

The Effects Of Sodium-Potassium Hydroxides And Sodium Orthosilicate On The Geotechnical Properties Of A-2-7 Clayey Sand

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Abstract— Non-traditional alkaline activators can provide an alternative approach for improving marginal soils for construction. This study presents a controlled comparative evaluation of sodium hydroxide (NaOH), potassium hydroxide (KOH), and sodium orthosilicate (SO) for stabilizing A-2-7 (SC) clayey sand. Soil-stabilizer blends were prepared at multiple dosages and assessed using Atterberg limits, compaction characteristics, and the California bearing ratio (CBR). NaOH and KOH reduced the plasticity index (PI) of the untreated soil (PI = 19) to 5–7 at the highest hydroxide dosage, indicating improved workability. Changes in maximum dry unit weight (γ_{dmax}) were limited for NaOH and KOH, whereas SO produced a clearer densification response (γ_{dmax} increased from 15.11 to 16.19–16.38 kN/m³). CBR increased approximately linearly with stabilizer dosage, reaching an average improvement from 77% (untreated) to ~86% at the highest evaluated dosage. Compared with earlier alkaline-stabilization studies that typically focus on a single activator, the side-by-side assessment reported here clarifies the relative effectiveness of hydroxide versus silicate-based activation for improving A-2-7 soil in pavement and foundation applications.

Keywords— Clay soil stabilization, Ground improvement, A-2-7 soil; Engineering index, Geopolymer stabilization, alkaline activation, Soil-binder interaction.

I. INTRODUCTION

The use of additives to stabilize soils has become a common strategy for enhancing the engineering properties of soils that would otherwise be unsuitable for construction purposes (Akinwumi et al., 2016; Ganapathy et al., 2016). Such soils are increasingly recognized as valuable resources, especially as the availability of adequate construction materials diminishes. Among the stabilizers that have garnered research attention are cement, lime, ecosand, precipitated silica, cactus mucilage, fly ash, waste marble fines, bottom ash, corncob ash, rice husk ash, steel slag, groundnut shell ash, reclaimed asphalt pavement, and calcium carbide residue (Gobinath et al., 2016; Akinwumi & Ukegbu, 2015; Cokca, 2001; Ahmad, 2015; Punthutaecha et al., 2006; Aziz et al., 2015; Akinwumi, 2014).

Two major categories of soil stabilizers are recognized: conventional and non-conventional stabilizers (Eisazadeh, 2010). Extensive research has focused on conventional stabilizers (e.g., cement, lime, fly ash, and bituminous materials), which have been acknowledged for their fundamental stabilization capabilities (Eisazadeh et al., 2011). Other viable options for soil treatment include several non-conventional stabilizers that lack calcium content. Typically, these non-conventional chemical stabilizers are available in concentrated liquid form, which are then diluted with water before being applied to the soil. The soil is then compacted or subjected to pressure to treat deeper layers. The chemical agents within non-conventional stabilizers vary widely in their composition, and their interactions with soil can significantly differ. However, the mechanisms by which these agents alter the geotechnical properties of soil or stabilize it are not well understood. Additionally, many effective stabilization additives

are proprietary, making their exact chemical compositions unavailable for public knowledge. As a result, the mechanisms behind non-conventional stabilizers are far less explored than those of traditional stabilizers.

Performance assessments, rather than mechanisms, have predominated in laboratory tests concerning non-conventional stabilizers. Previous studies have demonstrated that non-conventional liquid additives can strengthen soils over extended curing durations (Lui et al., 2011). It is important to note that different stabilizers enhance soil strength through distinct mechanisms. For instance, cationic exchange and flocculation improve soil strength through ionic stabilizers, while enzymes strengthen soil by encapsulating organic molecules. Polymers, on the other hand, strengthen soil through physical bonding, cementation, cation exchange, flocculation, or crystallization (Lui et al., 2011; Solanki & Zaman, 2012).

Alkaline activation, a sustainable alternative to cement, is considered a "geopolymer" due to its remarkable durability and strength (Suksiripattanapong et al., 2015). This process involves the reaction of an amorphous aluminosilicate source with alkali metals such as potassium (K) or sodium hydroxide (Na). The dissolution of mineral aluminosilicates, followed by the condensation and hydrolysis of silica and alumina, results in the formation of a three-dimensional aluminosilicate gel (Weng & Sagoe, 2007; Yunsheng et al., 2008). The waste materials used as precursors in alkaline activation contain abundant Si and Al, which enhance gel binding within the soil, resulting in the formation of sodium aluminum silicate hydrate (N-A-S-H) or calcium aluminum silicate hydrate (C-A-S-H) (Pourakbar & Haut, 2017). Several studies have confirmed the effectiveness of alkaline activation as a stabilizer, not only contributing to soil strength but also promoting microstructural compaction and filling soil voids (Pourakbar et al., 2017; Teing et al., 2019; Abdeldjouad et al., 2019a).

