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Effect of Geotextile Installation on Soft Soil Settlement Underneath The Bridge Approach Slab

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Abstract: A bridge is an essential element of a country's transportation system. The formation of bridge bumps between bridge abutments and bridge approach slabs is an expensive problem and puts people's lives in jeopardy. The soil settlement that occurs beneath the bridge approach slab was modelled and simulated using 2D PLAXIS software. A geotextile constructed of polyethylene terephthalate (PET) was used to stabilise the soil and reduce settlement. The efficacy of the geotextile on improving soil settlements was simulated using a varying number of geotextile layers, effective length, and axial stiffness of the geotextile. According to the findings, the installation of geotextiles reduced settlement. Geotextiles are best used at the interface between two layers. The results showed no significant improvement with the addition of a geotextile layer, length and a different elastic axial stiffness.

Keywords: Bridge Approach Slab, Bump, Settlement, Geotextile, PLAXIS

1. Introduction

Recently, many countries are stepping into modern urbanization. To develop a city, a well-developed transportation network is very important to ensure the overall transportation capacity of a city. A huge transportation volume will have an extremely positive effect on the development of the city. The bridge is one of the important elements in the transportation network.

In general, the bridge structure consists of the following major components, which are the superstructure (deck slab, girder, truss, etc.), bearing and substructure (abutments, piers, etc.). The bridge approach slab is a minor element of the bridge that is usually constructed using a reinforced concrete slab to connect the bridge abutment with the road pavement. However, this element is often overlooked by designers or engineers. The use of the bridge approach slab provides a smooth connection from the road pavement to the bridge structure and vice versa for the road users [1].

Sub-grade foundations and compacted fill materials that are used to construct embankments and pavements will experience compression over time. The compression that occurs will cause settlement. However, the total settlement that occurs on the pavement adjacent is more than the settlement on the

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bridge and results in a huge degree of settlement along the intersection between the bridge and the road pavement. Meanwhile, settlement of soil underneath the approach slab and bridge will cause it to lose contact and support from the soil and finally form a bump. The following section of this study will describe the effect of geotextile installation on the settlement behaviour of soft soil underneath the bridge approach slab using geotechnical software (PLAXIS 2D).

2. Literature Review

2.1 Bridge approach slab

The approach slab between the approach road and the bridge acts as a smooth transition system to reduce the effects of differential deformation from the embankment to the bridge abutment. However, due to the difference in settlement between the abutment and the roadway, the bridge approach sometimes undergoes a rough transition over time [2] [3].

2.2 Definition of bump

Bump or approach settlement as the differential settlement or heave of the approach slab with reference to the bridge abutment structure [2]. The appearance of the settlement is normally detected due to the different types of foundation constructed for roadways, embankments, and bridges. In contrast, the overall settlement of the bridge will be much smaller than the roadway and the outcome will be huge differential settlement.

2.3 Acceptable bump

Differential settlement tolerance needs to be determined and repair work must be started before the maximum acceptable settlement tolerance is reached. In Australia, the limit value of the bridge approach settlement problem for a design period of 40 years is a maximum of 100mm of residual settlement or 160mm for specific areas where 100mm settlement cannot be achieved and a slope change of 0.3% in longitudinal and 1% in transverse direction [4].

The riding quality of the approach slab was evaluated by the International Roughness Index (IRI) and profile measurement. The IRI is defined as the accumulation of undulations of a given segment length and is usually reported in m/km or mm/m. An approach slab with an IRI of 3.9 mm/m is considered to have good ride quality. On the other hand, if an approach slab has an IRI of 10 mm/m or higher, the approach is identified as having poor riding quality [5].

2.4 Cause of bump formation

The most common causes of bump formation are insufficient compaction of the fill materials, settlement of the soft soil due to embankment load, heavy traffic loads, poor construction practices, design of drainage, fill materials and joints [6].

The main contributing factors to this settlement problem are unsealed expansion joints, collapse and erosion of the granular backfill, and poor construction practices that lead to water infiltrating underneath the approach pavement and causing erosion and the formation of subsurface voids. Other than that, the elevation profiles of several bridges obtained have a slope higher than 1/200, which the maximum acceptable value for an approach slab is 1/200. Loose and insufficiently compacted backfill materials, unfunctional subdrains blocked by soil and rock chips or collapsed, and foundation soil or embankment fill settlement are also factors contributing to the settlement of the approach slab [5].

