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Soil reinforcement by re-using liquid packaging waste materials as a geotechnical engineering application

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ABSTRACT

The soil reinforcing procedure is a technique utilized to improve some soil's engineering properties. In this study, a laboratory test is improved for re-using liquid filling packaging waste made of Polyethylene Terephthalate (PET) for reinforcing a specific type of sandy soil in Baghdad province in Iraq. These types of plastic waste are chosen due to the recent increase in their quantity in Iraq for their multiple uses, which led to becoming an urgent environmental issue that must be disposed of by re-using it in several areas, including soil reinforcement. The plastic waste utilized in the presented work is prepared in strips to form with different dimensions ranging from 20 to 60 mm in length and width of 20 mm. In addition, the plastic strip mixture is added to the sandy soil sample used in this study at a weight rate of 0.5% of the weight of the used sample. The outcomes of laboratory experiments are represented by direct shear tests and bench-scape plate loading tests. The results revealed an improvement of the soil sample through some laboratory tests, indicating that this substance's inclusion in the selected sandy soil sample effectively reinforces this type of soil in the Baghdad governorate.

Keywords: Soil reinforcing, packaging waste, Polyethylene Terephthalate, shear tests

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1. Introduction

Soil reinforcement or soil stabilization is an old procedure for improving soil engineering properties. This technique is known as all chemical, biological, and physical treatments in addition to various natural or manufactured materials that might be added to the soil to improve the physical properties [1]. To improve the soil's physical properties, many researchers have studied the advantages of adding some materials to several kinds of soil, especially the weak clayey soil. These materials differ in their physical and chemical composition, such as lime, cement, plastic waste, etc. These materials increase the soil bearing capacity and other soil properties [2, 3]. In addition, most of these materials (stabilizers) do not provide efficient treatment for the sandy soil containing large silica amounts [4]. Therefore new methods of improving the material properties of sandy soils are still required. These materials seem uneconomical in some countries or, in some cases, need huge quantities of these materials, so alternative methods and materials should be adopted. Owing to its cheap, none-breakability and low weight, PET is a liquid packaging material of high importance in the world. The world's annual consumption of plastic bottles is rising yearly, and PET is one of the major abundant plastics wastes [5].

Serval studies highlighted the role of using liquid packaging bottles waste in soil reinforcement applications. For instance, in 2013, Laskar and Pal stated that bottle waste could be used as a soil reinforcing element for minimizing settlements or consolidations with the advantage of increasing the soil consolidation rate [6]. Also, Neopaney et al.[7] found through a sequence of California Bearing Ratio (CBR) experiments performed on randomly-reinforced soil via different percentages with different properties and lengths of plastic strips. CBR test results show that using waste plastic strips regarding soil reinforcement with sufficient quantities significantly enhanced resistance and deformation behavior related to subgrade soils. Furthermore, the suggested approach is used to construct embankments/roads, industrial yards etc. The increase in demand for this substance in the past few decades has generated large tons of waste, making it one of the challenges facing decision-makers in preserving the environment, wildlife and marine life [8-10]. In Iraq, a significant increase in the volume of waste produced from this material has been observed (see Figure 1). It is in the form of liquid packaging bottles. Due to the lack of waste recycling plants in Iraq, intelligent solutions must be found to benefit from it for various engineering purposes, mainly soil stabilization.

Figure 1. Collecting liquid packaging bottles and plastic waste in one of the Iraqi governorates

This study considers a laboratory analysis of soil engineering behavior enhanced with PET plastic waste. The main aim of the presented work is to find how waste plastic bottles are used effectively in geotechnical engineering applications, thus discussing certain aspects of plastic waste bottle recycling without adversely affecting the environment.

2. Materials and methods

2.1. Technical facts and soil properties

Common engineering characteristics of the soil in Baghdad through soil investigations carried out by the National Center for Construction Laboratories in Baghdad. Extensive statistical studies were carried out to determine the major engineering characteristics of soil layers in Baghdad. It can be summarized that the soil in Baghdad has acquired specific properties that are less similar to other cities. Due to the early human activity that accompanied successive civilizations for thousands of years (where most of the activity was agricultural). The methods used for irrigation and drainage led to rapid change in soil and its variation from one region to another.

Additionally, it altered the course of the river that deposited sandy soil when it flooded near the river's edge. At the same time, the water carries alluvial and soft substances to the distant regions of the river and deposits them. Thus, the succession of layers in this city is asymmetric and random (erratic). Generally, some areas have a higher burial layer, followed by a layer of coherent natural earth composed of brown clay or brown clay silt of medium to very hard. It is followed by a layer of sand or silty sand of medium to very dense density, and groundwater level ranges between (2.0 - 0.6 m) below the earth's natural surface. It is lower than the Tigris river because the area near it is paved.

