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Stabilization of expansive soil with lime and brick dust

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Abstract. Expansive soils in construction pose significant challenges due to their low strength, high compressibility, and potential for swelling. The article is dedicated to assessing the effectiveness of using lime and brick dust as additives to enhance the properties of highly plastic soils. Various tests were performed on soil samples treated with different lime and brick dust concentrations, including moisture content, maximum dry density, unconfined compressive strength, yield strength, plasticity, and swelling index. The results indicate that the addition of 5 % lime improved the soil's strength properties, resulting in a significant increase in its compressive strength. With increased lime concentration, a decrease in plasticity was observed, indicating that the soil became less plastic. Scanning electron microscopy analysis revealed changes in the surfaces and pores of the treated soil samples, suggesting structural changes induced by the lime and brick dust treatment. Furthermore, adding lime significantly reduced the plasticity index of the soil, and brick dust reduced the soil's swell index, with the lowest index of 8 % observed in the sample treated with 5 % lime and 30 % brick dust. The study's findings suggest that lime and brick dust can improve the stability of expansive soils, rendering them more suitable for construction purposes.

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1. *Introduction*

Soil stabilization is a crucial process in civil engineering involving additives to enhance soil properties, such as compressive strength, shear strength, and settlement problems. Soil stabilization is essential to enhance the problematic geotechnical properties of soil. Various soil stabilization techniques exist worldwide. Each method has its advantages and limitations [1-7]. The effect of nano-silica fume on gypseous collapsibility and shear strength was studied by [8,9]. The additives used for soil stabilization include Portland cement, lime, rice husk ash, asphalt, and rubber, among others. Some additives are combined with others to create substances with superior and well-controlled properties. Proper procedures are followed to replace the natural soil content with these additives, which are often less expensive, pozzolanic, and environmentally friendly.

Expansive soils are a common geological hazard that causes severe damage to structures, roads, and other infrastructure [10,11]. Lime stabilization is a popular and effective method to reduce the swelling potential of expansive soils [12,13]. In addition, adding brick dust to the soil-lime mixture can further enhance its stabilizing properties [14,15].

Previous research has shown that lime and brick dust can improve expansive soil's mechanical and geotechnical properties, including increased strength and reduced swelling potential [16,17]. Furthermore, researchers have also investigated the optimal mixture proportions of lime, brick dust, and expansive soil to achieve the best results [6,18,19].

Various techniques have been used to evaluate the effectiveness of the soil stabilization methods, including laboratory tests such as unconfined compressive strength, California Bearing Ratio, and Atterberg Limits, as well as field tests such as plate load tests and pavement performance evaluations [20]. However, it is essential to consider the stabilized soil's long-term performance; therefore, long-term monitoring and evaluation are also crucial .

Research in this field has explored various combinations of additives for soil stabilization. For instance, Kamon and Nontananandh [21] combined lime and industrial waste to stabilize soil, while Atom and Al-Sharif [22] evaluated burned olive waste as a soil stabilizer. Before initiating the stabilization process, it is essential to accurately assess the soil's characteristics [23], as locally available soil may differ from soil tested elsewhere. Climatic factors and soil types also require different technical stabilization techniques [24]. The rate of curing, for example, can be affected by temperature, while a wet climate may affect the stabilization process.

Agricultural nations face challenges related to agricultural waste, which contains minerals and silicates that plants ingest as they grow. Some plants, such as rice, wheat, sunflowers, and tobacco, contain higher concentrations of silicates in their bodies, while inorganic materials are present in plants in the form of free salts and particles that combine cationic and anionic groups from fibers [25]. In light of these issues, this study aims to investigate the effects of lime and industrial waste, specifically brick dust, on natural soil's strength, consistency, and density.

2. *Materials and Methods*

2.1. Materials

2.1.1. Soil Collection

This study aimed to investigate the effectiveness of soil stabilization techniques using lime and brick dust on a representative soil sample found in various locations. A soil sample weighing 60 kg was collected for this study. The sample was obtained at a depth of 1.5 to 2 meters, as shown in Fig. 1. The studied physical and chemical properties of the investigated soil are summarized in Tables 1 and 2.

