World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:9, No:8, 2015

# The Effect of Polypropylene Fiber in the Stabilization of Expansive Soils

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***Abstract*—**Expansive soils are often encountered in many parts of the world, especially in arid and semi-arid fields. Such kind of soils, generally including active clay minerals in low water content, enlarge in volume by absorbing the water through the surface and cause a great harm to the light structures such as channel coating, roads and airports. The expansive soils were encountered on the path of Apa-Hotamış conveyance channel belonging to the State Hydraulic Works in the region of Konya. In the research done in this area, it is predicted that the soil has a swollen nature and the soil should be filled with proper granular equipments by digging the ground to 50-60 cm. In this study, for purpose of helping the other research to be done in the same area, it is thought that instead of replacing swollen soil with the granular soil, by stabilizing it with polypropylene fiber and using it its original place decreases effect of swelling percent, in this way the cost will be decreased. Therefore, laboratory tests were conducted to study the effects of polypropylene fiber on swelling characteristics of expansive soil. Test results indicated that inclusion of fiber reduced swell percent of expansive soil. As the fiber content increased, the unconfined compressive strength was increased. Finally, it can be said that stabilization of expansive soils with polypropylene fiber is an effective method.

***Keywords*—**Expansive soils, polypropylene fiber, stabilization, swelling percent.



## I. Introduction

EXPANSIVE soils are one of the most serious problems that the geotechnical engineers encounter. They are considered as a potential natural hazard, which can cause extensive damage to structures such as spread footings, roads, highways, airport runways and earth dams if not adequately treated. In the United States damage caused by expansive clays exceeds the combined average annual damage from floods, hurricanes, earthquakes, and tornadoes [1]. Some measures can be taken to prevent the damages. These are; replacing the soil under the foundation with the other soil, controlled compaction of expansive soil, moisturizing, structure of moisture barriers, lime and cement stabilization, fortification of the structure and lowering the foundations from active layer to the lower level. Recently there is a growing attention to soil reinforcement with different types of fiber. The experimental results gathered over the past years show the potential of different types of fiber in reinforcing problematic soils. Lie et al. [2] indicated that there were significant increases in shear strength, toughness and plasticity of a cohesive soil after reinforcement with discrete polypropylene fiber. Loehr [3] conducted a series of one-dimensional free swell tests relevant with polypropylene fibers and found that inclusion of even small amounts of polypropylene fibers to an expansive soil can significantly reduce the magnitude of free swell displacements. Prabakar and Sridhar [4] carried out a laboratory study about the reinforcing of a non-expansive soil with sisal fiber and found and important improvement in the failure deviator stress and shear strength parameters. The testing results of Wu [5] indicated that fiber-cement-fly ash stabilized soil of higher strength and toughness was obtained by adding a little glass fiber into cement-fly ash treated soil and its strength increased with increasing content and length of glass fiber. Cai et al. [6] investigated the influence of the mixture of polypropylene fiber and lime on the engineering properties of a clayey soil. They found that an increase in fiber content caused an increase in strength and shrinkage potential but brought on the reduction of swelling potential. Puppala and Musenda [7] investigated the influence of discrete and randomly oriented polypropylene fiber reinforcement on expansive soil stabilization is presented. According to the results, fiber reinforcement enhanced the UCS of the soil and reduced both volumetric shrinkage strains and swell pressures of the expansive clays. Also fiber treatment also increased the free swell potential of the soils. Attom and Al-Tamimi [8] carried out a laboratory study about the effects of polypropylene fibers on the shear strength of sandy soil. They used two polypropylene fibers at different percentages and different aspect ratio to improve the physical properties of sandy soil. According to the results, the increase of the percentages of the both type of fiber will result in increasing the angle of internal friction and ductility of sand. Freilich and Zornberg [9] carried out a laboratory study about the reinforcing of soils with polypropylene fibers. They determined failure envelopes from isotropic consolidated-undrained triaxial testing and indicate an increase in the effective shear strength of the soil with the presence of polypropylene fibers. Yılmaz and Karatas [10] investigated the effects of discrete polypropylene fibers and low dosage ordinary Portland cement (OPC) on the stress-strain and unconfined compressive strength behavior of clayey soil. Three different lengths (6.0mm, 12.0mm, and 19.0mm) and two fiber dosages (i.e. 0.5% and 1.0% by dry weight of soil) were considered. The testing results indicated that the effect of fiber dosage on the stress-strain behavior is superior to the effect of fiber length. Olgun [11] investigated the effect of polypropylene fiber inclusions on the geotechnical characteristics of a clayey soil that was chemically stabilized with cement and fly ash. For all stabilized soils, cement and fly ash were added at 8% and 30%, respectively. Reinforced stabilized soil specimens were

