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Geotechnical Properties of Stabilized Brown Soil in Al-Karak, South Jordan

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Abstract
Sufficiently clayey brown soil from the north of Karak /Jordan was stabilized for civil engineering construction. Al-Karak climate is an arid and semi-arid region with long summers and low rainfall, in which the soil is unsaturated. The mineral content of Al-Karak brown soil is predominantly quartz and kaolinite minerals. Incorporating clay, though, keeps the hydraulic conductivity of soil low, increases the swelling and shrinkage potential, and increases the loss of strength due to a reduction in cohesion when the saturation state changes. This work aims to improve the geotechnical properties of Al-Karak brown soil and clay mixture with lime or cement. This research's most important results are enhancing the geotechnical properties of brown soil containing 15 % by weight clay and stabilizing using 1% by weight of lime or cement, particularly after curing for 28 days. The results indicate that the early gain in strength is better with cement, whereas its long-term strength gain is better with lime. Lime is the preferred choice for stabilization because, like cement, it provides chemical stabilization. However, lime offers additional advantages, including greater availability and cost-effectiveness. These benefits make lime particularly suitable for large-scale projects, such as road construction, which require substantial quantities of stabilizing material.

Keywords
Brown soil, Lime, Cement, Al-Karak, swelling and shrinkage.

Introduction

Most soils undergo continuous wetting and drying cycles (even in Al-Karak, which has long summers and low rainfall in winter) as a result of environmental variation (climate factor) and internal processes in soil pores, including low precipitation, irrigation of plant or vegetation near buildings or highways, drainage of sewer water, septic tanks, evaporation, etc. The wetting-drying cycles cause cracks and damage structures (buildings and highways) through the swelling and shrinkage of clay, capillary pressure, transfer, sedimentation, and solidification of salt, plant root, and inorganic and organic plastering material.

In soils with a significant amount of swelling clay, such as the one used in this study (Figure 1: any soil can swell and shrink), one of the prominent effects of variation in soil moisture is the simultaneous change of soil matrix volume. It is randomly drying (and thus random shrinkage), then the internal stresses due to variation in water content that eventually led to cracking in structure. In heavy, non-structural clay soils, forming cracks with a width and depth of several centimeters is common.

Figure 1: Karak brown soil (shrinking phenomena).

Jordan soils are subjected to cycles of wetting during winter and drying during long summer, which are known to undergo structural changes by the coalescence of adjacent aggregates. The strong tensile force of capillary water primarily drives the structural change process. Aggregate coalescence is responsible for post-tillage hardening of agricultural soils (Cockroft and Olsson, 2000). Micro morphological studies show that the coalescence of aggregates occurs by plastic flattening and fusion of inter-aggregate contacts without any need for an additional cementing agent (Day and Holmgren, 1952; Kwaad and Mucher, 1994).

The road network in Jordan is the only transportation and passenger transport mode. Natural soils are used for different civil engineering applications and highway construction of all highway layers of pavements (Base, subbase, and subgrade) except the surface of asphalt concrete (Maaitah et al., 2004). Natural soils are rock-weathering products. Therefore, soil properties are a crucial element influencing the success of road construction. Many soils cause significant problems in designing, constructing, and maintaining road surface layers, such as expansive subgrade soil. In Jordan, approximately 40% of the roads are covered with expansive subgrade soil, so Jordanian roads suffer from cracks due to soil unstabilization and insufficient geotechnical investigation and treatment. Therefore, there is a need for old and new stabilization techniques, such as chemical stabilization, to be adapted to the new road construction trend in Jordan.

Admixtures used for soil stabilization can be chemical binders, industrial wastes, cement, and fly ash. Soil stabilization is a technique used to change different soil properties and enhance its engineering performance (Maaitah, 2012; Winterkorn, 1975).

Standard and problematic soils can be stabilized by chemical stabilization, which treats them with chemicals to attain improved strength and stability properties (Mahasneh et al., 2023; Caterpillar, 2006). In addition to protecting the highway, chemical stabilization can decrease pavement thickness (base, subbase, and surface layer) by increasing the bearing capacity of the subgrade. In addition, a chemical agent can stabilize the base and subbase. Cement and lime are the most well-known base course, subbase course, and subgrade stabilizers.

