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Effect of Fibers on Some Engineering Properties of Cement and Lime Stabilized Soils

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Abstract

Recently, many attempts were made to use metal fiber reinforcements to improve some soil properties. In this research, the effects of fibers on the compaction and mechanical properties of cement and lime stabilized soils (silty and clayey soils respectively) were studied. Variables such as stabilizer (cement and lime) content, amount and type of metal fibers were studied. Results indicated that the addition of fibers lead to increase in the maximum dry unit weight. On the other hand, a maximum values of unconfined and tensile strength were obtained with the addition of 0.5 % short fiber (FS) and 1.5 % long fiber (FL) respectively. During the flexural test a brittle manner failure was observed for the unreinforced samples and samples prepared with little amount of fibers 0.5%. Finally, the addition of fibers increases the fracture energy of cement stabilized silty soil and lime stabilized clayey soil.

Keywords: soil stabilization, tensile strength, cement, lime, steel fibers.

تأثير الألياف على بعض الخصائص الهندسية للترب المثبتة بالسمنت والنورة

الخلاصة

ظهرت في الآونة الأخيرة العديد من المحاولات في استخدام تقنية التسليح بالألياف وذلك لتحسين بعض الخصائص الهندسية للتربة. يهدف هذا البحث إلى دراسة تأثير الألياف المعدنية على خصائص الرص وبعض الخصائص الميكانيكية (مقاومة الانضغاط غير المحصور ومقاومة الشد) لتربة طينية مثبتة بالنورة وأخرى غرينية مثبتة بالسمنت. أظهرت النتائج حصول زيادة في الكثافة الجافة العظمى وكل من مقاومة الانضغاط غير المحصور ومقاومة الشد مع زيادة نسبة الألياف المضافة. كانت أعلى مقاومة انضغاط غير محصور وأعلى مقاومة شد تحدث عند نسبة الألياف (FS % 0.5 و FL % 1.5) على التوالي. بينت منحنيات الحمل-الأود ان نوع الفشل كان من النوع المفاجئ لنماذج الترب الطبيعية والنماذج المثبتة بنسب الألياف القليلة. أخيراً سببت إضافة الألياف زيادة طاقة الانكسار (المساحة تحت منحي الحمل-الأود) للترب المثبتة, وان تلك الطاقة تزداد مع زيادة نسبة الألياف المضافة.

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1. Introduction

Over the last few years, environmental and economic issues have stimulated interest in the development of alternative materials that can fulfill design specifications.

The well established techniques of soil stabilization and soil reinforcement are often used to obtain an improved geotechnical materials through either the addition of cementing agents to soil (lime, Portland cement, asphalt, etc.) or the inclusion of oriented or randomly distributed discrete elements such as fibers[1,2,3 and 4].

Stabilized and reinforced soils are, in general a composite materials that resulted from combination and optimization of the properties of individual constituent materials. Reinforcing the subgrade soils with short length fibers have evoked considerable interest among both highway engineers and manufacturers for using these materials as reinforcing material in flexible pavement[5 and 6]. Fibers inclusions cause significant modification and improvement in the engineering behaviour of soils[7,8 and 9].

A number of research studies on fiber-reinforced soils have recently been carried out through unconfined compression test, CBR tests, direct shear tests and flexural tensile strength tests [2,6,8,10,11 and 12]. They found that, using fibers increases the strength and durability of the soils, and the increase in strength was accompanied by an increase in the strain to failure. Fiber-reinforcement was also found to increase the crack reduction significantly due to increase tensile strength of the soil[13 and 14].

In order, to provide information to help understand the overall behaviour of fiber-reinforced stabilized fine soils with cement or lime, a series of laboratory tests were carried out to define the response of such materials under static compression and flexural loading.

2. Experimental Program

2.1Materials Used

-Soils

The Soils used in this study are a clayey and silty soils obtained at (1.5 m) depth from Al-Hadbaa (denoted by H), and Hawi Al-Kanisa (denoted by K) districts respectively, at Mosul city. Some of the index properties and chemical tests of soils are listed in Table (1), using the relevant tests according to the ASTM standards.

-Cement and lime

Ordinary Portland cement from Badush cement factory was used in this study. The chemical composition of cement is shown in Table (2). High calcium hydrated lime brought from Al-Meshrag Sulphate factory (73 %) activity was used. The chemical analysis of the lime is shown also in Table (2).

-Water

Tap water was used in the preparation of samples as well as in all the tests.

-Fibers

Steel fiber is a common material which could be used economically to reinforced soil [1 and 7].The fiber is available in different lengths. Two fiber lengths was used in the present study, 16 and 32 mm, denoted by (FS) and (FL) respectively.

2.2Specimen Preparation

Soil samples were prepared and compacted according to an (ASTM D-1557) procedure using modified compaction effort. Lime (L) and cement (C) amounts of (2,4 and 6%) were used to stabilize soils H and K respectively. The required amount of water was added after mixing of stabilizers and soil. The mixture was then placed in plastic bags for mellowing time of (24) hours for untreated soil, (1) hour for lime [15] and (10) minutes for cement treated soils [16]. The mixtures were then compacted in a specific mould corresponding to the required tests. A short fibers 16mm (FS) percentages of 0.5%, 1.5% and 3.0% and long fibers 32mm (FL) of 0.5% and 1.5% were used in preparing reinforced soil mixtures. Soil treated with high value of (3.0 %) of (FL) was avoided because it causes clumping of fibers together and makes the mixing process difficult. A total of (24) different mixes were examined. These mixtures were prepared using (2 to 6 %) cement and (4%) lime (optimum lime content depends on the unconfined compression values [15]). Table (3) provides a summary of the various mixtures and types of tests conducted in this study.

2.3Strength Tests

The unconfined compression test was conducted to obtain the strength of untreated and fiber-reinforced soil samples in accordance with (ASTM D-2166) on cylindrical specimens of 50 x 100 mm size.

Brazilian test was carried out to determine the indirect tensile strength for untreated and treated reinforced soils. A Marshall mould with 100 mm dia. by 50 mm height was chosen to produce the samples under 25 blows of a standard Marshall hammer per face to obtain the modified compactive effort.

The flexural test was conducted on untreated and treated reinforced soils, using prismatic beam (50 × 50 × 300 mm). The specimens were prepared by compacting the soil in four layers using special square base hammer weighting (1652 gm) and falling from (285 mm) to obtain the modified compactive energy after (110) blows for each layer. The specimen was mounted in compression machine and a load was applied at a rate of (0.127 mm/min). The deflection at the center of the beam (bottom) with applied load were recorded every (1 min.), using a dial gauge with sensitivity of (0.002 mm / div.) and the flexural strength properties were evaluated.

All prepared samples treated with cement or lime with fibers, were used in the unconfined compression test, indirect tensile test and flexural tensile test, were sealed with aluminum foil, plastic bags and finally by paraffin to cure for different curing times (7, 14 and 28) days at a temperature of 25 ^{0}C.

3. Results and Discussion

3.1Compaction Characteristics

The compaction characteristics of untreated and treated soils (soil (k) and soil (H)) with different percentages of cement, lime and fibers are shown in Fig.(1). It could be noted that, the maximum dry unit weight (γ_{max}) decreases and the optimum moisture content (OMC) increases with the addition of cement or lime. In general, more considerable reduction was obtained when using lime as a stabilizer. This reduction results due to immediate reactions between lime and soil (flocculation and agglomeration).

