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ENHANCING THE ENGINEERING PROPERTIES OF COHESIVE SOILS USING PORTLAND CEMENT

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ABSTRACT

Different kinds of engineering problems could be occurred as a result of constructing foundations over cohesive soils. The majority of these problems are concerning the soils' volumetric changes that may lead the structure to be partially or totally failed; and accordingly, the idea of this research was shined in order to select a suitable global method to improve the properties of these soils in Jordan, and consequently to minimize their bad effects on structures that were erected on them. The methodology of this research was divided into two stages. The first of these was reviewing for the available literature related to the most applicable global methods in stabilizing fine grained soils; whereas, the second stage was focused on carrying out several laboratory tests to measure the influence of mixing different ratios of Portland cement material with fine grained soil (obtained from an excavated site in the Capital Amman) on the engineering characteristics of the original soil; and then to recommend the best mix ratio to be adopted in stabilizing fine grained soils in Jordan. Out of the conducted laboratory tests (Atterberg limits, permeability, and unconfined compression) the results of these tests showed that the plasticity indices had been decreased with increasing the percentages of mixing Portland cement and then a decrease trend in the soils' degree of expansiveness is expected to be occurred. Increasing of cement percentages had also showed a decrease in the coefficient of permeability of the soil. Moreover, a significant increase in the values of unconfined compressive strength was noticed as a result of mixing more cement ratios. Considering the results of this research, it was concluded that mixing about 5% of Portland cement with a cohesive soil had a pronounced enhancement on the engineering characteristics of the fine grained soil after being mixed, and therefore could improve its overall engineering behavior.

Keywords: soil stabilization, cohesive soils, soils' engineering properties, soil improvement, and Portland cement.

BACKGROUND

It is well known that a fine grained soil (a cohesive soil) is that formed by chemical weathering and consisted of particles mostly in the silt and clay size ranges [1]. A fine grained soil is regarded as one of the most problematic soils in the word when acted as a supported material below foundations [2]. The most popular expression to a fine grained soil is "expansive soil" (i.e., showing swelling behavior when they are wet, and per contra showing shrinkage behavior when they are dry) [3]. In general, a fine grained soil has low shear strength, and as a result, may exhibit very low bearing capacity [4].

In Jordan, several building projects are still suffering from different types of damages in their structural elements (i.e., their footings, columns, beams, and slabs) as a result of the frequent movements that derived from the existence of clayey materials beneath foundations. And consequently, there is always a need to look for a method that could control the above movements and therefore to stabilize this soil.

Along the four previous decades, different methods of soil stabilization had been proposed and implemented (particularly for fine grained soil). A lot of these methods adopted the concept of mixing different types of materials with the original soil in order to enhance its engineering properties. However, the following literature may clarify more than an idea of soil stabilization.

Degirmenci *et al* [5] investigated the ability of using cement in soil stabilization. In this investigation; soil samples assembled from tow deposits in Turkey were mixed with different ratios of cement. Measurements of Atterberg limits, unconfined compression tests, and standard Proctor compaction were taken for the original soil and mixed soil samples. The results showed that the optimum moisture contents and the plasticity index of the soil had been decreased with the addition of cement. Moreover, the maximum dry unit weights and unconfined compressive strengths had been raised as cement contents increased. The same results were pointed by Miller and Azad [6].

Bhattacharja and Bhatty [7] carried out a comparative study concerning the performance of "Portland cement" and "hydrated lime" in stabilizing moderate to high plasticity clayey soil. In this research, several laboratory tests were adopted namely; unconfined compression, plasticity index, hydraulic conductivity, and California bearing ratio. Out of the results of this research, it was concluded that significant improvements in the cement-stabilized soil properties had been recognized more than that for the lime-stabilized soil.

Goodarzi *et al* [8] investigated the potential of using cement and mixture of cement and silica fume to stabilize the clayey soil. The results of cement additive samples manifested that increasing cement content may improve the engineering soil's properties; however, it increases the electrical conductivity, the unconfined compressive strength, Calcium-silicate-hydrate values, and a further decrease in swelling potential.

