Effect of Granite Powder and Polypropylene Fiber on Geotechnical Properties of Expansive Soil

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Abstract - *Expansive soil shows dual swell-shrink under changing water content which is not suitable for construction. This soil is found in several places in Egypt, so it must be treated. In this paper, it was studied one of the methods of treating expansive soil, which was using of polypropylene fiber and granite powder to stabilize the expansive soil. In the investigation, the soil was taken from the 5th Settlement in Cairo, Egypt, and mixed with percentages of granite powder (1.5%, 3%, 6%, 9%, 20%,30%, and 40% by weight of soil) and polypropylene fiber (0.25%, 0.5%, 0.75%, and 1% by weight of soil). Specific gravity, Atterberg's limits, free swell, and compaction tests were applied to natural soil and soil treated with percentages of granite powder. Through tests, it was found that the optimum percentage of granite powder was 30%, so this proportion was mixed with percentages of polypropylene fiber. Then the direct shear and consolidation tests were conducted on these proportions. The direct shear samples were carried out immediately, with 14 and 28 days of curing. The results show the addition of 30% granite powder reduced the free swell index from 120% to 62%, reduced moisture content from 14.8% to 11.5%, increased maximum dry density from 17 KN/m^3 to 19.3 KN/m^3, increased the cohesion from 0.46 Kg/cm^2 to 0.72 Kg/cm^2 and increased the angle of internal friction from 15.38° to 24.23°. These results also indicated that polypropylene fiber with granite powder did not have an effective effect on the expansive soil.*

Key Words: Expansive soil, Granite powder, Polypropylene fiber, Cohesion & angle of internal friction.

1.INTRODUCTION

Expansive soils occur in climatic zones characterized by alternate wet and dry seasons. The expansive soils experience periodic swelling and shrinkage during the alternate wet and dry seasons. The montmorillonite clay mineral contributes mainly to this behavior. Such cyclic swell-shrink movements of the ground cause considerable damage to the structures found on them **[1]**. In the United States, damage caused by expansive clays exceeds the combined average annual damage from floods, hurricanes, and earthquakes **[2]**. So, it is important to study the properties of these soils and how to treat them to overcome these problems. Stabilization of soils can be done in two main ways, chemical, and mechanical techniques. Chemical techniques like using lime, cement, and granite. The mechanical approach such as polypropylene fiber and nylon **[3]**. Several researchers studied the effect of polypropylene fiber only on expansive soil, using polypropylene fiber was an effective method in reducing the swell potential and swelling pressure of soils **[2,4]**. Also, this research reported that the optimum percentage of (PPF) is 2% for stabilizing the soil, with 2% fiber given the highest from (UCS) and a lower value of swelling **[3]**. The addition of varying aspect ratios of fibers increases the optimum moisture content and decreases the maximum dry density, also increasing the value of cohesion and decreasing in value of the angle of internal friction **[5]**. Other studies that mixed polypropylene with materials, such as **[6]**; investigated the effect of polypropylene fiber and silica fume. The inclusion of silica fume and PPF reduces the plastic index and liquid limit of the soil and increases the plastic limit, the soil changed its classification from high-plastic clays (CH) to low-plastic clays (OH). **[7]**; reported that the effect of using rice husk ash, lime, and polypropylene fibers in expansive soil. The addition of RHA-lime increases the strength. As the pozzolanic reactions are time-dependent, the soil gains strength with an increased curing period. The addition of fibers to RHA-lime stabilized expansive soil mixes, increases the strength. **[8]**; studied using brick powder and PPF to improve the soil. The optimum quantity of brick powder and PPF was found to be 40% and 0.35% for 60% soil. these proportions increased the CBR values.**[9]**; showed the effectiveness of a collection of marble dust, cement kiln, and PPF to increase the unconfined compressive strength. **[10]**; the study found that coir fiber and Nano silica influence the strength, permeability, and swelling potential.

Recently, granite powder has been used as a soil stabilizer, **[11]**; studied the effect of granite dust and lime on black cotton soil. The result showed the CBR value increased, the optimum moisture content reduced and the maximum dry density increased. **[12]**; addition of the fine silica sand and granite powder waste change the swelling potential of expansive soils sample which classified as a high swelling potentially soil to low expansive soils. Here, in this project, soil stabilization has been done with the help of admixtures of polypropylene fibers as a mechanical reinforcement and granite powder as a chemical stabilization.

