

## IMPROVEMENT OF GEOTECHNICAL PROPERTIES OF CLAYEY SOIL THROUGH LIME AND SODIUM HEXAMETAPHOSPHATE TREATMENT

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### ABSTRACT

This study looks at how using lime along with sodium hexameta phosphate (SHMP) together can enhance the geotechnical characteristics of clayey soil. Because of their high compressibility, large volume fluctuations, and low strength, clayey soils are not recommended for building without stabilization. Because of their complementing impacts on soil behavior, chemical stabilization techniques using lime as well as SHMP has been investigated as a solution to these problems. Lime mainly improves the characteristics of soil through flocculation, pozzolanic reactions, and cation exchange, which results in less plasticity and more strength. Conversely, SHMP serves as a dispersion agent that increases stabilization efficiency and particle dispersal. In this research, soil specimens were exposed to laboratory tests such as Atterberg limits, compacting properties, & California Bearing Ratio (CBR) after being treated with different concentrations of lime (3–12%) as well as SHMP (1–7%). The findings show a considerable drop in the liquid limit and plasticity index, as well as a rise in the ideal moisture content & a fall in the maximum dry density. In comparison to untreated soil, the combined treatment demonstrated an important rise in strength, including CBR values rising significantly. The results show that the combination of lime and SHMP offers a practical and affordable way to improve the performance of engineering of clayey soils.

**Keywords:** Clayey Soil, Stabilization, Lime, Sodium Hexameta phosphate, Atterberg limits, OMC, MDD, CBR.

### 1. INTRODUCTION

Because of their poor technical qualities, clayey soils are common in many areas and can pose serious difficulties for civil engineering work. These soils usually show significant volume variations in response to changes in moisture content, high compressibility, and poor shear strength. These features render them unsuitable for foundations, pavements, and supporting structures without previous upgrading. As a result, soil stabilization has emerged as a crucial technique in the field of geotechnical engineering to improve the durability and performance of troublesome soils. Chemical

stabilization has become more popular among different stabilizing methods because of its efficiency and viability from an economic standpoint. One of the most popular techniques for enhancing fine-grained soils is lime stabilization. The addition of lime induces a series of physicochemical reactions, including cation exchange, flocculation, and pozzolanic reactions, which lead to improved workability, reduced plasticity, and increased strength over time. Lime-treated soils typically exhibit enhanced bearing capacity and reduced swelling potential, making them suitable for use in subgrade and foundation applications. In

recent years, attention has also been directed toward the usage of chemical additives such as Sodium Hexameta phosphate (SHMP) to further enhance soil properties. SHMP is a dispersing agent that alters the interaction between soil particles by modifying the electrochemical environment. It reduces particle aggregation and can improve the uniform distribution of stabilizing agents like lime within the soil matrix. When used in combination with lime, SHMP has the potential to optimize the stabilization process by enhancing reaction efficiency and improving overall soil performance. The combined application of lime and SHMP presents a promising approach for the stabilization of clayey soils. While lime primarily contributes to long-term strength development through pozzolanic reactions, SHMP facilitates better particle dispersion and interaction, leading to more uniform treatment and improved consistency. Important geotechnical parameters including unconfined compressive strength, Compaction characteristics, permeability, along with plasticity indices can all be significantly improved by this synergistic impact. Although lime and SHMP have their own advantages, little is known about how they work together on clayey soils. Developing effective and long-lasting stabilization methods requires an understanding of how these compounds interact and affect soil behavior. By methodically examining the enhancement of clayey's geotechnical qualities by a combination of lime and SHMP, this study seeks to close this gap. A number of lab tests are used in the study to assess how different amounts of lime along with SHMP affect the characteristics of the soil. To evaluate the efficacy of the treatment, parameters such Atterberg limits, compaction properties, unconfined compressive strength, & permeability are examined. It is anticipated that the results of this study will offer important insights into the mechanics of soil stabilization and aid in the creation of economical and ecologically sound building solutions for poor soils. The overall goal of this study is to

develop knowledge of sophisticated soil stabilization methods and encourage the application of novel material combinations to improve the geotechnical characteristics of clayey soils.

