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Study on Performance Polyurethane Cellular Foam (PUC) Block as Ground Improvement by Analysis Using Plaxis 2D

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Abstract

Immediate settlement, also known as initial or undrained settlement, occurs as soon as a load is applied is a common problem in road embankment construction, resulting in uneven surfaces, impaired structural integrity, and higher maintenance costs. This study uses the finite element method (FEM) software PLAXIS 2D to forecast road settlement behaviour and investigates the usage of Polyurethane Cellular Foam (PUC) Block as a ground improvement strategy. To simulate the real conditions of road embankments, the earth fill embankment's settlement will be applied as a control analysis to determine the characteristics that will eventually be compared with the embankment with the PUC block at base and subbase layer. Three totally different PUC block arrangements were applied during a simulation, the conventional rectangular PUC block method, the combination square and rectangular PUC block method, and the rectangular PUC block in a cross. Three types of data collection were used as guidelines for the parameter data which are site investigation data, road embankment drawing and supported data from previous study. The results of the analysis showed that PUC block is a useful technique for reducing the influence of road embankments on settlement on soft soil. The road embankment with combination PUC foam blocks is the one on the improved road that has the least amount of change in soil deformation value. Finally, it is determined that the road embankments can effectively use PUC block as ground improvement.

1. Introduction

Road failure is the most challenging issue in Malaysia, significantly when associated with problematic soft soil that consists of high moisture content, low strength, low permeability, and non-homogenous properties. Such properties caused excessive and differential settlement, which induced pavement distress including rutting and cracking. Pavement distress or deterioration can be caused by several circumstances, including inadequate pavement thickness, which indicates that subgrade soil is the source of the issue. Moreover, traffic loading-related cracks in asphalt layers. The majority of unstable soils for embankment foundations are clays or silts that are affected by water [1].

Using PUC block as a soil-improvement agent when constructing new roads is one creative way to reduce settlement issue. As an outcome of industrial operations, PUC block has the potential to improve soil qualities and lessen settling issues. With this kind of block, the risk of floating is reduced and overall performance is improved

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because of the optimized PUC block's unique characteristic open-cell structure, which allow to flow freely. Different regions have different types of soil, and depending on the type of soil, different PUC block may work better or worse. To provide a sustainable and environmentally friendly solution, the model should take into account elements like corrosion, degradation, and potential impact to ecosystems.

1.1 Problem statement

Using PUC block as a soil-improvement agent when constructing new roads is one creative way to reduce settlement issue. As an outcome of industrial operations, PUC block has the potential to improve soil qualities and lessen settling issues. However, ground improvement solutions can be customized to fit specific project needs by using PUC blocks, which are available in a variety of forms and sizes. Different regions have different types of soil, and depending on the type of soil, different PUC blocks may work better or worse.

1.2 Objective of the study

The objective of this study is to examine the existing earth fill settlement in terms of functionality and performance. Then, to determine the prediction road embankment settlement by using PUC block as soil improvement.

1.3 Scope of study

In this study, Plaxis 2D software was used to perform a finite element simulation of a road embankment with PUC block. A live load of $10kN/m^2$ is assumed for all models from the vehicle. Only the right side of the embankment model has been generated because it is symmetric. Road embankment's geometric model has dimensions of 40 m in width and 4.15 m in height. The analysis will conclude three type of collection data, the data of bore log laboratory site investigation which is properties of soil, type of soil, depth of soil and depth of water level, the data from drawing road embankment (JKR) which is material and type of road embankment and a 1V:2H slope inclination and lastly, soil parameters used in this study have been supported by previous studies as well as PUC block's certain results from laboratory tests conducted by undergraduates.

1.4 Significant study

By encouraging the formation of aggregates and raising the general porosity of the soil, the addition of PUC foam can help improve soil structure also to guarantee the sustainability of the sector and bring the industry into line with the Sustainable Development Goal (SDG) which are innovation, infrastructure and inclusive, sustainable industrialization may unleash competitive, dynamic economic forces that create jobs and revenue (SDG 9). Innovative ground stabilizing techniques using PUC blocks can improve the sustainability and dependability of structure.

