Utilization of Plastic Waste Polyethylene (PET) for reinforced subgrade

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Abstract. Plastic waste is a serious problem for the survival of all creatures on Earth. Recycling is one solution to reduce the negative impact of environmental pollution caused by plastic waste. A lot of plastic waste that pollutes the Earth comes from plastic bottle waste (PET). There had been many studies that discussed the use of plastic bottle waste (PET); however, this research used the plastic bottle waste (PET) as a geocell for subgrade reinforcement. To this date, the use of plastic bottle waste as geocell is still rare. The main purpose of this study was to determine the effect of adding geocell of plastic bottle waste on the subgrade using a capping layer that had a low bearing capacity. This research was expected to reduce the impact of environmental pollution due to plastic bottle waste, and be an alternative solution for additional reinforcement in the capping layer. Therefore, it could increase the ultimate bearing capacity and reduce the thickness of the cover layer on subgrades that had a CBR value below 5%. The results of the analysis using the Plaxis program showed that the geocell from plastic bottle waste could be used to save the use of capping layer materials by up to 65%.

1 Introduction

Between 1950 and the present, about 6.3 billion tons of plastic waste have been generated worldwide. As the human population grows, the demand for products that use plastic also increases. Recently, plastic waste production reaches 380 million tons per year. The disposal of plastic into the environment has had a negative impact, one of which is on international waters [1].

Indonesia still has problems with waste management, second worst in the world after China. Previous studies on plastic waste that pollute the environment show that Indonesia is responsible for 15% of plastic waste in global waters [2]. One type of plastic waste that is widely circulated and hurts the environment is Polyethylene Terephthalate (PET). This type of plastic is plastic with code 1. Its use as a primary material for packaging bottles reaches 30% of the world use [3].

Research and development of cellular (geocell) confinement system began with the U.S. Army Corps of Engineering in September 1975 to test the feasibility of contructing tactical bridge approach roads over soft ground [4]. Geocell made of geosynthetics such as geotextiles or geogrids, are thermally welded or mechanically bonded interconnected pocket structures in the form of mattresses used with in-filled soil. General reinforcing mechanisms of geocell is confining the in-fill soil from shearing away and derive anchorage resistance through the surrounding soil against the applied load [5]. The geocell mattress consists of a series of interlocking cell constructed from polymer. The more recent advancement of reinforcement of reinforced soil is to provide three-dimensional confinement to the soil using geocells. The geocell foundation mattress consists of a series of the interlocking cell constructed from polymer geogrids, which contains and confines the soil within its pockets. It intercepts the potential failure planes because of its rigidity and forces them deeper into foundation soil, thereby increasing the bearing capacity of the soil [6]. In pavement and road construction, the effect of geocell-reinforced recycled asphalt pavement (RAP) bases over weak subgrade under cyclic plate loading and found that geocell has improved the performance of RAP bases over weak subgrade as compared with the unreinforced base section and geocell significantly increased the percentage of resilient deformation of the RAP base. The geocell reinforcement reduced the vertical stresses transferred to the subgrade by distributing the load over a wider area [7]. The bearing capacity improvement of gravel base layer in road constructions using geocell and concluded that geocell layer placed within the gravel base layer of asphalt paved construction reduced the vertical stresses on subgrade during vehicle crossing about 30 % and increased the layer modulus of the gravel base layers compared to an unreinforced layer. As a result, the measured deflections on the asphalt surface were also reduced [8].

Transforming plastic bottle waste (PET) into geocell is a solution to overcome the existing plastic waste issue. Considering the enormous potential in the use of PET-type plastic (mineral water bottles), this study focused on the use of plastic bottle waste (PET) as a subgrade reinforcement. Plastic bottle waste planted under a road layer that resembles a geocell is expected to increase the ultimate bearing capacity of the subgrade to stabilize the subgrade and minimize the settlement.

