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Effect of Waste Bottle Chips on Strength Parameters of Silty Soil

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***Abstract*—**Laboratory consolidated undrained triaxial (CU) tests were carried out to study the strength behavior of silty soil reinforced with randomly plastic waste bottle chips. Specimens mixed with plastic waste chips in triaxial compression tests with 0.25, 0.50, 0.75, 1.0, and 1.25% by dry weight of soil and tree different length including 4, 8, and 12 mm. In all of the samples, the width and thickness of plastic chips were kept constant. According to the results, the amount and size of plastic waste bottle chips played an important role in the increasing of the strength parameters of reinforced silt compared to the pure soil. Because of good results, the suggested method of soil improvement can be used in many engineering problems such as increasing the bearing capacity and settlement reduction in foundations.

***Keywords*—**Soil improvement, waste bottle chips, reinforcement, silt, Triaxial test.

I. INTRODUCTION

THE construction of civil structures such as highways, buildings, bridges, etc. are carried out by force on soft soils, which have many engineering problems related to sufficient bearing capacity and allowable settlement. All of these structures need a proper foundation, and in many cases the original land could not sustain the load from the infrastructures. These issues lead to the establishment the development of ground modification or improvement techniques [1]. Along with the various applications for soil improvement, several different methods exist. The usual methods of soil stabilization include: mechanical stabilization, hydraulic stabilization, chemical stabilization, and stabilization by inclusion and confinement [2]. Among the various options for improvement the existing weak soil, reinforcing the soils with some elements is one of the successful alternatives. The concept of reinforced soil was first given by Vidal of France in 1966 [3]. The idea of fiber reinforced soils has been developed broadly over the past few decades. According to the laboratory tests results, many investigators established that there was an increase in strength and deformation properties of soils [4], [5]. A wide range of reinforcements has been used to improve soil performance. One of the simple methods of recycling plastic waste water bottles is to use them in the field of civil engineering as reinforcing materials that get more attention by researchers. Soil stabilization using waste plastic strips is an economic method since the stabilizer used is waste plastic materials, which are easily and cheaply available. Experimental results gathered over the last 20 years indicate that short fibers mixed into soils can have a noticeable reinforcement effect. In most studies, small and tiny separate fibers made of polymeric or natural material mixed into soils have been used to improve the shear strength of soils [6]. For example, different types of fibers used as reinforcing materials are: plastic fibers [7], glass fibers [8], polypropylene [9], geosynthetic fibers [10], and municipal solid waste (MSW) fibers [11]. Since the distribution of fiber orientation in practical applications is clearly anisotropic, many studies were carried out on the randomly distributed fibers [12]. Consoli et al. determined the engineering behavior of sand reinforced with plastic waste. They found that one of the most promising approaches is the use of fiber-shaped waste materials in the combination with soil and cement [13]. Consoli et al. planned a field application of polyethylene terephthalate (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 [14]. Kumar et al. studied the influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. They established that fly ash and polyester fibers are beneficial in combination with lime in improving the properties of expansive soil [15]. Babu and Vasudevan determined the strength and stiffness response of coir fiber-reinforced tropical soil. They indicated that stress–strain behavior of soil is improved by incorporating coir fibers into the soil [16]. Shukla et al. purposed the analytical model for fiber-reinforced coarse soils under high confining pressures and they found that the increase of apparent cohesion and shear strength parameters are proportional to the fiber content [17]. Sivakumar Babu et al. provide an approach for the use wastes plastic bottles as reinforcement material in soil. Based on experimental test results, it is observed that the strength of soil is improved, and compressibility reduced significantly with addition of a small percentage of plastic wastes to the soil [18]. The effect of human hair fibers on the soil improvement was studied by Pillai and Ayothiraman. They deduced that the influence of fiber presence on consistency limits was minimal, and the inclusion of human hair fibers slightly affects the dry density-moisture content relationships of Kaolinite clay [19]. Mohamed determined the enhancement of swelling clay properties using hay fibers. He found that there are no considerable or reasonable changes due to the addition of hay in the Atterberg limits, but the direct shear and tensile strength increase considerably with hay addition [20].