2. Literature Review

2.1 Road Embankment

A road embankment refers to an elevated structure constructed to support a road or highway. It is essentially a raised portion of the road that is build using various materials to provide a stable foundation for the road foundation for the road surface. Road embankments are essential components of transportation infrastructure and are designed to address a variety of engineering and environmental considerations. A road embankment's main function is to raise the road's surface over the surrounding landscape. To get over natural barriers like streams, hills, and uneven terrain fill material, which might be dirt, gravel, crushed rock, or artificial materials like geofoam, is used to build the embankment's basic structure.

2.2 The challenge of constructing road embankment

Soft ground is generally located close to coastal areas and has a high groundwater level. The crust layer at the top of soil profile is followed by a soft soil layer that can be as thick as infinitely deep below [2]. This soil is dark brown to light brown. Generally speaking, flexible particles smaller than 0.002 mm predominate in soft soils like clay. It has about 50% clay content and is made of mud and clay combined. This soil's structure is classified as cohesive, book house, scattered, flocculated, and turbotrain. The physical, mechanical, chemical, and biological characteristics of soil with weak geotechnical characteristics, such as soft clay [3]. The flow chart for this research methodology is displayed in Figure 1.

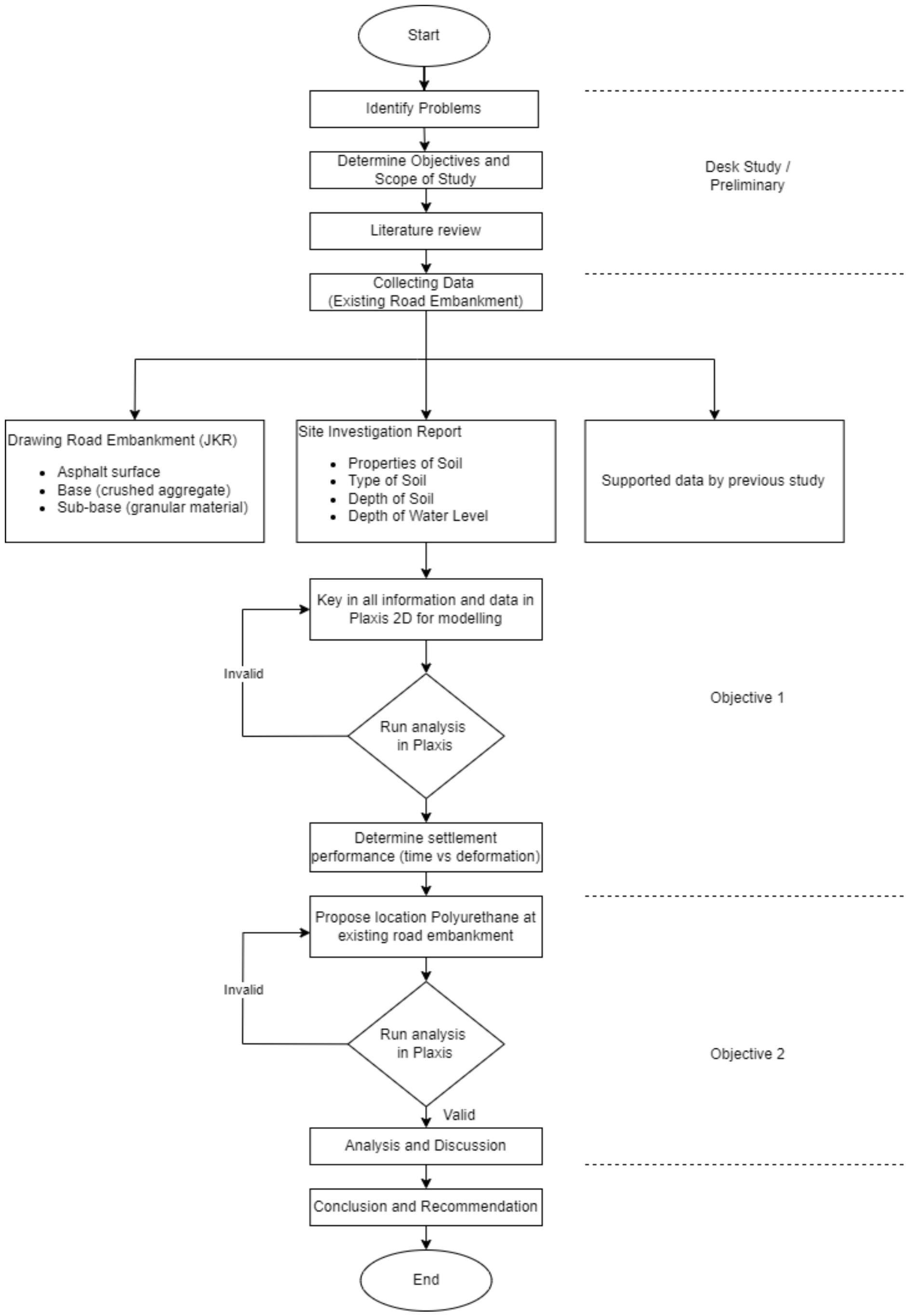

Fig. 1 Flowchart of study

3. Methodology

