Journal of Technology Research (JTR)
Volume 3, Special Issue, (2025), pp 192-201, ISSN 3005-639X
The 7th Conference of Engineering Sciences and Technology
(CEST-2025)

Environmental Sustainability in Geotechnical Engineering: Promoting the Use of Eco-Friendly Material

Maryam Gaber *[1], Manal Salem[1], Jamal Alsharef [2]

[1] Libyan authority for scientific research, Benghazi, Libya.

[2] Civil Engineering Department , University of Tripoli, Tripoli, Libya.

*Corresponding author email: Maryam.jaber@aonsrt.ly.

Received: 10-08-2025 | Accepted: 15-11-2025 | Available online: 25-12-2025 | DOI:10.26629/jtr.2025.21

ABSTRACT

Utilizing waste plastic for soil stabilization presents an environmentally sustainable alternative to traditional methods, aiding in the conservation of natural resources while enhancing soil's engineering properties. The continuous accumulation of plastic waste worldwide poses substantial environmental challenges, underscoring the urgent need for practical solutions. In this context, geotechnical engineering offers a promising avenue to transform these pressing environmental issues into beneficial and functional applications. Many construction projects also encounter challenges due to weak or unstable soils, which require improvement. This paper provides a comprehensive review of existing literature on incorporating waste plastic into geotechnical practices, with a particular focus on soil stabilization. The analysis reveals that waste plastics offer a green construction approach that minimizes carbon dioxide emissions, as these materials are both environmentally friendly and cost-effective in strengthening soils. Moreover, incorporating waste plastic bottles into the soil enhances its shear strength, load-bearing capacity, and compaction properties while reducing consolidation settlement, swelling, and the formation of cracks. Finally, this approach also shortens construction durations and helps minimize the need for land acquisition.

Keywords: Sustainable, Waste plastic, Recycle, Soil stabilization.

الاستدامة البيئية في الهندسة الجيوتقنية: تعزيز استخدام مواد صديقة للبيئة

مريم جابر[1]، منال سالم[1]، جمال الشريف[2]

[1] الهيئة الليبية للبحث العلمي، بنغازي، ليبيا.

[2] قسم الهندسة المدنية، كلية الهندسة، جامعة طرابلس، طرابلس، ليبيا.

ملخـــــــص البحـــــــث

يُمثل استخدام نفايات البلاستيك في تثبيت التربة بديلاً مستدامًا بيئيًا للطرق التقليدية، إذ يُسهم في الحفاظ على الموارد الطبيعية مع تحسين خصائصها الهندسية، يُشكل التراكم المستمر للنفايات البلاستيكية حول العالم تحديات بيئية جسيمة، مما يُبرز الحاجة المُلحة إلى حلول عملية، في هذا السياق تُقدم الهندسة الجيوتقنية سبيلاً واعدًا لتحويل هذه القضايا البيئية المُلحة إلى تطبيقات مفيدة وفعّالة، كما تُواجه العديد من مشاريع البناء تحديات بسبب ضعف أو عدم استقرار التربة، الأمر الذي يتطلب تحسينًا، تُقدم هذه الورقة مراجعة شاملة للأدبيات المُتاحة حول دمج نفايات البلاستيك في الممارسات الجيوتقنية مع التركيز بشكل خاص على تثبيت التربة، يُظهر التحليل أن نفايات البلاستيك تُقدم نهجًا للبناء الأخضر الذي يُقلل من انبعاثات ثاني أكسيد الكربون نظرًا لكونها مواد صديقة للبيئة وفعالة من حيث التكلفة في تقوية التربة، علاوة على ذلك يُعزز دمج نفايات الزجاجات البلاستيكية في التربة قوة القص وقدرتها على تحمل الأحمال

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وخصائص الضغط مع تقليل ترسبات التماسك والتورم وتكوين الشقوق، وأخيرًا يُقلل هذا النهج أيضًا من مدة البناء كما يُساعد على تقليل الحاجة إلى استملاك الأراضي.

الكلمات الدالة: استخدام مخلفات البلاستيك، إعادة التدوير، تثبيت التربة.

1. INTRODUCTION

Collapsible soils require to be stabilized to diminsh the possibility of unexpected collapse, settlements, and connected damages [1, 2]. The stabilization process goals to reinforce the strength and durability of soil. The introduction of the soil improvement methods has enabled engineers to utilize ill-suited soils successfully as reliable construction materials in a vast part of civil engineering applications. Where, the mechanism is utilized in assortment of applications such as retaining structures and embankments to subgrade stabilization under foundations and pavements. These approaches consist of; the using cement, bitumen, or specialized additives to hold the soil particles together [2].