2. MATERIALS

2.1 Expansive Soil

The Expansive soil used in the experimental work was obtained from the 5th Settlement in Cairo, Egypt. The soil was black to dark gray and highly clayey. It was collected at a depth of one meter below the natural ground surface. Before being used in this investigation, the soil was dried in an oven, pulverized, and then passed through 40 sieve size. The hydrometer analysis curve is shown in Fig.1 which was performed on the natural soil passing through the 75μ sieve. Table 1 summarizes the physical properties that were evaluated as a part of this research. Depending on the gradation and Atterberg's limits values, the soil was classified as CH as per the USCS classification method.

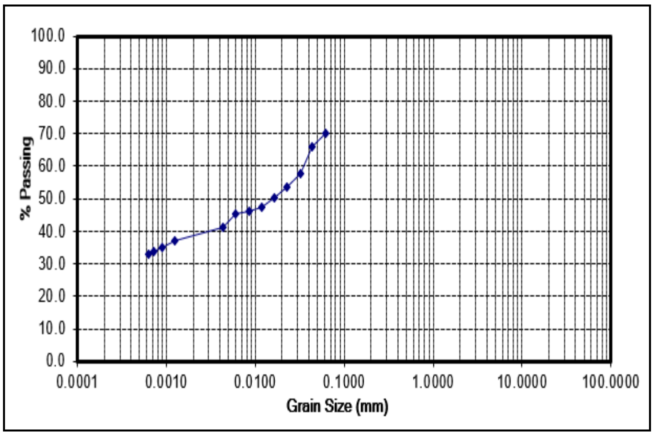

Fig- 1: Hydrometer Analysis for Natural Soil

Table -1: Summary of Physical Properties of Soil Used

Properties	Value	Properties	Value
Specific Gravity	2.54	Liquid Limit (%)	81.70
Water Content WC%	8.66	Plastic Limit (%)	31.68
Void Ratio(e0)	0.9	Shrinkage Limit (%)	20.60
Gravel (%)	0	Activity = PI/Clay (%)	1.31
Sand (%)	26.62	USCS Classification	CH
Passing percentage % (Sieve No,200)	73.38	Max-dry Density (KN/m^3)	17
Clay (%)	38.12	OMC (%)	14.80
Silt (%)	35.26	Free swell index	120

2.2 Polypropylene Fiber (PPF)

Polypropylene fiber has been used in the present study because they have several advantages, such as high strength, low cost, non-corrosive, chemically inert nature, and availability in various lengths. Polypropylene fiber doesn't allow any reaction with soil moisture. The polypropylene fiber was purchased from Sika company as shown in Fig. 2. The physical, chemical, and mechanical properties of PPF are illustrated in Table 2 below.

Fig- 2: Polypropylene Fibers

Table -2: Properties of Polypropylene Fiber

Properties	Values	Properties	Values
Fiber length	18 mm	Melting point	160 ºC
Diameter	0.018 mm	Ignition point	365 ºC
Density	0.91 gm/cm^3	Thermal conductivity	Low
Tensile strength	300–400 [N/mm^2]	Electrical conductivity	Low
Elongation	> 80%	Acid resistance	High
Absorption	Nil	Alkali resistance	100%

2.3 Granite Powder (GP)

Locally available granite cutting powder was used. Granite powder was obtained from the Shaq Al-Thouban district in South Cairo, Egypt. The granite powder was dried in an oven at 105°C for 24 hours to remove moisture, then pulverized repeatedly with a plastic hammer to remove any agglomeration as shown in Fig. 3. The important characteristic of granite powder as an additive material is the percentage passing through the No. 40 sieve.

Fig- 3: Granite Powder

3. METHODOLOGY

The experimental program was to use small granite powder proportions (1.5%, 3%, 6%, and 9%) by dry weight of soil, but after the granite powder proportions were tested on the basic soil properties tests. A slight improvement was observed for the soil, starting with the ratio of 9% of granite powder. So, the experimental program was modified suggested by **(Manal and Abdulrazzaq) [12]**, and **(Hassan and Abdelaal) [13]**. The proportions of the used granite powder were increased to (20%, 30%, and 40%). According to **(Nitin and Neelima) [6]**, the polypropylene fiber proportions were (0.25%, 0.5%, 0.75%, and 1%).

The experimental study had two phases. First, specific gravity tests, Atterberg's limits tests, free swell tests, and compaction tests were applied to natural soil and soil treated with granite powder.

