Influence of Plastic Waste Reinforcement on Compaction and Consolidation Behavior of Silty Soil

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Abstract**—**In recent decades, the amount of solid waste production has been rising. In the meantime, plastic waste is one of the major parts of urban solid waste, so, recycling plastic waste from water bottles has become a serious challenge in the whole world. The experimental program includes the study of the effect of waste plastic fibers on maximum dry density (MDD), optimum moisture content (OMC) with different sizes and contents. Also, one dimensional consolidation tests were carried out to evaluate the benefit of utilizing randomly distributed waste plastics fiber to improve the engineering behavior of a tested soils. Silty soil specimens were prepared and tested at five different percentages of plastic waste content (i.e. 0.25%, 0.50%, 0.75%, 1% and 1.25% by weight of the parent soil). The size of plastic chips used, are 4 mm, 8 mm and 12 mm long and 4 mm in width. The results show that with the addition of waste plastic fibers, the MDD and OMC and also the compressibility of soil decrease significantly.

Keywords**—**Silty soil, waste plastic, compaction, consolidation, reinforcement.

I. Introduction

DUE to growth of population, increasing urbanization and human activities, the large quantities of solid wastes are being generated all over the world. On the other hand, traditional construction materials such as concrete, bricks, cement etc. are being produced from the existing natural resources and also, the cost of them is increasing day by day. This is damaging the environment. Consequently, recycling of wastes by proper management is taking place in our ways of living and working. So, in this research, we focus to solve the problem partly and use plastic fibers in combination with soil as a stabilizer. The concept of reinforced soil was first given by Vidal [1]. Park and Tan studied the effects of short fiber reinforcement on the performance of soil wall [2].

The use of fiber as reinforcement is a useful method for improvement and stabilization of subgrade in road construction [3]. Gosavi et al. reported that soil can be reinforced with low-cost materials like natural fibers obtained from plastic fibers [4]. Ravishankar and Raghavan confirmed that for coir-stabilized lateritic soils, the MDD of the soil decreases with addition of coir and the value of OMC of the soil increases with an increase in percentage of coir [5]. Abdi et al. [6] worked on fiber reinforced soils and concluded that by increasing fiber content the consolidation settlement and swelling of soil and also the development of desiccation cracks reduced significantly.

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Console et al. [7] planned a filed application of polyethylene (PET) plastic bottles for improving the bearing capacity of spread foundations when placed on a layer of fiber-reinforced cemented sand built over a weak residual soil stratum. Chen et al. indicate that reuse of plastic waste is an important step in the development of clean energy and in conjunction with the promotion of new waste plastics recycling programs could contribute to additional reductions in fossil fuel consumption [8]. Babu et al. presented results of numerical analysis of stress strain response of coir fiber-reinforced sand and showed that presence of fibers alters the stress field and provides improved shear resistance due to pullout resistance of individual fibers [9].

In the last twenty years, the use of the recycled material has grown. Experimental results [10]-[17] indicate that short fibers mixed into soils can have a noticeable reinforcement effect. Most of these researches used different types of fibers as reinforcing materials, such as natural fibers, glass fibers, plastic fibers, polypropylene and polyester fibers. In the following paragraphs an attempt is made to briefly summarize the important fiber reinforcement developments achieved until about the present time. The mixing of waste plastic fiber to a soil mass may be considered similar to other admixtures (synthetic fibers like polypropylene, polyamide, and polyester fibers) used for soil stabilization.

Previous investigations [10]-[17] indicate that strength properties of fiber-reinforced soils consisting of randomly distributed fibers are a function of fiber content and fiber-surface friction along with the soil and fiber strength characteristics and report that the addition of fiber-reinforcement caused significant improvement in the shear strength, unconfined compressive strength and decreased the stiffness, MDD and OMC of the soil. More importantly, fiber reinforced soil exhibits greater toughness and ductility and smaller loss of post-peak strength, as compared to soil alone.