This chapter describes how to replace the soft soil with s lightweight made of PUC block to prevent future settlement. The road embankment' settlement was calculated using four different models. The earth fill embankment model is the first model. A road embankment with rectangular PUC block with dimension 0.61 m x 2 m x 8 m is the second model. The road embankment with combination of rectangular and square PUC block with dimension 0.61 m x 0.61 m x 8 m, is the third model. Also, the road embankment with rectangular PUC block that had arranged in a cross is the fourth model. The model with PUC block was then compared with different designs to see which was the optimal arrangement. Lastly, the dimension of PUC block was changed to compare the best thickness for road embankment which is 0.8m.

3.1 Geometry Model and Properties of Material

This study examined embankments that were 15 meters high and a slopes inclination of 1V:2H, as shown in Figure 2. A live load of 10kN/m^2 is assumed for all models from the vehicle. Only the right side of the embankment model has been generated because it is symmetric. Road embankment's geometric model has dimensions of 40 m in width and 4.15 m in height. Table 1, table 2 and table 3 illustrate the characteristic of soil, road embankment and PU to simulate the road embankment with PUC block. Five types of numerical stability analyses were identified. The earth fill embankment model is the first model (control) in Figure 3. A road embankment with rectangular PUC block with dimension 0.61 m x 2 m x 8 m is the second model (conventional) in Figure 4. The road embankment with combination of rectangular and square PUC block with dimension 0.61m x 0.61 m x 8 m, is the third model in Figure 5. The road embankment with rectangular PUC block that had arranged in a cross is the fourth model (cross) in Figure 6.