Seco *et al* [9] implemented a research to improve the soils' mechanical properties and to reduce the swelling capacity of a clayey soil. An experimental work was performed to achieve this purpose by adding waste materials of industrial origin to the original clayey soil. The outcome of this research proved that all treated soil samples showed significant improvements in the compressive strength and bearing capacity compared with the untreated soil. Moreover, the potential of swelling for all treated soils was less than untreated soil.

Referring to the results of the above literature and others, the method of mixing cement with a fine grained soil was adopted to be investigated in this research in order to test its ability in stabilizing the Jordanian cohesive soil.

RESEARCH METHODOLOGY

As stated before, the methodology of this research was divided into two stages. The first stage included collecting and reviewing for previous literature related to the subject of this research; whereas, the second stage was focused on carrying out laboratory tests program for the original and mixed soil samples, analyzing for results, and submitting of conclusions.

Through the period of performing the practical part, undisturbed cohesive soil samples (the original soil samples) were obtained from an excavated site in the Capital Amman (from a depth of 2m below ground surface) using Shelby tube samplers; whereas, cement material was brought from an adjacent local market. The collected soil samples were put inside waterproof plastic bags, then placed in a wooden box and transported to the laboratory.

Mixed soil samples (remoulded samples) comprising the original soil and two cement ratios (5%, and 10%, by weight) had been prepared (considering the same initial unit weight and moisture content for the original soil) for laboratory tests program.

Several engineering characteristics for the original soil and those for the mixed soil samples had been obtained through performing a set of laboratory tests namely; water content, specific gravity, bulk density, particle-size analysis, Atterberg limits, permeability, and unconfined compression. These tests were conducted in accordance with the American Society for Testing and Materials (ASTM) Standards [10].

RESULTS AND DISCUSSIONS

Tests results for the original soil

The results of water content, bulk density, and specific gravity for the original soil are indicated in Table-1.

Table-1. Some properties of the original soil.

Type of test	Results
Water Content (%)	20.1
Bulk Density (gm/cm^3)	1.62
Specific Gravity	2.71

Tables 2 and 3 show the results of sieve and hydrometer analysis tests for the same soil, respectively.

Table-2. Sieve analysis test results for the original soil.

Sieve number	Mass of retained soil (gm)	Retained soil (%)	Accumulative retained soil (%)	Percent finer
4	0	0	0	100
8	2	0.2	0.2	99.8
10	12	1.2	1.4	98.6
40	46	4.6	6	94
50	40	4	10	90
100	30	3	13	87
200	20	2	15	85

ARPN Journal of Engineering and Applied Sciences

Table-3. Hydrometer analysis test results for the original soil.

Time (sec)	**Temperature** (°C)	**R**	R_{cl}	R_{cp}	**L** (cm)	**D** (mm)	**Percent finer**
1	20	41	41	40	9.6	0.041	79.20
2	20	39	39	38	9.9	0.029	75.24
5	20	38	38	37	10.1	0.019	73.26
15	21	37	36	34.8	10.4	0.011	68.90
30	21	36	35	33.8	10.6	0.007	66.92
60	22	34	34	32.6	10.7	0.005	64.54
120	24	32	32	30	11.1	0.003	59.40
240	21	31	31	29.8	11.2	0.002	59.00
1440	21	29	29	27.8	11.5	0.001	55.04

R: hydrometer reading
R_{cl}: corrected reading for effective length
R_{cp}: corrected reading for % finer
L: effective length
D: diameter of particles

Referring to the results indicated in the last two tables, the grain size distribution curve for the original soil was illustrated in Figure-1. Accordingly, it was revealed that the percent of fine grained material was about 85%; whereas, the remaining percent (about 15%) was coarse. In order to classify this soil according to the Unified Classification System, liquid and plastic limit tests were carried out (as shown in Table-4). Based on the Plasticity Chart relationship shown in Figure-2, the soil was classified as (CL).

