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Examining the Performance Specifications of Dunesand Reinforced with Fibers Recycled from Waste Yarn Textiles in Subgrade

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Abstract

In the present study, the mechanical behavior of dune sand, harvested from the central desert, and reinforced with recycled fibers, has been investigated. The recycled fibers are made of yarn twisting with an average thickness of 0.11 mm and a width of 5 mm. The purpose of this study is to evaluate the role of reinforcing fibers in California bearing ratio (CBR), soil density in terms of weight percent (Wr), and the fiber's longitudinal (L) dimensions. Besides, in the present study, the results obtained from determining CBR and density were provided and analyzed. The variables considered in this study include utilizing one type of disposable plastic fiber waste in different weight percentages in the form of random reinforcing in the granular embarkment. The present study was a small-scale laboratory, and the CBR device is used. The results show that with the use of waste fiber in sandy soil, the bearing capacity has significantly increased. The optimal weight percentages of plastic pieces relative to the sand fell in the range of 2-2.5%. Moreover, adding fibers to the soil has reduced the maximum dry density and also the samples' ductility. The CBR curve, in terms of fibers' weight percentage, shows an incremental trend. However, the slope of the resistance change curve decreases in terms of fiber weight percentage; That is, from one place to another, adding fibers does not significantly change the resistance.

Keywords: reinforced soil, fibers, CBR, density, dune sand, recycling.

1. Introduction

Generally, soil reinforcement is a technique to enhance the soil resistance using the reinforcing elements for dealing with the soil's tensile weakness; Also, to protect the environment, various types of recycled materials are used in pavement and new asphalt mixtures (Nabiun and Khabiri, 2016). In recent years, several studies have been performed on utilizing reinforced soil and the bearing capacity of the granular soils. In many studies, the attention has been only focused on the subsoil reinforced with materials including geosynthetics, metal straps and belts, and even rubber pieces and wastes and polyethylene terephthalate tapes and fibers (Hejazi et al; 2012); and the utilizing waste pieces from polyethylene plastic with 3D function has not been considered in the embarkments. In the present study, examining the effect of using plastic waste pieces on enhancing the bearing capacity of the granular soils has been addressed.

Throughout history, using the reinforcing elements in the soil has been of human interest. Using the chaff and straw for reinforcing soil (thatch mortar) has been common since ancient times, and is still used. Today, the soil reinforcement is one of the branches of geotechnics science. By using scientific principles and novel technologies, this branch uses the appropriate materials for reinforcing soil to enhance the engineering specifications and mechanical properties such as resistance, stiffness, ductility, and bearing capacity. The materials used for reinforcing the soil include metals, polymers, and plant parts(Hejaziet al; 2012). The mechanism of action and behavior of traditional reinforced soil depends on the mutual effect between soil and reinforcing materials. The friction phenomenon between soil and reinforcing elements plays a significant role in the reinforced soil(Kumar et al; 2015).

Mixing with fibers is one way for reinforcing the soil. By mixing these elements into the soil, a mixed medium is created in which the interaction of tensile components (reinforcing elements) with soil grains enhances the strength and ductility of soil in different directions (Kumar et al; 2015). Although some plants' parts have been historically used for reinforcing the soil, from about half a century ago, extensive research has been performed on the recognition and evaluation of the mechanical behavior of fiber-reinforced soil.

Natural loose soil available in the projects' sites is not always suitable as a substrate. Considerable settlement may occur in the poor soil as the load is applied. Reinforcing poor soils for use in slopes and road subgrades to create earth configuration with desired engineering properties is an essential field in civil engineering. The consolidations, compression, pre-loading, reinforcement, etc., are methods for reinforcing soils. The reinforced soil, among these methods, has attracted considerable attention in recent years.

Increased plastic waste and its extensive environmental pollution have become a significant challenge(Comăniță et al., 2016). Plastics are wastes that have high mechanical and tensile strength and rarely react with acids and bases and other chemicals; besides, plastics are completely resistant to

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micro-organisms, and as a result, they remained unchanged in nature for many years. In this regard, many works have been conducted to find an appropriate solution to eliminate wastes and or reuse them as alternative materials in civil engineering (Grad ,2021). In the reinforced soil method, given that soils do not have enough tensile strength to resist applied load, some tensile elements, including metal tapes, geosynthetics, and waste plastic, are used in the soil (Kumar et al, 2015). It should be noted that utilizing plastic wastes in soil remediation is not costly, and therefore, this type of reinforcement is economically essential.

