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Numerical Modeling of Settlement Behavior on Soft Soil Improved with Plastic Bottles

Nur Hadirah Afiqah Abdul Razak[1], Mohd Fairus Yusof[1]*

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Used plastic bottles are frequently found among the waste that might pollute the environment. Because of their low density, these plastic bottles could be used to replace problematic soils that have a higher density than plastic bottles. Objectives of this study was carried out to assess the use of plastic bottles in terms of soil bearing capacity and soft soil settlement. Plastic bottles with a volume of 500 ml were subjected to physical properties such as density and compression tests in order to determine the Young's Modulus. Two models were created with PLAXIS 2D software to compare soil improvement behaviour without plastic bottles and soil improvement with plastic bottles. This model was created using the axisymmetry model. The results demonstrate that the soft soil model with the plastic bottle lining has a better bearing capacity than the soil model without the plastic bottles. In terms of settlement behaviour, it also demonstrates that using plastic bottles can lower settlement, however the difference is not statistically significant.

Keywords: Soft Soil, Plastic Bottles, PLAXIS 2D

1. Introduction

Due to rapid development, numerous highways have been built over soft soil. Excessive settlement is caused by soft soils with low intensity, low permeability, low shear strength, low bearing capacity, and high compressibility [1]. As a result, numerous approaches to improvement have been used to remediate soft soil in long-term ways.

Plastic bottles are a non-renewable and biodegradable material that was used in this study[2]. Despite the fact that recycling is unsuccessful, the widespread use of plastic bottles has contributed to an increase in the quantity of plastic bottles in municipal land waste around the word [3]. Thus, using numerical modelling, this study was carried out to investigate the performance of plastic bottles employed in the improvement of soft soil in terms of bearing capacity and settlement behaviour. The soft soil properties utilised in numerical modelling were derived from Abdulnafa et.al[4], whereas the parameters of plastic bottles, which is the Young Modulus, were determined by a compression test. The proposed soft soil model with and without plastic bottles is axisymmetric with 15-noded elements. A static uniform load of 20 kN/m^2 was used to simulate the heavy traffic load. Plastic bottles are used as soft soil improvement materials to reduce waste and develop valuable materials from useless garbage,

*Corresponding author: fairus@uthm.edu.my

laying the groundwork for a sustainable civilization. This research has the potential to reduce construction and maintenance costs while also enhancing overall structure and surface quality.

2. Soft Soil on Plastic Bottles by Numerical Modelling

The soil distribution in Malaysia's coastal areas is primarily soft soil. Soft soils having a high moisture content, such as silty soils and clays, due to the presence of a high percentage of tiny particles [5] . Soft soil is greasy and sticky when wet and hard and greyish when dry. Excessive settlement is a serious problem since it usually exceeds the allowed limits. When a uniform load is applied to soft soil, three components of settlement are identified as being more than typical as immediate settlement, which happens shortly after the load is applied. Second, consolidation settlement occurs as a result of excessive pore pressure dissipation. Finally, secondary compression takes place following significant dissipation of excess pore water pressure.

Polymers are chemically bonded to generate materials like polyethene and polystyrene, which are used to produce plastic bottles. This plastic has the capability of being moulded or shaped by the application. Plastic bottles have a low density but are strong and lightweight. The physical state of plastic has a significant impact on its mechanical properties. Plastic bottles are becoming more popular as a cost-effective and environmentally friendly alternative. Plastic is also more resistant to chemical corrosion and biodegradable degradation[6]. According to[7], plastic bottles only deform and fail when they reach their ultimate failure condition under very high compressive pressure. In the field of geotechnical engineering, this work demonstrates an easy approach to recycling waste plastic bottles as reinforcement materials in geotextiles.

Finite element analysis is an essential tool for current research and design, which will be carried out using PLAXIS computer software. This program is a finite element program used extensively in geotechnical engineering [8]. In most cases, conventional design approaches are used in the geotechnical design of finite elements that play a vital role in the analysis of settlement, bearing capacity, and stability. An appropriate model and parameters for a particular application need to be selected. PLAXIS 2D is a program used for two-dimensional analysis based on the finite element method. It is a software for accessing geotechnical engineering and design issues like settlement, stability, and groundwater flow in the soil. PLAXIS software is constantly being improved and expanded to cover all aspects of geotechnical engineering.

