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The Compressibility of Clayey Soils Reinforced with Fiberglass

Maysam Th. Al-Hadidi

Baghdad University, College of Engineering, Water Resources Engineering Department, Baghdad, Iraq

Abstract: ***During the prior three decades numerous research works presented to investigate the behavior of reinforced soil. All these studies indicated that the use of reinforcements will increase the bearing capacity and reduce the settlement of soil foundations. The modern soil engineering is concentrating on the using of the reinforcements like metal strips and synthetic fabrics. The reinforcement of soil by separated fibers is still a relatively new technique in geotechnical projects. This research presents an experimental study on the reinforcement by glass-fiber for treating the swelling of clayey soil. Different ratios of fiberglass have been mixed with the soil (0.0%, 0.5%, 1% and 2%).The objective of this research includes studying the compressibility of clayey soil reinforced with fiber glass. The tests have been done to understand the effect of the fiberglass on the soil and check the validity of using the fiberglass to avoiding the use of the soil from elsewhere. The study showed that the swelling coefficient decreases with increasing the ratio of glass fiber. Also the reason of not to increase the proportion of fiber over 2% is the difficulty of mixing with the soil. The results of this research show that there is no excessive difference in the improvement results between the ratio of 1 %and 2 %ratio of fiberglass, and as recommendation from this research the mixing 1% from fiberglass with clayey soil could improve its compressibility and reducing the swelling potential.***

Keywords: Fiberglass, reinforcement, clayey soils, Compressibility, synthetic fabrics, swelling potential

1. Introduction

The swelling of the expansive soil appearing clearly of these soils which initially unsaturated, so if the water added to that soil it will swell. on the other hand , it will be shrinking if water content decreased ,wherefore, the considerable interesting in geotechnical engineering is identifying of expansive soils and assessment of their swelling quantity when undergo to variation in circumference conditions. [34]; [11] ; [1].

2. Expansive Soils

The expansive soils are an extensive problem. Mainly the expansion of soil related to the existing of minerals and that main minerals are: bentonitic mudstones and silty mudstone, argillaceous dolomitic limestones where these materials are found in the areas where the problems of expansive soils are appeared. [4]. After [3].

3. Swell Potential

The swell potential is defined as “the quantity of heaving for a soil for assumed water content and loading position” and used for a comparison. A special oedometer test has been found to specifie the amount of that potential for soils “ASTM D 4546–90 Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soils”. [3]

The swell potential calculated at the seating load and relative to the initial void ratio e_o and found as:

$$swell\ potential = \frac{e_{se}-e_o}{1+e_o} \times 100 \qquad (1)$$

Where e_{se} is “void ratio after constant swell at seating load” and e_o is “the initial void ratio of the soil sample at the seating load”.

4. Classification of soil as Expansive

According to the results of oedometer swelling potential test, both Holtz and Gibbs in 1956 and Seed et al. in 1962 precent a classification to find the ability of expansive for the swelling soils.

Holtz and Gibbs in (1956) classification is related to the swell potentials of undisturbed samples that were submerge under a pressure of about (7 kPa). Seed et al. (1962) standards is founded on the swelling potential of remolded samples that were compacted to maximum dry density and optimum moisture content and under immerse under pressure of 7 kPa.Table 1 show the expansive denomination that suggest by these researchers.

Table 1: Classification of degree of expansion soils after Rao, 2006

Degree of expansion	*Holtz and Gibbs' (1956) classification of percent swell*	*Seed et al's (1962) classification of percent swell*
Low	0–10	0–1.5
Medium	10–20	1.5–5
High	20–35	5–25
Very high	>35	>25

5. The Time-Swell Curve

The Time-Swell curve is the curve that represents the relation between time and the swelling and usually consisting of three zones:
1) Initial swelling zone.
2) Primary swelling zone.
3) Secondary Swell Zone

As shown in figure (1). The minor initial swell is refer to swelling of the macrostructure, while the main primary swell and minor secondary swell is refer to microstructural swelling [31].

