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Improving Some Geotechnical Properties of Cohesive Soils by Adding Basalt Fibers and Portland Cement in Basra Governorate - Southern Iraq

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Abstract

A cohesive soils sample was chosen, and soil improvement was completed in three stages. After a series of geotechnical studies, the first stage involved adding 2, 4, 6, and 8% Portland cement to the soil to identify the appropriate proportion for improvement. Experiments have shown that Portland cement with an 8% content is the best. In the second stage, 2, 4, 6, and 8% of basalt fibers with a length of around 1 mm were added to the soil to see how they affected it, and it was discovered that adding the fibers resulted in a significant improvement , , it reached 4269.93 kPa. It was noticed that the values of the internal friction angle increased in the direct shear strength test from 0.4° to 16.5°, and the cohesion increased from 2 kPa to 26.56 kPa. In the consolidation test, it was noticed that the values of the swelling index decreased from 0.027% to 0.005%, the compressive index was 0.38% to 0.05%, and the Pre-Consolidation increased from 65 kPa to 121 kPa, and the absorption percentage decreased from 25.2% to 10.5%.

The process for the third stage is then followed, which entails adding the proportions of 2, 4, 6, and 8%. We proceeded from basalt rock fibers to better soil with the best percentage of Portland cement, which is 8%, to find the best proportion of fibers and to know the progress in specifications. The findings show that adding basalt fibers to Portland cement-treated soils considerably enhanced the categorization and engineering characteristics of the cohesion soils from the study site. After a 28-day treatment period, mixing 8% fibers with 8% cement resulted in a considerable increase in unconfined compressive strength, as well as a large increase in the liquid limit and plasticity limit.

1-Introduction

In many nations around the world, including Iraq, soil improvement is a modern technology. It has been widely employed in engineering disciplines such as foundations, embankments, dams, roads, airstrips, garages, and others to improve many of the geotechnical qualities of soil (Alrobaiee,2008). Some soils in Basra Governorate have low strength and load capacity, posing a threat to the integrity of the structures that will be built on them. The engineering study and economic feasibility are used to determine the best therapy. Physical and chemical procedures can be used to improve soils, and their combination has been widely used in engineering to improve various soils (Bekhiti et al,2019).

One of the approaches for improving various geotechnical qualities of soil is to use natural basalt fibers. The influence of basalt fibers and cement on engineering characteristics has been studied, and it has been discovered that a mixture of fibers and cement with ideal contents can achieve a bigger improvement in the qualities of soils treated with only one stabilizer (Cao et al., 2019). The cement ingredients are responsible for the increased strength because they cause cohesion between soil particles and fill the fine pores. To boost efficiency, waste basalt fibers were employed. , and they are characterized by low cost and environmental protection. Previous studies showed that fibers improve the various engineering properties of soils treated with chemicals (Ndepete and Sert, 2016). Although basalt fibers are widely used in improving concrete, they are used sparingly for soil improvement. Chemical stabilizers have been used to strengthen the soil and reduce the swelling behavior of clay soils. . Basalt fibers are added to the soil randomly to improve its engineering properties such as the unconfined compressive strength (Gao et al., 2015).

This study aims to improve some geotechnical properties of cohesive soil samples selected from the study site by using a mixture of Portland cement and basalt rock fibers, which are wastes resulting from the remnants of Iraqi mining factories in Baghdad, Figure 1, and investing them to improve the soil instead of the environmental problems that it causes in the surrounding areas, and to identify the optimum Portland cement and basalt fibers mixing ratios to determine.

Fig.1. Waste basalt fibers from the General Company for Mining Industries in Baghdad

2-Materials and Methods

This study includes conducting some geotechnical tests on a model of selected cohesive soils from the Al-Ribat Al-Kabeer area in Basra city as shown in Figure 2. The pickled model was taken from a depth of 60 cm, weighing 50 kg, and some geotechnical tests were conducted on it, namely Atterberg limits, unconfined compressive strength , direct shear strength, consolidation and absorption ratio. Then soil samples were mixed with proportions of 2, 4, 6 and 8% of Portland cement, and some geotechnical tests mentioned above were conducted on the models to determine the best percentage for improvement . Other soil samples were mixed with proportions of 2, 4, 6, and 8% of basalt fibers after crushing them down to a length of about 1 mm (through a sieve of 1.18 mm) and the same tests

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were conducted on them to determine the effect of the fibers in improving the soil, then other soil samples were mixed with 8% of cement and 2, 4, 6, and 8% of basalt fibers to determine the best proportion. Basalt fibers are a type of inorganic fiber that is formed from molten basalt rocks and is inert. The chemical analysis of basalt fibers, as well as the proportions of their constituents, are shown in Table 1. It was chosen as a soil addition to help strengthen poor soils. The following geotechnical examinations were carried out in order to complete this study.

Grain Size Analysis: On cohesive soils, two types of analyses were performed. The sieve test, which is used to categorize sandy and gravelly soils, was the first. A hydrometer was used to calculate the percentage of silt and clay in the second type. The test was carried out according to American standards in a construction laboratory in Basra (ASTM D-421, D-422).