In this research, two constitutive models were used to simulate models of soft soil with and without plastic bottles, such as the Linear Elastic model (LE) and the Soft Soil Model (SS). The LE model is highly non-linear and irreversible when considering massive structures in the soil or bedrock layers. The LE model is used for the plastic bottle layer. The SS model is suitable for soft soil that is normally consolidated and does not take secondary compression into account [9]. The SS model is used for soft soil layers.

3. Methodology

The characteristics for the material to be used were obtained via laboratory experiments and a literature review for simulation using PLAXIS 2D software. A compression laboratory test was performed at the structural laboratory of the Faculty of Civil Engineering and Built Environment, UTHM, to get the plastic parameters of the bottle. The parameters for soil the layer were taken from Abdulnafa et al [4].

3.1 Preparation of Plastic Bottles

Two types of recycled soft drink plastic bottles with capacities of 330ml and 500ml were employed in this study. Bottle was wrapped in cloth tape and the bottle caps were carefully bonded with a hot glue gun. To calculate the area of plastic bottles, a Vernier calliper was used to measure the diameter of the bottles. Compression tests were performed on both bottles in order to get Young Modulus (E) for use in PLAXIS 2D. Compression testing is performed using a Lloyd Instrument Universal Test machine LD series with a load cell of 500N, as indicated in Figure 1, in accordance with the ASTM D888-02 standard [10]. Bottles were tested vertically at 50mm/min crosshead speed until the values decreased. To determine the density values, the bottles were weighed before and after testing.

Figure 1: Compression test on soft drink bottles

3.2 Material Properties

PLAXIS 2D in axisymmetry can be used to simulate a simple soft soil model. In this study, the PLAXIS 2D 2015 version was utilized to demonstrate soft soil with and without a plastic bottle. The Linear Elastic model is employed for the plastic bottle layers, while the Soft Soil model was adopted for the soft clay soil since it produces more accurate results. Settlement and bearing capacity were investigated. Table 1 shows the properties of materails used in this study.

Table 1: Summary of material properties for soft clay soil and plastic bottles

Parameter	Soft Clay Soil	Plastic bottle
Material type	Soft Soil (SS)	Linear elastic (LE)
Material behavior	Undrained (A)	Non-porous
$\gamma_{unsaturated}$ (kN/m^3)	15	5
$\gamma_{saturated}$ (kN/m^3)	18	5
Elastic modulus, E_{ref} (kN/m^2)	-	126.75
Poisson's ratio, v	-	0.3
Cohesion, C_{ref} (kN/m^2)	1	-
Friction angle, ϕ	25	-
Dilatancy angle, ψ	0	-
Compression index, λ	0.05	-
Swelling index, κ	0.01	-

3.3 Modelling Procedures

There are two models of soft soil for each simulation in terms of bearing capacity and settlement behavior in PLAXIS 2D to compare soil improvement behavior without plastic bottles and soil improvement with plastic bottles. These models were simulated under axisymmetric condition with 15-Noded element to achieve accurate results.

3.3.1 Bearing Capacity Model

The bearing capacity of the model can be model by applying the line displacement of about 0.4 m on the surface of soft soil and plastic bottles. The maximum horizontal axis, X_{max}, was set to 20m, the minimum horizontal axis, X_{min}, was set to 0 m, the maximum vertical contour (y-axis), Y_{max}, was set to 0m and the minimum vertical contour (y-axis), Y min, was set to -20m. The groundwater table is located 2 m from the soft soil surface. Figure 2 and 3 show the geometry and model of soft soil without plastic bottles under bearing capacity simulation. Figure 4 and 5 show the geometry and model of soft soil with plastic bottles under bearing capacity simulation.