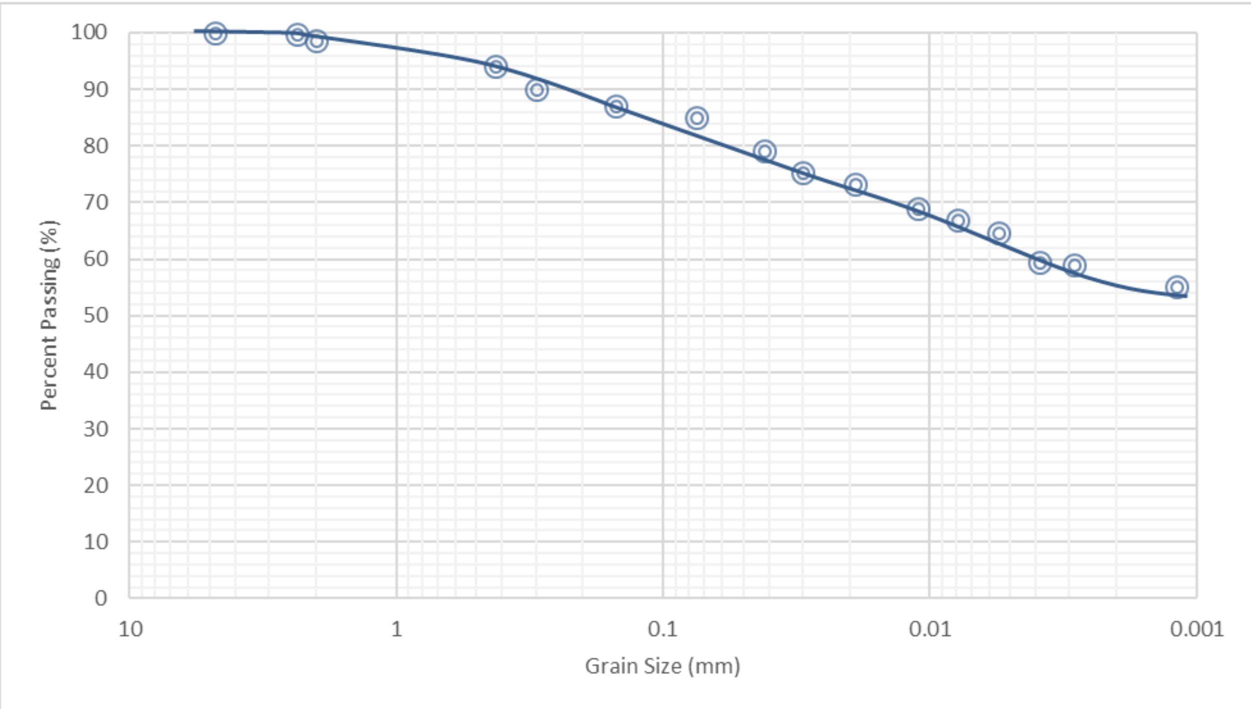

Figure-1. Grain size analysis for the original soil.

VOL. 13, NO. 22, NOVEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-4. Liquid and plastic limits tests results for the original soil.

	Liquid limit test results					**Plastic limit test results**		
Test No.	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**
Number of blows	34	31	28	23	18			
Mass of wet soil sample + container (gm)	22.76	25.64	25.03	28.61	25.03	17.89	16.16	16.45
Mass of dry soil sample + container (gm)	19.50	21.50	20.45	22.97	20.12	17.08	15.51	15.78
Mass of container (gm)	10.90	10.85	9.70	10.11	10.25	14.02	12.86	13.12
Water content (%)	37.9	38.9	42.6	43.9	49.8	26.5	24.5	25.2
Summary of Results	Liquid Limit = 44					Plastic Limit = 25		