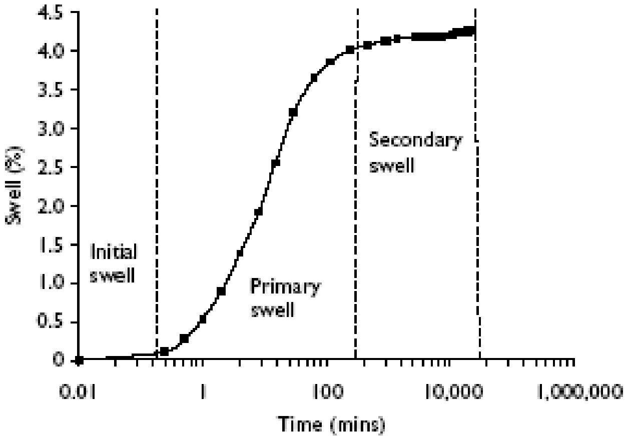

Figure 1: Time-swell behavior of compacted soil

6. Expansive soil and there problems

When the structures constructed on swelling soil a lot of Damages to structures could be appear due to the change in moisture conditions. And that are current problems that occur repeatedly in many parts of the world. Damages can range from petty cracking of pavement or inner termination in the structures, which is very unusual, to unfixable damages on foundations and upper structures elements [29] after [2].

7. Expansive soil stabilization

The chemical and mechanical stabilization methods have been used to qualify expansive soils [33] .one of the methods used in improving the expansive soil is by using fibers as a reinforcing material.

Fibers classified in two style, normal fibers and artificial fibers.

Normal fibers like cane, fiber of the African palm, coconut fibers which named as coir and the core of wood.A normal fiber used to produce cleaning brushes [13], [30].

Artificial fibers like polypropylene (discrete, bundles or in jalousie shapes) ([17], [23], [26] and [37]), polyamide [24] and polyvinyl chloride (PVC) fibers. Other types of fibers like glass [30], chopped fiberglass [9] and steel fibers [24].

8. Reinforcing Materials

The material that used in soil reinforcement is comparatively strong in tension in order to alleviate shrinkage cracking. Many of reinforcing methods used embedded material oriented in preferred directions like (geotextiles, geogrids), which sometimes are expensive and could be levels for the failures if it not embeded duly. in another hand there are vast quantities of research on the using of separated and arbitrarily distributed, artificial or natural fibers in soil stabilization . [27] After [29]

9. Fiberglass

The essential materials of manufacturing the fiberglass is the silica (SiO_2) .it's pure shape is a polymer in its stable condition It has no real fusion point but it is melt at temperature up to 2000°C, where it starts to breaking down when the temperature reach to 1713°C , [14].

The method of forming Glass fiber is consist of extruding many fibers in a shape of thin strands of the melt silica with small diameters .This method has been known from old millennia; however, the use of these fibers as tensile elements is modern technic.

10. Fiberglass Application

The fiberglass used in different range of live and in the following below some of these applications:

A-in the medical field: because of the demands of clients and patients and their anxiety for metallic allergies [25] the researchers developed a metal-free prosthesis, using fiberglass and thermoplastic polymers [35], [5], where it used in producing dental clasps, Dentures industry , Splinting fractures and more applications, [19] Where it is used as a reinforcing elements.

B- Fiberglass use in space structures: It could be used as electrical isolation, and for industry many of space's thematic ingredients such as reinforced plastic structural panels, large fiberglass cylinders, and small-diameter tubing as struts [22] after [10].

C- In civil engineering:
1) The fiberglass used as pore water sampler which is modern device working by capillary used to secure pore water and solution samples from unsaturation soil in order to observe the groundwater genus [15], [8], [28] after [18].
2) Fiberglass as thermal resistance: fiberglass blanket used as thermal resistance underneath a hot roof where it can reduce safely series of materials. It could reduce room-temperature value because the effective thermal conductivity of fiberglass changes with temperature.

Several handbooks classified effective thermal conductivity for fiberglass at different densities and temperatures. One of these handbooks lists the conductivity of more than 60 different insulators of different densities at 100° F intervals over diverse ranges of temperature [36].

Another study collected the data on thermal conductivity for fiberglass at many densities, but at only one range of temperatures between (24 and 249) ° C [38] The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) provided an executive table for the conductivity for temperatures ranging from 94° -132° C at intervals of 14° C, and for densities ranging from 12 to 48 kg/ m^3 as shown in (Figure 2) (ASHRAE 1985).

