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APPLICATION OF WASTE PET (POLYETHYLENE TEREPHTHALATE) BOTTLE-DERIVED GEOCELLS FOR STABILIZATION OF UNPAVED ROAD

Insan Kamil [1]
Lecturer, Civil Engineering, Polytechnic of Samarinda
Raudah Ahmad[2], Dwiana Dwi Widyawati[2], Kukuh Prihatin[2]
Lecturer, Civil Engineering, Polytechnic of Samarinda
Mustika[3]
UG, Civil Engineering, Polytechnic of Samarinda
Fitri Wulandari[4]
PG Student, Civil Engineering, Polytechnic of Samarinda

ABSTRACT

Unpaved road constructions in clay which connect the rural area of East-Kalimantan is inevitable which frequently involves the damages in rainy season. Those damages are frequently occur only at segmental spots. Moreover, road construction on clay is challenging due to reduced excessive deformation and bearing area. Where, a cheap soil stabilization system which applied in a large area will be expensive if implemented in small area such as the application of geo-cells due to the small number of volume in purchasing. However, there had been many studies of the utilization of waste pet bottle-derived geo-cells for stabilization carried out. This paper presents the field test model of waste PET bottle-derived geocells. The study evaluated performances of the waste PET in terms of deformation patterns, settlement values, and the effectiveness of application in the field by dividing the test area as clay soil, formation 1 which is waste plastic glass installation with the open side facing up, and formation 2 which is plastic glass application facing downwards. Infill material is soil in group A-7-5 based on the AASTHO classification with saturated conditions. In the clay soil, the pattern of plastic deformation or general shear failure was obtained with a maximum settlement of 15,2%. Furthermore, the deformation pattern that occurs in formation 1 is a plastic deformation pattern or local shear failure which reduces settlement by 37,8% and formation 2 elastic deformation pattern or penetration shear failure with a settlement reduction of 63,7%. Based on field testing, it is known that in clay soil the application of reinforcement is more efficient in formation 2. Overall, the use of waste PET bottle-derived geocells is a sustainable and cost-effective solution for stabilization of unpaved roads. It promotes recycling, easy to install, reduces plastic waste, and provides a durable, long-lasting road surface that requires minimal maintenance.

Keywords:
Clay, PET, Geo-cells, Deformation, settlement, bottle-formation

INTRODUCTION

Particularly in rural and developing regions, where they provide crucial connectivity and access, unpaved roads are a common component of transportation infrastructure. However, rutting, potholes, and general deterioration are triggered by these roads' frequent lack of stability and durability [1]. Geocell, a three-dimensional, honeycomb-like cellular confinement system, has emerged as a versatile and effective solution in the realm of geotechnical engineering, addressing a wide range of challenges encountered in infrastructure development, soil stabilization, and slope protection [2], [3], [4], [5], [6]. The unique characteristics of geocell, such as its ability to distribute loads, enhance bearing capacity, and reinforce weak soils, have made it a popular choice among engineers and researcher. [7], [8], [9], [10].

Waste polyethylene terephthalate bottles can be used as reinforcing material for road stabilization, which is one viable solution to this issue. One promising approach to address this challenge is the use of waste polyethylene terephthalate bottles as a material for constructing geo-cells, which can then be utilized to stabilize the subgrade of unpaved roads [11], [12]. Plastic waste, particularly from discarded PET bottles, poses a significant environmental concern globally. Researchers have explored various methods to repurpose this waste material, and the application of PET bottle-derived geo-cells for road stabilization represents a novel and eco-friendly solution. The findings indicate that the use of waste PET bottles as a reinforcing material can lead to significant improvements in the mechanical performance of road structures, such as reduced rutting and increased resistance to deformation. Furthermore, the collective recycling of waste PET bottles and waste rubber tires into performance-increasing modifiers for asphalt pavements has been shown to be a promising approach, addressing both environmental and infrastructural concerns [2], [3], [11], [12], [13], [14], [15]. In conclusion, the application of waste polyethylene terephthalate bottle-derived geo-cells for the stabilization of unpaved roads is a promising approach that addresses both environmental and infrastructural concerns. This technique has the potential to improve the durability and stability of unpaved roads, while also providing a sustainable solution for the recycling of waste plastics.

