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UTILIZING NATURAL ADDITIVES IN STABILIZING CLAYEY SOIL

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Some Clayey soil in Alkarak is stabilized using Cement and natural resources including zeolites and Dead Sea Sand (DSS) (south of Jordan). To examine how different additives can be used to improve the mechanical and physical qualities of problematic clayey soil, field and laboratory experiments have been done. Clayey soils are surface deposits that vary in thickness and mineral makeup. With varying percentages, the two main components are kaolinite and montmorillonite. Due to Jordan's semi-arid location and the soil's unsaturated state, Clayey soils are very vulnerable to changes in moisture content due to their sheet-like structure. As a result, infiltration depth varies depending on the area. The Ca-montmorillonite content and moisture content, which change between the summer and winter seasons, determine how troublesome Clayey soils respond, including swelling and shrinkage to varying degrees. Utilizing 4% (DSS), 12% (Zeolites), and up to 12% (Ordinary Portland Cement) improved the physical and mechanical qualities of the examined clayey soil. The Clayey soil could be improved by the 4% fixing percentage of (DSS). 12% of zeolites, meanwhile, improve the clayey soil's qualities. The physical characteristics of Clayey soil could be enhanced by mixing up to 12% ordinary Portland cement with it.

Keywords: dead sea sand, clayey soil, soil improvement, zeolites and cement

1 INTRODUCTION

Jordan is situated in areas that can be categorized as being arid and semi-arid, which means the soil is unsatiated. The degree of saturation, or in other words, the climate, affects the mechanical properties of the soil. Soil stabilization is essential to every engineering project, but is especially important for highway building. From a geotechnical perspective, Clayey soils are viewed as problematic soil in Kerak (south of Jordan). Clayey soils are classified as soil that can expand and contract. More than 40% of the material is composed of clay, which has a varied kaolinite and montmorillonite mineralogical composition. Additionally, Clayey soils are characterized by their high plasticity indices and medium to high plasticity.

Interest in the mechanical behavior of unsaturated soils has increased since the 1950s. This interest has grown over the past 15 years, and substantial experimental laboratory testing programs that have led to the creation of numerous constitutive models for these soils have followed. The pore-water suction, or level of saturation, affects the mechanical behavior of unsaturated soil.

Techniques for improving soil include adding naturally occurring non-plastic elements at the same time as static or dynamic compaction to Clayey soils to reduce plasticity,swelling, and increase shear strength. Pavements, backfilled ground, embankments,foundations, and channel or reservoir linings are all susceptible to cracking and breaking.

The use of various chemicals to improve soil has been the subject of numerous studies. [1] Researched the rice husk's pozzolanic activity and amorphous silica concentration. [2] Used calcium chloride to remediate the soil. [3] looked into the potential for an alkali pozzolanic reaction when biomass ash and calcium carbide residue were used as chemical additives to dissolve silica in the ash. [4] studied how lime stabilization affected the geotechnical characteristics of several soil types, particularly clayey soils in Amman (Jordan). [5] demonstrated that the mechanical properties of the lime treated composites were improved by minor additions of lime by weight of soil.

[6] Stabilized brown clayey soils with high calcium ash from the Allajun region. [7] Used organic materials to stabilize the soil and polyacrylamide and Gellan gels to prevent erosion and soil crushing. [8] Used road bond, which lessens clayey soils' shrinkage and expansion, to try to stabilize soil in India. [9] Researched the use of crushed limestone sand and polymer fibers to stabilize expansive clays in the Amman region.

Several soil tests were carried out in this paper, and the following materials (cement, sand, and zeolites) were added to Clayey soil in various percentages as additives. Zeolite is regarded as a new raw resource for clayey soil improvement. This project uses cement, silty sand, and zeolite to improve Clayey soil. Large sections of Jordan's southern region are covered in Clayey soils (Al-Kerak County). Clayey soils must be dug up, removed, and replaced with another suitable soil, which is costly, time-consuming, and causes significant environmental harm to the surrounding natural landscape.