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The literature review clearly indicates that there are many researches on the use of plastic waste bottles on cohesive soil, but studies on silty soils are limited. This laboratory program was performed to determine the strength properties of fiber-reinforced soil by using consolidated undrained triaxial tests. The influence of different fiber length and different fiber content on shear strength of silty soil is detected.

II. MATERIALS AND METHODS

A. Soil

The silty soil sample was collected from west of Iran. As Unified Soil Classification System (USCS), the silty soil is classified as MH [21]. The particle size distribution of the silt used in the present study is illustrated in Fig. 1, and Table I shows the engineering properties of this soil.

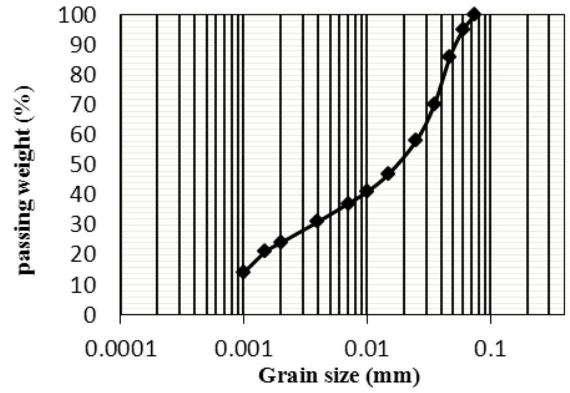

Fig. 1 Particle Size Distribution of silt

TABLE I
ENGINEERING PROPERTIES OF SOIL

Soil properties	values
Specific gravity (G_s)	2.65
Consistency limit	
Liquid limit	43%
Plastic limit	21%
Plasticity index	22
USCS classification	MH
Grain size analysis	
Gravel	0%
Sand	0%
Silt	86%
Clay	14%

The compaction curves obtained by the standard Proctor compaction test show that the used soil has a maximum dry density (MDD) of 17.9 kN/m³ and optimum moisture content (OMC) of 17.58% according to the ASTM D698 standard specification [22]. Fig. 2 shows the standard Proctor compaction curve of used silty soil.

B. Reinforcement Element

In this study, plastic bottles wastes made of PET, in the form of chips are used as a reinforcing material. The size of used plastic chips is 4mm, 8mm and 12 mm long and 0.2 mm thickness width of 4mm constantly with rectangular cross-section. In present research, different percentages of plastic bottle chips include of 0.25, 0.50, 0.75, 1.00, and 1.25% by dry weight of soil are used. The physical properties of plastic waste fiber used as reinforcement are shown in Table II.

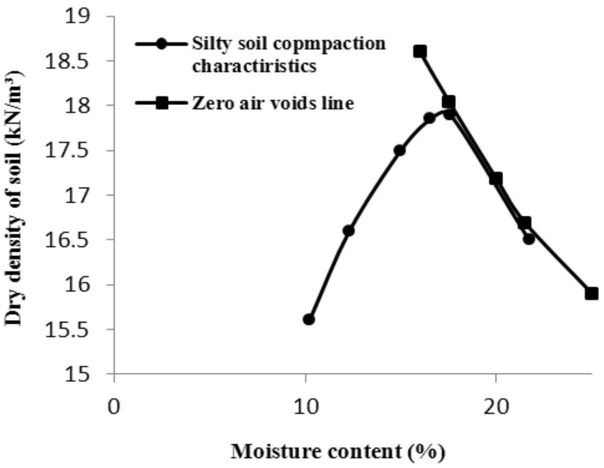

Fig. 2 Compaction characteristic of silty soil

TABLE II
TYPE AND PROPERTIES OF PLASTIC WASTE CHIPS

Plastic waste properties	values
Type	waste plastic chip
Specific Gravity	1.42
Color	white
Water Absorption	Nil
Length	4-8-12 mm
Cross-section	Rectangular
Thickness	0.20 mm
Width	4mm