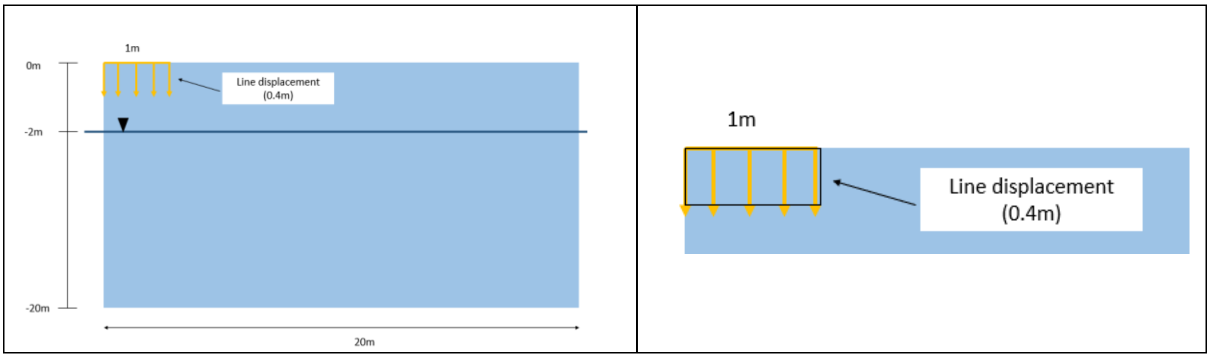

Figure 2: Model of soft soil without plastic bottles for bearing capacity

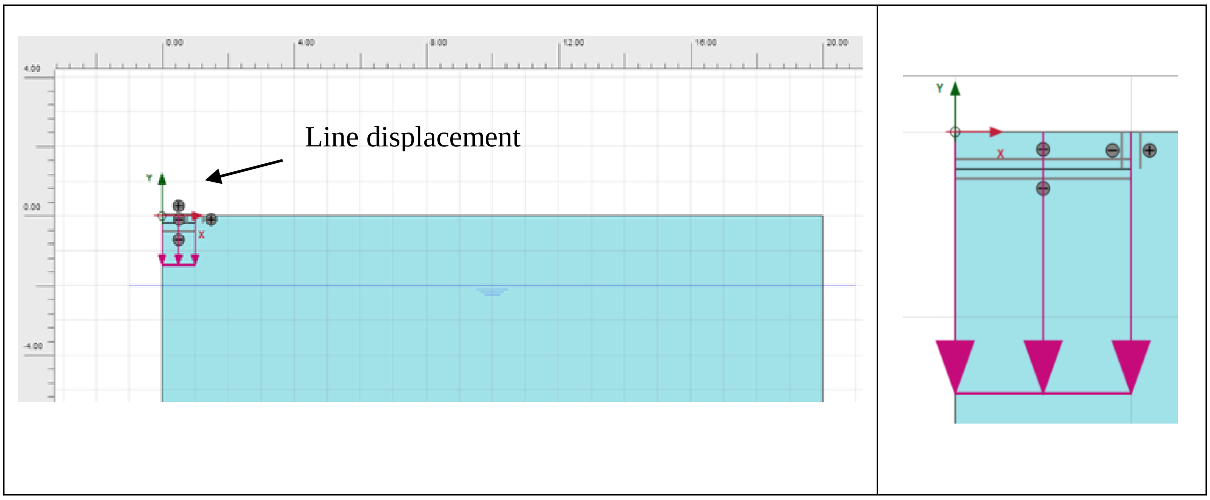

Figure 3: Model of soft soil without plastic bottles for bearing capacity in PLAXIS 2D