Figure 1. Collection of Undisturbed Soil Sample at 2-meter depth.

2.1.2. Brick Dust

In recent years, various additives have been used to improve the properties of expansive soils. However, many of these additives have adverse environmental effects. Brick dust, for example, can increase soil salinity, which affects plant growth. Researchers have suggested using this waste product to address this issue to create stable soil for construction foundations and road subbases. For this study, 10 kg of class B brick dust was collected from the kiln industry.

2.1.3. Lime

In this research, lime was employed as an optimizing agent to minimize the maximum amount of brick dust required while enhancing the strength of the soil. For this purpose, a quantity of 5 kg of lime was prepared.

2.2. Methods

Mixing lime and brick dust for soil stabilization in the laboratory was carried out in several key steps. Soil samples were obtained from the site, and their properties, including plasticity, density, and moisture content, were tested to determine the appropriate amount of lime and brick dust to be added to the soil. The additives were weighed and thoroughly mixed to ensure a homogenous mixture, with the percentage of lime and brick dust calculated based on the soil properties. The resulting mixture was gradually added to the soil while being constantly mixed.

The optimum levels of lime are prepared for soil samples at 2 %, 4 %, 5 %, and 6 %. According to test results, the hydration reaction for high plastic clay is almost finished at 5 % lime. Therefore, 5 % is chosen as the optimized value. Further, Brick dusts were added at 5 % and 15 %, 20 %, and 30 % to the optimized lime.

After the preparation process, the stabilized soil was tested to determine its properties. The properties of the stabilized soil were compared to those of the original soil to evaluate the effectiveness of the stabilization process, with the percentage of lime and brick dust used is a critical factor in determining the results.

The investigation involved testing the prepared soil reference and treated samples using various methods, including sieve analysis, liquid Limit, plastic Limit, shrinkage limit, standard Proctor test, and unconfined compression strength test. The particle size distribution of the soil samples was determined through a wet sieve analysis in accordance with the ASTM D 7928-16 standard, with soils that passed through a #200 sieve classified as clayey. The liquid limit and plastic limit of the samples were determined using ASTM D422-63 and ASTM D4318-00 standards, respectively. The shrinkage limit was determined following the guidelines outlined in ASTM-D4943 standard. The samples' maximum dry density and optimum moisture content were determined through the standard Proctor test as per ASTM D698. Finally, the unconfined compression strength test was performed as per ASTM D2166 to evaluate the strength of the treated samples.

Unsoaked curing of samples was performed at different lime and binder dosage levels (2, 4, 5, and 6 percent) to optimize the lime treatment process for seven days. Both lime and BD were used as binders in the curing process. Unsoaked curing was reported up to 28 days at intervals of (2, 4, 7, 14, and 28 days).

Furthermore, SEM (Scanning Electron Microscope) analysis was conducted on reference and treated soil samples to evaluate their physical and chemical properties at a microscopic level.

Table 1. Summary of properties of the reference soil samples.

SAMPLE №.	PROPERTIES	VALUE
1	Liquid Limit (%)	55.3
2	Plastic Limit (%)	28.02
3	Plasticity Index	25.78
4	Shrinkage Limit (%)	22.82
5	% age Passing #200	95
6	Soil Type (USCS)	CH
7	Soil Type (AASHTO)	A-6-7
8	MDD (g/cm3)	1.58
9	OMC (%)	20.49
10	Unsoaked UCS (MPa)	0.5
11	Swell Index (%)	29.63

Table 2. Summery of chemical properties of the reference soil samples.

SAMPLE №.	PROPERTIES	VALUE
1.	pH value	>7(Alkaline)
2.	Organic content	0.4 to 204 %
3.	$CaCO_3$	5 to 15 %
4.	SiO_2	50 to 55 %
5.	SiO_2, Al_2O_3	3 to 5 %
6.	Montmorillonite mineral	30 to 50 %

3. Results and Discussion

3.1. Sieve Analysis

The fine particle gradation of the reference soil is given in Fig. 2.