In recent years, the economic and environmental problems have led to utilize waste resulting from Worn tires, bottles, glasses, etc. to modify and enhance the soil specifications. The soil's reinforcing and stabilizing methods are usually performed using geosynthetics, cementing agents (lime, cement, etc.), synthetic and non-synthetic fibers, or rubber crumbs (Jamshidi et al., 2018; Rezaeimalaek et al.2017; Mousavi and Karamvand, 2017; Estabragh et al. 2017; Hamidi and Hooresfand 2013; Malidarreh et al. 2018). Saberian and Khabiri (2017) investigated the effects of coal on pavement performance in mine haul roads. Their research indicated that with an increase in coal the maximum dry density, California bearing ratio before (CBR), and coefficient of permeability increased. Stabilized or reinforced soils are usually composite materials that are obtained from combining and optimizing the properties of every single ingredient. One of the pioneer methods in modifying soil specifications is utilizing plastic materials obtained from bottles.

During the last decade, many studies have been performed on utilizing reinforced soil to increase the bearing capacity of granular soils. In most cases, it has been observed that research has been limited to the embarkment reinforced with geosynthetics and metal straps and belts(Abu-Farsakh et al, 2007; Yan et al, 2010; Ferreira et al, 2015), and utilizing plastic wastes in the embarkments have not been taken into accounts. Therefore, this study investigates the effect of using plastic wastes to improve the bearing capacity of granular soils. The variables considered in this study include utilizing one type of disposable plastic fiber waste in different weight percentages in the form of random reinforcing with specified layering in the granular embarkment. In this research, the plastic parts obtained from polyethylene terephthalate bottle wastes, used for packaging and storage of beverages such as soft drinks and water, are used for improving sandy materials. The existence of plastic parts will cause considerable changes in the shear and tensile strengths of reinforced soil. The tests have been performed on the materials without/with reinforcing materials, for different irregular (random or scattered) and regular (with specified layering) weight percentages.

Various research has examined the load-displacement behavior of a kind of needle-shaped non-woven geotextile under the free and fixed conditions on the clay layer (equivalent to soft bed) from natural mines, and also beneath the sand layer (equivalent to subgrade) using the modified CBR tests with a specified mold. They concluded that geotextiles would increase the bearing capacity of the pavement, which increases as the settling increases (Garber and Rasmussen, 2010; Sudarsanan et al, 2018).

Research has investigated the strain-stress behavior of sand reinforced by scattered plastic fibers by performing three-axis compression tests. They have concluded that the plastic fiber-reinforced soil has higher tensile and shear strength compared to sandy soil. Besides, they have observed that reinforced soil will be fractured in higher strains than the sandy soil. According to their investigations, it can be concluded that the strain-stress behavior of the sand reinforced with scattered plastic fibers depends on fibers' specifications and fibers-sand friction (Lee and Barr, 2003).

In a field study, the engineering behavior of sand was reinforced by strip wastes made of polyethylene terephthalate (PET) plastic. The reinforcing material used in their investigation was fibers obtained from plastic bottles that have been used with/without quick-setting Portland cement. They performed some uniaxial and three-axial drainage tests on the samples. Their results indicate that utilizing plastic wastes, both in cemented and non-cemented cases, will increase the yield and ultimate strengths of the samples(Peddaiah et al., 2018).

In a recent study, some experimental tests have been performed to evaluate the strength and stiffness of the granular soil. The soil was stabilized chemically with cement and fly ash and mechanically with a thin cut of compressed recycled polyethylene terephthalate plastic (obtained from recycling plastic containers for water and milk). They concluded that using plastic waste strips with appropriate length and weight percentages can enhance the integrity between pavement materials, which delays and prevents the propagation of tensile cracks in the pavement. Besides, they reported that utilizing plastic waste materials will improve strength and mechanical specifications in the pavement mixture. Some researchers investigated the effect of polypropylene fibers on the mechanical specifications of the cemented and non-cemented clay soil using unconfined compression and direct shear tests. Their results indicate that an increase in plastic fibers in cemented and non-cemented fibers will lead to an increase in compression strength, shear strength, and axial strain at the fracture time and flexibility; on the other hand, it will lead to a decrease in concrete stiffness. From the electron microscopy tests, they concluded that utilizing plastic fibers increases the integrity between the materials, increases the internal friction angle, and reduces the cracking (Mishra & Gupta, 2018).

