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Investigating the effect of PET plastic bottle strips on the strength and compressibility properties of clayey soil

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Abstract. The production of plastic bottles by the manufacturing industry has increased drastically over the last six decades across the globe. This rapid production has led to the generation of many waste plastic bottles, thus causing environmental pollution. About 180 tonnes of plastics are generated daily in Kampala, the capital city of Uganda, and around 50% is dumped into the Kiteezi landfill. Instead of putting pressure on the landfill, these plastic bottle wastes could be reused in stabilizing soils with poor engineering properties. The current study investigates the engineering properties of clayey soil reinforced with Polyethylene-terephthalate waste plastic bottle strips. In order to achieve the objectives of the study, the geotechnical and engineering properties of the soil reinforced with waste plastic bottle strips at 0.1, 0.2, 0.3 and 0.4% of the dry unit weight of the soil and non-stabilized soil were determined by conducting laboratory tests, such as particle size distribution, Atterberg limits, compaction test and California Bearing Ratio. The results revealed that the California Bearing Ratio of the soil reinforced with Polyethylene-terephthalate waste plastic bottle strips increased with the increase in the percentage of Polyethylene-terephthalate waste plastic bottle strips up to 0.3%. Beyond 0.3%, a drop in California Bearing Ratio was observed. It indicates that 0.3% Polyethylene-terephthalate waste plastic bottle strips is the optimum percentage for stabilizing low plasticity clayey soils.

1. Introduction

Plastic waste management is becoming a significant challenge in developing countries like Uganda. Data from various sources reveal that out of 180 tons of plastics that are generated [1,2], 40-50% are transported and dumped to the Kiteezi landfill that is located in Kampala, Uganda [3]. It means that the rest of the waste plastic bottles are disposed in a manner that is not safe. Even those dumped on landfills increase pressure or are poorly managed, as shown in Figure 1 [1]. It is noted that since the population is increasing, the number of wastes generated will also keep on increasing. It calls for looking for alternative ways of utilizing plastic wastes in other sustainable ways. Among the ways of reusing waste plastics could be stabilizing soil. Different solid waste materials, like waste tyres, industrial wastes, incinerator ash, and others, have been used to stabilize soils with poor engineering properties, showing positive results [4–6]. The basic idea about soil stabilization is about improving or altering the index properties, improving the gradation, and improving the soil's strength properties to be suitable for



constructing the engineering infrastructure. These improvements occur due to a series of chemical reactions when a stabilizer is introduced in the soil [7–9].

Several studies have been conducted on Polyethylene-terephthalate (PET) waste plastic bottles as additives in concrete [10–14], and it has been shown that the strength properties increase upon the inclusion of PET waste plastics. For example, the study by Borg et al. [13] in determining the early age performance and mechanical characteristics of concrete reinforced with recycled PET bottles found out that 1% by volume of PET plastic deformed fibres of length 50 mm gave the best results, as cracks were not observed. Thus the study concluded that PET plastic fibres play a significant role in structures delicate to cracking. The study by Ongpeng et al. [14] showed that PET plastic waste bottles showed an increase in the ultimate compressive strength of concrete. Besides, some studies were conducted on stabilizing soil with PET waste plastic bottles also showed significant results. Mishra and Gupta [15] used a combination of fly ash and PET waste plastic bottles, having ratios ranging from 0% to 20% (fly ash) and 0% to 1.6% (PET waste plastic bottles) of the weight of the soil. The results obtained from various tests showed improvement in the index and engineering properties—for example, plasticity index decreases, CBR and shear strength increase. The optimum percentage of the materials from their study was 1.2%, and 15% recycled PET waste plastic bottles, and fly ash, respectively. Bozygit et al. [16] determined the effect of PET plastic bottle strips on the mechanical properties of cement stabilized kaolin clayey. Their study found out that the mechanical properties of cement stabilized kaolin soil increased after the inclusion of PET waste plastic bottle strips. Based on the above findings, it can be concluded that PET waste plastic bottle strips could successfully be used in the field. However, studies on using PET plastic studies in Uganda are still limited. The current study tries to address the gap in knowledge by checking the possibility of using PET plastic bottle strips to stabilize clayey soils. Their usage is two way, that is to say, improving the geotechnical properties of the soil, and reducing environmental pollution that could happen if they are disposed in an inappropriate way. When plastics are dumped in landfills, they do not break up or decay fast, and as a result, they interact with water and form hazardous chemicals [17]. Therefore, it becomes essential to modify the properties of expansive soils with a cheaper alternative method like plastic waste bottles which reduces plastic waste pollution and its effects.