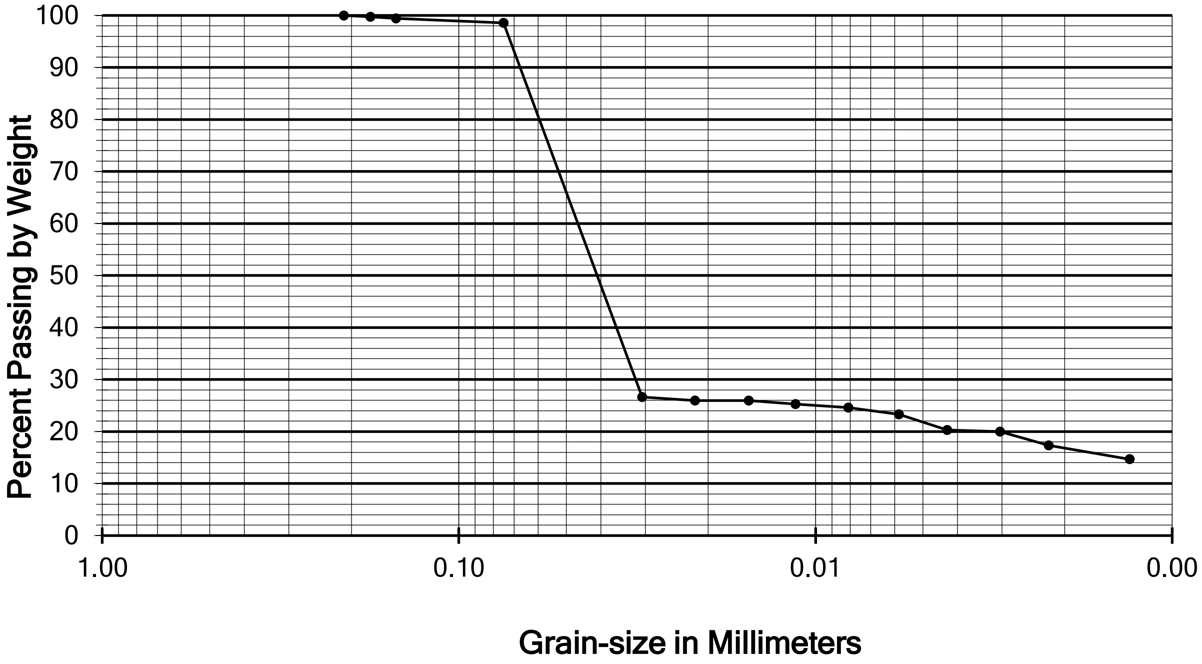

Figure 2. Fine Particle Gradation of the reference soil.

3.2. The moisture content and maximum dry density for Different Lime Content

Four tests were carried out by adding 2, 4, 5, and 6 % lime by the weight of the soil. A standard Proctor test was conducted on all soil-lime samples at the given 2, 4, 5, and 6 % of the soil to determine the moisture content and maximum dry density for each sample.

The maximum dry density and moisture content relationship of the reference and treated samples were determined and presented in Fig. 3. This figure illustrates the effect of the added lime content on the soil's maximum dry density and moisture content.