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Fig. 1. Geocell plastic bottle waste

The geocell used in this study was a geocell made from PET plastic bottle waste (600 ml mineral water bottle). The bottle was cut into two height variations, 50 mm and 75 mm, then the pieces of the bottle were joined by using a blind rivet measuring 2.4 mm × 6 mm in a square shape. Figure 1 shows the geocell of the assembled PET plastic bottle waste.

2 Experimental methods

2.1 Plate load test

Laboratory scale plate load, test was carried out according to ASTM D-1194, and by adding a plastic bottle waste geocell to the subgrade [9].

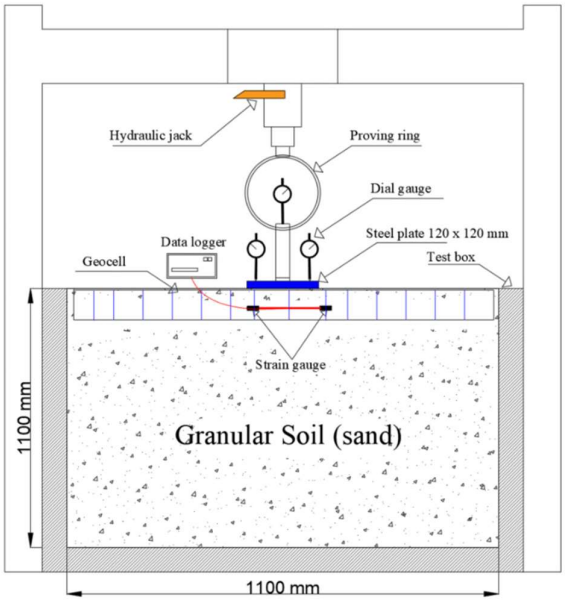


Fig. 2. Schematic view of the test setup.

The test was conducted in the laboratory of the Department of Civil and Environmental Engineering, Gadjah Mada University. The loading test was conducted to determine the ultimate soil bearing capacity and the settlement at the laboratory scale. In this case, maximum soil holding capacity and settlement with geocell reinforcement and without reinforcement from bottle waste. The subgrade used during laboratory testing was sand with a classification (USCS) SP (poorly graded sand) Friction angle ϕ =32º and *Cohesion, c* = 0 kN/m^2. The loading test results are presented in Table 1.

The ultimate bearing capacity is defined as the maximum load per unit area where the soil can still support the load without collapsing, which is expressed in the following equation [10].

$$q_u = \frac{P_u}{A} \quad (1)$$

in which qu is the ultimate bearing capacity (kN/m^2), Pu is the maximum load (kN), and A is the plate area or foundation (m^2).

Bearing capacity ratio (BCR) is the ratio of the carrying capacity value in the presence of geosynthetic materials or geocells from PET plastic bottle waste and the carrying capacity values without geosynthetic material or geocell from PET bottle. The equation for the bearing capacity ratio (BCR) is as follows [11].

$$BCR = \frac{q_r}{q_o} \quad (2)$$

in which BCR is the bearing capacity ratio, q_r is the bearing capacity value in the presence of geosynthetic reinforcement (kN/m^2), and q_o is the bearing capacity value without geosynthetic reinforcement (kN/m^2).

Table 1. The results of the bearing capacity of the soil and its decrease.

Variation of loading test	Ultimate soil bearing capacity (kN/m^2)	Settlement (mm)
Unreinforced	416,67	8,93
Reinforced geocell 50 mm	1111,11	17,59
Reinforced geocell 75 mm	1250	15,153

The results of the loading test in the laboratory can be seen in Table 1. It shows that the increase in the ultimate soil bearing capacity increased when geocells were added from plastic bottle waste. The average increase in the carrying capacity of the soil after adding the geocell reinforcement of plastic bottle waste was 183.82%. The bearing capacity ratio (BCR) value on average increased to 2.94.

Table 2. The results of soil bearing capacity and its settlement

Variation of loading test	Soil bearing capacity (kN/m^2)	Settlement (mm)
Unreinforced	416,67	8,93
Reinforced geocell 50 mm	416,67	3,01
Reinforced geocell 75 mm	416,67	3,035

It can be seen in Table 2 that the percentage of settlement experienced a decline if given the similar load of about 416.67 kN/m^2 for each variation of the loading test. The decrease without reinforcement was 8.93 or 100% to 3.0225 mm or 33.85%. This decrease proves that the geocell from plastic bottle waste can affect the characteristics of sandy soil by increasing the bearing capacity and declining the settlement.