OBJECTIVES

The objective of this research is to assess the efficacy of employing waste plastic cups as a substitute for geocells in enhancing clay reinforcement. A primary focus of this study is to ascertain the deformation pattern of clay soil prior to reinforcement, with the intention of comparing it with the condition subsequent to geocell replacement utilizing two predetermined formations. By comparing the deformation patterns before and after reinforcement, this study seeks to determine the extent to which waste plastic cups can contribute to enhancing soil stability. Additionally, the study examined the variation in soil deformation values resulting from the implementation of two geocell formations of plastic glass waste, with the objective of ascertaining the most efficacious configuration for minimizing soil deformation. Furthermore, this research investigated the time and labor efficiency of implementing the two formations in a field setting, with the aim of determining the most effective and practical method for implementing soil reinforcement using waste plastic cups.

METHODOLOGY

The research commenced with the collection of soil samples from Bukit Pinang Bahari Housing Estate, followed by the preparation of 400 pieces of plastic glass waste, which were utilized as a mixture. Subsequently, the soil samples underwent a series of tests to ascertain their physical properties. These tests encompassed methods such as wet sieve, sieve analysis, Atterberg limit testing, and specific gravity measurement. The outcomes of these tests were then employed to categorize the soil according to the AASHTO system. The classification of the tested soil samples revealed their belonging to the A-7-5 clay group. Subsequently, the soil samples were filled with plastic glass waste, which had been disturbed and saturated, and manually compacted until reaching a weight of 320-340 grams per package.

The field application was executed through the excavation of the soil on a flat road, thereby establishing a testing area measuring 0.75 × 1.5 × 0.5 meters. This area was subdivided into four sections, arranged in two longitudinal and two transverse areas, with a distance of 1 meter between each section. Subsequent to the excavation, the clay soil was distributed to a height of 0.5 meters, then compacted using a frog stamper with four passes back and forth until it decreased by 10 cm. Thereafter, plastic glass waste was arranged at a height of 40–50 cm in accordance with the predetermined formation.

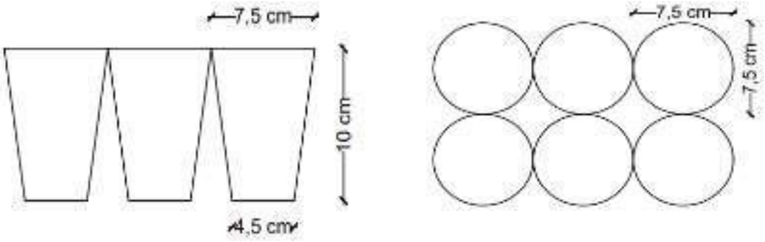


Figure 1 Formation 1

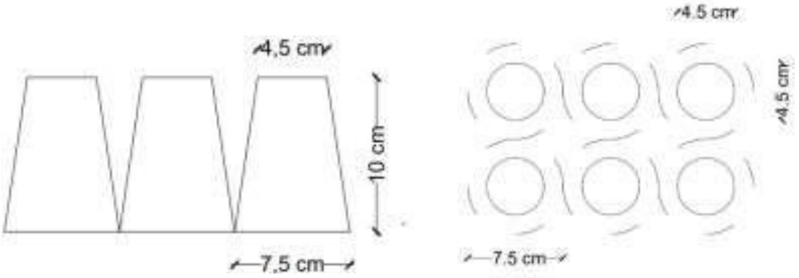


Figure 2 Formation 2

As illustrated in **Figure 1** Formation 1, the plastic cups are positioned in an upright orientation, with the base filled with the same clay soil as the sample in the cup. In **Figure 2** Formation 2, the plastic cups that have been filled and compacted are rotated in a face-down position, and the space between the cups at the top is filled with the tested clay soil. This configuration aims to analyze the effectiveness of waste plastic cups in improving the stability of clay based on different configurations.