Second, the optimum proportion of granite powder and different proportions of polypropylene fibers was used on the direct shear box test and the one-dimensional compression test. The direct Shear box samples were carried out immediately, with 14, and, 28 days of curing period. All tests were carried out according to ASTM and the Egyptian code of soil mechanics in the laboratory of Al-Azhar University Cairo, Egypt.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Effect of Granite Powder on Atterberg's Limits

The Liquid limit, Plastic limit, and Shrinkage limit were carried out for the natural soil and soil treated with granite powder. The relationship between the plasticity index and the swell behaviour has been identified by several researchers; in this study, the relationship suggested by **(O'Neil and Poormaayed) [14]** was used as shown in Table 3.

Table -3: Relationships Between Plasticity Index (PI) and Swell Potential

Swelling Potential	Plasticity Index	Liquid Limit
Low	<25	<50
Medium	25-35	50-60
High	>35	>60

When the proportions of granite powder were added from 0% to 9%, the plasticity index, the liquid limit, and the plastic limit decreased slightly. Then, when adding higher percentages of granite powder (20%, 30%, and 40%), the plasticity index, the liquid limit, and the plastic limit decreased to 25.9%, 48.5%, and 22.6%, respectively as illustrated in Table 4.

Table -4: Properties of Soil Samples Treated with Granite Powder

Additive (GP)%	Gs	LL (%)	PL (%)	PI (%)	Change in L.L (%)	Change in P.L (%)	Change in P.I (%)	O'Neil and Poormaayed class.
Control (0%)	2.54	81.7	31.6	50.1	-	-	-	High
1.5% GP	2.60	75.0	30.7	44.3	-8.2	-2.8	-11.5	High
3% GP	2.65	72.9	30.5	42.4	-10.7	-3.4	-15.3	High
6% GP	2.66	70.7	29.5	41.2	-13.4	-6.6	-17.7	High
9% GP	2.71	70.0	28.2	41.8	-14.3	-10.7	-16.5	High
20% GP	2.75	52.5	25.6	26.9	-35.7	-18.9	-46.3	Medium
30% GP	2.79	49.6	23.7	25.9	-39.2	-25.0	-48.3	Low
40% GP	2.80	48.5	22.6	25.9	-40.6	-28.4	-48.3	Low

*(-) Shows the decrease in values

The addition of granite powder from 0% to 40% caused a decrease in the capacity of water absorption, as shown in Fig.4, similar results were obtained by, **(Manal and Abdulrazzaq) [12]**.

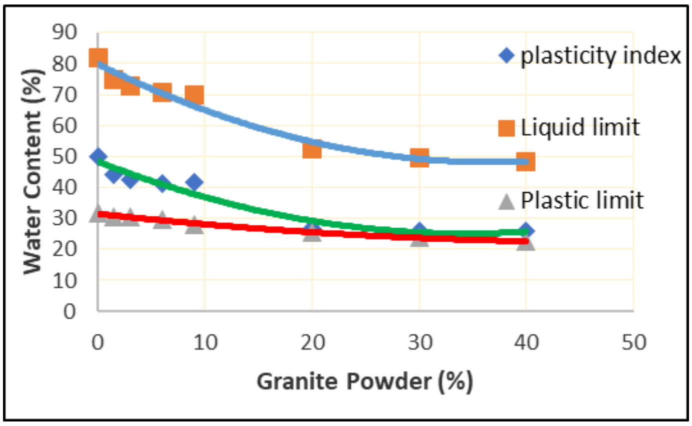

Fig- 4: Variation of LL, PL, and PI with Various Percentages of Granite Powder

Fig. 5 shows that the increase in the granite powder content shifts nature soil from high-plasticity clay (CH) into low-plasticity clay (CL) according to the unified soil classification system (USCS).