The increase in soil-bearing capacity and settlement is affected by the height of the geocell and locking of the sandy soil in the geocell structure, thus, there is no excessive lateral force on the sand. The increase in the ultimate bearing capacity occurred when a 75 mm geocell was used. This is because the area to accommodate and lock the sandy soil in the geocell is slightly wider. This condition reduces the lateral forces of the sandy soil caused by the load on it.

2.2 Tensile strength test

After the loading test was conducted, a tensile test was also carried out for the plastic bottle material using the ASTM E8 reference using universal testing machine (UTM). After testing the tensile material on 9 samples, the average working force was 101.59 N with the maximum strain of 3.79 mm or 37.97% of the original form.

From the results, an approach was conducted by using an equation referred to previous studies [12], which defines geocells as a composite material or plate with the following equation,

$$E_g = 4(\sigma_3)^{0,7}(Ke + 200M^{0,16}) \quad (3)$$

in which E_g is the young's modulus of the geocell-reinforced soil, σ_3 is the average horizontal stress at the mid-height of the geocell layer, Ke is the young's modulus parameter of the unreinforced soil and M is the line of intersection of the geocell material modulus.

The geocell connection test (blind rivet) was carried out simply by giving the load gradually on three plastic bottles that had been cut and hung. The previously mentioned load was by increasing load of 1 kg per 30 sec on the hung geocell until it failed at the connection or broke. From the results of 30 samples tested for connection, the average load that could be held by the connection on this PET bottle waste geocell was 14.56 kg. The geocell connection test is presented in Figure 3.

Fig. 3. Geocell connection test (blind rivet).

After trial and error in the Plaxis program, the values obtained were E_g = 107259 kN/m, E_gA= 5362.96 kN/m, and EI = 1.117 kN/m^2. These values were used in the material input parameter that defined the geocell material as a plate in the Plaxis 8.6 program.

2.3 Subgrade analysis with Plaxis 8.6 program

The subgrade analysed in this study was a subgrade with a CBR value below 5%. One example is silt (*lanau*) which was given special treatment by increasing the thickness of the capping layer (granular soil) — classified by USCS as sand with poor grade or SP — of 300 mm to stabilize the above pavement [13].

2.3.1 Traffic load input parameters on Plaxis

The traffic load used the "D" load intensity, with uniform load (BTR) q = 9 kN/m^2 on the entire body of the road, as referred to [14].

2.3.2 Soil input parameters on Plaxis

The soil parameter included in the Plaxis was silt soil. The material model used in this research was Mohr-Coulomb. In accordance with the results of the soil study, there was attempt to input the following silt (*lanau*) parameters in the Plaxis program.

γ_{unsat} = 15 (kN/m^3) $\quad \nu$ = 0,30 $\quad \psi$ = 0 (º)

γ_{sat} = 18 (kN/m^3) $\quad c$ = 40 (kN/m^2)

ϕ = 10 (º) $\quad E$ = 3000 (kN/m^2) (4)

The above parameters were used for the input of soil material on the silt (drained) subgrade. The parameters of the soil on the road layer and the overburden layer above the subgrade refer to [15].

2.3.3 Geocell input parameters on Plaxis (plate)

EA = 5362,960 kN/m $\quad w$ = 0,850 kN/m

EI = 1,117 kN/m^2 $\quad \nu$ = 0,250

d = 0,050 m (5)

AC WC : 40 mm
AC BC : 60 mm
AC BASE : 170 mm
AGREGAT A : 300 mm
AGREGAT B : 300 mm
SUBGRADE (SILT)

Fig. 4. Road layer.

