

Compressive and Tensile Strength of Fibrous Clayey Soil Stabilized with Lime

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Abstract

This investigation was conducted to assess the efficacy of the glass, hay and polypropylene fibers for enhancing the unconfined compressive and tensile strengths of clayey soil stabilized with lime. Lime was mixed with the clayey soil in different proportions. Based on the optimum value obtained for lime (according to the unconfined compressive strength values), the compressive and tensile strength characteristics, stress – strain and load – deflection behaviors of lime stabilized samples mixed with different percents of glass, hay and polypropylene fibers were investigated. Fibers were added to the soil at range of (0.5 – 1.5 %). All stabilized samples were cured for 7 days at 25⁰ C.

Results indicate that the inclusion of fibers does not meaningfully improve the compressive strength, but significantly enhances the tensile strength, stress – strain and load – deflection behaviors. Also, it was found that the stress – strain and load deflection curves can be utilized to evaluate the performance of a fiber – reinforced stabilized soil for geotechnical and pavement applications.

Keywords: Lime stabilization, fibers, tensile strength, stress – strain behavior, load – deflection behavior.

مقاومة الانضغاط والشد للتربة الطينية الحاوية على الألياف والمثبتة بالنورة

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الخلاصة

يهدف هذا البحث إلى دراسة تأثير إضافة كل من الألياف الزجاجية وألياف التبن والبولي بروبيلين على خصائص مقاومة الانضغاط والشد للتربة الطينية المثبتة بالنورة. تم إضافة نسب مختلفة من النورة إلى التربة وتم إيجاد نسبة النورة المثلى بالاعتماد على نتائج فحص الانضغاط غير المحصور. تم إضافة نسب مختلفة من ألياف الزجاج، التبن والبولي بروبيلين إلى نماذج التربة المثبتة بنسبة النورة المثلى، إذ تراوحت هذه النسب بين (0.5 – 1.5%) وتم إنضاج النماذج المثبتة لمدة 7 أيام بدرجة حرارة 25 درجة مئوية. بعدها تم إيجاد خصائص مقاومة الانضغاط والشد، كذلك تم إيجاد كل من منحنيات الإجهاد – الانفعال ومنحنيات الحمل – الأود.

أظهرت النتائج حصول زيادة في كل من مقاومة الانضغاط ومقاومة الشد، وكان مقدار التحسن في مقاومة الشد أكثر منه في مقاومة الانضغاط لنماذج التربة المضاف إليها الألياف. أيضا بينت النتائج أنه يمكن الاستفادة من منحنيات الإجهاد – الانفعال ومنحنيات الحمل – الأود في تقييم أداء الطرق المثبتة والمضاف إليها الألياف.

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Introduction

In geotechnical and geoenvironmental engineering practice, the tensile strength of soil is assumed to be zero and insignificant, because it is a relatively small value as compared to the compressive strength, and some times assumed as a percent of the compressive strength [1]. It is known that, pavement layers are subjected to tensile stresses due to traffic loads, and failure is initiated due to formation and propagation of tensile cracks [2], especially when the tensile stresses reach or exceed the tensile strength of the pavement layers.

The importance of cracking failure related to tensile strength of soil in many highway pavements, earth dams and soil liners has been given considerable attention [3 and 4]. So, soils stabilization and reinforcement with fibers are widely used techniques for increasing tensile strength of soils [5,6,7 and 8].

The concept of reinforcing soils with fibers has been widely accepted in engineering practices, because reinforcing the subgrade soils with fibers appears to have a great potential for successful application in the design of flexible pavements [9 and 10]. These benefits can be realized by extending the service life of the pavement or reduction in sub-base or base thickness.

In this paper polypropylene, glass and hay fibers were mixed with soil-lime mixture as reinforcement materials to improve the strength and deformation behavior of the clayey soil. The tests conducted on the stabilized fibrous samples were unconfined compression and flexural tensile tests. Also stress – strain characteristics curves in tension during flexural test were determined using the direct method of analysis.

Materials.

Soil.

The soil used in this study was sampled from Al-Hadbaa district in Mosul city, at depth (1.0 m) below the ground surface. The particle size analysis indicates a UCCS classification of (CL) with (46%) clay, (38%) silt and (16%) sand. The liquid limit is (48%) with a plasticity index of (25%) and the specific gravity of solids is (2.72). Also, some other physical and chemical properties of soil are shown in Table (1), using the relevant tests according to the ASTM standards.

Table (1) Physical and chemical properties of natural soil.

Properties	Values
Liquid Limit (%)	48
Plastic Limit (%)	23
Plasticity Index (%)	25
Linear shrinkage (%)	12.5
Total Soluble salts (%)	2.7
Organic matter (%)	1.4
Specific gravity	2.72
Sand (%)	16
Silt (%)	38
Clay (%)	46
Soil Classification (USCS)	CL

Lime.