In the case of cement, some of compaction effort could be dissipated to broken the early cementing bonds created during the mellowing time (10 min.). Similar behaviour was obtained by (Al-Jobouri [16]). The increase of OMC with increasing both stabilizers (cement and lime) may be due to the more fine materials added, and/or to the hydration of chemical stabilizers. In case of fiber addition, there was no fundamental difference in the OMC of stabilized reinforced soils, while there was a slight increase in the maximum dry unit weight (γ_{max}) This could be attributed to the high density of fibers. Similar behaviour was noticed by (Santoni et al. [5] and Maher and Ho [17]).

3.2Strength of Natural and Stabilized Reinforced Soils

Fig. (2) Shows the results of the unconfined compressive strength UCS (q_u), indirect tensile strength ITS (σ_{it}) and flexural tensile strength FTS (σ_{ft}) of natural (untreated) and stabilized soils. The maximum values of (q_u), (σ_{it}) and (σ_{ft}) were (800, 80 and 110 kN/m^2) : (500, 30 and 70 kN/m^2) for soil (H) and (K) respectively. All these values were found in the dry side of modified compaction curves.

In this section, the results of unconfined compressive strength (q_u), indirect tensile strength (σ_{it}) and flexural tensile strength (σ_{ft}) have been presented for stabilized reinforced soils, effect of stabilizers, curing period, type and amount of fibers was studied on the strength of the composite soils (soil (k) and soil (H)).

3.2.1Cement Content and Curing Period

Figures (3,4 and 5) and Table (4a – 4c) show the effect of cement content and curing period on the (q_u), (σ_{it}) and (σ_{ft}) of Silty soil (soil K). The data in these figures and table indicated that the (q_u), (σ_{it}) and (σ_{ft}) increased from (500, 30 and 70 kN/m^2) for untreated soil to (1300, 100 and 345 kN/m^2) : (1900, 180 and 660 kN/m^2) (2825, 210 and 753 kN/m^2) respectively, for 2, 4 and 6 % cement, consequently, an improvement ratio of (2.6, 3.3 and 4.9) : (3.8, 6.0 and 8.57) : (5.65, 7.0 and 10.75) times that of the untreated soil for the same curing period (7 days at 25^0 C) were obtained. The increasing in strength is directly proportional to increase in cement content with the studied range. It is also found that, generally, a maximum values of (q_u) are obtain at (0.5% FS and 0.5% FL) and for all the curing periods. Comparing mix 1 with mix 13 for (7) days curing, it was found that the compressive strength, indirect and flexural tensile strength increased by almost (2.17, 2.1 and 2.18) times respectively, when cement content was increased from (2.0 to 6.0 %). Higher cement content may leads to much higher strength values but also economical factor should be considered.

The curing period effect could be discussed through Figures (6,7,8, and 9) and Tables (4a - 4c and 5) for soils (K) and (H). It is clear that there was a continuous strength progress with respect to time due cement hydration and pozzolanic reaction between soil particles and chemical stabilizer as well as any complicated reactions causing cementation of soil particles.

On the other hand, considering the lime stabilized (H) soil with (4.0 %) lime, the optimum lime percent based on Illinois procedure (little[15]). The (q_u), (σ_{it}) and (σ_{ft}) were found to increase from (800, 80 and 110 kN/m^2) for untreated soil to (3500, 240 and 350 kN/m^2) : (4600, 435 and 585 kN/m^2) : (5870, 600 and 800 kN/m^2), for 7, 14 and 28 days respectively at 25^0 C. The improvement ratio of (q_u), (σ_{it}) and (σ_{ft}) were (1.67, 2.5 and 2.28) times, when the curing time increased from (7) to (28) days.

3.2.2Length and amount of fibers

The effect of length and amount of fiber reinforcement on the strength of stabilized soils were determined as a function of unconfined compressive and tensile strength (indirect and flexural). The inclusion of fiber reinforcement was found to a mostly enhanced the strength of stabilized soils as shown in previous Figs.(3 – 9) and Tables (4a – 4c and 5). Unconfined compressive and tensile strengths were determined for natural soil samples and considered to be a reference samples for comparison with different stabilized fibrous soils. As shown in these figures, the strength of stabilized fibrous soils was found to decrease generally, with fiber content. For the soil (H), the (q_u), (σ_{it}) and (σ_{ft}) of stabilized samples curried for 7 days, decreased from (5900, 396 and 780 kN/m^2 (mix 20) to 4600, 376 and 740 kN/m^2 (mix 22)).

For soil (K) the values decreased from (1500, 135 and 430 kN/m^2 (mix 2) to 1250, 115 and 390 kN/m^2 (mix 4)) : (2150, 220 and 780 kN/m^2 (mix 8) to 1690, 200 and 740 kN/m^2 (mix 10)) : (3200, 245 and 880 kN/m^2 (mix 14) to 2200, 220 and 850 kN/m^2 (mix 16)) for (2, 4 and 6%) cement respectively, when the small fiber (L = 16 mm) increased from (0.5 to 3.0 %). The percent 1.5 % FS (L = 16 mm) gave maximum values of indirect and flexural tensile strength of soil (K), than the other percentages of fibers for all percents of cement and curing periods. These values are (170, 270 and 300 kN/m^2) : (575, 950 and 1040 kN/m^2) for (2, 4 and 6 %) cement respectively at (7) days curing. While the percent 0.5 % FS gave max. values of unconfined compressive strength (1500, 2150 and 3200 kN/m^2) for the same cement content and curing periods. Soil (H) have the same behaviour of soil (K), but the mixes prepared by the long fibers (L = 32 mm) gave maximum values of unconfined compressive and tensile strength for different curing periods. The max. values of the (q_u), (σ_{it}) and (σ_{ft}) were found to be (6300, 585 and 935 kN/m^2) for (7) days curing respectively.

3.3Load-Deflection Response

Figure (10) shows a typical load – deflection curves for stabilized unreinforced and fiber-reinforced stabilized samples with 6% cement and 4% lime cured for 28 days at 25^{0}C for soil (K) and soil (H) respectively. The load-deflection curves are almost linear for both stabilized unreinforced and fiber-reinforced samples up to the first crack. The unreinforced samples were failed in a brittle manner, after reaching their peak load. Similar behaviour have been noted for samples prepared with a little amount of short fibers (0.5% FS). Reinforced samples with (3.0% FS and1.5% FL) Showed some modifications in the post peak behaviour as the load carrying capacity dropped more gradually. However, significant different post peak response was observed for beams reinforced with (1.5% FS and 0.5% FL). Immediately following the peak, there was generally, a sharp drop about (9.7% and 11.4% for soil K and 30.7% and 28.7% for soil H) in the load carrying capacity for these samples. The drop indicates that the tensile strength has been exceeded. The maximum deformation (deflection at failure) for reinforced stabilized samples with different percentages of fibers was approximately (1.13, 1.26, 2.29, 1.34, 1.88 for soil K :1.54, 2.15, 3.46, 2.38, 3.0 for soil H) times the deformation for unreinforced stabilized samples.