Dynamic loading tests were conducted using a 1.1 axle passenger car weighing 1.3 tons. The loading simulation was carried out by crossing the front and rear tires of one side of the car using a speed of 20 km/h on the prepared test area. The crossing was carried out on the test area, which was still in the form of soil without reinforcement, as well as soil with reinforcement that had been arranged with formations 1 and 2. Deformation patterns were observed through the use of a cell phone camera, which facilitated the documentation of the patterns at the initial and final conditions of the track.

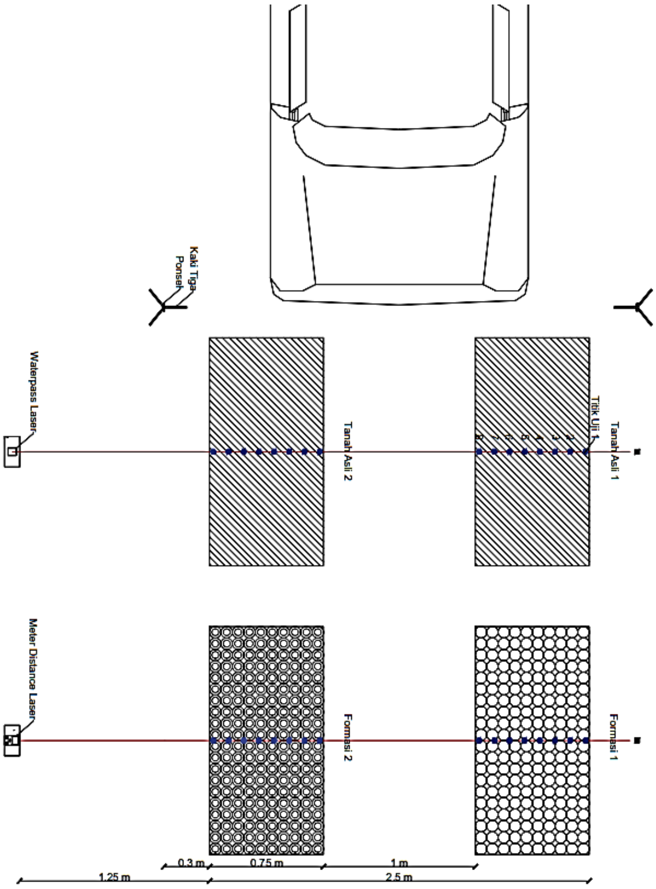


Figure 3 Field Application Top View

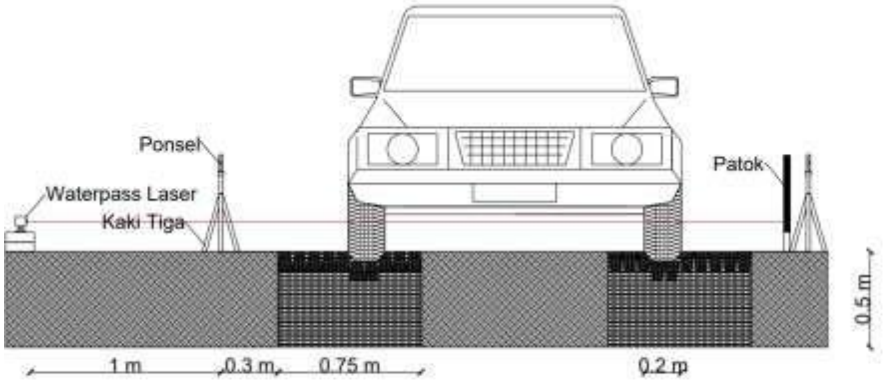


Figure 4 Cross Section Field Application

RESULTS AND DISCUSSION

Scrap materials were used as an efficient alternative to geocells for small scale and easy to implement in field testing to evaluate the performance of clay soils. Tests were conducted on clay soil 1 in the left wheel path and clay soil 2 in the right wheel path of a passing passenger car. In addition, this test also aims to analyze the strength of the soil that has been reinforced with formation 1 in the left wheel path and formation 2 in the right wheel path. The test was also conducted to identify the deformation pattern of the soil before and after the reinforcement was added.

