Physical modeling of loose sand bearing capacity improvement using recycled PET bottle geocell

Manesht Maleki Vasegh[1], Vahid Rostami[2*], Hamidreza Rabieefar[3]

1. Department of Civil Engineering, Ki.C., Islamic Azad University, Kish, Iran.

M.malekivasegh@iau.ac.ir

2. Department of Civil Engineering, Ha.C., Islamic Azad University, Hamedan, Iran.

Rostami.vahid@iau.ac.ir

3. Department of Civil Engineering, STB., Islamic Azad University, Tehran, Iran.

rabiefar52@iau.ac.ir

ABSTRACT

The plastic waste crisis, particularly polyethylene terephthalate (PET) bottles, poses a serious environmental challenge with destructive impacts on ecosystems. In this regard, the present study aims to propose an innovative and sustainable solution by evaluating the reuse of PET bottles in the form of geocells for improving soil foundations. To achieve this, a laboratory-scale physical model was designed, and plate load tests were conducted on a shallow foundation placed on loose sand under two conditions: unreinforced and reinforced with geocells made from recycled PET bottles. The geometric parameters of the geocell layer, including height, embedment depth, and width, were investigated to analyze their effects on bearing capacity, initial stiffness, and load–settlement behavior. The results demonstrated that PET geocells significantly enhance the bearing capacity and initial stiffness of the foundation and improve stress distribution beneath the footing. In the optimum configuration, the ultimate bearing capacity increased by up to eight times compared with the unreinforced case. Increasing the geocell height improved load distribution and compressive resistance, while reducing the embedment depth facilitated more effective load transfer from the foundation to the geocell and then to the soil. Moreover, increasing the geocell width amplified the membrane effect and reduced stress concentration beneath the foundation. Overall, the use of PET bottles in geocell construction represents an economical and environmentally friendly method for improving the geotechnical performance of shallow foundations.

KEYWORDS

PET bottle; Foundation bearing capacity; Plastic bottle geocell; Geocell height; Geocell embedment depth

1. Introduction

The increasing accumulation of non-biodegradable Polyethylene Terephthalate (PET) plastic waste poses a significant global environmental challenge [1]. While current waste management strategies—such as landfilling and incineration—are often unsustainable or environmentally harmful, recent research highlights the potential of repurposing waste PET bottles in infrastructure projects [2]. Specifically, in geotechnical engineering, utilizing these bottles in their original form as three-dimensional geocell-like mattresses offers a sustainable, cost-effective alternative to commercial reinforcement materials [3, 4]. This approach not only eliminates the energy-intensive processing required for shredding or granulating plastic but also provides an efficient method for soil stabilization, enhancing bearing capacity and stiffness while offering long-term environmental benefits [5].

2. Methodology

To evaluate the performance of this recycled reinforcement, a small-scale physical model was designed and constructed. The experimental setup consisted of a steel box measuring 110 cm × 100 cm × 80 cm, filled with uniform Hamadan sand to ensure consistency. Static plate load tests were conducted using a square footing (10 cm width).

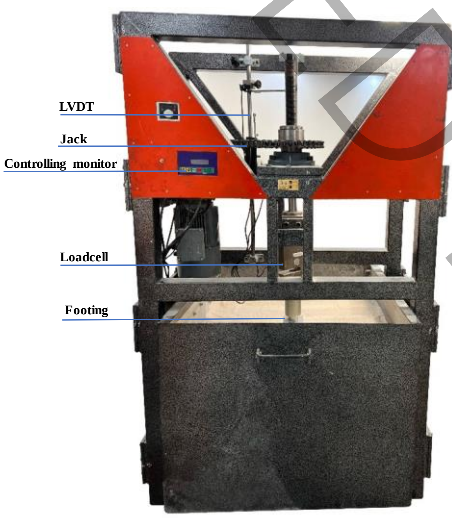

Fig 1. A schematic view of the experimental apparatus

The reinforcement mattress was fabricated using waste PET bottles with a diameter of 5.6 cm. The experimental program examined various geometric configurations, including grid sizes ranging from 11 cm to 56 cm, and varying mattress heights (h = 2.5, 5, 10, and 15 cm) at different embedment depths (u = 0, 2.5, and 5 cm). The tests were conducted at a relative density of 35% for the sandy soil. The testing matrix, detailing the specific parameters and their variations, is summarized in Table 1.

Table 1. Experimental testing program for PET mattress configurations

Test series	Test No.	u/D	b/D	h/D
S 1	00	-	-	-
	01	00	4.5	0.25
	02	00	4.5	0.50
	03	00	4.5	1.00
	04	00	4.5	1.50
S 2	00	-	-	-
	05	00	4.5	1.00
	06	0.25	4.5	1.00
	07	0.50	4.5	1.00
S 3	00	-	-	-
	08	00	1.1	1.00
	09	00	2.2	1.00
	10	00	3.4	1.00
	11	00	4.5	1.00
	12	00	5.6	1.00

3. Results and Discussion

The PET mattress significantly improves the ultimate bearing capacity and initial stiffness of the soil across all footing types. The reinforcement functions through three primary mechanisms:

- Confinement Effect: The stiff walls of the PET cells restrict lateral soil displacement, increasing the shear strength of the soil matrix.
- Tensioned-Membrane Effect: Under vertical loads, the mattress

undergoes tensile deformation, effectively redistributing stresses over a broader area of deeper soil layers.

- Load Distribution Effect: The mattress acts as a semi-rigid slab, reducing stress concentration directly beneath the footing and mitigating settlement.

Geometric Parameter Analysis:

- Mattress Height (h): Increasing the cell height improves load distribution and bearing capacity by engaging a larger soil volume and activating the confinement and membrane mechanisms. While an optimal height range of 0.5D < h < 1.0D maximizes structural efficiency, exceeding this height can lead to localized rupture of the PET joints due to excessive tensile stresses, causing a post-peak reduction in capacity.
- Embedment Depth (u): As shown in figure 2 placing the mattress directly beneath the footing (u/D = 0) provides the most effective load transfer and highest initial stiffness by intercepting the failure wedge. Although deeper placement (u/D = 0.25) reduces initial stiffness, it can enhance ultimate resistance at higher settlements by delaying pull-out failure through increased soil confinement.
- Mattress width (b): Increasing the mattress width enhances the membrane effect and stress distribution by expanding the influence zone, leading to substantial gains in bearing capacity. However, there is a threshold of approximately 5.6D beyond which marginal improvements diminish and the risk of structural tensile failure in the PET joints increases.

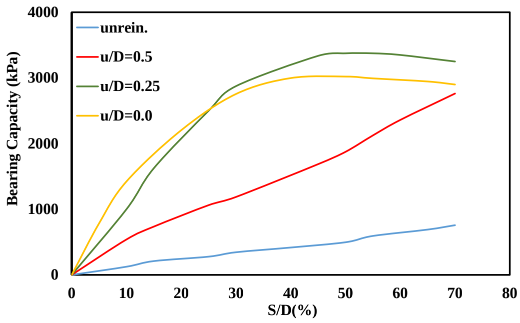

Fig 2. Load-settlement curves comparing reinforced and unreinforced soil behavior with different u/D

4. Conclusion

The reuse of waste PET bottles as three-dimensional geocell-like mattresses represents a highly effective and sustainable approach to geotechnical soil stabilization. This study confirmed that the proposed reinforcement significantly improves the bearing capacity, initial stiffness, and stress distribution of sandy soil beds. By converting environmental waste into a structural component, this method provides a cost-effective solution for small-scale foundation projects.

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