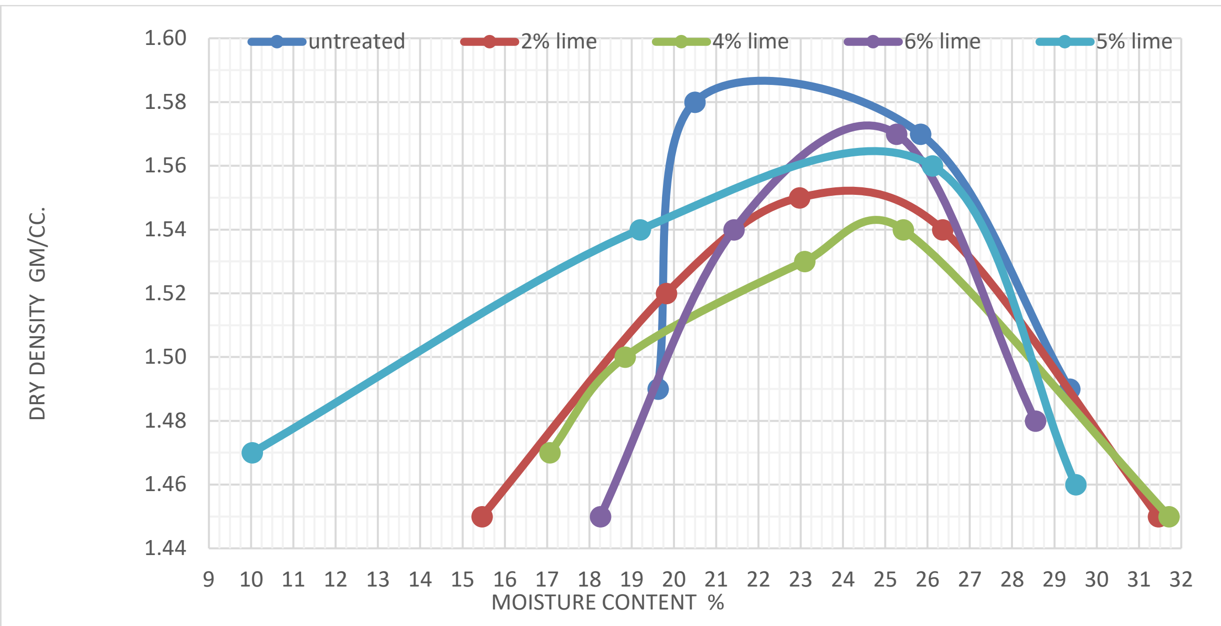

Figure 3. The maximum dry density and moisture content at different Lime contents.

3.3. Optimization of lime using unconfined compression test UCS

Unconfined compression tests were conducted in this study to determine the strength properties of the investigated high plastic soils. The soil samples were treated with different levels of lime, namely 2 %, 4 %, 5 %, and 6 % by weight of the soil, to improve their strength characteristics. Based on the gained results, it was observed that the hydration reaction of the high plastic clay was almost complete at 5 % lime concentration, which resulted in the maximum strength improvement. Consequently, 5 % was chosen as the optimal lime content for the soil samples.

A comparison of the compressive strength results of the reference (untreated) and the soil samples treated with 5 % lime showed a significant improvement in the strength of the treated soil samples (Fig. 4). The data showed that the soil samples stabilized with 5 % lime had a compressive strength of 3.335 MPa, which was considerably higher than the strength of the reference samples (0.488 MPa).

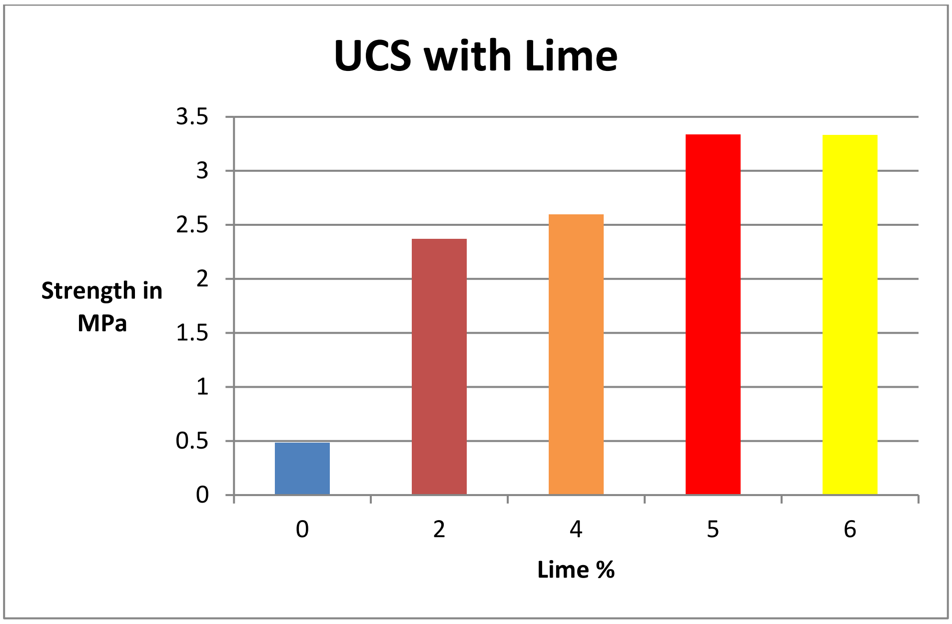

Figure 4. The average strength of the reference and treated samples at the given lime percentage.