The lime used in this study is high calcium hydrated lime with (73 %) activity, and was obtained from Meshrag Sulphur factory. The chemical analysis of the lime is shown in Table (2).

Table (2) Chemical composition of lime

Composition	Ca(OH) ₂	CaO	CaCO ₃	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	MgO	H ₂ O	L.O.S
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

Fibers.

Fibers are the most common materials used to reinforce soil [11]. Three different types of fibers were selected for reinforcing the soil. These types were polypropylene (PF), glass (GF) and hay (HF) fibers. Some properties of the polypropylene and glass fibers are presented in Table (3), these properties were provided by the manufacturers.

Hay fibers are available in large quantities in Iraq, especially during the harvest time. The hay pieces were very long compared with their width. The length of the used hay fibers were graded from (4 cm) approximately as a maximum length to very fine pieces with (1.5 %) passing sieve No. 200. All fibers were used in different percentages of (0.5, 1.0 and 1.5 %) by dry weight of soil. .

Table (3) Some properties of the polypropylene and glass fibers

Fiber Type	Specific Gravity (Gs)	Length (mm)	Color	Absorption	Thermal Conductivity
Polypropylene	0.91	32	Natural	None	Low
Glass	2.5	12	White	None	Low

Experimental program and test procedures.

The experimental program consisted of two phases: (1) preliminary geotechnical characterization of natural soil (2) a series of unconfined compression and flexural tests on natural, stabilized unreinforced and stabilized fiber-reinforced samples prepared from mixes containing various percents of fibers.

All samples in this study were prepared using a modified Proctor compaction (ASTM D-1557). Different percentages of lime (2,4 and 6%) by weight of dry soil were added, thoroughly mixed in dry state was carried out. The required amount of water was then added and again mixed. Visual examination of exhumed samples proved the mixtures to be satisfactorily uniform. The mixture was then placed in plastic bags for mellowing time of (24 hours) for untreated samples and (1 hour) for lime treated samples [12]. Mixtures were then compacted in a specific mold corresponding to the required tests. For the stabilized fibrous samples different percents (0.5, 1.0 and 1.5 %) of polypropylene, glass and hay fibers were added to the soil and the same previous procedure was repeated for samples as in stabilized case. A total of (10) mixes were investigated in this study. The samples were designated with a common coding system consisting of two terms. The first term, stands for the lime percent 4% lime depends on the unconfined compressive strength values [12], while the second term shows the fiber name and percent. Table (4) provides a summary of the various mix designs.

Table (4) Mix design used in experimental program

Mix No.	Mix Design
1	4 % Lime
2	4 % Lime + 0.5 % PF
3	4 % Lime + 1.0 % PF
4	4 % Lime + 1.5 % PF
5	4 % Lime + 0.5 % GF
6	4 % Lime + 1.0 % GF
7	4 % Lime + 1.5 % GF
8	4 % Lime + 0.5 % HF
9	4 % Lime + 1.0 % HF
10	4 % Lime + 1.5 % HF

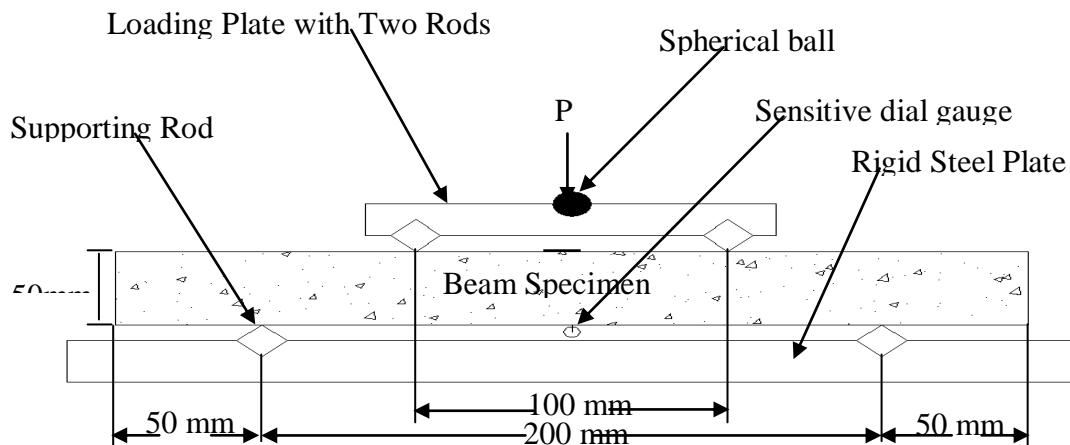
- PF = Polypropylene Fibers.
- GF = Glass Fibers.
- HF = Hay Fibers.

