

## Evaluation of Sand-Clay mixture stabilized with hydrated lime for backfill application in earth retaining structures

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**ABSTRACT :** The clay's tendency to expand and contract with changes in moisture levels makes it difficult to use as backfill material. This study explores the potential of using sand and hydrated lime as stabilizing agents to address this trend. Clay was mixed with the right amount of sand and with hydrated lime at 0, 5, and 10% weight of clay. The sand-clay mixture stabilized with hydrated lime was subjected to an experimental procedure to access the strength, permeability, and proper compaction under British Standard Heavy (BSH) and British Standard Light (BSL) compaction efforts. The engineering properties of sand-clay mixtures were significantly enhanced by the inclusion of hydrated lime. The free swell index decreased significantly, approaching minimal levels, while the unconfined compressive strength notably rose, surpassing 200% in different mixtures. Both the cohesion and internal friction angle showed significant improvements. While the addition of hydrated lime slightly lowered the maximum dry density and permeability, the adjusted values still exceeded those of untreated clay and fell within the suitable range for compacted backfill. The use of hydrated lime also led to a significant decrease in active lateral pressure in untreated clay and sand-clay mixtures, improving stability through reduction of lateral pressure. Overall, a mixture of 50% sand and 5% hydrated lime shows the most effective option for stabilizing clay as backfill material in earth retaining structures during compaction for BSL and BSH projects.

**KEYWORDS:** Backfill material, Earth retaining structures, Optimal mixture, Sand-clay suitability, Compaction effort

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### I. INTRODUCTION

Earth retaining structures are essential components in civil engineering, intended to hold back soil, ensure stability, and prevent soil erosion in different landscapes. These constructions depend greatly on the characteristics of backfill materials, which are used to back retaining walls and provide support and stability to the soil mass. Choosing the right backfill materials is essential as they need to have the right strength, permeability properties, and long-lasting durability to maintain the structure's stability and functionality (Igwe and Umbugadu, 2020; Md Yusof *et al.*, 2022; Hashim *et al.*, 2023).

Sand and clay are commonly used as traditional backfill materials because they are easily found and cost-effective. Nevertheless, these materials have intrinsic constraints that can affect their ability to

effectively support earth retaining structures. Sand, for example, usually has good drainage capabilities but lacks enough cohesion and shear strength, particularly when subjected to dynamic loading conditions (Guan and Madabhushi, 2020). Clay has better cohesive properties but is highly prone to swelling and shrinking with changes in moisture content, which could potentially compromise the stability of the structure over time (Md Yusof *et al.*, 2022).

Engineers use different stabilization techniques to improve the engineering characteristics of backfill materials in order to tackle these challenges. Soil stabilization entails adjusting soil properties by incorporating chemical agents or other substances to achieve desired enhancements in strength, durability, and permeability. Obtained from limestone, hydrated lime has become a potential soil stabilizer because of

its pozzolanic and chemical reactivity (Firoozi *et al.*, 2017).

The use of hydrated lime in soil stabilization not only improves instant engineering characteristics but also supports sustainable construction methods. Lime stabilization provides a cost-effective and eco-friendly option compared to traditional stabilizers like cement or chemical additives by using local materials and reducing environmental impact. This method aligns with the ideals of green engineering by decreasing carbon emissions linked to production and transportation, and by using materials that are easily sourced locally or regionally (Md Yusof *et al.*, 2022).

Prior studies have investigated different methods of stabilization and their use in backfill materials, providing important information on how well they work and any constraints they may have. Research has shown that hydrated lime can greatly enhance the mechanical and hydraulic characteristics of soil, rendering it appropriate for various engineering uses. Research has demonstrated that lime stabilization decreases soil permeability, boosts bearing capacity, and improves the long-term durability of backfill materials in various environmental conditions (Firoozi *et al.*, 2017; Yusof *et al.*, 2022).

Despite the progress made, there are still gaps in understanding how well sand-clay mixtures stabilized with hydrated lime perform in certain applications, like using them as backfill in earth retaining structures in ideal conditions. Current literature mainly discusses individual or mixed soil types and stabilization methods, frequently neglecting the synergistic impact of lime stabilization on diverse soil mixtures. Hence, there is an urgent requirement for more research to methodically assess these interactions and their impact on engineering design and construction practices (Hashim *et al.*, 2023).

This study seeks to fill these gaps in knowledge by assessing the performance of sand-clay mixtures stabilized with hydrated lime in ideal conditions. The research goals involve examining the mechanical properties, like shear strength, hydraulic permeability, and unconfined compressive strength, through thorough laboratory testing and numerical computation. The empirical data and analytical insights will enhance design practices and decision-making processes for engineers and stakeholders working on earth retaining structures.

## II. MATERIALS AND METHODS

### 2.1 Materials

The materials used in this research are clay soil, river sand and hydrated lime. The clay was obtained from Chanchaga and the river sand from Gidan Mangoro. Both locations situated in Minna, Niger State in Nigeria. On the other hand, the hydrated lime was obtained from a local supplier in Kaduna State, Nigeria. The Oxide composition of the clay soil and sand is presented in Table 1.

### 2.2 Methods

The different experiments were conducted in the Civil Engineering laboratory at Federal University of Technology, Minna. The clay soil was blended with river sand in the ratios of 0%, 50%, and 60% by weight of the clay sample. Laboratory tests were conducted following BS 1377 (1990) to characterize materials and evaluate the suitability of clay soil mixed with sand as backfill material.