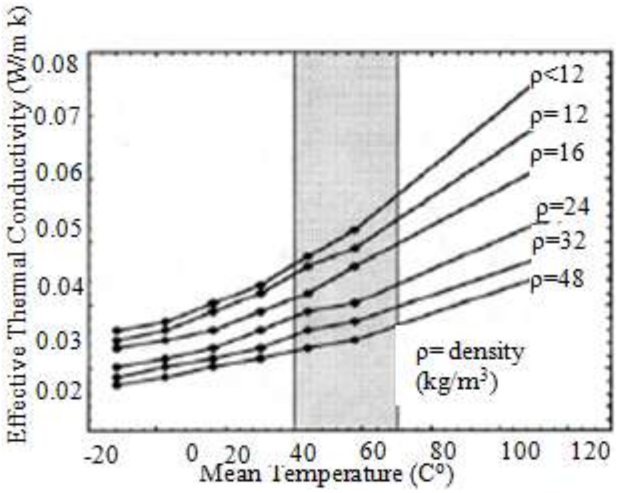

Figure 2: Effective Thermal Conductivity of Fiberglass vs. Temperature and Density, Source: Based on ASHRAE (1985).after Levinson et al.

3-High strength sandwich panels: Sandwich panels are used for a assortment of structural implementation, comprehensive constructing building, transmission, decoration and nautical [20] After [21].

There are many studies confirm the possibility of the use of fiberglass as a reinforcement elements in many applications so in this research the fiberglass was used as a reinforcement element with soil.

11. The Desirable Features of Fiberglass

The fiberglass has a lote of features as below[22] after [10]:

1) It has High tensile strength acording to weight ratio.
2) Its tensile strength ranging from 2* 109 to 3.5* 109 N/m2
3) It is have a very good stability, durability and its dimension is stable.
4) It is corrosion-resistant to moisture, most alkalis, and acids.
5) It is having a very good thermal property: incombustible, with low coefficient of thermal expansion; most fiberglass maintains 50 percent of its original tensile strength at 700 K.
6) Excellent electrical insulation characteristics: low dielectric constants and high dielectric strength.

12. Experimental Procedure

The experimental work consists of two parts:
Part no. 1 represents general tests done on the soil that will studies in this research, and part no. 2 which consist of four series with four mixing ratio of fiberglass that will done to study the variation of compressibility properties of that clayey soil in order to found the best mixing ratio.

Part no.1:
The soil used in this study is clayey soil**;** the following tests are done first to found the general properties of this soil:

1) Standard sieve analysis and hydrometer test according to ASTM standard no.D421.and D422 respectively.
2) The total dissolved salts test as described [12].
3) The specific gravity test according to ASTM standard no. D 854-02.
4) The compaction test according to ASTM standard no.D698.
5) Liguid limit and plastic limit test according to standard no.D4318.

The results of these tests will show in table (3) and figures (3 and 4). Where figure (5) show the fiberglass that used in this research.

Part no.2:
This part consist of operating free swelling test and consolidation test on the natural soil mixed with three percent of fiberglass (0.5, 1 and 2) %, the fiberglass used was in 2.5 cm length and each sample prepared in density equal to maximum dry density and optimum water content, and the weight of the fiberglass included in the dry weight of the sample.

After the preparation of the samples the following test are done as mention above:

1) Free swelling tests according to ASTM standard no 4546-90.
2) Consolidation test according to ASTM standard no 2435-70.

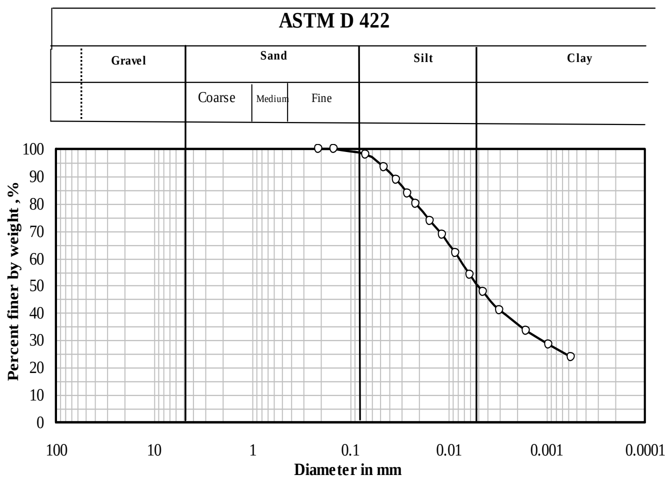

Figure 3: Hydrometer test of the natural clayey soil.