Unconfined compression test.

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

Flexural test.

The tensile strength of the stabilized soil is a vital parameter to judge its suitability as road base material. Flexural strength determination is one of the effective alternative methods to determine the combined compressive and tensile strength capacity of a stabilized material [13] (Natt and Joshi 1984). In the present study an attempt has been made to study the flexural strength characteristics of lime stabilized and lime stabilized-fibrous soil with varying percentages of fibers that are cured for (7) days at 25⁰ C. However, a prismatic beam (50*50*300 mm) was used in this investigation. The samples were prepared by compacting the soil at the optimum moisture content (OMC) in four layers using special square base hammer weighing (1652 gm) and falling from (285 mm) to obtain the modified compactive effort. The samples were mounted in the compression machine as shown in Fig. (1) and a load was applied at rate of (0.127mm/min). The deflection at the center of the beam (bottom) with applied load were recorded every (60 min) and the flexural strength properties were evaluated.

**Fig. (1) Mounting of the soil beam sample**

Method of analysis.

Stress analysis of the beam have been carried out by direct method. This method was used to calculate the tensile stress at the bottom and the compression stress at the top of the beam from the applied bending moment. In direct method it is assumed that plane sections remain plane after bending, that the elongation and contraction of longitudinal fibers are proportional to their distance from the neutral axis. The value of deformation modulus in tension may differ from that in compression (hence the neutral axis is not necessarily at the mid-height of the beam) and no creep occurs during bending [14].

Duckworth, [15] derived the following equations for tensile stress (σ_t) and compressive stress (σ_c):

$$\sigma_t = \frac{3M(\varepsilon_c + \varepsilon_t)}{bh^2\varepsilon_t} \quad (1)$$

$$\sigma_c = \frac{3M(\varepsilon_c + \varepsilon_t)}{bh^2\varepsilon_c} \quad (2)$$

Where:

σ_t = tensile stress. σ_c = compressive stress. M = applied bending moment.

b = width of the beam. h = height of the beam ε_t = tensile strain.

ε_c = compressive strain.

The strain of the beam is found from the following equations:

$$\varepsilon_t = \frac{48\delta_t * M C}{Pb(3L^2 - 4b^2)} \quad (3)$$

$$\varepsilon_c = \frac{48\delta_c * M C}{Pb(3L^2 - 4b^2)} \quad (4)$$

Where:

δ = observed deflection at the center of the beam which can be obtained directly from the sensitive dial gauges (0.002 mm/div) fixed at top and bottom of the beam.

$C = h/2$.

P = applied load.

L = the distance between the lower supports.

In this study only the tensile stress at the bottom of the soil beam will be considered.

Results and Discussion.

Compaction characteristics.

The compaction characteristics of untreated (natural) and treated soil with different percentages of lime (2, 4 and 6%) are shown in Fig.(2). The maximum dry unit weight (γ_{max}) decreases with the addition of lime, while the optimum moisture content (OMC) increase. This reduction is due to the immediate reactions between lime and soil, which represented by

the flocculation and agglomeration [12]. The increase of the (OMC) with increasing lime may be due to increase fine materials and due to the hydration of lime.

In case of fibers addition, Fig. (3) show that, there was a slight decrease in the maximum dry unit weight (γ_{max}), while there was no fundamental different in the (OMC) of stabilized reinforced soils, except the soil reinforced by the hay fibers, which the (OMC) was greater than that (OMC) of lime stabilized soil. This behavior may be due to that, hay fibers absorbed water which tends to increase the optimum moisture content (OMC).