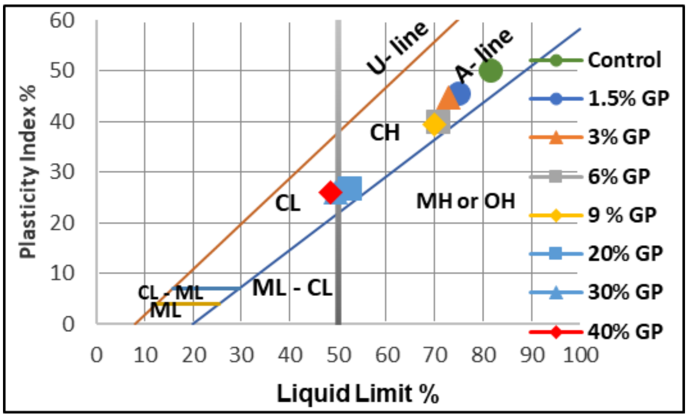

Fig- 5: Effect of Granite Powder on Plasticity Chart

4.2 Effect of Granite Powder Addition on Free Swell Index

The free swelling index can be considered a property of expansive soils. It reflects the potential of the soil to expand. It is determined by knowing the volume of swollen soil passing through sieve No. 40, after allowing 10 g of dry soil to soak in water for 24 hours. Fig. 6 shows that the free swell index for natural soil was 120% then, as the percentage of granite powder used increased, it decreased to 62%.

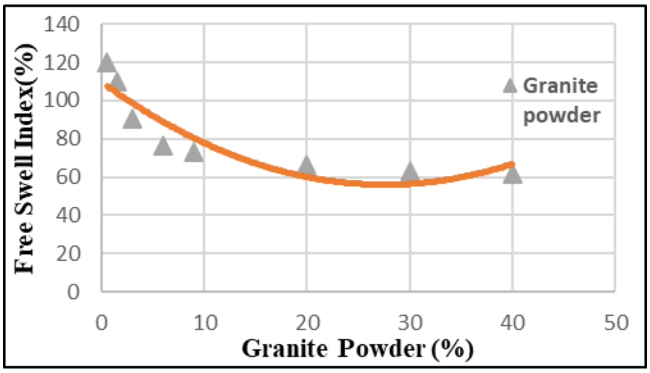

Fig- 6: Effect of Granite Powder Additives on Free Swell Index

4.3 Effect of Granite Powder Addition on Compaction Test

The compaction test has been performed on samples with different granite powder contents of 1.5%, 3%, 6%, 9%, 20%, 30%, and 40% of dry mass. Fig. 7, and Fig. 8 show the variation of maximum dry density MDD and optimum moisture content OMC with the variation of granite powder. It is observed that as increased granite powders the MDD increased from 17 KN/m³ to 19.3 KN/m³, and OMC reduced from 14.8 % to 11.5%.

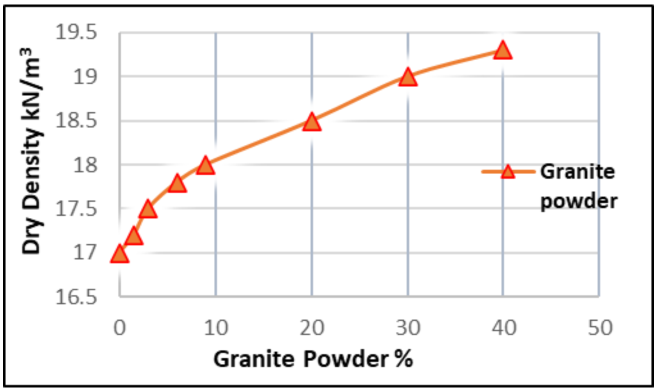

Fig- 7: Effect of Granite Powder Additives on Dry Density

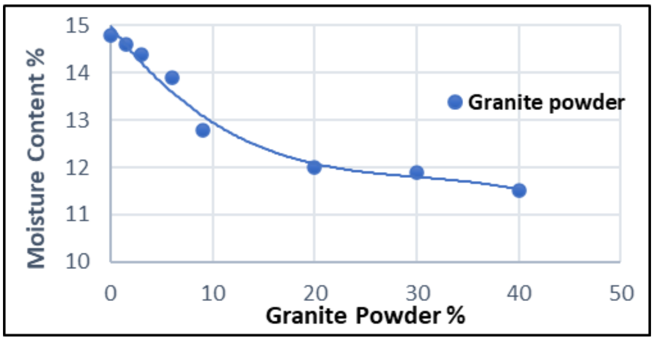

Fig- 8: Effect of Granite Powder Additives on Moisture Content

4.4 The One-dimensional Compression Test Results

The one-dimensional compression test determines the rate and magnitude of soil consolidation when the soil is restrained laterally and loaded axially. Soil samples were made first by using only granite powder as a soil treatment material, the amount of granite was 9, 20, 30, and 40 percent by the dry weight of the soil. The specimens were compacted directly into the oedometer ring (63 mm in diameter and 20 mm in height). The initial height of the specimens was approximately 16 mm. The consolidation cell was mounted on the loading platform of the odometer. Dial gauge readings were taken for 24 hours or until the soil specimen was consolidated. After the specimen consolidation was completed under maximum stress, the load was gradually removed. Each stress increment during unloading was again maintained for 24 hours, then the soil specimen was allowed to swell. All results were drawn as the void ratio(e) versus the logarithm of effective stress (log σv) as shown in Fig. 9. Through tests, it was noted that adding 30% of granite powder to the expansive soil made it bear a weight of up to 12 kg, while other proportions could take a weight of 4 kg.