Moisture Content: Tested under American standard (ASTM D2216-05). The examination was conducted in the laboratories of the Department of Geology - University of Basra.

a- **Chemical Tests:** It includes checking the organic content, Sulphate content, total soluble salts and gypsum content. The tests were carried out in the construction Al- Amar laboratory. According to British standard(BS. 1377: 1990).

b- **Atterberg Limits:** A sample of cohesive soil free of selected additives was taken from the study site. After the sample was dried at a temperature of 105°C for 24 hours, it was passed through a sieve No. 40 with openings of 0.425 mm, and in the same way, the tests were conducted on the samples treated with cement, basalt fibers and the mixture according to the American standard (ASTM D-4318) in the construction Al- Amar Laboratory.

c- **Unconfined Compression Strength:** Several re-molded cylindrical samples have been made. The diameter is 3.8 cm and the height is 7.6 cm. Two samples of cohesive soil were prepared without additives to test unconfined compressive strength, and 16 samples of cohesive soils were treated with cement to test strength after 1, 7, 14, and 28 days of maturation, After a maturation time of 1 and 7 days to allow the basalt fibers to fill in the soil particles, 8 samples of basalt fibers were evaluated for strength, and the optimum % of cement was identified. which is 8%, was mixed with various percentages of fibers to create 16 samples, which were then tested for strength and left for 1, 7, 14, and 28 days of treatment. The test was carried out in the Al- Amar Laboratory in accordance with the American standard (ASTM D-2166)..

d- **Direct Shear Strength Test:** Samples free of additives for cohesive soils were prepared and direct shear strength was tested with dimensions of 6 x 6 cm. Then four samples were prepared for the cohesive soil sample treated with cement at rates of 2, 4, 6 and 8% and four other samples installed with basalt fibers at rates of 2, 4, 6 and 8% and then prepared, four samples of treated soil were with the optimum amount of cement with the different percentages of fibers mentioned previously. The examination was conducted in the construction Al- Amar Laboratory according to the American standard (ASTM D-3080).

e- **Consolidation Test:** prepared remolded sample of natural soil free of additives in a cylindrical mold of 7.5 cm in diameter and 2 cm in height, then prepared four remodels sample were after adding weight percentages of cement, which are 2, 4, 6 and 8% and four others after adding by weight percentages of basalt fibers, which are 2, 4, 6 and 8% The remaining four models were prepared to

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mix the optimum proportion of cement with the previously mentioned different proportions of fibers. The test was carried out according to the American standard (ASTM D-2435) in the construction Al-Amar Laboratory.

f- **Rapid Absorption Test:** Five cylindrical samples of cohesive soil with dimensions of 15 x 7.5 cm were prepared by the method of preparing the samples in the examination of the California tolerance ratio according to the American Standard (ASTM D-1883), one of these samples was prepared from cohesive soil free of additives and was tested for rapid absorption. As for the other four samples, they were prepared by adding the optimum percentage of Portland cement 8%, which was determined from the previous tests, with four weight ratios of basalt fibers, 2, 4, 6, 8%, and a rapid absorption test was conducted on them in the laboratories of the Department of geology - University of Basra according to the British Standard (BS. 1377: 1975).

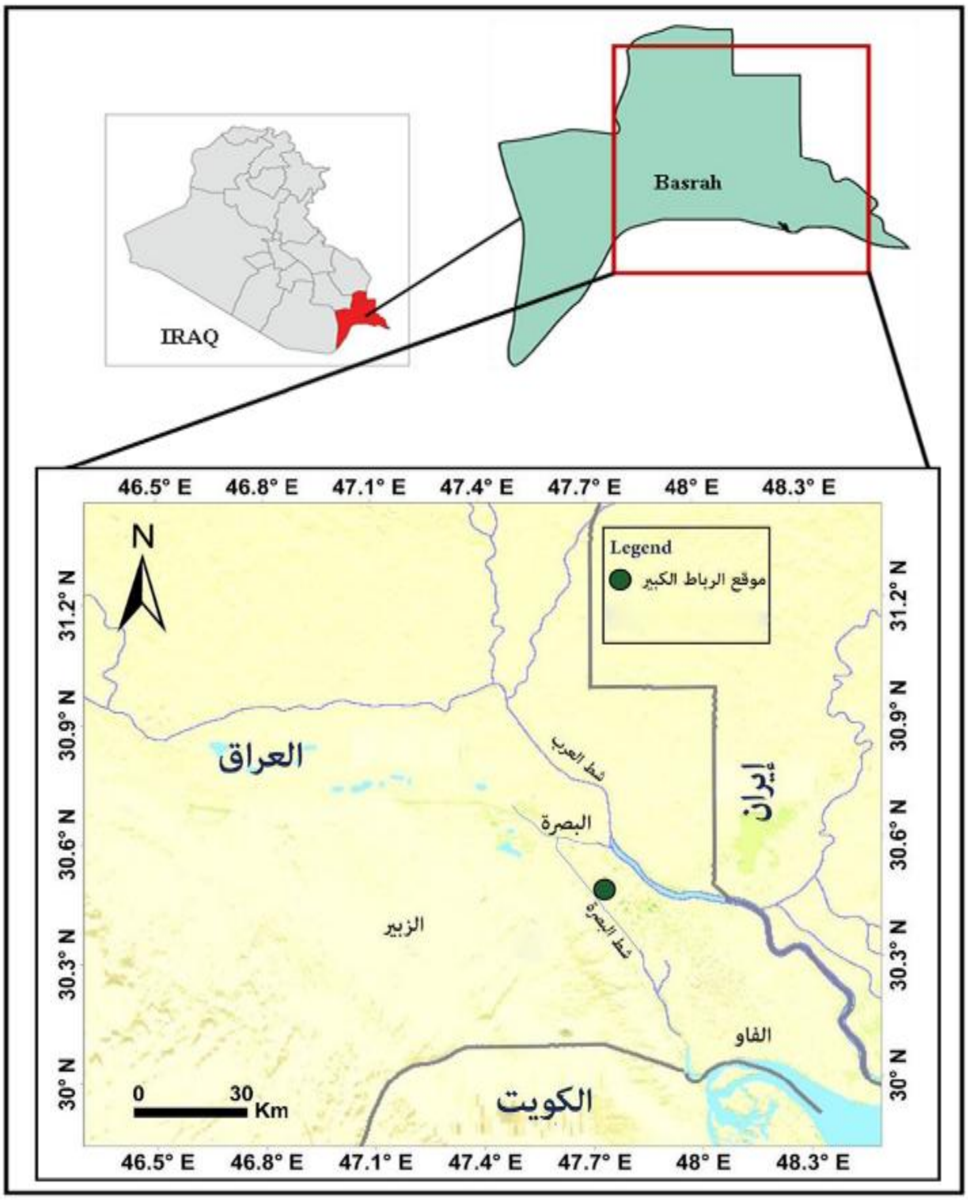

Fig.2. The location of the study area

Table 1 Percentages of basalt fiber components

Chemical components	Percentage %
SiO_2	43.54%
Al_2O_3	15.01%
Fe_2O_3	10.82%
CaO	11.82%
MgO	4.51%
Na_2O	4.6%
TiO_2	4.9%
K_2O	4.8%

3- Result

3-1 Grain Size Analysis

The results of the grain size analysis of the studied cohesion soil sample show that the proportion of clay is 60%, silt is 29%, and sand is 11%. As shown in Table 2, the soil is described as Silty clay with a little sand.