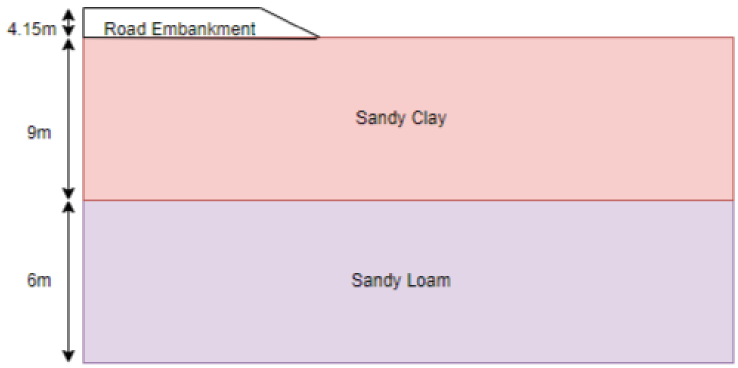

Fig. 2 Earth fill road embankment

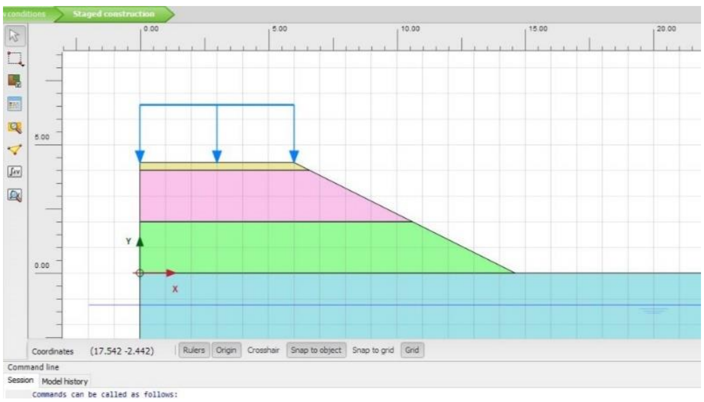

Fig. 3 Model 1 which analyses the earth fill road embankment

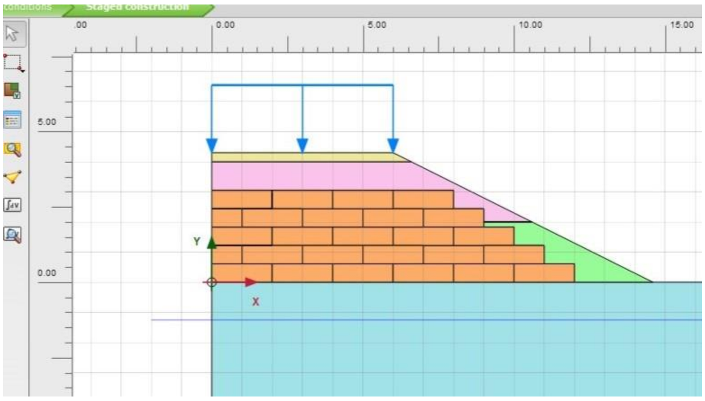

Fig. 4 Model 2 which analyses road embankment with rectangular PUC block with loading.

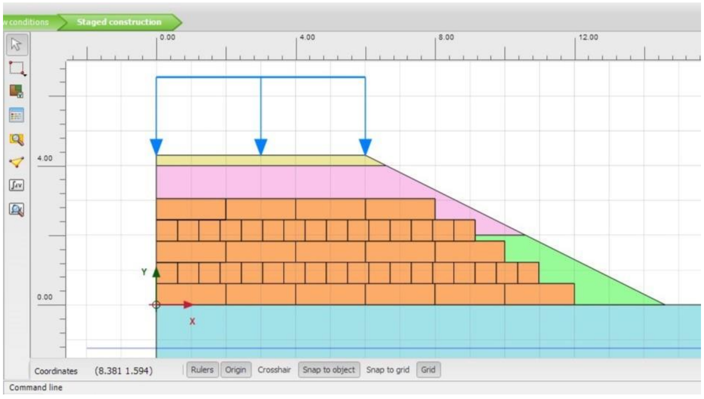

Fig. 5 Model 3 which analyses road embankment with combination rectangular and square PUC block with loading.

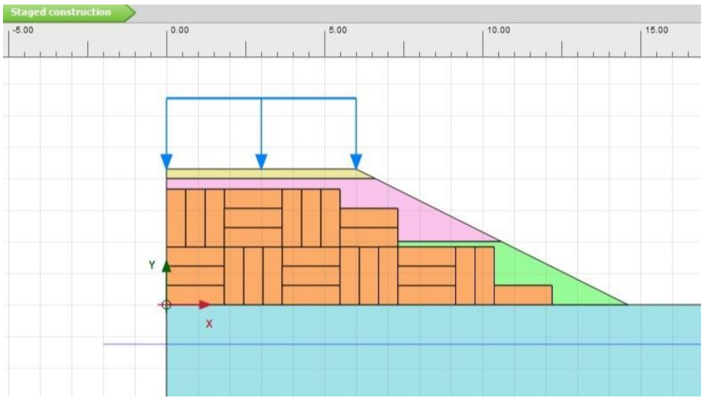

Fig. 6 Model 4 which analyses road embankment with rectangular PUC block in a cross with loading.

Table 1: Road embankment parameter for simulation

Parameter	Unit	Asphalt Surface	Base	Sub Base
Material model	-	Linear elastic	Mohr-Coulomb	Mohr-Coulomb
Drainage type		Non-porous	Drained	Drained
Dry unit weight	kN/m2	23.5	22	20
Wet unit weight	kN/m2	-	24	22

Permeability in x-direction (kx)	m/day	-	1.000	1.000
Permeability in y-direction (ky)	m/day	-	1.000	1.000
Young's modulus	E50	2,100,000	120,000	90,000
Poisson ration	v	0.40	0.35	0.35
Cohesion	C	-	20	30
Friction angle	ϕ	-	44	43
Dilatancy angle	ψ	-	14	13
Reference	-	[6][9]	[5][9]	[9]