Particle size distribution was analyzed for both individual materials and the clay and river sand mixture. The Laboratory test was conducted following the guidelines of BS 1377: Part 2: 1990. Determining the soil's size distribution involves analyzing the particle size distribution. Typically, two approaches are used: sieve analysis (for particles with a diameter greater than 0.075mm) and hydrometer analysis for particles with a diameter less than 0.075mm. The former method was utilized in this research and was conducted on both soil samples (Clay and Sand). The sieve analysis followed Clause 9 of the BS standard as required.

The Atterberg limit test complied with the standards set in BS 1377-2:1990. The Atterberg limit is identified by certain moisture content levels that signify important points in soil behavior. The goal of the test was to assess the firmness of the clay and the uniformity of the clay-sand-hydrated lime mixture by calculating the plastic limit (PL), liquid limit (LL), and plasticity index. The best combination of clay and sand was mixed with hydrated lime in ratios of 0%, 5%, and 10% by weight of the sand-clay mixture.

The strength, permeability, and stability of the sand-clay mixtures stabilized with hydrated were evaluated. Al-Taiea and Ahmedb (2024) emphasized the importance of these parameters in choosing backfills. In order to achieve this, a compaction test was carried out to ascertain the highest dry density and the best moisture content. The compaction test followed the specifications outlined in BS 1377-4:1990, Clause 3.3 for standard proctor test and Clause 3.5 for modified proctor test. The compaction

test was conducted on clay soil, river sand, and an optimal sand-clay mixture with hydrated lime in accordance with British Standard Heavy (BSH) and British Standard Light (BSL) conditions. The optimum moisture content (OMC) at maximum dry density (MDD) was employed in the experimental process for conducting the permeability test, triaxial tests, and the unconfined compressive strength (UCS) test. The constant head permeability test method was utilized to determine the hydraulic conductivity (k) of both the clay sample and the sand-clay mixtures with hydrated lime, while the falling head permeability test was employed for measuring the k of the river sand. The triaxial test provided values for cohesion (C) and internal frictional angle (Ø). The unconfined compressive strength at 0 and 7 days was obtained using the optimum moisture content retrieved from the compaction test outcomes. Numerical computations were used to analyze the lateral earth pressure on a 10 m profile retaining wall, utilizing the internal frictional angle obtained from triaxial tests (refer to Equation 1 and 2). The untreated clay sample and the clay and sand mixtures with hydrated lime were also subjected to the free swell test (FSI).

$$K_a = \frac{1 - \sin(\theta)}{1 + \sin(\theta)} \tag{1}$$

$$P_a = K_a \gamma H - 2c\sqrt{K_a} \tag{2}$$

Where:  $K_a$  = active pressure coefficient;  $\theta$  = internal friction angle;  $P_a$  = active earth pressure;  $\gamma$  = dry unit weight;  $H$  = depth of retaining structure;  $c$  = cohesion

**Table 1: Oxide composition of Clay soil and Sand (Godwin et al., 2024)**

Oxide	Clay soil (%)	Sand (%)
SiO <sub>2</sub>	56.30	40.25
Al <sub>2</sub> O <sub>3</sub>	29.69	20.74
Fe <sub>2</sub> O <sub>3</sub>	4.64	30.87
MnO	0.09	0.07
CaO	1.60	0.42
P <sub>2</sub> O <sub>5</sub>	-	-
K <sub>2</sub> O	0.89	0.66
TiO <sub>2</sub>	1.19	1.35
MgO	4.65	4.84
Na <sub>2</sub> O	0.89	0.65
SO <sub>3</sub>	0.12	0.13
LOI	0.03	0.04

LOI = Loss on ignition

### III. RESULTS AND DISCUSSION

#### 3.1 Materials Index Properties

The majority of particles in the clay soil sample are fine-grained, with over 50% of the grain size being smaller than 0.075 mm, suggesting a composition mainly of silts and clays (refer to Table 2).

**Table 2: Basic Characteristics and Description of the Clay Soil**

Physical property	Value	
Natural Moisture content (%)	17	
Percent passing No. 4 sieve (2.00 mm)	95.52	
Percent passing sieve 0.075 mm	51.67	
Liquid limit (%)	59.00	
Plastic limit (%)	16.50	
Plasticity index (%)	42.50	
Specific gravity, G <sub>s</sub>	2.56	
USCS classification	CH	
AASHTO classification	A-7-6	
Colour	Dark brown	
<b>Mechanical</b>		<b>property</b>
<b>BSH</b>	<b>BSL</b>	
Maximum dry density, MDD (g/cc)	1.858	1.655
Optimum moisture content, OMC (%)	16.4	19.6
Unconfined compressive strength, UCS test (kPa)	120.51	60.63
Permeability, k (cm/sec)	4.29E-7	7.93E-7
Triaxial Ø (degree)	8.2	7.4
test C(kPa)	43.4	17.81

The river sand examined in Table 3 is categorized as well-graded sand (SW) based on the Unified Soil Classification System, with a coefficient of curvature (Cc) of 3.33, showing a satisfactory dispersion of particle sizes. The sand is mostly fine to medium, with 89.60% passing the No. 4 sieve (2.00 mm) and only 3.52% finer than 0.075 mm, resulting in low clay and silt content for improved drainage and reduced swelling potential. The hydrated lime was white in color with a specific gravity of 2.33.