For the soil's natural humidity of Baghdad, it ranged between (30-17%) and the water limit for the soil of the city of Baghdad, in general, ranged between (55-25) except for some high values (more than 60%), which gives an indication. In the presence of swollen soil, the values of the plasticity index in Baghdad ranged between (37-9) %, indicating the presence of medium plasticity in plastic soil. In contrast, the strength of the soil (Undrained Shear Strength) ranged between (250 - 25) kn/m2, which indicates that it is a medium to solid soil. The angle related to internal friction of granular soil ranges between (41-32) degrees. The carrying

capacity ranged between (15 - 5) tons / m2 and (150 - 50) kn/m2 to ensure precipitation within the permissible limits. Soil is also described as soil over-joining, ranging from low to very low, and the permeability of the soil ranges from low to very low. Furthermore, the existence of a high percentage of sulfate concentrations necessitates using salt-resistant cement type V in all concrete works adjacent to the soil since the soil of the city of Baghdad is alkaline soil. Gypsum has been found in the cohesive upper soil of Baghdad in many areas, such as Sheikh Omar, Al-Sadr, Al-Wehdah, Riyadh, Al-Waziriya and Al-Mustansiriya.
In this study, the classification and description of Baghdad soil profile according to the depth made by Buringh in 1960 (see Table 1) and the database for Baghdad soil that was initiated using GIS techniques by [11]. Also, the classification and distribution of Iraqi soils results were created by [12]. They were adopted in this study as soil properties and technical facts for the soil in the study area. This study has been carried out with local silty clay loam (clay = 37%, silt = 51.6% and Sand = 11.4%). The engineering and physical characteristics of the utilized soil are listed in Table 2.

Table1. Baghdad soil profile according to the depth [13]

Depth	Soil type
0-20 cm	Friable when moist, hard when dry, angular blocky porous Silt Loam and dark grey-brown.
20-75 cm	Extremely friable when moist, hard when dry, porous Silty Clay, sub-angular blocky and dark brown.
75-135 cm	Friable, porous Silty Clay Loam, sub-angular blocky and brown.
135-225 cm	Porous, friable, dark yellowish-brown Silty Clay.
225-285 cm	Porous Loam, friable and brown.
285-350 cm	Friable, dark-brown, porous Clay Loam and water table at 340 cm.

Table 2. The engineering and physical characteristics of the used soil

Property	Test result
Physical Properties	
Liquid limit (%)	30.39
Plasticity index (%)	8.87
Specific gravity	2.41
Shrinkage limit (%)	22.17
Plastic limit (%)	19.50
Grain size:	
Clay (%)	37
Silt (%)	51.6
Sand (%)	11.4
Engineering Properties	
Permeability (m/s)	6.40E-10
Maximum dry density (MDD) (kN/m3)	18.14
Shear angle (ϕ) (in degree)	10.45
OMC (%)	16.80
Compression index (Cc)	0.12

2.2. Used Plastic Material

The PET is made from petroleum hydrocarbons through ethylene glycol reaction to terephthalate acid. This material is mainly characterized by its high density. It is widely used in packaging liquid foodstuffs of all kinds. These materials are cheap, making them economical in addition to their durability and strong Barrier to Moisture. Because of its distinctive qualities, it is considered one of the excellent additives for soil stabilization for enhancing soil engineering properties. For PET, the chemical formula was $(C_{10}H_8O_4)_n$ [14].

2.3. Prepare plastic samples

According to the literature, the properties related to reinforced soil with the plastic waste change with addition to the plastic waste strip content with different sizes [2, 14]. Thus, three types of plastic samples were prepared in three different sizes (20 mm) in length and three different widths (20, 40, and 60 mm) (see Figure 2).

Figure 2. Prepare three plastic samples of different sizes

The percentages of the plastic material added to the soil sample were determined by default. The values of these percentages are 40, 60, and 80%. By employing equation 1, the plastic strips' quantity is added to soil samples. The quantity of plastic strips added to the raw soil sample was determined according to Equation 1. After mixing the soil samples with the necessary amount of plastic materials, a little water was added to the samples to make them slightly moist.

$$Wp = aWd \qquad (1)$$

where: Wp refers to the quantity of plastic strips, a can be 0.40, 0.60 and 0.80% of waste plastic contents, and Wd indicates the amount of raw soil (in grams).

The waste plastic strips were added to the raw soil with optimum moisture content (OMC), then kept in an airtight bag within lab conditions for 24 hours at (27 C) (see Figure 3). Three mixture samples were prepared to use in soil reinforcement tests.

Figure 3. One of the three mixture samples

2.4. Test methods and procedures

A Series of laboratory tests will be carried out on mixed soil with plastic waste and raw soils. CBR, Direct Shear Test and Compaction test have been carried out in 2 cases. First, raw soil samples and second samples were reinforced soil with plastic waste and three quantities (0.4, 0.6 and 0.8%) of the total raw samples.