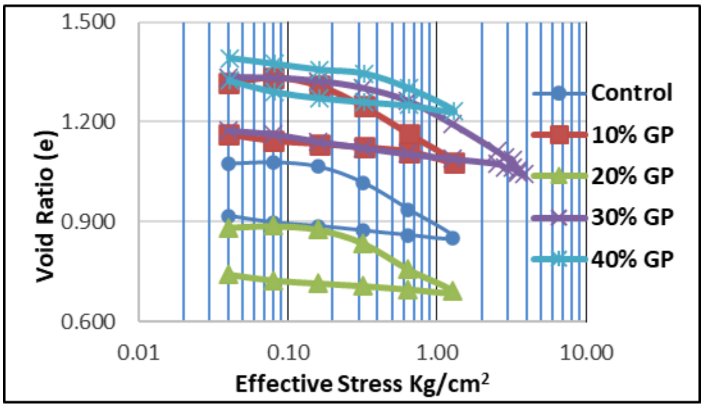

Fig- 9: E- log σv for Soils Treated with Various Percentages of Granite Powder

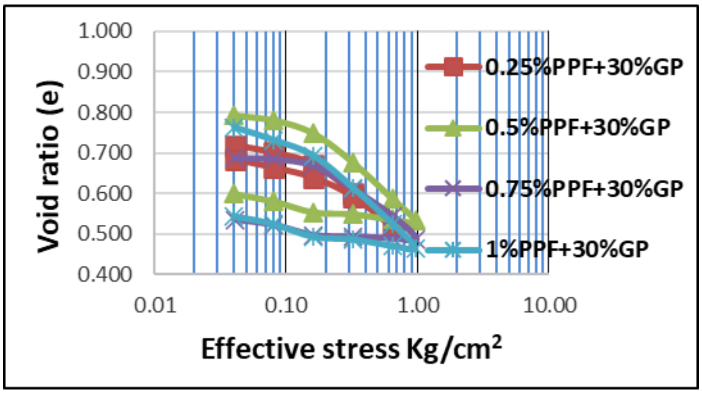

Fig-10: E- log σv for Soils Treated with Optimum Proportion of Granite Powder and Various Percentages of Poly propylene Fibers

Fig. 11 shows the addition of granite powder causes a reduction in the rebound index; this decrease is due to a reduction in the amount of clay minerals replaced by granite. At 30% granite powder, the maximum decrease of Cr, 48.5% compared to the control sample, then increased at 40% of granite powder. In the case of the addition of fibers, the Cc increased compared to the control sample. And values of Cr decreased, due to the effect of granite powder as shown in Fig. 12.

Table 5 shows that the proportion of 30% granite powder had a small settlement compared to carrying the highest load. As for using fiber with granite powder, the consolidation settlement increased compared to the control sample.