C. Specimen Preparation

A series of laboratory tests on pure and reinforced silty soil specimens by randomly distributed waste plastic fiber were carried out. In the first stage, the water plastic bottles were cut into length of 4, 8, and 12 mm with constant value of width and thickness, 4 and 0.2 mm, respectively. The content of plastic chips in reinforced soil is defined as ratio of the weight of the plastic chips to the weight of the oven-dried soil sample. In the next stage, the plastic chips were added with soil at five different percentages 0.25, 0.50, 0.75, 1.0, and 1.25%. To make comparison, plastic chips have been added to soil with OMC to prepare samples in the same condition at the MDD and kept them in a plastic bag for equilibration of moisture content of mix for 24 hours. For this purpose, the required amounts of air-dried silty soil and the specified weight of plastic waste percent by dry weight of silt were hand mixed under dry conditions very carefully to obtain a homogeneous mix. Then, the required amount of water was added to soil-plastic waste mix and mixed uniformly.

D. Standard Proctor Compaction Test

To determine the maximum dry unit weight and OMC of pure silt and silt mixed with different percentage of plastic bottle chips, standard Proctor compaction tests were performed. The standard Proctor compaction test was performed in accordance with ASTM D 698–12 standards. Water was added to silt-fibers mixture with different water

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moisture, and then, its weight was taken to determine the density.

E. Triaxial Test (CU)

To investigate the effects of reinforcement form and content on the strength behavior of silty soil, series of consolidated undrained triaxial compression tests (CU) are performed on pure soil and silt reinforced with different percentage of plastic bottle chips in different sizes. All tests have been carried out in a standard strain-controlled triaxial apparatus based on ASTM D4767 standard under the confining pressures of 100, 200, and 300 kPa [23]. All samples are prepared with of 38 mm diameter and an aspect ratio of 2. The specimens are made by a method like to that assumed for preparing specimens of usual unconsolidated undrained triaxial tests. Plastic bottle chips-reinforced silty soil was prepared with the chips contents of 0, 0.25, 0.50, 0.75, 1.00, and 1.25% by weight of dry soil with the constant width of 4 mm and keeping the dry density of all specimens constantly. The tests were repeated using three different fiber lengths of 4 mm, 8 mm, and 12 mm. Plastic bottle chips were mixed with soil randomly, and mixed soil was compacted in three layers into a split cylindrical mold. Each layer has been compacted to the required unit weight by special blows with small tamping rod.

III. RESULTS AND DISCUSSION

As discussed in the previous section, various soil samples, with and without plastic bottle chips, were tested to study the strength behavior of pure and reinforced silty soil. Now, the results of these laboratory tests will be interpreted.

A. Standard Proctor Compaction Test Result

The variations of the maximum dry unit weight and OMC with percentage of plastic bottle chips are determined. Figs. 3 and 4 show the results of Proctor compaction tests conducted on pure soil and reinforced silt mixtures with plastic bottle chips contents varying from 0% to 1.25% by the weight of dry soil. These tests were performed to determine the OMC and MDD to be used to prepare samples for laboratory test. The figures indicate that both of OMC and MDD parameters decrease with the increasing of plastic bottle chips contents in mixed soil.

B. Consolidated Undrained Triaxial Tests

A series of consolidated undrained triaxial tests (CU) have been performed to study the effect of size and content percent of plastic bottle chips as reinforcement material in silt on strength properties of mixed soil. The stress–strain response of silt reinforced with waste plastic chips at confining pressure of 300 kPa with 8 mm length is compared with the response of unreinforced sand in Fig. 5. This figure indicates that the plastic chips-reinforced silt showed higher deviator stress compared to the unreinforced specimens. The strain corresponding to the maximum deviator stress is increased by reinforcement content, but the deviator stress increases gradually with strain, and after reaching peak values, it becomes constant. The peak deviator stress for unreinforced soil is 293 kPa at 300 kPa confining pressure and it increases to 408 kPa when the silt is mixed with 1.25% waste plastic chips with 8 mm length as shown in Fig. 5.