3.4 Fracture Energy

One of the main reasons for adding fibers to soils with chemical stabilizes is to increase their energy absorbing capacity or toughness, so that the composite materials (soil, fibers and stabilizers) will exhibit a more ductile post peak behaviour. Although the area under the stress – strain or load – deflection curve is a measure of the energy absorption capacity of a materials, the relevance of toughness in practice depends on the application. For highway pavements, however, it is more appropriate to consider a given level of serviceability (expressed in terms of a limiting deflection, crack width, or residual strength), beyond which rehabilitation must be under taken. The area under the load – deflection curve up to failure can be used to estimate the total energy absorption capacity of each sample, this energy divided by the cross – sectional area, is termed the fracture energy of the sample. For unreinforced stabilized samples which generally fail immediately after reaching their peak strength, only the area up to the peak load is relevant. Table (6) shows the fracture energy for unreinforced and reinforced stabilized samples with 6% cement for soil (K) and 4% lime for soil (H), cured for 28 days at 25^{0}C. These results indicate that the energy absorption capacity increased by as mush as (1.29, 1.79, 3.67, 1.58, 2.68) times due to the inclusion of (0.5, 1.5, 3.0% FS and 0.5 and 1.5% FL) for soil (K), while it increase by (2.38, 4.72, 8.11, 5.05, 7.18) times for soil (H) for the same fibers percents. On the other hand, the samples reinforced with (0.5 % FS), the fracture energy increased by more than (1.29 and 2.38) for soil (K) and soil (H) respectively compared to corresponding unreinforced samples.

As expected from the load– deflection curves shown in the Fig. (10), the stabilized reinforced samples of soil (H) gave higher values of fracture energy than the samples of soil (K). The behaviour could be attributed to the adhesion factor.

Finally, The stabilized reinforced samples with (3.0% FS and 1.5% FL) fiber content demonstrated a significantly higher fracture energy, compared to the other percents of fiber.

4. Conclusions

Based on the results of this study, it could be concluded that:

1- Lime or cement addition to the clayey and silty soils respectively cause a decreases in the maximum dry unit weight (γ_{max})

2- And an increase in the optimum moisture content (OMC). Adding fibers, lead to a slight increase in the maximum dry unit weight (γ_{max}) of the mixture with no fundamental difference in the OMC of stabilized reinforced soils.

3- Lime and cement stabilization increase the strength of stabilized soils, this increment was found to be directly proportional to the increase in cement content with the studied range for silty soil, while a maximum strength was obtained at 4% lime for the clayey soil. Higher cement content may leads to much higher strength values of the mixtures.

4- Fiber reinforcement addition improves the compressive and tensile (flexural and Brazilian) strengths of stabilized soils till an optimum values. Generally, these values (i.e. optimum values) were found to be (0.5 FS and 1.5 FS) : (0.5 FS and 1.5 FL) for silty and clayey soil respectively, corresponding to unconfined and tensile strengths. Further addition of fibers decreases the unconfined compressive and tensile strengths of stabilized fibrous soils.

The load-deflection curves are almost linear for both stabilized unreinforced and fiber-reinforced samples up to the first crack. A brittle manner failure was noted for the unreinforced samples and samples prepared with a little amount of fibers (0.5% FS). Reinforced samples with (3.0% FS and 1.5% FL) Showed some modifications in the post peak behaviour.

5- The fracture energy for unreinforced and reinforced stabilized samples with 6% cement for silty soil and 4% lime for the clayey soil, cured for 28 days at 25^0C increased significantly with the augmentation of fiber content.

6- Finally, The stabilized reinforce d samples with (3.0% FS and 1.5% L) fiber content demonstrated a significantly higher fracture energy, compared to the other percents of fiber.

From the above stated results, it worth mentioning that, a several values of optimum fiber contents were found corresponding to the related tests (unconfined compression test, tensile tests and fracture energy test). So, it is recommended from the engineer to use the value related to the studied case (problem), which could be better simulated by the above stated test.

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Table (1) Chemical & physical properties of natural soils

Properties	**Hawi Al-Kanisa soil (K)**	**Al-Hadbaa soil (H)**
Liquid Limit (%)	24	51
Plastic Limit (%)	NP	25
Plasticity Index (%)	-----	26
Linear shrinkage (%)	0.58	14.8
Total Soluble salts (%)	3.5	2.1
$SO_3^{=}$ (%)	0.07	0.16
Organic content (%)	2.1	1.1
Specific Gravity	2.65	2.69
Gravel (%)	2	-----
Sand (%)	42	8
Silt (%)	48	39
Clay (%)	8	53
Soil Classification	ML	CH

Table (2) Chemical composition of cement and lime

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	AL_2O_3	Fe_2O_3	SiO_2	MgO	H_2O	L.O.S
Cement	-----	62.2	-----	2.69	5.47	21.8	2.65	0.05	5.14
lime	73.0	6.1	5.2	0.17	0.04	10.1	4.19	0.09	1.11

- **L.O.S** = Loss of Ignition.

Table (3) Mix design for type of tests (UCS, ITS and FTS) conducted in experimental program

Mix NO.	Mix Design
1	2 % C
2	2 % C + 0.5 FS (L = 16 mm)
3	2 % C + 1.5 FS (L = 16 mm)
4	2 % C + 3.0 FS (L = 16 mm)
5	2 % C + 0.5 FL (L = 32 mm)
6	2 % C + 1.5 FL (L = 32 mm)
7	4 % C
8	4 % C + 0.5 FS (L = 16 mm)
9	4 % C + 1.5 FS (L = 16 mm)
10	4 % C + 3.0 FS (L = 16 mm)
11	4 % C + 0.5 FL (L = 32 mm)
12	4 % C + 1.5 FL (L = 32 mm)
13	6 % C
14	6 % C + 0.5 FS (L = 16 mm)
15	6 % C + 1.5 FS (L = 16 mm)
16	6 % C + 3.0 FS (L = 16 mm)
17	6 % C + 0.5 FL (L = 32 mm)
18	6 % C + 1.5 FL (L = 32 mm)
19	4 % LI
20	4 % LI + 0.5 FS (L = 16 mm)
21	4 % LI + 1.5 FS (L = 16 mm)
22	4 % LI + 3.0 FS (L = 16 mm)
23	4 % LI + 0.5 FL (L = 32 mm)
24	4 % LI + 1.5 FL (L = 32 mm)

-UCS = Unconfined compressive strength.
- ITS = Indirect tensile strength.
- FTS = Flexural tensile strength.