Soil-lime reactions can be categorized into short and long-term, according to (AASHTO, 2008). The short term involves cation (replacing the exchangeable ion (Na^+ or K^+) in the clay with the Ca^{+2}ion of the lime. The soil pH will increase (12-13), so the media will be alkaline. By this replacement of ions, the double layer around the platy or flaky clay particle will decrease in thickness, resulting in a significant change in the plasticity characteristics of the soil (Molenaar, 2005).

Longer-term reactions involve interactions between free lime $Ca(OH)_2$ and soil particles. These interactions are referred to as pozzolanic as they involve pozzolans, alumina, and silica made available from the soil by the high pH lime-water solution. These pozzolanic reaction products resemble cementation products formed when Portland cement hydrates. Maintaining a pH level that is high enough, typically a pH of 12.4, is required to stabilize soil pozzolans that participate in these reactions (AASHTO, 2008).

Portland cement is widely used as a soil stabilizer because of its easy handling and quality control properties (Saitohet al., 1985). In addition, many geotechnical problems are related to unsaturated states in soils, for instance, landslides, construction of dams, shallow foundations, and pavements constructed in unsaturated soils such as shrink-swell clay and collapsible loess, etc. There is also a need to ensure infrastructure serviceability and integrity in the future, especially with the apparent adverse effect of climate change that result in more intense rainfall and a more extended period of drought. The importance of unsaturated soil mechanics thus cannot be overemphasized.

In Jordan, mechanical stabilization of soil is usually used for soil stabilization, but it is not sufficient due to the change in water content during the year. Therefore, chemical fixation must support mechanical stabilization, especially in road construction. On the other hand, in the case of roads, the process of protection from climate change and the imbalance in the water content is large and complex to control and requires a high cost. Therefore, the chemical fixation process is essential. Chemical stabilization using lime or cement has become necessary to improve the soil behavior under highway footing (subgrade).

This research study was carried out to investigate the capability of using cement and lime to improve the geotechnical properties of the KS from south Karak and Kaolin from Batn El-Ghul, southeast Jordan.

Geology and Geomorphology ofKarakArea

The Karak Plateau is an area of about 750 squarekilometers, with the highest elevation of the upland surface approximately 1,200 meters above sea level in its southwestern quadrant and its lowest elevation approximately 900meters above sea level toward the east and the desert (Mattingly et al., 1998). The study area is located within the Dead Sea Jordan rift valley, which originated as a zone of weakness in Precambrian times (Bender, 1968). The rock units encountered in the study area are Cambrian, Cretaceous, Tertiary, and Quaternary (Bender, 1968; Masri, 1963). The brown soil from south Al-Karak belongs to the Quaternary ages (Bender, 1975).

Materials and Methods

The collected soil samples (No additives) used in the improvement experiments were obtained from two locations:

1. Karak Brown Soil

The brown soil (KS) samples were collected from different sites in North Karak by open excavation. The KS samples were taken from a depth of one meter below natural ground level. The KS was air-dried in order to maintain the soil properties as it was in situ. Then, it was sieved through a 425-micron sieve.

2. Natural Kaolin (K) from Batn El-Ghul, southeast Jordan, was used in this study:
   a) Portland cement
   b) Hydrated lime Ca $(OH)_2$ is commercially available in the Jordan Portland cement factory.

All materials were characterized before and after the improvement process. The X-ray diffraction (XRD) method is used to determine the mineral content of Kaolin. The compaction test was carried out for one hour, one week, and four weeks for KSKL and KSKC. Many tests were conducted, such as particle size distribution, liquid limit, plastic limit, swelling test, and shear strength tests.

Experimental Methods

Experiments were conducted on two groups. The first group,Karak brown soil, was mixed with Kaolin (KSK) at a rate of 15% kaolin by weight of the soil, and then 1% lime by weight was added to the soil and Kaolin. The mixture was then mixed well until it became homogeneous. It will be symbolized by (KSKL). The second group,Karak brown soil, was mixed with Kaolin at a rate of 15% kaolin by weight of the soil, and then 1% Portland cement was added. The mixture was then mixed well until it became homogeneous. It will be symbolized by (KSKC). The two groups were summarized as shown in Table (1).

