et al. reported similar observations, noting that both LL and PI decreased as the percentage of lime increased with the curing period[6]. Lakshmi et al. also observed a decrease in the plasticity index up to the addition of 50% quarry dust; beyond this level, no further decrease was found[9]. A.K. Jain et al. reported a decrease in LL, PL, and PI when adding quarry dust up to 80%, although the decrease was not linear. A similar trend was observed in the present study; however, marble dust was replaced with quarry dust[11].

3.2 Free Swell Index (FSI)

Figure 11 presents the results of the Free Swell Index test for untreated, lime-treated, and quarry dust-treated clay at 0, 7, 14, 21, 28, and 56 days of curing. From the figure, it is evident that the curing period plays a more significant role in the reduction of swell compared to the percentage addition of stabilizers.

As shown in Figures 11(a) and 11(b), both lime and quarry dust treatments significantly reduced the swell index of Puducherry inland clay compared to the untreated sample. For lime-treated clay, the reduction ranged from 6–39%, with greater improvements observed at higher lime contents (21–28%) and longer curing periods. Similarly, quarry dust-treated clay showed reductions in swell index ranging from 1–45%, with the most substantial improvement achieved at higher quarry dust contents (21–28%), particularly at early curing stages. These results confirm that both stabilizers effectively control the swelling potential

Fig 9. Unconfined Compressive Strength Test

of the clay, with lime showing more consistent long-term performance, while quarry dust exhibits pronounced improvements at higher dosages.

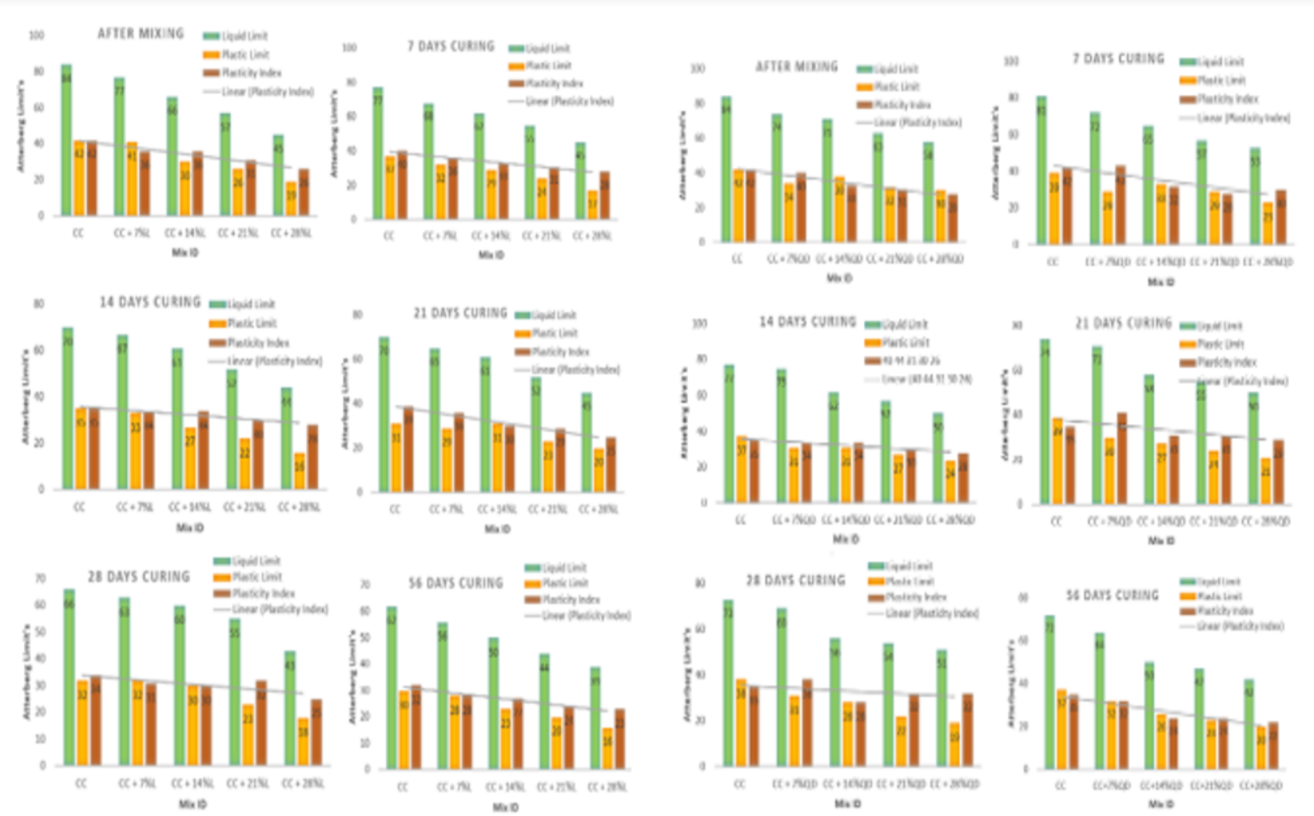
Both lime-treated clay and quarry dust-treated clay show a significant reduction in swelling behavior; however, lime-treated clay performs better than quarry dust-treated clay. This is because quarry dust lacks a pozzolanic reaction and primarily acts as a filler material. In addition, quarry dust exhibits higher water absorption compared to lime, which also contributes to the difference in the swell index between quarry dust-treated clay and lime-treated clay. lime stabilization proved more effective and reliable in controlling swelling behaviour, while quarry dust can serve as a supplementary stabilizer, particularly when combined with lime, contributing to both soil improvement and sustainable use of industrial by-products.