2.4.1. Compaction test

The compaction test derives the water content dry density correlation related to mixed soil samples with plastic waste. Furthermore, a series of Standard Proctor Tests (SPTs) are performed on these samples. Three raw soil samples (where each weighted 2.5kg) were mixed with three types of plastic waste. Using equation 1, the quantity of the plastic strips (Wp) mixed with three raw soil samples is determined. Three samples were partially wetted to ensure that the soil samples were roughly uniform and getting plastic paste form. The soil samples and the plastic waste are extensively combined until mixtures become approximately uniform and homogeneous.

2.4.2. Shear strength test

The direct shear tests have been performed on reinforced soil with various plastic waste percentages (0.4, 0.6 and 0.8 %) with different strip lengths (20, 40 and 60 mm) [1]. For horizontal displacement, calibrated proving ring with 2.5kn capability and 0.002 as dial gage accuracy, as well as dial gage of 0.01, was applied. The strain speed was (1 mm/min), while the test was done using standard stresses (45, 75 and 95 kn.m2) to determine the angle of internal friction and cohesion. In addition, the strain rate used in the presented work was integrated with the direct shear testing system utilized for analysis. Yet, changes in normal stresses and strain rate don’t impact the final parameters of the shear strength of soil, only the time needed for adjusting the soil sample’s shear failure. Initially, enough soil was taken and blended with the plastic strips, thoroughly mixed till achieving uniformity and homogeneity. At the respective OMC, all the test samples were compacted in a (60x60) mm2 shear box corresponding to values acquired from SPT. Following the shear failure related to the soil samples, the chosen normal stresses were used to test specimens, while shear charge and horizontal displacement were indicated.

2.4.3. California Bearing Ratio (CBR) Testing

A set of the unsoaked tests of the California bearing ratio (Parto and Kalantari [15] have been carried out on the reinforced soils with various types of plastic waste. For this test, 5 Kg of the raw soil was used. Three samples have been prepared for this examination. Each sample comprises five kilograms of raw soil mixed with plastic waste slices. For example, the first sample (5 kg of raw soil mixed with 20* 20 mm plastic strips) and so on for the other two samples. It was noted that the required load for penetrating through these samples is up to 14 mm penetration depths.

3. Results and discussions

3.1. Tests conducted on raw soil

SPT, Direct shear, and CBR tests have been carried out on the utilized raw soil (without reinforced waste plastic strips). Table 3 shows the results obtained from the tests.

Table 3. The engineering properties results of the conducted tests on raw soil

Properties		Value
Specific gravity (Gs)		2.57
Particle size distribution	Silt (0.075–0.002mm)	51.6%
	Clay (0.002mm)	37%
	Sand (4.75–0.075 mm)	11.4%
Atterberg limits	Plastic limit	26%
	Liquid limit	33.8%
	Plasticity index	10%
Compaction properties	MDU (kn/m3)	16.12
	OMC	16.3%
Un-soaked CBR test	CBR	2.9%
Shear strength parameters	Cohesion(C) kn/m2	18.3
	İnternal friction angle (u)	22.85

The dry sieve analysis was conducted on the dry raw soil to determine the coarse grain soil percentage. Also, the hydrometer analysis was carried out on the soil sample to determine the percentage of fine materials represented by clay and silt (see Table 2). The amount of soil observed passing 0.075 mm is more than 50 %. As illustrated in Figure 4, when the proportion of one of the components of soil is more than 50%, then this kind of soil is classified as soft soil. Optimum moisture, maximal dry unit weight and optimal moisture content for raw soil type were estimated using SPT, where the values were 16.52 kn/m and 16.6%. The soil samples are prepared in a shear box with a diminution of (60x60) mm2 at OMC and MDU to perform the direct shear test. The friction angle and stiffness of the used soil samples are 23.2 and 18.3 Kn / m^2. At 2.9 %, the CBR value for the acquired soil is extremely low and needs enhancements via admixtures such as plastic strips. Furthermore, the following subsection describes the findings with different plastic contents strip sizes for soil reinforcement.

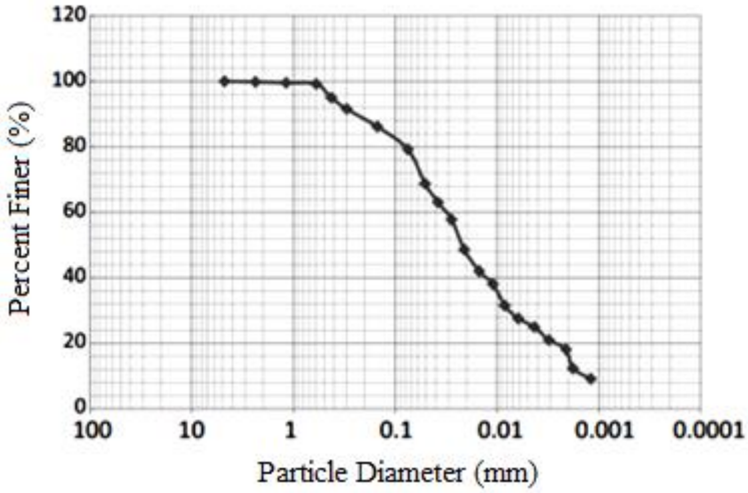

Figure 4. Particle distribution curve for soil classification

3.2. The effect of using plastic wastes on the soil reinforcement

In this section, adding plastic wastes in strip forms to the soil reinforcement was discussed in detail. Three different sizes were employed in this study (20, 40, and 60 mm) in length and the same width (20 mm). The discussion was based on the results acquired from the next examinations, such as compaction, CBR tests and direct shear. As illustrated in Tables 4, 5, and 6, it is clear that the estimated test results are related to reinforced soil with plastic wastes.