The above literature review clearly indicates that studies are available on the use of wastes from plastic fiber are limited and little attention has been given to the effect of waste plastic on the geotechnical properties of soils. The main objectives of this research are to investigate the use of waste plastic in geotechnical applications and to evaluate the effects of plastic fiber on the consolidation and compaction behavior of silty soils.

II. Material

A. Soil Type

The silty soil used in the present study is classified as a high plasticity silty soil (MH) according to the Unified Soil Classification System ASTM D 422-63 [10]. The grain-size distribution and its physical properties of selected soil are presented in Fig. 1 and Table I, respectively.

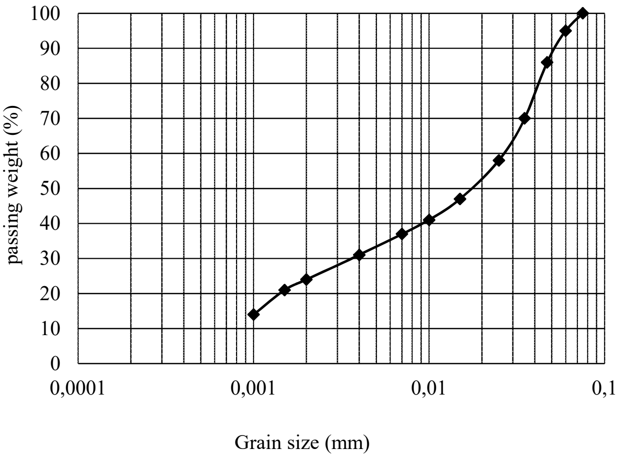

Fig. 1 Grain-size distributions of selected soil

TABLE I
ENGINEERING PROPERTIES OF SOIL USED IN THE PRESENT STUDY

Soil properties	Values
Specific gravity (G_s)	2.65
Liquid limit	51%
Plastic limit	21%
Plasticity index	30
USCS Classification	MH
OMC (%)	17.58
MDD (KN/m³)	17.9

B. Reinforcement

The plastic waste is a large portion of solid waste. It is a strong but light weight form of clear polyester which is used to make containers for soft drinks, juices, mineral water and other food and nonfood applications. The physical properties of plastic waste fiber used are shown in Table II.

TABLE II
PROPERTIES OF PLASTIC WASTE CHIPS

Plastic waste properties	Values
Type	Waste plastic chip
Length	4-8-12 mm
Cross-section	Rectangular
Thickness	0.20 mm
Width	4mm
Density (gm/cc)	1.395

III. SPECIMEN PREPARATION AND TESTING PROCEDURES

Series of tests including compaction and one dimensional compression tests were conducted on moist-compacted silty soil samples by varying plastic waste content and length. Under dry conditions, the required amounts of air-dried silty soils and plastic waste were mixed thoroughly by hand. Then, required water content was added to soil-plastic waste mixture. Before compacting the soil in the mold, inside of mold was coated with lubricate to reduce the possibility of fraction of specimens during removal. In order to maintain moisture, the waste-soil mixture was kept in a plastic bag. The plastic waste mixed with silty soil was transferred in cylindrical mold at standard temperature in approximately 3 equal layers and each layer was statically compacted. The specimen preparation method was adapted from the standard compaction test method, ASTM D698 [11].

All the specimens were prepared at OMC and MDD corresponding to the values obtained from the compaction curve of silty soil.

The distribution of fiber reinforcement was random in all specimens. The experiments were conducted for different plastic waste contents (0%, 0.25%, 0.50%, 0.75%, 1% and 1.25% by dry weight of silty soil). The tests were repeated using three different fiber lengths of 4 mm, 8 mm and 12 mm in the constant width of 4 mm. Fig. 2 shows the plastic waste mixed soil.