In a case study, a specific method for producing PET fibers from waste drink bottles was proposed to produce fiber-reinforced concrete. They compared specifications of different types of fibers, including polypropylene and polyvinyl alcohol, with PET fibers. According to the comparison, it was concluded that the PET fibers, among the others, have higher Alkaline resistance and are more appropriate in terms of water penetration depth test. Also, by performing bending and uniaxial tests, they concluded that by increasing the weight percentage of fibers, the compressive and tensile strengths of the reinforced concrete are increased.

In another research, the waste plastic strips and volcanic ash were used to reinforce the soil. Different amounts and sizes of these stripes have been used to investigate the effect of their sizes. It was found that by increasing the plastic strips in the saturated clay, the bearing capacity and scant modulus are increased. With an increase in the number and length of these strips, the increase in bearing capacity and scant modulus increases. The increase in the bearing capacity increases until the optimal value of 2%. However, by increasing the number of plastic strips, no changes in the bearing capacity are seen (Salimi, & Ghazavi, 2019).

Today, the soil reinforcement is one of the branches of geotechnics science. Using scientific principles and novel technologies, this branch uses the appropriate materials for reinforcing soil to improve the engineering specifications and mechanical properties. The elements used for reinforcing soil include metals, polymers, and plant parts. The mechanism of action and behavior of traditional reinforced soil depends on the mutual effect between soil and reinforcing materials. Soil-reinforcing material friction plays a significant role in reinforcing soil. One method for reinforcing soil is mixing the soil with fibers randomly and disorderly. Different studies materials such as compost, silica, bentonite, and various types of ash have been used to improve the clay specification (Firoozi, et al. 2017). In these methods, a mixed environment is created in which the interaction of tensile (reinforcing) elements with soil grains improves the strength and ductility of the soil. Although soil reinforcement has a long history, during the recent half-century, extensive research has been performed to identify and evaluate the mechanical behavior of fiber-reinforced soil.

In research, the samples are reinforced with fiber by triaxial tests, and a criterion has been provided, based on the experimental and theoretic studies, for the fracturing of sand reinforced with steel fibers and polyamide. According to their results, it was found that reinforcing soil will increase the compressive and shear strengths of the soil. On the other hand, reinforcing soil improves the response of soil mass to the dynamic loads, increases the soil's dynamic shear module, reduces the liquefaction potential, and increases the soil's ductility. According to the literature review, the present study aims to examine the qualitative specifications of the sandy soil, including density, bearing capacity, and penetration, along with different contents of recycled polymer fibers available in the packing industries' wastes.

2. Methodology

In this study, the dunesand prepared from the countryside of Yazd city has been used. The crushed polymer fiber particles with sizes of 5mm to 15mm and a density of 1.2kg/cm^3 were provided from recycled factory products to reinforce the soil. Then, the recycled polymer fibers were mixed with sandy soil with weight percentages of 0.0, 0.25, 0.5, and 1, to determine their effect on the qualitative parameter in the lab.

To prepare and reinforce soil, the Sandy soil sample was first held at a temperature of 115 °C and dried in the oven. After preparation, the particles were separated by a scissor. To prepare polymer waste fibers, first, pass the polymer fibers through a 200 sieve; so that the adhered particles separate from the polymer fibers.

3. Determining soil's mechanical specifications

In this study, the following tests were used to determine the subgrade's qualitative specification of primary and secondary roads before and after being reinforced with recycled fibers. It should be noted that all soil's mechanical tests have been conducted according to the American society for testing and materials (ASTM) standards.

3.1. Dunesand

The soil used in this study as mentioned, the eastern deserts of Yazd were sampled at three points and since the characteristics of the sampled soils were the same, three soil samples were mixed to continue the work. Figure 1 shows the soil sampling location. This soil is of sedimentary dune sand type with uniform granulation. The unified soil classification system (USCS) falls in the SP-SM soil group, its specification is provided in Table 1.