Sodium silicate, commonly known as water glass, serves various functions, including use as an adhesive, drilling fluid, and fire protection (Zuo Lu & Baudet, 2015). One study indicated that combining sodium silicate with cement improved soil strength and reduced moisture content (Kazemian et al., 2012). Another investigation found that mixing sodium silicate with slag further enhanced the strength of cemented soil (Vakili et al., 2016).

Recent research has extensively explored the mechanisms of alkaline activation, focusing on various alumino-silicate source materials and the role of alkaline activators, which typically consist of high-alkalinity solutions mixed with high-silica sources (Pacheco-Torgal et al., 2008; Khale & Chaudhary, 2007; Duxson et al., 2016; Rattanasak & Chindaprasirt, 2009). Studies have also examined the environmental benefits of alkaline activation. These advantages have driven investigations into the production of alkali-activated binders and their reaction mechanisms in civil engineering applications (McLellan et al., 2011; Turner & Collins, 2013).

However, research on the use of alkaline activation for soil enhancement remains in its early stages (Ariffon et al., 2013; Habert et al., 2011). Alkaline activation affects soil stiffness based on the starting materials, the concentration of the alkaline solution, and curing conditions. Soils subjected to alkaline activation treatment exhibit significant brittleness, similar to soils treated with cement and lime. Both cement and lime contain aluminum silicate hydrates (ASH) and calcium silicate hydrates (CSH), which act as cementitious agents and result in significant strength improvements (Pourakbar et al., 2017; Abdeldjouad et al., 2019a; Abdeldjouad et al., 2019b). This laboratory-based study

aims to assess the performance of sodium hydroxide (SH), potassium hydroxide (KH), and sodium orthosilicate (SO) in stabilizing A-2-7 soil, while determining its indices and strength behavior under treatment with varying proportions of these additives.

II. EXPERIMENTAL WORK

A-2-7 soil was used to investigate soil stabilization via alkaline activation; the soil was collected from Amman (Jordan), extracted from a depth of 0.25 m, and had a natural water content of 7%. Prior to treatment, the soil was air-dried for 24 h (Figure 1) and characterized by sieve analysis in accordance with ASTM C136; the grain-size distribution is presented in Figure 2 and Table 1, and the sieve-based characterization was considered sufficient for the objectives of this study.



Figure 1. A-2-7 soil used in experiments, showing its untreated texture before stabilizer application.

Table 1. Sieve analysis of A-2-7 soil, showing particle distribution and classification.

Sieve number	Passing %
4	99.4
8	91
16	88.6
30	87
35	43.6
50	41.8
200	23.2
Clay (%)	17

Potassium hydroxide (KH) and sodium hydroxide (SH) were selected as alkaline activators due to their efficiency and practicality, while sodium orthosilicate (SO) was used in liquid form and stored in plastic containers at ambient temperature. The hydroxide activators were procured in pellet form and prepared as a 1% pre-established concentration by dilution with distilled water; for sample preparation, the activator solutions were prepared at the target concentration and allowed to cool for approximately 24 h before mixing with soil.

The soil was classified as SC (USCS) and A-2-7 (AASHTO) based on its grain-size distribution and index properties ($LL = 43\%$, $PI = 19\%$), with baseline compaction characteristics of $\gamma_{dmax} = 15.11 \text{ kN/m}^3$ and $OMC = 20.87\%$ (Table 2). Stabilized mix designs were prepared using multiple stabilizer dosages: KH and SH were evaluated at 5%, 10%, and 15% addition levels, and SO was evaluated across 5–30% addition levels as part of the comparative program. Atterberg limits (LL , PL , and PI) for untreated and treated soils were determined in accordance with ASTM D4318-17, and Proctor compaction characteristics (OMC and γ_{dmax}) were determined following ASTM D698a using air-dried soil passing the 4.75 mm sieve. California Bearing Ratio (CBR) testing was carried out for the mix designs following ASTM D1883-05; specimens were compacted at the corresponding OMC and γ_{dmax} , prepared with standard CBR mold dimensions (150 mm diameter and 175 mm height), and the reported values represent the mean of three replicate specimens for each stabilizer dosage.