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prepared at four different percentages of fiber content (0.25%, 0.50%, 0.75%, 1.0%) and three different fiber lengths (6 mm, 12 mm, 20 mm). According to the results, the compressive and especially the tensile strength values increased to a great extent following the addition of fiber into the stabilized soil. The highest strength values were obtained with 0.5–0.75% content for the 12 mm-long fibers. The shrinkage limits and crack reduction values increased with increased fiber content and greater fiber length, whereas volume changes decreased. However, there is limited research done on fiber reinforcement of expansive soils, especially its effect on compaction characteristics and strength properties.

Construction of the buildings and other civil structures on weak and soft soils have high risk because these type of soils have low shear strength and high compressibility. Apa-Hotamış conveyance channel which is 125km long will be built in Konya that take the water with 70m$^3$/sec from Mavi tunnel to Hotamış storage. With this channel, 200.000m$^2$ of land will be irrigated. The expansive soils were encountered on the path of this channel. In this study, it is thought that instead of replacing swollen soil with the granular soil, by stabilizing it with polypropylene fiber and using it its original place decreases effect of swelling pressure, in this way the cost of structure will be decreased. An experimental study had been done to study the effect of polypropylene fiber reinforcement on the improvement of physical and mechanical properties of the expansive soil. The experimental program was carried out on compacted soil specimens with 0%, 0,5%, 0,75% and 1% polypropylene fiber additives and the results of compaction, unconfined compression and one dimensional swell tests on 0%, 0,5%, 0,75% and 1 % fiber were discussed.

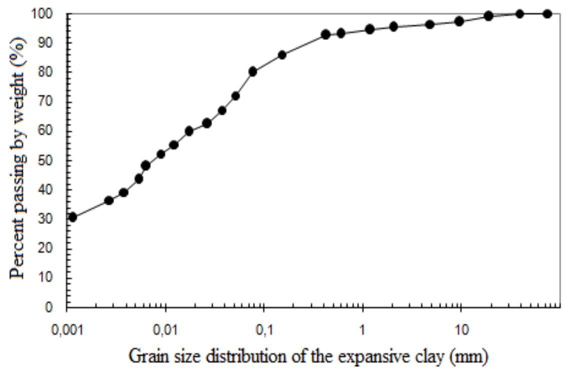


Fig. 1 Granulometric curve of the expansive clay

TABLE I
PHYSICAL PROPERTIES OF THE EXPANSIVE SOIL

| Property | |
|---|---|
| Specific Gravity | 2,58 |
| Sand (%) | 6 |
| Silt (%) | 54 |
| Clay (%) | 36 |
| Liquid limit (%) | 63 |
| Plastic limit (%) | 29 |
| Plasticity index (%) | 34 |
| Linear shrinkage (%) | 22 |
| Optimum moisture content (%) | 26 |
| Maximum dry density (kN/m$^3$) | 14.53 |
| Soil classification (USCS) | CH |

Fig. 2 Photograph of the polypropylene fiber used in this study

TABLE II
PHYSICAL AND CHEMICAL PROPERTIES OF FIBER USED

| Physical and chemical properties | Values |
|---|---|
| Fiber type | Single fiber |
| Unit weight | 0,91 g/cm$^3$ |
| Average diameter | 0.034 mm |
| Average length | 12 mm |
| Breaking tensile strength | 350 MPa |
| Modulus of elasticity | 3500 MPa |
| Fusion point | 165 ºC |
| Burning point | 590 ºC |
| Acid and alkali resistance | Very good |
| Dispersibility | Excellent |

## II. MATERIALS AND EXPERIMENTAL PROGRAM

### A. Materials

The soil used in this investigation has been obtained from some regions of Konya-Dinek where irrigation channels of Konya State Hydraulic Works pass through. The granulometric curve of the expansive clay is shown in Fig. 1. Owing to high initial moisture content, the soil was air-dried at first and then broken into pieces in the laboratory. Engineering properties of the collected soil are presented in Table I. Polypropylene fiber used in this investigation was provided by a company in Istanbul. Fig. 2 shows the photograph of the polypropylene fiber. Physical, chemical and mechanical properties of the polypropylene fiber used in this investigation are presented in Table II.