The causes can vary, such as embankment fill or foundation deformation, poor drainage conditions, design, and construction practices. Infiltration of water through cracks or joints into the soil where the drainage system failed to remove the surface runoff causes increased water content in the soil and reduces the bearing capacity of the soil [7].

2.5 Mitigation Techniques

The quality and compaction of fill material, use of geosynthetic material, approach slab stiffness, and drainage improvement can mitigate settlement problems. Graded material with a plastic limit of less than 15, material passing 0.425 mm sieve less than 20% and a coefficient of uniformity greater than 3 are more suitable for compression. The use of geosynthetic material and increase in slab thickness and reinforcement can improve the soil bearing capacity and minimize soil deformation [8].

Various solutions to reduce different settlement problems, such as foundation soil improvement, well-graded backfill material, geosynthetic reinforcement backfill, use of abutment support on shallow foundation, collapse inclusion or expandable material behind abutment, improvement of drainage system, and small inclination of approach slab construction. Most bridges did not implement the full solution [5]. A detailed field investigation is required to recognize the cause of the problem and completely implement the change to the bridge.

Backfill deformation can be reduced or improved through tighter backfill, proper compaction, scheduling construction delays, controlled low strength materials (CLSM), geosynthetic material and reinforcement approach slab. Depending on the foundation soil's strength, the mitigation method can be varied from exchanging loose soil into better materials, mechanical or chemical improvement of soil strength, surcharging, deep foundation as embankment support or may not be necessary [9].

3. Methodology

The soil properties used in the modelling was presented in Table 1 obtained from PLAXIS 2D tutorial manual 2018. The embankment and sand layer were model using the hardening soil model, while the clay layer was modeled using the soft soil model. Properties of concrete and asphalt are shown in Table 2 were obtained from Hassona et al. [10]. Table 3 shows the tensile strength and elongation of the geotextile of different polyethylene terephthalate geotextile to obtain the axial stiffness used in PLAXIS 2D software. The parameters obtained as a standard value as this thesis is mainly study on the performance of the geotextile.

The bridge approach system consists of concrete pile, concrete approach slab, sleeper slab and pavement. A 15-noded and plane strain with medium refinement was utilized in this model. The bridge was modelled as a multilayer with embankment, soft clay and sand layer which subjected to a static load above the pavement that simulate the traffic load. Plaxis-2D was used in this study to model the structure and analyze the performance of bridge approach with geotextile reinforcement and unreinforced difference. To access the performance of geotextile layers, four models were be compared which are non-geotextile layer, one layer, two layers and three-layer geotextile. Next, different length of geotextiles was installed at the interface of embankment and clay to see the effectiveness. Lastly, three different stiffness of geotextile (PET200, PET 600 and PET 1000) was install. In initial PLAXIS calculation phase, K0 procedure will be assign. Second phase was construct first layer of embankment follow by second layer and third layer with plastic analysis and load input staged construction. Next phase, the bridge structure, pavement, pile and approach slab were active and calculate plastic analysis with staged construction. Final phase will be traffic of 10kN static load applied.

To assess the performance of the approach slab, two models as shown in Figure 1 and 2 were compared. Figure 1 shows the bridge system without an approach slab and reinforced which the bridge is directly connected with the pavement. Figure 2 shows the model with the approach slab and sleeper slab between the bridge abutment and the pavement. To see the effect of varying length and axial stiffness, initially the geotextile studied was 10m with 6000kN/m of elastic axial stiffness as shown in Figure 3.

Table 1: Soil Properties

Parameter	Name	Embankment	Sand	Clay	Unit
General					
Material model	Model	Hardening soil	Hardening soil	Soft soil	-
Type of material behaviour	Type	Drained	Drained	Undrained	-
Soil unit weight above phreatic level	γ_{unsat}	16	17	15	kN/m^3
Soil unit weight below phreatic level	γ_{sat}	19	20	18	kN/m^3
Initial void ratio	e_{init}	0.5	0.5	1.0	-