Table (4 – a) Increasing in Strengths Values for (2 %) Cement (soil K)

Curing Period (day)	Fiber (%)	2 (%) Cement					
		U.C.S (kN/m^2)	Increase (%)	I.T.S (kN/m^2)	Increase (%)	F.T.S (kN/m^2)	Increase (%)
Natural Soil		500	-----	30	-----	70	-----
7	0.0	1300	160	100	233	345	393
	0.5 S	1500	200	135	350	430	514
	1.5 S	1390	178	170	467	575	721
	3.0 S	1250	150	115	283	390	457
	0.5 L	1380	176	140	367	500	614
	1.5 L	1200	190	110	267	380	443
14	0.0	1650	230	130	333	525	650
	0.5 S	2100	320	160	433	610	771
	1.5 S	1975	295	205	283	755	979
	3.0 S	1750	250	140	367	560	700
	0.5 L	2000	300	175	483	690	886
	1.5 L	1680	236	150	400	545	679
28	0.0	2200	340	200	567	700	900
	0.5 S	2800	460	250	733	810	1057
	1.5 S	2750	450	310	933	990	1314
	3.0 S	2350	370	240	700	770	1000
	0.5 L	2700	440	265	783	900	1186
	1.5 L	2310	362	235	683	730	943

Table (4 – b) Increasing in Strengths Values for (4 %) Cement (soil K)

Curing Period (day)	Fiber (%)	4 (%) Cement					
		U.C.S (kN/m^2)	Increase (%)	I.T.S (kN/m^2)	Increase (%)	F.T.S (kN/m^2)	Increase (%)
Natural Soil		500	-----	30	-----	70	-----
7	0.0	1900	280	180	500	660	843
	0.5 S	2150	330	220	633	780	1014
	1.5 S	2010	302	270	800	950	1257
	3.0 S	1690	238	200	567	740	957
	0.5 L	1980	296	230	667	860	1129
	1.5 L	1670	234	195	550	720	929
14	0.0	2400	380	220	633	900	1186
	0.5 S	2850	470	275	817	1050	1400
	1.5 S	2800	460	320	967	1200	1729
	3.0 S	2525	405	260	767	1040	1386
	0.5 L	2680	436	290	867	1100	1471
	1.5 L	2425	385	230	667	950	1257
28	0.0	2820	464	300	900	1230	1657
	0.5 S	3430	586	380	1167	1430	1943
	1.5 S	3660	632	470	1467	1630	2229
	3.0 S	3000	500	360	1100	1300	1757
	0.5 L	3350	570	395	1217	1540	2100
	1.5 L	2925	485	325	983	1280	1729

$$\textbf{Increasing (\%)} = \frac{\textbf{Value of Stabilized Sample – Value of Natural Sample}}{\textbf{Value of Natural Sample}}$$

Table (4 – c) Increasing in Strengths Values for (6 %) Cement (soil K)

Curing Period (day)	Fiber (%)	6 (%) Cement					
		U.C.S (kN/m^2)	Increase (%)	I.T.S (kN/m^2)	Increase (%)	F.T.S (kN/m^2)	Increase (%)
Natural Soil		500	-----	30	-----	70	-----
7	0.0	2825	465	210	600	753	976
	0.5 S	3200	540	245	717	880	1157
	1.5 S	2970	494	300	900	1040	1386
	3.0 S	2200	340	220	633	850	1114
	0.5 L	2880	476	250	733	930	1229
	1.5 L	2100	320	220	267	825	1079
14	0.0	3250	550	270	800	1000	1329
	0.5 S	3700	640	310	933	1185	1593
	1.5 S	3850	670	365	1117	1400	1900
	3.0 S	3400	580	300	900	1125	1507
	0.5 L	3550	610	320	967	1230	1657
	1.5 L	3400	580	275	817	1095	1462
28	0.0	4000	700	425	1317	1410	1914
	0.5 S	4820	864	510	1600	1620	2214
	1.5 S	5250	950	680	2167	1900	2614
	3.0 S	4250	750	480	1500	1500	2043
	0.5 L	4750	850	540	1700	1760	2414
	1.5 L	4130	726	460	1433	1460	1986

Table (5) Strength results of reinforced stabilized clayey soil (Al-Hadbaa soil)

Curing Period (day)	Fiber (%)	4 (%) Lime		4 (%) Lime		4 (%) Lime	
		U.C.S (kN/m^2)	Increasing (%)	I.T.S (kN/m^2)	Increasing (%)	F.T.S (kN/m^2)	Increasing (%)
Natural Soil		800	-----	80	-----	110	-----
7	0.0	3500	338	240	200	350	218
	0.5 S	5900	638	396	395	780	609
	1.5 S	5250	556	492	515	860	682
	3.0 S	4600	475	376	370	740	573
	0.5 L	6300	688	435	444	805	632
	1.5 L	5400	575	585	631	935	750
14	0.0	4600	475	435	444	585	432
	0.5 S	7000	775	633	691	1025	832
	1.5 S	6550	719	788	885	1170	964
	3.0 S	6010	651	600	650	980	791
	0.5 L	7500	838	700	775	1085	886
	1.5 L	6700	738	900	1025	1235	1023
28	0.0	5870	634	600	650	800	627
	0.5 S	8250	931	850	1000	1405	1177
	1.5 S	7900	888	1105	1281	1560	1318
	3.0 S	7500	838	810	913	1365	1141
	0.5 L	8800	1000	990	1138	1485	1250
	1.5 L	8050	906	1240	1450	1630	1382

Table (6) Fracture energy values of stabilized reinforced soils

Curing Period (day)	Fiber (%)	4 (%) Lime		6 (%) Cement	
		Fracture energy (kN/m)	(%) Increasing	Fracture energy (kN/m)	(%) Increasing
28 @ 25^0C	0.0	0.1612	-----	0.3416	-----
	0.5 S	0.3838	138	0.4413	29
	1.5 S	0.7624	373	0.614	80
	3.0 S	1.308	711	1.255	267
	0.5 L	0.8152	408	0.5416	59
	1.5 L	1.158	618	0.916	168

$$\text{Increasing (\%)} = \frac{\text{Value of Reinforced Sample} - \text{Value of Unreinforced Sample}}{\text{Unreinforced Sample}}$$