The soil stabilization typically concentrates on the figuration of cementations material when cured with various proportion of stabilizing factor, which will further become the principal cause of soil improvement [3, 4]. In general, stabilized soil is the synthesized material outcomes from the chemical response takes place between the naturalistic soil and stabilizing factor. Nowadays, several techniques of soil stabilization are available identical to Mechanical, Chemical, Polymer and Plastic Stabilization and etc., each of these has its features and downsides but the major issue is that these techniques do not protect the environment [5]. The applications of eco-friendly geotechnical engineering concentrate on reducing environmental change while maximizing sustainability in construction and ground use. The reinforcement kind of used is not restricted to any particular material. In 2005, Ref. [6] spotlighted some materials, which can be utilized to enhance soil from an engineering outlook. These materials are found ordinarily in the shape of strips, grids, anchors and sheet material, chain, planks, rope, vegetation, steel, concrete, glass, fibre, wood, rubber, aluminium and thermoplastics.

Despite its challenges, many researchers have carried out studies to discover powerful methods to minimize the pollution of waste materials by recycling and reusing these materials in applications of civil engineering as a solution to protect the environment. One of beneficial method is to utilize these wastes as additive materials to stabilize the soil under road construction. Conventional soil stabilizers like cement and lime are vastly used to improve the geotechnical properties of problematic soils [7, 8, 9]. Various researchers confirmed the successfulness of these materials on improving soil properties [10, 11, 12, 13, 14]. In spite of that, the wide consumption of these materials makes them non-cost-effective materials. Consequently, many researchers try to realize alternative cost-effective soil stabilizers such as plastic, rubber, glass and rice husk.

In 2005, the Waste Recovery Program (WRAP), Ref [15] reported that reducing waste is not only benefits to natural environment but also to offer considerable economic advantages, as waste represents a substantial loss of raw materials as well as resources that could be recycled. Presently, water bottle industry increases rapidly beverage sector globally. Over the past decade, water bottle sales have surged by 500%, based on the International Bottled Water Association (IBWA), causing in the use of 1.5 million tons of plastic for packaging yearly [16]. Nevertheless, recycling of plastic bottle has not kept up with the significant increase in sales of virgin resin polyethylene terephthalate (PET). Since the PET is produced from oil, coal and natural gas, which are nonrenewable resources and due to their resistance so, dumping of PET waste implies that the material will require to be stored in the landfill space for many years, possibly decades, before degraded. Thereby, a valuable resource is lost in the form of waste, while the potential for re-using or renewing is nowadays high.

The main benefits of utilizing waste plastic as additive material to foundation soil over traditional techniques are the environmental friendliness and cost effective. Currently, the combination of using eco-friendly and smart materials in the field of geotechnical engineering will assist to improve soil properties and make it useful infrastructure projects. When merged with the encouragement of up to date recycling systems for waste plastics, it could guide to further reductions in greenhouse gas (GHG) emissions and fossil fuel using up. Hence, it is essential to make concerted efforts to reuse plastic waste of water bottles, and this work aims to contribute to that target.

A global focus needs to achieving the Sustainable Development Goals (SDGs), conserving energy and resources, as well as worthily recycling solid waste products. This calls for extensive study to find out innovative applications of waste materials. Overall, the current study highlights a sustainable solution for reusing plastic waste and transforming it into a valuable material for geotechnical engineering solicitations. Reusing waste plastic as additive materials in soil stabilization technique have been documented in the literature, showcasing the progressions in methodologies within this field.

2. LITERATUER REVIEW

2.1 Soil Stabilization with recycled waste plastic

Since the beginning of the current century and due to new life styles and a lack of proper treatment and disposal of materials, the quantity of waste has been rising rapidly, which has caused serious issues. It is necessary to use wastes effectually, principally in light of the latest developments in engineering applications. The finest method to handle plastic waste is to utilize it for engineering fields in order to save natural valuable resources. Reusing and recycling allow to reduce the waste with better managing energy consumption and carbon emissions connected with the manufacturing of new products from raw materials and their ultimate disposal. Amongst the numerous kinds of wastes which are generated normally, plastic have earned the interest of geotechnical engineering researchers and have been more often employed to upgrade the sand properties [17, 18, 19, 20].