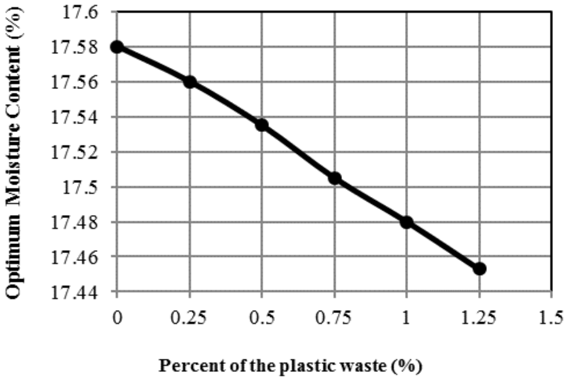

Fig. 3 Effect of reinforced material on OMC

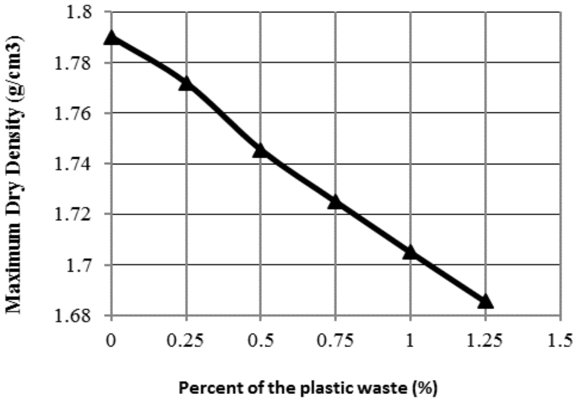

Fig. 4 Effect of reinforced material on MDD

Fig. 6 shows the typical results of pore water pressure variation versus axial strain at confining pressure of 300 kPa for the unreinforced and reinforced silt with 12 mm length. Patterns of this figure for all reinforced soil indicate that the excess negative pore pressure increased due to plastic chips. Thus, the effective stress for any given strain will be more with the inclusion of plastic waste, and hence, the reinforced silt with waste plastic chips will have a higher stiffness with respect to the pure soil. As shown in Fig. 6, increase in negative pore pressure was higher for greater percentage of plastic chips.

According to the results, the maximum cohesion value of reinforced silt was observed for waste plastic content of 1.25% with 12 mm fiber length as 51.8 kPa, which is 1.56 times more than that of the pure silty soil. Though the cohesion value is increased with increasing the length of plastic chips, the intensity of increase versus the length is relatively low for the small percentage of plastic chips content. The increase in the cohesion of reinforced samples might be due to the development of tension in the fiber, and the moisture content in the fiber favors formation of absorbed water layer on the silt particles, which enables the reinforced soil to act as a single coherent matrix of soil–fiber mass.