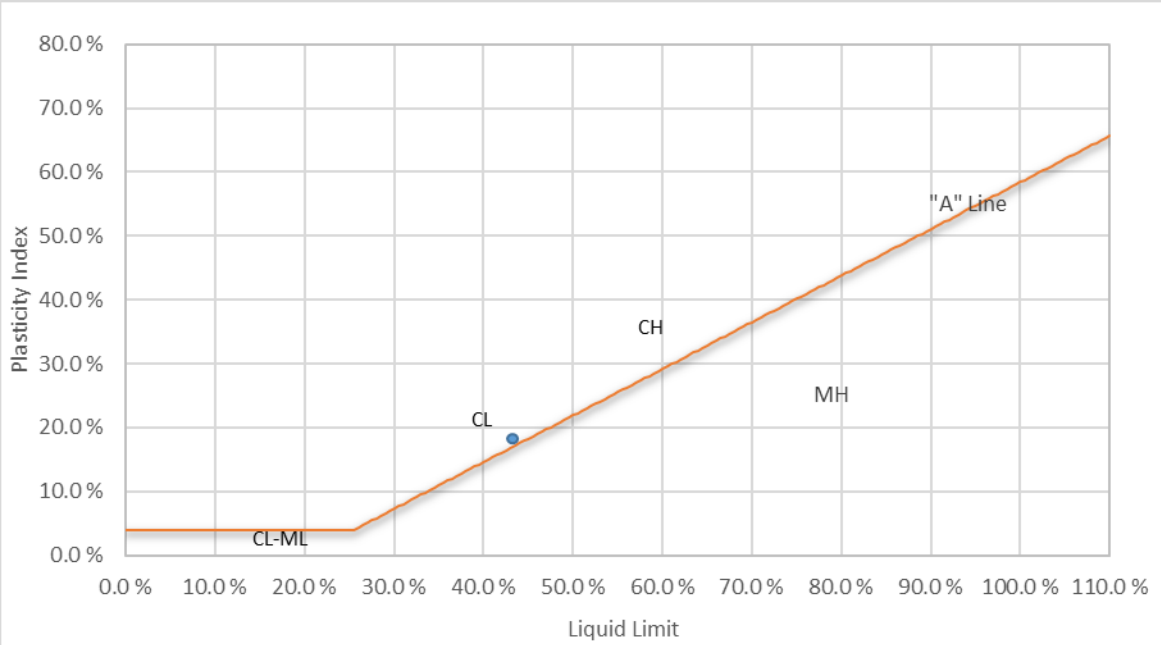

Figure-2. Plasticity chart for classifying the original soil.

Falling head permeability test was conducted to obtain the coefficient of permeability of the original soil. According to Das and Sobhan [11], the value of this coefficient was calculated using the following equation:

$$K = 2.3 \times \frac{a \times L}{A \times t} \times \log \frac{h}{h_1} \quad (1)$$

Where:

a: Cross-sectional area of the stand pipe = 0.7088 cm^2

L: Length of soil sample = 11.67 cm

A: Cross-sectional area of the soil sample =78.5 cm^2

t: Elapsed time of test = 370 min

h: Initial head of water = 100 cm

h_1: Ending head of water = 94 cm

Correction Factor for a temperature of 22 °C = 0.953

And therefore, the value of this coefficient was calculated to be (corrected to 20 °C) 2.79×10^{-7} cm/sec.

The unconfined compression test results was used to obtain the stress-strain relationship for the original soil as shown in Table-5.

Table-5. Unconfined compression test results for the original soil.