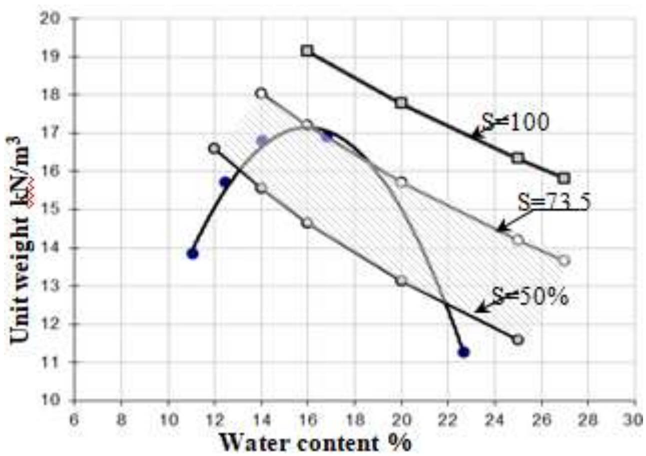

Figure 4: Compaction test of the natural clayey soil.

The standard compaction test has been chosen in order not to make the natural soil very stiff (to show its ability to the swelling).

The compaction test results (max. Dry density and optimum water content) are used to preparing the testing samples.

From the compaction test also it appear that the max. Dry density and the optimum water content fail in 73.5 % degree of saturation so the soil as appear fail in range between (50-73.5) % degree of saturation (unsaturated soil) and that make the soil more sensitive for variation of seasonal water content and give it the possibility for swell, and this made this soil very suitable to study the validity of using fiberglass as a material used to modify the swelling potential of the clayey soil.

Table 2: The properties and the description of the soil.

The property	*Value*
γdry max.(kn/m^3)	17.3
O.M.C %	16
Gs%	2.79
L.L%	54
P.I %	27.5
Gravel %	0
Sand %	2
Silt %	47
Clay %	51
USCS classification	CH
SO3 %	1.67
Cl^-(mg/l)	17500
T.D.S %	2.96
O.M. %	0.95

Figure 5: Fiberglass used in this search

The results of consolidation tests for different fiberglass added ratios represented in a lot of parameters and indexes, Figure (6) show the relation between the applied stress and the void ratio for soils with different mixing ratio of fiberglass. For each load increment, the coefficient of consolidation (C_v) calculated applying Casagrande method ,in addition to the coefficient of volume change (m_v), and then the coefficient of permeability (k) was calculated according to the following equation:

$$k = c_v \times m_v \times \gamma_w \quad (2)$$

Where: γ_w is the unit weight of water.

Figures (7 and 8); represent the variation of the coefficient of compressibility and the coefficient of volume change with applying load for different ratios of fiberglass added respectively. The modulus of elasticity are studied also and the results shown in figure (9) beside that the Variation of the Compression index with increasing fiberglass ratio and the vertical stress Damocles found also and presented in figure (10), and in order to study the effect of the fiberglass on the permeability of the soil the coefficient of permeability with increasing fiberglass ratio and the vertical stress loads are shown in figure (11).and finally the effect of increasing fiberglass ratio on the swelling potential and figure (12) show that's results . For all these factors and indexes analysis made by numbers for each fiberglass ratio to find the efficiency of adding and tables from (3 to 7) show that analysis.

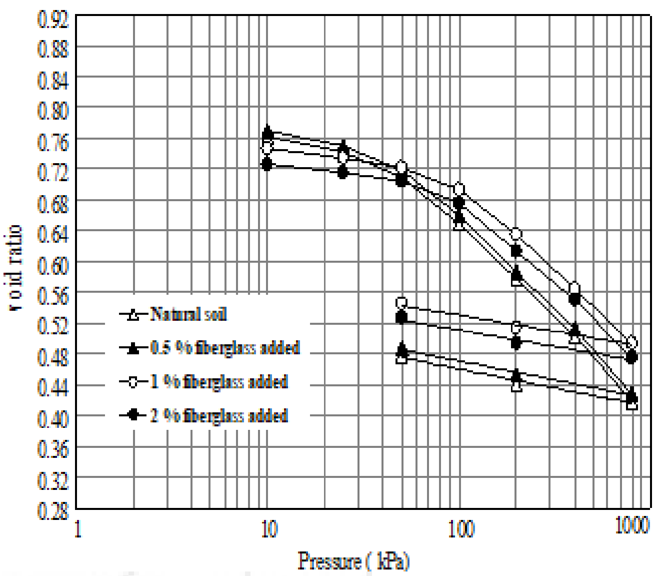

Figure 6: The relation between the applied stress and the void ratio for soils with different mixing ratio of fiberglass.