Secant stiffness in standard drained triaxial test	E_{50}^{ref}	2.5 x 10^4	3.5 x 10^4	-	kN/m^2
Tangent stiffness for primary oedometer loading	E_{oed}^{ref}	2.5 x 10^4	3.5 x 10^4	-	kN/m^2
Unloading / reloading stiffness	E_{ur}^{ref}	7.5 x 10^4	1.05 x 10^5	-	kN/m^2
Power for stress-level dependency of stiffness	m	0.5	0.5	-	-
Modified compression index	λ^*	-	-	0.05	-
Modified swelling index	κ^*	-	-	0.01	-
Cohesion	c	1.0	0.0	1.0	kN/m^2
Friction angle	ϕ	30	33	25	°
Dilatancy angle	ψ	0.0	3.0	0	°
Horizontal permeability	k_x	3.499	7.128	0.04752	m/day
Vertical permeability	k_y	3.499	7.128	0.04752	m/day
Change in permeability	c_k	1.10^{15}	1.10^{15}	0.2	-

Table 2: Concrete and asphalt properties [10]

Parameters	Unit	Concrete	Asphalt
Material model	N/A	Linear elastic	Linear elastic
Modulus of elasticity	kN/m^2	30 x 10^6	-
Poisson's ratio	N/A	0.20	0.35
Unit weight	kN/m^3	25	25
Secant stiffness in standard triaxial test	kN/m^2	-	5400 x 10^3

Table 3: Geotextile properties [11]

Properties (Standard)	Unit	PET 200	PET 600	PET 1000
Tensile Strength (EN ISO 10319)	kN/m	200	600	1000
Elongation at minimum strength (EN ISO 10319)	%	10	10	10
Min. tensile strength at 5% (EN ISO 10319)	kN/m	100	300	500

Figure 3 shows the one-layer reinforced model with geotextile installed 3m below the sleeper slab. Next, the model changed the material of the geotextile with varying lengths (10m, 6m, and 18m) and axial stiffness (6000kN/m, 2000kN/m, and 10,000kN/m). In order to determine the effect of the number of geotextile layers, initially four embankments were modeled without geotextiles as in Figure 2. In the second step, one layer of geotextile was introduced as shown in Figure 3. In the next step of analysis, two- and three-layers of geotextile reinforced were modeled as shown in Figure 4 and 5 respectively.