3.4. 'Atterberg's Limits of Soil Treated with Lime and Brick Dust

In this study, testing was carried out on optimized lime, i.e., 5 % and 15 %, 20 % and 30 % BD, to observe how the liquid Limit and plasticity of high plastic soil changed while shrinkage limits increased. The liquid Limit of soil was measured using the Casagrande apparatus. The Atterberg's Limits Test was run on optimized lime and various BD percentages in this phase. The liquid Limit of the treated soil is given in Fig. 5-8. Table 3 summarizes ' 'Atterberg's limits of reference and treated soil. The results indicate the change in the liquid Limit of the treated soil with increasing BD and lime concentration. The addition of lime had a significant effect on the plasticity of the soil. The plasticity index decreased as the lime concentration increased, indicating that the soil became less plastic. The study also showed that adding lime significantly affected the plasticity of the soil—the plasticity index decreased, indicating that the soil became less plastic. The plasticity index was found to be 26 % for the reference sample, while it decreased to 22 %, 21 %, 19 %, and 16 % at 5 % lime and 15 %, 20%, 25 %, and 30 % brick dust, respectively.

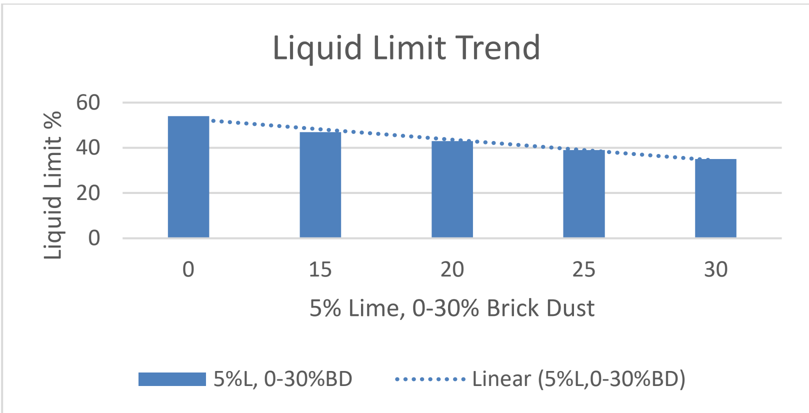

Figure 5. Liquid limits of treated soil.

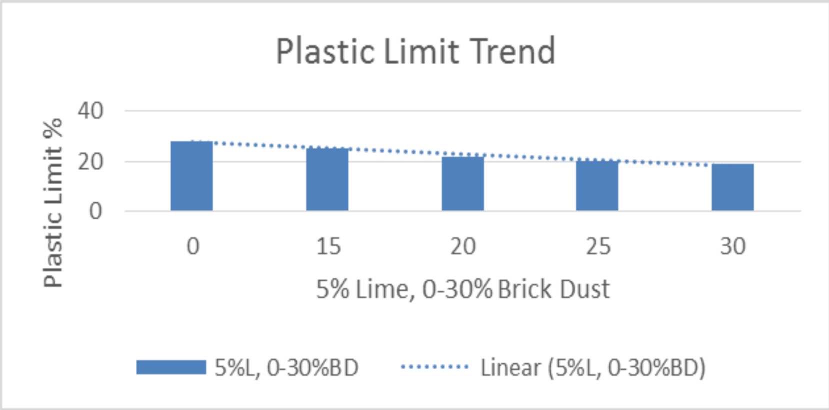

Figure 6. Plastic limits of treated soil.