Table 4. Results regarding the reinforced soil with plastic wastes of 20*20 mm

Test no.	Plastic waste percentage	Parameters of Compaction			Parameters of shear strength		Ratio of the CBR
		OMC (%)	MDU (kn/ m3)	Saturation Degree (Sr) (%)	C (kn/m^2)	φ (°)	(kn/m^2)
1	0% (raw soil)	16.1	16.2	71	18.2	22.6	3.1
2	0.4%	14.2	18.4	83.45	34	32.8	16.5
	Increasing in percentage a	- 15.5 b	9.90	11.30	78.90	42.0	400
3	0.60%	15.0	18.10	83.25	18.0	27.0	13.70
	Increasing in percentage a	- 10.7 b	8.10	11	- 5.3 b	16.90	315.20
4	0.80%	16.40	17.70	79	13	25	12.50
	Increasing in percentage a	- 2.4b	3.30	5.30	- 31.6 b	8.20	278.80

[a] An increase in soil characteristics' percentage for all percent of plastic contents was estimated in the characteristics of the applied raw soil.
[b] Negative sign indicates a decrease in soil characteristics regarding the properties of the applied raw soil.

Table 5. The testing results related to reinforced soil with plastic wastes of 20*40 mm

Test no.	Plastic waste percentage	Parameters of Compaction			Parameters of shear strength		Ratio of the CBR
		OMC (%)	MDU (kn/m3)	Saturation Degree (Sr) (%)	C (kn/m2)	φ (°)	(kn/m2)
1	0% (raw soil)	15.9	16.1	62	17.2	21.4	3.0
2	0.4%	14.1	18.0	83.0	32	32.7	17.5
	Increasing in percentage a	- 15.1b	9.4	11.0	74.9	41.0	402.0
3	0.6%	14	18.3	83.15	18	25	14.7
	Increasing in percentage a	- 10.2b	8.0	10.8	- 5.1b	16.2	319.2
4	0.8%	16.1	17.2	75	13	23	13.5
	Increasing in percentage a	- 2.2b	3.1	5.1	- 31.4b	8.1	288.8

[a] An increase in soil properties' percentage for all percent regarding plastic contents was estimated in terms of the properties related to the applied raw soil.
[b] Negative sign indicates a decrease in the soil properties in the applied raw soil.

Table 6. The testing results of the reinforced soil with plastic wastes of 20*60 mm

Test no.	Plastic waste percentage	Parameters of Compaction			Parameters of shear strength		Ratio of the CBR
		OMC (%)	MDU (kn/m3)	Saturation Degree (Sr) (%)	C (kn/m2)	φ (°)	(kn/m2)
1	0% (raw soil)	16.3	16.5	71	18.8	22.9	3.1
2	0.4%	15.2	18.3	83.8	34.7	32.9	16.9
	Increasing in percentage a	- 17.5b	10.2	11.6	79.9	42.5	407.1
3	0.6%	15.7	18.9	83.85	18.1	27.7	13.9
	Increasing in percentage a	- 12.7b	8.5	11.4	- 6.3b	17.9	365.2
4	0.8%	16.7	17.2	79.5	13.8	25.7	13.6
	Increasing in percentage a	- 3.4b	3.7	5.9	- 38.6b	8.6	298.1

[a] An increase in soil properties' percentage for all percent regarding plastic contents was estimated in terms of the properties related to the applied raw soil.
[b] Negative sign indicates a decrease in the soil properties in terms of the properties related to the applied raw soil.

As documented in Tables (4, 5, and 6), the comparison of MDU values for the raw soil with the soils with plastic content for all sizes shows that the MDU values increase for soils samples mixed with 20% and 40% of plastic waste. However, the MDU values decreased for the soil samples mixed with 60% plastic waste. In the case of OMC, the result is just the other way around. Thus, 0.40% of the plastic content by soil mass has been considered the optimum value where the maximum weight of the dry unit and optimum moisture content was achieved. Plastic bits are removed from compacted soil and held in an oven for assessing the moisture content related to plastic reinforced soil following compaction. Thus, just the compacted reinforced soil portion is put in an oven that doesn't include plastic bits.