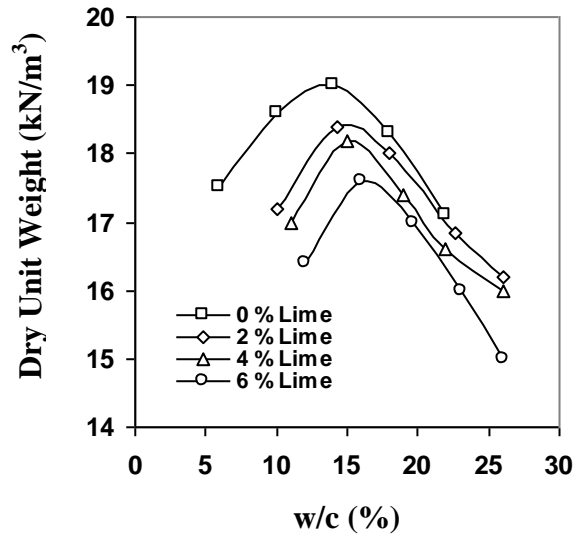


Fig. (2) Compaction curves of natural and lime stabilized soil

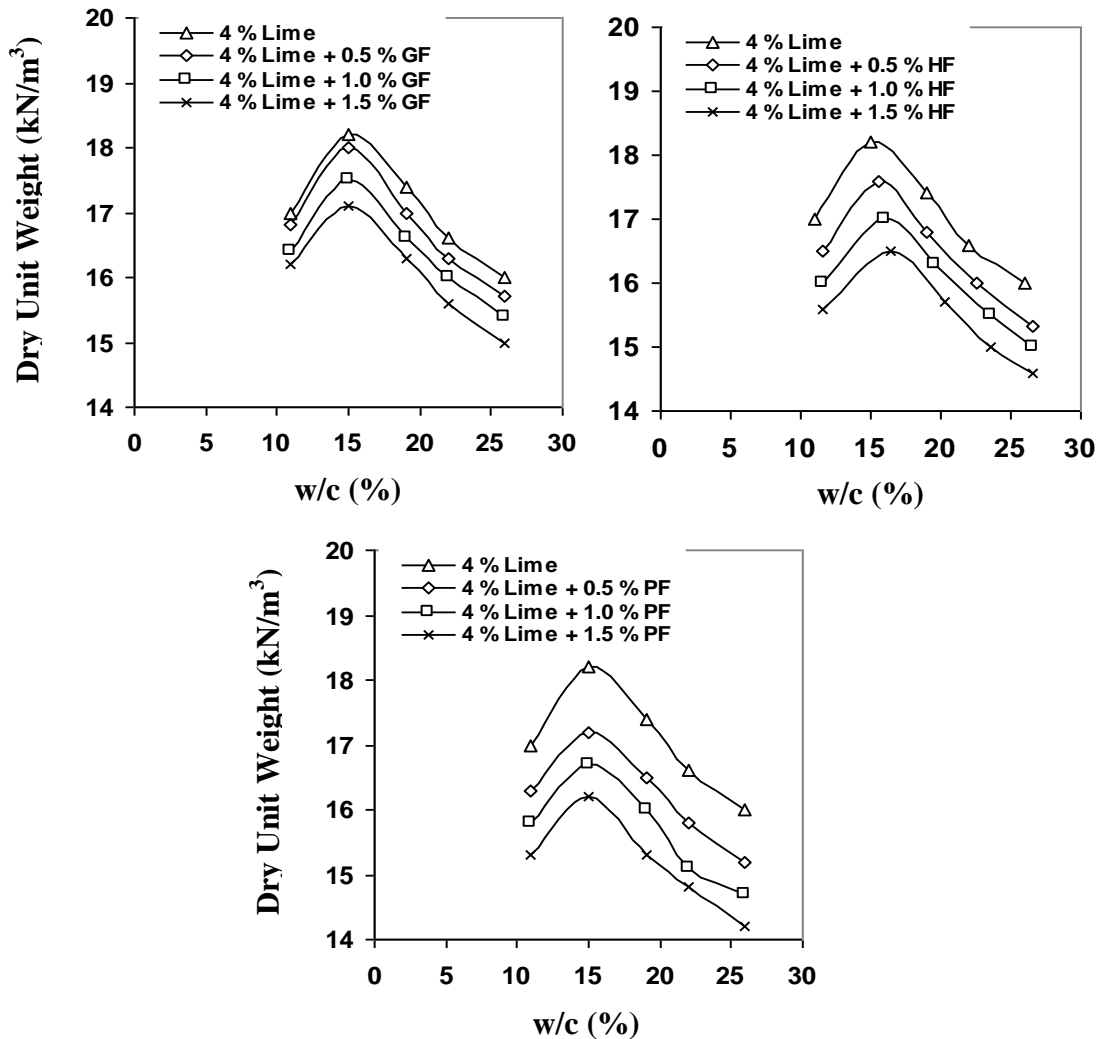


Fig. (3) Compaction curves of stabilized reinforced soil

Unconfined compressive and tensile strengths.

The results of the unconfined compressive strength (σ_c) and the tensile strength (σ_t) have been presented for natural and stabilized soil, also soil reinforced with different types and percent of selected fibers. The values of (σ_c) and (σ_t) have been illustrated in Fig. (4) and Table (5). It is observed that, the (σ_c) and (σ_t) increased upon the lime addition. This belongs to the reactions that may occur between the soil particles and the lime. The (σ_c) and (σ_t) increase up to (4%) then decrease. The reduction in strengths when soil is treated with (6%) lime may be due to the extra lime, which acts as a fill material due to uncompleted reaction with the short curing period (7 days).

