University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 30 Number 2 February 2024

Improving the Bearing Capacity of Clay Soil Using Plastic Bottle Waste

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ABSTRACT

With the increase in industry and industrial products, quantities of waste have increased worldwide, especially plastic waste, as plastic pollution is considered one of the wastes of the modern era that threatens the environment and living organisms. On this basis, a solution must be found to use this waste and recycle it safely so that it does not threaten the environment. Therefore, this research used plastic waste as an improvement material for clay soil. In this research, two types of tests were conducted, the first of which was a laboratory test, where the undrained shear strength (cohesion), compression index (Cc), and swelling index (Cr) of the improved and unimproved soils were calculated (plastic was added in proportions (0.5, 1, 1.5, 2)%. The second part of the examination was done through physical modeling, where 2% of plastic was used, considered the optimal percentage in this research, and the calculation of the carrying capacity-settlement relationship for both the improved and unimproved soils. Using this percentage of plastic showed an improvement in the relationship between the bearing capacities of soil vs. subsidence, as an increase in the amount of stress was observed from 405 KPa to 459 kPa at 10% of subsidence.

Keywords: Carrying capacity, Plastic waste, Compression index (Cc), and Swelling index C(Cr)

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2024.02.08

Article received: 19/06/2023
Article accepted: 25/12/2023
Article published: 01/02/2024

تحسين قابلية تحمل التربة الطينية بأستعمال مخلفات القناني البلاستيكية

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الخلاصة

مع زيادة الصناعة والمنتجات الصناعية ، ازدادت كميات النفايات في العالم ، وخاصة النفايات البلاستيكية ، حيث يعتبر التلوث البلاستيكي من مخلفات العصر الحديث التي تهدد البيئة والكائنات الحية. وعلى هذا الأساس لابد من إيجاد حل لاستخدام هذه النفايات وإعادة تدويرها بطريقة آمنة لا تهدد البيئة. لذلك ، في هذا البحث ، تم استخدام النفايات البلاستيكية كمادة تحسين للتربة الطينية ، حيث تم في هذا البحث إجراء نوعين من الاختبارات ، أولهما مختبري ، حيث تم حساب معامل القص (التماسك) Cc و Cr للتربة المحسنة و غير المحسنة (تمت إضافة البلاستيك بنسب (0.5،1،1.5،2) ٪). أما الجزء الثاني من الفحص ، فقد تم عن طريق استخدام نموذج مصغر لاساس ، حيث تم استخدام 2٪ من البلاستيك ، وهي النسبة المثلى في هذا البحث ، وحساب علاقة قابلية تحمل التربة مع الهبوط لكل من التربة المحسنة وغير المحسنة حيث تم ملاحظة تحسن في العلاقة بين قدرة تحمل التربة مقابل الهبوط ، حيث لوحظ زيادة في مقدار الإجهاد من 400 كيلو باسكال إلى 450 كيلو باسكال عند 10٪ من الهبوط.

الكلمات الرئيسية: قابلية تحمل التربة, النقايات البلاستيكية, معامل الضغط ، معامل الانتفاخ

1. INTRODUCTION

The engineering properties of the soil are essential for construction materials for dams, embankments, and other projects, in addition to serving as the project's foundation. To solve many engineering issues like excessive settlement and instability of the constructions soil qualities need to be improved. The requirement for an upgrade emerges in areas where the soils cannot support loads, such as the subgrade soil of highways and airfield runways **(Atkins, 1980)**. Since soil improvement processes of all kinds, whether mechanical or chemical additives (cement and lime), are among the costly processes, Engineers have recently been seeking novel, eco-friendly methods to enhance the geotechnical characteristics of problematic soils. The geotechnical qualities of poor soils are frequently enhanced by the application of cement and lime, among other conventional soil stabilizers **(Yadav and Tiwari, 2016**; **Yadav et al., 2018)**. Therefore, alternatives to these materials must be found, and one of these alternatives is waste **(Alzaidy, 2019)**.
Recent years have seen a growth in industrial development, which includes the plastic industry (1950 is considered the year in which the manufacture and production of plastic began). Since plastic has a very long analytical life pollutes the environment **(Qasim et al., 2021; Ogundairo et al., 2021; Iravanian and Ali, 2020)**. The daily generation of plastic garbage is estimated at 15.4 billion pieces. Numerous environmental issues are raised due to the regular use of plastic products such as bottles, polythene bags, food crates and containers, pallets, kitchenware, appliances, and toys. **(Geyer, 2017)**. It is harmful to both