Deformation dial reading	**Proving ring dial reading**	**Strain***	**Corrected area** (cm²)	**Vertical load**** (kg)	**Vertical stress** (kg/cm²)
0	0	0	11.21	0	0
10	4	0.1322	11.23	2.48	0.22
20	7	0.2645	11.24	4.34	0.38
30	9	0.3968	11.26	5.58	0.49
40	12	0.5292	11.27	7.44	0.65
50	14	0.6613	11.29	8.68	0.76
60	19	0.7936	11.30	11.78	1.04
70	23	0.9259	11.32	14.26	1.25
80	29	1.0582	11.33	17.98	1.58
90	33	1.1904	11.35	20.46	1.80
100	42	1.3227	11.36	26.04	2.29
110	35	1.4550	11.38	21.70	1.90

* Considering a sample height of 75.6 mm
** Using a dial gauge factor of 0.62

Tests results for the mixed soil samples

Liquid and plastic limits tests were conducted for the mixed soil samples. The determination of "moisture content corresponding to 25 blows" test results (i.e., liquid limit results) for soil samples of various cement mix ratios are presented in Figure-3. This figure shows that the liquid limit values for samples with cement mix ratios of 0%, 5%, and 10% are 44, 43, and 37 respectively. Accordingly, it is indicated that the liquid limit is decreasing with the increase of the cement mix ratio.

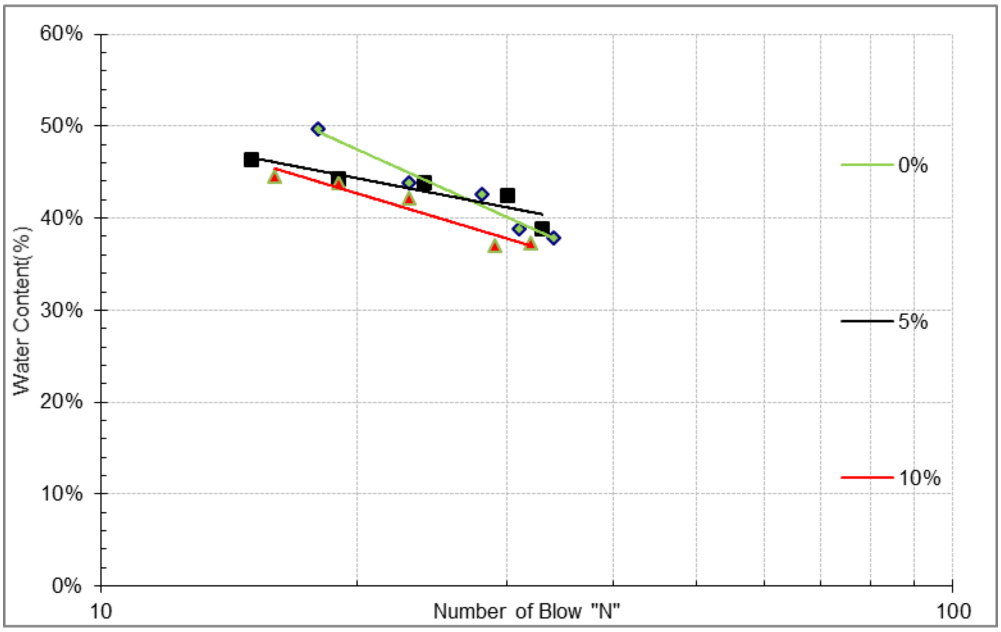

Figure-3. Liquid limit for various cement mix ratios.

Figure-4 summarizes Atterberg limits tests results for both the original and mixed soil samples. Again, the general trend for this figure shows a decrease of plasticity index with the increase of cement mix ratio, and that will definitely affect the degree of expansiveness of the soil (i.e., the degree of expansiveness will be decreased).