In a thorough investigation on lime stabilization, Bell described how the addition of lime starts a fast cation exchange that substitutes calcium ions for weaker molecules in clay minerals. Particle agglomeration and flocculation result from this, decreasing plasticity and increasing workability. Pozzolanic reactions create cementitious compounds over time, greatly boosting the durability and strength of the soil [1]. According to Little's analysis of the geotechnical behavior of lime-treated soils, lime lessens the expansive soils' shrink-swell properties. The study highlighted that lime stabilization improves bearing capacity and makes soils more resistant to moisture variations, which is crucial for pavement and foundation applications [2,3]. Ingles and Metcalf presented early work on soil stabilization methods and identified lime as a highly effective stabilizing agent for clayey soils. Their study showed that lime alters soil texture by binding particles together, thereby increasing shear strength and reducing compressibility [4]. Mitchell focused on the physico-chemical aspects of soil behavior and emphasized that additives influence inter-particle forces. The study suggested that proper mixing and dispersion of stabilizers are essential to ensure uniform treatment and maximize effectiveness [5]. Sherwood examined stabilization techniques for road construction and reported that lime-treated soils exhibit increased stiffness and resistance to deformation. The study also found that lime improves durability under cyclic wetting and drying conditions [6]. Mallela et al demonstrated the long-term performance of soil which is lime stabilized soils in field conditions. The findings indicated that lime stabilization increases pavement life by reducing rutting and deformation, while also

improving resistance to environmental stresses [7]. Grim investigated clay mineralogy and demonstrated that the behavior of clay soils is largely governed by their mineral composition. The study showed that chemical additives can significantly modify soil structure and engineering properties [8]. Van Olphen studied clay-water systems and explained that dispersing agents, particularly phosphates, reduce particle attraction forces. This results in better dispersion of soil particles, which can enhance the effectiveness of stabilizing agents [9]. Locat et al analyzed chemically treated clays and found that additives improve soil structure by increasing bonding between particles. This leads to enhanced strength and reduced sensitivity to environmental changes [10]. Eades and Grim created a technique to ascertain the ideal lime level needed for soil stabilization. Their work showed that insufficient lime leads to incomplete reactions, while excess lime may not contribute to additional strength gain [11]. Rogers et al studied lime stabilization and observed that increasing lime content reduces plasticity index and significantly improves unconfined compressive strength. The study also emphasized the importance of curing time [12]. Al-Rawas et al investigated expansive soils treated with lime and found a substantial reduction in swelling potential along with improved strength characteristics, making soils more suitable for construction [13]. Kavak and Baykal investigated how lime affected silty soils and found improvements in compaction characteristics, such as lower optimal moisture content and higher maximum dry density. Thompson demonstrated that lime stabilization improves soil workability, making it easier to compact and handle during construction. The study also reported increased strength with curing time. Basma and Tuncer analyzed consistency limits of lime-treated soils and found a significant reduction in plasticity index, indicating improved soil stability and reduced deformation potential. Dash and Hussain investigated lime-treated clay and observed that pozzolanic reactions lead to the formation of

cementitious compounds, resulting in increased strength and reduced compressibility. Koliass et al reported that lime stabilization enhances long-term strength through continuous pozzolanic reactions, which form stable compounds such as calcium silicate hydrate (CSH). Rao and Shivananda studied compaction and permeability of lime-treated soils and found that lime reduces permeability while improving density and strength characteristics [14]. Osinubi reported that lime stabilization increases maximum dry density and improves load-bearing capacity, making soils suitable for subgrade applications. Boardman et al highlighted that lime treatment improves soil durability and resistance to environmental degradation, particularly under repeated wetting and drying cycles. Mitchell and Soga emphasized that combining stabilizers can enhance soil improvement by improving reaction efficiency and creating stronger inter-particle bonds. Kamon and Bergado studied chemical stabilization and found that additives modify soil structure at a microscopic level, leading to improved engineering properties. Abdullah et al investigated chemical dispersants and reported that they improve the uniform distribution of stabilizers within soil, enhancing overall stabilization efficiency [15]. Zhang et al studied electrochemical behavior of soils and found that dispersing agents reduce particle attraction forces, leading to better particle separation and improved soil structure. Chen et al focused on phosphate-based additives such as Sodium Hexametaphosphate (SHMP) and concluded that they act as dispersing agents, improving particle distribution and enhancing the effectiveness of stabilizers like lime.

The objectives for the current study are:

- i. To assess the fundamental geotechnical features of undisturbed clayey soil, such as strength parameters, compaction traits, and Atterberg limits.
- ii. To examine how lime and SHMP work together to stabilize soil, with an

- emphasis on engineered property gains above individual treatments.
- iii. To ascertain the ideal lime and SHMP dose needed to maximize soil performance improvement.
- iv. To provide a practical and affordable stabilizing method for enhancing clayey soil for use in engineering applications.

**2. METHODOLOGY**

Through a series of carefully monitored laboratory tests, this study's approach seeks to determine how well lime with sodium hexametaphosphate (SHMP) improve the characteristics of clayey soil. To guarantee consistency for testing, the gathered soil was oven dried out, crushed, and sieved through a 4.75 mm screen. Different proportions of SHMP (1%, 3%, 5%, and 7%) and soil (3%, 6%, 9%, and 12%) were combined by dry weight. Laboratory tests including Atterberg limits, Conventional Proctor compaction, including California Bearing Ratio (CBR) were used to assess the effects of stabilization by analyzing changes in the treated soil's strength, plasticity, and compaction characteristics.