3 Result and discussion

3.1 Total displacements (Extream U_{tot})

A comparison of the settlement that occurred in the subgrade before and after the installation of geocells from plastic bottle waste can be seen in Figure 4 and Figure 5. It was found that the geocell from the plastic bottle waste can reduce the settlement due to the load above the subgrade up to 15,27 mm or 57,26 % of the total settlement without geocell reinforcement. The largest settlement reduction was occurred in the middle part of the loading area. The reduction effect was confirmed by both plane strain and axisymmetric model by using Plaxis FEM software.

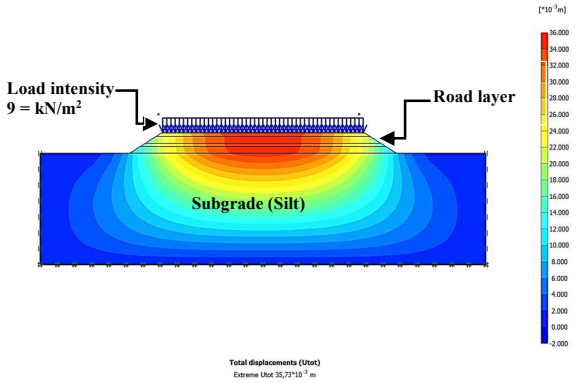


Fig. 5. Extreme U_{tot} unreinforced geocell plane-strain ($35{,}73*10^{-3}$m).

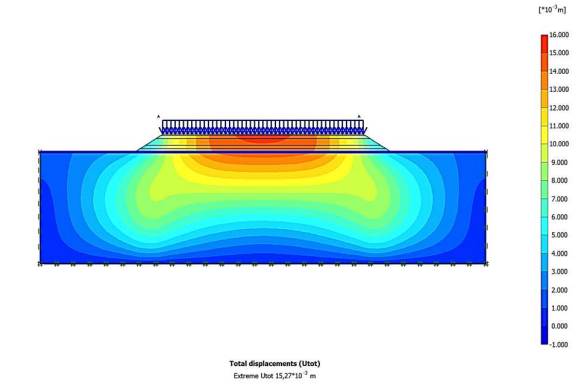


Fig. 6. Extreme U_{tot} reinforced geocell plane-strain ($15{,}27*10^{-3}$m).

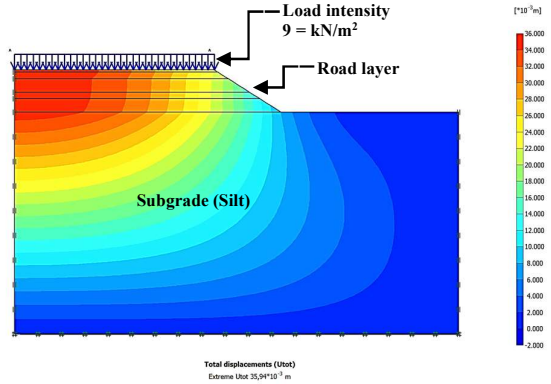


Fig. 7. Extreme U_{tot} unreinforced geocell axisymmetry ($35{,}94*10^{-3}$m).

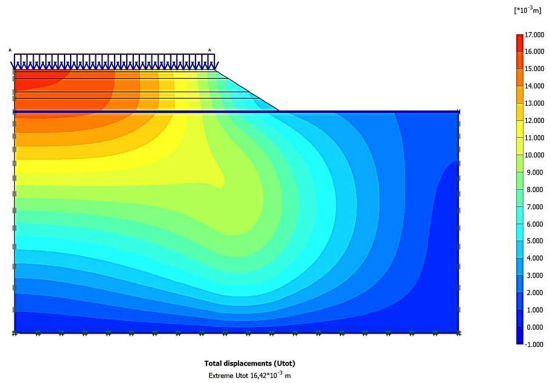


Fig. 8. Extreme U_{tot} reinforced geocell axisymmetry ($16{,}42*10^{-3}$m).