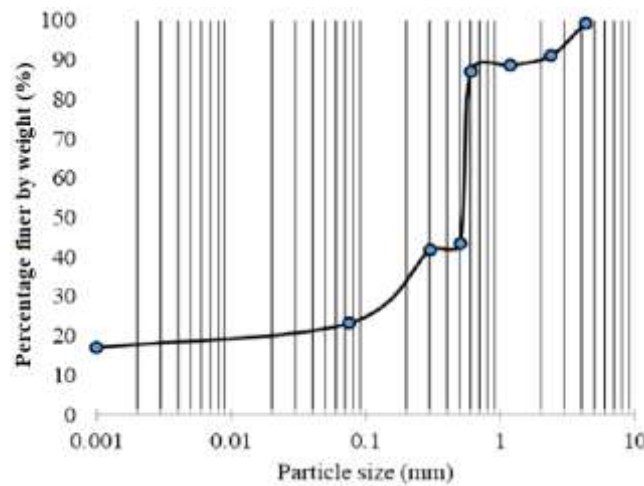


Figure 2. Grain size distribution of A-2-7 soil, illustrating particle size composition before treatment.

The effect of adding specific doses of additives evaluated on three samples for each addition, and the results presented are the statistical averages of three measurements for each test.

Table 2. A-2-7 soil properties and classification according to AASHTO and USCS.

Soil property	Values
Liquid limit, LL (%)	43
Plastic limit, PL (%)	24
Plasticity index, PI (%)	19
Maximum dry unit weight γ_{dmax} (kN/m^3)	15.11
Optimum water content OMC (%)	20.87
Passing sieve No. 200 ($75 \mu\text{m}$) (%)	23.2
Clay fraction (%) $< 2 \mu\text{m}$	17
AASHTO Soil classification	A-2-7
Unified soil classification system	SC

After mixing each soil–stabilizer blend, specimens were prepared at the corresponding OMC and compacted to γ_{dmax} . The compacted specimens were then sealed and cured at laboratory ambient temperature prior to testing. For CBR, specimens were tested in the soaked condition; molded samples were submerged in water for 4 days and maintained under surcharge weights in accordance with ASTM D1883-05 before penetration testing.

3. Results and discussions

The Atterberg limits—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)—define the plastic nature of the soil. An overview of the impact of potassium hydroxide (KH), sodium hydroxide (SH), and sodium orthosilicate (SO) additives on the LL, PL, and PI of treated A-2-7 soil provided in Table 3. The effects of KH and SH additives on these three index properties of the soil blends at various concentrations are illustrated in Figure 3 that presents the changes in the Atterberg limits, including LL, PL, and PI, as a function of increasing KH concentration in the A-2-7 soil. Figure 4 demonstrates the impact of sodium hydroxide on the Atterberg limits (LL, PL, and PI) for A-2-7 soil at varying concentrations.

Table 3. Index properties of A-2-7 soil at different stabilizer concentrations.

Soil property	LL (%)	PL (%)	PI (%)
A-2-7	43	24	19
05% KH	47	35	12
10% KH	38	29	9
15% KH	38	32	7
05% SH	26	18	8
10% SH	34	28	6
15% SH	36	31	5
05% SO	34	24	10
10% SO	42	31	11
20% SO	41	21	20
30% SO	41	20	22

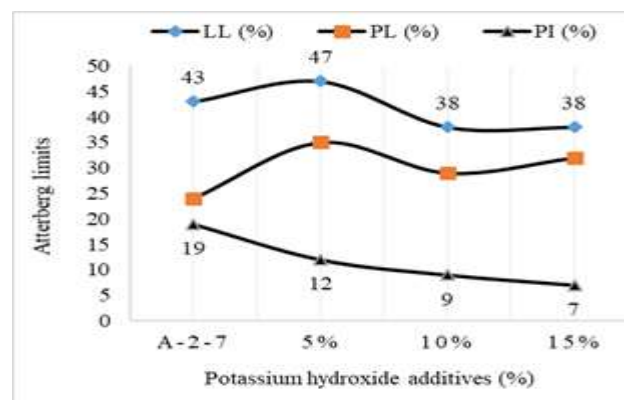


Figure 3. Effect of KH concentration on LL, PL, and PI of A-2-7 soil.