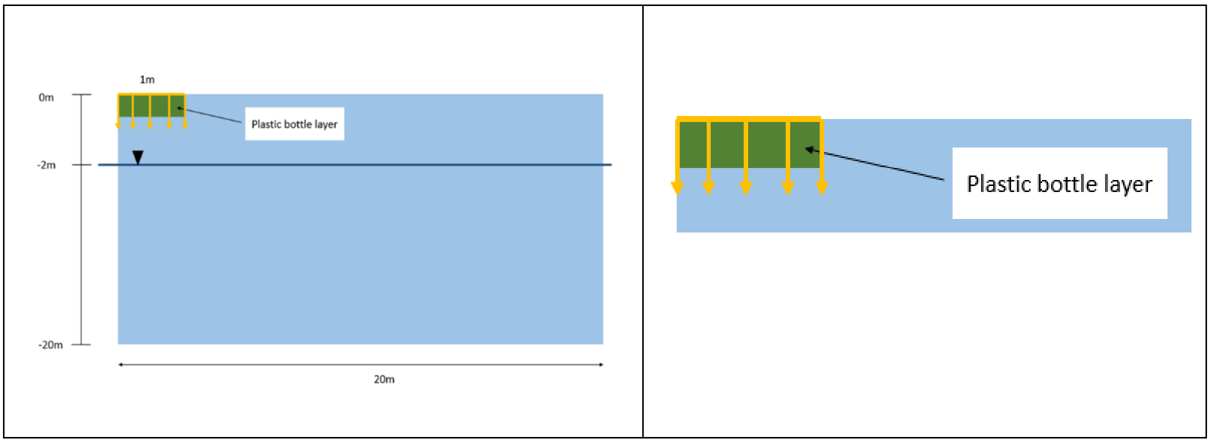

Figure 4: Geometry model of soft soil with plastic bottles for bearing capacity

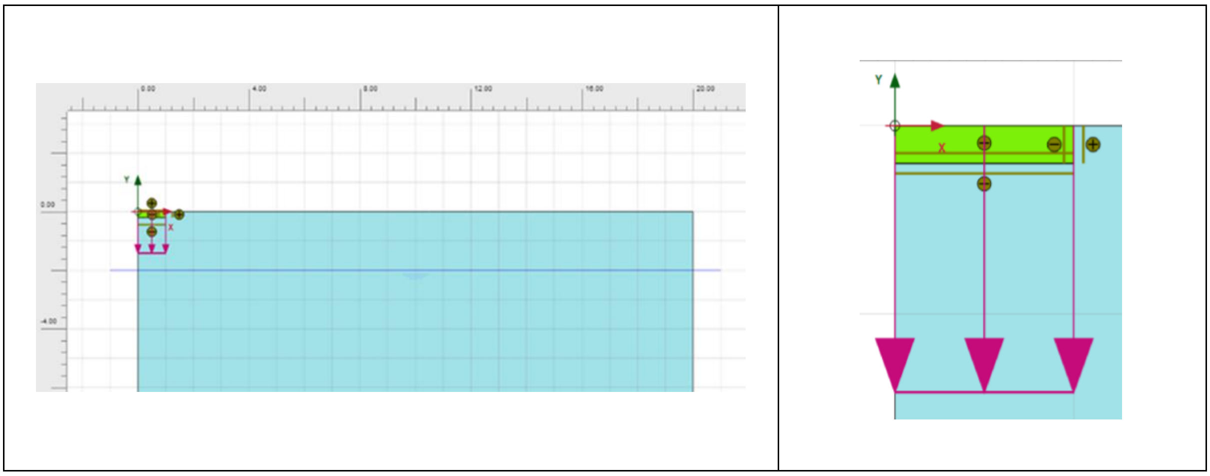

Figure 5: Model of soft soil with plastic bottles for bearing capacity in PLAXIS 2D

3.3.2 Settlement Model

Model on soft soil with and without plastic bottles was generated to determine the settlement behaviour with vertical displacement of 20kN/m^2 with consolidation types of calculation by 30 days. The phase on defining soil stratigraphy which properties of soft soil and plastic bottles are same as bearing capacity model. No major different between the bearing capacity model and settlement behaviour model. However, it was different in the structure mode where 20kN/m^2 was applied as line load on top of 1m soft soil and plastic bottles. Figure 6 to 7 shows the geometry and model of soft soil without plastic bottles under settlement behavior. Meanwhile, Figure 8 to 9 shows the geometry and model of soft soil with plastic bottles under settlement behavior.