3.2 Ultimate bearing capacity

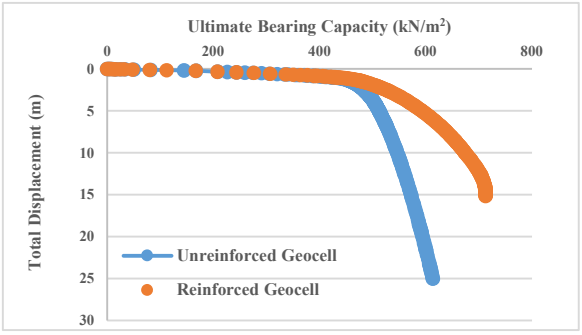


Fig. 9. Curve ultimate bearing capacity Plaxis 300 mm capping layer.

In Figure 9 the total displacements that occurred were more than 25 mm. This is because in order to obtain the ultimate bearing capacity value in the Plaxis program, the subgrade must receive as much load as possible until the subgrade collapses. A trial of uniform loading was carried out on the road body that tested at 1000 kN/m^2. When the subgrade collapses, the comparison of the bearing capacity between the unreinforced geocell and the

reinforced geocell can be seen as the result curve Plaxis in Figure 9. More details of the results curve ultimate bearing capacity capping layer of 300 mm are presented in Table 3.

Table 3. Result of curve Plaxis capping layer 300 mm.

Result Plaxis	Ultimate bearing capacity (kN/m^2)	BCR
Unreinforced geocell PET	613,534	1
Reinforced geocell PET	712,911	1,162

The results of the ultimate bearing capacity on Plaxis had increased up to 16.2%. These results prove an increase occurred when geocells were added to the subgrade. In addition, the results validate the results of the experiments in the laboratory (plate load test) where geocells from plastic bottle waste can increase bearing capacity and decline the settlement.

3.3 Analysis of capping layer thickness efficiency

In this analysis, we tried reducing the thickness of the capping layer material up to 50% followed by adding the geocell material from the plastic bottle waste. The purpose of the analysis was to observe the behaviour of the geocell when the capping layer thickness is only 50% (150 mm).

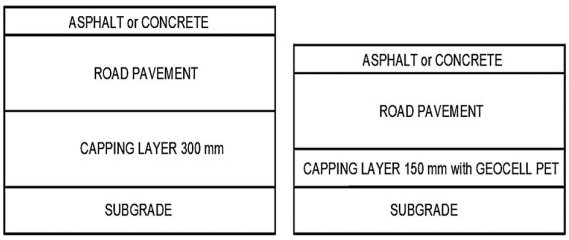


Fig. 10. Trial 50% less capping layer.

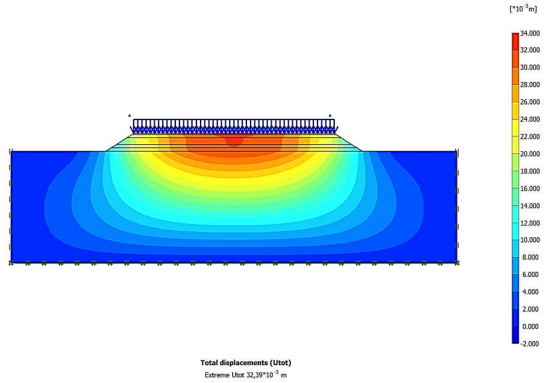


Fig. 11. Extreme U_{tot} unreinforced geocell plane-strain ($32,39*10^{-3}$m).

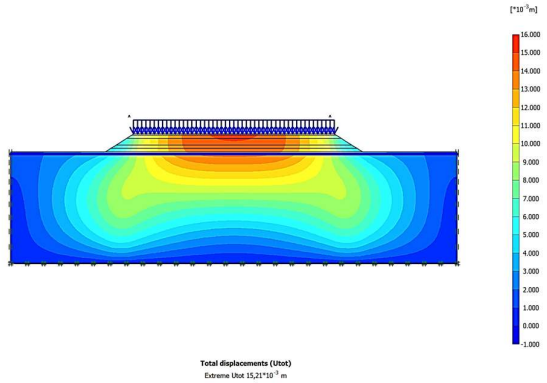


Fig. 12. Extreme U_{tot} reinforced geocell plane-strain ($15,21*10^{-3}$m).