**Table 3: Basic Properties of the River Sand**

Property	Description/value	
Percent passing No. 4 sieve (2.00 mm)	88.60	
Percent passing sieve 0.075 mm	3.52	
Specific gravity, $G_s$	2.66	
USCS classification, $C_c = 3.33$	SW	
<b>BSH</b>		
<b>BSL</b>		
Maximum dry density, MDD (g/cc)	1.894	1.854
Optimum moisture content, OMC (%)	11	18
Permeability, $k$ (cm/sec)	1.74E-1	4.28E-1

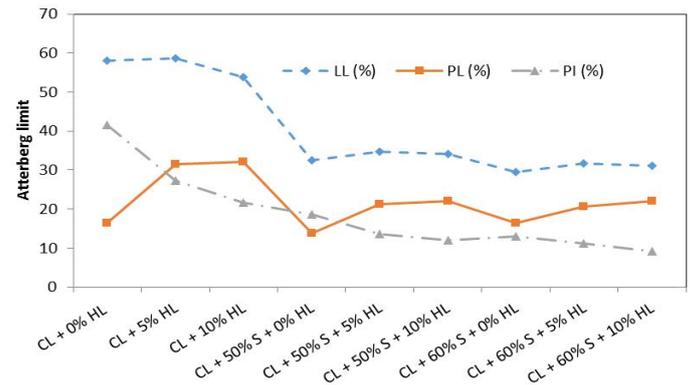
**3.2 Atterberg Limit**

The Atterberg limits, including Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), offer valuable insights into the consistency and behavior of soil mixtures. This study investigates how these limits are influenced by varying proportions of clay (CL), sand (S), and hydrated lime (HL) as can be seen from Figure 1. Initially, the pure clay sample exhibited an LL of 58%, a PL of 16.5%, and a PI of 41.5%. Upon the addition of 5% HL, the LL marginally increased to 58.75%, while the PL significantly rose to 31.47%. However, the PI decreased to 27.28%, indicating a reduction in plasticity and an enhancement in soil stability. Further increasing the HL content to 10% resulted in a more pronounced improvement in stability and a further reduction in plasticity.

When 50% sand was mixed with the clay, the LL, PL, and PI all decreased significantly. The addition of 5% HL to this mixture led to an increase in LL and PL, while the PI decreased. A similar trend was observed with 10% HL, further improving soil stability and reducing plasticity. For a 60% sand-clay mixture, the LL decreased significantly, while the PL remained nearly unchanged. The addition of 5% and 10% HL resulted in increases in LL and PL and decreases in PI, indicating enhanced stability and reduced plasticity.

Basically, the addition of sand and hydrated lime to clay significantly impacts the Atterberg limits. Sand generally reduces the LL and PI, leading to a more

stable and less plastic soil mixture. Hydrated lime, on the other hand, increases the PL and reduces the PI, further enhancing soil stability. These modifications are essential for engineering applications requiring stable and less plastic backfill materials. The findings align with previous research by Amadi and Okeiyi (2017), Aqel *et al.* (2024), Hashim *et al.* (2023), and Dasgupta (2014), which have shown similar trends in the effects of stabilizers on soil properties.



**Fig. 1: Effect of hydrated lime on Atterberg limit of sand-clay mixture**

**3.3 Compaction Characteristics**

The Maximum Dry Density (MDD) is a critical parameter for evaluating the compaction characteristics of soil mixtures. The illustration in Figure 2a for various sand-clay mixtures stabilized with hydrated lime (HL) under both British Standard Heavy (BSH) and British Standard Light (BSL) compaction efforts reveals significant changes in MDD with the addition of HL and sand. For pure clay without HL, the MDD was 1.848 g/cm<sup>3</sup> under BSH and 1.625 g/cm<sup>3</sup> under BSL. The addition of 5% HL slightly decreased the MDD, and increasing the HL content to 10% further reduced it, suggesting that HL can reduce the compactibility of clay.

When 50% sand was mixed with the clay, the MDD significantly increased to 2.181 g/cm<sup>3</sup> under BSH and 2.05 g/cm<sup>3</sup> under BSL, representing the highest MDD values observed in this study. However, the addition of 5% and 10% HL to this mixture reduced the MDD, indicating that HL can negatively impact the compactibility of sand-clay mixtures. For a 60% sand-clay mixture, the MDD was 2.17 g/cm<sup>3</sup> under BSH and 2.085 g/cm<sup>3</sup> under BSL, slightly lower than the peak values observed for the 50% sand-clay mixture. Similar to the 50% sand-clay mixture, the addition of 5% and 10% HL reduced the MDD of the 60% sand-clay mixture.

In general, the addition of HL generally reduces the MDD of both pure clay and sand-clay mixtures. The reduction in MDD may be attributed to the increased friability and decreased plasticity of the soil mixtures caused by HL. While sand significantly improves the compactibility of clay, the addition of HL can

counteract this positive effect, leading to a decrease in MDD. The highest MDD values were observed for the 50% sand-clay mixture without HL, indicating that this particular mixture exhibits the best compaction characteristics under the given conditions.