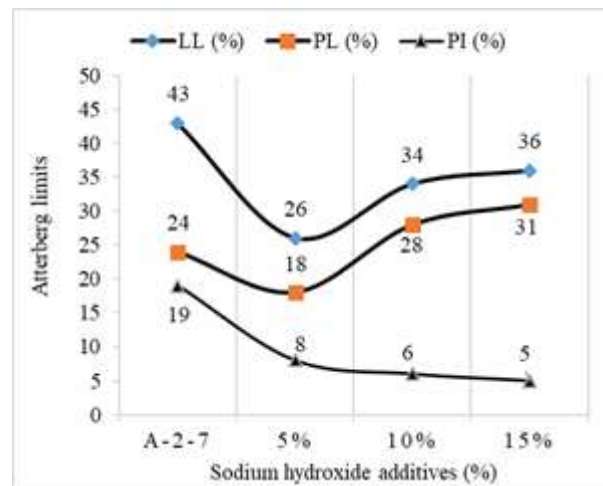


Figure 4. Effect of SH concentration on LL, PL, and PI of A-2-7 soil.

When 10–15% potassium hydroxide (KH) was added to the blended A-2-7 soil, a reduction in the Liquid Limit (LL) and Plasticity Index (PI) was observed (Table 3 and Figure 3). In contrast, a lower concentration of sodium hydroxide (SH) (5%) had a more pronounced effect on the LL of the blended A-2-7 soil, while a marked decrease in Plastic Limit (PL) occurred as the SH concentration increased (Figure 4). These reductions in LL and PI following hydroxide treatment are commonly attributed to high-pH chemical stabilization mechanisms including cation exchange, flocculation–aggregation, and compression of the diffuse double layer, which reduce the soil’s affinity for water and thereby lower plasticity (Lui et al., 2011; Solanki & Zaman, 2012). In alkaline activation systems, the formation of binders can also occur when an amorphous aluminosilicate source reacts with alkali (K or Na), promoting dissolution of aluminosilicate phases followed by condensation/hydrolysis of Si and Al and the development of a three-dimensional aluminosilicate gel (Weng & Sagoe-Crentsil, 2007; Yunsheng et al., 2008). The impact of sodium orthosilicate (SO) on A-2-7 index properties is detailed in Figure 5, which shows that increasing SO concentration generally increased LL and decreased PL, with 5% being the only addition associated with a reduction in both PI and LL; conversely, increases in both LL and PI were recorded at higher SO additions (20–30%). This behavior is consistent with silicate–clay interactions in which negatively charged silicate species adsorb onto clay particle edges, potentially altering edge charges and interparticle forces; at higher dosages, charge reversal and increased electrostatic repulsion may promote dispersion and higher measured plasticity (Abdeldjouad et al., 2019b; Sargent et al., 2013; Yilmaz & Civelekoglu, 2009). Because SO supplies soluble silicate species, subsequent polymerization/gel formation in the presence of moisture can further modify interparticle bonding and water retention, influencing Atterberg limits (Zuo & Baudet, 2015).

For clarity, the corresponding LL, PL, and PI values for the untreated soil and each stabilizer dosage (KH, SH, and SO) are reported explicitly in Table 3.

The formation of binders takes place when an amorphous aluminosilicate source reacts with alkali, typically involving alkali-earth (Ca) metals, potassium (K), or sodium (Na) in the dissolution of mineral aluminosilicate, followed by the condensation and hydrolysis of silicon (Si) and aluminium (Al) elements. This process is crucial for the development of a three-dimensional aluminosilicate gel (Weng & Sagoe-Crentsil, 2007; Yunsheng et al., 2008). The impact of sodium orthosilicate (SO) on the A-2-7 index properties detailed in Figure 5. Here, the figure outlines the variations in the Atterberg limits, such as LL, PL,

and PI, with changes in the SO concentration applied to the soil. An increase in SO concentration resulted in a rise in LL and a decrease in PL, with 5% being the only addition associated with a reduction in both PI and LL. Conversely, an increase in both LL and PI recorded with SO additions of 20-30%. Because SO introduces soluble silicate species into the soil–water system, these species can undergo hydrolysis and subsequent polymerization/gel formation in the presence of moisture, which can modify interparticle bonding and water retention and thereby influence the measured Atterberg limits.