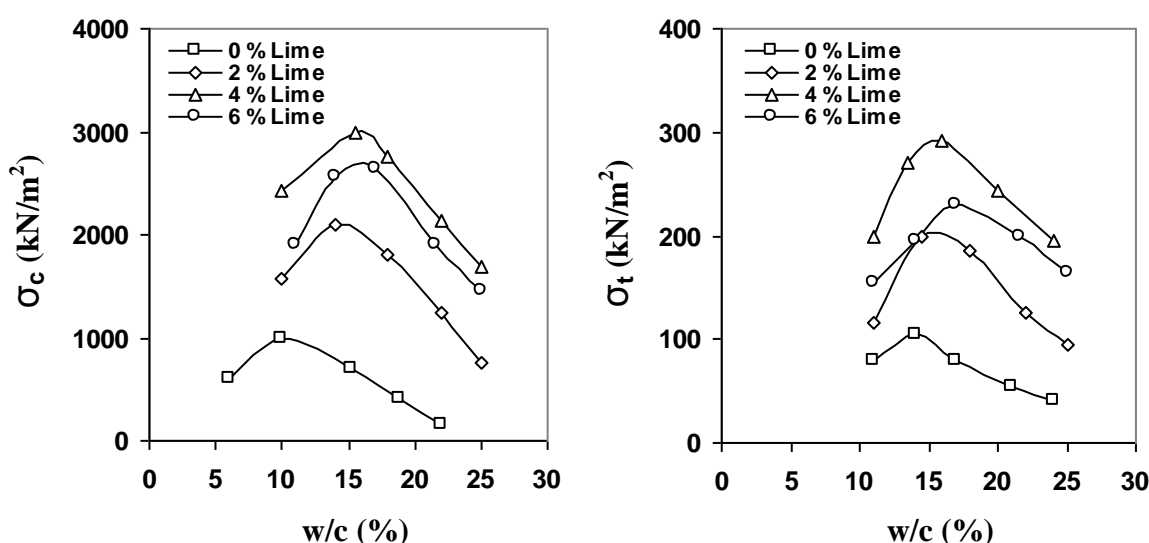


Fig. (4) Unconfined compressive and tensile strength curves of natural and lime stabilized soil

For natural soil the (σ_c) and (σ_t) are (1000 and 105 kN/m²) respectively, and the soil treated with (2, 4 and 6 %) lime attains after (7 days) curing maximum values of (σ_c) and (σ_t) of order (2100, 3000 and 2640 kN/m²) : (200, 292 and 230 kN/m²) respectively, which gave an improvement ratios (2.1, 3.0 and 2.64) : (1.9, 2.78 and 2.19) times that of natural soil, respectively.

In case of fibers additions, the inclusion of fibers was found to a mostly enhanced the compressive and tensile strengths of soil. As shown in Fig. (5) and Table (5) the strengths initially increases with increasing fibers percent up to (1%) then decreases for the all types of the fibers which used in this study (i.e. glass, hay and polypropylene fibers). The high percent of the fibers (i.e. 1.5%) causes reduction in strengths may be due to the fibers clumping together, which lead to reduce the interlocking (bond) between soil and fibers. The maximum values of (σ_c) and (σ_t) of stabilized reinforced soil with (1%) of glass, hay and polypropylene fibers are (4620, 3750 and 3400 kN/m²) : (1084, 932 and 788 kN/m²) respectively. These values gave an improvement ratios (4.62, 3.75 and 3.4) : (10.32, 8.87 and 7.5) times of natural (untreated) soil.

It is worth mentioning that, the maximum values of (σ_c) and (σ_t) are obtained when glass fibers were used.

Finally, the effect of fibers on the tensile strength (σ_t) and unconfined compressive strength (σ_c) can be visualized by considering the ratio (σ_t / σ_c) of the maximum strength values