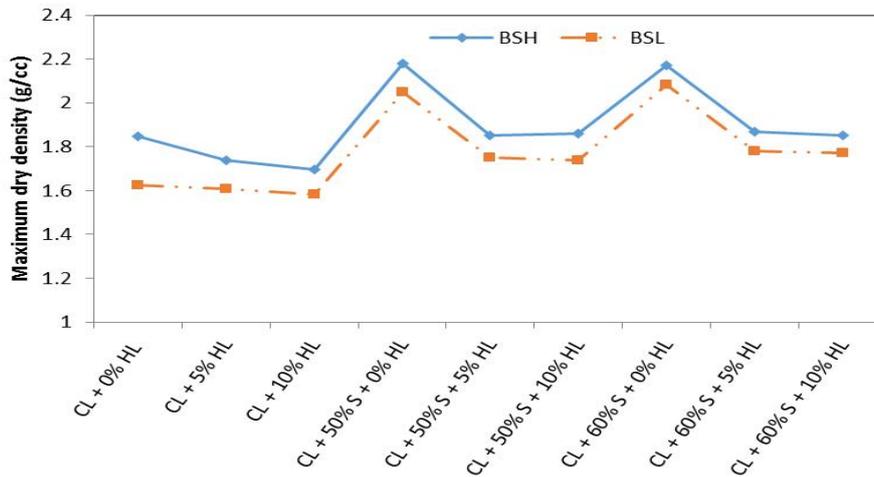


Fig. 2a: Effect of hydrated lime on maximum dry density of sand-clay mixture

The Optimum Moisture Content (OMC) is a key parameter for soil compaction. The illustration in Figure 2b reveals how the OMC of various sand-clay mixtures is affected by the addition of hydrated lime (HL) under both British Standard Heavy (BSH) and British Standard Light (BSL) compaction efforts. For pure clay without HL, the OMC was 16% under BSH and 19% under BSL. The addition of 5% HL decreased the OMC, and increasing the HL content to 10% further reduced it, suggesting that HL can reduce the water requirement for optimum compaction of clay, likely due to increased stabilization and reduced plasticity (Cheshomi *et al.*, 2017).

When 50% sand was mixed with the clay, the OMC significantly decreased to 9.61% under BSH and 11.25% under BSL, reflecting the lower water requirement for the compaction of sandy soils. However, the addition of 5% and 10% HL to this mixture increased the OMC, indicating that HL can

increase the moisture requirement for sand-clay mixtures (Kollaros and Anthanasopoulou, 2017; Dasgupta, 2014). For a 60% sand-clay mixture, the OMC was similar to the 50% sand-clay mixture, demonstrating that increasing sand content to 60% maintains similar moisture requirements for compaction. Similar to the 50% sand-clay mixture, the addition of 5% and 10% HL increased the OMC of the 60% sand-clay mixture.

In overall, the addition of sand significantly decreases the OMC of clay mixtures, indicating a lower water requirement for optimum compaction. However, the introduction of hydrated lime generally increases the OMC, suggesting higher moisture requirements, likely due to changes in soil texture and stabilization. These variations are crucial for optimizing soil mixtures for specific engineering applications, such as earth retaining structures, where precise moisture control is critical for achieving desired compaction.

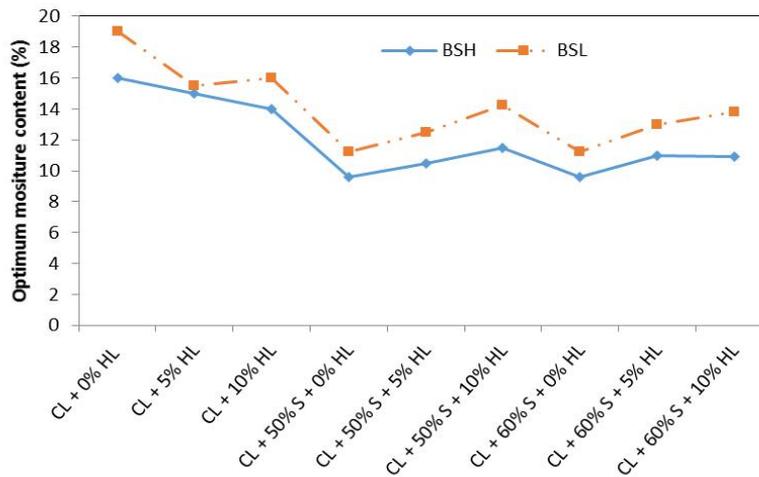


Figure 2b: Effect of hydrated lime on optimum moisture content of sand-clay mixture

### 3.4 Free Swelling Index

The addition of hydrated lime (HL) and sand to clay significantly reduces the free swell index, as illustrated in Figure 3. Pure clay exhibited a high free swell percentage of 32%. Incorporating 5% HL decreased this to 20.77%, a reduction of 35.1%. Further increasing HL to 10% reduced the free swell to 14.81%, demonstrating HL's effectiveness in mitigating clay's swell potential (Hussein, 2021).

The combination of sand and HL further enhances the reduction in free swell. For a 50% sand and 50% clay mixture with 5% HL, the free swell decreased to 9.52%, a 54.2% reduction compared to clay with 5% HL alone. Increasing HL to 10% in this mixture reduced the free swell to 4.55%. A 60% sand and 5% HL mixture had a free swell of 5%, while a 60% sand and 10% HL mixture had a free swell of only 1.9%. These results indicate that higher sand content, combined with HL, significantly mitigates clay's swell potential, leading to a more stable and reliable soil composition (Schanz and Elsway, 2017).