The reaction of a silicate solution yields a colloid that undergoes additional polymerization to produce a gel, which promotes the cohesion of sediment particles or soil while filling empty spaces within the soil. However, the improvement of soil may not be successful when only sodium silicates added to hydrated clay. Generally, clay particles exhibit a positive charge along their margins due to interrupted bonds, while their faces possess a net negative charge (Abdeldjouad et al., 2019b; Sargent et al., 2013). In contrast, the treatment of A-2-7 soil with sodium orthosilicate (SO) in proportions exceeding 10% yielded a different outcome. The addition of SO to the soil triggers the adherence of the negatively charged silicate ions from the sodium silicates to the margins of the clay particles, resulting in the acquisition of a negative charge by the clay particles. If all clay particles become negatively charged, they will repel each other, leading to diminished strength and scattering of the clay structure (Yilmaz & Civelekoglu, 2009).

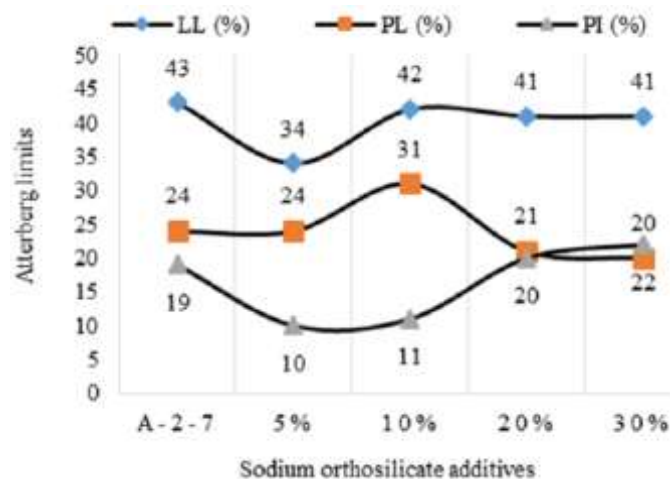


Figure 5. Effect of SO concentration on LL, PL, and PI of A-2-7 soil.

The addition of sodium silicates alone may reduce clay strength; however, when combined with lime, sodium silicates can enhance clay strength (Yilmaz & Civelekoglu, 2009). The results indicate that the enhancement of A-2-7 soil promoted by the addition of sodium orthosilicate (SO), both independently and in conjunction with sodium ions and silicate ions. The formation, hydration, and hardening of sodium silicate gel stimulate particle cohesion.

Compaction primarily aims to maximize soil density. The introduction of a single cation or anion through stabilizers can significantly affect the compaction properties of the soil. Therefore, it can be inferred that the original compaction effort influences the reactions of soil stabilizers due to its direct impact on particle spacing and the subsequent crystallization process.

During the initial design phase, the general premise is that the treated soil has a maximum dry unit weight (γ_{dmax}) that is either identical to or exceeds that of A-2-7 soil. However, this premise contradicted by the results indicating that the γ_{dmax} may be lower

than expected, as shown in Table 4. This table details the compaction properties of A-2-7 soil; including maximum dry unit weight (γ_{dmax}) and optimum moisture content (OMC), for soil treated with different stabilizer concentrations.

Both the optimum moisture content (OMC) and maximum dry unit weight (γ_{dmax}) exhibited variation with the proportions of the three stabilizers (KH, SH, and SO), as illustrated in Figures 6, 7, and 8. According to the compaction data, A-2-7 soil containing 5-15% KH displayed a lower γ_{dmax} compared to A-2-7 soil without additives.

Table 4. Compaction properties of stabilized A-2-7 soil at various stabilizer concentrations.

Soil property	γ_{dmax} (kN/m ³)	OMC (%)
A-2-7	15.11	20.87
5% KH	14.22	21.94
10% KH	14.72	19.06
15% KH	14.81	16.93
5% SH	14.72	23.37
10% SH	14.81	18.12
15% SH	15.11	17.97
5% SO	14.42	27.15
10% SO	16.09	20.34
20% SO	16.19	17.51
30% SO	16.38	17.40

Conversely, γ_{dmax} showed a significant increase at a 30% SO concentration. In contrast, the OMC decreased with elevated SO concentration. However, with all three stabilizers, a 5% concentration resulted in an increase in the OMC. The addition of SH and KH to A-2-7 soil led to a decrease in dry density and changes in OMC. Figure 6 illustrates the relationship between varying concentrations of KH and their corresponding effects on the compaction characteristics (γ_{dmax} and OMC) of A-2-7 soil and Figure 7 shows how different concentrations of SH influence the compaction properties of A-2-7 soil, specifically γ_{dmax} and OMC, although these alterations were not significant. One possible explanation for the reduction in dry density is the rapid exchange of cations in the mixture of soil and stabilizer, which leads to flocculation and accumulation of particles. Microstructurally, the SH/KH-treated mixtures are expected to undergo rapid cation exchange that promotes edge-to-face flocculation and aggregation, producing a more open fabric with larger inter-aggregate voids; this can reduce the achievable packing efficiency and thus lower γ_{dmax} despite chemical bonding effects (Sargent et al., 2013). In contrast, SO at $\geq 10\%$ likely yields silicate-rich gel products that coat particles and partially fill pore space, enabling denser packing and lowering the water demand during compaction (Zuo & Baudet, 2015). At low SO dosage (5%), incomplete gel formation and increased surface charge effects may limit pore-filling benefits, consistent with the observed reduction in γ_{dmax} relative to the untreated soil (Yilmaz & Civelekoglu, 2009).