Phanikumar et al. observed a reduction in the FSI with increasing lime content, which was attributed to flocculation triggered by lime, leading to a decrease in FSI [6]. A.K. Jain et al. studied stabilization with marble dust, and their results differed from the present study in that up to 80% addition of marble dust significantly reduced the FSI due to its granular structure [11].

3.3 Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

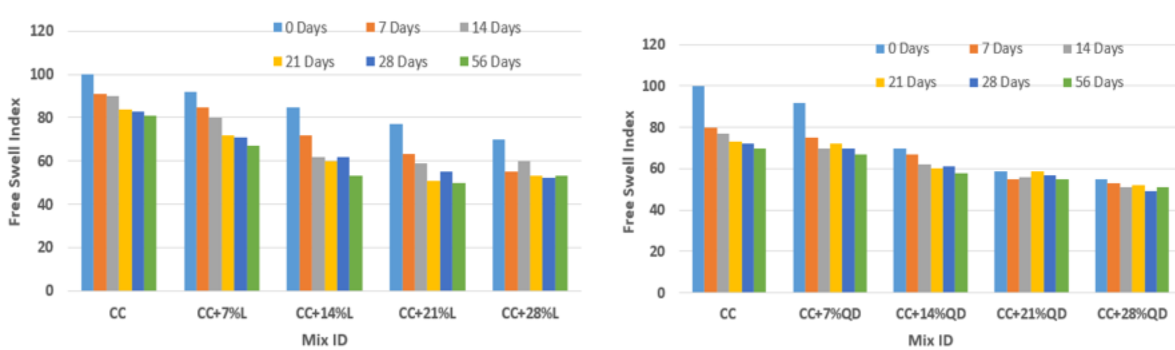
Figure 12 presents the results of OMC and MDD for untreated, lime-treated, and quarry dust-treated clay at 0, 7, 14, 21, 28, and 56 days of curing. Treatment with lime and quarry dust enhanced both the OMC and MDD of the inland clay.

As shown in Figures 12(a–d), the addition of lime and quarry dust significantly influenced the compaction characteristics of Puducherry inland clay. The optimum moisture content (OMC) decreased consistently with increasing stabilizer content, showing reductions of about **6–33%** across curing stages, with maximum reductions observed at higher dosages (21–28%). In contrast, the maximum dry density (MDD) increased progressively with both lime and quarry dust addition, recording increments in the range of **6–41%**, again with the greatest improvements at higher contents and longer curing periods. These results highlight that lime and quarry dust stabilization enhance the soil's compaction efficiency by reducing water demand and improving particle packing, thereby leading to higher dry densities.