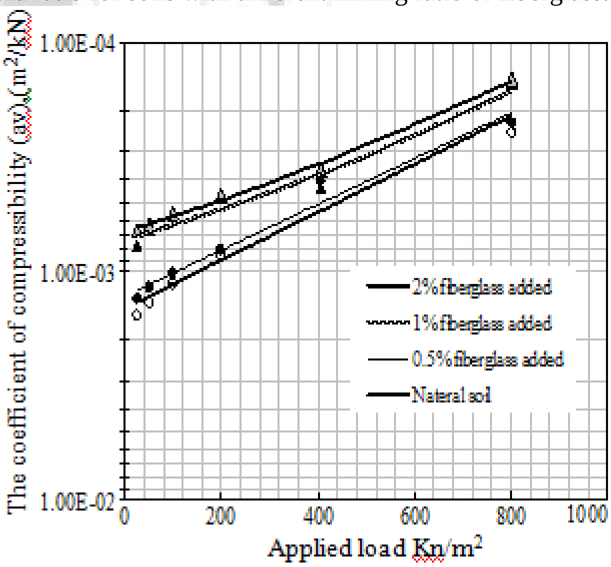

Figure 7: Variation of the coefficient of compressibility with applying load for different ratios of fiberglass added.

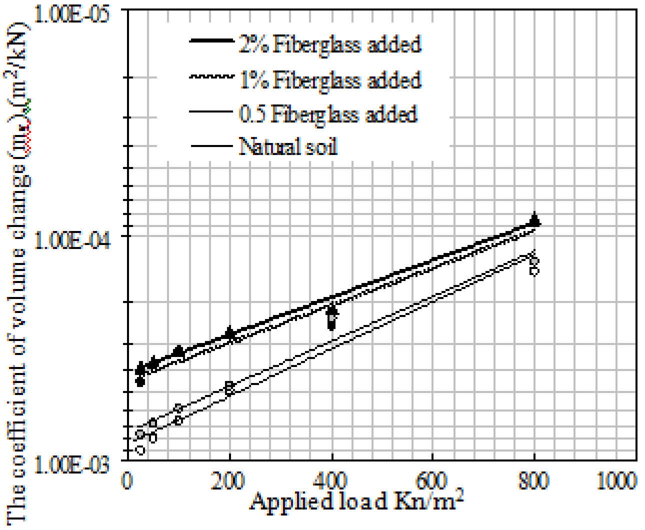

Figure 8: Variation of the coefficient of volume change with applying load for different ratios of fiberglass added.

Table 3: The variation ratio of the coefficient of volume change with applying load for different ratios of fiberglass added.

Applied load kn/m² / Fiberglass Ratio %	variation ratio %						
	25	50	100	200	400	800	average
0.5	-15.66	-14.49	-10.87	-4.93	3.03	-9.21	-8.69
1	-50.23	-52.36	-50.24	-43.86	10.66	-39.19	-37.54
2	-57.45	-54.29	-51.11	-45.42	-8.17	-41.79	-43.04

As shown the increasing fiberglass ratio will reduce the coefficient of volume change, and from the analysis its appear that 0.5 ratio given average reduce of 8.69 % only while (1 % and 2%) give average reduce of (37.59 and 43.04) % respectively, from above adding ratio of 1% fiberglass of maximum dry density give the best reduction value of coefficient of volume change as a comparison made between 1 % and 2 %.