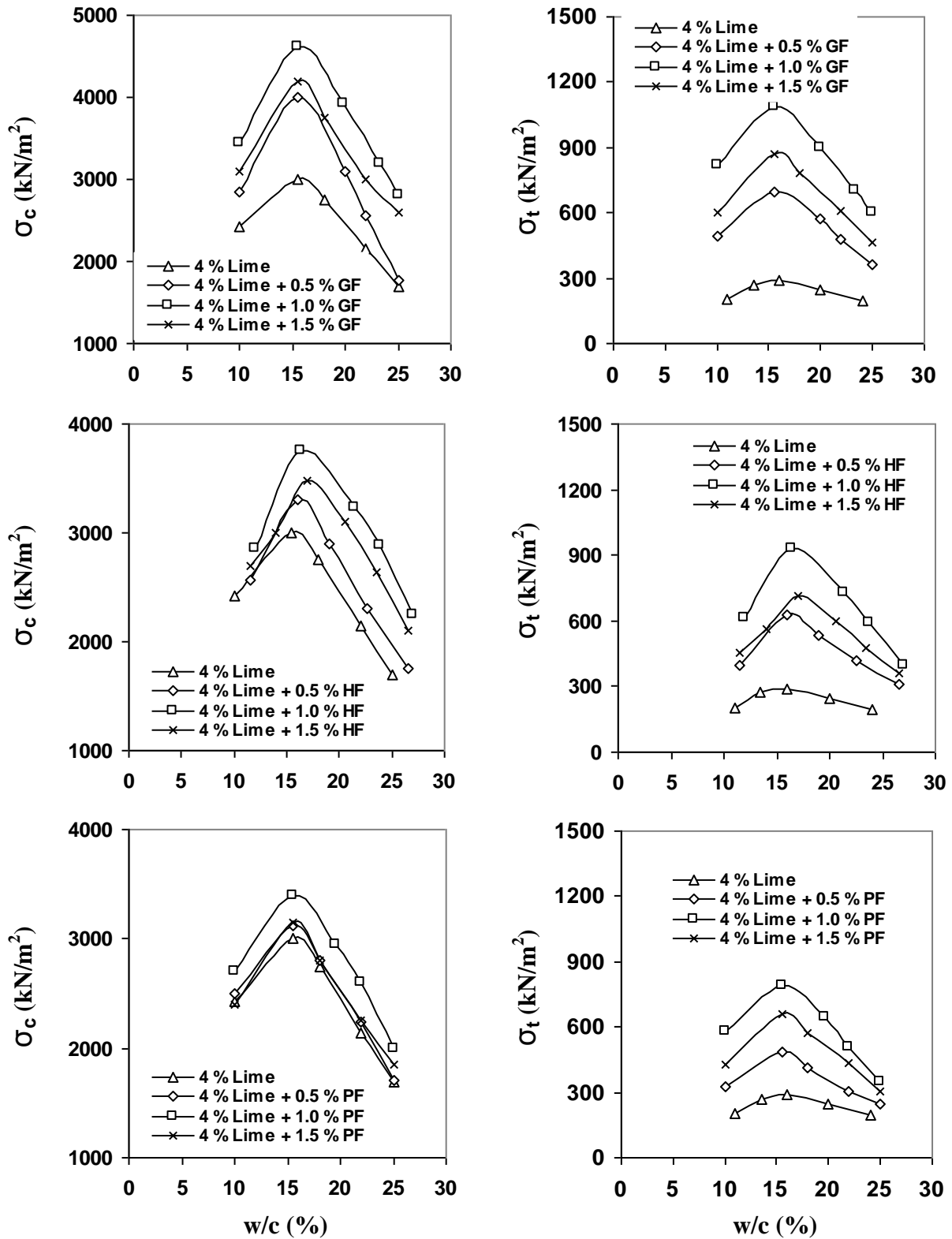


Fig. (5) Unconfined compressive and tensile strength curves of stabilized reinforced soil

obtained when (1%) of different fibers (i.e. glass, hay and polypropylene fibers) were used , these results are shown in table (6). For natural (untreated) soil the ratio is (10.5 %), while the ratio became (23.46, 24.85 and 23.17 %) for glass, hay and polypropylene fibers respectively. This means that, the relative increment of increase in tensile strength is more than that in unconfined compressive strength

Tensile stress – strain curves.

Stress – strain curves of stabilized unreinforced and fibers reinforced samples have been illustrated in Fig. (6). In general, the curves of unreinforced and fibers reinforced stabilized samples are irregular in their shape. It is believed that such irregularities in the stress – strain curves are due to the progressive type of failure which took place during the test, or may be due to non uniform distribution of fibers in the samples.

Table (5) strength results of reinforced stabilized soil

Fiber Type	Fiber (%)	σ_t (kN/m ²)	Increasing (%)	σ_c (kN/m ²)	Increasing (%)
.....	0.0	292	178	3000	200
Glass	0.5	696	563	4000	300
	1.0	1084	932	4620	362
	1.5	868	727	4200	320
Hay	0.5	627	497	3300	230
	1.0	932	788	3750	275
	1.5	711	577	3480	248
Polypropylene	0.5	487	364	3120	212
	1.0	788	650	3400	240
	1.5	656	525	3150	215

- Max. σ_t of natural soil = 105 kN/m²
- Max. σ_c of natural soil = 1000 kN/m²
- F.T.S = Flexural tensile strength.
- U.C.S = Unconfined compressive strength.

- Increasing strength (%) = $\frac{(\sigma)_{max} - (\sigma)_{natural}}{(\sigma)_{natural}} \times 100$

Table (6) results of the tensile and unconfined compressive strength for untreated and lime treated reinforced soil

Fiber Type	σ_t (kN/m ²)	σ_c (kN/m ²)	σ_t / σ_c (%)
Glass	1084	4620	23.46
Hay	932	3750	24.85
Polypropylene	788	3400	23.17

For the mode of failure, the cracks are clearly visible near the bottom center of the beam, and as expected the cracks run right through the beam sample since after the formation of a crack at the bottom. Also, not all the beam samples failed in the center, but none of the samples broke near either the loading or supporting points. The failure invariably occurred in the central region where the applied bending moment was constant.