2 EXPERIMENTS METHODS

To ascertain the physical characteristics of native Clayey soil and additional materials, numerous tests have been conducted. The materials utilized in this work will be briefly described in this section, and references to the laboratory tests' findings, curves, and tables will be made.

2.1 Native clayey soil

The main component of this job, 200 kg of native Clayey soil, was transported from Alkarak in Southern Jordan and required to be enhanced. As shown in Tables 1 through 3, this material has been examined for its general properties. The grain size distribution of the tested clayey soil is shown in Fig. 1.

The native clayey soil is classified as low plastic clay (CL) according to the Unified Soil Classification System (USCS).

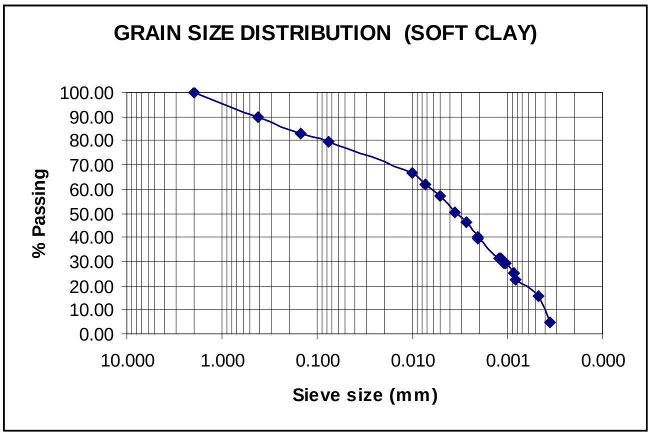

Fig. 1. Native clayey soil's distribution of grain size

2.2 Native sand

To remediate Clayey soil, a sample of 50 kg of local sand from the Alsafi region (in southern Jordan) was brought. As shown in Tables 1 through 3, this material has been examined for its general properties.

2.3 Natural Zeolites

Popular group of minerals known as zeolites generally forms in the crevices of volcanic rocks. In nature, zeolites are created when volcanic glass and salt water undergo a chemical reaction, and they have at least one silicon atom for every one aluminum atom. The percentages of the following chemicals that could be present in zeolite structures are: SiO2 = 42.7%, Al2O3 = 13.7%, MgO = 9.7%, Fe2O3 = 12.3%, CaO = 8.9%, and LOI (others) = 3.2%. (Shawabkeh et al., 2004).

To treat Clayey soil, a sample of 100 kg of natural zeolite was transported from AL Azraq in eastern Jordan. The general characteristics of this material have been tested and are shown in Tables 1–3.

Table 1. The physical characteristics of the materials being studied

Soil description	Plasticity index (PI)	Specific gravity Gs (at 20oc)
Native clayey soil	19	2.745
Sand	Non-PI	2.661
Cement	N/A	3.15

Table 2. The optimum moisture content (OMC) and maximum yd for the materials

Soil description	Optimum moisture content %	Maximum dry unit weight (kN\m^3)
Native clayey soil	22.7%	16
Zeolites	19.53%	12.25
Native Sand	24.73%	15.3

Table 3. Parameters of the soil for the materials

Soil Description	C (using (UU) test (kPa)	φ (using (UU) test (degree)	C (using (direct shear) test (kPa)	φ (using (direct shear) test (degree)	(K avg) (cm/sec)	Cu (kPa)
Native Clayey soil	200	13	27	17	0.000032	83.4
Natural Zeolites	30	45	5	48	0.00003	4.1
Native sand	4	37	16	22	0.0049	N/A

Grain size distribution of Native sand is clear in Fig. 2, where the classification was detected to be (Poorly graded sand little or no fines).