Yet, after compaction, the plastic's moisture content is too limited and may be ignored. The decline in MDU with regard to the high percentage related to plastic content was because the amount of solid soil fraction does not make a very strong bond with the plastic pieces as the number of plastic strips increases. Also, void spaces between the soil grains were totally filled up via plastic strips for the high percentage of plastic content is due to this phenomenon. Furthermore, the plastic strips will be bent and rolled into even small shapes under various compaction attempts. This allows more packing regarding soil grains along with plastic strips. The results in high overall dry unit weight (MDU) and low optimum moisture content (OMC) compaction test on hardened soil with plastic strips. Moreover, the scientific reason for such activity is that soil and plastic grains have content of 0.4 % throughout compaction. Suppose there is a continuous increase in plastic content. In that case, the plastic strips and soil grains will be segregating even with more comp active attempts since finer soil grains were replaced with the comparatively coarser plastic strips. Besides, the soil is mixed with the plastic strips (0.60% and more), thus reducing MDU throughout compaction testing. Typically, with the increase in the specific gravity related to the soil sample, there will be an increase in dry unit weight. As plastic content increases, there will also be an increase in the specific gravity related to the sample of soil and dry unit weight.

3.3. Direct shear tests

Direct shear tests have been utilized for each one of the proportions regarding plastic strips and all strip sizes implemented in this analysis. The results of these tests indicated that the increment in shear strength parameters was optimal for all strip sizes at 0.4% plastic material. There is an increase in shear stress because of the distributions of plastic parts in many directions along the shear surface between 2 halves of direct shear boxes. The Mohr enveloping lines of cohesion and angle of the internal tension are also well found to be growing. Typically, adding plastic to the soil shows a decrease in cohesion or no changes and increases the internal friction angle by up to a specific plastic percentage [16]. Yet, this study indicated an increased internal friction angle and cohesion with increasing the plastic content. Such phenomenon was due to characteristics of plastic mass and combined soil that might be distinctive from the behavior's type shown via exclusively soil material throughout shearing. Increasing the internal friction angle happens because of the increase in interlocking capacity between particles. The decrease in cohesion or no changes and the growing trend in internal friction angle up to a specific plastic percentage was typically indicated via adding plastic to soil [14]. But, most interestingly, this study shows that the trend toward increasing the internal tension angle and cohesion will cause an increase in plastic content. This phenomenon was because of the combined plastic mass and soil properties that might vary from the activity type shown throughout shearing through the soil material. Increasing the angle of internal friction might be because of improved interlocking potential between the particles.

3.4. CBR tests

As listed in Tables (4, 5, and 6), CBR tests are performed regarding each percentage related to plastic strips for all sizes. Comparisons have been made utilizing graphs, as seen in Figures (5 and 6).

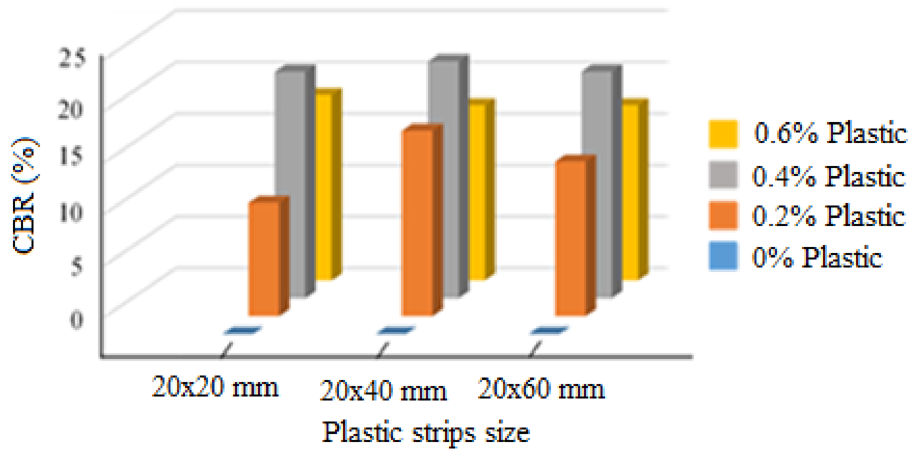

Figure 5. CBR versus pavement thickness curves [17]

Obviously, it has been indicated that CBR value increases due to using plastic strips in the soil. The sub-grade thickness will considerably decrease when using reinforced soil with plastic strips in pavement constructions as one of the sub-grade materials. Decreasing the pavement thickness contributes to decreasing the pavement construction costs. Additionally, maximum CBR values happen by mass at 0.4 percent of the raw soil plastic material (see Figure 5). The reduction in CBR at 0.60 percent is related to plastic content. It often occurs because the soil plastic matrix crosses the limit (for instance, 0.40 percent by soil mass) as the number of plastic parts in the soil increases, in which maximum improvements in MDU and shear strength parameters are reached.