3-2 Moisture Content

The results of the examination showed that the percentage of the moisture content of the study site sample is 27.9%, which is a rather high percentage, the reason is due to near of the area to the Shatt al-Basra and the high level of groundwater in it, which is 50 cm in the study area, which affects the loading capacity of the surface layers of the soil. The high percentage of clay leads to the absorption and retention of a large proportion of water, and this affects the geotechnical properties of the soil, including swelling and reduces the shear strength (Scott, 1968).

3-3Chemical Tests

Some chemical tests were carried out on the cohesive soil selected from the study area and the results were as shown in Table 2.

3-3-1 Organic Content

The results show that the percentage of organic matter is 1.13%. This ratio is relatively influential in the engineering behavior of the soil.

3-3-2 Sulphate Content (SO_4)

The results show that the percentage of Sulphate in the cohesive soil sample is 0.68%, noting that the recommended upper limit for the presence of sulfate in the cohesive soil is 4% according to the conditions of the Iraqi specification for roads and bridges 1999 and its 2003 amendments. The reason for the presence of this percentage of sulphate is due to the presence of sulphate-rich groundwater in addition to its near to the Basra Shatt which contains it.

3-3-3 Total Soluble Salts The results showed that the percentage of soluble salts is 1.20%. The reason for the existence of this percentage of salts is the existence of relatively saline groundwater in the region, which show at a depth of less than 0.5 meters.

3-3-4 gypsum content

The results showed that the gypsum content is 4.35%, which is considered a somewhat influential percentage in the engineering behavior of the soil. The reason for the existence of this percentage is due to the rise in the level of the groundwater by capillary action, and then the evaporation of water near the surface, which leads to the accumulation of gypsum on the layers near the surface.

Table 2 Characteristics of the soil cohesion sample in the study area

Grain Size Analysis(%)	**Clay**	**Silt**	**Sand**	**Moisture Content (%)**
	60	29	11	27.9
Chemical Material Ratio(%)	**ORG**	**SO_4**	**Gypsum**	**T.S.S**
	1.13	0.68	4.35	1.20

3-4 Atterberg Limits

The limits of liquid and plasticity were tested out on natural cohesive soils. It was found that the limit of liquid is 46% and the limit of plasticity is 22%, according to the plasticity chart as in Fig. 3, the natural soil was classified as clay soil of low plasticity (CL). With the increase of cement ratios, it was noticed that the liquid limit and the plasticity index decreased, and the plasticity limit increased, as shown in Fig.4. The soil installed with the best percentage of additives was classified as clay and of low plasticity.

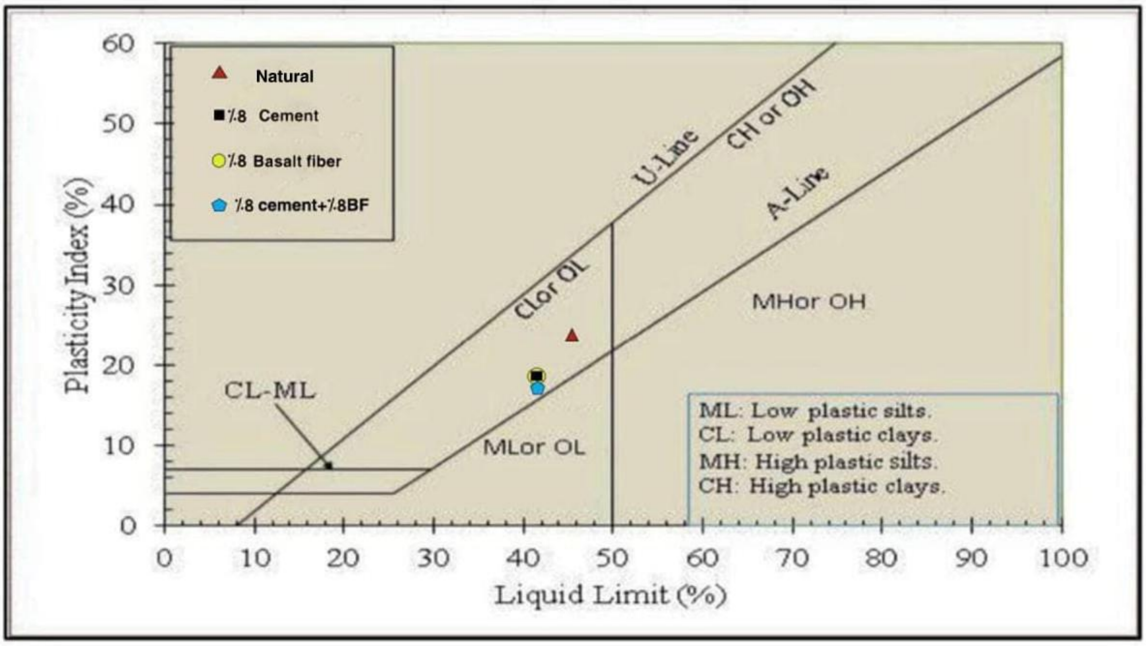

Fig.3. The values of the liquid limit and plasticity index for natural soil and after adding the best proportions of the additives, which is 8% in the plasticity chart