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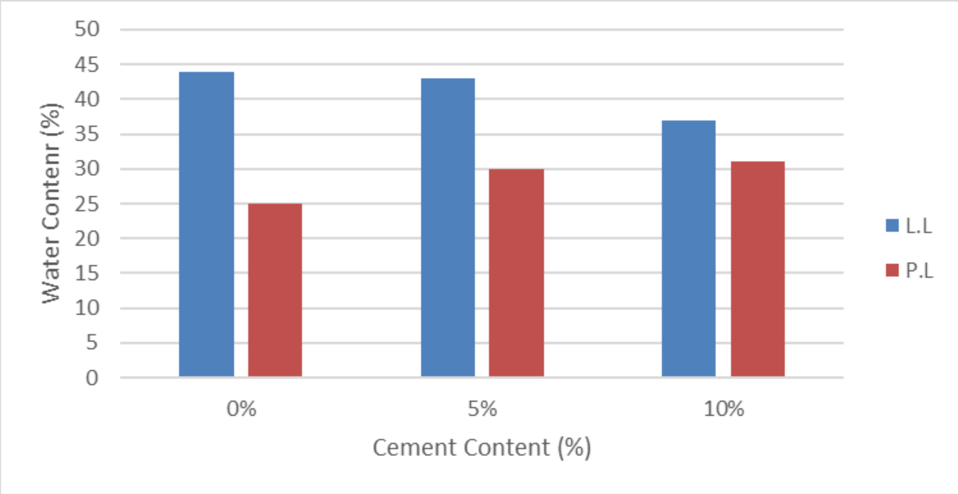

Figure-4. Liquid limit and plastic limit for various cement mix ratios.

Falling head permeability test results for the mixed soil samples are shown in Table-6. The variation of this coefficient with cement content is shown in Figure-5. Considering these results, it is indicated that increasing of cement additives causes a decrease in a soils' permeability. However, this behavior may be attributed to the decrease in the voids between the soil particles which created by mixing cement with the original soil.

Table-6. Falling head permeability tests results for different cement mix ratios.

Cement content (%)	**5**	**10**
Cross-sectional area of the stand pipe (cm^2)	0.7088	0.7088
Diameter of soil sample (cm)	10	10
Length of soil sample (cm)	11.67	11.67
Cross-sectional area of the soil sample (cm^2)	78.5	78.5
Initial head of water (cm)	120	120
Ending head of water (cm)	115	116
Elapsed time of test (min)	355	395
Coefficient of permeability (cm/sec)	2.10×10^{-7}	1.51×10^{-7}
Correction Factor RT at t = 22°C	0.953	0.953
Coefficient of permeability (cm/sec) (corrected to 20°C)	2.00×10^{-7}	1.43×10^{-7}

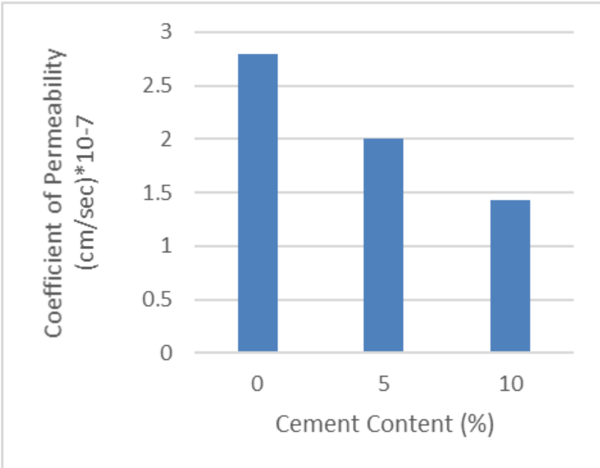

Figure-5. Coefficient of permeability for the original and mixed soil samples.

Figure-6 shows the stress-strain relationship to determine the peak stress for both the original and mixed soil samples.