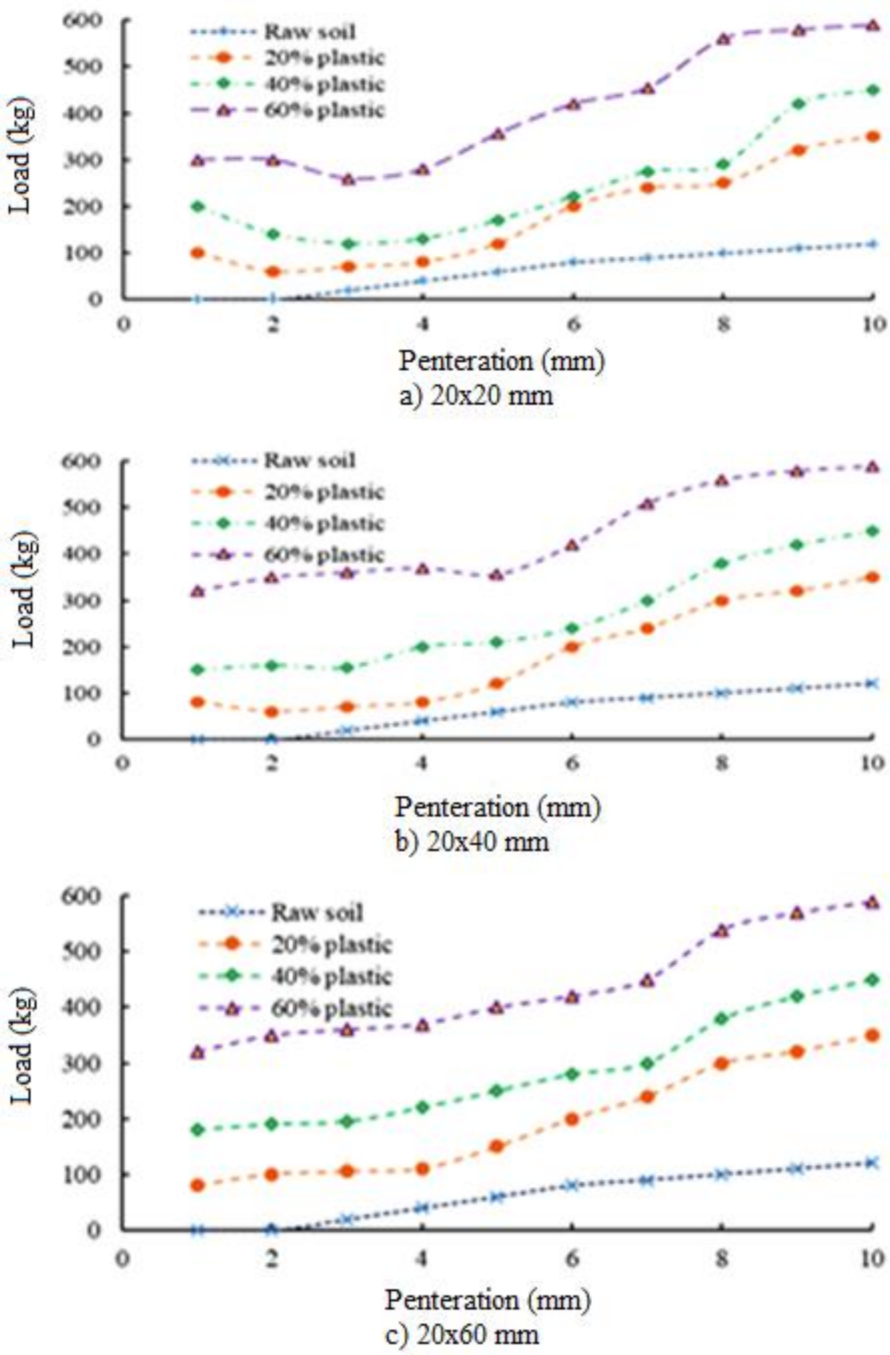

Figure 6. Load penetration curve of the plastic reinforced soil for different sizes

Beyond this cap, soil plastic matrix strength and MDU decrease. This form of soil with plastic strips can be called over-reinforced soil. Soil's over reinforcement indicates that, during compaction, large numbers of the plastic pieces might result in soil plastic matrix segregation. As illustrated in Figure 6, the variance regarding load applied to the penetration depth of the soil sample using plastic. Figure 7 demonstrates the thickness curve CBR vs. Pavement for building versatile pavements. Figure 7 indicates that the thickness of the natural soil subgrade was about 55cm for the heavy traffic (wheel load of 55kN) for the 3.30 percent CBR value. It decreases to 20cm for 0.4 percent plastic with 16.2 percent CBR value for the same traffic situation. In other words, it means that there is a substantial decrease in the pavement thickness between 55cm and 20cm, the amount of aggregate materials as well as soil (i.e., borrowed) deployed in the thickness of the sub-grade and the amount of bitumen which has been utilized in the base thickness. A significant amount thus decreases construction costs and the time spent creating pavements.