The observed deformation patterns refer to changes in the shape of the clay surface before and after the application of reinforcement during tests involving passenger car crossings. An overview of the deformation pattern after the third crossing is shown in Figure 5.

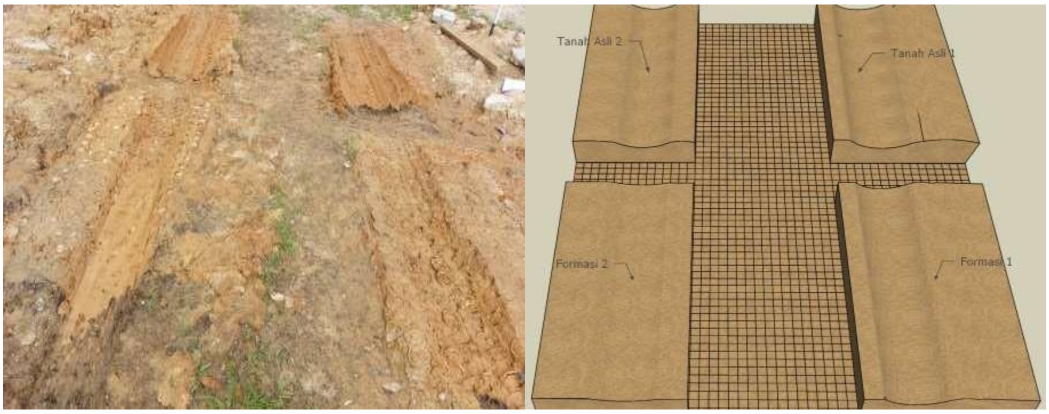


Figure 5 Top view after the third pass

The search for collapse deformation patterns in field testing aims to understand the mechanism by which soil or material changes shape until it reaches a collapse state, which is an important aspect of geotechnical stability analysis. These deformation patterns provide critical information on soil response to loads, such as pressure distribution, settlement rate, and potential collapse zones. They are also used to compare the effectiveness of reinforcement methods in reducing settlement and improving stability. By predicting long-term deformation behavior, the results of this analysis can improve design safety and efficiency, and provide a sound scientific basis for decision-making regarding the stability and sustainability of geotechnical structures.

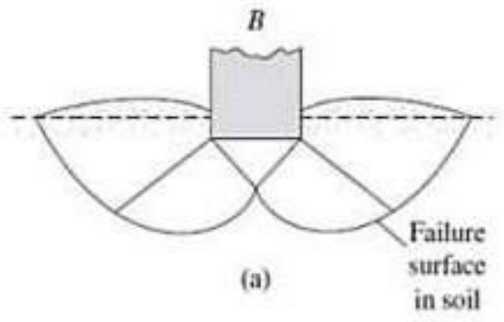


Figure 6 General shear failure

Figure 7 Plastic deformation pattern

In clay soil 1, the settlement that occurs is in accordance with the plastic deformation narrative, i.e. the soil crossed by the tire experiences a significant decrease. Furthermore, due to the presence of mounds around the settlement area, the form of collapse that occurs is considered a generalized collapse pattern.