Table1: Testing group and symbol of each group.

Group	Additive percentage	Symbol
First: Karak brown soil was mixed with Kaolin (KSK) at a rate of 15% kaolin by weight of the soil,	1 % lime	KSKL
Second: Karak brown soil was mixed with Kaolin at a rate of 15% kaolin by weight of the soil,	1 % of Portland cement	KSKC

Results and Discussion

Soil Characterization Results

The samples of KS and K were characterized before the stability improvement. The soil used in this work can be classified as A7-6 according to the AASHTO standard. Particle size distribution (Fig. 2) indicated that the major components of KS are sand and silty loam with a significant amount of clay (Kaolin).

Kaolin (K) clay showed a basal spacing of 12.02 A˚ corresponding to the montmorillonite mineral. The results of the XRD pattern show that it consists primarily of the mineral kaolinite. The cation exchange capacity (CEC) of the clay was 108.6meq/100gm. The exchange capacity of the clay was constituted by 30.6 meq/100gm of calcium, 4.9 meq/100gm of magnesium, 56.2 meq/100gm of sodium, and 0.6 meq/100gm of potassium. This indicates that the soil is medium to highly expansive soil.

The physical properties of these soils used in the investigation are shown in Table 2. Liquid limit (LL) can be considered one of the most significant index properties since it is correlated with various engineering properties. The liquid limit of Kaolin is very high compared to that of Karak soil, as shown in Table 2. It is clear from Table 1that the Plastic index (PI) for Kaolin is very high because of its ability to disperse into extremely small particles with a tremendous amount of potential adsorbing surface. The factors that control the liquid limit of Kaolin arewell-studied in the literature.

The LL behavior of Kaolin is essentially controlled by the thickness of the diffused double layer and that of kaolinite by shearing resistance at the particle level (Sridharan et al., 1986). The LL of the Karak soil-Kaolin mixture used in this study is 75%. Soils with high LL are generally preferred for some engineering applications because of low hydraulic conductivity. Therefore, the soils with LL of about 80% are suitable for use as liners for any engineering construction. In contrast, the high LL indicates high volume change and low strength. The result presented in Table 2 was the average of three trials.

Table 2:Physical properties of Karak soil and Kaolin clays.

Physical property	Karak soil				Kaolin			
	Trial 1	Trial 2	Trial 3	average	Trial 1	Trial 2	Trial 3	average
Specific gravity	2.7	2.7	2.72	2.71	2.79	2.78	2.77	2.78
Liquid Limit LL(%)	48	48	51	50	322	318	320	320
Plastic index (PI) (%)	23	23	24	24	268	272	270	270
Shrinkage limit SL(%)	17.4	17.4	17.3	17.2	10.9	11.1	10.8	11

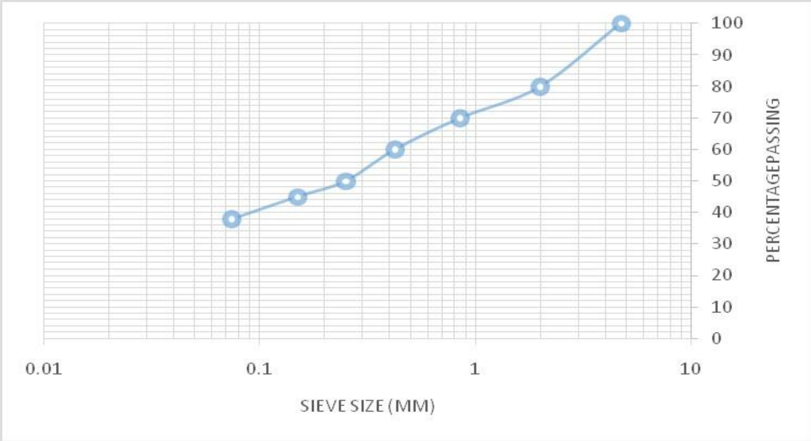

Figure 2: Particle size distribution of Karak brown soil (KS).