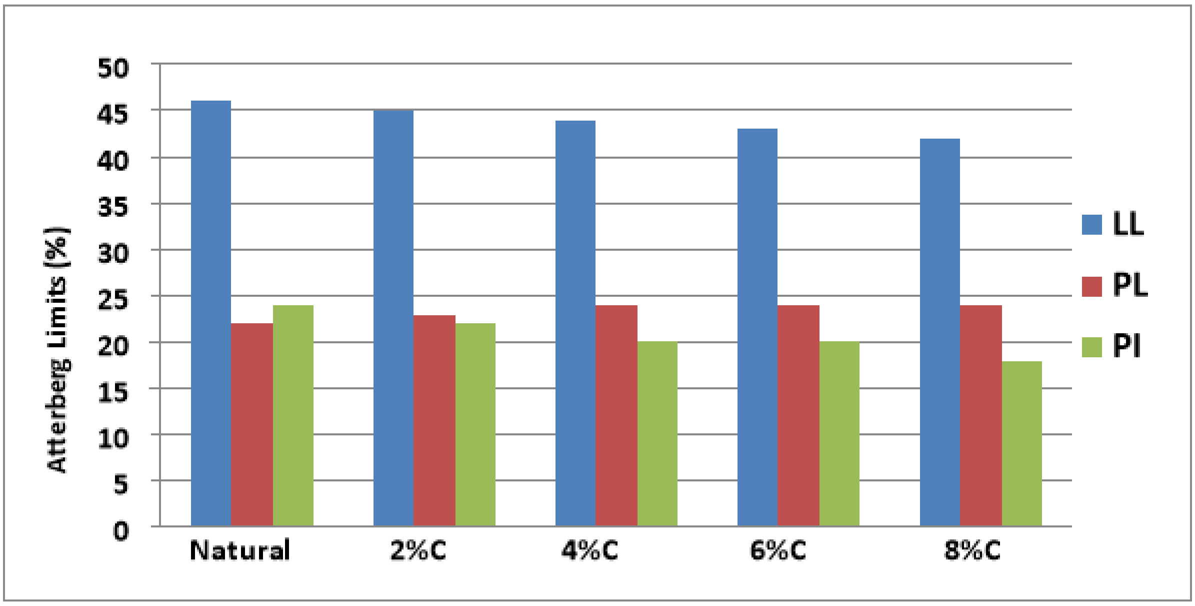

Fig.4. The values of the liquid and plasticity limits and plasticity index before and after cement addition

It was observed from Fig.5 that the basalt fibers behaved like cement, but with less effect on Atterberg limits in the soil, but when mixed with the best percentage of cement, which is 8%, the effect of Atterberg limits showed greater than when adding improvement materials alone to the soil as shown in Fig. 6. The reason is that the fibers work to form connecting bridges between the soil particles, and the addition of cement worked to increase the bonding between the basalt fibers through the interaction of the fiber components with the cement.

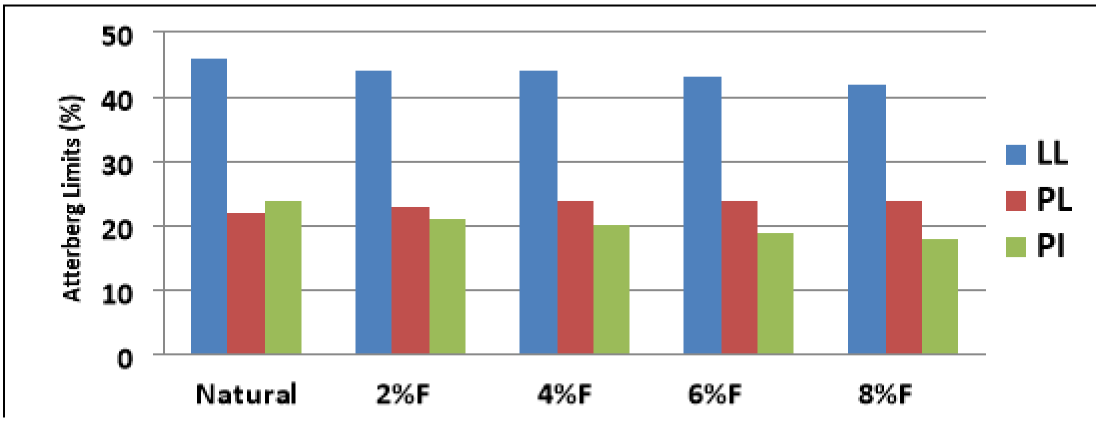

Fig.5. The values of the liquid and plasticity limits and plasticity index before and after addition of basalt fibers

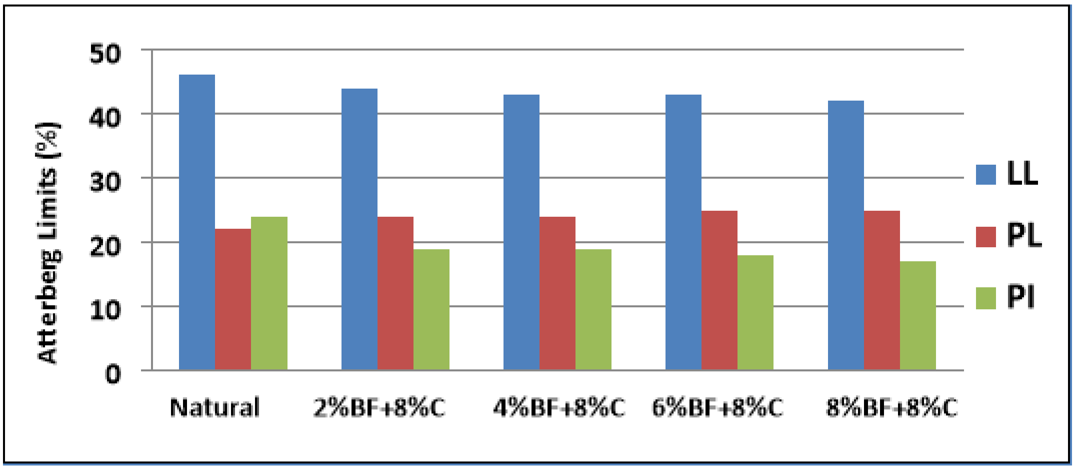

Fig.6. The values of the liquid and plasticity limits and plasticity index before and after adding improvement materials

3-5 Unconfined Compression Strength

The unconfined compressive strength test was carried out on a remodeled sample of natural cohesive soil, and the results showed that the strength of the natural soil is 4.40 kPa. The results of the cohesive soil sample treated with additives showed that there was an increase in the unconfined compressive strength with the increase in the percentages of additives and processing time. It is noted in Fig.7 that the strength increases when adding the cement ratios 2, 4, 6 and 8% with the curing time of 1, 7, 14 and 28 days, and the best percentage that achieved the highest strength after a treatment period of 28 days is 8% of the cement and its value is 3630.14 kPa.