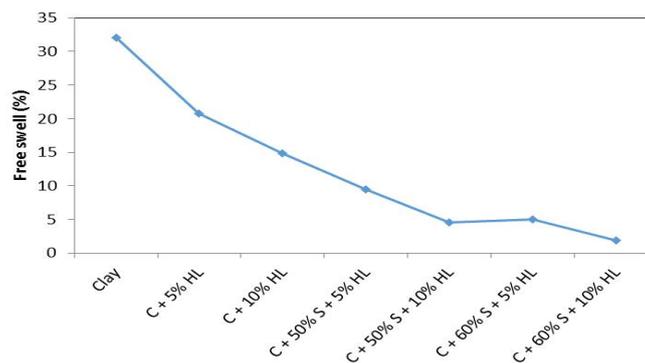


Fig. 3: Effect of hydrated lime on Free Swell index properties of sand-clay mixture

### 3.5 Hydraulic Conductivity

Hydraulic conductivity, which measures how easily water flows through soil, varies significantly with the addition of sand and hydrated lime (HL) as presented in Figure 4. For pure clay without HL, the hydraulic conductivity decreases as more HL is added.

Specifically, adding 5% HL reduces the conductivity by approximately 15.76% under BSH and 32.83% under BSL. With 10% HL, the decrease is about 24.57% under BSH and 15.85% under BSL, indicating improved soil stabilization and reduced permeability.

Introducing 50% sand to the clay substantially increases hydraulic conductivity, with increases of approximately 384.93% under BSH and 683.52% under BSL compared to pure clay. Adding 5% HL to this sand-clay mixture decreases the conductivity by about 11.88% under BSH and 4.18% under BSL. Further increasing HL to 10% results in a 5.02% decrease under BSH and a 2.69% decrease under BSL, showing a slight reduction in permeability despite the high sand content.

In a mixture with 60% sand, the hydraulic conductivity increases by 8.87% under BSH and 13.98% under BSL compared to the 50% sand mixture. Adding 5% HL reduces conductivity by

7.24% under BSH and 3.80% under BSL. With 10% HL, the reduction is about 8.29% under BSH and 11.18% under BSL. This demonstrates that while sand increases permeability, the addition of HL helps lower it, albeit not to the extent observed with pure clay.

In summary, the addition of HL consistently reduces hydraulic conductivity, improving soil stabilization and decreasing permeability. Sand significantly increases hydraulic conductivity, but its effect is moderated by the addition of HL. These changes are crucial for optimizing soil properties for various engineering applications, particularly those involving drainage and compaction.

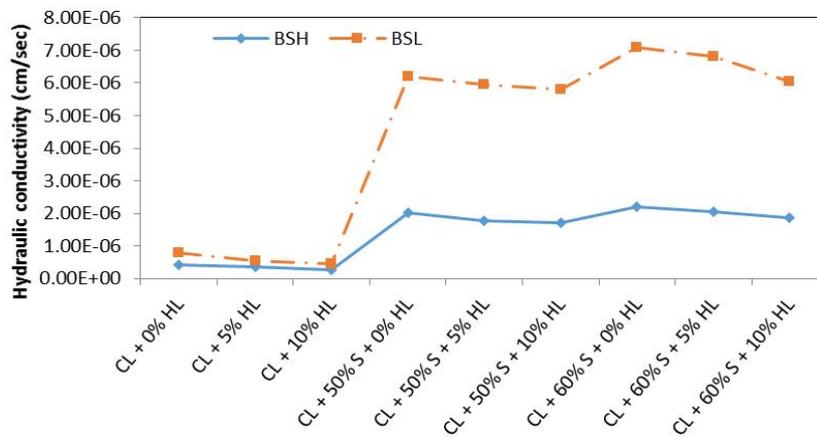


Fig. 4: Effect of hydrated lime on the hydraulic conductivity of sand-clay mixture

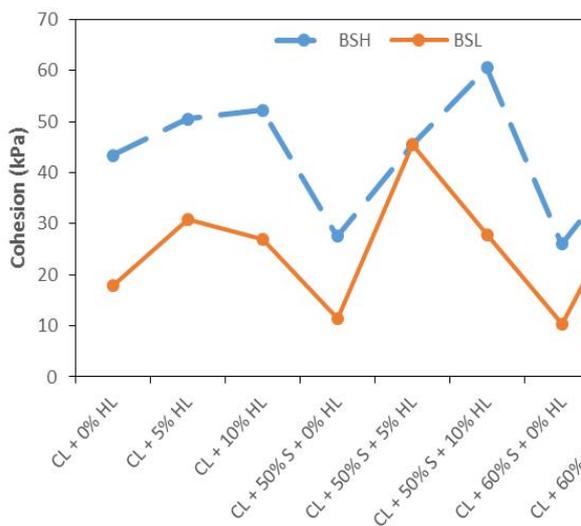
3.6 Shear Strength Parameters

Cohesion, which measures the internal strength of soil, varies significantly with the addition of hydrated lime (HL) and sand (see Figure 5a). For pure clay with 0% HL, the cohesion under BSH is 43.4 kPa. Adding 5% HL increases cohesion to 50.51 kPa, a significant 16.38% rise, likely due to chemical bonding from HL that enhances soil particle binding. With 10% HL, cohesion further increases to 52.27 kPa, marking a 20.41% increase from pure clay, indicating optimal cohesion with higher HL content under BSH conditions. In mixtures with 50% sand, cohesion decreases to 27.54 kPa without HL, as the high sand content reduces the clay matrix's natural cohesion. Adding 5% HL to this mixture boosts cohesion to 45.4 kPa, a 64.86% increase, suggesting that HL partially restores binding strength despite the high sand content. When 10% HL is added, cohesion reaches 60.52 kPa, an even larger 119.87% increase

from the no-HL, 50% sand mix, demonstrating that HL effectively compensates for the sand-induced loss in cohesion under BSH compaction.