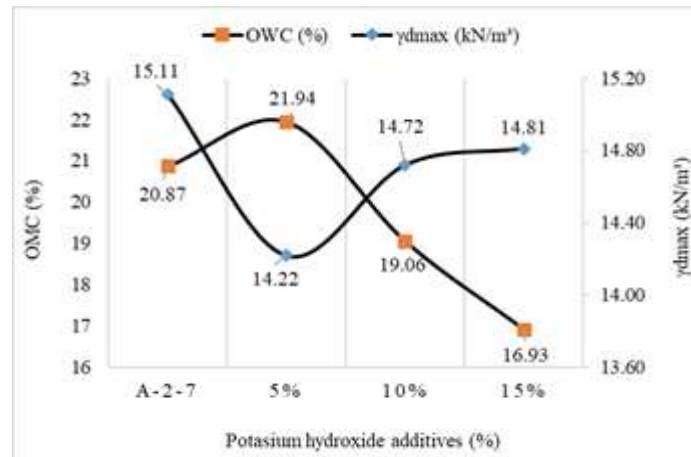


Figure 6. Effect of KH stabilizers on γ_{dmax} and OMC of treated A-2-7 soil.

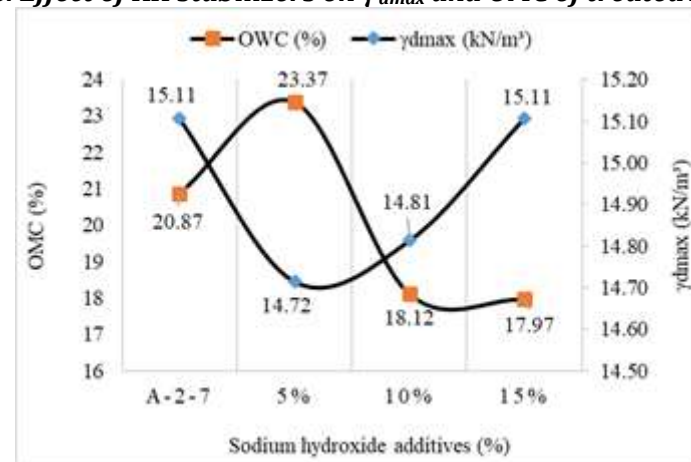


Figure 7. Effect of SH stabilizers on γ_{dmax} and OMC of treated A-2-7 soil.

Furthermore, the soil-stabilizer reaction was rapid and exothermic, resulting in water loss, which could account for the rise in moisture levels. The results obtained align with those from Zuo and Baudet (2015), which focused on the stabilization behavior of silty clay soil incorporating soil, fly ash, sodium silicate solution, and sodium hydroxide solution. It is important to note that the regulatory effect of the liquid limit (LL) on the optimum moisture content (OMC) in low-swelling silty clays may explain the negligible modifications in the OMC of the stabilized soil (Sukmak et al., 2013).

The selected activator, potassium hydroxide (KOH), is an alkaline cation known for its high efficiency. The K^+ ion contributes to enhancing the strength of soil treated through alkaline activation over the long term by facilitating further compact and close polycondensation reactions. Several studies have reported that matrices containing K^+ exhibited reduced crystallinity and increased specific surface area and compressive strength during extended curing periods (Pourakbar and Haut, 2017; Elkhebu et al., 2018).

Among the various concentrations of sodium orthosilicate (SO) added to A-2-7 soil blends (5, 10, 15, and 20%), only the 5% concentration resulted in a reduction of the maximum dry unit weight (γ_{dmax}). The compaction data related to SO blends with different stabilizer contents presented in Figure 8. This figure demonstrates the effects of SO concentrations on the compaction characteristics of A-2-7 soil, focusing on changes in γ_{dmax} and OMC. Although a 5% SO concentration caused a decrease in γ_{dmax} , the

optimum moisture content (OMC) consistently declined as the stabilizer concentration increased, while γ_{dmax} exhibited satisfactory improvement.