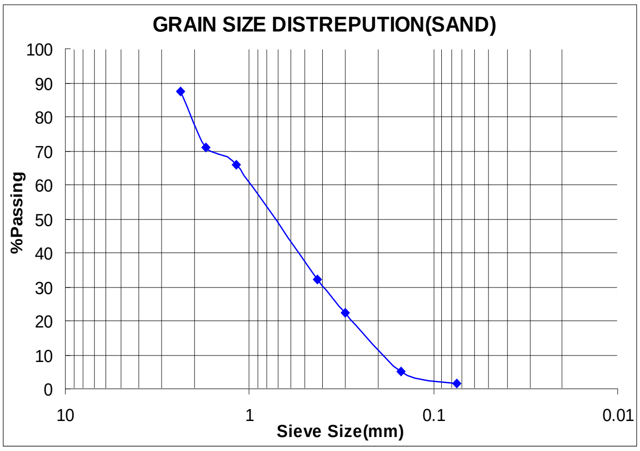

Fig. 2. Native sand's grain size distribution

Grain size distribution for Natural Zeolites is clear in Fig. 3, where the classification was detected to be (Well graded sand and gravelly sand little or no fines).

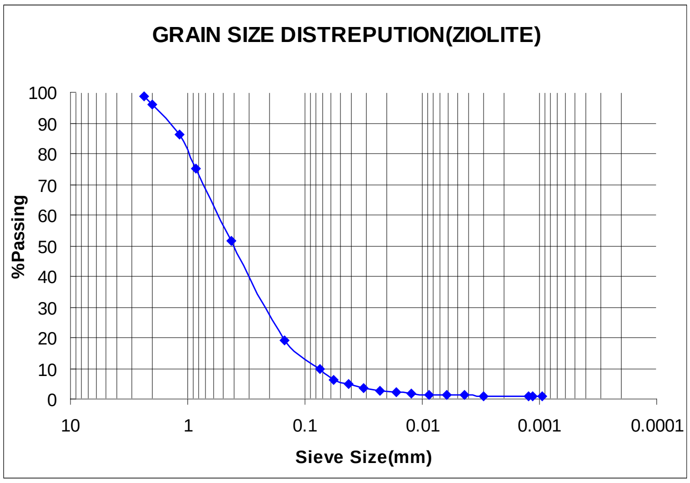

Fig. 3. Natural Zeolites' distribution of grain sizes

2.4 Cement

A sample of 50 kg of Ordinary Portland Cement (Type I) was brought from AL Rashadia cement factory (southern part of Jordan) in order to treat Clayey soil.

2.5 Percentages of added materials

On native materials (clay, sand, and zeolite), a permeability test has been conducted. Cement was added at percentages of (2%, 8%, and 14%). Zeolites were introduced in percentages of (2%, 12%, and 24%). The additional percentages for sand were (4%, 24%, and 36%).

On native materials (clay, native sand, and zeolites), a Triaxial (UU) test has been conducted. The materials described above were used in this test. Cement was added at percentages of (2%, 8%, and 14%). Sand was added in percentages of (4%, 24%, and 36%). The additional percentages for zeolites were (2%, 12%, and 24).

Native materials (clay, silty sand, sand, cement, and zeolite) have undergone a direct shear test. The following percentages of each ingredient were put to the Clayey soil; for cement, they were (2%, and 14%). Zeolites was (2%, and 24%) while Sand's were (4%, and 36%).

Native (clay, native sand, cement, and zeolites) have undergone a consolidation test. The following were the added percentages for each material: 36% sand, 14% cement, and 24% zeolite are present.

3 RESULTS AND DISCUSSION

3.1 Permeability test (constant and falling head)

The permeability of native clayey soil has been examined. The permeability of various additional materials was evaluated after being combined with Clayey soil at various percentages to see how much the permeability of the native Clayey soil was improved. Fig. 4 shows the impact that adding various ratios of native sand to the clayey soil samples has on the permeability coefficient kavg. The kavg value of is increases from 0.0048 to 0.0065 cm/sec as the proportion of sand increases from 4% to 24%.