the environment and people's health **(Iravanian and Haider, 2020)**. Ethiopia's waste materials contain a substantial amount of polyethylene products, and in 2015, the country consumed about 172,000 tonnes of plastic **(Tilaye and Dijk, 2014)**. By 2025, it's anticipated to reach about 308,000 tonnes of plastic. Because of the dangerous toxic emissions they produce, both procedures are considered significant sources of pollution worldwide **(Alasadi and Ali, 2022).** Therefore, there is a growing awareness that there is an immediate demand to cut down on the amount of plastic we use, which has led to a rise in the level of worry regarding the impact of waste plastic on the environment **(Al-Haddad et al., 2022)**. The plastic strips may be applied to stabilize soil **(Yetimoglu and Salbas, 2003)**. They behave like fiber-reinforced soil when combined with soil. The efficiency of soil modified by plastic trash has been the subject of numerous experimental experiments by various researchers **(Babu and Chouksey, 2011; Ahmadinia et al., 2012; Modarres and Hamedi, 2014; Peddaiah et al., 2018; Singh and Mittal, 2019; Salimi and Ghazavi, 2021)**. They found that by reducing soil plasticity while raising unconfined compressive strength (UCS), California Bearing Ratio (CBR), and maximum dry density (MDD), stabilizing poor soils with plastic waste materials improved their attributes. When used as a substitute for aggregate in the base and sub-base of roads, plastic trash has also been proven to increase pavement shear, stiffness, and bearing capacity **(Salih et al., 2022; Fauzi et al., 2016)**.

Similar findings on improved properties of pavement reinforced with recycled plastic strips were made by **(Choudhary et al., 2014)**. Their research showed that polyethylene plastic granules with a composition of about 5% are suitable as road construction materials when combined with demolition trash. Their study is crucial because using demolition debris and plastics as building materials will hasten the construction industry's adoption of recycled byproducts. The soil can sustain heavier loads and have a higher UCS due to the high tensile strength of fiber **(Tang et al., 2007; Abousninal et al., 2021)** mixed polyethylene waste material (water bottles) in the form of fibers with cement to increase the compressive and tensile strength of clayey soils. The fiber lengths were 1.0 cm, 2.0 cm, and 3.0 cm, and the fiber concentrations were 0.4%, 0.8%, and 1.2% of the dry soil weight. He discovered fiber-stabilized soil performed better in unconfined compressive strength (UCS) than tensile strength. The ideal fiber lengths and content were 2.0 cm and 1.2%, respectively. According to **(Sorsa et al., 2020),** the soil in Jimma Town is unsuitable for use as a highway subgrade, and they advise stabilizing the soil before use. As a result, it was suggested in this study to use recycled plastic debris to stabilize poor subgrade. A series of laboratory tests examined the strength and compaction characteristics of natural soil from the Jimma University campus and combinations of natural soil-plastic strips from PET bottles. To determine the effects of plastic fiber concentration on the mechanical properties of the improved soil, several common geotechnical laboratory experiments were conducted, including the conventional Proctor test, unconfined compression test, and California bearing ratio (CBR).

This work aims to improve the engineering properties of clay soil like cohesion, Cr, Cc, and increase the soil's bearing capacity using waste plastic material and observing its' behavior.

2. THE USED MATERIAL

2.1 Soil

The soil location was in the southern part of Baghdad in the Yossfia area. This area is selected because it is close to Highway No. 1 and an affiliated area within the borders of the Baghdad Governorate. It is one of the areas where roads are continuously paved and covered. Soil properties are given in **Table 1.**

Table 1. Soil properties.

Geotechnical property	Clayey soil	Standard of the test	Geotechnical property	Clayey soil	Standard of the test
Liquid Limit (LL)	34	ASTM D 4318	Gravel, (%)	0	ASTM D 422
Plastic Limit (PL)	18		Sand, (%)	14	
Plasticity index (PI)	16				
Natural water content	11%	ASTM D 2216	Silt and Clay, (%)	86	
Specific gravity(G_S)	2.70	ASTM D 854	Undrained Cohesion, Cu	53	ASTM D 2166
MDD (g/cc)	1.859	ASTM D 698	Compression index, Cc	0.129	ASTM D 2435
OMC, (%)	16		Swelling index, Cr	0.017	
Soil Classification, USCS	CL	ASTM D 2487	Initial void ratio, e_0	0.450	

where:
UCS is the Unconfined Compression Strength
MDD is the Maximum dry density.
OMC is the Optimum moisture content.
Cc is the Compression index.
Cr is the Swelling index.
PWS is the Plastic waste shredded.