Table 2: PUC block parameter for simulation

Parameter	Unit	PU
Material model	-	Linear elastic
Drainage type	-	Non-porous
Dry unit weight	kN/m2	3
Wet unit weight	kN/m2	-
Permeability in x-direction (kx)	m/day	-
Permeability in y-direction (ky)	m/day	-
Young's modulus	E50	30,000
Poisson ration	v	0.3
Cohesion	C	-
Friction angle	ϕ	-
Dilatancy angle	ψ	-
Reference	-	[10]

Table 3: Soil parameter for simulation

Parameter	Unit	Sandy Clay	Sandy Loam
Material model	-	Soft soil	Mohr-Coulomb
Dry unit weight	kN/m^2	16	14.89
Wet unit weight	kN/m^2	16	17.91
Permeability in x-direction (k_x)	m/day	-	7.128
Permeability in y-direction (k_y)	m/day	-	7.128
Young's modulus	E50	-	35,000

Poisson ration	v	-	0.025
Cohesion	C	10	0
Friction angle	ϕ	10	33
Dilatancy angle	ψ	0	3
Modified compression index	k*	0.10	-
Modified sweeling index	λ*	0.00667	-
Reference	-	[3][4][6][7]	[8][9]

4. Results and Discussion

The Plaxis 2D software findings with the predicted settlement value for the various arrangements are shown in this section. In order to determine which PUC block has optimal arrangement and have lowest settlement value, comparison is very crucial. The maximum settlement value on a road embankment with same loads applied with a minimum of four layers of arrangement is shown in Figure 3 until Figure 6. There are seven nodes that have been selected as shown in Figure 7.

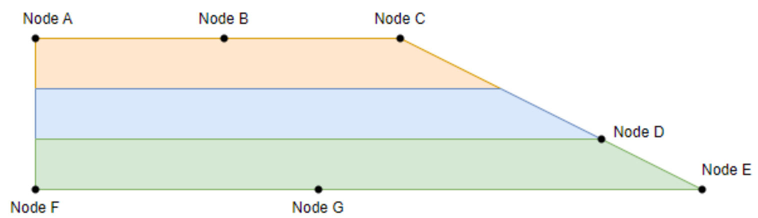

Figure 7: Seven nodes that have been chosen at the area of road embankment

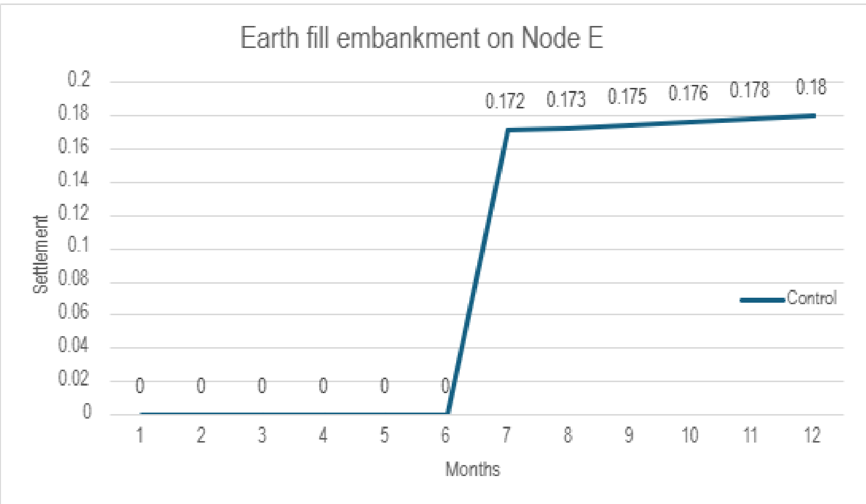

Figure 8: Earth fill embankment on Node E

The graph for the earth fill embankment on node E without any PUC block shows the settlement after one year is 0.18m based on Figure 8. The graph shows the settlement (m), which is represented by the y-axis, against the x-axis of time (day). Node E has been selected because the maximum value of settlement occurs on this area.