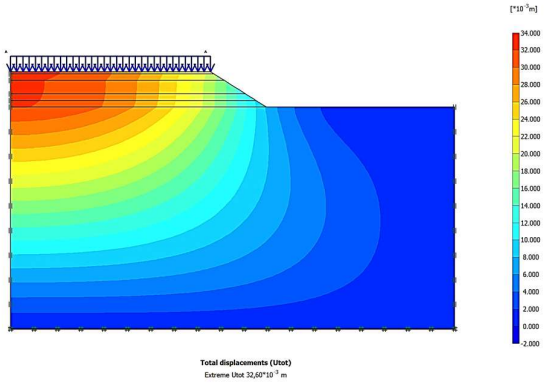


Fig. 13. Extreme U_{tot} unreinforced geocell axisymmetry ($32,60*10^{-3}$m).

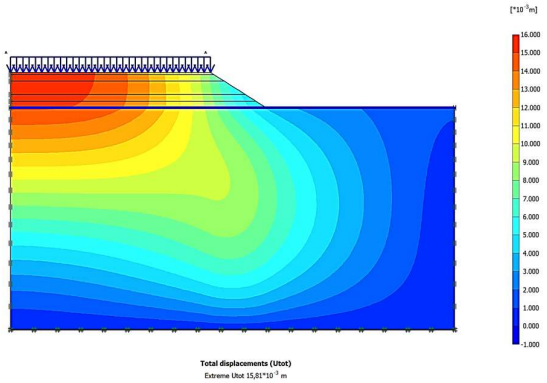


Fig. 14. Extreme U_{tot} reinforced geocell axisymmetry ($15,81*10^{-3}$m).

After the capping layer was reduced to 50% (150 mm) by applying the same load when loading the capping layer of 300 mm above the road pavement, the geocell can reduce the settlement to 53,04% of the total settlement without geocell reinforcement. The results are shown in Figure 11 and Figure 12.

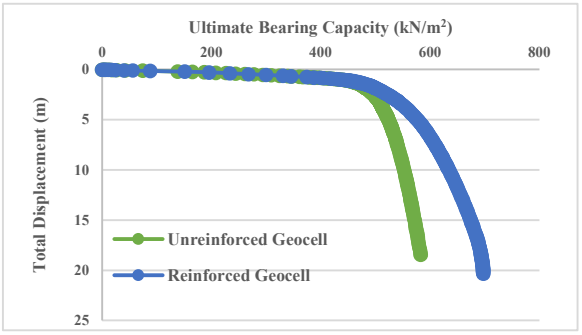


Fig. 15. Curve ultimate bearing capacity Plaxis 150 mm capping layer.

The results of the curve from the Plaxis program showed the ultimate bearing capacity behaviour with and without geocell reinforcement were relatively similar. This is due to there was only one parameter was made for the soil material and loading in the Plaxis program, with only the thickness of the capping layer that was different. The results of the 150 mm Plaxis capping layer curve are shown in Table 4.

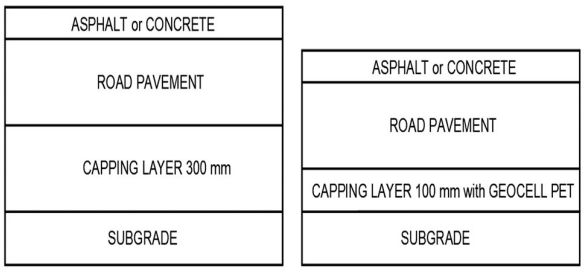
Table 4. Result curve Plaxis capping layer 150 mm

Result Plaxis	Ultimate bearing capacity (kN/m^2)	BCR
Unreinforced geocell PET	582,435	1
Reinforced geocell PET	696,733	1,197

The results of the Plaxis program in Table 4 show that the performance of geocell from plastic bottle waste could increase the bearing capacity of the soil up to 19.7% when the capping layer was reduced to 150 mm.