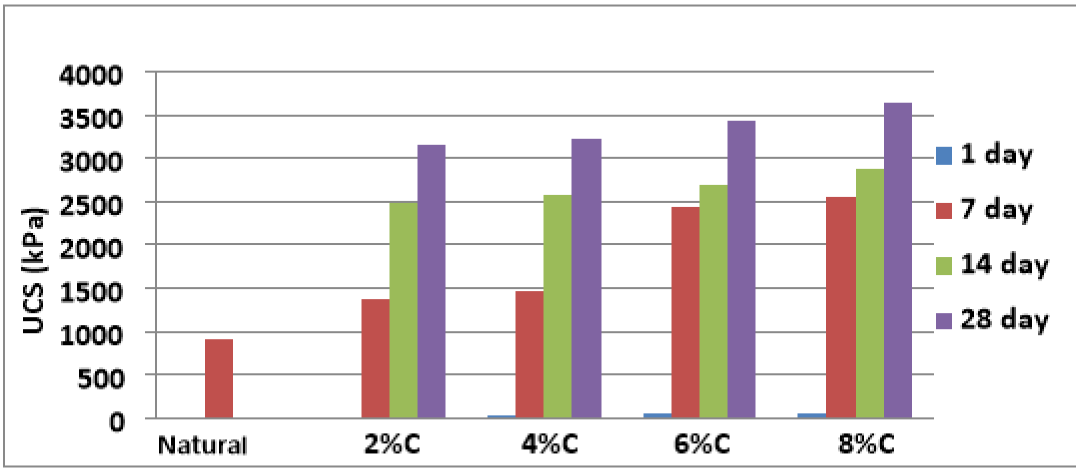

Fig.7. Unconfined compressive strength values before and after adding Portland cement

In Fig.8, when adding the different percentages of basalt rock fibers, which are 2, 4, 6 and 8%, it is noticed that the strength increases with the increase in the percentages and the processing time of 1.7 days, so that the basalt fibers take their time to fill between the soil particles and bridges are built to connect them.

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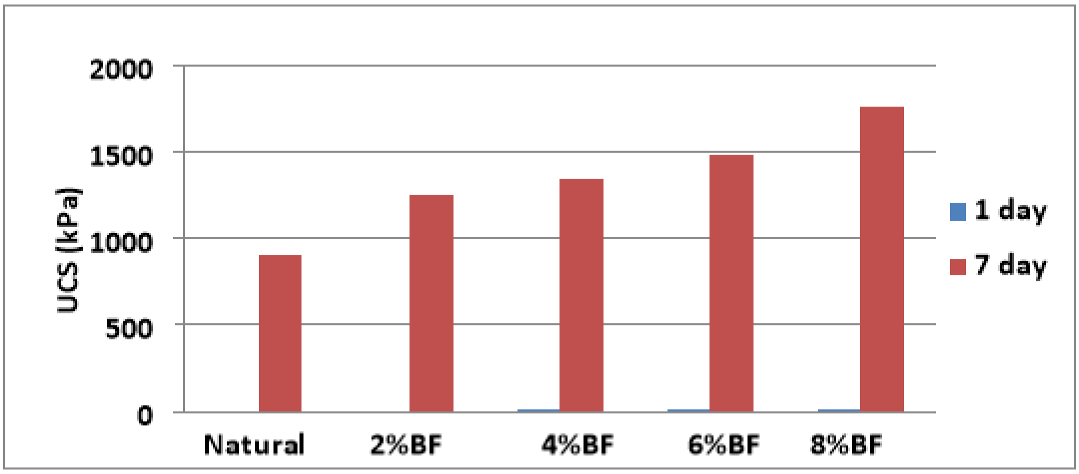

Fig.8. Unconfined compressive strength values before and after adding basalt fibers

In Fig.9., it was observed from the results that the resistance values increased more than when using the additives alone, especially after the 28-day treatment period, where the strength value at 8% C + 8%BF reached 4269.93 kPa.

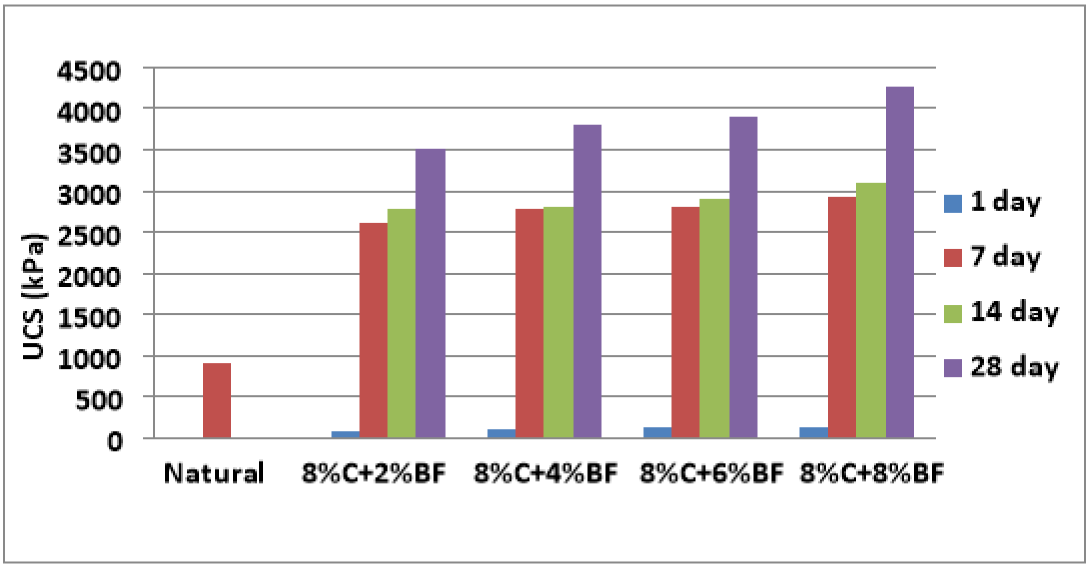

Fig 9. Unconfined compressive strength values before and after adding improvement materials