The disposal of PET typically occurs in three main ways: landfilling, incineration, and recycling [21, 22]. Research indicates that when PET is disposed of in landfills, only 1–5% of the carbon in the plastic degrades over a span of 150 years, while the remaining carbon may take thousands, or even millions, of years to be released [23]. Furthermore, PET bottles can emit volatile organic compounds (VOCs) into both the air and water (leachate) when placed in landfills [24]. Moreover, when PET is sent to landfills, it occupies significant space that could be utilized more effectively, even though it is usually shredded into smaller pieces. The slow degradation of plastic means that this land remains unavailable for extended periods. Additionally, the anaerobic conditions in landfills, caused by limited oxygen, further hinder the degradation process [24].

Recycling PET bottles encompasses a series of processes, starting with the collection of waste materials, followed by sorting, cleaning, and grinding. These steps lead to the production of plastic pellets through washing, drying, and heating. These pellets are then used to manufacture various products, including jackets, pillow fibers, and geosynthetics. Fig. 1 illustrates the key stages involved in the recycling of PET bottles.

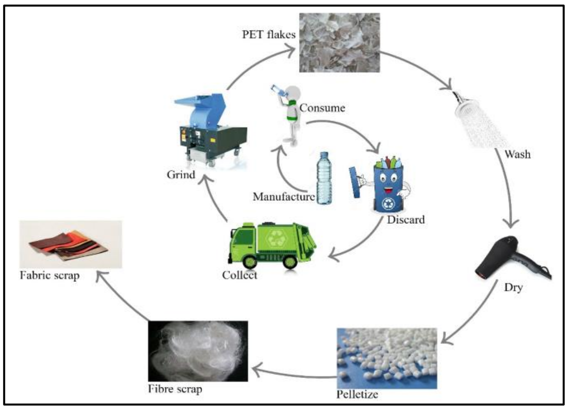

Fig 1. Recycling process stages of plastic.

Among the various types of waste generated, plastic has attracted the attention of geotechnical engineering researchers, who see its potential for use in the construction industry, despite being derived from non-renewable resources. This review compiles a range of studies in the geotechnical field that consistently highlight plastic as a viable soil reinforcement material. In many instances, plastic was randomly mixed with soil to prepare samples for testing. However, Ref. [25] took a different approach by using collected waste PET bottles to create a new geogrid, which was placed in four distinct layers within the soil. The performance of this geogrid was then compared to that of a conventional geogrid.

Commonly, plastic reinforcement have been used to enhance the characteristics of sand [18, 25, 26, 27, 28, 29]. Nevertheless, their utilize in clays and silts soil, usually of inorganic nature, have also been investigated [30, 31, 32]. The causes of using plastics as reinforcement were mostly to achieve the following: (1) to improve the bearing capacity of soil, (2) to improve the shear strength resistance and (3) to reduce the settlement.

With considering the investigation approaches of reinforced soil by misuse plastic, a variation is obvious. While numerous researchers opted to carry out the California Bearing Ratio test CBR [17, 18, 29, 33], others rather accepted tests like the direct shear test DST [17, 19, 26, 29], the triaxial test TT [20, 34], unconfined compression tests UCT [27], consolidation tests CT [30, 35] and plate load tests PLT [25, 36]. Actuality, the differing options specify the intensiveness of work conducted in this part of studies. The outcomes achieved continuously demonstrated the benefits of using plastic as additive material to soil.

Soil stabilization by utilizing plastic wastes can enhance various geotechnical projects, including landfills, slope stabilization and foundation strata of pavement [29, 37, 38]. Consequently, this can find the answer to the wastes issue by minimizing the quantities and recycling these materials for improving the soil properties where plastics made up of 12.3% of total waste manufacture most of which is from discarded PET water bottles, [39]. One way of utilizing plastic to stabilize the soil is to use the plastic in the form of separate fibres [40], for the reason that, when plastic materials are incorporated with soils, they behave similar to fibre-reinforced soil.

A number of researches have been performed to examine the effectiveness of plastic waste materials in the form of discrete fibres on soil properties [16, 32, 34, 36, 41, 42, 43, 44, 45, 46, 47]. These investigators reported that utilizing plastic waste materials to stabilize the soil will enhance the properties of problematic soils such as an increase in CBR, UCS, and reduce in the plasticity of soil.

Ref. [16] investigated the benefit of using of plastic waste as a reinforcement material in soil. Experimental results indicate that adding a small percentage of plastic waste significantly improves the soil strength and reduces the compressibility. These enhancements can be beneficial for increasing bearing capacity and reducing settlement in the design of shallow foundations. Nevertheless, the study done by ref. [34] examined the use of plastic fiber (1%, 2%, and 4% concentrations) as an additive in soft clay to enhance its properties and address environmental concerns related to waste. Results indicated that increasing plastic fiber content decreased the liquid limit LL and increased the plastic limit PL, leading to a 50% reduction in the plasticity index PI at 4% fiber. Maximum dry unit weight and optimum moisture content decreased by 11% and 7.5% respectively, with 4% fiber. Unconfined compressive strength improved by 180%, while the compression-to-recompression index ratio varied with fiber content. The California Bearing Ratio (CBR) raised by 210% with 4% plastic fiber, displaying significant improvements in soil properties.