Under BSL compaction, the pure clay mixture with 0% HL exhibits a cohesion of 17.81 kPa. Adding 5% HL raises cohesion substantially to 30.84 kPa, a 73.18% increase, indicating that HL significantly enhances cohesion under lighter compaction. However, increasing HL to 10% reduces cohesion slightly to 27.01 kPa, suggesting that under BSL, higher HL content may not fully counteract the reduction in compaction energy. For mixtures with 50% sand and no HL, cohesion drops to 11.41 kPa, showing how sand decreases cohesion under BSL. Adding 5% HL sharply increases cohesion to 45.48 kPa, nearly 298.59% higher, showing HL's impact in strengthening the matrix even with substantial sand content. With 10% HL, cohesion drops to 27.78 kPa, suggesting that excessive HL with high sand content

can reduce effectiveness under lower compaction. In mixtures with 60% sand and no HL, cohesion reaches just 10.45 kPa, reflecting a strong cohesion reduction due to the high sand content. Adding 5% HL raises cohesion to 38.36 kPa, a 266.99% increase, but further HL to 10% slightly decreases cohesion to 28.51 kPa. This indicates that moderate HL levels help regain cohesion with high sand content under BSL, though excessive HL can lead to diminishing returns. Overall, the results suggest that moderate HL additions enhance cohesion, especially in clay-sand mixtures, but too much HL can reduce gains, especially under lower compaction, due to the disrupted balance between binder content and compaction energy.



**Fig. 5a Effect of hydrated lime on cohesion of sand-clay mixture**

The internal friction angle, indicative of the soil's shear strength, is influenced by the addition of hydrated lime (HL) and sand as can be seen Figure 5b. The analysis of the internal frictional angle for different clay-hydrated lime (HL) and clay-sand mixtures under BSH and BSL compaction efforts highlights varying effects of HL and sand on soil strength characteristics. For pure clay (0% HL) under BSH, the internal frictional angle is initially 8.2 degrees. Adding 5% HL increases it to 11 degrees, a 34.15% rise, as HL enhances particle bonding, leading to better resistance against sliding. With 10% HL, the angle further rises to 13.8 degrees, a 68.29% increase from the pure clay, indicating that a higher HL content continues to enhance internal friction under BSH compaction. In the mixture with 50%

sand and no HL, the internal frictional angle significantly increases to 20.8 degrees due to the addition of sand particles, which improve the granular nature of the soil. When 5% HL is added to this mix, the angle further increases to 22.7 degrees, a 9.13% increase, showing that HL supports interparticle friction in sand-rich soils under BSH. However, with 10% HL, the angle decreases to 14.8 degrees, possibly because excessive HL can hinder the sand particles' direct contact, slightly reducing frictional efficiency under higher compaction. For the mixture with 60% sand and no HL, the angle is 22.3 degrees. Adding 5% HL reduces it to 18.2 degrees, a 18.39% decrease, likely due to the interruption of particle contact by the binder. Adding 10% HL further reduces the angle to 15.5 degrees, indicating that high HL levels may reduce frictional performance in very sand-rich mixes under BSH.

Under BSL compaction, the pure clay mixture starts with an internal frictional angle of 7.4 degrees. With the addition of 5% HL, the angle dramatically rises to 16.5 degrees, a 122.97% increase, suggesting that even a low HL content significantly improves the mixture's frictional capacity under lighter compaction. Increasing the HL content to 10% results in an even greater internal frictional angle of 27.6 degrees, a 272.97% increase from pure clay, highlighting the substantial impact of HL on internal friction under BSL. In the 50% sand mixture with no HL, the internal frictional angle reaches 13.7 degrees, indicating a strong effect of sand on friction under lower compaction. However, adding 5% HL to this mixture reduces the angle sharply to 7.4 degrees, likely due to the reduced effectiveness of particle interlocking as the HL binds particles rather than allowing them to move freely. At 10% HL, the angle then increases significantly to 29.8 degrees, indicating that at high HL levels, frictional properties improve as the binder's effect stabilizes the matrix under BSL. In the 60% sand mixture with no HL, the internal frictional angle is 15 degrees, which increases slightly to 16 degrees with 5% HL, a modest 6.67% rise that suggests minimal improvement under low compaction. With 10% HL, the angle rises to 28 degrees, an 86.67% increase from the base mixture, showing that high HL content strongly boosts internal friction in sand-rich mixtures under BSL. Overall, the results suggest that HL additions can significantly increase internal frictional angles, especially under BSL compaction, though

high HL levels may reduce friction in sand-dominant

mixtures under BSH due to changes in particle interaction dynamics.