3-6 Direct Shear Strength Test

The results show that the value of the internal friction angle for natural soil is 2.3° and the cohesion value is 0.02 kPa. While the value of the internal friction angle and the value of the cohesion of the soil treated with additives increase with the increase in the content of the additives. From Fig.10, we notice that the internal friction angle increases with the increase in the proportion of additives. For Portland cement, it gave the highest value of the friction angle at 8%, which is 5.9 degrees. We also notice that the angle values increased with the increase in the proportions of basalt fiber additives. Then these different percentages of fibers were mixed with the highest percentage of cement, which gave the best value to achieve the best percentage of the mixture and was at 8% C + 8% BF and its value was 16.5˚. The reason for this is the interaction of randomly distributed basalt fibers with Portland cement settled in soil particles with each other.

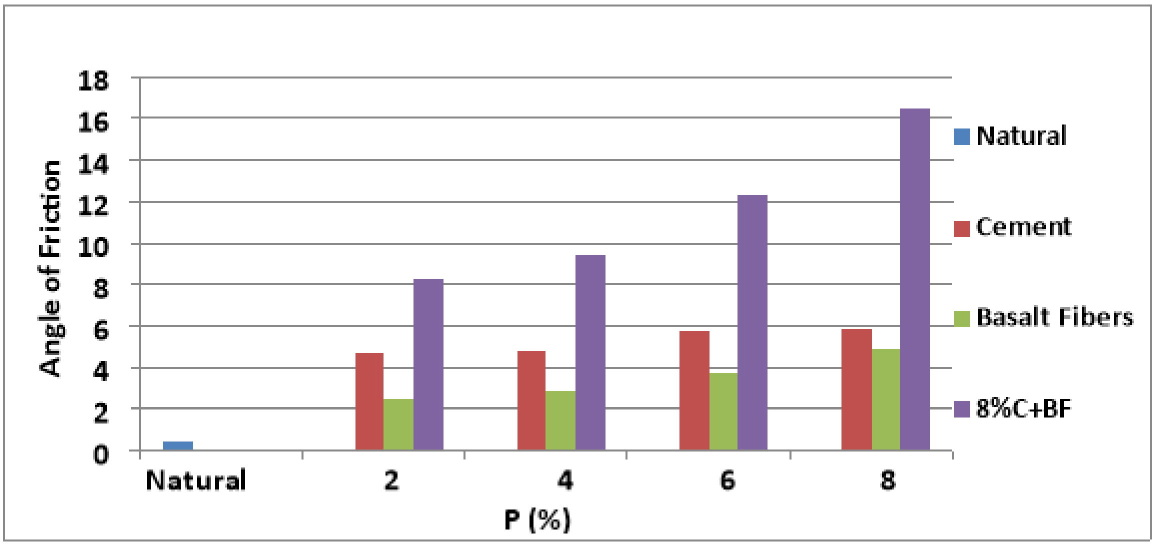

Fig.10. Values of the internal friction angle before and after adding the improvement materials in different proportions

It was noticed that the cohesion value increased with the increase in the percentage of additives. For cement, it gave the highest value for it at 8% content, which is 16.22 kPa . As well as for basalt fibers, it was observed that there was an improvement with the increase in the proportions of fibers, they were mixed with the highest value of cement as mentioned previously. The results of the mixture showed a clear improvement in the cohesion values and the highest cohesion obtained by the cohesive soil at C + 8% BF8%, which is 26.56 kPa, as shown in Fig.11.

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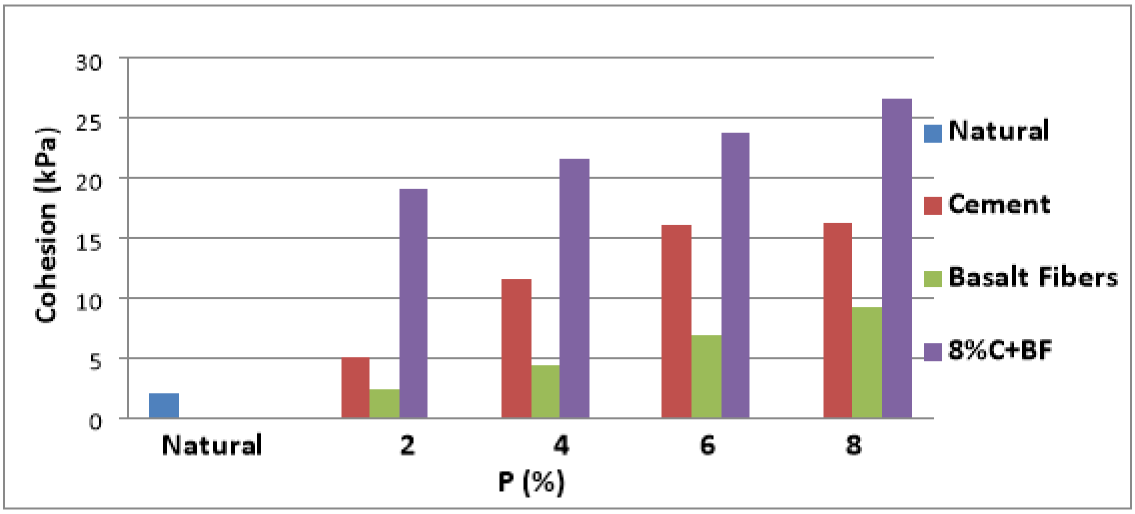