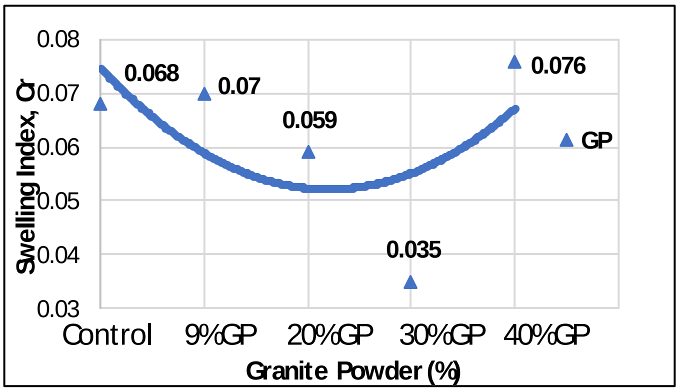

Fig-11: Effect of Granite Powder on Swelling Index

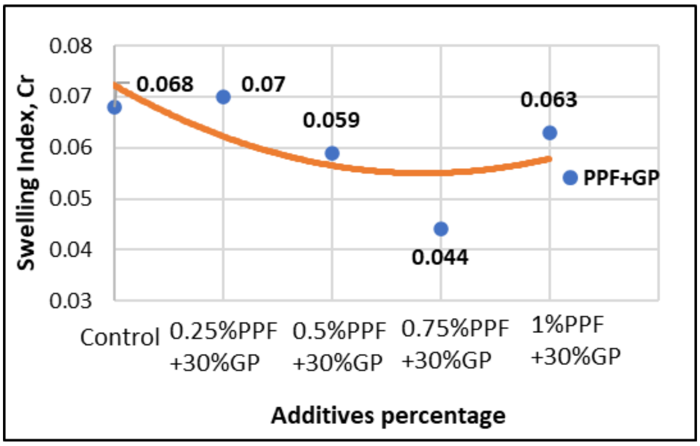

Fig- 12: Effect of Granite Powder and Polypropylene Fiber on Swelling Index

Table -5: Result of Consolidation Test

Additives	Cc	Cr	Pre-consolidation Pressure (Kg/cm²)	mv (cm²/kg)	Cv (cm²/min)	consolidation settlement (mm)
Control (0%)	0.28	0.068	0.22	0.070	0.0056	0.025
9% GP	0.25	0.070	0.28	0.058	0.0061	0.024
20% GP	0.22	0.059	0.29	0.062	0.0062	0.030
30% GP	0.60	0.035	0.50	0.038	0.0068	0.029
40% GP	0.22	0.076	0.40	0.046	0.0042	0.027
30% GP+ 0.25 PPF	0.28	0.070	0.18	0.170	0.0020	0.048
30% GP+ 0.5% PPF	0.31	0.059	0.23	0.110	0.0030	0.040
30% GP+ 0.75% PPF	0.32	0.044	0.25	0.110	0.0050	0.042
30% GP+ 1% PPF	0.34	0.063	0.24	0.120	0.0040	0.043

4.5 The Direct Shear Box Test Results

Samples were conducted on soil treated with granite powder by different proportions (9,20,30, and 40 percent by the dry weight of soil), and were prepared with respective OMC obtained from the compaction test. The remolded samples were weighed and placed in the ring of the test, then the direct shear test specimens with size (55x55x25) mm were extracted, then the specimens were tested in the direct shear box. Shear box samples were made without curing and with curing for 14 days and 28 days, Fig. 13, Fig. 14, and Fig. 15 show that 30% granite powder was the highest shear strength for normal stresses. At 30% GP, the cohesion and angle of internal friction increased without curing from 0.46 kg/cm² and 15.38° to 0.72 kg/cm² and 24.23° respectively, increased at curing 14 days from 0.48 kg/cm² and 16.20° to 0.79 kg/cm² and 25.1° respectively, increased at 28 days of curing from 0.55 kg/cm² and 20.28° to 0.8 kg/cm² and 26.52° respectively. When the addition of 40% of granite powder with and without curing, it was observed that slightly less than or equal to 30%. The increase in shear strength parameters is due to the addition of non-expansive material to expansive soil samples, which reduces the amount of clay minerals and the void spaces between the clay particles **(Hassan and Abdelaal) [13]**. Then, polypropylene fibers were added with the optimum percentage of granite powder as shown in Fig. 16, Fig. 17, and Fig. 18. When the fibers percentage was increased, the cohesion between the soil particles decreased from 0.8 kg/cm² to 0.44 kg/cm² without curing, from 0.76 kg/cm² to 0.38 kg/cm² at 14 days of curing, and from 0.84 kg/cm² to 0.34 kg/cm² at 28 days of curing.

The internal friction angle increased from 19.47° to 28.22° without curing, from 18.26° to 27.46 ° at 14 days of curing, and from 21.28° to 34.44° at 28 days of curing. Because the length of the fibers used was 18 mm, having long fibers causes problems in sample preparation and will eventually have larger voids, these results are compatible with the study **(Arif and Munwar) [15]**. When too much fiber was added reduced the benefit, as the fibers adhere to each other to form lumps and cannot contact soil particles fully **(Akshaya Kumar) [7]**.