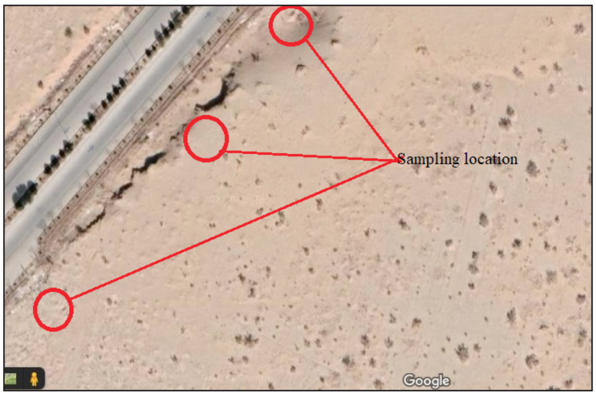

Figure 1. Sampling location

Table 1. Specifications of the soil used in this study.

Soil type	SP-SM
G_s	2.7
D_{50}	0.14 mm
Sand content	93.9%
Silt content	5.61%
Clay content	0.49%
C_u	4
C_c	1-3

Figure 2 shows the soil granulation curve. This soil has been prepared from the desert around the Yazd province located in the central desert.

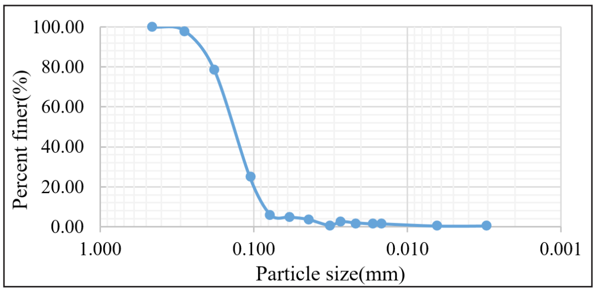

Figure 2. The granulation curve of the quicksand.

3.2. Waste textile fibers

The element used was made of thin and short fibers provided by the waste textile after being consumed. The reinforcing elements are generally polyethylene and aluminum types, with an average thickness of 0.11mm and a width of 5mm. In the soil-fibers mixture, fibers are mixed with 0.0, 0.25%, and 0.5% by dry weight of soil and longitudinal dimensions of 1, 5, 9, and 13. The density of fibers is G_r =1.18, and the maximum tensile strength and the initial elasticity module, according to the tensile tests (ASTM D4595), were 107 MPa and 9611 MPa. Figure 3 indicates these fibers and sand aggregate.

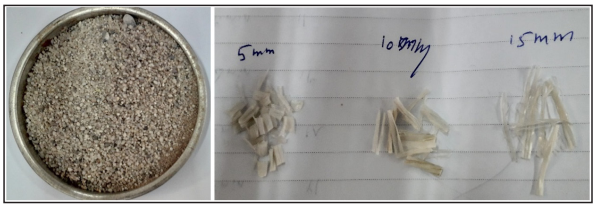

Figure 3. A sample of fibers with different dimensions and sand aggregate.

3.3. Samples preparation

The dry soil, fibers, and water were used to prepare samples. Given the geometrical specifications, density mold, and fibers content, and for better mixing of soil and fibers, the soil, first, was moistened with about one-third of water (Optimal moisture percentage), and then the fibers were added. In the following, by gradually adding the remaining water and fully mixing the mass by hand, the sample moisture is increased to the optimal limit (14/5%) so that a homogeneous mixture is obtained. Then, the samples of CBR and compression tests were prepared using the standard method. It should be noted that 27 samples were prepared in this study; So for each percentage of fibers in a specific test, three samples were prepared and tested. The reinforced samples are shown in Figure4.

Figure 4. A reinforced sample

3.4. Compression test

These tests have been performed according to the ASTM D1557-78 standard in a small mold on samples of primary sandy soil and reinforced soil. Details of the performed tests are shown in Figure 2. This figure indicates the variations of maximum specific gravity in terms of moisture for soil and reinforced-soil samples (Wr= 0.0%, 0.5%, 1%).