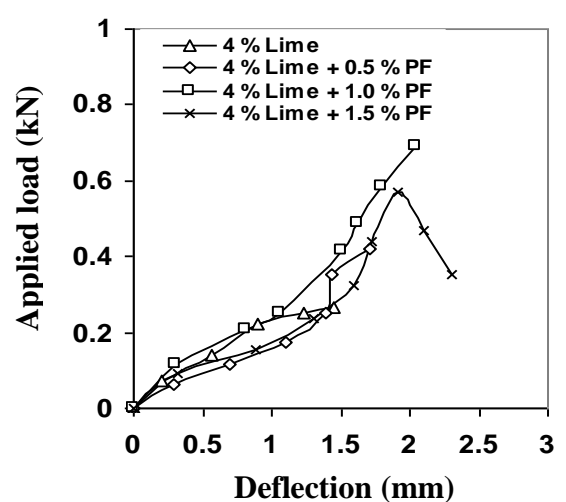
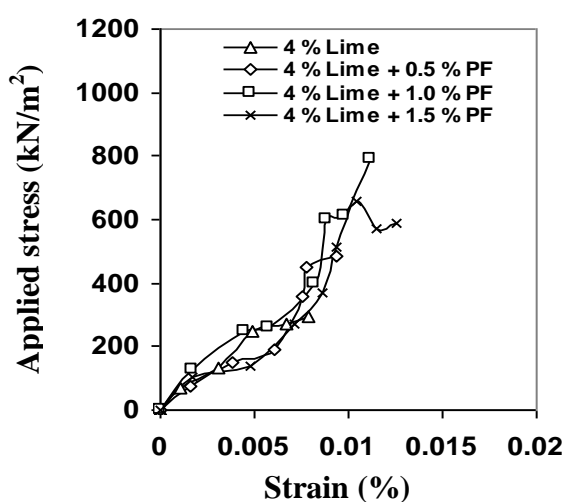
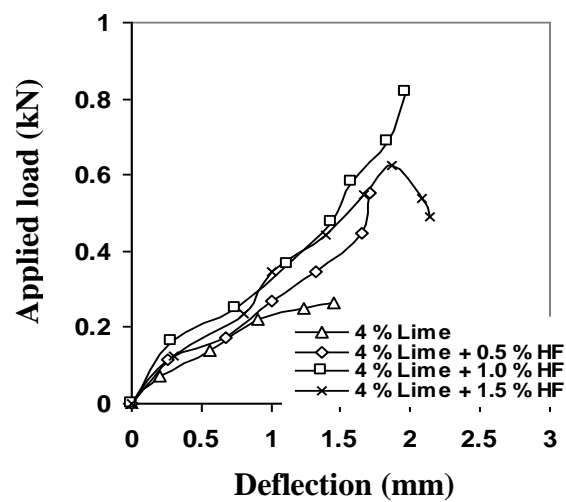
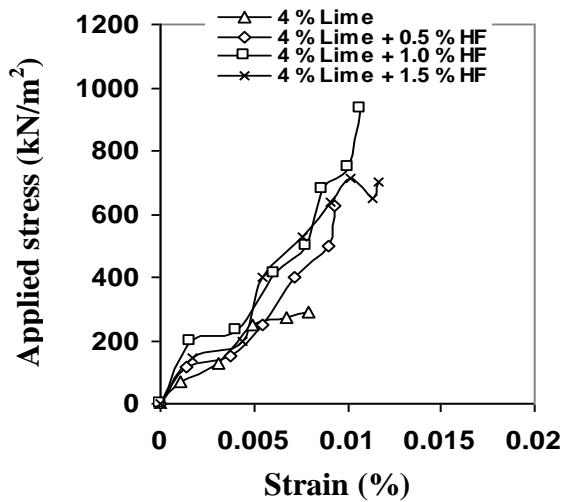
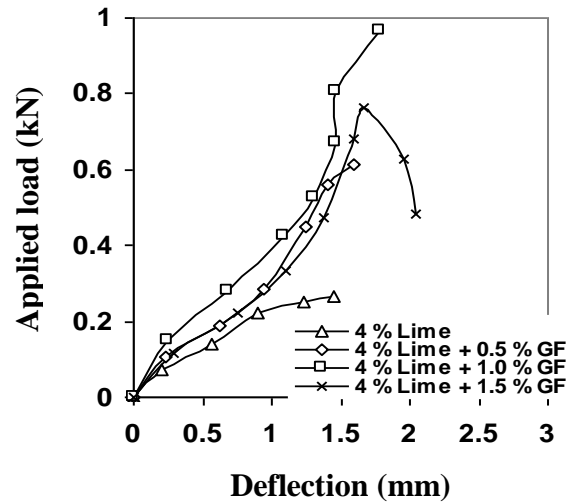
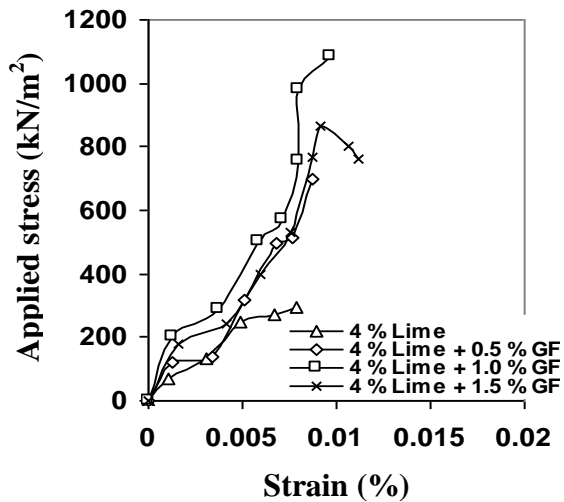