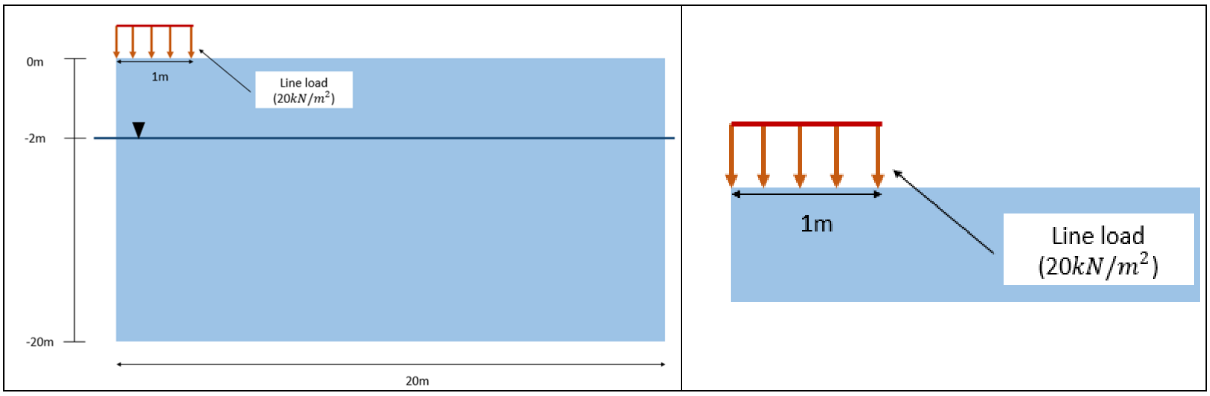

Figure 6: Geometry model of soft soil without plastic bottles for settlement

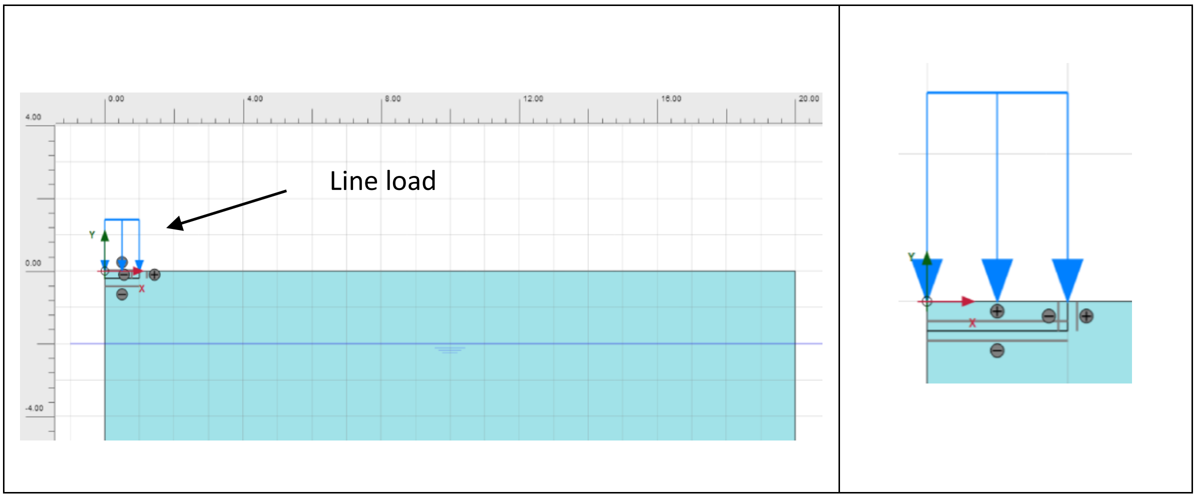

Figure 7: Model of soft soil without plastic bottles for settlement in PLAXIS 2D

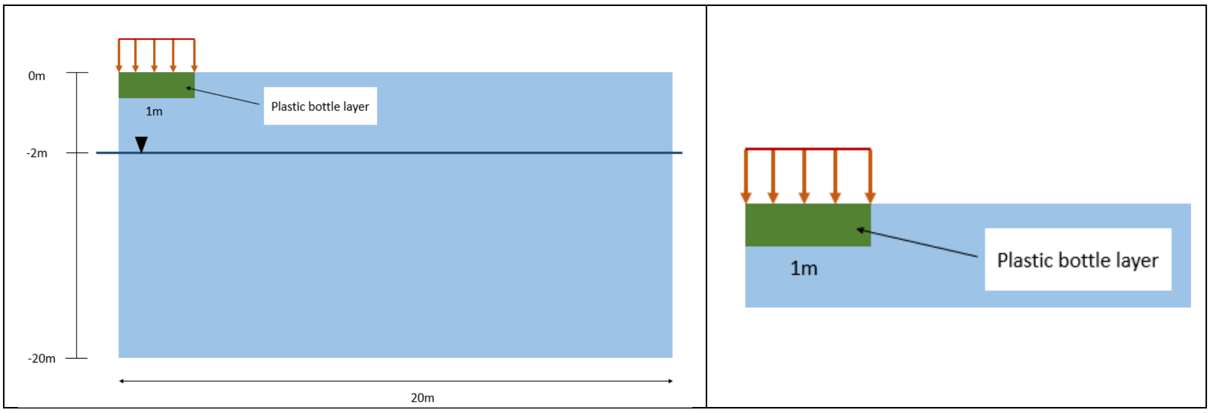

Figure 8: Geometry model of soft soil with plastic bottles for settlement

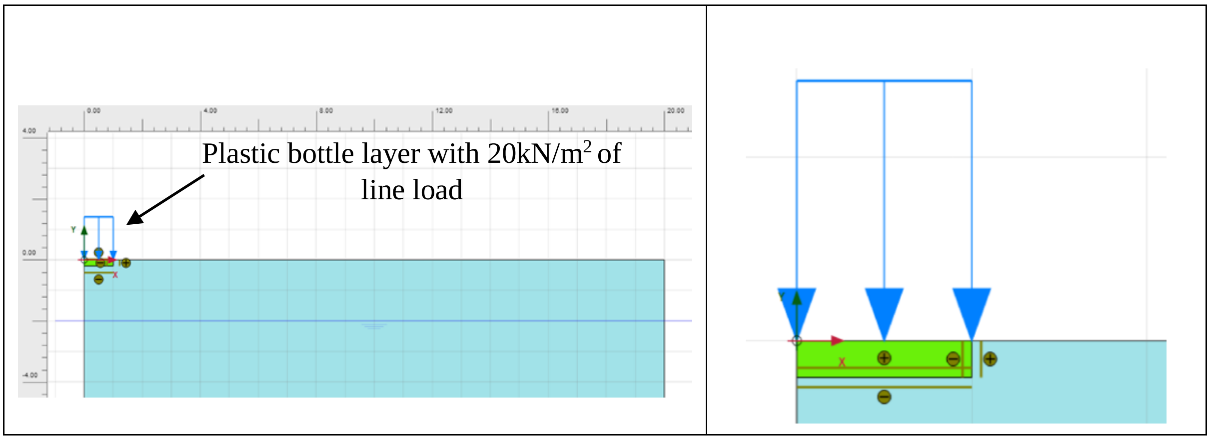

Figure 9: Model of soft soil with plastic bottles for settlement in PLAXIS 2D

4. Result and Discussion

The results and discussion section presents data and analysis of the study. In order to achieve the objective, laboratory testing was conducted on plastic bottles to obtain Young Modulus to be substituted into PLAXIS 2D. Once the mechanical properties of plastic bottles obtained, soft soil with and without plastic bottles was simulated to determine bearing capacity and settlement behaviour.

4.1 Compression Test

Compression test was conducted on plastic bottles because of the application of traffic load on the road where the soft soil being compressed until the settlement occurred. Stress-strain curve is clearly illustrated in Figure 10 whereby the 500ml has the higher compression strength than 330ml bottle. Plastic is recognized as a ductile material. At first, 330ml plastic bottles exhibit a highly linear stress strain relationship up to defined to yield points compared to 500ml. This happened because top of bottles has lower strength than the middle and bottom parts where 330ml achieved the stability faster than 500ml. Yield points is the point at which plastic material exhibits significant irreversible plastic deformation where the plastic will no longer return to previous state in this section. Only ductile materials will have well defined yield point. 500ml bottles has a higher value on lower yield point part