Geotechnical Results

1. Liquid Limit (LL) and Shrinkage Limit (SL)

Figure 3 shows the liquid limit (LL) for the mixture KSKL and KSKC, while Figure 4 shows the shrinkage limit for the same mixtures. As shown in Figures 3 and 4, adding 1% lime or 1 % Portland cement reduced the LL and SL of (brown Karak soil with 15% kaolin mixture from 80% to 60%. For a curing period of 28 days, the LL was further reduced to about 50%. Generally, adding lime or Portland cement immediately reduces the LL of Kaolin due to the replacement of monovalent exchangeable clay cations by calcium ions (Bell, 1988). However, with curing, the liquid limit of Kaolin increases due to the flocculation of the particles (Mateos, 1964; Sivapullaiah et al., 2000).

Suppose the clay will be used as a liner, which should have minimal shrinkage. The cracks will appear if the shrinkage limit (SL) is high. It is well known that Kaolin alone possesses a very high-volume change (swelling and shrinkage potential). The addition of 15% of Kaolin to Karak brown soil only marginally increases the swelling potential of the soil. The SL of the Karak brown soil Kaolin mixture is about 14% (see Figures 1 and 2). Adding 1% of lime increases the SL of a mixture to about 20%. This reasonably high SL indicates its suitability as a fill or line material. Curing with lime only marginally increases the shrinkage of the mixture. The increase in SL is marginal on red earth since it is already flocculated. The addition of cement also increases the shrinkage limit of the Karak brown soil Kaolin mixture (Figures 1 and 2). Here again, the effect of curing is very small. It can be concluded that the addition of lime is slightly better than cement when increasing the SL of the mixture.

On the other hand, it is known that the liquid limit or shrinkage limit of brown Karak soil is not affected either immediately or after curing (Sivapullaiah et al., 2000). This is because the cation exchange capacity of brown Karak soil is lower, and their particles have already flocculated. However, in this study, the liquid limit of Kaolin- brown Karak soil mixture is mainly affected immediately, and there is not a significant drop with curing. This indicates that the cation exchange of the mixture is high, and their particles are mostly flocculated even before the addition of lime.

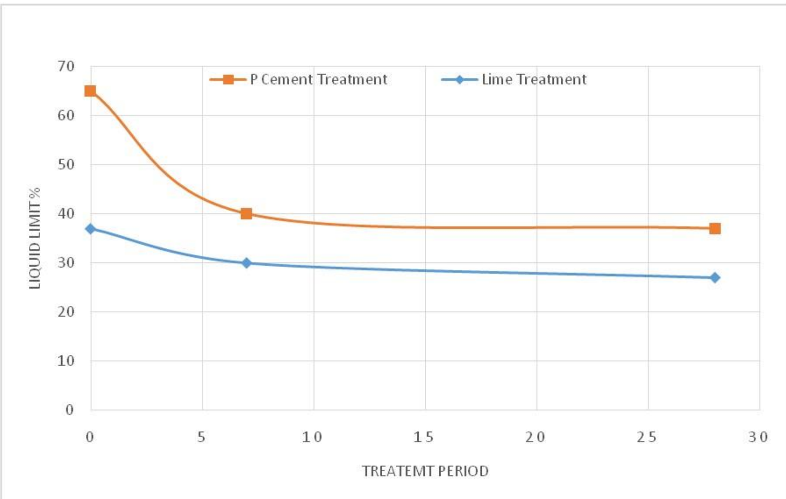

Figure 3: Mixture of brown Karak soil with 15% Kaolin and1% lime.