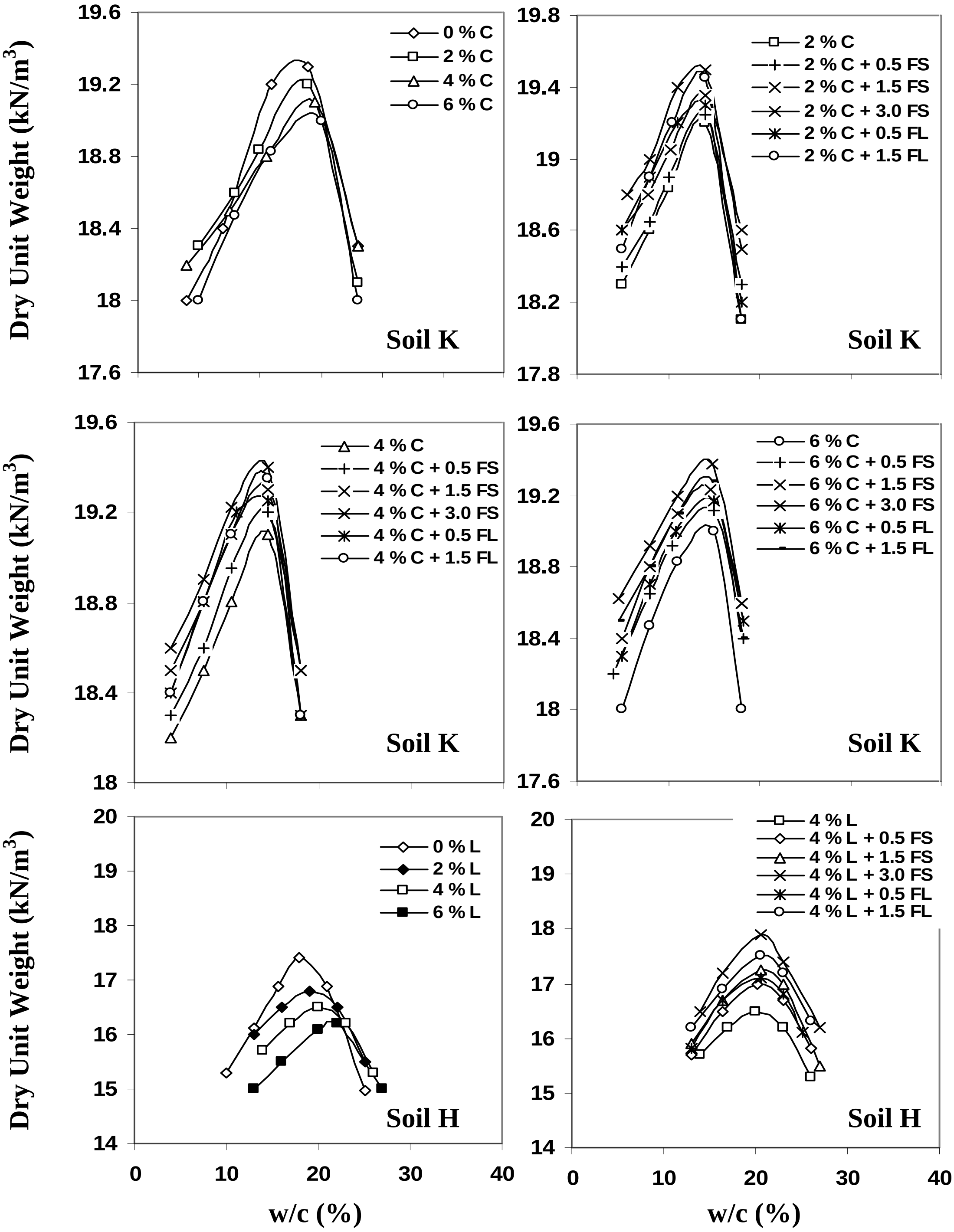

Figure. (1) Compaction Curves of Natural and Stabilized Reinforced Silty and Clayey Soils.

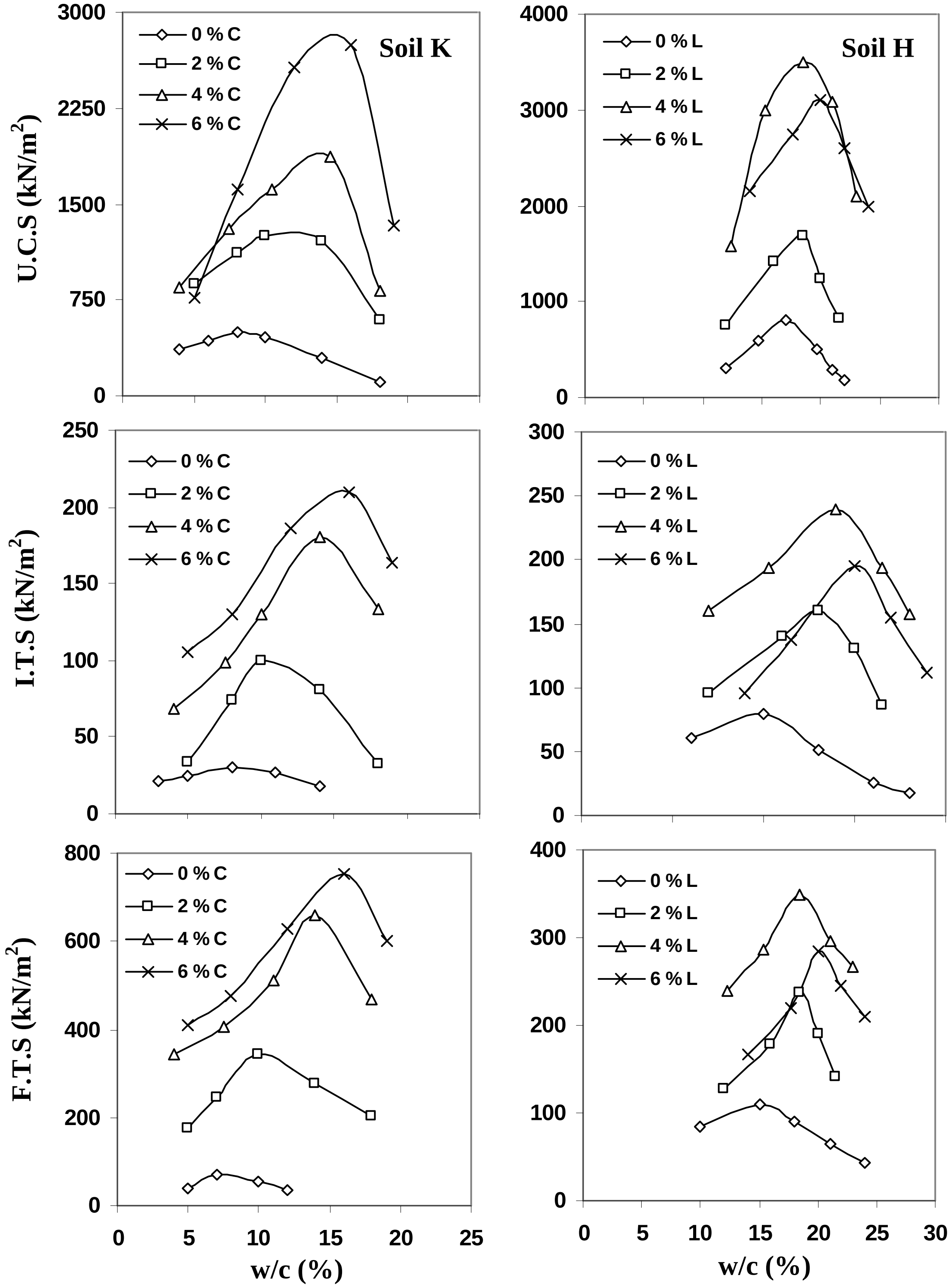

Figure. (2) Unconfined Compressive and Tensile Strength Curves of Natural and Stabilized Silty and Clayey Soils.