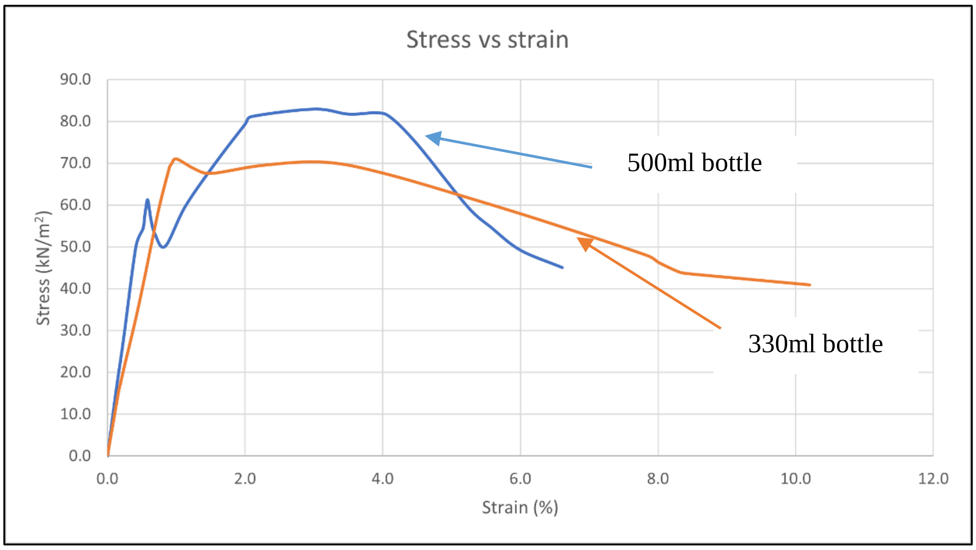

Figure 10: Compressive stress-strain curve of soft drink bottle

From the stress-strain curve, modulus of elasticity or Young Modulus, *E* can be determined by calculating the slope or gradient of curve. The Young Modulus, *E* obtained as presented in Table 2 where 500ml bottles with 126.75 is higher than 330ml with 93.52. From this result, the properties of volume 500ml soft drink bottles are taken to be substituted into the PLAXIS 2D under the plastic bottle layer.

Table 2: Young Modulus, E for both soft drink plastic bottle

Plastic bottle	Young Modulus, E
500ml	126.75 kN/m^2
330ml	93.52 kN/m^2

4.2 Bearing Capacity on Soft Soil

0.4m vertical displacement applied on top of 1m length of soft soil and plastic bottles resulted in graph 11. From the graph, soft soil without plastic bottle layer obtained 40.18 kN of bearing capacity while soft soil with plastic bottle layer gained about 94.92kN of bearing capacity. For bearing capacity model, plastic as known as elastroplastic drained or undrained analysis where consolidation is not considered choose as calculation type. This type of calculation ignores the time interval and directly performed to maximum bearing capacity for each model.