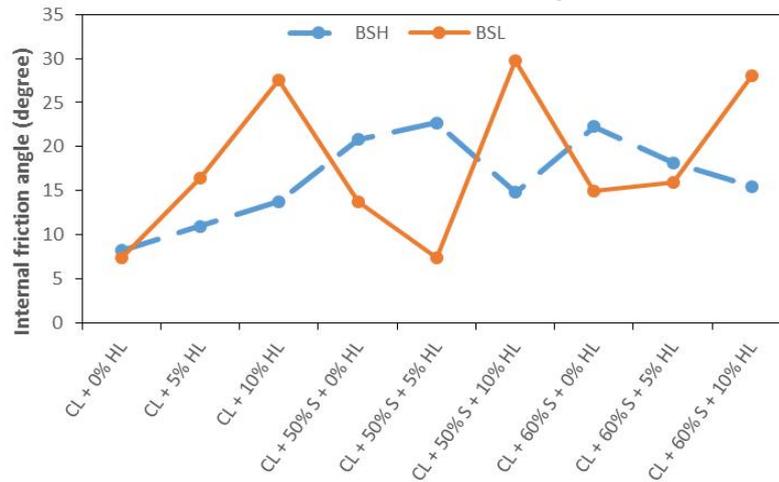


Fig. 5b: Effect of hydrated lime on the internal angle of sand-clay mixture

### 3.7 Unconfined Compressive Strength

The addition of hydrated lime (HL) and sand significantly influences the unconfined compressive strength (UCS) of soil mixtures, as shown in Figure 6a and 6b. For pure clay without HL, the UCS remained constant at 120.51 kPa under BSH conditions, indicating no strength gain over time. Adding 5% HL led to a remarkable increase, rising from 172.6 kPa at 0 days to 510.93 kPa at 7 days, a 196% improvement. Increasing HL to 10% further boosted the UCS to 1172.2 kPa at 7 days, a 476% increase. These results highlight the significant role of HL in enhancing the compressive strength of clay.

Mixtures containing 50% sand exhibited higher initial UCS values compared to pure clay with the same HL content. For example, the 50% sand mixture with 5% HL increased from 211.79 kPa to 844.84 kPa after 7 days, a 299% improvement. The 10% HL mixture showed a 504% increase. These

findings indicate that sand enhances the initial strength and contributes to substantial strength gains after curing. Mixtures with 60% sand showed moderate initial strength. With 5% HL, the UCS increased from 129.23 kPa to 527.12 kPa at 7 days, a 308% increase. The 10% HL mixture showed a 276% improvement. These results suggest that while sand contributes to initial strength, the combination of sand and HL is crucial for significant strength gains over time.

In summary, the addition of hydrated lime significantly enhances the compressive strength of both clay and sand-clay mixtures. Sand contributes to initial strength, but the combination of sand and HL leads to substantial strength gains, especially under curing. These findings are crucial for optimizing the stability and strength of soils in various engineering applications, demonstrating the efficacy of HL for soil stabilization.

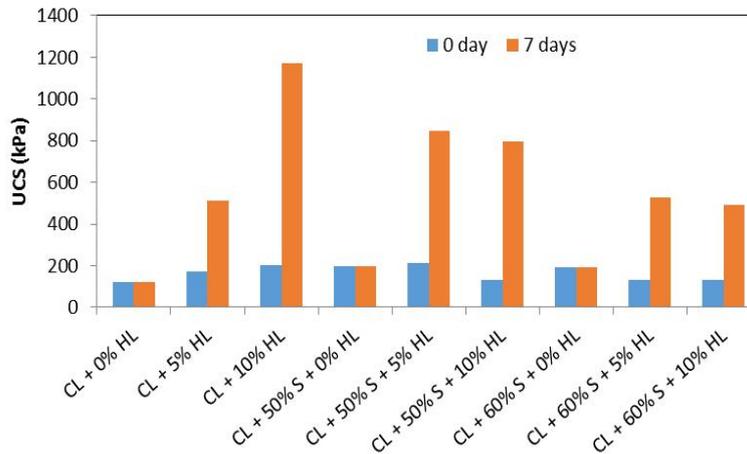


Fig. 6a: Unconfined compressive strength of hydrated lime stabilized sand-clay mixture for BSH

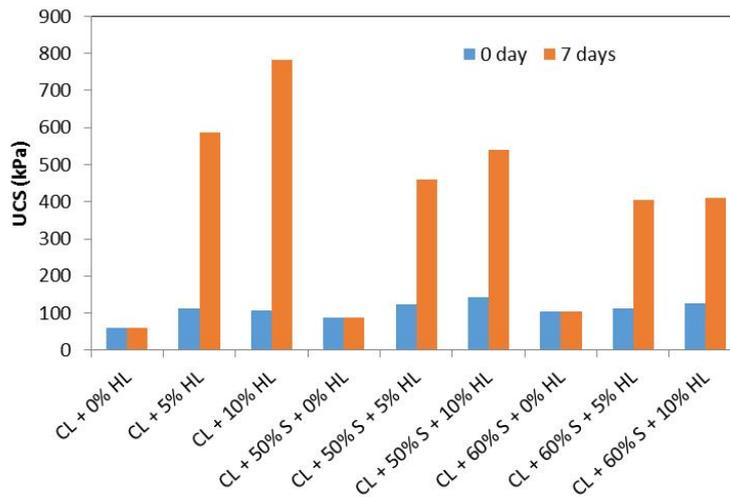


Fig. 6b: Unconfined compressive strength of hydrated lime stabilized sand-clay mixture for BSL