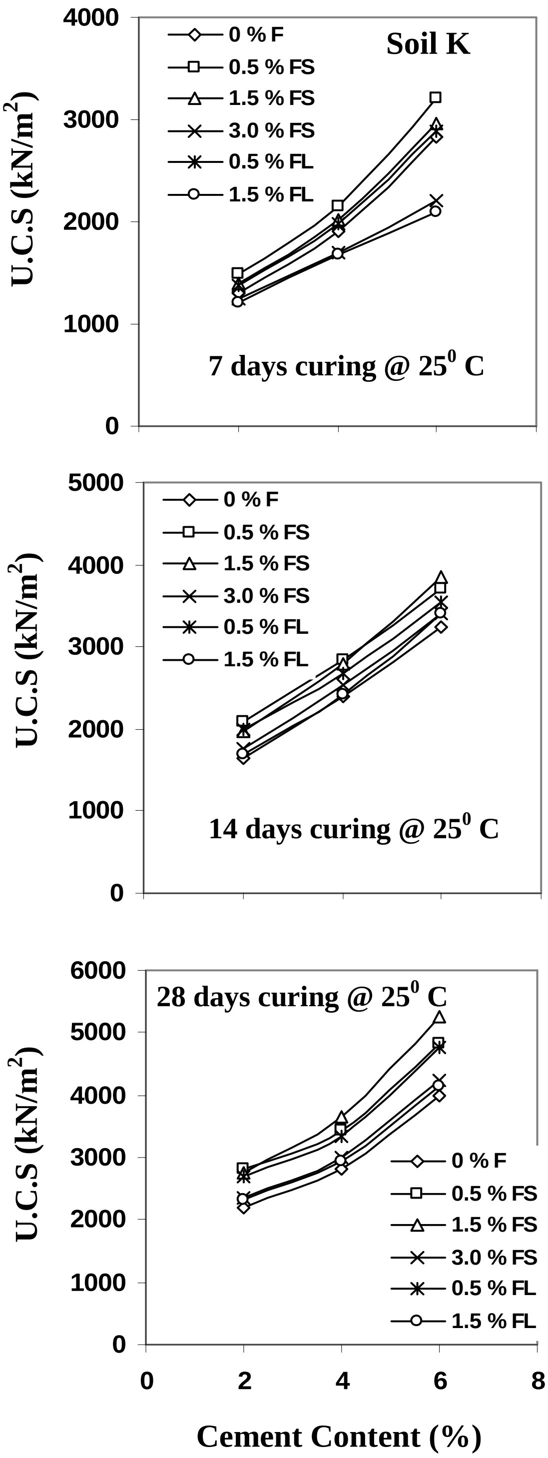

Figure. (3) Correlation between Cement Content and Unconfined Compressive Strength of Stabilized Reinforced Silty Soil.

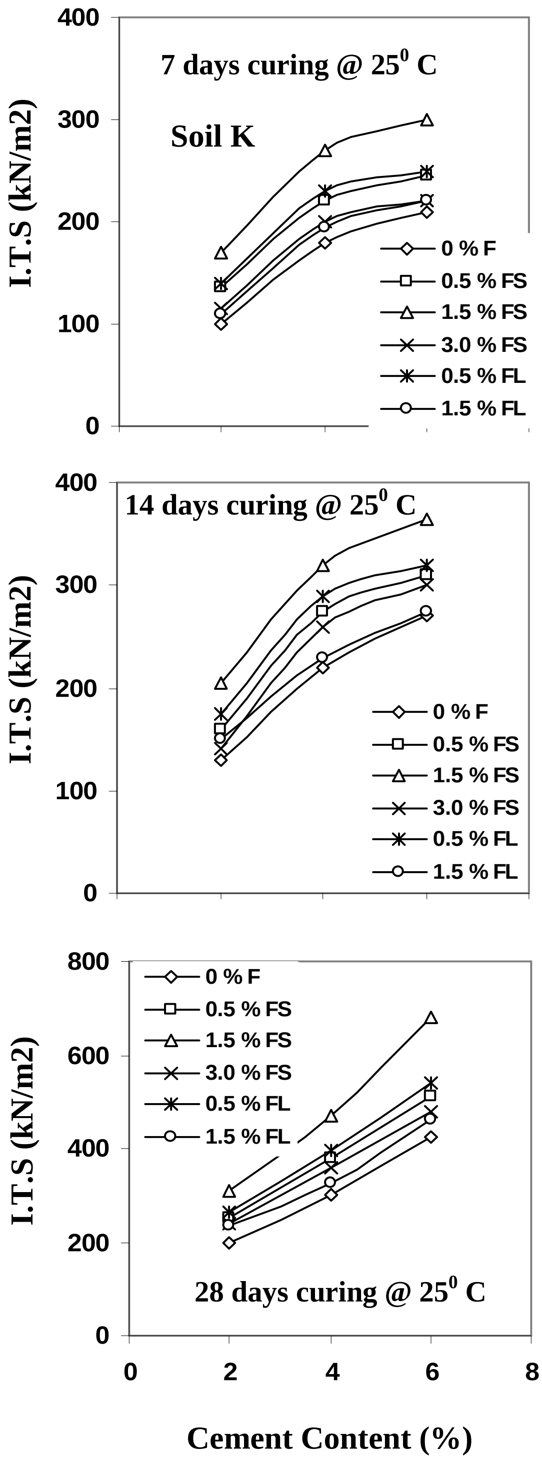

Figure. (4) Correlation between Cement Content and Indirect Tensile Strength of Stabilized Reinforced Silty Soil.

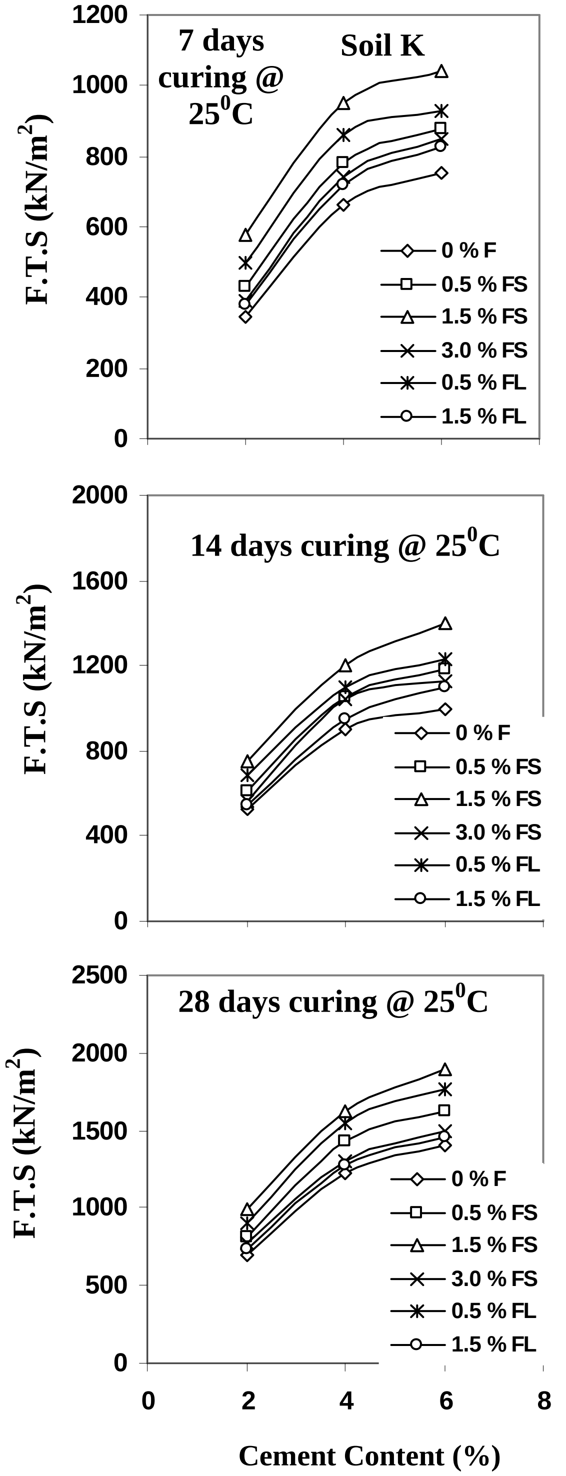

Figure. (5) Correlation between Cement Content and Flexural Tensile Strength of Stabilized Reinforced Silty Soil.