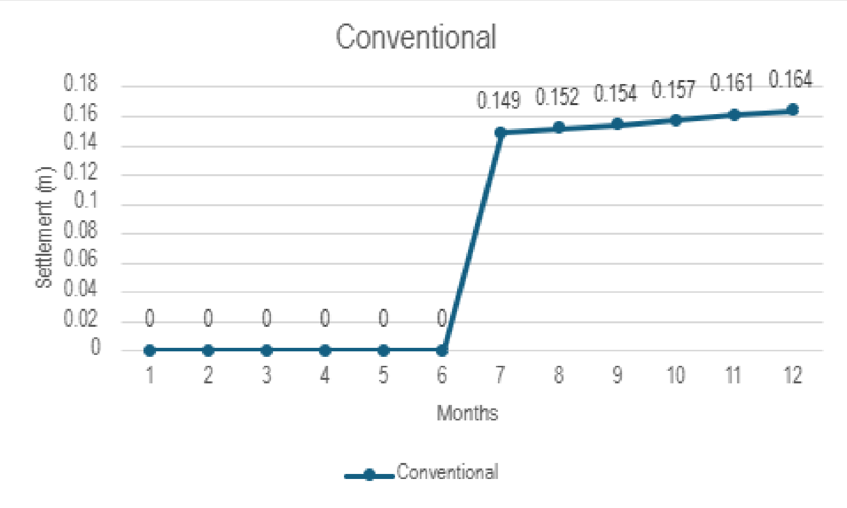

Figure 9: Earth fill embankment with conventional PUC block on Node A

The graph for the earth fill embankment with conventional PUC block on node A shows the settlement after one year is 0.164m based on Figure 9. This model has rectangular PUC block with dimensions 0.61m x 2 m x 8 m and conventionally arranged by five layers. The graph shows the settlement (m), which is represented by the y-axis, against the x-axis of time (day). Node A has been selected because the maximum value of settlement occurs on this area.

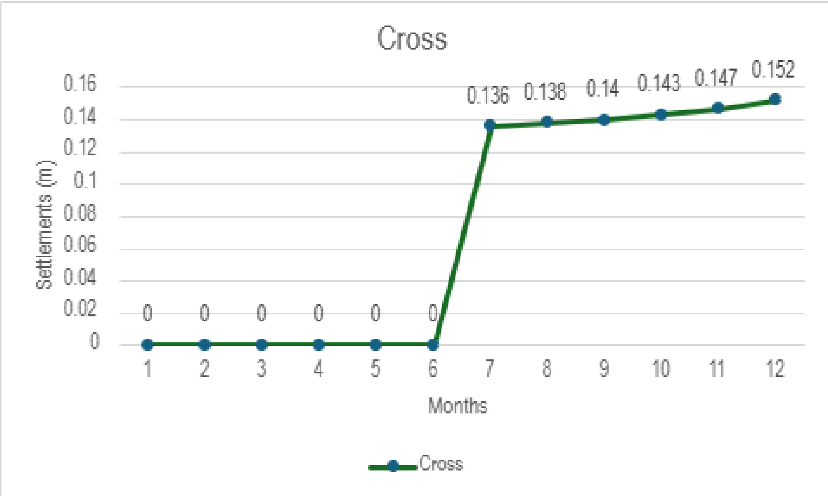

Figure 10: Earth fill embankment with PUC block in a cross on Node A

The graph for the earth fill embankment with PUC block in a cross on node A shows the settlement after one year is 0.152m based on Figure 10. This model has rectangular PUC block with dimensions 0.61m x 2 m x 8 m which the same as conventional but the difference is the PUC block arranged in a cross by six layers. The graph shows the settlement (m), which is represented by the y-axis, against the x-axis of time (day). Node A has been selected because the maximum value of settlement occurs on this area.