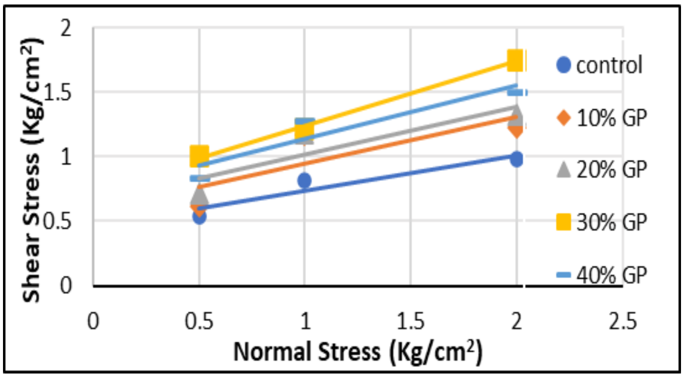

Fig-13: Mohr-Coulomb Failure Envelope for Soil Treated with Various Percentages of Granite Powder (Without Curing)

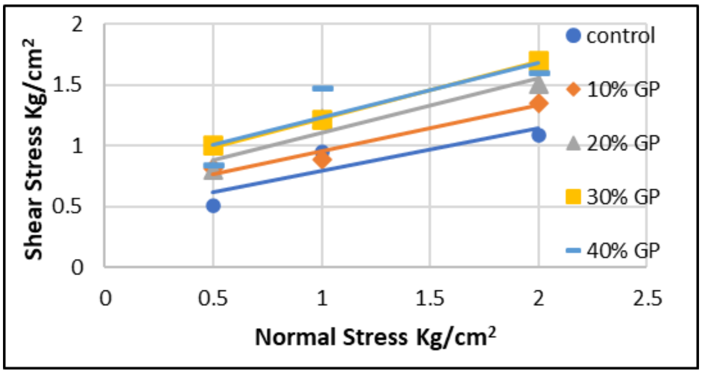

Fig-14: Mohr-Coulomb Failure Envelope for Soil Treated with Various Percentages of Granite Powder for 14 Days of Curing

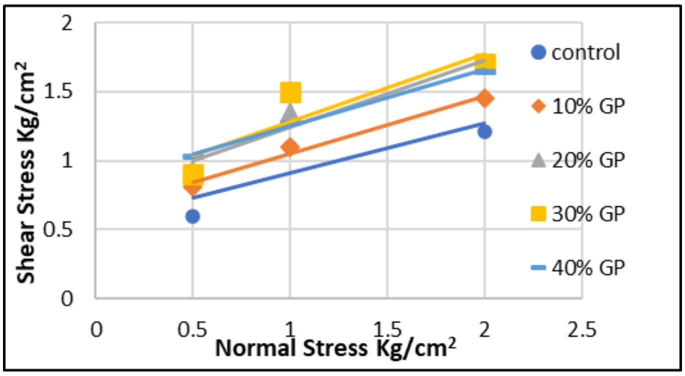

Fig-15: Mohr-Coulomb Failure Envelope for Soil Treated with Various Percentages of Granite Powder for 28 Days of Curing

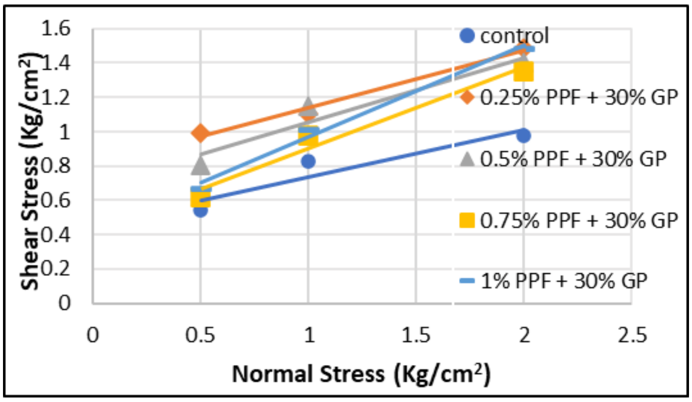

Fig-16: Mohr-Coulomb Failure Envelope for Soil Treated with The Optimum Percentage of Granite Powder and Polypropylene Fibers (Without Curing)

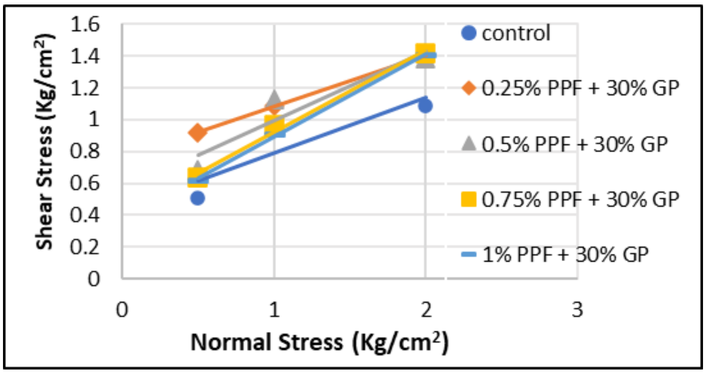

Fig-17: Mohr-Coulomb Failure Envelope for Soil Treated with The Optimum Percentage of Granite Powder and Polypropylene Fibers for 14 Days of Curing