2.2 Plastic Waste Material

The plastic Polyethylene Terephthalate Plastic-type (PET, PETE, or Polyester) was obtained from the waste of local drinking water bottles shown in **Fig. 1a**. The plastic was cut into very small pieces (less than 1 mm) (shredded) with ratios (0.5, 1, 1.5, and 2) %, Plastic shredded as presented in **Fig. 1b**.

Figure 1. Plastic waste bottles, (a) As collected, (b) As shredded.

3. TEST METHOD

Soil tests were conducted before and after improvement according to ASTM standards.

3.1 Unconfined Compression Strength Test

An unconfined compression test was carried out on disturbed samples according to ASTM D 2166 standards to calculate the clay cohesion. The soil was compacted inside the mold (with a height of 7.6cm and 38mm in diameter) at MDD and OMC calculated from the compaction test. The test was run at a 1.25 mm/min strain rate.

3.2 Consolidation Test

1D-consolidation tests have been performed, in accordance with ASTM D2435-04, to investigate the impact of adding various plastic waste addition percentages on soil's compressibility properties. Adding 0. 5, 1, 1.50, and 2% plastic garbage to the soil, where the soil was compacted inside the odometer ring (50mm in diameter and 20mm in height) at MDD and OMC obtained from compaction test. The consolidation tests were carried out in a space kept at a constant temperature of 20°C. Sample compression was measured at various time intervals while the sample was under a constant, varying vertical force. The slope of the loading and unloading curves is used to determine the compression index, Cc, and expansion index, Cr.

3.3 Physical Modeling

The soil container is a steel box of dimensions (600×600×600 mm depth) made of a steel plate of 3 mm thickness. The side of the box was made from glass with 1cm thickness.
The loading system comprises a steel arch frame and a 2-ton mechanical jack used to impart centric loads. A load is attached to the jack load cell to calculate the applied load on the footing. The cell had a 20 kN maximum capacity. Two LVDTs with a 75 mm capacity were used. An LVDT is positioned evenly apart on the right and left of the jack sides to measure settlement when applying load to the footing. The cell is connected to a digital indicator, which may be used to read the applied load. Data from the test was read using two LVDTs coupled to a data logger, along with a load cell, as shown in **Fig. 2.**
The soil was compacted inside the bin at MDD and OMC using a tamper with dimensions (15 * 15) cm, a central load was applied to it, and the carrying capacity vs. Settlement relationship was calculated. As for the foundation, a square foundation was used with dimensions (10 * 10 * 1) cm.

4. RESULTS AND DISCUSSION

4.1 Unconfined Compression Strength

Different amounts of shredded plastic were incorporated into the soil. The outcome demonstrates that as the PWS percentage rises, the UCS value increases and rises to a certain threshold. This indicates that PWS plays a big part in the increases in UCS value. **Table 2**

Figure 2. Loading system and soil container.

illustrates the fluctuation of the treated soil's UCS values at various PWS percentages. The ideal PWS percentage for obtaining noticeable improvements was 2%. The UCS value improvement that could be made was 56 kPa. Therefore, UCS's value rises as the PWS content rises for all WPS percentages, where these results agree with what was reached by each **(Muntohar et al., 2013; Olgun, 2013).**

Table 2. Plastic percent and cohesion relationship.

Plastic %	Cohesion (kPa)
0.0	53.0
0.5	53.5
1.0	54.1
1.5	55.0
2.0	56.0

4.2 Consolidation

It was noted from the consolidation test that the coefficients of Cc didn't change. Cr decreased with the rise in the proportion of added plastic from 0.017 to 0.014 and reached its optimum percentage at 2% of the added plastic, as given in **Table 3** and shown in **Fig. 3**. Whereas, the change in the values of both Cc and Cr was very slight, in contrast to the results obtained by **(Abd Al-kaream et al., 2022)**.

Table 3. The relationship between plastic percent, Cc, and Cr.