Tried to reduce the capping layer with a thickness of 100 mm by Plaxis analysis

Fig. 16. Trial 65% less capping layer.



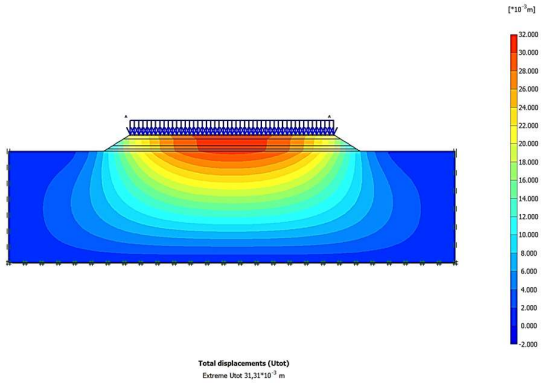


Fig. 17. Extreme U_{tot} unreinforced geocell plane-strain ($31{,}31*10^{-3}$m).

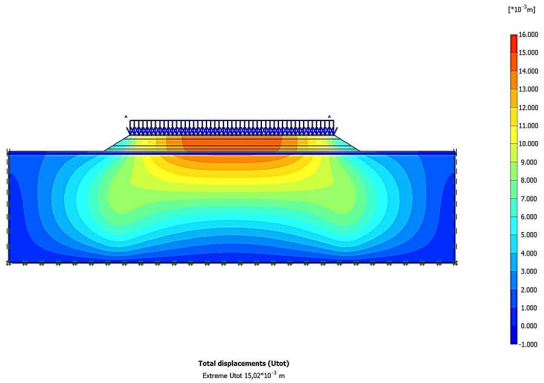


Fig. 18. Extreme U_{tot} reinforced geocell plane-strain ($15{,}02*10^{-3}$m).

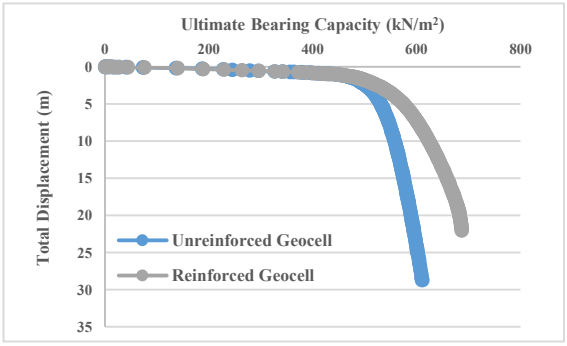


Fig. 19. Curve ultimate bearing capacity Plaxis 100 mm capping layer.

Table 5. Result curve Plaxis capping layer 150 mm.

Result Plaxis	Ultimate bearing capacity (kN/m^2)	BCR
Unreinforced geocell PET	610,818	1
Reinforced geocell PET	686,784	1,197

The results of the Plaxis program in Figure 19 show that the performance of geocell from plastic bottle waste could increase the bearing capacity of the soil up to 11,94 % when the capping layer was reduced to 100 mm.

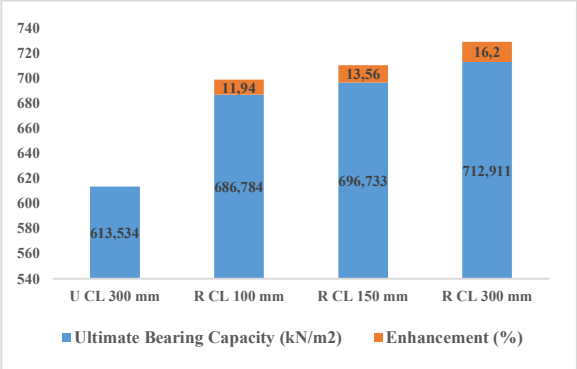


Fig. 20. Percentage on ultimate bearing capacity increase with capping layer of 100 mm, 150 mm, and 300 mm.