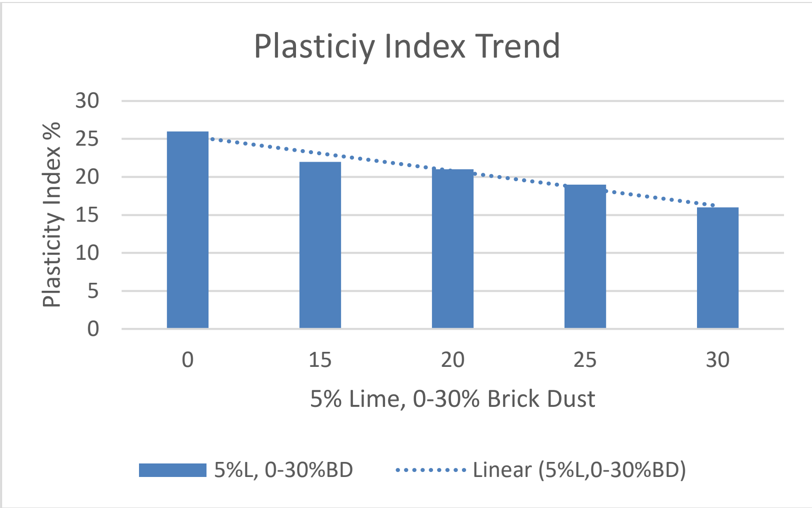

Figure 7. Plasticity index of treated soil.

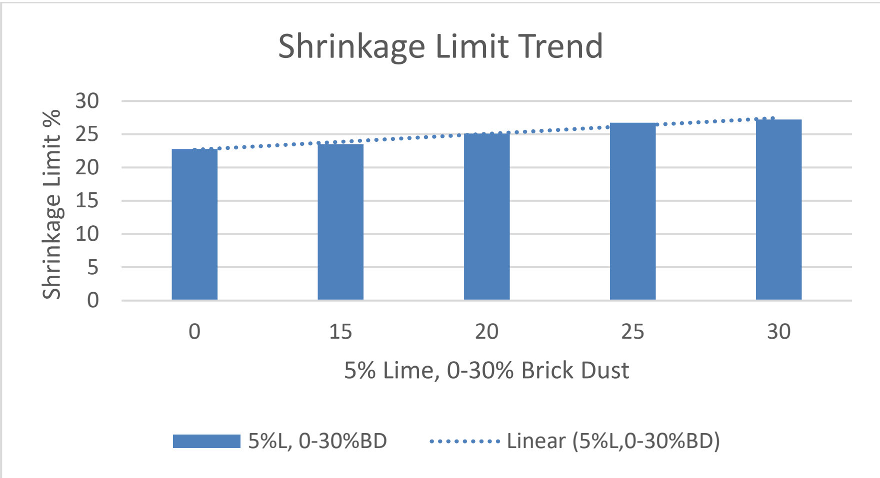

Figure 8 Shrinkage limits of treated soil.

Table 3. Summary of the 'Atterberg's limits of untreated and treated soil.

'ATTERBERG'S LIMIT	UNTREATED SOIL	5%LIME, 15%BD	5%LIME, 20%BD	5%LIME, 25%BD	5% LIME, 30%BD
LIQUID LIMIT	54%	47%	43%	39%	35%
PLASTIC LIMIT	28%	25%	22%	20%	19%
PLASTICITY INDEX	26%	22%	21%	19%	16%
SHRINKAGE LIMIT	22.82%	23.5%	25.1%	26.72%	27.2%

3.5. Free Swell Index

Fig. 9 represents the relationship between the percentage of lime and brick dust and the swell index of the soil. The results clearly show that the swell index decreases as the percentage of lime and brick dust increases. As shown in Table 4, the untreated soil had a swell index of 29 %, which is significantly higher than the treated soil samples. Adding 5 % optimized lime and increasing amounts of brick dust reduced the swell index, with the lowest swell index of 8 % observed for the sample treated with 5 % lime and 30 % brick dust.