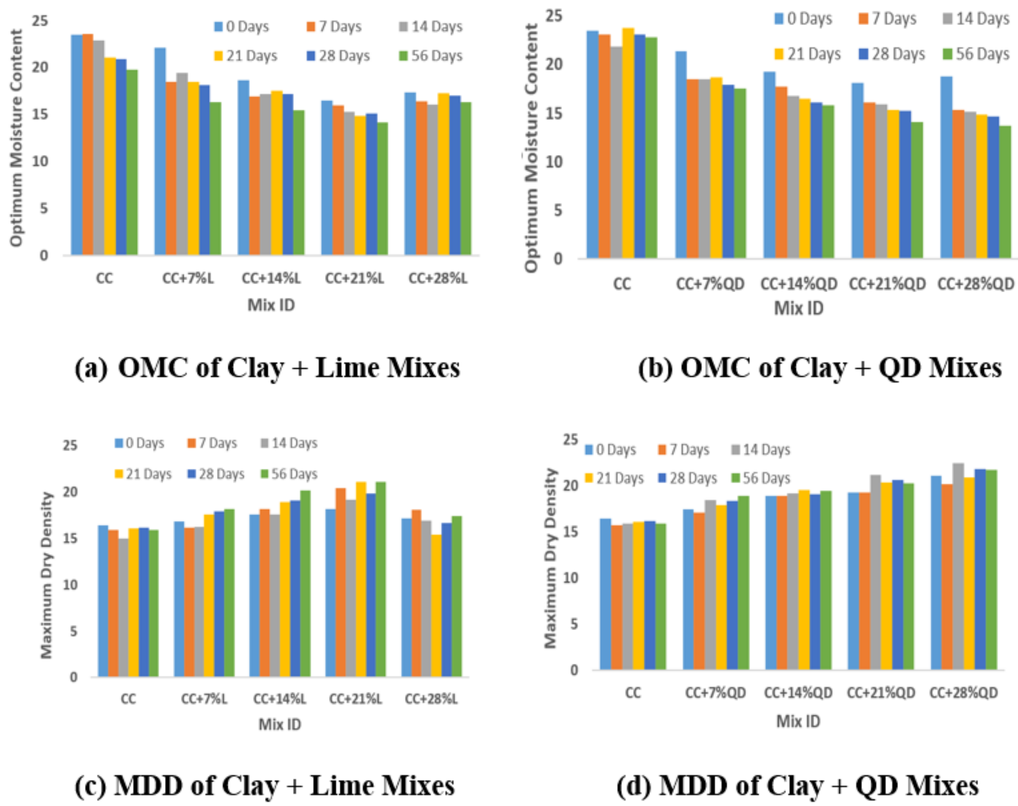
(a) Clay + Lime Mixes (b) Clay + Quarry Dust Mixes

Fig 10. Effect of Lime and Quarry Dust on Atterberg Limits



(a) Lime treated Clay (b) Quarry Dust treated Clay

Fig 11. Free Swell Index of Untreated and Treated Clay



(a) OMC of Clay + Lime Mixes

(b) OMC of Clay + QD Mixes

(c) MDD of Clay + Lime Mixes

(d) MDD of Clay + QD Mixes

Fig 12. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

From the experimental results, it is evident that both lime and quarry dust significantly influence the compaction characteristics of inland clay. The OMC consistently reduced with increasing percentages of stabilizers and longer curing periods. It shows that the treated soil requires less water to achieve maximum compaction compared to untreated clay. This reduction is attributed to improved particle rearrangement and pozzolanic reactions, which reduce the affinity of clay particles for water. In contrast, the MDD increased with the addition of lime and quarry dust across all curing periods. The improvement was more pronounced at higher stabilizer contents and longer curing durations, reflecting enhanced particle packing, reduced void spaces, and the formation of cementitious compounds that strengthen the soil matrix. From the above observations, it is found that lime and quarry dust stabilization enhance the compaction properties of inland clay by reducing OMC and increasing MDD, thereby improving the soil's suitability for engineering applications.

Mahdi et al observed lowest OMC and highest MDD were achieved when using crushed concrete as a stabilizer which is somewhat similar to the quarry dust used in our study shows similar results [5]. A. K. Jain et al found similar observations when stabilizing the clay with marble dust up to 80% [11]. R. A. Blayi et al found that adding waste glass powder also shows similar trend as in our study but beyond 18% the scenario became reversed [12].

3.4 Direct Shear Strength

Figure 13 shows the variations in cohesion (c) and angle of friction (ϕ) for untreated clay, lime-treated clay, and quarry-dust-treated clay at 0, 7, 14, 21, 28, and 56 days of curing.