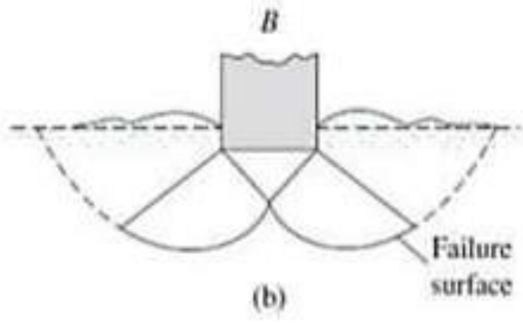
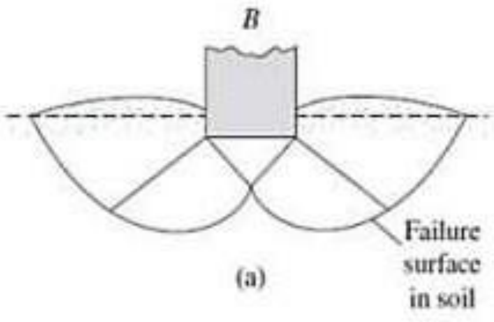


Figure 8 Local shear failure

Figure 9 Plastic deformation pattern

Formation test area 1, the pattern that corresponds to the conditions in formation pattern 1 is an illustration of the local shear collapse pattern. Settlement that occurs is plastic deformation with the state of the soil crossed by the tire decreasing and there are grooves around the track area.



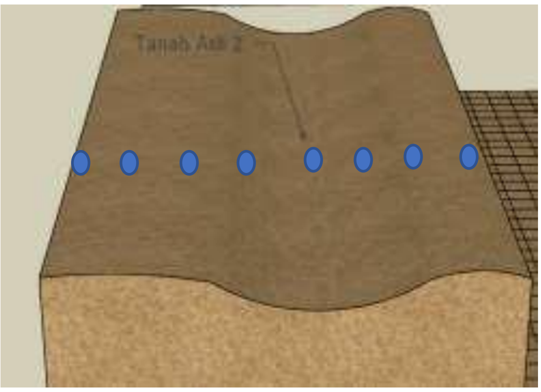


Figure 10 General shear failure *Figure 11 Plastic deformation pattern*

In clay 2, the soil experienced settlement at points 4-6 and experienced bumps at points 3 and 7 due to vehicle tire tracks. As illustrated above, it can be seen that the illustration in formation pattern 2 is in accordance with the illustration in the general shear collapse pattern. Settlement that occurs is in accordance with the plastic deformation narrative, namely the soil crossed by the tire decreases in the area it crosses.

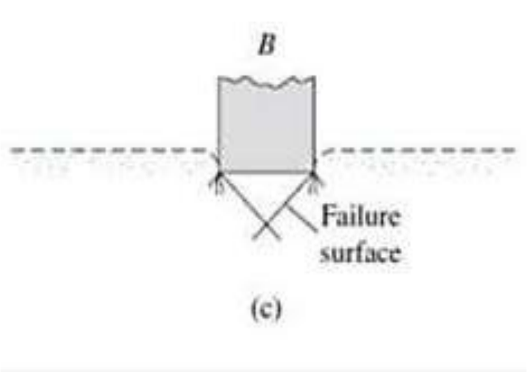


Figure 12 Penetration Failure

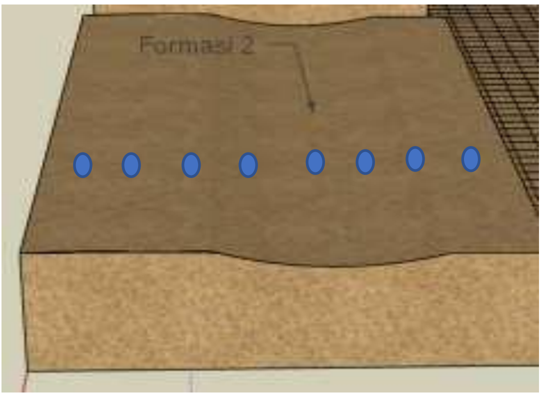


Figure 13 Elastis deformation pattern

Formation 2 test area shows the soil settlement at points 4 to 6 and pushed up by the tires at points 3 and 7. This shows that the picture matches the illustration of the penetration shear collapse pattern. Settlement that occurs is in accordance with the elastic deformation narrative with a sign that the settlement that occurs is limited to the grooves of the wheels of passing vehicles. Furthermore, due to the presence of mounds around the settlement area, the form of collapse that occurs is considered a penetration collapse pattern.