### B. Preparation of Samples

All specimens were prepared with static compaction method specified in ASTM D698-91. Water is added to the soil and mellowed for 24 hours for preparing unreinforced samples. The content of fiber is defined herein as

$$\rho_f = \frac{W_f}{W} \tag{1}$$

where $W_f$ is the weight of fiber, and W is the weight of air-dried soil (the final moisture is 2.9%). To obtain reinforced samples, the prescribed content of fibers was first mixed into the air-dried in small increments by hand, making sure all the fibers were mixed thoroughly to achieve a fairly uniform mixture, and then the required water was added. All of the mixing was done manually and proper care was taken to prepare homogeneous mixtures at each stage of mixing.

### C. Experimental Program

1. Compaction Tests

Standard Proctor test was performed to determine the moisture content-dry unit weight relationship according to ASTM D- 698-91. In the proctor test, the soil was compacted in the mold that has a volume of 944 cm3. The diameter of the mold is 101.6 mm. The soil was mixed with varying amounts of water and then compacted in three equal layers by a hammer that delivers 25 blows to each layer using an automatic dynamic compacter with a hammer of 2.5 kg dropping from 305 mm height that produce a compactive effort of 592.7kJ/m$^3$. The compaction test has been performed on soils with different fiber contents of 0.5%, 0.75% and 1% of dry mass.

2. Unconfined Compression Tests

The unconfined compression test is widely used as a quick and economical method to obtain the approximate compressive strength of cohesive soil. Unconfined compression tests using strain-controlled application of the axial load was carried out according to the ASTM D2166-06. Samples were shaped in a mold with a length of 80 mm and an inner diameter of 39.1 mm at the state of maximum dry density versus optimum moisture content. In order to ensure uniform compaction, the required quantity of material was placed inside the mold and compressed in three steps.

3. Swelling Tests

One-dimensional test swell tests were carried out to determine the swelling characteristics of unreinforced and fiber reinforced samples. The 50 mm diameter, 19 mm height oedometer samples were prepared in a purpose-made compaction unit containing the oedometer ring at the required dry unit weight and optimum water content determined from the compaction tests. After the compaction test, specimens were placed into the oedometer and the swell tests were carried out. The specimens were allowed to swell freely under a low surcharge of 7 kPa and full swell was measured. Thereafter, the specimens were loaded until its initial void ratio was obtained.

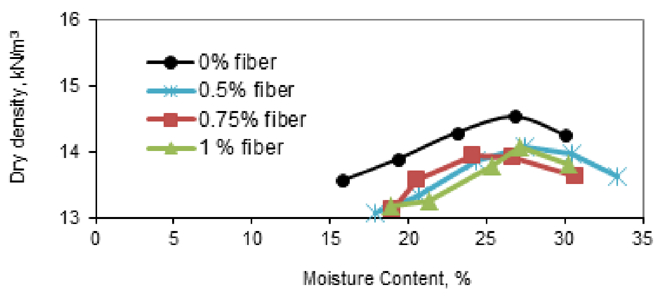


Fig. 3 Effect of fiber content on maximum dry density-optimum moisture content of the soil

## III. Results and Discussion

### A. Effect of Fiber on Soil Compaction

The compaction curves for reinforced and unreinforced soil specimens in Fig. 3 indicate optimum moisture content does not show a significant change by addition of polypropylene fiber whereas maximum dry density reduces as fiber content increases. This reduction can be explained with the reduction of average unit weight of solids in the mixture of soil and fiber [4].

### B. Effect of Fiber on the Unconfined Compressive Strength Behavior of Soil

The stress-strain curves of unreinforced soil and reinforced with different percentages of fiber are given in Fig. 4. It can be seen from Fig. 4 that as the content of fiber increased, the unconfined compressive strength of the soil is increased. It can also be seen that fiber-reinforced soil shows more ductile behavior and smaller loss of peak strength than unreinforced soil. Fig. 5 exhibits the change of unconfined compression strength according to fiber percentage.