Fig. 2 Plastic waste mixed soil

IV. COMPACTION TESTS

The Proctor Compaction test is a process of reducing the volume of soil by applying the specific compactive effort and removing air while the volume of the solids and water content remain constant. A series of tests is carried out at various moisture contents. Soil dry density is determined for each test. The peak point of a dry density-moisture content curve indicates the MDD and optimal moisture content (OMC).

In this study, the standard Proctor's tests in accordance with ASTM D 698-07 [11] were carried out to determine MDD and OMC for selected soils, in both reinforced and unreinforced conditions. Each soil sample was prepared by initial dry mixing of raw soil and corresponding quantity of plastic waste according to percentage (by weight of raw soil) of plastic waste content (0%, 0.25%, 0.50%, 0.75%, 1% and 1.25%). Then water was added and mixed again until the water spreads all over the soil. All the test samples were subjected to this test and respective OMC and maximum dry densities of all combinations were determined. The results obtained for standard proctor tests at different percentages and sizes of plastic waste are given in Figs. 3 and 4, respectively.

As shown in Fig. 3, for any particular percentage of plastic waste content, dry density decreases with increase in plastic length. Therefore, it implies that the MDD of the soil decreases with increase in plastic waste length. This is due to low specific gravity and reduction of average unites weight of the solids in the soil-plastic content. For given compaction energy, the presence of the reinforcement provides higher resistance to the compaction and so a less dense packing (low MDD) is obtained once the quantity of fiber is increased. With the increase of the fiber content in soil, energy absorption capacity of reinforced soil is increased. As presented in Fig. 3, MDD of silty soil varies between 17.90 and 17.08 kN/m³ for plastic length of 4 mm, between 17.90 and 16.95 kN/m³ for 8 mm and between 17.90 and 16.77 kN/m³ for 12 mm. It is observed that the MDD for plain silty soil is 17.90 kPa, whereas for 1.25% plastic waste mixed soil with 4 mm, 8 mm and 12 mm plastic waste length, it reaches to 17.08 kN/m³, 16.95 kN/m³ and 16.77 kN/m³, respectively. The results indicate that there is redaction in MDD with different plastic waste content of reinforced soil compared to plain soil. The results also indicate that the OMC of silty soil decreases by increase of plastic waste content at different plastic waste length (Fig. 4).