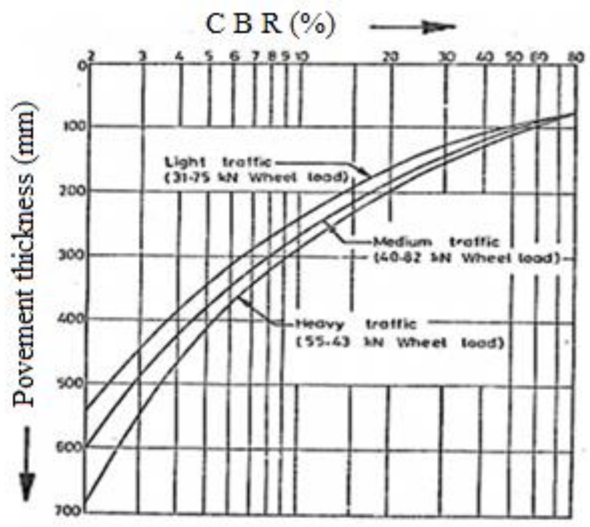

Figure 7. CBR vs. pavement thickness curves [17]

3.5. Effects of plastic strip size

In this section, detailed discussions were carried out for each plastic strip length based on the data obtained from Tables 4, 5, and 6. The compaction test was extended to compare the characteristics with changes via different strip lengths and keep a constant width of 0.40 percent plastic strips through the raw soil mass. This is because the optimal enhancements of the related parameters were acquired at 0.40 percent soil plastic content. Three types of strips have been used (20mm x 20mm), (20mm x 40mm) and (20 mm* 60 mm). Tables (4, 5, and 6) list the findings with a shift in the strip length, and Figure 8 illustrates the comparisons.

Results revealed an increase in OMC and MDU values with a decrease in strip length. The values are decreased when the strip length is extended to 60 mm, while the increase in dry weather density was because of small strip lengths since it allows the strips to be distributed more evenly. This results in denser packing within the soil mass and therefore increases the dry density of soil. For strip lengths (20.0mm and 60.0mm) of 0.40 percent plastic strip material, Direct Shear Tests are performed. It is concluded from the Mohr envelopes for plastic reinforced soil with various 20, 40- and 60-mm plastic strip lengths that parameters of shear strength, for instance, internal friction angle and cohesion, show a trend (20 mm* 20 mm) for strip size. There is a decrease in shear strength parameters when increasing the plastic strip's length. However, for other soil types, the improvements in the shear strength parameters can vary for the same proportion of plastic. More tests are needed to quantify the enhancements in associated parameters while utilizing soil plastic matrix with different plastic contents.

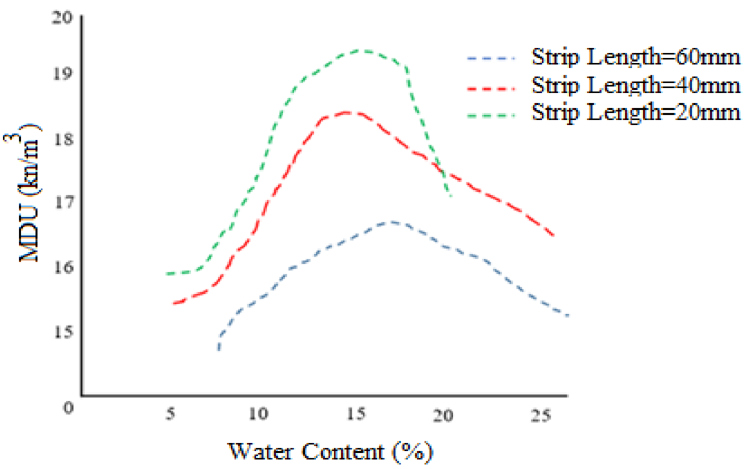

Figure 8. Compaction curves for different strip lengths

The impact of the size of the plastic strip variations on the plastic reinforced soil was extended to study the behavior related to the depth of the load penetration for different lengths of the plastic strip (20, 40 and 60 mm). As shown in Figure 9, the soil sample was prepared by taking soil of 4.5 kg and mixing the soil with plastic content of 0.4 percent by mass as well as strip lengths (20, 40 and 60 mm). These plastic parts were uniformly mixed throughout the soil sample, and light static compaction with three layers was used. Fifty-five blows for every 2.60kg rammer are given to every one of the layers. The impact of plastic strip size variations on the plastic reinforced soil was extended to evaluate the behavior related to loading penetration depth for various length values of the plastic strips (20, 40 & 60mm) (see Figure 9). The soil sample was prepared by taking soil of 4.5 kg and combining the soil with plastic content of 0.4 percent by mass as well as strip lengths (20, 40 and 60 mm). These plastic parts were uniformly mixed throughout the soil sample, and light static compaction with three layers was used. Fifty-five blows per 2.60kg rammer are given to every one of the layers.