### 3.8 Lateral Earth Pressure

Figure 7 shows the impact of adding hydrated lime (HL) and sand to clay on the active pressure under British Standard Heavy (BSH) and British Standard Light (BSL) compaction efforts. For pure clay (0% HL), the baseline active pressure under BSH is 60.83 kPa. Adding 5% HL reduces this pressure significantly to 32.57 kPa, a 46.45% decrease, likely due to HL’s stabilization effect, which increases cohesion and reduces lateral movement. Increasing HL to 10% further reduces the active pressure to

20.25 kPa, representing a 66.70% reduction from pure clay, indicating that higher HL content under BSH compaction effectively minimizes soil expansion. In mixtures with 50% sand and no HL, the active pressure increases to 63.80 kPa, suggesting that sand introduces a granular structure that resists lateral compaction forces. When 5% HL is added, the pressure decreases sharply to 20.13 kPa, a 68.44% reduction, indicating that HL mitigates the active pressure even in sand-rich mixtures. With 10% HL, the active pressure drops further to

demonstrating an even greater reduction as HL continues to stabilize the mixture under BSH compaction. For the mixture with 60% sand and no HL, active pressure is similar to pure clay at 60.79 kPa, while adding 5% HL reduces it to 31.64 kPa, a 47.96% decrease. Adding 10% HL to this mixture further lowers active pressure to 16.02 kPa, showing the consistent effect of HL in reducing lateral pressure across varying sand contents.

Under BSL compaction, the pure clay mixture with 0% HL exhibits an active pressure of 91.73 kPa. Adding 5% HL decreases this value to 41.83 kPa, a 54.39% reduction, as HL contributes to structural stability and reduces lateral forces under lighter compaction. With 10% HL, the active pressure falls to 24.19 kPa, a 73.63% decrease from pure clay, indicating that even under BSL, increased HL content has a strong stabilizing effect. For mixtures with 50% sand and no HL, active pressure is higher at 106.14 kPa, reflecting sand’s tendency to increase lateral resistance under low compaction. However, adding 5% HL to this mixture reduces active pressure

to 52.81 kPa, a 50.23% decrease, showing HL’s influence in moderating sand’s lateral force. When 10% HL is introduced, active pressure decreases further to 25.13 kPa, demonstrating a significant reduction as HL effectively stabilizes the soil structure even with high sand content. In the mixture with 60% sand and no HL, the active pressure is 104.37 kPa. Adding 5% HL reduces it to 41.44 kPa, a 60.29% reduction, while 10% HL further lowers it to 28.48 kPa. This trend indicates that HL consistently reduces active pressure in high sand content mixes under BSL as well.

Altogether, the addition of hydrated lime significantly reduces the active pressure of both clay and sand-clay mixtures, improving the soil’s stability by decreasing the lateral pressure exerted. Sand alone contributes to a reduction in active pressure, but the incorporation of HL leads to even greater improvements. These findings are crucial for optimizing backfill material stabilization techniques in earth retaining structure, demonstrating the effectiveness of HL in reducing lateral soil pressure.

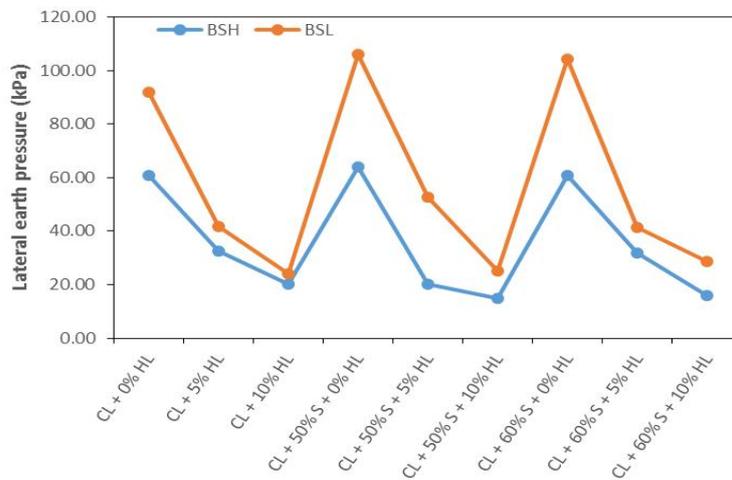


Fig. 7 Effect of hydrated lime on active earth pressure of sand-clay mixture under moist condition

IV. CONCLUSION

The following highlights the conclusions of the research findings base on the results obtain:

The addition of hydrated lime to sand-clay mixtures notably improved their engineering properties. The free swell index was reduced to near minimal values, and unconfined compressive strength showed a marked increase, exceeding 200% across various mixtures. Both cohesion and internal friction angle

were significantly enhanced. Although the inclusion of hydrated lime slightly decreased maximum dry density and permeability, the modified values remained higher than those of untreated clay and well within the acceptable range for compacted backfill.

The application of hydrated lime also contributed to a considerable reduction in active lateral pressure in both clay and sand-clay mixtures, enhancing stability

by lowering lateral pressure. While sand alone helps reduce active pressure, the addition of hydrated lime further amplified this effect, achieving over a 40% reduction across all mixtures.

Overall, the sand-clay mixture with 50% sand and 5% hydrated lime (CL + 50% S + 5% HL) demonstrates a strong balance of compaction, permeability, and stability for both BSH and BSL compaction efforts, making it a highly suitable option for backfill applications in earth retaining structures. For uses requiring greater stability, such as embankments and foundations, a mixture of 60% sand with 5% hydrated lime is recommended

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