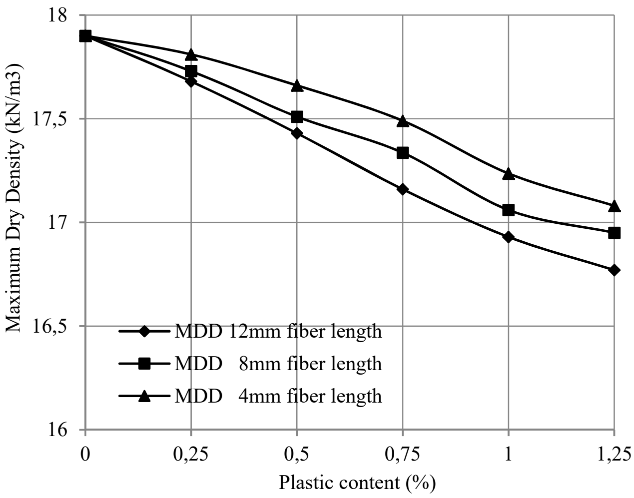

Fig. 3 Effect of plastic waste content and length on MDD

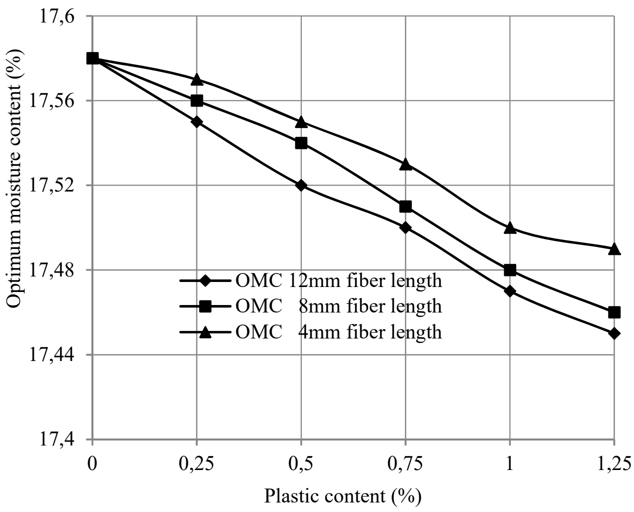

Fig. 4 Effect of plastic waste content and length on OMC

V. One Dimensional Consolidation Tests

Consolidation refers to transfer of stress from the pore pressure to effective stress, gradually. The permeability and compressibility of soil, the layer thickness and the boundary conditions affect the rate of settlement.

According to the ASTM D2435-04 [12], one-dimensional consolidation tests have been conducted to study the effect of addition of various percentages of plastic waste on compressibility characteristics of silty soil. Statically compacted soil specimens have been prepared OMC and MDD by adding 0.25, 0.50, 0.75, 1 and 1.25% plastic waste by the weight of parent soil. For comparison of the results, the initial dry density and water content of all the specimens are kept constant. All specimens were installed in a rigid brass ring with 60-mm inner diameter, a height of 20 mm. The consolidation tests were conducted in a room maintained at a uniform temperature of 20 ±1 ◦C. The sample was subjected to a constant different vertical stress and compression of sample was measured at different time intervals. Compression Index, C_c and Expansion Index, C_e are calculated from the slope of the loading and unloading curves, respectively. Fig. 5 presents the results of e-logp for given soil.

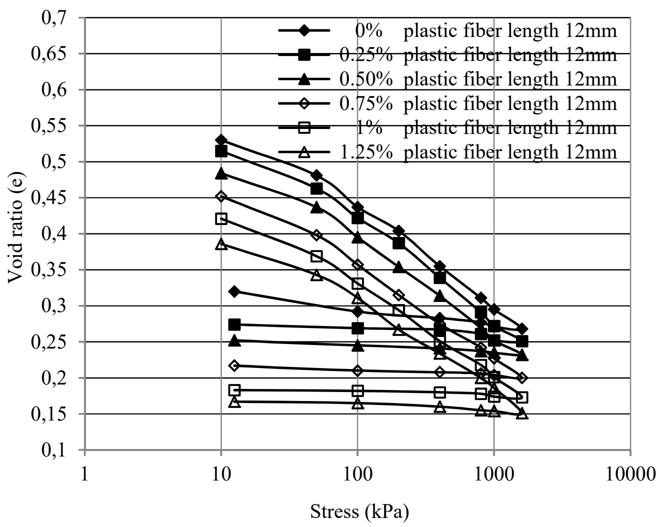

Fig. 5 Consolidation test results for silty soil at different percentage of plastic waste

The results show that the slope of e-log p curve decreases as the plastic waste content increases and the values of void ratio decrease with the increase of fibers in soil. As the percentage of plastic waste increases in soil, more voids are occupied with plastic waste and leads to an overall reduction in void ratio. Similar trend is observed by Kar and Pradhan [13]. From the results it is clear that the compression index (C_c) and recompression index (C_r) values decrease with the increase of plastic waste fibers in tested soil. Compression index (C_c) and recompression index (C_r) values are decreasing for all the observed percentages of plastic waste. It indicates that the compressibility of soil reduces as the plastic waste content increases.

VI. Conclusions

Experimental study of waste plastic fibers reinforcement behavior of silty soil was investigated by performing a series of compaction and consolidation tests. The results show that:

- The MDD and optimum water content of silty soil decrease with increase of plastic waste length and plastic waste contents.
- The void ratio value of soil decreases with increase of plastic waste fibers.
- The recompression index and compression index values decrease with increase of plastic waste fibers, so with increasing of plastic waste content, the compressibility of soil reduces.

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