As shown in the figure 13 (a), cohesion values fluctuate with curing days, decreases up to 14 days and beyond that it increased slightly however angle of friction increased consistently increased with the curing period. Addition of 7% lime decrease cohesion from 3.2 to 2.4 kN/m^2, then recovers slightly at 56 days but angle of friction increases consistently from 12 $^\circ$ to 18 $^\circ$. Addition of 14%, 21% and 28% lime also show similar trend as in the 7% addition. Decrease in cohesion in the early stage is due to the flocculation, dispersion and reduction in double layer thickness. But in the later curing stages cohesion enhanced due to the pozzolanic reactions. Addition of lime enhance the pozzolanic reaction makes the improved particle interlock leads to increase the angle of friction consistently.

As shown in the figure 13 (b), cohesion values start high in the clay but gradually decreases with curing time and angle of friction remains low and slightly increase with curing time. Untreated clay shows high cohesion for strength with limited frictional resistance. Quarry dust treated clay reduce cohesive bonding but improves frictional resistance due to its granular nature. When percentage of quarry dust addition increases it decreases cohesion and increases the internal angle friction ultimately it increases the shear strength of stabilized soils.

Adding quarry dust to the clay dilutes it and reduces the cohesion, enhances interparticle friction due to its angular and granular nature which ultimately leads to higher internal friction values. Addition of quarry dust making the soil more stable and after prolonged curing resistant to shear failure also enhanced.

3.5 Unconfined Compressive Strength (UCS)

Figure 14 presents the UCS test results for untreated, lime-treated, and quarry dust-treated clay at 0, 7, 14, 21, 28, and 56 days of curing.

As shown in the figure 10 untreated clay shows very low UCS values at all curing stages representing its weak load bearing capacity. Addition of lime up to 21%, increases UCS consistently was observed across all curing days. This strength is attributed to the pozzolanic reaction between clay and lime, leading to the formation of C-S-H and C-A-H. But at 28% lime addition UCS values at all curing stage dropped so low drastically and it is due to excess free lime weakens the soil structure instead of strengthening it. At high percentages of lime can absorb moisture, leach out and form weak planes inside the soil matrix. The UCS value becomes zero after 28% lime addition because the optimum lime content has already been exceeded. Beyond this limit, there is no further chemical reaction possible, and the excess lime leads to poor bonding, increased voids, and potential brittleness, thereby collapsing the soil structure under loading.

In contrast, UCS test results of quarry dust treated mixes are superior than the lime treated mixes. The increase in the strength is consistent in almost all the percentage of quarry dust and at all stages of curing. At 28% quarry dust content, the UCS value is 1600 kN/m^2 at 56 days of curing, the highest value among all the mixes. Overall, both lime and quarry dust effectively stabilized the clay, with strength gain being more gradual in lime-treated mixes due to slow pozzolanic activity, while quarry dust provided a higher and more rapid improvement in UCS. Hence, quarry dust can be considered more effective than lime, particularly at higher replacement levels (21–28%), for enhancing the strength characteristics of the studied clay.

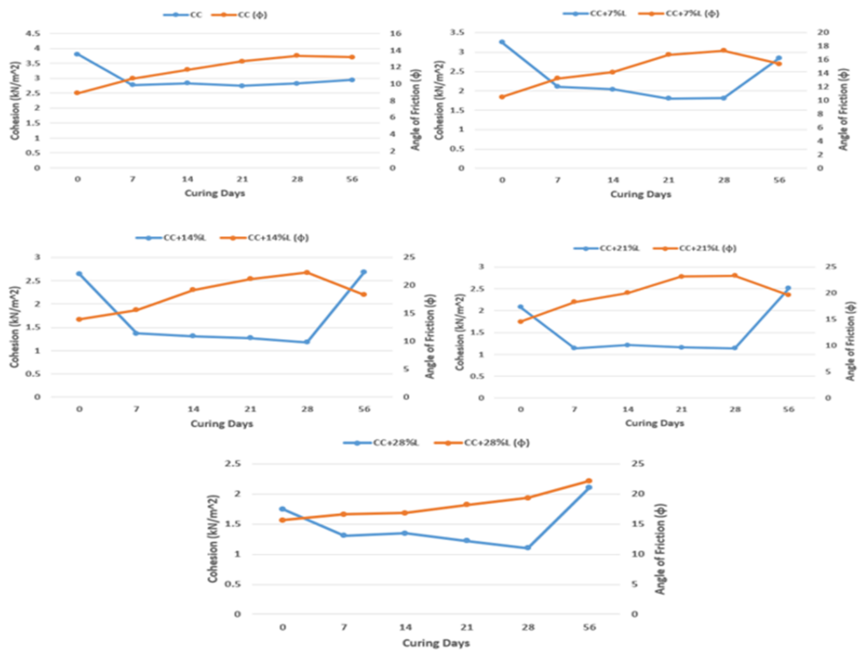
Shelema studied stabilization of clay with waste brick powder, in that UCS test upto 20% addition shows increment whereas beyond 28% drastic reduction was found its very similar to the current study when adding lime to the clay[(13)].