The desirable properties that enable PET plastic bottles to be effective stabilizers could be the high modulus of elasticity (around 2950 MPa) and high resistance to acid and alkaline [16]. Since PET plastic bottles have a high modulus of elasticity, once reinforced in soil enables it to resist deformation when subjected to loading.



Figure 1. Poor disposal of wastes at Kiteezi landfill [1].

2. Methodology

2.1. Materials

The materials used in the current study include; expansive soil and PET (Polyethylene-terephthalate) waste plastic bottle strips. Both the materials were obtained locally.

2.1.1 Clayey soil. The clayey soil sample used in the current study was collected at Kyitetika village in Kasangati Town Council, Wakiso District, Uganda, at a coordinate of 02440323521'E. The samples were picked at a depth of 0.5 m. The sample was then taken to the laboratory for testing. Physical and index properties were determined following the British Standards.

2.1.2 PET (Polyethylene-terephthalate) plastic waste bottles. PET raw plastic bottle strips were used with a length and width of 5 mm and 0.5 mm, respectively. Accordingly, four different percentages of 0.1, 0.2, 0.3, and 0.4% by weight of the soil were used. These sizes and percentages of plastic strips were adapted from previous studies conducted by Akbulut et al. [18].

2.2. Methods

The methodology used was conducting laboratory tests on both PET stabilized soil and non-stabilized soils. All the tests were conducted following British Standards, as shown in Table 1 [19]. Sieve analysis was considered to determine the particle size distribution of the soil. Particle size distribution significantly impacts other properties like strength, the solubility of the mixture, and surface area properties. The liquid limit (LL) was obtained using the cone penetration test. After doing the Particle size distribution and Atterberg limits test, the soil was classified using the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification system (USCS) methods. According to Das [20], under cone penetration test, the LL is obtained as a moisture content where a standard cone of apex angle 30° and a weight of 0.78 N penetrates a distance of 20 mm in 5 seconds. Based on how the test is conducted, cone penetration could yield better results than Casagrande's method. Heavy compaction was done to determine the maximum dry density (MDD) and optimum moisture content (OMC), and California Bearing Ratio (CBR) test was conducted under wet conditions.

Table 1. Test and the standard [19].

No	Test	Purpose	Standard
1	Particle size distribution	Grading	BS1377: Part 2
2	Atterberg Tests	Plasticity index	BS1377: Part 2
3	Compaction Test	To determine OMC content and MDD	BS1377: Part 3
4	California Bearing Ratio	To determine the bearing capacity of soil	BS1377: Part 9

3. Results and discussion

3.1. Geotechnical Properties of the soil understudy

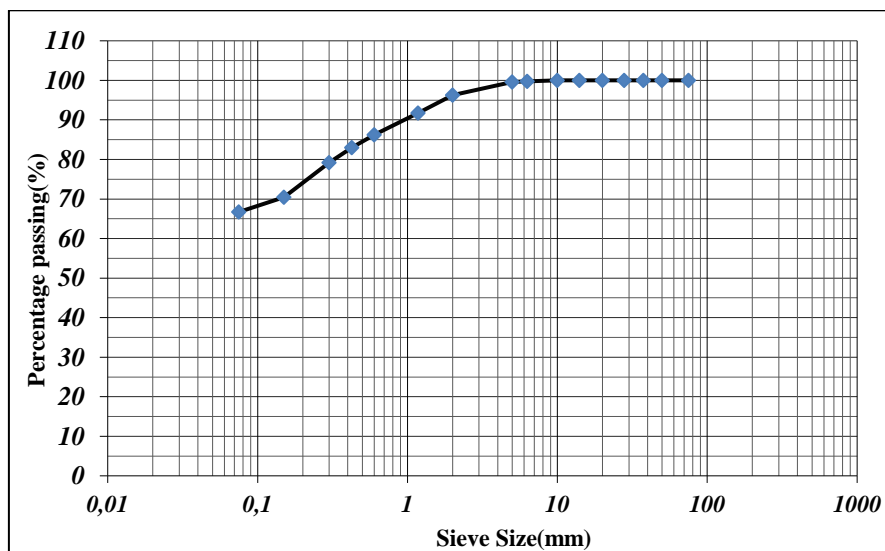
A brief description of the geotechnical properties of the soil used in the current study is summarized in Table 2. The soil that was used was light greenish-grey clays with black organic matter. It was classified as A-6 using the AASHTO soil classification system and low plastic clay under USCS [20]. According to AASHTO, the soil under class A-6 possesses poor engineering properties, hence a need for stabilization.