The percentage comparison of ultimate bearing capacity when unreinforced capping layer 300 mm (U CL 300 mm), reinforced capping layer 100 mm (R CL 100 mm), reinforced capping layer 150 mm (R CL 150 mm), and reinforced capping layer 300 mm (R CL 300 mm) can be seen in Figure 20. These percentages show that the strengthening of the 100 mm capping layer using plastic bottle waste geocells with a settlement in the thickness of the capping layer can be applied to road pavements that have low bearing capacity.

4 Conclusion

The results of this study were aimed to save the environment from the negative impacts of plastic bottle waste that damaged the environment on land, sea, and air pollution due to the burning of plastic waste. The results of the analysis using Plaxis showed that the geocell of plastic bottle waste could increase the bearing capacity up to 11,94%. This could be an alternative to increase the efficiency up to 65% by reducing capping layer thickness. Therefore, geocells from plastic bottle waste could provide a solution to save granular materials, which consequently reduce the transportation cost of materials from quarries to project site and as an alternative for plastic bottle waste management to prevent the environment pollution.

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List of symbols

q_u	ultimate bearing capacity (kN/m^2)
P_u	maximum load (kN)
A	plate area or foundation (m^2)
BCR	bearing capacity ratio
q_r	bearing capacity value without geosynthetic reinforcement (kN/m^2)
q_o	bearing capacity value in the presence of geosynthetic reinforcement (kN/m^2)
E_g	young's modulus of the geocell-reinforced soil (kN/m^2)
σ_3	confining pressure (kN/m^2)
K_e	young's modulus parameter of the unreinforced soil (kN/m^2)
M	line of intersection of the geocell material modulus (kN/m)
γ_{unsat}	unsaturated soil (kN/m^3)
γ_{sat}	saturated soil (kN/m^3)
ϕ	friction angle (º)
ν	poisson's ratio of soil
ψ	angle of dilatancy (º)
c	cohesion of soil (kN/m^2)
E	young's modulus (kN/m^2)

References

1. O. Alabi, K. Olagbonjaye, O. Awosolu, O. Alalade, Toxicol Risk Assess. **5**, 1 (2019)
2. P. Purwaningrum. JTL. **8**, 141−147 (2016)
3. Y. Sofiana, Humaniora. **1**, 331−337 (2010)
4. Dhane, D. Kumar, A. Priyadarshe. *Geocell : an emerging technique of soil reinforcement in civil engineering field*, IOSR-JMCE, in Nasional Converence on Advances in Engineering, Technology & Management (2015)
5. Krishna, A. Biswas, *Geocell reinforced fondations, in training course on introduction to geosynthetics and their applications*, December 14 2015 NIT Surat India (2015)
6. S.K. Dash, N.R. Krishnaswamy, K. Rajagopal, Geotextiles and Geomembran. **19**, 235−256 (2001)
7. J. K. Thakur, J. Han, S. K. Pokharel, R. L. Parsons, Geotextiles and Geomembran **35**, 14−24 (2012)
8. A. Emersleben, N. Meyer, *Bearing capacity improvement of gravel base layer in road constructions using geocell*, in International Association for Computer Methods and Advances in Geomechanics IACMAG, 1−6 October 2008, Goa India (2008)
9. A. Hedge, T.G. Sitharam, Geotextiles & Geomembran **43**, 171181 (2015)
10. H.C. Hardiyatmo, Fondasi I, Edisi 4 (Gadjah Mada University Press, Yogyakarta, 2020)
11. H.C. Hardiyatmo, Geosintetik untuk rekayasa jalan raya, edisi 2 (Gadjah Mada University Press, Yogyakarta, 2015)
12. I. Mehdipur, M. Ghazavi, R. Ziaie , Geotextiles & Geomembran, **37**, 23−34 (2013)
13. H. C. Hardiyatmo, Perancangan perkerasan jalan & penyelidikan tanah, edisi 2 (Gadjah Mada University Press, Yogyakarta, 2015)
14. SNI (1725:2016). Pembebanan Untuk Jembatan, 39 (2016)
15. Manual Desain Perkerasan (Revisi 2017). Kementrian PUPR, 7−10 (2017)