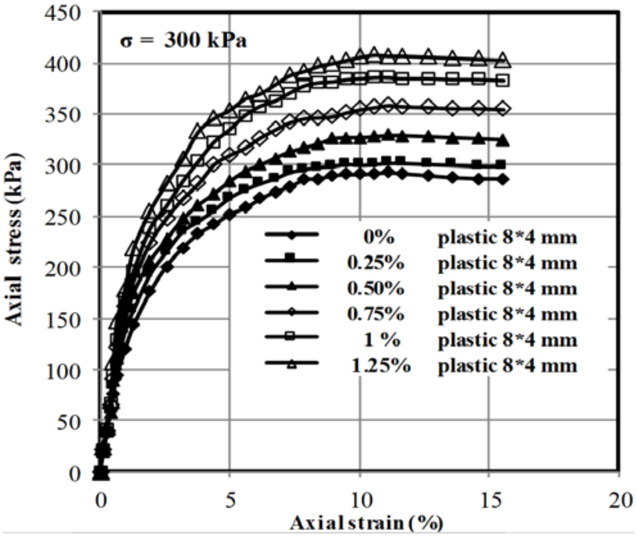

Fig. 5 Stress- strain response at confining pressure of 300 kPa

The value of cohesion increases by increasing the plastic chips length and plastic chips content. Fig. 7 shows that the variation of cohesion with plastic chips length for all of different percentage of plastic chips is approximately linear.

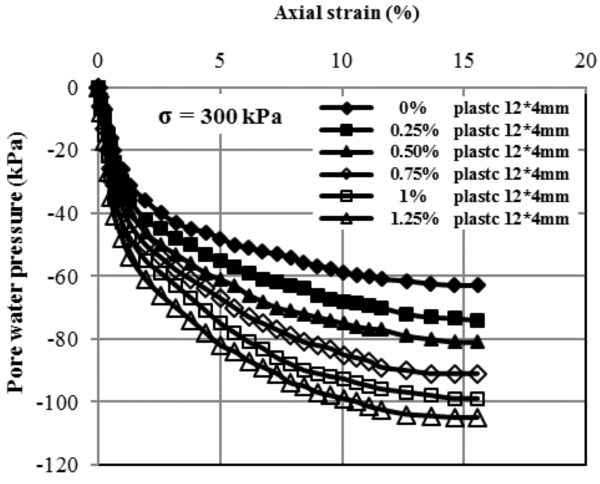

Fig. 6 Pore water pressure variations with axial strain

The variation of effective friction with plastic chips length for all of different percentage of plastic chips is illustrated in Fig. 8. Like the cohesion variations, this parameter also changes almost linearly with respect to the plastic chips length. The internal friction angle value of each reinforced sample increased and these values ranged from 13.20° to 20.1°. The maximum friction angle values of reinforced samples were observed for plastic chips content of 1.25% with 12 mm chip length as 20.1°, which is 1.53 times more than that of the unreinforced soil.

To better evaluate the influence of content percentage and length of waste plastic chips in enhancement of shear strength parameter, the normalized cohesion and friction angle (ratio of the C and Φ values of reinforced soil to unreinforced soil) variations are shown in Figs. 9 and 10, respectively.