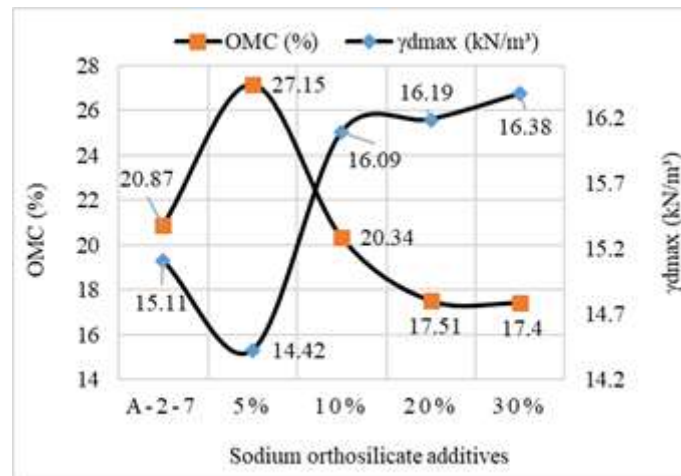


Figure 8. Effect of SO stabilizers on γ_{dmax} and OMC of treated A-2-7 soil.

The California Bearing Ratio (CBR) values obtained for various concentrations of stabilizers added to the A-2-7 blended soil presented in Figures 9 and 10. Figure 9 presents the variation of CBR values with increasing KH and SH concentrations in the stabilized A-2-7 soil samples, while Figure 10 illustrates the CBR results for A-2-7 soil treated with different concentrations of sodium orthosilicate, highlighting the soil's improvement in terms of strength. For all blended soil specimens, the increase in CBR was approximately linear with the increase in concentrations of potassium hydroxide (KH), sodium hydroxide (SH), and sodium orthosilicate (SO).

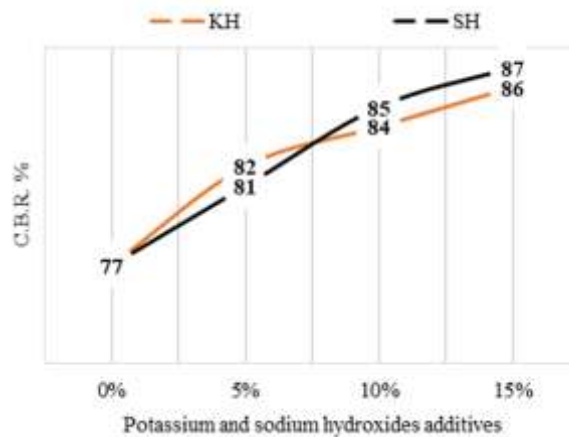


Figure 9. CBR results for A-2-7 soil with varying SH and KH stabilizer content.

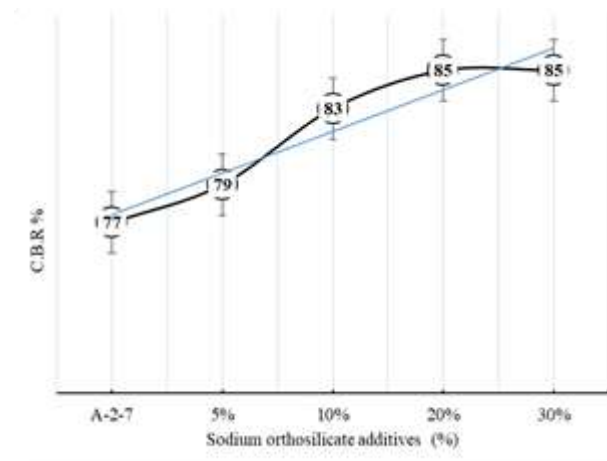


Figure 10. CBR results for A-2-7 soil with varying SO stabilizer content.

The blended A-2-7 soil improved according to the rate of stabilizer additions. The California Bearing Ratio (CBR) for the host soil increased from 77% to an average value of 86% for all alkaline stabilizers used in this study at a 15% addition rate. This rate of improvement, approximately 10%, satisfies the requirements for construction projects. From an engineering design perspective, the measured soaked CBR values indicate a very strong load-supporting material: common subgrade classifications typically consider CBR < 5 as very poor, 5–10 as poor–fair, 10–20 as fair–good, and 20–30 as very good subgrade, with higher values generally associated with high-quality pavement support layers.