Table 2. Test and the standard.

No	Property	Value
1	Percentage passing BS No 20 Sieve	66.7%
2	Natural moisture content	20.2%
3	Liquid limit	25%
4	Plastic limit	13.3%
5	Plasticity index	11.7%
6	AASHTO classification	A-6
7	Unified Soil Classification System	CL

3.2. Particle size distribution

The results show that the soil sample under the current study was uniformly graded, as seen in Figure 2. The percentages of different types of soil were determined as Gravel= 3.3%, Sand = 29.6%, Silts and Clays = 66.7%. It showed that the soil is dominated by silts and clays since they have a higher percentage content.

**Figure 2.** Particle size distribution

3.3. Atterberg limits

The liquid limit (LL) was determined using the cone penetrometer apparatus, and the results are seen in Figure 3. The moisture content obtained at a cone penetration of 20 mm was taken as the liquid limit, which is 25%. According to Whitlow [21], the soil under study exhibits low plasticity. The plastic index was calculated as the difference between the liquid limit and the plastic limit, as seen in Table 3. Based on the results, the soil is low plastic clayey because the plasticity index is 11.7%, which is less than 35%.

Table 3. The results from the Atterberg test

No.	Parameter	Results (%)
1.	Liquid limit (LL)	25.0
2.	Plastic limit (PL)	13.3
3.	Plasticity Index (PI)	11.7

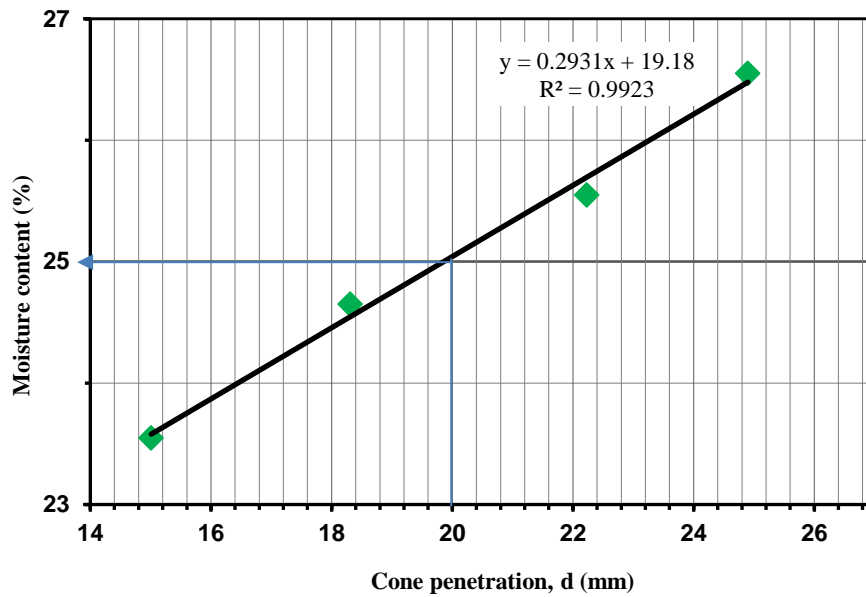


Figure 3. Determination of liquid limit

3.4. Compaction Test

The values for the dry density of the soil samples starting from 0% of PET plastic bottle fibre strips to 0.4% PET plastic bottle fibre strips reinforced samples are 1946, 1960, 1970, 1981 and 1972 kg/m³, respectively. This increasing pattern shows that the density of the soil kept increasing with increasing percentages of plastic inclusion. While for 0.4% inclusions of plastic strips, the value for dry density decreased because the plastic content is found to be in large amounts in the plastic soil matrix. The maximum dry density and the optimum moisture content were 1946 kg/m³ and 9.1%, respectively, as seen in Figure 4. The vital role of compacting is to increase on shear strength of the soil, decrease permeability, and increase density [15].