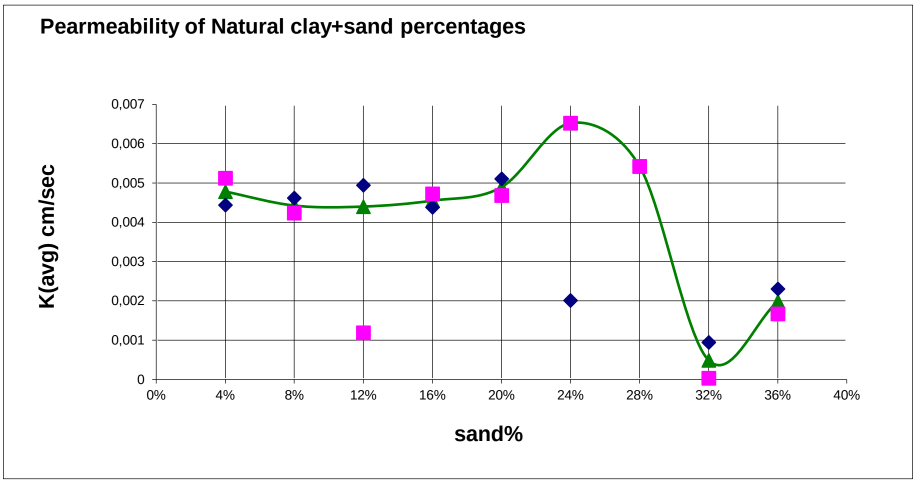

Fig. 4. The relationship between the percentages of sand added to Clayey soil and k_{avg}

When 32% more sand was added, the curve's (k_{avg} value steeply decreased to have an average value of 0.00049 cm/sec. When 36% more native sand was added, the permeability coefficient appears to increase once more, rising to a value of 0.002 cm/sec. Fig. 5 shows the impact that adding various ratios of natural zeolites to Clayey soil samples had on the permeability coefficient k_{avg}.

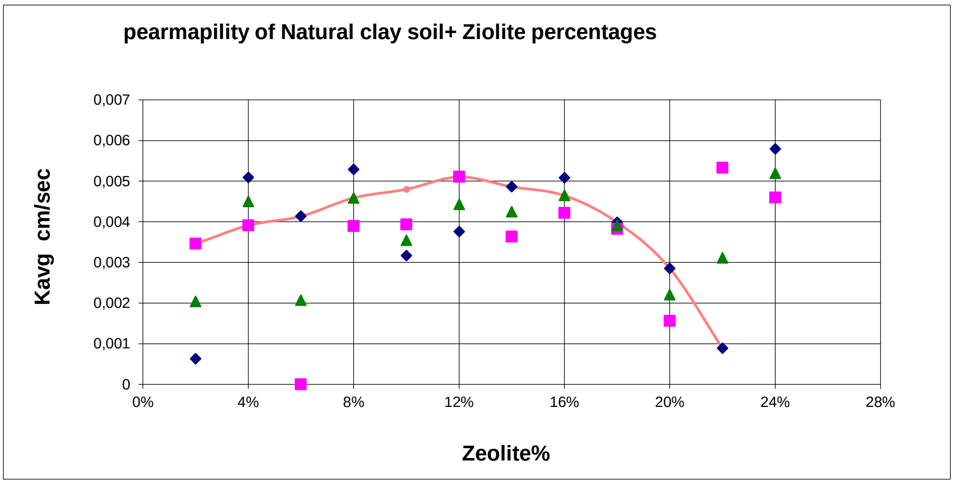

Fig. 5. The relationship between the percentages of kavg and zeolite added to clayey soil

As the proportion rose from 2% to 12%, the value of kavg climbed from 0.0035 to 0.0051 cm/sec. The addition of 22% natural zeolite percentage resulted in a stair-step decline with a kavg. value of 0.0009 cm/sec. The value of kavg has steadily dropped from 0.0034 to 0.00049 cm/sec as the native silty sand percentage rises from 4% to 32%. This pattern shows how employing silty sand causes the permeability of the combined materials to decrease. The impact on the permeability coefficient caused by applying various cement amounts to the silty clayey soil samples is shown in Fig. 6