Therefore, the increase observed in this study (approximately 77% → ~86%) places the treated material well above typical minimum requirements used in practice for pavement subgrade support and is consistent with the conclusion that the stabilized A-2-7 soil is suitable for pavement and subgrade applications.

Sodium silicate was used as a soil stabilizer, as it fills the interspaces between soil particles, making the soil more stable and stiffer, thereby acquiring properties akin to adhesive materials. An earlier study found that the use of sodium silicate for the stabilization of medium to fine soil led to an improvement in soaked CBR (Ravindran et al., 2020). These findings are consistent with the present study, which revealed that the mechanical properties of A-2-7 soil enhanced by sodium orthosilicate (SO).

Often, conditions arise in which an attempt to stabilize extremely wet soils would be justified. However, when builders cannot afford the time required drying the soil, or when conditions are such that the soil cannot be dried by conventional methods, these situations may justify the additional expense, despite sometimes yielding diminished effectiveness.

III. CONCLUSIONS

This study investigated the effectiveness of sodium hydroxide (SH), potassium hydroxide (KH), and sodium orthosilicate (SO) as stabilizers for A-2-7 soil, which commonly found in construction applications. The results demonstrated that the addition of these alkaline activators significantly improved the geotechnical properties of the soil, offering a sustainable and cost-effective solution for soil stabilization.

The key findings include a notable reduction in the plasticity index (PI), which is a crucial indicator of soil's workability and suitability for construction. The PI for the untreated A-2-7 soil was 19%, but with the addition of 15% SH and 15% KH, the PI decreased to 5%

and 7%, respectively, making the soil less plastic and more stable for engineering purposes. Moreover, the maximum dry unit weight (γ_{dmax}) of the soil significantly improved, especially with the addition of sodium orthosilicate (SO), where the γ_{dmax} increased from 15.11 kN/m³ to 16.38 kN/m³ at a 30% SO concentration. This increase in dry unit weight indicates that the stabilized soil has a higher compaction, improving its strength and load-bearing capacity—critical properties for soil used in foundation and pavement construction.

In addition to these changes in plasticity and compaction characteristics, the California Bearing Ratio (CBR) of the soil improved linearly with increasing stabilizer concentrations, achieving an average increase of 10%, from 77% in the untreated soil to approximately 86% with the highest concentrations of SH, KH, and SO. This increase in CBR highlights the soil's enhanced strength and suitability for use in pavements, subgrade layers, and other structural applications.

The improvements observed in this study suggest that alkaline stabilizers such as SH, KH, and SO can be effective alternatives to traditional soil stabilization methods like cement or lime, which have higher environmental impacts due to their carbon emissions and energy-intensive production processes. The use of these alkaline stabilizers can offer a more sustainable solution by reducing the reliance on conventional stabilizers while simultaneously improving soil properties in a cost-effective manner.

From a practical standpoint, these findings offer significant implications for the construction industry, particularly in regions where high-quality soil for construction is scarce or expensive. The use of non-traditional stabilizers like sodium hydroxide, potassium hydroxide, and sodium orthosilicate presents a potential pathway for enhancing locally available soils that may not meet the required engineering standards. This could lead to significant cost savings and reduce the environmental footprint associated with transporting or importing specialized construction materials.

However, despite the promising results, the study's scope was limited to certain geotechnical tests under controlled laboratory conditions. While the improvements in soil properties are substantial, further research is needed to better understand the long-term durability and performance of stabilized soils under varying environmental conditions. Future work should therefore include: (i) field trials or pilot test sections to validate constructability and performance under real traffic and moisture regimes; (ii) durability testing under repeated wetting–drying and prolonged soaking to confirm retention of strength; and (iii) microstructural investigations using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) (and where possible SEM–EDS/FTIR) to quantify bonding products, fabric changes, and the mechanisms governing the observed improvements after treatment with these stabilizers.

The findings of this study contribute significantly to the body of knowledge regarding soil stabilization and provide a foundation for future advancements in this area. The use of alkaline activators such as SH, KH, and SO offers a promising alternative for improving weak or expansive soils, making them more suitable for civil engineering applications. As this research progresses, it could lead to the development of more environmentally friendly and economically viable solutions for soil stabilization in construction, ultimately contributing to the broader goal of sustainable development in the civil engineering industry.

ACKNOWLEDGEMENT

It would not have been possible to undertake this experimental work at the College of Engineering without the support of Amman Arab University.

Declaration of interest

The author has no conflicts of interest to declare. There is no financial interest to report.

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