Table 4: The variation ratio of the modulus of elasticity with applying load for different ratios of fiberglass added

Applied load kn/m² / Fiberglass Ratio %	variation ratio %						
	25	50	100	200	400	800	average
0.5	18.6	16.9	12.2	5.2	-2.9	14.3	10.7
1	100.9	109.9	100.9	78.1	-9.6	64.4	74.1
2	135.1	118.8	104.6	83.2	8.9	71.8	87.1

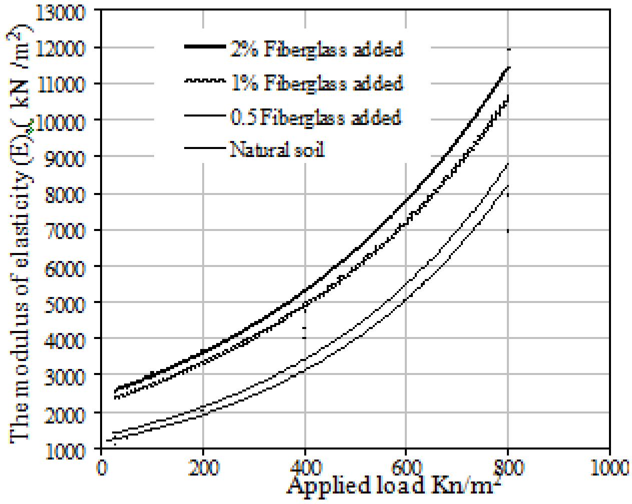

Figure 9: Variation of the modulus of elasticity with applying load for different ratios of fiberglass added.

From figure no. 9 and the analysis showed in table 4 the modulus of elasticity improvement show results similar to that for the coefficient of volume change. So 1% also is the best adding value according to improving modulus of elasticity.

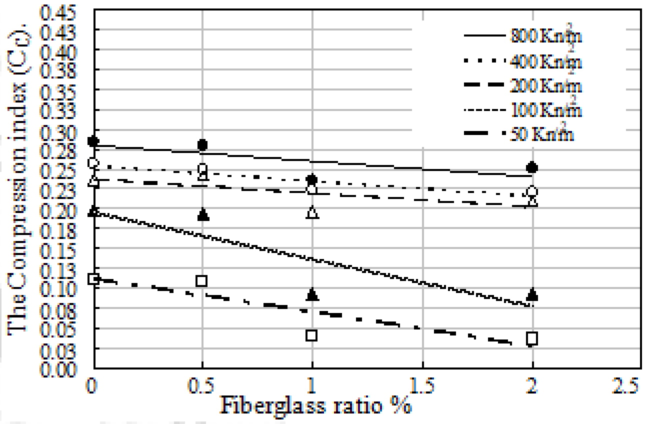

Figure 10: Variation of the Compression index with increasing fiberglass ratio and the vertical stress Damocles.

Table 5: The variation ratio of the Compression index with increasing fiberglass ratio and the vertical stress Damocles.

Applied load kn/m² / Fiberglass Ratio %	variation ratio %						
	25	50	100	200	400	800	average
0.5	2.12	3.09	3.33	-2.23	3.06	1.99	1.89
1	36	64.14	53.33	17.37	13.23	17.17	33.54
2	50	67.16	53.33	11.67	14.39	11.93	34.75

As shown in figure 10 and the analysis in table 5 the increasing fiberglass ratio will increase the compression index, but 0.5 ratio given average increase of 1.89 % only while (1 % and 2%) give average increase of (33.54 and 34.75) % respectively , which meaning 0.5 ratio adding didn't improve the compression index while 1 ratio nearly similar to 2 ratio adding . So, adding ratio of 1% fiberglass of maximum dry density give the best increasing value of compression index.

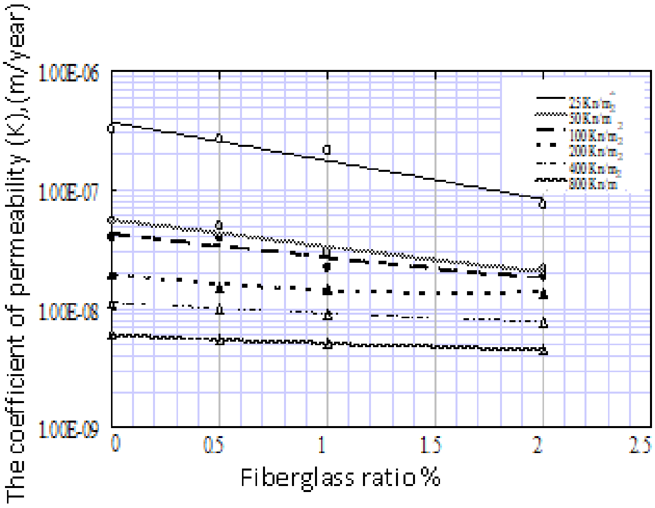

Figure 11: Variation of the coefficient of permeability with increasing fiberglass ratio and the vertical stress Damocles.