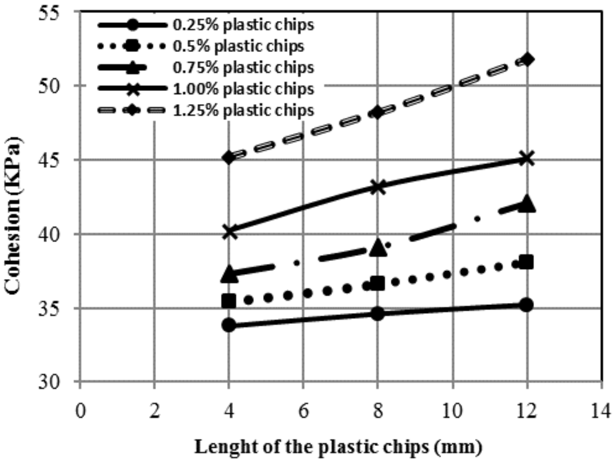

Fig. 7 Variation of cohesion with length of plastic chips

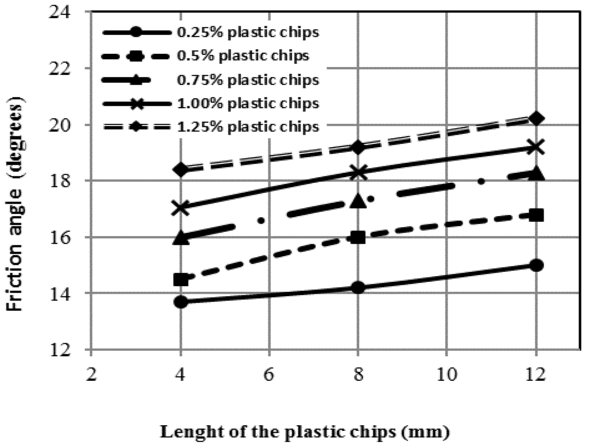

Fig. 8 Variation of friction angle with length of plastic chips

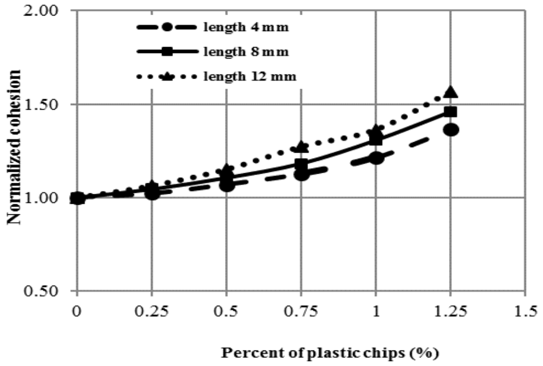

Fig. 9 Normalized cohesion with percent of plastic chips

As shown in the figures, the cohesion and friction angle of reinforced silty soil increased with the length and percentage of plastic chips. The rate of increase with increasing of length and percentage of plastic chips increased.

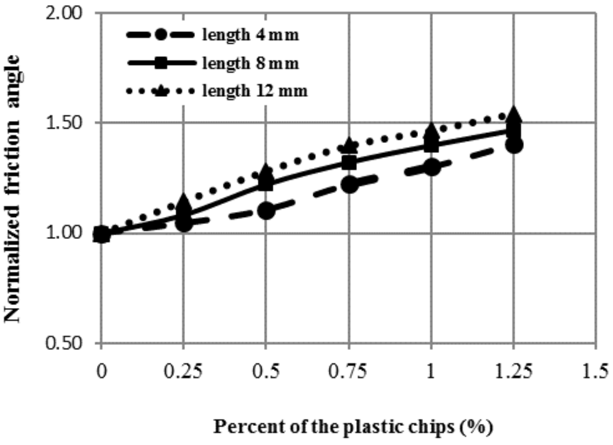

Fig. 10 Normalized friction angle with percent of plastic chips

IV. CONCLUSIONS

According to the laboratory tests conducted to investigate the effect of using the various percentages of waste plastic chips with different length as reinforced material to improve the strength behavior of silty soil, the following conclusions are obtained:

When the silty soil is reinforced with the waste plastic chip, the dry density of the soil due to a low specific gravity and unit weight of plastic chip decreased. The MDD of reinforced soil ranges from 1.790 to 1.685 g/cm^3. The increase in the waste plastic chip percentage reduces the dry density of the reinforced soil and the variation is approximately linear.

Based on laboratory tests, the amount and length of plastic waste bottle chip played a significant role in the increase of the strength of silty soil. The increase in strength is due to the confinement effect which results in the increase of cohesion and friction of soil.

Pattern of the stress–strain response of silt reinforced with waste plastic chips and pure soil at various confining pressure indicates that the plastic chips-reinforced silt showed higher deviator stress compared to the unreinforced specimens, and the strain corresponding to the maximum deviator stress is increased by increasing of reinforcement content.

By increase in plastic waste chip content, the value of cohesion and internal friction angle of each reinforced silty soil increased.

The increase in shear strength is a function of confining pressure as well as plastic waste length and their percentage.

The effective stress for any given strain will be more with the inclusion of plastic waste due to the excess negative pore pressure. Thus, the silty soil with plastic waste bottle's chips will exhibit a higher stiffness than unreinforced soil.

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