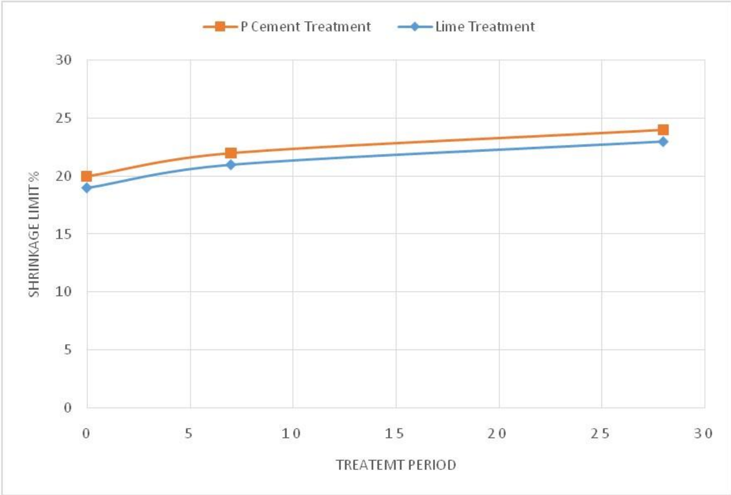

Figure 4: Mixture of brown Karak soil with 15% Kaolin and 1 % Portland cement.

2. Compaction Test

Figure 5 shows the compaction test for the KSKL mixture, while Figure 6 shows the compaction test for the KSKC mixture. As shown in Figure 5, for the KSKL mixture, four weeks is the best time for compaction, while Figure 6, the KSKC mixture, shows that all times are best compacted.

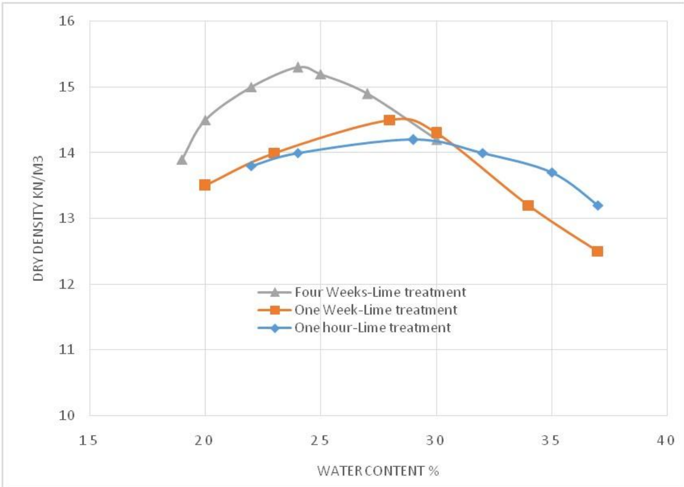

Figure 5: Compaction test for lime treatment for brown Karak soil with 15% Kaolin.

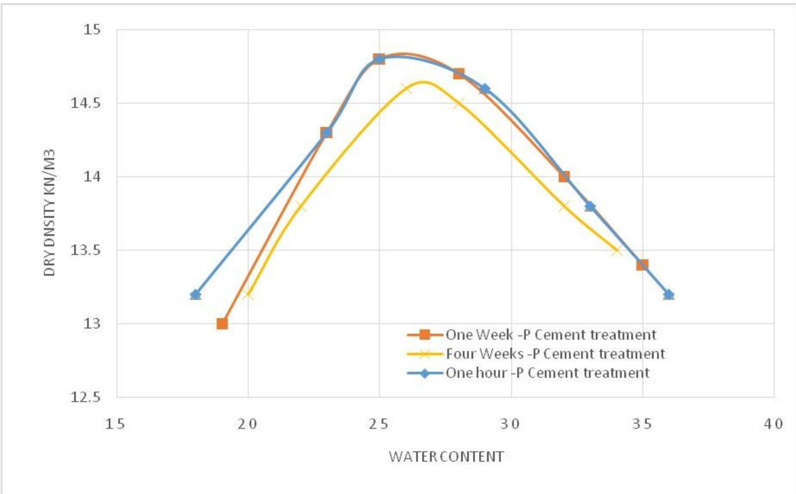

Figure 6: Compaction test for Portland cement treatment for brown Karak soil with 15% Kaolin.

i. Unconfined Compressive Strength Tests

The sample for the unconfined strength test was prepared by statically compacting for brown KSK to the maximum dry density at optimum water content in a static compaction mold. The sample obtained was of height of 7.6 mm and diameter of 38 mm. The tests were repeated on three identical samples. As shown in Figure 7, the stress-strain curves were plotted, and peak stress was obtained. The peak stress reported was an average of three values. Figure 7 shows the stress versus strain behavior for brown Karak soil with 15% Kaolin and 1% lime after curing for seven and 28 days. The strength of the soil, which was relatively low, improved considerably after curing for seven days.