The experimental results clearly indicate that quarry dust stabilization provides superior improvement in the geotechnical properties of Puducherry inland clay compared to lime stabilization. While lime is effective in reducing plasticity and initiating pozzolanic reactions with clay minerals, its performance is limited by several factors. Excessive lime addition beyond the optimum level leads to the presence of free lime, which does not participate in reactions and can weaken the soil structure, as evidenced by the reduction in strength at higher dosages. Moreover, lime stabilization requires longer curing periods for significant pozzolanic activity to develop, delaying strength gain and durability.

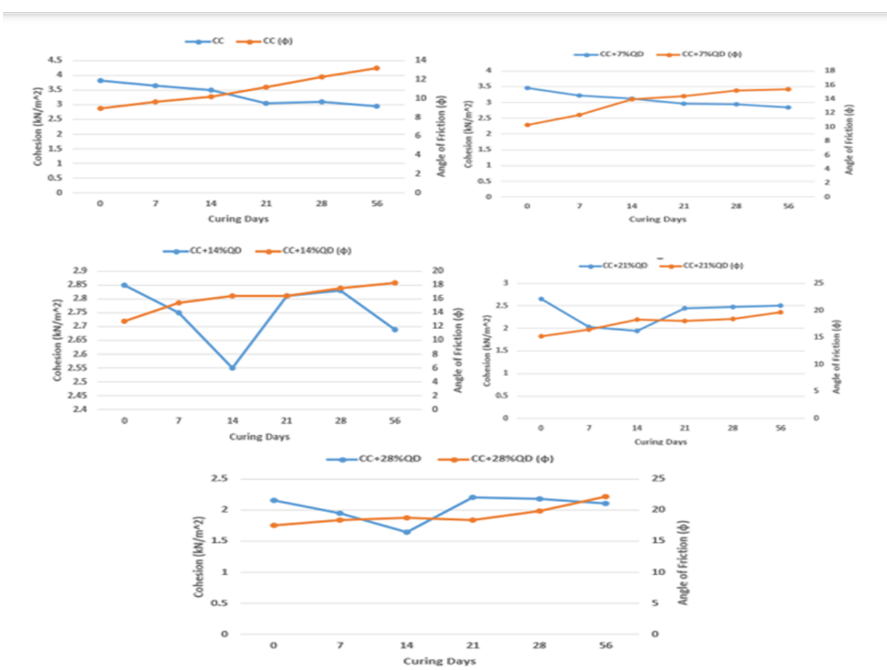
In contrast, quarry dust exhibits both immediate and long-term benefits. The reduction in swell index with quarry dust addition was substantially higher than that achieved with lime at equivalent dosages and curing periods. For example, at 28% addition, quarry dust reduced swelling by up to 45%, while lime achieved a maximum reduction of only 39%. This demonstrates the stronger ability of quarry dust to control volume instability, a critical property for expansive clay soils.

The superiority of quarry dust can be attributed to its dual role as a mechanical stabilizer and micro-filler. Being a coarse, non-plastic material with angular particles, quarry dust improves soil gradation, increases maximum dry density (MDD), and reduces optimum moisture content (OMC), leading to a denser and more stable soil matrix. Unlike lime, which primarily relies on chemical reactions, quarry dust physically occupies voids and reduces water absorption pathways, offering faster and more consistent improvement without the drawbacks of excessive lime demand or curing dependency.

Therefore, the results confirm that quarry dust is a more effective stabilizer than lime for Puducherry inland clay, particularly in terms of reducing swelling potential, improving compaction characteristics, and enhancing long-term dimensional stability. This makes quarry dust a cost-effective and sustainable alternative to lime, especially in regions where quarry dust is abundantly available as an industrial by-product.