Ref. [47] developed a method to improve the engineering properties of dry fine sand by utilizing sheets of plastic. They carried out triaxial compression tests on unreinforced and reinforced sand, revealing that the plastic sheets had a beneficial impact on the strength properties, friction angle, and cohesion of the sandy soils. Furthermore, they conducted numerical simulations with the finite element software ABAQUS to model a reinforced slope incorporating plastic sheets. The results indicated that adding plastic sheets to sandy soil could enhance the stability and slope's factor of safety, thanks to the high tensile strength of the plastic sheets.

In 2021, ref. [48] carried out series of unconfined compression tests on clayey sand soil to assess the impact of adding waste plastic strips on the soil's shear strength. Two types of plastic strips were used; plain and corrugated, both with 0.4 mm thickness. The strips were added in varying percentages (0.25%, 0.5%, 0.75%, and 1.0%) based on the dry weight of the soil sample. the results indicated a significant increase in unconfined compressive strength when 1.0% plain plastic strips (1x15 mm) were added, with even greater strength improvements observed when using corrugated plastic strips of the same size and ratio. These findings are in agreement with that obtained by ref. [46] when they investigated the effect of reinforcing silty sand soil with corrugated plastic bottle strips. Authors stated that the nature of plastic strip surface has a great positive influence on the cohesion and angle on internal friction of soil. Besides, they observed higher shear strength parameters when reinforcing soil by corrugated surface plastic strips.

In the same framework, authors in ref. [49] investigated the use of waste plastic bottles as a stabilizing agent to improve soil properties. The study focused on evaluating how various percentages of waste plastic (0%, 0.5%, 1.0%, 1.5%, and 2.0%) impact the soil's engineering characteristics, including UCS, CBR, and proctor compaction tests. The results of study showed that the addition of waste plastic bottles improved the soil's shear strength, bearing capacity, and compaction characteristics. This suggests that incorporating plastic waste can enhance the soil's ability to withstand heavy loads.

Author in ref. [32] studied the use of polyethylene (PE) and polypropylene (PP) fibers for soil stabilization through standard laboratory tests of four fiber contents (1%, 2%, 3%, and 4% of soil weight). The findings demonstrated that the maximum dry density (MDD) and optimum moisture content (OMC) of the stabilized soils were reduced by adding plastic fibers, which is advantageous for lightweight embankment construction. The UCS increased significantly, with improvements of 76.4% and 96.6% for PE fibers, and 57.4% and 73.0% for PP fibers, depending on the length. The CBR tests showed that 4% fiber content could enhance the strength and deformation behavior of clayey soils, with increases of 185% for PE and 150% for PP. The study emphasizes the importance of determining the optimal fiber content for effective soil stabilization.

Recently, Al-Mohammedi and Seyedi in ref. [50] investigated the use of a mixture plastic and glass waste for soil stabilization. Laboratory experiments tested different proportions of waste (0%, 4%, 5%, 6%) mixed with clayey soil. The findings revealed that adding waste materials significantly reduced swelling by 2%, 3%, and 5%, and improved soil density with increases in maximum dry unit weight of 4%, 5%, and 9% which is agree with findings of ref. [51]. Likewise, ref. [52] reported series of laboratory tests on single columns installed in a steel cylindrical tank and subjected to a vertical compression load. The reinforced granular columns were improved with PET bottles in the form of flakes. The authors observed that the highest improvement in vertical applied load was 143% and the lowest settlement was 13mm when the column installed in wetter silt bed, with a flakes concentration of 5.6%. Additionally and depending on the testing conditions, inclusion of the flakes also reduced the extent of lateral bulging.

The experimental study presented in ref. [29] included sieve analysis, Proctor compaction tests, California Bearing Ratio (CBR) tests, and direct shear box tests. The sand was reinforced with varying percentages of PET plastic waste flakes specifically 5%, 10%, and 15% relative to the weight of the soil sample used in the tests. The inclusion of PET plastic flakes enhanced several soil properties, including shear strength and friction angle, and improved the CBR value of the composite, making it suitable for pavement construction. Additionally, the reduction in dry density further supports the use of this composite in lightweight structures.

In total, all the researches highlighted in this study demonstrate the effectiveness of recycled plastic waste materials in soil stabilization, promoting environmental sustainability and offering a cost-effective alternative to traditional methods while also contributing to waste management and resource conservation.