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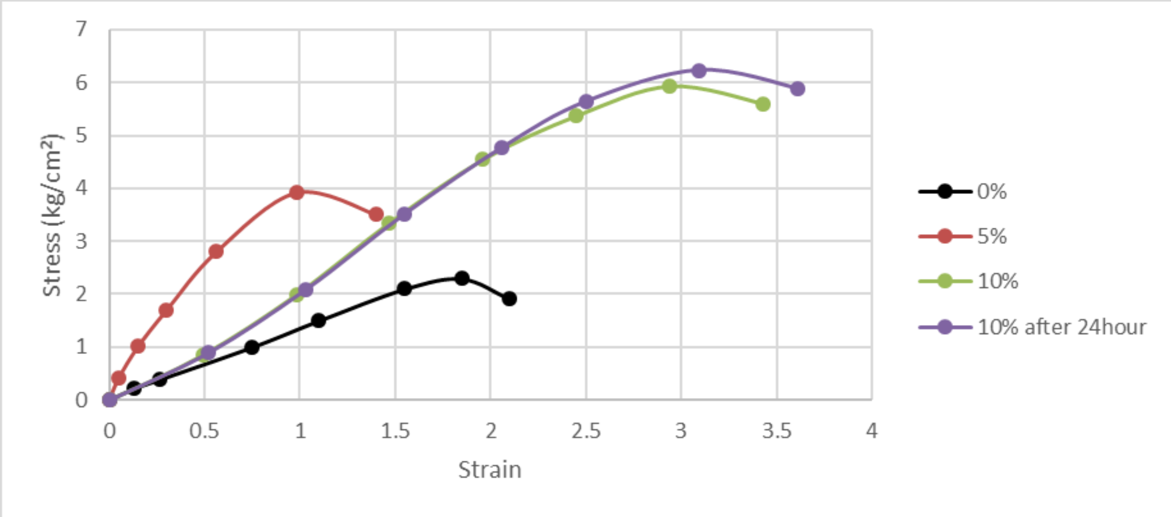

Figure-6. Stress-strain relationship for the original and mixed soil samples.

Referring to the previous relationship, the unconfined compressive strength and the soils' cohesion were summarized in Table-7.

Table-7. The unconfined compressive strength and cohesion for the original and mixed soil samples.

Soil type	Unconfined compressive strength (kPa)	Cohesion (kPa)
Original soil	2.23	1.11
Original Soil + 5% cement	3.92	1.96
Original Soil + 10% cement	5.94	2.97
Original Soil + 10% cement (after 24hr of sample preparation)	6.23	3.12

Considering the previous figure and table, it was realized that the peak stress value and soils' cohesion are significantly increased with the increase of the cement mix ratio, and also with the increase of the period of leaving the prepared (mixed) sample before testing. However, the above behavior could be explained due to the increase in the bond between the soil particles that was reflected in the form of an increase in soils' strength.

CONCLUSIONS

The results of laboratory tests related to this research revealed the following conclusions:

a) Mixing of 5% and 10% Portland cement with a fine grained soil showed a decrease in the plasticity index of 32% and 68% (respectively) compared with that resulted for the original soil. With this behavior, the mixed soil could show a lower ability to expand or shrink.

b) The coefficient of permeability had been decreased with about 28% and 49% (for cement contents of 5% and 10%, respectively) compared with that resulted for the original soil, which means a decrease in the voids between soil particles; and therefore increase the possibility of using this mix as an impermeable material in some civil engineering projects.

c) Higher soils' cement content showed a massive increase in the values of unconfined compressive strength (about 76% and 166% for cement content of 5% and 10%, respectively), and therefore this behavior could show a good enhancement regarding the soils' bearing capacity.

d) The influence of aging for the soil mix preparation (i.e., letting the mixture for 24 hours before testing) showed a further increase in strength of the soil. Therefore, the final (real) strength that resulted from this mixing may show more values than that obtained in the initial stages.

e) In general, mixing of Portland cement with a fine grained soil could create clear effects on the overall engineering behavior of the resulted soil (if it was used as a supported material) provided that this soil shall be carried out through compacted layers and based on the available standards.

f) Per the expected enhancement in the soils' engineering properties using a 5% cement mix ratio seams good; therefore this addition could be regarded as an optimum percent to be recommended in the Jordanian projects due to its effectiveness and economy. However, the 10% cement addition could be used in case of dealing with structures that need more bearing capacities.

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