Plastic content (%)	Cc	Cr
0	0.129	0.0177
0.5	0.1285	0.0173
1	0.126	0.0167
1.5	0.124	0.0150
2	0.120	0.0140

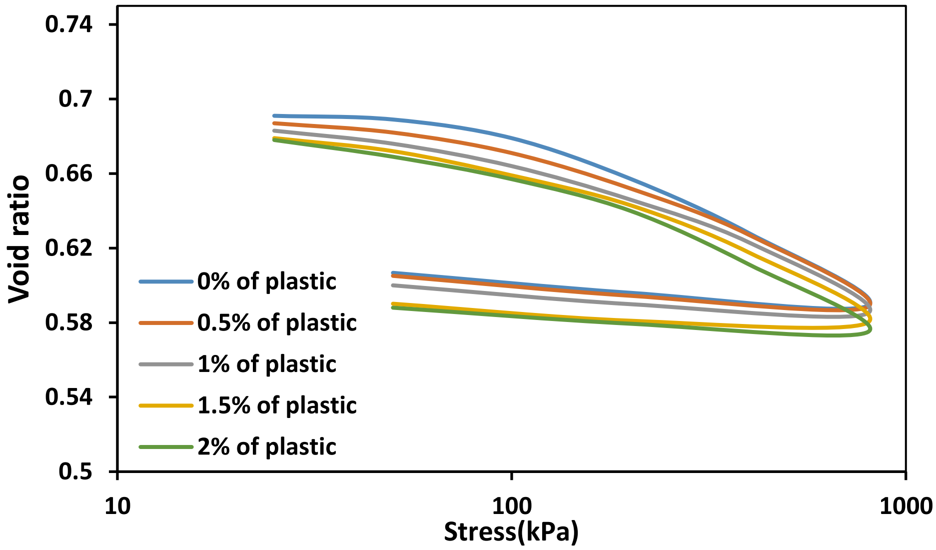

Figure 3. Variation of void ratio with stress.

4.2 LOAD-SETTLEMENT BEHAVIOR

The failure load in the current study is the load that causes a settlement that accounts for 10% of the width of the footing. In the case of untreated soil, the footing failure pressure is (405kPa), While When 2% plastic trash is added to the soil, the failure pressure at 10% of the footing width is (459 kPa). This rise is because the plastic is a stiff material with high tensile strength. The pressure-settlement relation for a footing model on clay soil mixed with 2% plastic trash and for the clay soil without any additions is shown in **Fig. 4**.

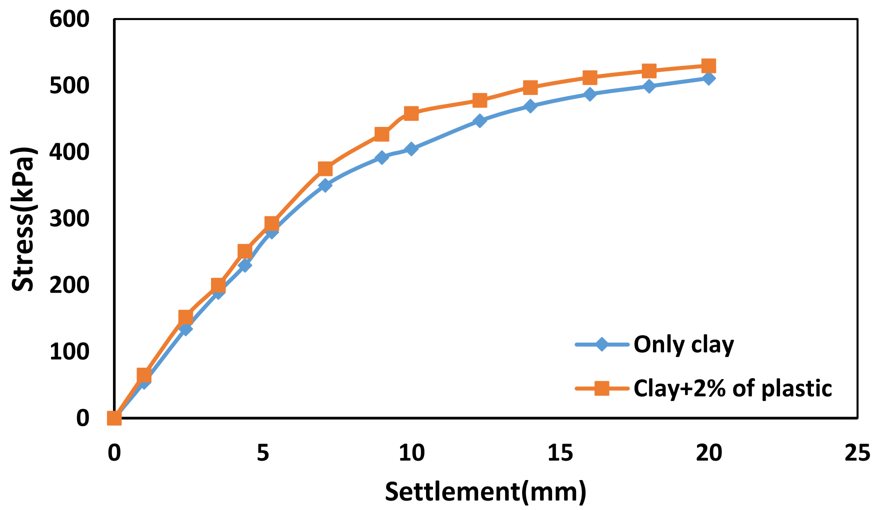

Figure 4. Stress variation with settlement relationship.

5. CONCLUSIONS

As a result of the alarming increase in plastic waste being thrown away, estimated at millions every year, in addition to the fact that 90% of this waste is thrown directly into the environment without being recycled. In this research, plastic waste was used as a soil improver, being economical, in addition to reducing the risks of this waste to the environment, and the following was noted:

1. The cohesiveness of clay soil is not significantly improved by shredded plastic, where the cohesion rose from 53 to 56 at 2% of plastic.
2. A slight decrease was observed in the Cc and Cr coefficients at 2% of plastic by adding plastic to the soil.
3. Adding 2% of plastic to the clay soil improved the carrying capacity of this soil compared to unimproved soil.
4. Plastic waste can be used as soil reinforcement, as the percentage of improvement depends largely on the soil type first and the added percentage of plastic waste second.

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