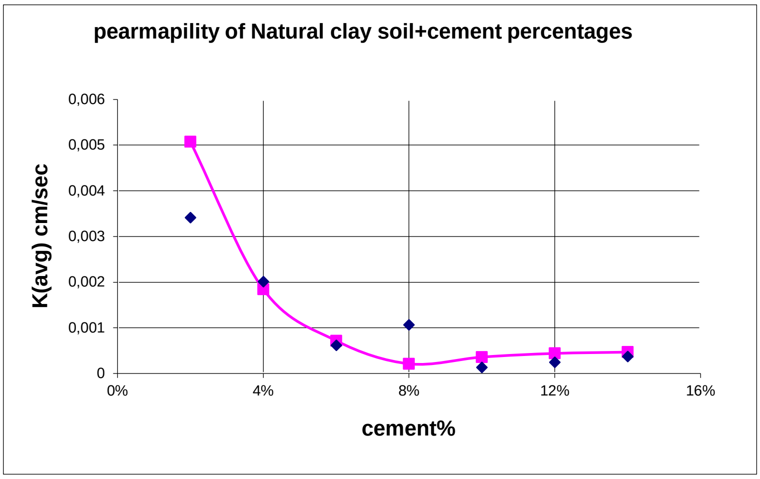

Fig. 6. The relationship between cement and k_{avg}, percentage added to soil that is clayey

The value of kavg decreases from 0.005 to 0.0005 cm/sec when cement content rises from 2% to 14%. When 14% of cement is added, resulting in a k_{avg} value of 0.00042 cm/sec, the curve starts to rise by a modest amount.

3.2 Unconfined compression test

The value of the obtained and tabulated undrained cohesion is made clear in Table 4. It was found that the value of C_u increased from 83.4 kPa to 114.1 when native sand was added to clayey soil at a rate ranging from 4% to 36%. Natural zeolite at concentrations of 2%, 12%, and 24% increases the C_u value in clayey soil, but at a greater difference, resulting in values of 180.2, 137.7, and 175.9 kPa, respectively.

Table 4. Cohesive Coefficient for all materials-unconfined

Materials	C_u (kPa)
Native clayey soil	83.4
Clayey soil+4% sand	114.1
Clayey soil+24% sand	100.9
Clayey soil+36% sand	93.6
Clayey soil+2% Zeolites	180.2
Clayey soil+12% Zeolites	137.7
Clayey soil +24% Zeolites	175.9
Clayey soil +2% cement	107
Clayey soil +8% cement	206
Clayey soil +14% cement	337

Adding 2%, 8%, and 14% of cement to clayey soil exhibits an ascending manner in Cu values, starting with 107 kPa increasing up to reaches 337 kPa.

3.3 Triaxial (UU) test

The values of Moho's circle's effective cohesion intercept are shown in Table 5. The table revealed the following:

The value of C is decreased from 200 kPa for native clayey soil to 125 kPa when 4% of native sand is added to the clayey soil sample, where increased from 13° to 20°.

Table 5. The relationship between C and φ, triaxial test (UU test) with various ratios

Materials	φ (degree)	C (kPa)
Native clayey soil	13	200
clayey soil +4% sand	20	125
clayey soil +24% sand	15	100
clayey soil +36% sand	5	80
clayey soil +2% Zeolites	13	145
clayey soil +12% Zeolites	20	100
clayey soil +24% Zeolites	20	125
clayey soil +2% cement	12	130
clayey soil +8% cement	30	140
clayey soil +14% cement	34	125

When 24% native sand was added, the same outcome was seen for C, where the pressure dropped from 200 kPa to 100 kPa while rising slightly from 13o to 15o. The values of C continue to decline until they approach 80 kPa when 36% native sand is added to clayey soil, while the values of decrease from 13 to 5o. The value of C decreases from 200kPa for native clayey soil to 145kPa when 2% of natural zeolite is added to the Clayey soil sample, but remains the same. The same outcome was seen for C, where it dropped from 200 kPa to 100 kPa when natural zeolites were added at a ratio of 12%, but increased to 20 kPa when values rose from 13 to. The value of C begins to rise when 24% of zeolite is added, reaching 125 kPa, while maintains the value it has attained.

C values show a tendency to fall from 200 kPa to 130, 140, and 125 kPa when cement is used as a treatment agent at 2%, 8%, and 14%. The friction angle indicates a slight drop from 13° to 12° when 2% cement is added. While increasing the cement by 8% and 14% generates a significant variation in the final temperature, which can reach a maximum of 34°.