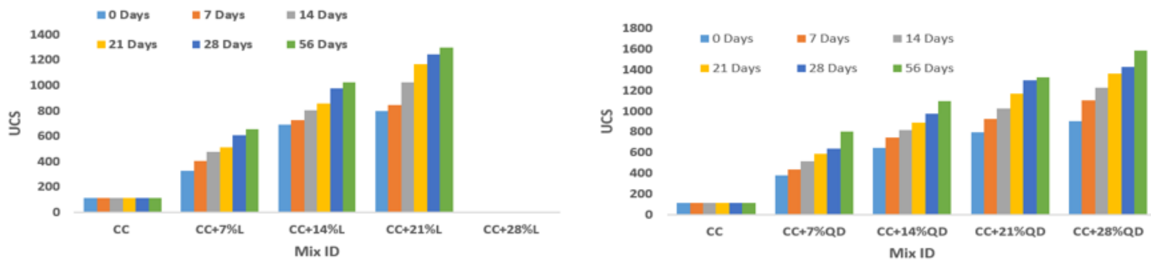


(a) Clay + Lime Mixes



(b) Clay + Quarry Dust Mixes

Fig 13. Direct Shear Test results of untreated clay, lime treated clay and quarry dust treated clay



(a) Clay + Lime Mixes **(b) Clay + Quarry Dust Mixes**

Fig 14. Unconfined Compressive Strength Test Results of untreated clay, lime treated clay and quarry dust treated clay

3.6 Cost Analysis of lime and quarry dust stabilized clay

Compared to lime stabilisation, quarry dust stabilisation has a lower unit treatment cost (INR/m^3). This is mostly owing to quarry dust's cheaper material unit pricing and similar handling and transportation logistics. Common execution costs (mixing, compaction, curing, and QA/QC) are comparable between alternatives; hence the difference is driven by additive purchase and transportation. As a result, quarry dust provides a cost-effective stabilisation option, especially where local availability reduces haul distances. Table 5 presents the cost analysis of lime and quarry dust as a stabilizer.

Table 5. Cost Analysis of Lime and Quarry Dust as a Stabilizer

Sl. No	Dosage (% Dry Mass)	Lime (INR) (m^3)	Quarry Dust (INR) (m^3)
1.	7	1548	331
2.	14	2893	458
3.	21	4237	585
4.	28	5581	712

4 Conclusion

The present study provides a comprehensive geotechnical evaluation of Puducherry inland clay stabilized with lime and quarry dust. The results demonstrate that both stabilizers significantly reduce plasticity and swelling potential while enhancing compaction characteristics and strength. The use of lime and quarry dust offers clear advantages: lime initiates cation exchange and pozzolanic reactions, while quarry dust improves particle packing and reduces lime demand. The reductions in plasticity index (up to 38%), swell index (up to 45%), and optimum moisture content (up to 33%), together with increases in maximum dry density (up to 41%) and strength parameters, establish the effectiveness of the proposed method. Unlike previous studies that investigated only for short term geotechnical properties whereas the properties for longer curing periods (0–56 days) on this soil type that has not been studied extensively. In addition to technical improvements, the method promotes sustainability by utilizing quarry dust, a waste by-product, and minimizing lime consumption.

- The study discovered that treatments with lime and quarry dust significantly decreased the inland clay's plastic limit, liquid limit, and plasticity index. Longer curing times and higher stabiliser contents resulted in a greater reduction. While quarry dust-treated clay underwent some initial fluctuations before plummeting well beyond mid-level replacement, lime-treated clay improved steadily and gradually throughout the course of the curing process.
- Due to pozzolanic reactions and reduced water absorption, lime outperformed quarry dust in lowering the swell index of clay. Although it worked best at greater dosages, quarry dust primarily served as a filler. When used together, they improve oedema management and encourage the sustainable use of industrial byproducts.
- Lime and quarry dust improved compaction characteristics through pozzolanic reactions and better particle packing, lowering OMC and raising MDD of inland clay. The results support the usefulness of industrial by-products in soil stabilisation and are consistent with earlier research employing crushed concrete, marble dust, and leftover glass powder.

- Lime continuously increases the friction angle while decreasing cohesiveness at first because of flocculation and then increasing it later on during curing through pozzolanic reactions. Because quarry dust is granular, it improves frictional resistance while decreasing cohesiveness. While quarry dust improves interparticle friction and lime strengthens bonding, both stabilisers increase shear strength.
- Clay that has not been treated exhibits low UCS, whereas lime increases strength by up to 21% through pozzolanic processes, but at 28% it decreases because of too much free lime. With a maximum strength of 28%, quarry dust continuously improves UCS and outperforms lime at higher replacement levels for stabilising clay.