3.5. Permeability test

The permeability coefficient shows that the amount of pores in the soil causes the way water moves in the soil. In this research, the permeability test of primary sandy soil reinforced with fibers according to the ASTM D 2434 standard was performed(Figure 5).

Figure 5. A view of the sample in the permeability test

3.6. California bearing capacity (CBR) test

This experiment was performed to investigate the effect of weight percentage (Wr) and dimension ratio (LR) parameters of recycled synthetic fibers on the load-bearing capacity of primary and fiber-reinforced sandy soils. For this evaluation, CBR experiments were performed on soil and reinforced soil samples containing weight percentages (Wr) of 0, 0.25, 0.5, 0.75, 1% and dimension ratio (LR) of 13.9, 5, 1. In this study, the samples were based on ASTM D1557 compact standard and the CBR test was performed by ASTM D1883 standard method (Figure 6).

Figure 6. A sample of the CBR test

The samples were consolidated according to the ASTM D1557 standard, and the CBR test was performed according to ASTM D1883 standard. The details of the sampling method, how to perform tests, and the results obtained are described in the following. After preparing the mix according to clause 3, the mix was consolidated in 5 layers (by ASTM D1557 standard method) inside the specific CBR molds. As the sample was made, a loading was applied to the sample in the CBR test device with a penetration rate of 1.27 mm/min. The load applied was continued until the approximate penetration of 12.7 mm of the mandrel in the sample, then the results were recorded. In the next step, the samples were consolidated again using the same method mentioned above, and then the required overhead weights grid was placed on the mold containing soil, and the samples were immersed in the water reservoir. After 24h, the samples were removed, and after drainage of the additional water from the sample (about 15 min), the sample undergoes a loading according to case A.

4. Results

4.1. Analysis of compression tests results

By examining Figure 7, it can be found that in constant compression energy, by adding fibers to the soil, the maximum dry specific gravity of the samples reduces. This may be attributed to the lower density of reinforcing elements compared to the soil particles. On the other hand, the placement of these elements between the soil particles prevents the particles from getting closer to each other. As a result, these factors will reduce maximum dry specific gravity in the reinforced samples.

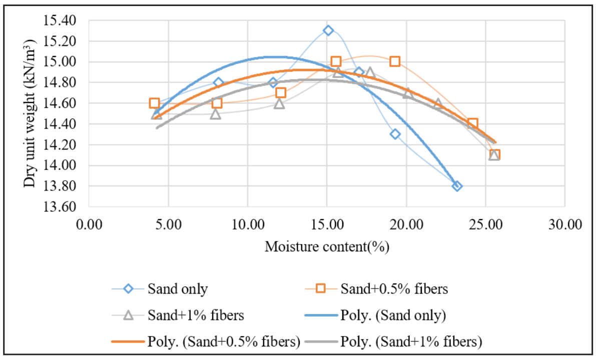

Figure 7. Plot showing the compression curves of soil and reinforced soil.

According to Figure 6, it can be seen that with an increase in the weight percentage of reinforcing elements, the sample's optimal moisture percentage increases. The reason for this increase may be attributed to the increased porosity of the samples.

Some other researchers, in a part of their studies, investigated the behavior of the sand reinforced with artificial fibers in the compression test (Claria and Vettorelo; 2016). Their results suggest that fibers have no significant effect on reducing dry specific gravity and an increase in the moisture percentage. Similar results were reported by studying the laminated sand with polyester synthetic fibers. In sum, it can be concluded that the addition of a reinforcing element with a specific gravity less than that of soil will reduce the maximum dry specific gravity and increases the optimal moisture in the samples.

4.2. Analysis of permeability tests results

Drainage of surface waters, which is penetrated pavement structure through cracks, is essential. Entering these waters into subgrades and the layers without cohesive material and remaining in these layers will reduce the strength and increases the damage. Impermeability of the substrate or foundation prevents the surface water from penetrating the subgrade and reducing its strength, which effectively reduces failures due to cracking and rutting of the pavement. The permeability test of recycled fibers-reinforced samples in different content was performed according to the ASTM D2434-87 standard. Figure 8 is depicted to show the results of permeability tests on three different mixtures that have been stabilized with different contents of additives. As can be seen from the figure, by adding the additives, the permeability rate has considerably reduced, and the permeability of three types of soil with additive content of 0.75% has reached zero.