3.4 Direct shear test

The effective cohesion intercept C and angle of friction values from the direct shear test are shown in Table 6. When adding 4% of native sand as a minimum proportion to the Clayey soil sample, the value of C decreased from 27 kPa to 5 kPa for native Clayey soil, while the value of friction angle increased from 17° to 28°. In contrast, C' showed results when a high proportion of 36% native sand was added to the Clayey soil, increasing from 27 kPa to 40 kPa, while the angle of internal friction decreasing from 17° to 9°, respectively.

Using Zeolite as an additive, the value of C decreases from 27 kPa to 7 and 14 kPa for two percentages of 2% and 24%, respectively, while the φ values increase from 17º to 27º and 25º for the same percentages.

Table 6. The relationship between C and φ values as a function of Direct Shear Test

Materials	φ (Degree)	C_u (kPa)
Native Clayey soil	17	27
Clayey soil +4% Sand	28	5
Clayey soil +36% Sand	9	40
Clayey soil +2% Zeolite	27	7
Clayey soil +24% Zeolite	25	14
Clayey soil +2% Cement	31.5	6
Clayey soil +14% Cement	30	12

When 2% and 14% of cement are added to Clayey soil, the values of the shear strength parameters C and are stated in the opposite way. Whereas the C values significantly reduced, reaching 6 kPa and 12 kPa, respectively, the values of φ significantly increased, reaching 31.5º and 30º, respectively.

3.5 Consolidation Test

The consolidation test of native Clayey soil under various pressure values and various mixed percentages of improving materials is shown in Tables 7 through 11. The influence of load variation on variations in soil specimen height has been recorded in the aforementioned tables, which take into consideration various applied pressure values.

Table 7. Consolidation test for Native clayey soil at different stress values

Pressure (P) (Kg/cm^2)	Final Dial Reading (mm)	Change in Speciment Height (mm)	Final Specimen Height (mm)	Height of Void H_v (mm)	Final Void Ratio (e)	Average Height (mm)	Fitting time (sec)		CVfrom (mm^2/sec)	
							t90	t50	t90	t50
0.1	0.189		13.189	4.129	0.4557					
		0.0005				13.1893	5284.58	1440	0.007	0.0059
0.25	0.1895		13.1895	4.1295	0.4558					
		-0.1305				13.1242	7227.08	3180	0.005	0.0027
0.5	0.059		13.059	3.999	0.4414					
		-0.365				12.8765	7326.3	4350	0.0048	0.0019
1	-0.306		12.694	3.634	0.4011					

Soil Description: Native Clayey soil   Initial specimen height, H_t(i) = 13 mm

Height of solids = 9.06mm   Weight of dry soil specimen = 100 gm

Specimen area = 40 cm^2 Specific gravity = 2.76

The consolidation behavior of clayey soil under various loading circumstances is shown in Table 7. The specimen volume of the Clayey soil was seen to gradually grow to equal 0.189 mm when the applied tension was equal to 0.1 kg/cm^2. The consolidation was influenced by the 36% sand addition to the clayey soil. Table 8 shows that a progressive volume decrease of 0.11 mm was observed, indicating that the addition of this amount of sand prevents the volume of Clayey soil from increasing.

As shown in Table 9, the addition of 14% cement to the clayey soil had an impact on consolidation, resulting in a progressive volume rise of 0.009 mm and a decrease in the volume of Clayey soil of 0.18 mm. The volume of the Clayey soil grows to a value of 0.883mm after the addition of 24% zeolite, as shown in Table 10, which results in a progressive increase in soil value of 1.072mm. The volume of the soil will grow by a value of 0.018 mm upon the addition of 32% of soft sand material, causing the volume of the Clayey soil to decrease to a value of 0.171 mm.