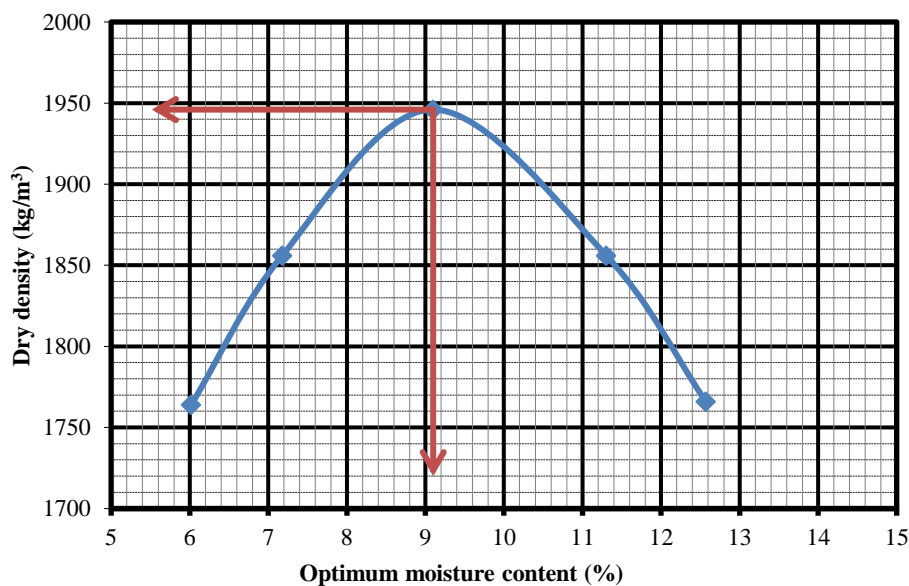


Figure 4. Compaction test results

3.5. California Bearing Ratio (CBR)

The CBR test was conducted on samples soaked for four days. The CBR value of unreinforced expansive clayey soil obtained was 12.2%, while the highest CBR achieved for the PET plastic bottle strips reinforced soil is 16.2%, as seen in Figure 5. After reinforcing the soil with different percentages of PET plastic bottles, the CBR values increase up to 16.2% at 0.3%. An increase in CBR is a significant indication of improved strength of the soil [9,15]. However, a drop was observed at a percentage after reinforcing the soil with 0.4% PET plastic bottle strips. It could be attributed to the large quantities of waste plastics that could have weakened the soil. Based on the highest CBR achieved after reinforcing the soil with PET waste plastics, it can clearly be stated that the optimum percentage of stabilizing the soil under study is 0.3%.

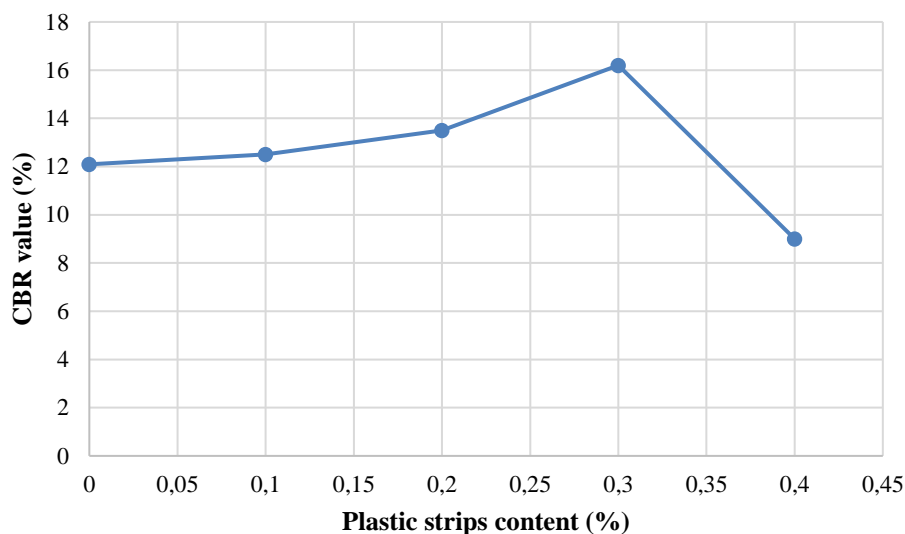


Figure 5. The effect of plastic strips on CBR values

4. Conclusion

The current study investigated the effect of waste PET plastic bottle strips on soil strength and compressibility parameters. Based on the findings, the soil under study was classified as A-6 under AASHTO classification, hence possessing poor engineering properties. Considering CBR values, soils reinforced with 0.3% plastic strip bottles yielded higher CBR values than other percentages. It shows that 0.3% PET plastic bottle strips inclusion could stabilize clayey soils under study. However, the study recommends conducting durability tests to determine how waste PET bottle strips reinforced soil will behave in the long run since the design life for engineering structures is relatively long.

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