Fig.11. Cohesion values before and after adding the improvement materials in different proportions

3-7 Consolidation Test

The results of the consolidation test of natural soils show that the value of the compression index (Cc) is 0.38% and the value of the Swelling Index (Cr) is 0.027%, while the value of the Pre-Consolidation (Pc) is 65 kPa. It was noted that after adding Portland cement to the cohesive soil selected from the study area, there is an improvement in the consolidation coefficients. The compressive index (Cc) and swelling index (Cr) decreased, while the Pre-Consolidation increased with the increase of the ratios and it gave the best improvement value at 8% of cement. It was also noted that there was a clear improvement in the consolidation coefficients when adding basalt fibers and their different proportions to the cohesive soil, so it behaved like cement, but with less improvement than it is in cement. The fibers were mixed in different proportions, which are 2, 4, 6 and 8%, with the best percentage of cement, which is 8%. The results of the mixture showed a better improvement than it is when adding the improvement materials separately, as shown in Fig. 12, 13 and 14, respectively.

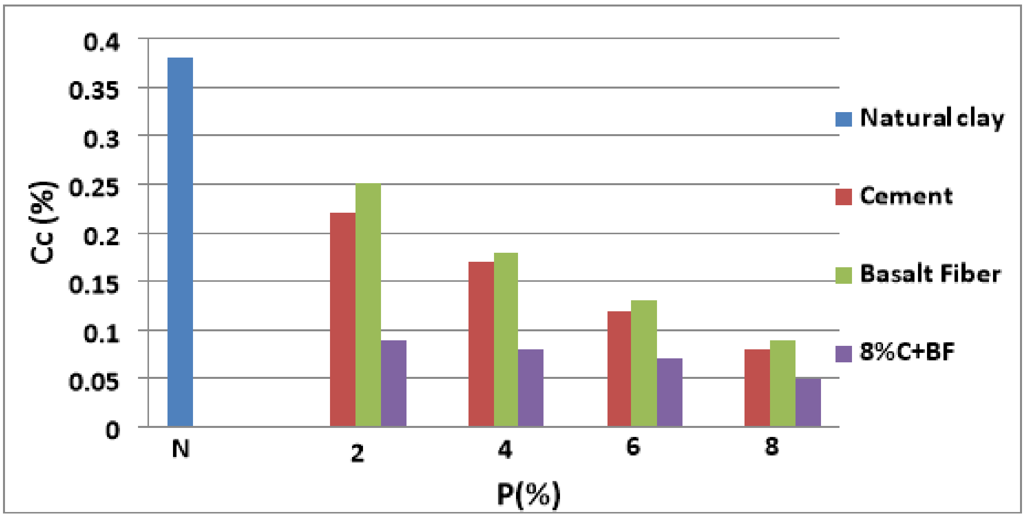

Fig.12. compression index(C_c) values of cohesive soil before and after adding the improvement materials

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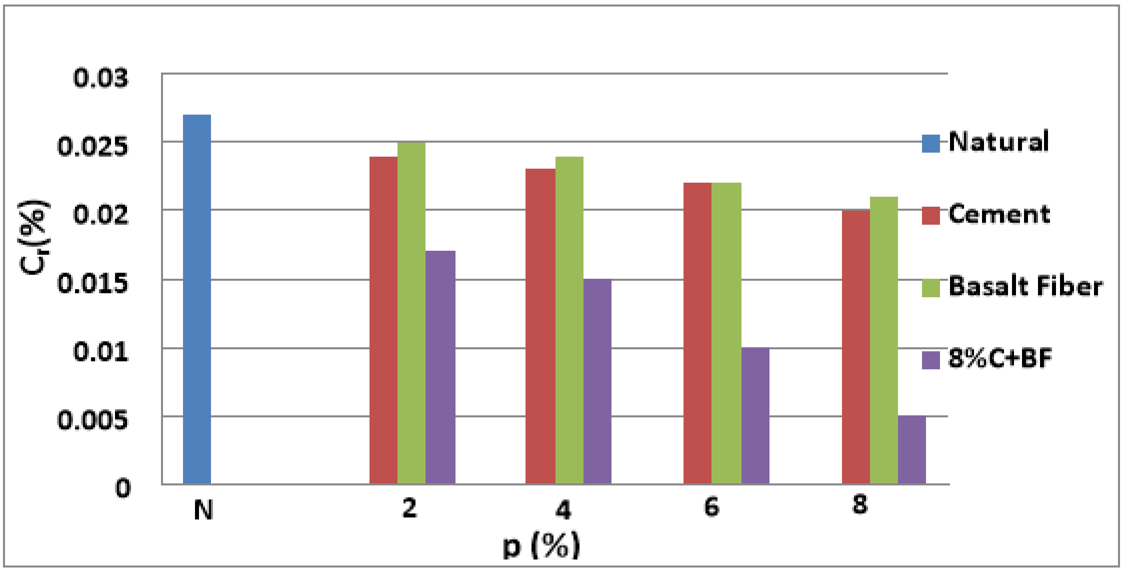

Fig.13. Swelling Index (C_r) values for cohesive soil before and after adding the improvement materials