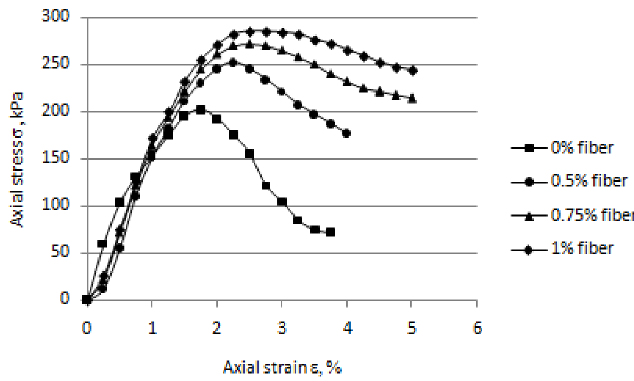


Fig. 4 Results of the unconfined compression tests

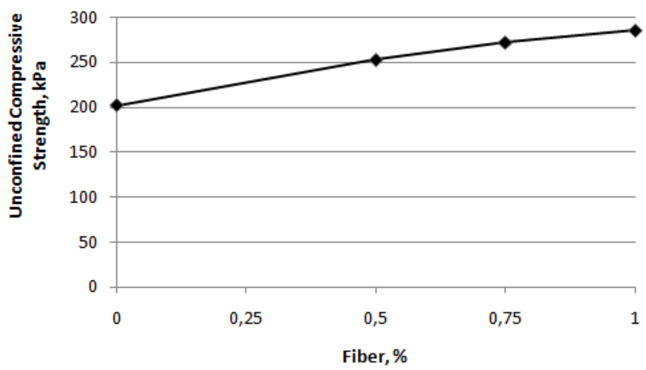


Fig. 5 Effect of fiber on unconfined compressive strength of soil

### C. Effect of Fiber on the Variation of Percent Swell of Unreinforced and Reinforced Soil Samples with Time

The swelling characteristics of unreinforced and fiber reinforced samples were investigated according to one-dimensional swell test. Fig. 6 shows the free swell response in percent swell with respect to time in minutes for different fiber percentages. The final swell of unreinforced soil was greater than the final swell of reinforced soil with polypropylene fiber.

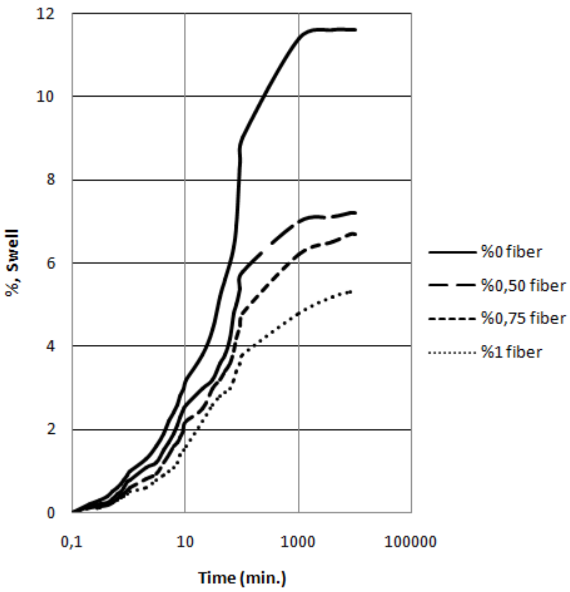


Fig. 6 Variation of percent swell of unreinforced and reinforced soil samples with time

## IV. Conclusions

A series of tests were conducted to study the effects of polypropylene fiber on swelling characteristics of expansive soil from the place of Apa-Hotamış conveyance channel. The effects of fiber on compaction, unconfined compressive strength and swelling characteristics of expansive soil were determined. The following are the conclusions from these tests.

- The optimum moisture content does not show a significant change by addition of polypropylene fiber whereas maximum dry density reduces as fiber content increases in compaction tests. This can be explained by the reduction of average unit weight of solids in the mixture of soil and fiber.
- The inclusion of fiber within unreinforced and reinforced soil caused an increase in the unconfined compressive strength of expansive soil. Increasing fiber content had increased the peak axial stress and decrease the loss of post-peak strength. For example, unconfined compression strength increased from 202 MPa to 285 MPa for samples reinforced with 1% fiber. The fiber reinforced soil exhibits more ductile behavior than unreinforced soil.
- Swell percent was reduced as the fiber increased. One dimensional swell decreased considerably with 1% fiber addition. For example it decreased from 11,60% for unreinforced samples to about 5,3% for reinforced samples with 1% fiber.
- As a result of this investigation, it is clearly indicated that the stabilization technique with polypropylene fiber is a very useful method for ground improvement. It can be used very easily than the other stabilization methods in many fields of geotechnical engineering.

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