**3. RESULT ANALYSIS**

**3.1 Atterberg's Limits**

The graph in Figure 1 shows how the Atterberg limits—Liquid Limit (LL), Plastic Limit (PL), as well as Plasticity Index (PI)—vary as the lime level in clayey soil increases from 0% to 12%. The Liquid Limit consistently drops with increasing lime concentration, from around 60% when 0% lime to about 43% at 12% lime. This suggests a decline in the soil's compressibility and water-holding ability. The Plastic Limit steadily drops to about 30% at 12% lime after first showing a minor rise from 41% by 0% lime to roughly 42% at 3% lime. Lime's better flocculation and workability may have contributed to the early increase, whereas the soil's stability and stiffening are responsible for the following decline. With a minor variation at 6%, the Plasticity Index, which

shows a variety of moisture content across which the soil stays plastic, generally drops from 20% to around 13%. This decrease suggests that adding lime makes the soil less pliable and more stable. Overall, the graph shows that lime stabilization successfully lowers plasticity and enhances clayey soil's engineering performance.

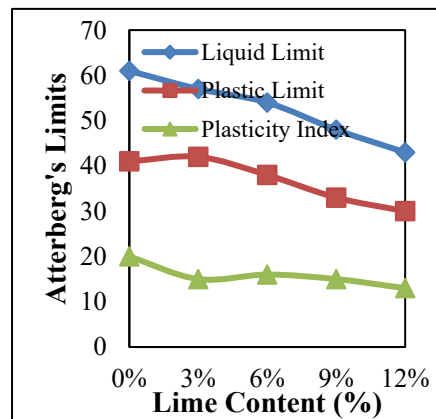


Figure 1: Atterberg's Limits for Soil with lime.

**3.2 Compaction Characteristics**

In Figure 2, Figure 3, Figure 4, graphs collectively illustrate the influence of lime and Sodium Hexametaphosphate (SHMP), both individually and in combination, on the compaction characteristics of silty clay soil, specifically in terms of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). In the first graph (soil–lime mixes), it is evident that the untreated soil (100:0) achieves the highest MDD at a relatively lower water content, indicating its natural compaction state. As lime content increases from 3% to 12%, the MDD consistently decreases while the corresponding OMC shifts toward larger values. This trend is typical of lime stabilization, where flocculation and agglomeration of finer particles occur, foremost to an extra open soil structures that requires more water for lubrication and compaction but results in lower density. The second graph (soil–SHMP mixes) shows a similar but less pronounced trend. With increasing SHMP

content from 1% to 7%, the MDD gradually decreases, and the OMC increases slightly. SHMP acts as a dispersing agent, modifying the soil fabric and reducing interparticle attraction, which enhances workability but slightly reduces achievable density. Compared to lime, SHMP exhibits a milder impact on density reduction, suggesting its role is more chemical than structural. The third graph (combined soil–lime–SHMP mixes) demonstrates the interactive effect of both stabilizers. Here, the untreated soil again shows the highest MDD at lower OMC, while the addition of lime (fixed at 6%) along with increasing SHMP (1% to 7%) results in a further fall in MDD and a noticeable rise in OMC. This combined effect indicates that while lime induces flocculation and strength gain, SHMP enhances dispersion and moisture sensitivity, leading to a balanced but lower-density structure. The peak points in each curve represent the optimal moisture content at which maximum compaction is achieved, and these peaks shift rightward (toward higher moisture content) as stabilizer content increases. Overall, the graphs reveal that both lime and SHMP reduce the maximum dry density of the soil while increasing its optimal moisture requirement, with the combined treatment producing the most significant modification in compaction behavior. These changes are important for field applications, as they indicate improved workability and potential strength gains despite lower density, which is desirable in many geotechnical engineering practices such as subgrade stabilization.