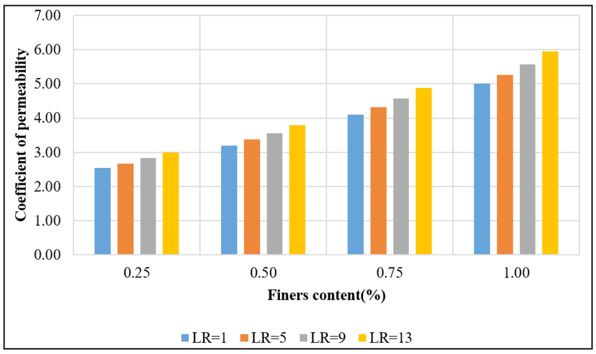

Figure 8. Results of the permeability test.

4.3. Analysis of CBR tests results

The permeability-stress curves obtained from CBR tests that are performed on the reinforced and non-reinforced sands with 0, 0.5%, and 1% by dry weight of soil and L of 1, 5, 9, and 13 in the moisture and submerged conditions are shown in Figure 9 to Figure 16. These plots indicate the behavior of brittle materials (such as dense sands of stiff clays) for non-reinforced samples in both optimal moisture and submerge conditions. by adding fibers to the soil, a turning point appears in the permeability-stress curve, so that in low penetration, the strength in reinforced soil is less than that of non-reinforced soil. This trend will increase as the content and L of the fibers is increased. It should be noted that the CBR plots for different soils usually have one turning point that is due to the non-uniformity of the sample surface and its complete contact with the loading piston at the test start. In this case, the plots must be modified according to the standard method. However, since no turning point is seen in the non-reinforced soil plot, these plots have not been modified. In other words, the creation of a turning point is usually due to the effect of the fiber.

Besides, adding fibers to soil increases the soil strength and permeability at maximum strength, and also reduced the distance between peak strength and post-peak strength. This means that by adding the fibers, the samples become more ductile.

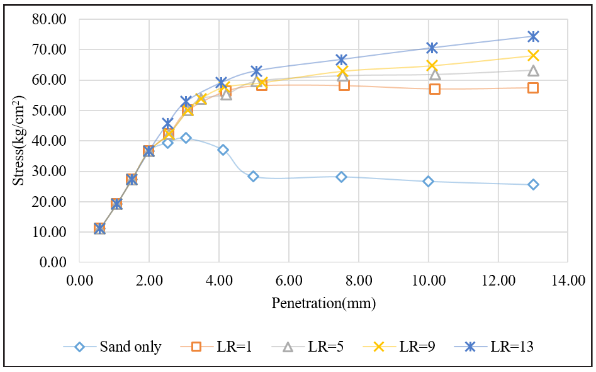

Figure 9. The variation of stress in terms of mandrel penetration for samples with optimal weight percentage and L in CBR test.

Examining these plots show that the increase in CBR (about 3%) is for submersion and optimal moisture occurs at LR=1. While, for LR=13 in the submersion and the optimal moisture cases, this increase is 22% and 17%, respectively. In the constant fibers content, the number of fibers in the longitudinal direction is more, which can indicate the higher effect of fibers length against their numbers in the reinforced soil mass. This behavior may be due to the increased lap-length of the reinforcing element as the L increases; this will improve the mutual effects of the soil and reinforcing materials.

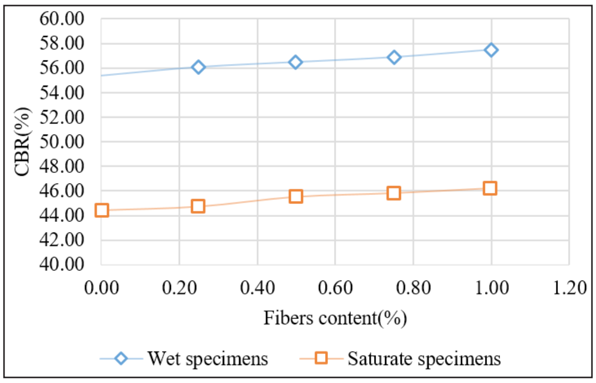

Figure 10. The CBR variations in terms of fibers' weight percentage for samples with optimal moisture and submersion with L=1.