The study shows that combining lime and quarry dust improves the geotechnical qualities of Puducherry inland clay by lowering fluidity and increasing strength, providing a long-term alternative for soil stabilisation. Future research could concentrate on long-term durability under changing environmental conditions, microstructural studies to better understand reaction mechanisms, field-scale validation for road and embankment applications, optimisation of lime-quarry dust proportions for economic efficiency, and assessment of environmental impacts such as leachability and carbon footprint to strengthen the case for large-scale practical adoption.

5 Acknowledgements

The study is part of the research conducted by the first author towards a Ph.D. Dissertation.

References

1) Tiwari N, Satyam N. An experimental study on the behavior of lime and silica fume treated coir geotextile reinforced expansive soil subgrade. *Engineering Science and Technology, an International Journal*. 2020;23(5):1214–1222. https://doi.org/10.1016/j.jestch.2019.12.006.
2) Barman D, Dash SK. Stabilization of expansive soils using chemical additives: A review. *Journal of Rock Mechanics and Geotechnical Engineering*. 2022;14(4):1319–1342. https://doi.org/10.1016/j.jrmge.2022.02.011.
3) Gosk W. The use of cohesive soils improved with lime as an example of circular economy in earthworks. *Inżynieria Bezpieczeństwa Obiektów Antropogenicznych*. 2022;30(3):10–20. https://doi.org/10.37105/iboa.146.
4) Avinash B, Kumar SR. Influence of industrial wastes and lime on strength characteristics of clayey soil. *Magazine of Civil Engineering*. 2023;120(4):12002. http://dx.doi.org/10.1108/JEDT-12-2019-0350.
5) Karkush MO, Yassin S. Improvement of geotechnical properties of cohesive soil using crushed concrete. *Civil Engineering Journal*. 2019;5(10):2110–2119. http://dx.doi.org/10.28991/cej-2019-03091397.
6) Phanikumar BR, Raju ER. Compaction and strength characteristics of an expansive clay stabilised with lime sludge and cement. *Soils and Foundations*. 2020;60(1):129–138. https://doi.org/10.1016/j.sandf.2020.01.007.
7) Hasan M, Zaini MS, Yie LS, Masri KA, Jaya RP, Hyodo M, et al. Effect of optimum utilization of silica fume and eggshell ash to the engineering properties of expansive soil. *Journal of Materials Research and Technology*. 2021;14:1401–1418. https://doi.org/10.1016/j.jmrt.2021.07.023.
8) Beyene A, Tesfaye Y, Tsige D, Sorsa A, Wedajo T, Tesema N, et al. Experimental study on potential suitability of natural lime and waste ceramic dust in modifying properties of highly plastic clay. *Heliyon*. 2022;8(10). https://doi.org/10.1016/j.heliyon.2022.e10993.
9) Lakshmi SM, Sivakumar VL. Utilizing Crushed Stone Waste in Stabilization of Expansive Clay for Sustainable Development;vol. 621. EDP Sciences. 2025. https://doi.org/10.1051/e3sconf/202562101012.
10) Godfrey WTJ, Telema N, Horace IJ. Investigation of the Geotechnical Properties of Laterite Soil Combined with Quarry Dust and Lime. *Heliyon*. Available from: https://www.cell.com/heliyon/fulltext/S2405-8440(21)02381-1.
11) Jain AK, Jha AK. Geotechnical behaviour and micro-analyses of expansive soil amended with marble dust. *Soils and Foundations*. 2020;60(4):737–751. https://doi.org/10.1016/j.sandf.2020.02.013.
12) Blayi RA, Sherwani AF, Ibrahim HH, Faraj RH, Daraei A. Strength improvement of expansive soil by utilizing waste glass powder. *Case Studies in Construction Materials*. 2020;13:e00427. https://doi.org/10.1016/j.cscm.2020.e00427.
13) Amena S. Experimental study on the effect of plastic waste strips and waste brick powder on strength parameters of expansive soils. *Heliyon*. 2021;7(11). Available from: https://www.cell.com/heliyon/fulltext/S2405-8440(21)02381-1.