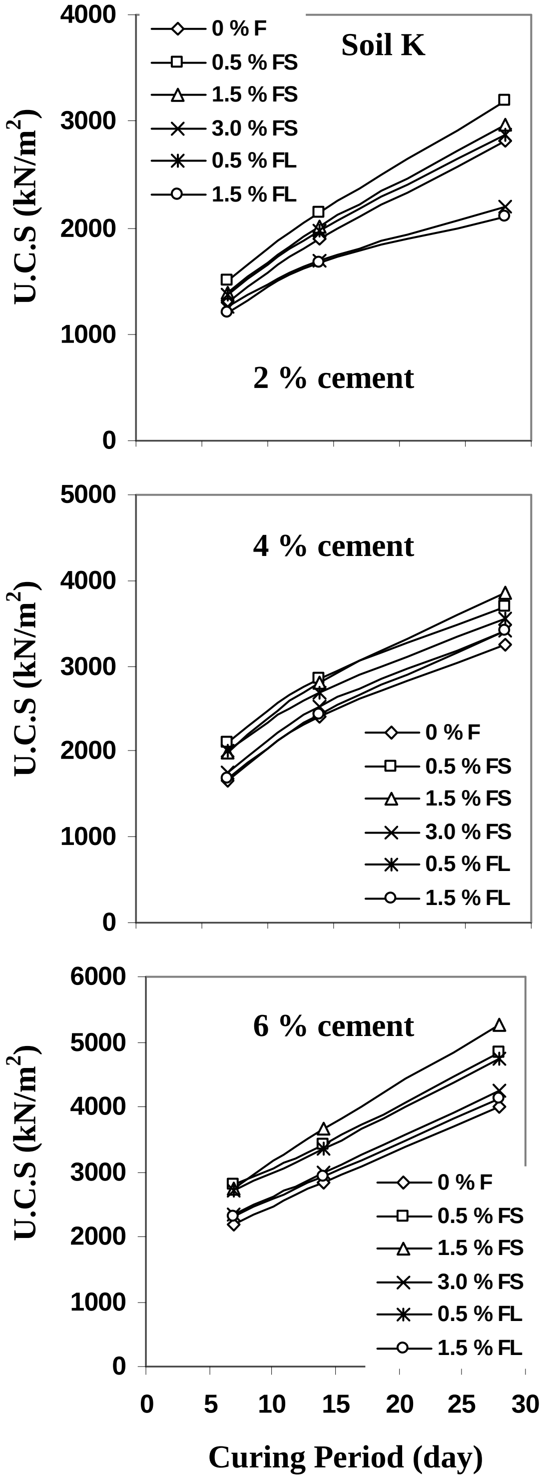

Figure. (6) Correlation between Curing Period and Unconfined Compressive Strength of Stabilized Reinforced Silty Soil.

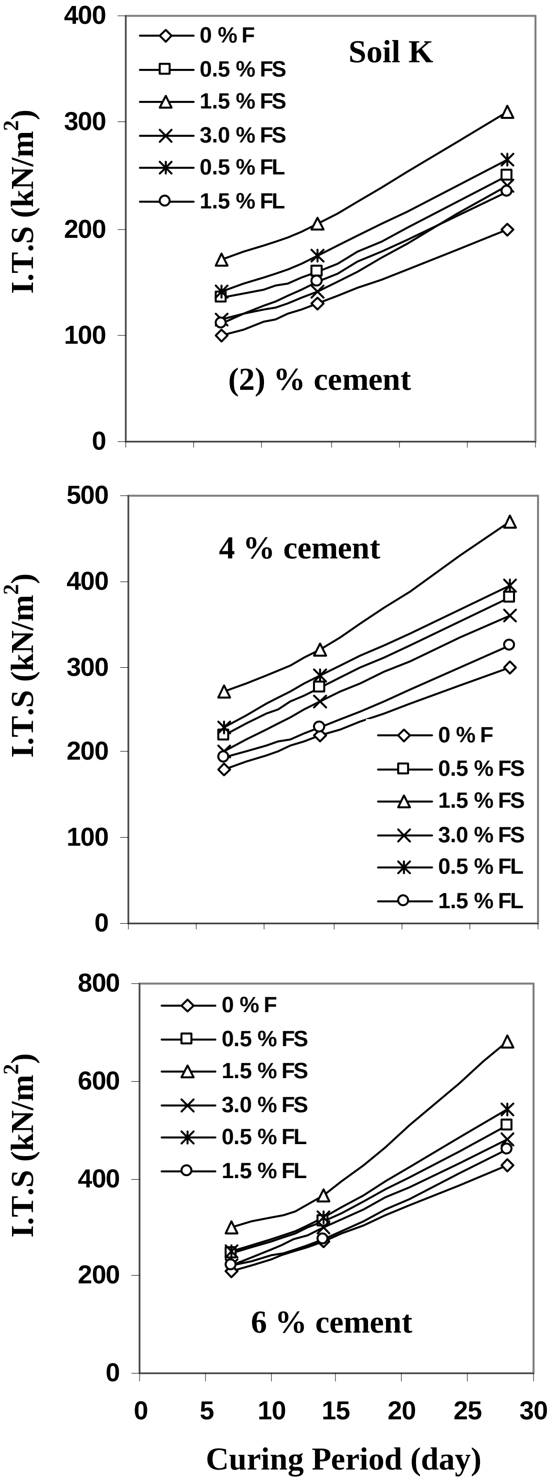

Figure. (7) Correlation between Curing Period and Indirect Tensile Strength of Stabilized Reinforced Silty Soil.