2.2 Categories of Plastic Waste Suitable for Soil Stabilization

Certain types of plastic waste are particularly effective in enhancing soil stability and overall performance. Table 1 outlines some of the most commonly utilized plastic waste materials that prove beneficial for soil stabilization purposes.

Table 1. Types of Plastic Waste Suitable for Stabilization.

Categories of Plastic	Description	Benefit
Polyethylene PE	A versatile thermoplastic polymer employed across diverse industries.	It improves soil stability and longevity while decreasing water uptake.
Polyvinyl chloride PVC	A commonly utilized plastic recognized for its robustness.	it improves the stability of the soil and helps prevent erosion.
Polypropylene PP	A versatile material with excellent resistance to chemicals.	it strengthens the soil's structure, making it more resistant to shifting and loss, while also boosting its ability to bear loads.
Polyethylene terephthalate PET	A lightweight yet sturdy plastic frequently employed in the manufacturing of beverage bottles.	it enhances soil compaction, minimizes settlement issues.
High density Polyethylene HDPE	A resilient plastic that boasts high tensile strength.	It increases shear strength, and decreases the plasticity index for better overall soil performance.

As mentioned above, plastic waste materials can be processed by shredding or grinding them into tiny particles, which can then be incorporated into soil to enhance its engineering characteristics. Selecting the appropriate type of plastic waste relies on the specific soil conditions and the intended results. Careful testing and thorough analysis are essential to identify the most suitable kind and amount of plastic waste to achieve effective soil stabilization.

2.3 Use of Local Materials

Incorporating local materials into sustainable geotechnical engineering practices offers significant environmental, economic, and social benefits. It encourages the development of resilient, context-sensitive infrastructure while promoting the efficient use of resources. Challenges exist, but with careful planning, testing, and community engagement, the advantages of using local materials can be realized, contributing to sustainable development goals. In short, the benefits of using local materials can be summarized as follow:

Reduced Environmental Impact: Using materials sourced locally, recycled, or renewable materials minimizes energy consumption and greenhouse gas emissions associated with transporting materials over long distances.

Cost Efficiency: Local materials are often less expensive than imported ones, as they reduce transportation costs which lead to decrease overall project costs.

Support for Local Economies: Sourcing materials locally stimulates the regional economy by creating jobs in material extraction and processing.

Waste Reduction: Locally sourced materials can include recycled or repurposed materials, helping to reduce waste and conserve resources.

In summary, utilizing plastic waste for soil stabilization offers an inventive and environmentally friendly approach to reducing ecological harm. Repurposing plastic materials not only helps decrease overall waste production but also conserves natural resources, consumes less energy, and plays a vital role in preventing soil erosion.

3. CONCLUSIONS

By integrating these eco-friendly practices into geotechnical engineering, the aim is to create a built environment that harmonizes with nature, reduces resource consumption, and enhances resilience against environmental challenges. In summary, the findings of this study offer important insights into the use of waste plastic materials as eco-friendly soil stabilizers to mitigate the environmental impact of plastic waste. Consequently, the main conclusion of current study can be written as follow:

Positive impact on soil properties: research indicates that recycled waste plastic can effectively stabilize and reinforce various soils. The addition of waste plastic bottles improved the soil's shear strength, bearing capacity, compaction characteristics and reduction in consolidation settlement, in swelling and cracks. This suggests that incorporating plastic waste can enhance the soil's ability to withstand heavy loads.

Environmental and economic benefits: using waste plastic bottles for soil stabilization provides an environmentally friendly solution to reduce plastic waste while also offering an economical alternative to traditional soil stabilizers.

Potential for waste management: the research highlights the dual benefit of using waste plastic for soil stabilization, it addresses plastic waste disposal issues and improves soil properties for construction and infrastructure projects.

Other benefits of using waste plastic for soil stabilization: are to lower the time of construction and to minimize land acquisition.

The observations noted in the present study are useful in the reuse of plastic waste and contribute better practices in geotechnical aspects of waste management.

4. RECOMMENDATIONS

Designers and engineers ought to prioritize eco-friendly approaches rather than relying on conventional techniques when addressing issues related to construction soil.

Government agencies should actively promote the recycling of plastic waste to encourage its widespread use. This can be achieved through organized public awareness campaigns aimed at enhancing understanding and encouraging the effective recycling and reuse of waste materials.

5. To enhance the sustainability of the construction sector, significant efforts must be dedicated to recycling and repurposing waste materials. By transforming waste into valuable resources, we can foster sustainable development and generate social and economic benefits

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