When the applied stress is equal to 0.25 kg/cm^2, the addition of 36% of sand to the Clayey soil reduces the volume by a value equal to 0.098mm, which reflects the effect of adding sand to stop increasing the volume of Clayey soil by a value of 0.208mm. Adding 14% of cement to the Clayey soil reduces the volume by a value of 0.014mm. That means, the added amount of cement will decrease the volume of Clayey soil by a value of 0.005mm. The addition of 32% of silty sand to the Clayey soil will reduce the volume by a value of 0.118mm; this addition decreases the volume of Clayey soil by 0.1mm. Adding 24% of zeolite to the Clayey soil reduces the volume of the soil by a value of 1.058mm. This addition can cause a reduction in the volume of Clayey soil to a value of 0.1755mm.

Adding 36% of sand to Clayey soil results in a volume reduction of 0.242 mm when the applied tension is equal to 0.5 kg/cm2, which corresponds to the effect of adding sand to prevent the Clayey soil's volume from growing by 0.45

mm. The volume of the Clayey soil is decreased by a value of 0.03mm when 14% cement is added. This indicates that the volume of Clayey soil is reduced by 0.025mm as a result of the addition of cement.

The addition of 24% of zeolite to Clayey soil reduces the volume by a value of 0.105mm; this addition can cause a reduction in the Clayey soil volume to a value of 0.091 mm.

The addition of 36% of sand to Clayey soil results in a volume reduction of 0.032 mm when the applied stress is equal to 1 kg/cm^2, which corresponds to the effect of adding sand to prevent the Clayey soil's volume from growing by 0.482 mm. The volume of the Clayey soil sample is decreased by a value of 0.123mm after the addition of 14% cement. This indicates that the volume of Clayey soil is reduced by 0.098mm as a result of the addition of cement.

The addition of 24% of zeolite to the Clayey soil reduces the volume of the soil by a value of 0.516mm; this addition can cause a reduction in the Clayey soil sample to a value of 0.425mm.

Table 8. Consolidation test for clayey soil with 36% sand at various stress levels.

Pressure (P) (Kg/cm^2)	Final Dial Reading (mm)	Change in Speciment Height (mm)	Final Specimen Height (mm)	Height of Void H_v (mm)	Final Void Ratio (e)	Average Height during Consolidation H_t (av) (mm)	Fitting time (sec)		CVfrom (mm^2/sec)	
							t90	t50	t90	t50
0.1	-0.11		12.89	3.87	0.429					
		-0.098				12.841	2220	660	0.0157	0.0123
0.25	-0.208		12.792	3.772	0.418					
		-0.242				12.671	2982.3	780	0.0114	0.0101
0.5	-0.45		12.55							
		-0.032		3.53	0.391	12.534	3199.8	1110	0.0104	0.007
1	-0.482		12.518	3.498	0.388					

Soil Description: Clayey soil+36% sand
Initial specimen height, Ht(i) =13 mm
Height of solids = 9.02mm
Weight of dry soil specimen = 98 gm
Specimen area = 40 cm^2
Specific gravity = 2.715

Table 9. Clayey soil consolidation test with 14% cement at various stress levels.

Pressure (P) (Kg/cm^2)	Final Dial Reading (mm)	Change in Speciment Height (mm)	Final Specimen Height (mm)	Height of Void H_v (mm)	Final Void Ratio (e)	Average Height during Consolidation H_t (av) (mm)	Fitting time (sec)		CVfrom (mm^2/sec)	
							t90	t50	t90	t50
0.1	0.009		13.009	4.129	0.429					
		-0.014				13.002	11760	7740	0.003	0.0011
0.25	-0.005		12.995	4.115	0.418					
		-0.03				12.985	11760	7740	0.003	0.0101
0.5	-0.025		12.975	4.115	0.461					
		-0.123				12.939	12615	9615	0.0028	0.0009
1	-0.098		12.902	4.022	0.453					

Soil Description: Clayey soil+14 % cement, Initial specimen height, Ht(i) = 13 mm
Height of solids = 8.88mm
Weight of dry soil specimen = 105 gm
Specimen area = 40 cm^2
Specific gravity = 2.955

Table 10. Consolidation test for clayey soil containing 24% zeolites under various stresses