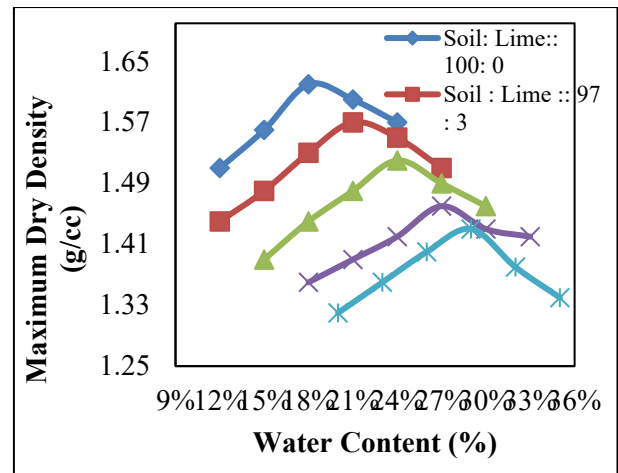


Figure 2: OMC vs MDD for Soil with lime

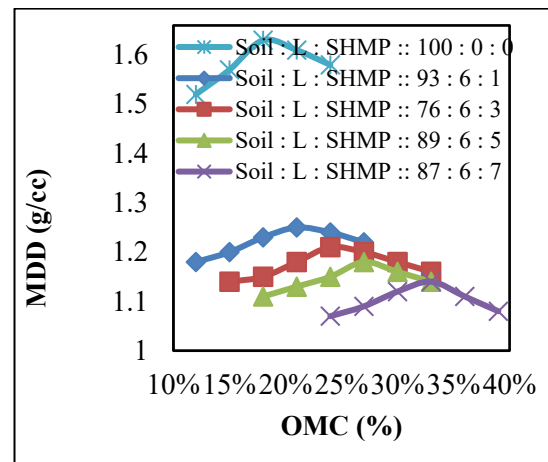


Figure 3: OMC vs MDD for Soil with SHMP.

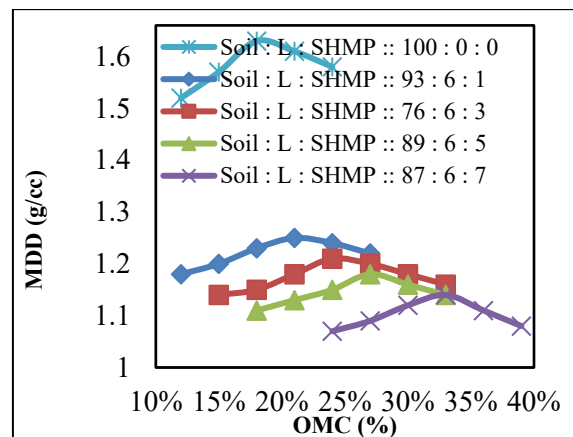


Figure 4: OMC vs MDD for Soil with Lime and SHMP.

### 3.3 Strength Characteristics

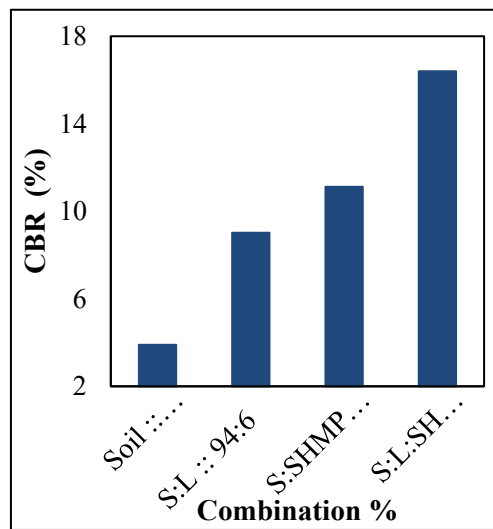


Figure 5: CBR value for Soil with Lime and SHMP.

The graph shows how various stabilizer combinations affect the California Bearing Ratio (CBR) of silty clay soil, emphasizing the strength gain brought about by the addition of sodium hexametaphosphate (SHMP) and lime (L). The untreated soil (100:0) exhibits the lowest CBR value, approximately 4%, indicating poor load-bearing capacity and limited suitability for subgrade applications. Upon the addition of lime in a proportion of 6% (S:L :: 94:6), the CBR value increases significantly to around 9%, demonstrating how lime can improve soil strength through pozzolanic reactions and flocculation. Similarly, the use of SHMP at 4.5% (S:SHMP :: 95.5:4.5) results in a further increase in CBR to about 11%, indicating that SHMP also contributes to strength improvement, likely by modifying particle interactions and improving soil structure. The most notable improvement is observed in the combined mix (S:L:SHMP :: 74.5:15:6:4.5), where the CBR value reaches approximately 16%. This substantial increase reflects the synergistic effect of both stabilizers, where lime enhances bonding and strength while SHMP improves dispersion and compaction efficiency. Overall, the graph clearly demonstrates that the combined use of

lime and SHMP yields the highest strength improvement in silty clay soil.

### 4. CONCLUSIONS

The study comes to the conclusion that applying lime along with sodium hexametaphosphate (SHMP) together improves the geotechnical characteristics of clayey soil. Because stabilizers alter the structure of the soil, they decrease maximum dry density, increase optimal moisture content, & decrease flexibility. Significant improvement in strength is observed through increased CBR values, with the combined treatment showing the best performance. Lime contributes to flocculation and pozzolanic reactions, while SHMP improves particle dispersion and workability. Overall, the synergistic effect of lime and SHMP makes the treated soil more suitable for subgrade and construction applications, ensuring better stability and load-bearing capacity.

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