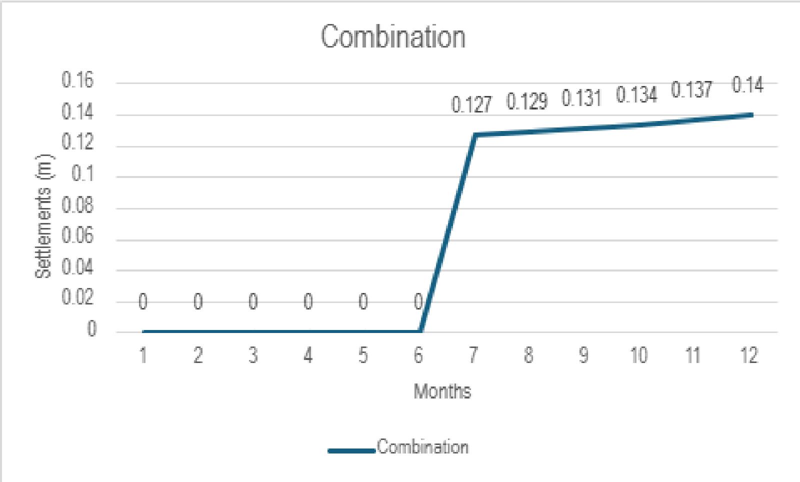

Figure 11: Earth fill embankment with combination PUC block on Node A

The graph for the earth fill embankment with combination PUC block on node A shows the settlement after one year is 0.14m based on Figure 11. This model has rectangular PUC block with dimensions 0.61m x 2 m x 8 m and square PUC block with dimension 0.61 m x 0.61 m x 8 m arranged alternately up to five layers. The graph shows the settlement (m), which is represented by the y-axis, against the x-axis of time (day). Node A has been selected because the maximum value of settlement occurs on this area.

Based on figure 12, it is evident that the presence of PUC foam blocks in the base and subbase embankment layer has generally resulted in little change and lower value in the soil deformation curve for the road embankment. The road embankment with combination PUC foam blocks is the one on the improved road that has the least amount of change in soil deformation value.

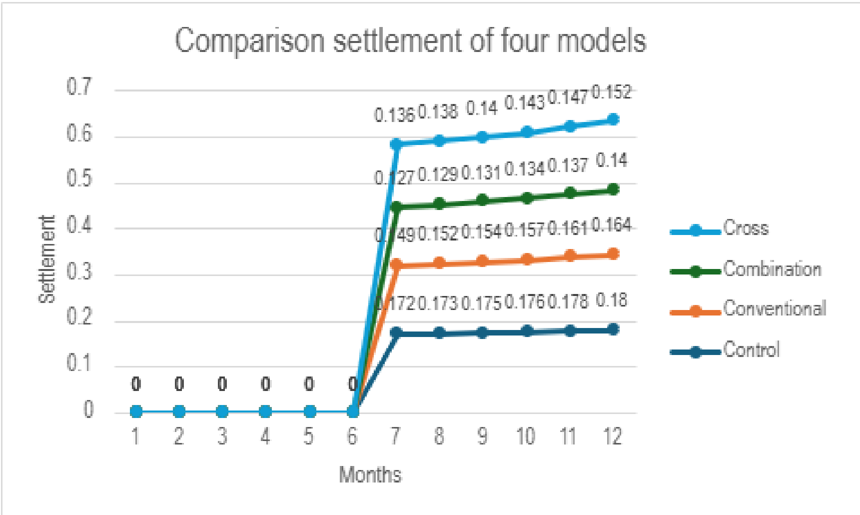

Figure 12: Comparison settlement of four models

5. Conclusion

To sum up, PLAXIS 2D provides a wide range of tools for geotechnical engineers and is an essential tool for the analysis and design of road embankments. The use of PUC blocks for ground improvement is one of the most economical methods for improving the geotechnical characteristics of soils. As a substitute material, PUC clay composite may be able to increase soil improvement's buoyant force, compressive strength, and shear strength. PUC block can be used as a ground improvement technique.

5.1 Objective attained

Objectives 1: To examine the existing backfill settlement in terms of functionality and performance.

The goal of analyzing the functionality and performance of the current backfill settlement has been accomplished. This accomplishment shows that an accurate analysis of the earth fill material's settling over time is a crucial step in backfilling excavated areas has been carried out.

Objectives 2: To determine the prediction road settlement by using polyurethane cellular blocks as soil improvement.

Evidently, just before the occurrence of PUC blockages. Settlement happens along the side of road embankment, at Node E, where there is a chance for the embankment to collapse. But once the PUC block was replaced at Node A, the finest location for the PUC block, had the maximum value of the embankment above embankment which is better than another node. PUC blocks can improve soil stability and lessen settlement by distributing loads more uniformly, but they cannot stop settlement entirely. Even yet, there is still a chance that settlement will happen eventually because of things like further soil consolidation, increasing groundwater levels, or adding more weight to the region.

5.1 Recommendation

Since this combination is the most effective, it is advised to keep improving this arrangement in order to effectively and further reduce settlement. Additionally, it is advised to enhance PUC block material itself, such as injection, or otherwise. Lastly, as PUC block material is the primary focus of this research, it is advised that future studies be carried out via physical laboratory model testing. Insufficient data will have an impact on all of the other research.

Acknowledgement

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