Pressure (P) (Kg/cm^2)	Final Dial Reading (mm)	Change in Speciment Height (mm)	Final Specimen Height (mm)	Height of Void H_v (mm)	Final Void Ratio (e)	Average Height during Consolidation H_t (av) (mm)	Fitting time (sec)		CVfrom (mm^2/sec)	
							t90	t50	t90	t50
0.1	1.072		14.072	5.272	0.599					
		-1.058				13.543	4036.8	1250	0.0096	0.007

Pressure (P) (Kg/cm²)	Final Dial Reading (mm)	Change in Speciment Height (mm)	Final Specimen Height (mm)	Height of Void H_v (mm)	Final Void Ratio (e)	Average Height during Consolidation H_t (av) (mm)	Fitting time (sec)		CVfrom (mm²/sec)	
							t90	t50	t90	t50
0.25	0.014		13.014	4.214	0.478					
		-0.105				12.962	4546.8	1650	0.0078	0.005
0.5	-0.091		12.909	4.109	0.467					
		-0.516				12.742	4137.5	1920	0.0067	0.0042
1	-0.425		12.575	3.775	0.429					

Soil Description: Clayey soil+24 % Zeolites, Initial specimen height, Ht (i) = 13 mm,
Height of solids = 8.8mm Weight of dry soil specimen = 95 gm
Specimen area = 40 cm² Specific gravity = 2.7

Table 11. Consolidation test results for various amounts of additional materials applied at various stress levels

Soil Description	C_v for stresses (0.1-0.25) Kg/cm²		C_v for stresses (0.25-0.5) Kg/cm²		C_v for stresses (0.5-1) Kg/cm²	
	t90	t50	t90	t90	t50	t90
Native Clayey Soil	0.007	0.0059	0.005	0.0027	0.0048	0.0019
Clayey+24% Zeolites	0.0096	0.007	0.0078	0.005	0.0067	0.0042
Clayey+ 36% sand	0.0157	0.0123	0.0114	0.0101	0104	0.007
Clayey+14% cement	0.003	0.0011	0.003	0.0011	0.0028	0.0009

4 CONCLUSIONS AND RECOMMENDATIONS

It is considered feasible and, from an economic perspective, good and promising to use the three aforementioned materials in stabilizing Clayey soil of Alkarak. These materials are durable, cost-effective, and improve the soil's capacity against shear strength, permeability, and plasticity, among other physical properties.

The natural clayey soil sample was tested at its maximum dry density and optimum moisture content. The results of the strength parameters were not changed when tested directly after the preparation and at 28 days. The clayey soil with additives were tested at higher moisture content directly after mixing and it gave low strength parameters at early ages, while the clayey soil cement mixtures gave higher strength parameters when tested at 28 days due to cement hydration and the building up of the strong matrix in the soil structure of the samples were cured and tested at 28 days with cement.

The clayey soil Zeolites mixture showed an increase in the internal friction angle and decrease in the cohesion. This is due to the improvement of the mixture plasticity index, and the higher grain size of the silty Zeolite material.

Due to low non plastic of the silty zeolites material, the plasticity index of the clayey soil zeolites decreases, and cohesion decreased as well, and the angle of internal friction increased.

It is advised that certain proportions of the elements under inquiry be used since they improve the physical characteristics of Clayey soil. Native sand makes up 4% of this quantity. The percentage is 12% for natural zeolite whereas it is 14% for regular Portland cement. The following chart illustrates how the aforementioned percentages improved the Clayey soil physical characteristics:

- Increasing the permeability coefficient k_{avg}, obtained from the falling head permeability test, so that soil gains well-drainage conditions, will prevent water from remaining below the footing and will prevent problems caused by water presence, such as swelling and settlement.
- Increasing the angle of friction ø obtained from both direct shear and Triaxial UU tests improves shear strength, which improves the Clayey soil bearing capacity and resistance to settlement.
- Increasing the undrained cohesion property of Clayey obtained from an unconfined undrained compression test.
- Adjust the consolidation settlement obtained from the consolidation test.
- Most of these materials are relatively inexpensive and abundant in Jordan, making them ideal for geotechnical applications.

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