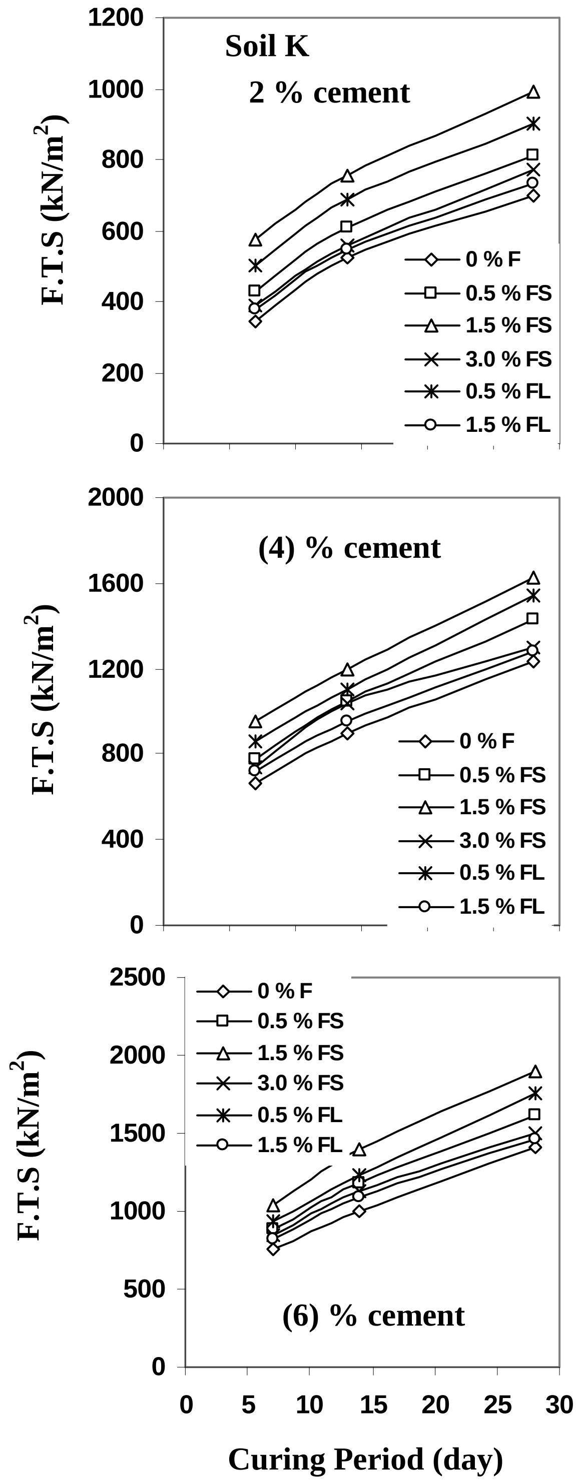

Figure. (8) Correlation between Curing Period and Flexural Tensile Strength of Stabilized Reinforced Silty Soil.

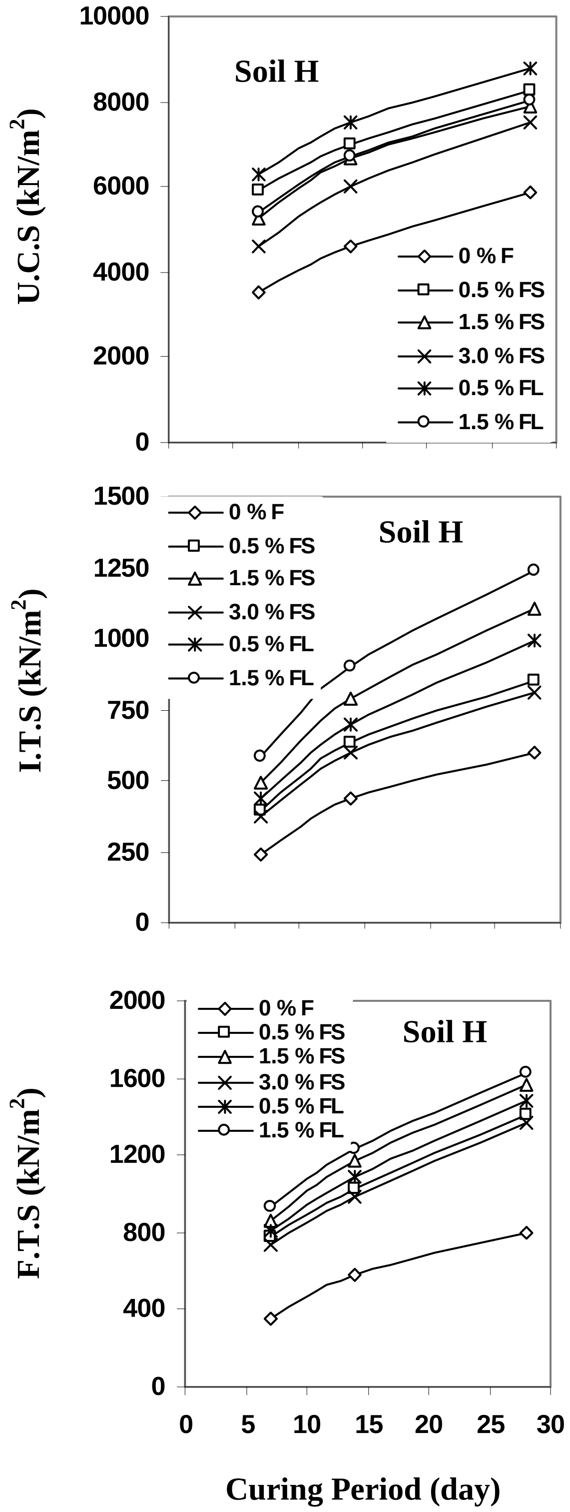

Figure. (9) Correlation between Curing Period and Values of Strength of Stabilized Reinforced Clayey Soil.

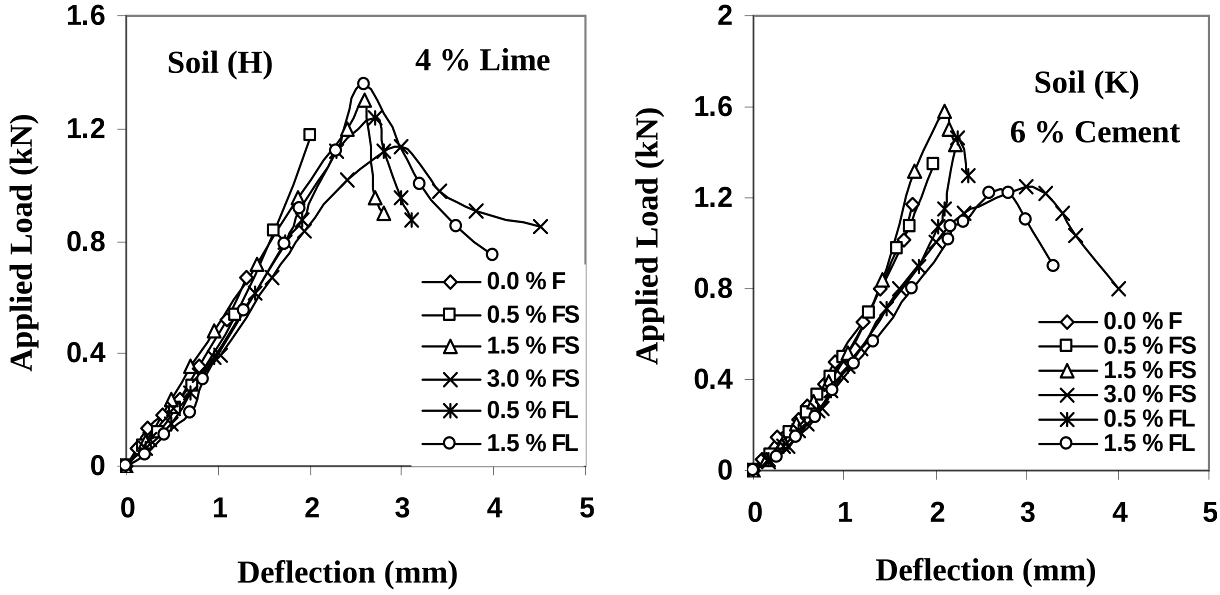

Figure. (10) Load – Deflection Curves for Unreinforced and Stabilized Fiber – Reinforced Soils.