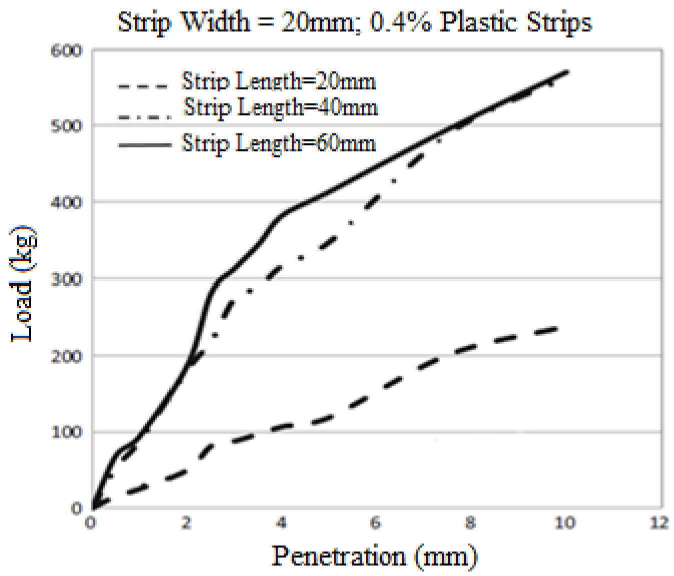

Figure 9. The behavior of the load penetration of the soil with strip length values of (20 * 20 mm)

It can be observed from Figure 9 that the plastic strip size (20* 20 mm) shows the best load-penetration action. It also demonstrates that the plastic strip size (20* 20 mm) reinforced soil mobilizes the optimum stiffness of the plastic matrix soil. Tables /84,5 and 6) reveal that the maximum CBR value for the (20* 20 mm) scale of plastic strips can be calculated. Increasing the size of strips contributes to a decrease in CBR values. Increasing the strip size in the soil plastic mixture from 20 to 40 mm and then to 60 mm led to decreased CBR value. Also, it was indicated that increasing the strip size creates a problem with nonuniform distributions regarding plastic parts in the soil's mass. Therefore, after enhancing soil properties, strip size (20* 20 mm) and 0.4 percent soil plastic content were of high importance.

4. Conclusions

We conclude that the results obtained from experimental works concerning the aspect of soil strength enhancement because of plastic strips' mixing as means of the reinforcement of soil. However, the overall dry unit weight (MDU) was indicated to be at 0.40 percent plastic content by the raw soil weight for plastic strips of (20* 20 mm) from discussions and results of the Standard Proctor Test on the plastic reinforced soils. Regarding the high percentage related to plastic contents (0.60 and 0.80 percent) and for large plastic strip sizes, for instance (20 * 20 mm) and (20 * 60 mm), MDU values will be decreased. It is indicated that the OMC value. Nevertheless, an opposite trend was revealed regarding the values of the MDU for the plastic-reinforced soils.

The results of direct shear testing showed that the angle of the internal friction and cohesions increased the natural soil's mass by up to 0.4 percent of the plastic material. In contrast, the shear parameters decreased with a high plastic content percentage. Additionally, the shear strength increased by 0.4 percent regarding plastic material about small strip sizes (i.e., 20* 20 mm). Furthermore, the inclusion related to plastic in percentages increased the CBR value from 3.30 (i.e., the natural soil) to 7.10 (for 0.20% plastic content) and 16.50 (for 0.40% plastic content) from the results of the CBR test. Moreover, CBR values decreased beyond the 0.4 percent plastic content cap. To enhance the strength properties of soil plastic mass, the quality of surfaces regarding plastic strips is extremely considerable. The plastic strips used in this work have undulated surfaces, resulting in improved cohesion and internal friction angles. In the case when the essence of plastic strip surfaces was plain/smooth, there will be a possibility for boosting the two shear strength parameters, as formerly indicated via Mercy Joseph et al. 2014. The findings indicated that the increase in strip size led to a decrease in CBR value from 20.60% (for 20.0mm strip length) to 5.90% (for 60.0mm strip length). In contrast, plastic strip width was kept constant at 20.0mm, indicating that sub-base thickness might be decreased to approximately 30cm, directly contributing to the savings in pavement construction costs. It is suggested to utilize 0.40 percent plastic content and the size plastic strip (20 * 20 mm) with raw soil for better results on the engineering characteristics of soil reinforced with plastic strips. PET plastic bottle cut pieces with adequate shape and size might be prepared for practical applications with PET Bottle Shredding Machine. Based on the standards for silty sands, plastic might be utilized for stabilizing embankments, pavement sub-grades and other fields of civil engineering. More tests are needed to find the adequate amount of changes in silty sand properties with the addition of plastics. However, the authors were certain that by adding plastic strips, there would be improvements in the properties related to artificial soil. When the plastic form is changed to HDPE or LDPE, there will be different changes in soil characteristics. The cost of soil stabilization has been reduced when plastic strips prepared from the waste plastic bottles were utilized for soil stabilization rather than expensive admixtures like lime, cement, and so on. The topic related to plastic waste disposal is going to be discussed efficiently. Thus, expensive stabilization techniques might be replaced via plastic reinforcement, which will make buildings cost-effective and help recycle the non-biodegradable plastic wastes.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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