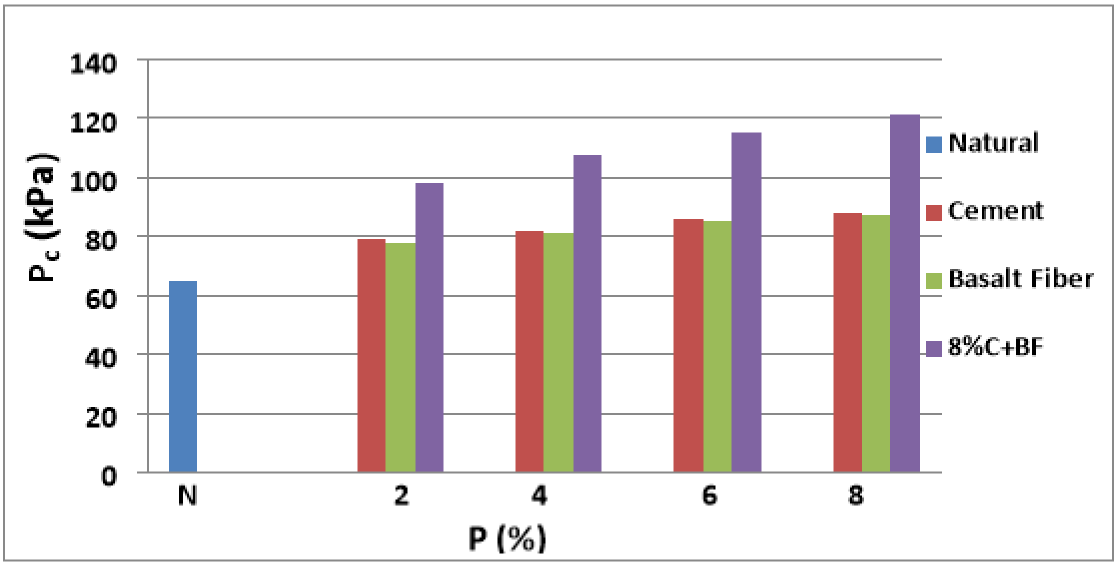

Fig.14. Pre-Consolidation (P_c) values for cohesive soil before and after adding the improvement materials

3-8 Rapid Absorption Test

A rapid absorption test was conducted on the natural cohesive soil, and it was noted that its absorption rate is 25.2%. The best percentage of Portland cement was selected based on the previous tests, which is 8%, and it was mixed with different percentages of basalt fibers, which are 2, 4, 6 and 8%. The results showed that there was a decrease in the absorption rate when the cement was fixed by 8% and the fiber percentages increased, as shown in Fig. 15.

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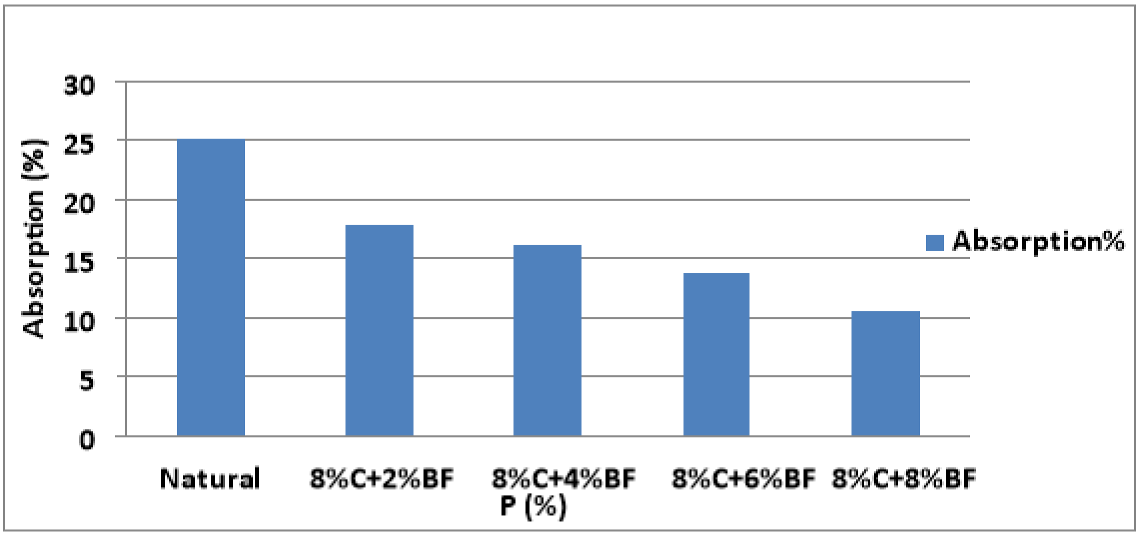

Fig.15. values of the rapid absorption before and after adding the improvement materials

The reason for the decrease in the absorption rate is due to the fact that the cement and basalt fibers acted as a binder that filled the pores of the soil, thus reducing the permeability of the soil.

4- Discussion

Discussion of the cohesiveness soil test results' reaction mechanism:

1- During the reaction of double and triple calcium silicates in cement with water in cohesive soils, it generates a group of calcium silicate hydrates with calcium hydroxide, which reacts with the silica in the 11 percent sand content. Which is capable of gaining strength over time? (Maruyama et al., 2007).The addition of basalt fibers to the soil works to form connecting bridges between soil particles by a process known as bridging, where the higher the percentage of basalt fibers, the greater the process of forming larger bridges (Elshafie and Whittleston, 2015).

2- 2- The interaction of the silica present in the composition of the basalt fibers, which is about 43 percent, with dissolved calcium hydroxide Ca $(OH)_2$ with the cohesive soil water improves the chemical reaction and bonds the soil particles more. Also, the alumina Al2O3 present in the composition of the fibers, which is about 15.01 percent, reacts with calcium hydroxide dissolved in the soil to form a gritty substance..

5-Conclusions

The following conclusions can be taken from the investigation of the soil's geotechnical properties:

The study area's selected cohesive soils are classified as low plasticity (CL) clay soils. The mechanical behavior of cement-stable soils improved significantly as the proportions of basalt fibers increased, and the values of the liquid limit and the plasticity index gradually decreased as the proportions of additives in cohesive soils increased and the plasticity limit increased, indicating the occurrence of improvement. The unconfined compressive strength was also shown to rise.

As well as an increase in internal friction and cohesion angles. With increasing proportions of different additives, the compressive index (C_C) and swilling index (C_r) drop, and the Pre-

Consolidation (P_c) steadily increases, as well as the high rate of absorption with increasing proportions of basalt fibers for cohesive soil treated with 8% cement.

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