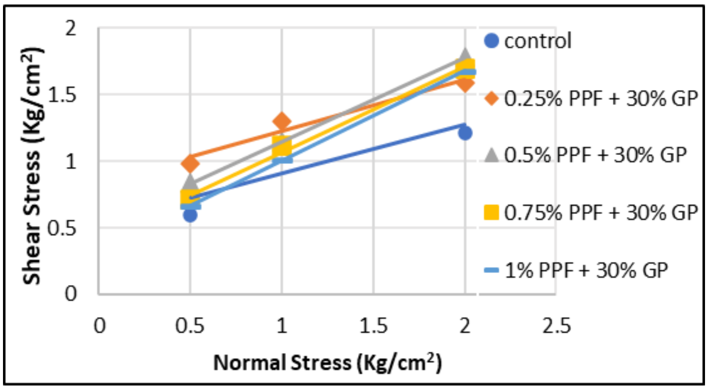

Fig-18: Mohr-Coulomb Failure Envelope for Soil Treated with The Optimum Percentage of Granite Powder and Polypropylene Fibers for 28 Days of Curing

5. CONCLUSIONS

A series of tests were conducted to study the effect of granite powder & polypropylene fiber on swelling characteristics of the expansive soil from the 5th Settlement in Cairo, Egypt. The proportions of granite powder were 1.5%, 3%, 6%, 9%, 20%,30%, and 40% by weight of soil, and polypropylene fiber were 0.25%, 0.5%, 0.75%, and 1% by weight of soil. As the result of this investigation, it is indicated that the stabilization technique with 30% of granite powder is a very useful method and the stabilization by using polypropylene fiber was an ineffective method, as problems appeared when preparing the sample and increased the voids in the soil. The following are the conclusions from these tests.

1) With the addition of granite powder plasticity index, liquid limit, and plastic limit of expansive soil decreased from 50.1%, 81.7%, and 31.6% to 25.9%, 48.5%, and 22.6% respectively. Due to this alteration in the property of expansive soil, the soil changed its UCSC classification from high-plasticity clay (CH)to low-plasticity clay (CL).

2) The Addition of granite powder changes the swelling potential of the expansive soil sample which was classified as a high swelling potentially soil to low expansive soil.

3) The granite powder addition decreased the expansive soil's free swell index from 120% to 62%.

4) Addition of granite powder increased the MDD from 17 KN/m^3 to 19.3 KN/m^3 and reduced OMC from 14.8 % to 11.5%.

5) In the case of using granite powder on the direct shear box, shear strength parameters increased, Where the highest value was at 30% of granite powder. The cohesion and angle of internal friction increased without curing from 0.46 kg/cm^2 and 15.38° to 0.72 kg/cm^2 and 24.23° respectively, after 14 days of curing increased from 0.48 kg/cm^2 and 16.20° to 0.79 kg/cm^2 and 25.1° respectively, and after 28 days of curing increased from 0.55 kg/cm^2 and 20.28° to 0.8 kg/cm^2 and 26.52° respectively.

6) As for the addition of 30% granite powder and proportions of polypropylene fiber, the cohesion between the soil particles decreased from 0.8 kg/cm^2 to 0.44 kg/cm^2 without curing, from 0.76 kg/cm^2 to 0.38 kg/cm^2 at 14 days of curing, and from 0.84 kg/cm^2 to 0.34 kg/cm^2 at 28 days of curing. The internal friction angle increased from 19.47° to 28.22° without curing, from 18.26° to 27.46 ° at 14 days of curing, and from 21.28° to 34.44° at 28 days of curing.

7) In the case of using granite powder on the consolidation test, 30% of granite powder decreased the Cr values from 0.068 to 0.035. While using polypropylene fiber with granite powder, the Cr decreased compared to the control sample, due to the presence of granite powder.

ACKNOWLEDGEMENT

The author wishes to acknowledge the support of the Laboratory of Civil Department, Faculty of Engineering at Al-Azhar University, Cairo, Egypt.

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