The decrease in the test area due to the load of passing vehicles, for comparison between the values of the two test areas, namely clay 1 and formation 1 can be seen in the table below.

Settlement (cm) / Test Point	Area Uji	
	Lempung 1	Formasi 1
1	4.3	1
2	-2.4	-2.9
3	-8.2	-5.1
4	-4.3	-4
5	4.3	1
6	5	-0.3
7	3.3	-0.4
8	2	0.2

Table 1 Difference of the 3rd Trajectory Ground Subsidence to the Initial Ground

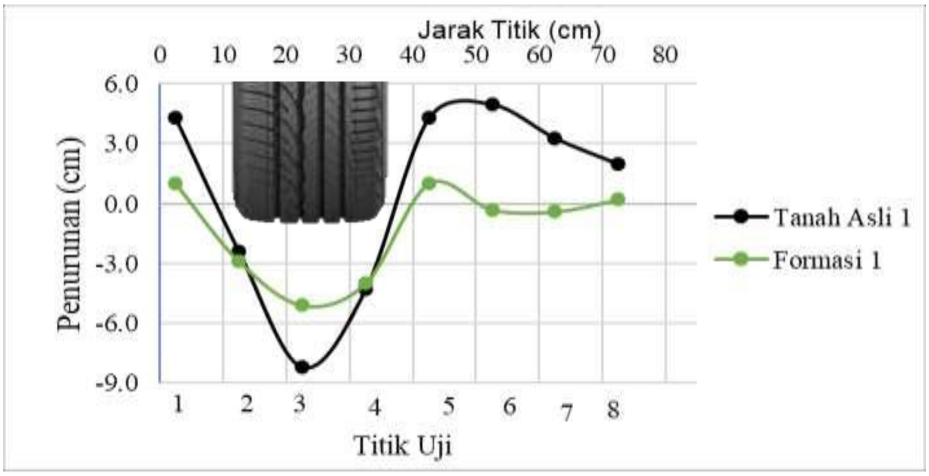


Figure 14 Subsidence Graph of Original Soil 1 and Formation 1 against the 3rd Passage

The graph shows a comparison of the difference in settlement values between the soil before crossing and the soil after the third crossing. Furthermore, the difference between the test results of native soil 1 and reinforced formation 1 with a glass filled with soil facing upwards was analyzed, both of which were crossed by the left wheel. The largest decrease at point 3 of the third pass showed that both soils experienced the largest decrease respectively for clay soil 1 and reinforcement formation 1 of 8.2 and 5.1 cm, so formation 1 succeeded in reducing the decrease of 37.8% compared to clay soil without reinforcement.

The difference in settlement that occurs is due to the glass in the glass formation facing upwards the soil in the glass is retained by the glass the movement that occurs is retained by the embedded glass, then the water content in the soil in the glass is not as high as the water content in the clay. So compared to clay soil overlay, it is more recommended to apply reinforcement using waste plastic cups in formation 1.

Furthermore, **Table 2** shows the value of the difference in settlement in the clay test area 2 and formation 2.

Settlement (cm) / Test Point	Area Uji	
	Tanah Asli 2	Formasi 2
1	1.5	0.6
2	2.1	-0.2
3	3.9	-0.1
4	-1.9	-3.2
5	-10.2	-3.7
6	-6.1	-2.0
7	3.2	-0.8
8	2.3	-0.5