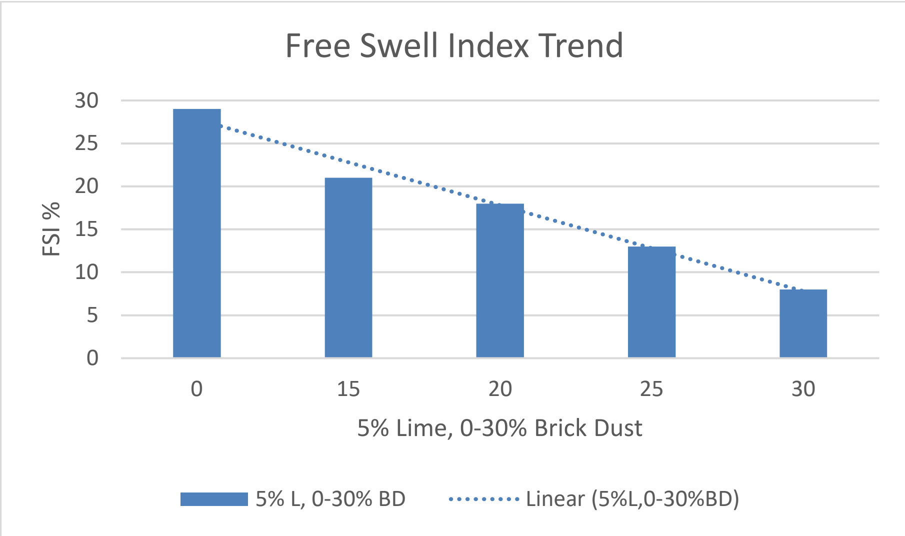

Figure 9 Swell potential of treated soil.

Table 4. Summary of Free Swell Index (FSI).

FSI %	UNTREATED SOIL	5%LIME, 15%BD	5%LIME, 20%BD	5%LIME, 25%BD	5%LIME, 30%BD
SWELL%	29	21	18	13	8

3.6. SEM Analysis

Various SEM tests were carried out on the reference and treated samples. The SEM analysis results are shown in Fig. 10–13. Fig. 13 displays the SEM images of the treated sample, which was cured for 28 days with 5 % lime and 25 % BD. Comparing the images at scales of 10, 20, and 100 micrometers reveals various variations in faces (shape, size, homogeneity), and holes (size, open or closed).

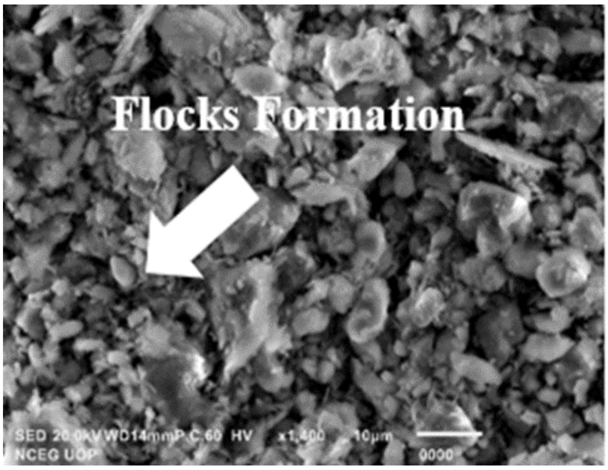

Figure 10 Untreated Sample (10 micrometer).

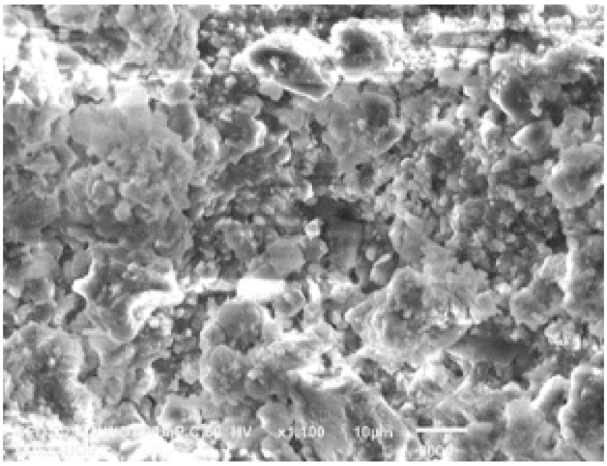

Figure 11 Treated Sample (10 micrometer).