Fig. (6) Stress – strain curves of stabilized reinforced soil

Fig. (7) Load – deflection curves of stabilized reinforced soil

Load – deflection curves.

Fig. (7) shows a typical load –deflection curves for stabilized unreinforced and fibers reinforced samples. As in the stress – strain curves, the load – deflection curves are irregular in their shape and these curves are almost linear in the first primary portion. The unreinforced samples and samples reinforced with a little amount of fibers (i.e. 0.5%) were failed in a

brittle manner, after reaching their peak load. while the samples reinforced with (1.5%) showed some modification in the post peak behavior as the load carrying capacity dropped gradually. The drop indicates that the tensile strength has been exceeded.

The maximum deformation of stabilized reinforced samples with (1.5%) of glass, hay and polypropylene fibers was approximately (1.4, 1.47 and 1.58) times the deformation of unreinforced stabilized samples.

Suggested model to estimate unconfined compressive and flexural tensile strength.

It is interesting to note that although the unconfined compressive and flexural tensile tests are two different tests, there is a close correlation between the strengths obtained from each of them. Different models were initially studied to obtain the best fit among the unconfined compressive and flexural tensile strengths. The models investigated were exponential, binomial and linear.

For natural and lime stabilized unreinforced samples, the best fitting model is represented by following exponential model:

$$\sigma_t = 1.0123 * \sigma_c^{0.6873} \quad (R^2 = 0.9267) \quad (5)$$

For the lime stabilized samples reinforced with glass and hay fibers, is represented by the following binomial models respectively:

$$\sigma_t = 0.00003 * \sigma_c^2 + 0.0856 * \sigma_c - 22.342 \quad (R^2 = 0.7959) \quad (6)$$

$$\sigma_t = 0.0001 * \sigma_c^2 - 0.4169 * \sigma_c + 571.72 \quad (R^2 = 0.7959) \quad (7)$$

While, the samples reinforced with polypropylene, the best fitting model is represented by linear model as follow:

$$\sigma_t = 0.2507 * \sigma_c - 221.47 \quad (R^2 = 0.5323) \quad (8)$$

These models cover a variety of statistical relationships that vary from the simple linear model to the exponential one. Each model was evaluated based on its coefficient of determination (R^2). It is worth mentioning that, the reason for the lower (R^2) values (especially when polypropylene fibers were used) is probably ascribable to the smaller number of samples that were tested in the laboratory and hence, decreasing the accuracy of correlation. Thus, the use of correlation formulas suggested above is limited to range of results of the present study. For more general formula, further samples need to be tested.

Conclusions.

On the basis of the present study, the following conclusions are made:

1. Stabilization of the clayey soil with lime is to an extent effective to enhance the tensile and compressive strengths.
2. With the increase in lime content, the maximum dry unit weight decreases and optimum moisture content increases.
3. In general, fibers addition causes a slight decrease in the maximum dry unit weight, while there was no fundamental different in the optimum moisture content.
4. The addition of (1.0 %) of glass, hay and polypropylene fibers gave a maximum values of the compressive and tensile strengths.
5. The ratio of tensile strength and unconfined compressive strength showed that, fibers are more efficient when soil was subjected to tension rather than to compression.
6. Stress – strain curves have irregular shape when direct method of analysis is used.

7. Load – deflection curves are almost linear in the first primary portion. Reinforced samples with (1.5 %) of glass, hay and polypropylene showed some modification in the post peak behavior.

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