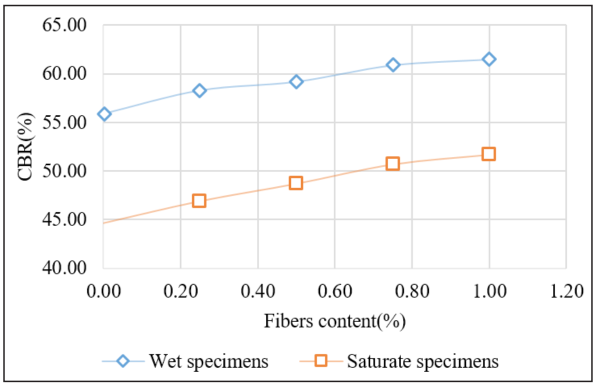

Figure 11. The CBR variations in terms of fibers' weight percentage for samples with optimal moisture and submersion with L=5.

Figures 9-11 show the CBR variations of samples with optimal moisture and submersion against fibers' weight percentage. The plots show a reduction of about 11 units for CBR of the submersion case compared to the case with optimal moisture. The reason for this reduced strength can be attributed to the uniform granulation of soil due to the loss of capillary force in submerged cases relative to optimal moisture conditions. Besides, increased pore pressure and reduced friction force between the soil particles are the other reasons.

Figures 13 and 14 show that by increasing the weight percentage of the elements, the CBR increases; however, this increase has a decreasing rate, which indicates the existence of an ultimate limit for the addition of reinforcing elements. This is because of the replacement of fibers with soil grains. In fact, by adding fibers, they gradually change the nature of composite mass.

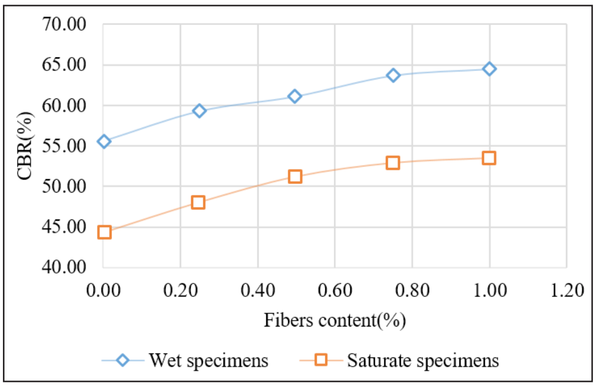

Figure 12. The CBR variations in terms of fibers' weight percentage for samples with optimal moisture and submersion with L=9.

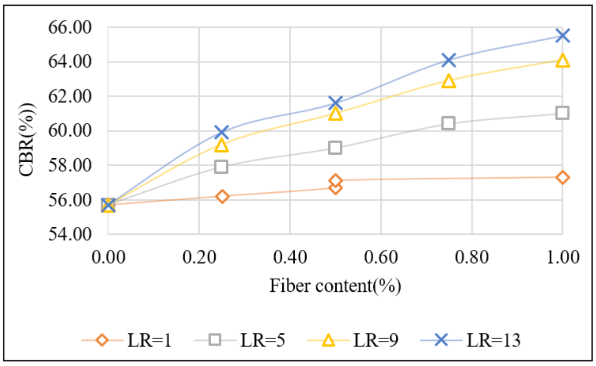

Figure 13. The CBR variations in terms of fibers' weight percentage for samples with optimal moisture.

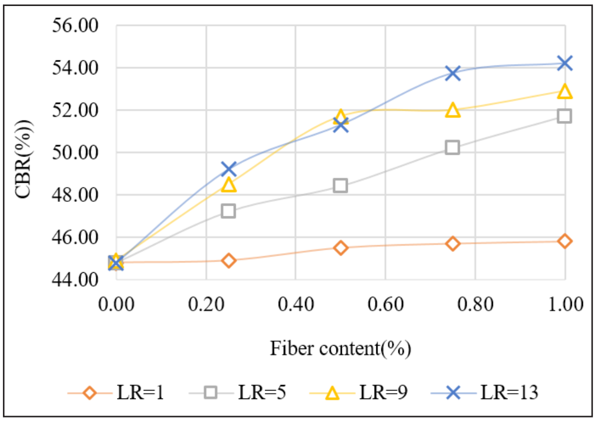

Figure 14. The CBR variations in terms of fibers' weight percentage for submerged samples.