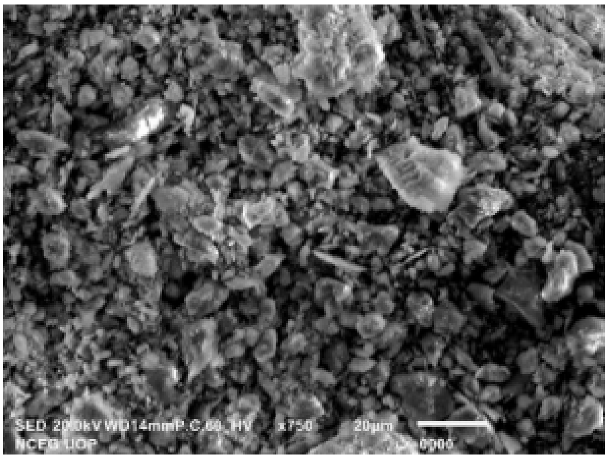

Figure 12 Untreated sample (20 micrometer).

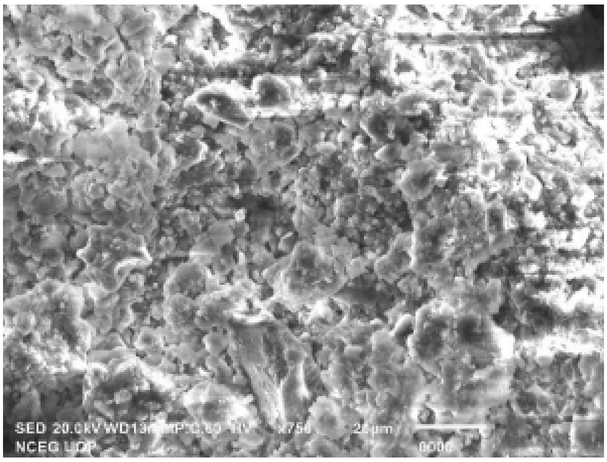

Figure 13 Treated sample (20 micrometer).

4. Conclusion

The study investigated the effects of lime and brick dust additives on the shear strength and limits of expansive soils at an optimized percentage. The main findings are:

1. The addition of 5 % lime concentration improved the maximum shear strength for the soil samples.
2. Adding lime significantly reduced the plasticity index of the soil, with a decrease observed as the lime concentration increased. The plasticity index decreased from 26 % for the reference sample to 22 %, 21 %, 19 %, and 16 % at 5 % lime and 15 %, 20 %, 25 %, and 30 % brick dust, respectively.
3. Adding lime and brick dust reduced the swell index of the soil, with the lowest swell index of 8 % observed for the sample treated with 5 % lime and 30 % brick dust.
4. The SEM analysis revealed variations in the faces and holes of the treated sample, indicating the effectiveness of lime and brick dust as stabilizers.
5. The study suggests that the optimized 5 % lime by the soil weight is the optimum percentage for stabilizing the investigated soil type. This percentage significantly improves the soil's shear strength and physical properties, enhancing stability and reducing plasticity.

5. Future Recommendations

1. BD used in this research was taken from only one source and one class, i.e Class B only. As composition and properties of BD varies with class and region so efforts should be made to compare the effect of brick dust taken from various sources and classes of all over the country.
2. To determine the swell potential of soil, this research focused on determining one dimensional swell potential. The overall free swell potential of soil should also be determined.
3. In this research, only lab testing was taken into consideration, field investigations should be done to implement the suitability of BD and lime as a stabilizing agent for high plastic clays.
4. Stabilization projects should be planned at ideal temperature conditions for trials in the field. The temperature is around 30 °C.
5. Compaction effort should commence as soon as possible after mixing.
6. Soil should be cured for at least 28 days at ambient temperature before subsequent construction.

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