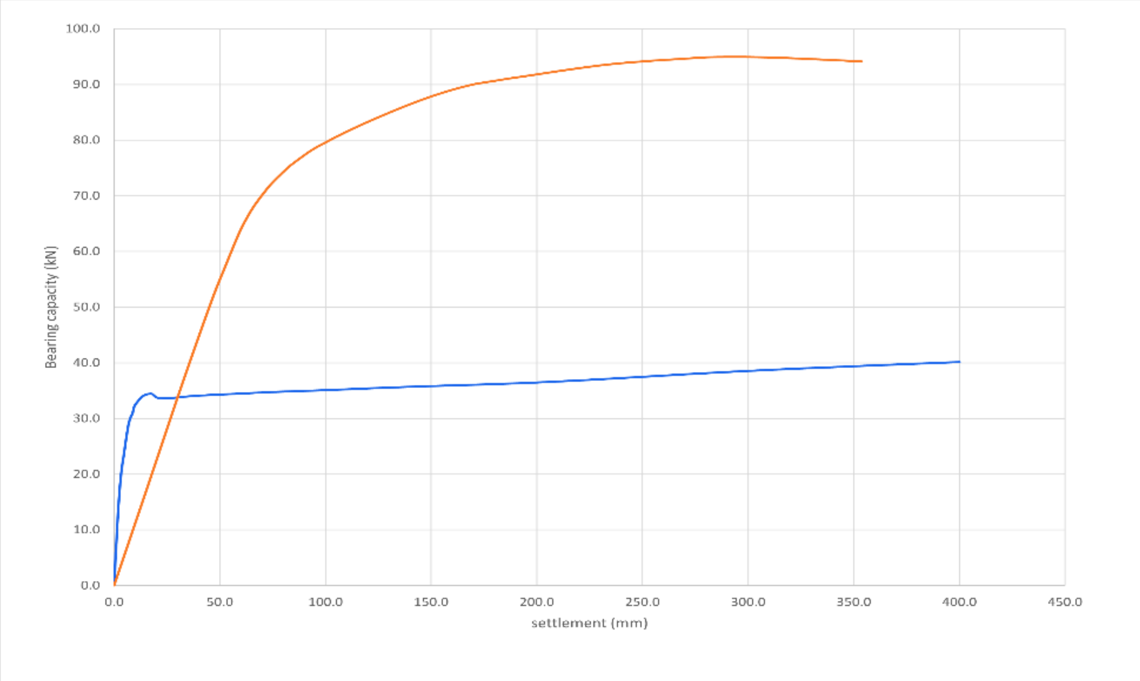

Figure 11: Result of bearing capacity

4.3 Settlement Behaviour on Soft Soil

A uniform static load described as a heavy truck load with 20kN/m^2 was placed on a soft soil model with and without plastic bottles. The bar chart in Figure 12 was generated to distinguish the settlement occurred in soft soil with and without plastic bottles. Model of soft soil without plastic bottles obtained about 70.24mm of settlement. Meanwhile, model of soft soil with plastic bottles decreased with 58.57mm settlement. It is clearly presented that model of soft soil improved with plastic bottles has lower settlement than model of soft soil without plastic bottles.

Table 3: Result of settlement behaviour

Model	Soft soil without plastic bottles	Soft soil with plastic bottles
Settlement	70.24mm	58.57mm

4.4 Comparison of Result

Table 3 shows the bearing capacity and soft soil settlement behaviour with and without plastic bottles. The bearing capacity of soft soil without plastic bottles was 40.18 kN, but the bearing capacity of soft soil with plastic bottles was approximately 94.96 kN. The bearing capacity of soft soil improved with plastic bottles performed better, increasing by 136% over soft soil without plastic bottle layers. Furthermore, soft soil settlement without plastic bottles was 70.24 mm, whereas soft soil settlement with plastic bottles was 58.57 mm. Settlement of a soft soil model with a plastic bottle layer was reduced by 19.9 percent when compared to a soft soil model without plastic bottles.

Overall, the results show that soft soil models improved with plastic bottle layers have higher bearing capacity and lower settlement than soft soil models without improved with plastic bottles. This finding also implies that plastic bottles are a good long-term alternative or technique for stabilising soft soil, which has a low bearing capacity and causes significant settlement in construction.

In physical modeling, a vertically compressed plastic bottle layer will be arranged in area of 0.2m x 1m in an un-uniformly to minimize the void between the plastic bottles. Previous research also shown that soft soil can be improved with plastic bottles. Research from [11] stated combination of virgin soil sample with raw plastic bottles in various quantities range from 5% to 25% with 5% increments had result in improvement of cohesion, unconfined compression strength of soil sample and dry density at 20% of soil with raw plastic bottles. Other than that, earlier research from [12] that involved conducting plate load tests on soil reinforced with layers of plastic bottles filled with sand and bottles cut in half and placed in the middle and one-third positions of the tanks. The result shown that cut bottles in the middles position were the most effective at enhancing soil strength.

Table 4: Results comparison of soft soil with and without plastic bottles

Model	Soft soil without plastic bottles	Soft soil with plastic bottles	Differences between model
Bearing capacity	40.18 kN	94.96 kN	136%
Settlement	70.24 mm	58.57 mm	19.9%

5. Conclusion

Construction on unsuitable ground is prone to bearing capacity failure. Excessive settlement is one of the reasons for the failure of construction bearing capacity on problematic soil. The conventional and common approaches of reduce settlement are excavate and replaced with competent soil which can be costly and time consuming. The use of plastic bottles for soil improvement should be evaluated as an effective and sustainable strategy to save the construction time and cost. Research objectives have been achieved where to investigate the performance of soft soil improved with plastic bottles in terms of bearing capacity and settlement behaviour by numerical modelling. As conclusion, model of soft soil is improved with plastic bottles layers due to lower settlement and higher bearing capacity compared to model of soft soil without plastic bottles.

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