On the other hand, from Figures 15 and 16, it is evident that by increasing the L of reinforcing elements, the slope of the plots decreases. This suggests that the increased rate of CBR against the fibers' length is decremental. This may be attributed to the increase in reinforcing materials' deformation as their length increases, such that by increasing the elements' length, the possibility of bending and thus reducing their length increases during sampling. This effect of reinforcing elements on the CBR strength is also reported by other researchers (Patel, & Singh, 2019).

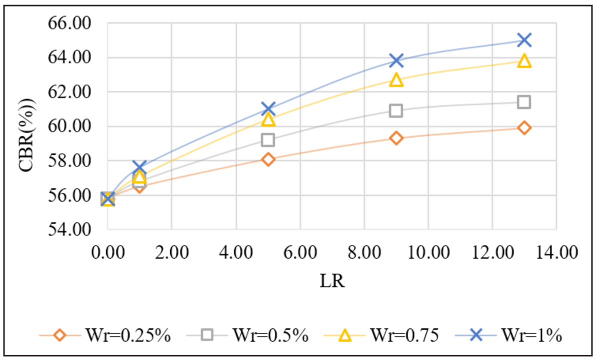

Figure 15. The CBR variations in terms of L of reinforcing elements for samples with optimal moisture.

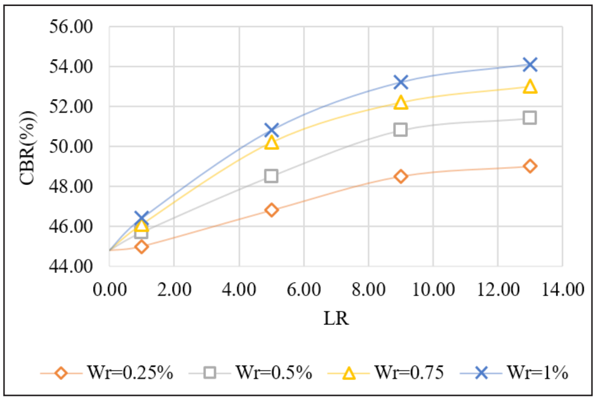

Figure 16. The CBR variations in terms of L of reinforcing elements for submerged samples.

5. Conclusions

The results of this study regarding the use of waste fibers can be summarized as follow:

Results show that adding fibers to the soil reduces the maximum dry density and increases the CBR and deformability of the samples. The variations of CBR curves in terms of fibers' weight percentage have an increased rate. However, the rate of the slope of the strength curve in terms of fibers' weight percentage has a decreasing trend. The effect of an increase in L on the CBR of samples is also similar to the Wr effect.

With the addition of reinforcing elements to the soil, the specific gravity of the set is reduced. On the other hand, it is expected that by increasing the fibers' weight percentages in the soil, the porosity increases enough which reduces the soil strength. By the examining results of CBR tests with constant weight percentages of fibers and different LR, it was found that the elements' length plays a more significant role than their number. This result indicates the effect of a minimum value for the lap-length of reinforcing elements.

An increase in the reinforcing elements in the sample will increase the optimal moisture compared to the non-reinforced sample. This may be attributed to the increase in the porosity of the sample due to the addition of fibers. Adding reinforcing fibers to the soil increases the CBR and reduces the stiffness, and improves the ductility of the sample. However, the increasing trend of the strength has a decreasing rate, indicating the existence of an ultimate limit for using fibers in both weighted and longitudinal cases. This means that, after a certain weight percentage and L, the addition of fibers has no positive effect on the soil bearing capacity.

Submerging samples will decrease their CBR values compared to samples with optimal moisture. The reason behind this can give the uniform granulation of soil due to the loss of capillary force in submerged cases relative to optimal moisture conditions. Besides, increased pore pressure and reduced friction force between the soil particles are the other reasons.

Using reinforcing fibers of the soil must be examined in terms of durability; however, due to the very low permeability of the soil reinforced with this material, it is expected that the repetition of frost and thawing has no significant effect on its performance.

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