Table 2 Difference of the 3rd Trajectory Ground Subsidence to the Initial Ground

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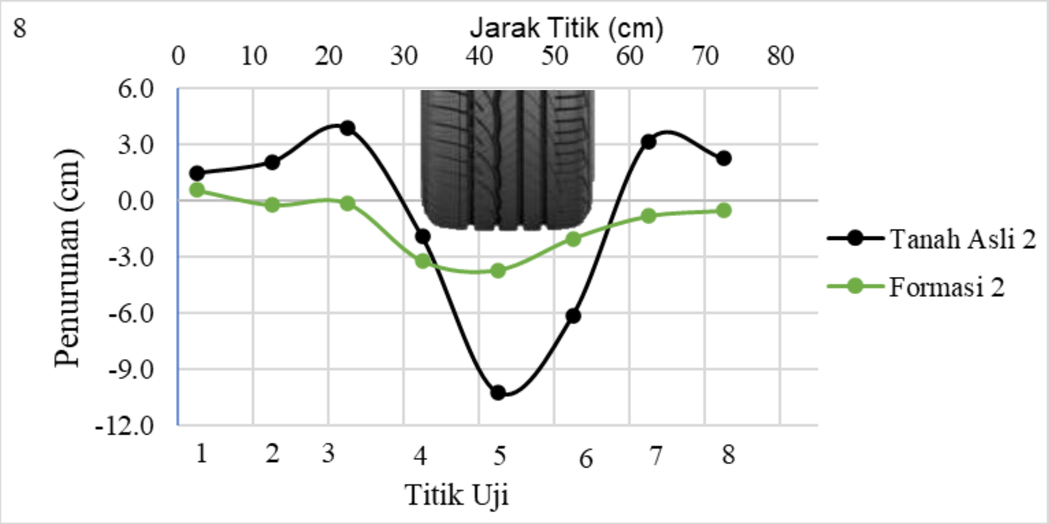

Figure 15 Subsidence Graph of Original Soil 2 and Formation 2 Against 3rd Pass

Comparisons were made of the differences in test results between existing soil 2 and soil reinforced with formation 2 using downward facing waste glass. This test was conducted before and after the right-hand wheel crossing until the third crossing. In the third traverse, the greatest settlement occurred at point 5, where the clay soil 2 had a settlement of 10.2 cm, while formation 2 had a settlement of 3.7 cm. This shows that formation 2 is able to reduce the settlement by 63.7% compared to the original clay.

Previous research revealed that geocells are able to reduce the settlement of red clay soil up to 70% [2]. Thus, there is a difference in settlement reduction of 6.3% between geocells and waste plastic cups in formation 2. However, the reduction rate is still much higher than formation 1, with a difference of 25.9%.

Based on the analysis of the results of the application of both formations in the field, formation 2 is more recommended because it has several advantages. The soil experiences a lower shrinkage-deflation rate because it is protected by the bottom of the glass facing upwards, so water does not directly absorb into the soil. In addition, the larger size of the bottom cross-section of formation 2 ensures that the top of the glass does not immediately move when crossed by a vehicle.

CONCLUSION

Based on the results of traffic testing of clay and clay soil using plastic cup reinforcement, it was found that the deformation patterns in both types of clay soil were similar, showing generalized shear collapse and/or plastic deformation. However, when reinforcement was applied, there was a significant difference in the deformation pattern between formation 1 and formation 2. In formation 1, the dominant deformation pattern was localized shear collapse and/or plastic deformation, while in formation 2 the pattern formed was penetrative shear collapse and/or elastic deformation. This difference indicates that formation 2 has more stable deformation characteristics and tends to be elastic, providing better performance than formation 1.

Quantitatively, the reinforced soil with formation 1 showed a deformation reduction of 37.8% against the unreinforced clay, while formation 2 was able to achieve a deformation reduction of 63.7%. This confirms that formation 2 is more effective in reducing deformation and improving soil stability. In addition, it is easier to implement formation 2 in the field due to its design which allows for more efficient filling of the clay through the intersection at the top. In contrast, formation 1 has a more complicated cross-sectional design, making it difficult to fill certain areas. However, the potential effectiveness of these formations may change if the fill material is changed, for example from clay to sand, as the characteristics of the fill material also affect the deformation pattern and applicability.

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