Further, after curing for 28 days, there is a steep increase in strength. Also, the stress-strain curves of 28 days cured samples show pronounced peaks, and the strain corresponding to the peak stress decreases. This is because of the cementation of the soil particles due to pozzolanic reaction compounds. The unconfined strength of brown Karak soil with 15% kaolin has also been studied after curing with cement for 0, 7, and 28 days. In contrast, in the case of lime, the strength of samples cured with cement reaches a maximum within seven days of curing. Then, there is no strength improvement beyond seven days of curing. Consequently, the stress-strain curves (Figure 6) of samples cured for seven days and 28 days exhibit similar behaviors. Curing with cement binds the soil particles faster than in the case of lime. Thus, in the case of cement, maximum peak strengths are obtained within seven days.

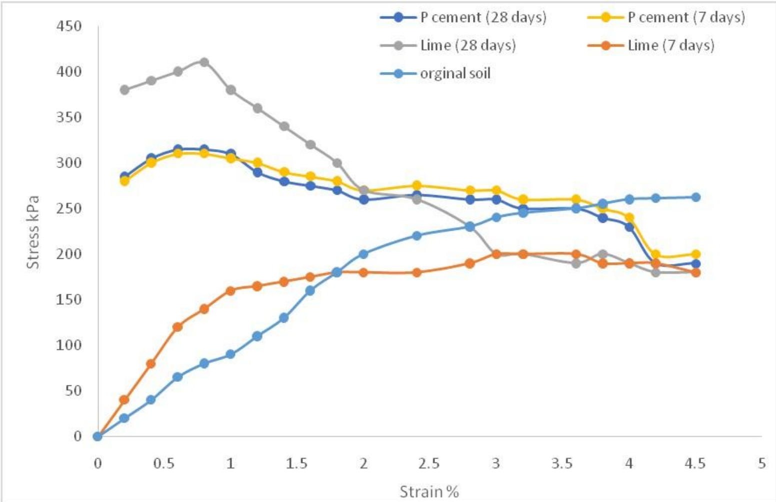

Figure 7:Stress Strain curves of soil cured with lime and cement for brown Karak soil with 15% Kaolin

ii. California Bearing ratio (CBR)

The harder the material is, the higher the CBR value. A CBR value of 2% is usually found for clay;high-quality sub-base will have CBR values between 80% and 100%, and some sands may have values around 10%.

Table 3: CBR valuefor brown Karak soil with 15% Kaolin.

Original soil	7 days lime	28 days lime	7 days P Cement	28 days Portland Cement
10	22	35	16	28

iii. Swell Pressure

The results of swell pressure are listed in Table 4. The pressure thatthe expansive soil exerts, if it is not allowed to swell or the volume change of the soil is arrested.

Table 4: Swell pressurefor brown Karak soil with 15% Kaolin.

Original soil	7 days lime	28 days lime	7 days P Cement	28 days Portland Cement
1.6	0.8	0.5	0.9	0.6

Conclusion

Using cement and lime as soil stabilization materials has proven effective through numerous studies. Since Karak soil falls within the range of unsaturated soils, it requires mechanical and chemical stabilization. In Jordan, lime is the preferred choice for stabilization. It shares the exact chemical stabilization mechanism as cement but offers additional advantages, such as availability and cost-effectiveness. This makes lime particularly suitable for extensive road work projects, which demand large quantities of stabilization material.

The utilization of Kaolin as a cementations stabilizer for brown Karak soil reveals that as the kaolin content increases by up to 15%, the swelling pressure of expansive soil decreases. Meanwhile, lime maximizes dry density and reduces the optimum moisture content of expansive soils. Adding 1% lime by dry weight of the soil is optimal for improving plasticity and swelling properties. In conclusion, traditional stabilizers such as lime and cement are significantly more effective than liquid stabilizers in enhancing soil strength.

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