Table 6: The variation ratio of the coefficient of permeability with increasing fiberglass ratio and the vertical stress Damocles

Applied load kn/m² / Fiberglass Ratio %	variation ratio %						
	25	50	100	200	400	800	average
0.5	-18.33	-9.34	-0.42	-22.18	-10.38	-8.74	-11.57
1	-35.08	-45.66	-44.09	-24.04	-19.95	-15.04	-30.65
2	-77.05	-60.53	-52.66	-30.2	-31.4	-24.59	-46.07

The variation of the coefficient of permeability and as figure 11 and table 6 show reduction with increasing fiberglass ratio. And one more time the 1% adding of fiberglass is the best adding ratio .also the analysis show that adding fiberglass is less effect with increasing stress applied and the best effect appear with 25 kN/m^2.

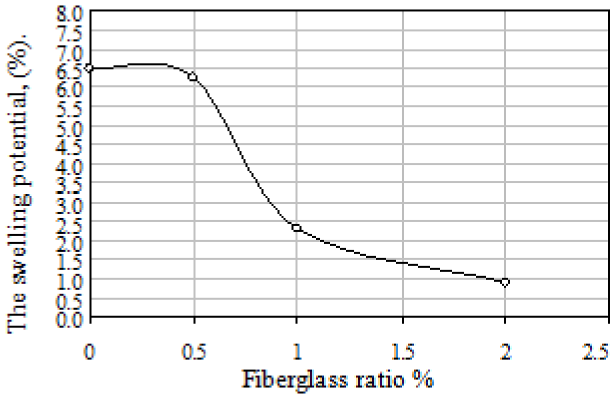

Figure 12: Variation of the swelling potential with increasing fiberglass ratio

The initial swelling potential of the soil could be classify as slightly high according to seed et al., where according to Holtz and Gbbs the soil classify as low expansion ability, this different in classification related to the type of preparing the samples where seed give these limits for disturbed samples and (Holtz and Gbbs) limits for undisturbed samples. So the samples in this research are disturbed so the soil classified as high expansion.

Table 7: The variation ratio of the swelling potential with increasing fiberglass ratio

Fiberglass Ratio %	variation ratio %
0.5	3.75
1	64.42
2	86.32

The effect of adding the fiberglass is shown in figure (12) and the results analysis shown in table 7 from that analysis the same results shown that adding 0.5 ratio show no great different from natural soil and the improvement of adding 1% and 2% didn't show high different from that adding 1% fiberglass ratio is better from 2% if the difficulty of mixing take in mind.

13. Conclusions

1) The fiberglass has a good ability to improve the clayey soil where the swelling potential were reduced by (3.75, 64.42 and 86.32) with adding fiberglass ratio of (0.5, 1 and 2) respectively.
2) The addition of 0.5 % percent did not show a significant change on the clay soil acted as the permeability coefficient decreased by an average rate of (11.57 %).
3) The results adding 1% somewhat close of the results of add 2% where the coefficient of permeability decreased by 30.65 % and 46.07 %, respectively, as an average. The same matter appears for coefficient of compressibility and compressibility index where they reduce by (37.54 % and 33.54 % respectively for adding ratio of 1% from fiberglass) and 43.04 % and 34.75 % respectively for adding ratio of 2% from fiberglass).
4) The improving ratio appears specifically with low loads (less than (100 kn/m^2)), where with high loads the effect of fiberglass become less effective.
5) As a result, the addition of 1% of fiberglass gives a very good result in terms of reduced swelling potential as mention above (decreased by 64.42%), where the coefficient of compressibility , coefficient of permeability and compressibility index reduce by (37.54%,30.64% and 33.54%) respectively as average, while the modulus of elasticity increased by (74.12 %)as average.

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Author Profile

Assistant professor **Maysam Th. Al-Hadidi** received her B. Sc. in civil engineering - University of Baghdad in 1999. She received her M. Sc. degrees in Geotechnical Engineering from the University of Baghdad in 2002. Since 2002 she is a faculty member in University of Baghdad.