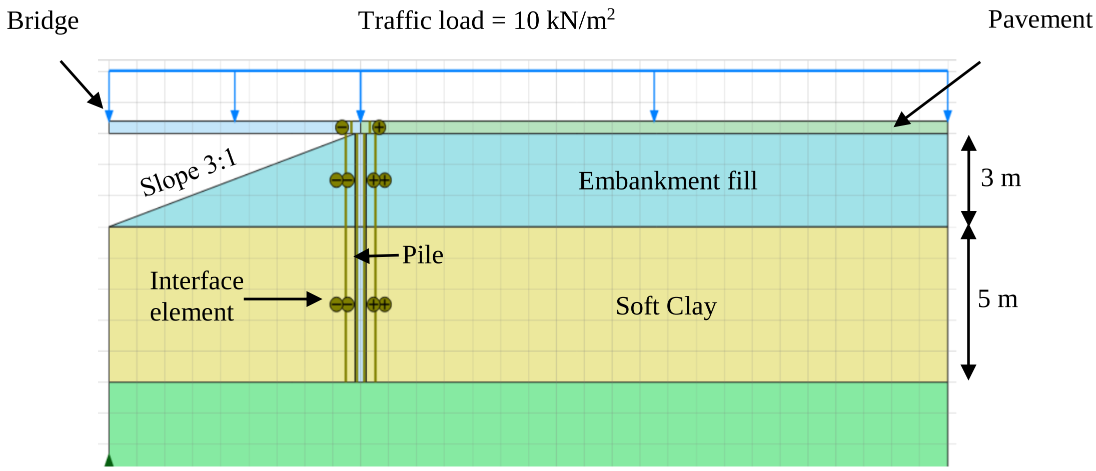

Figure 1: Model for unreinforced pavement

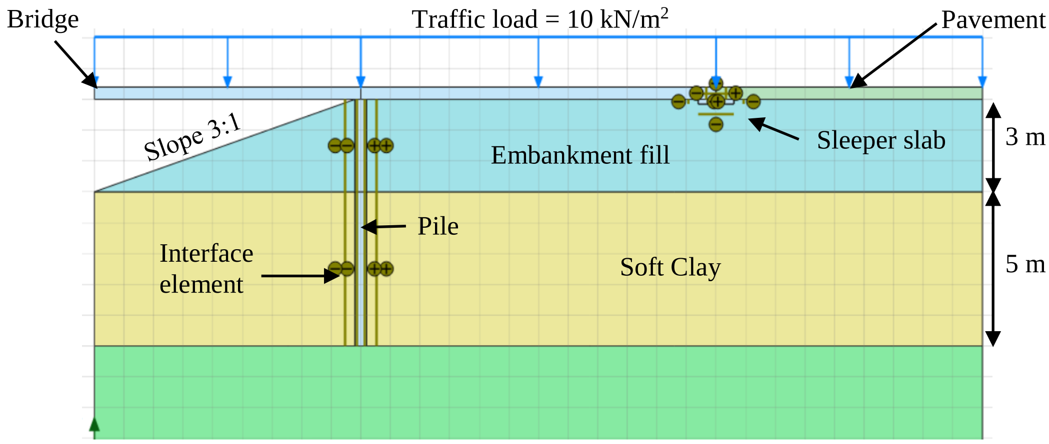

Figure 2: Model for unreinforced approach slab

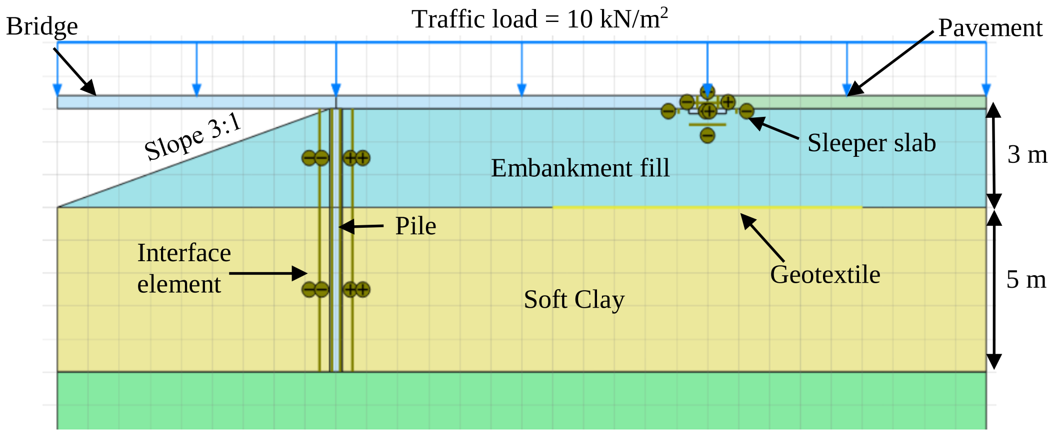

Figure 3: Model for a single layer of geotextile

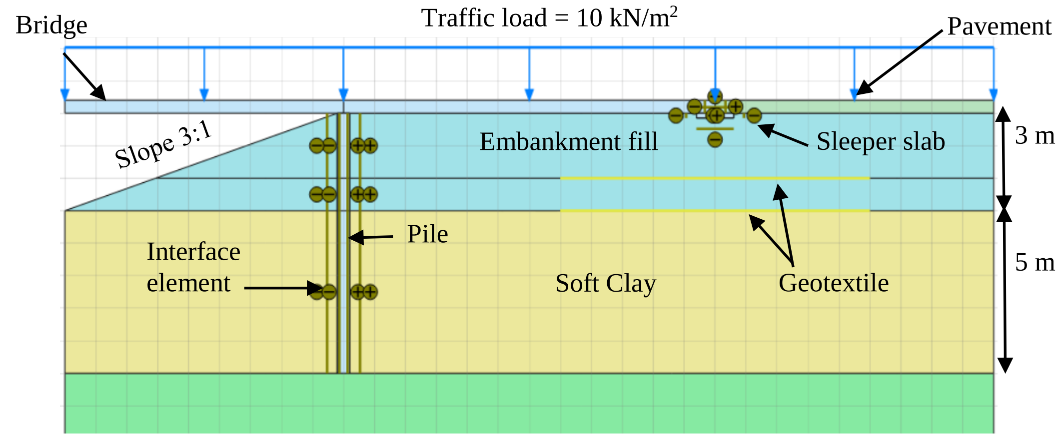

Figure 4: Model for double layers of geotextile

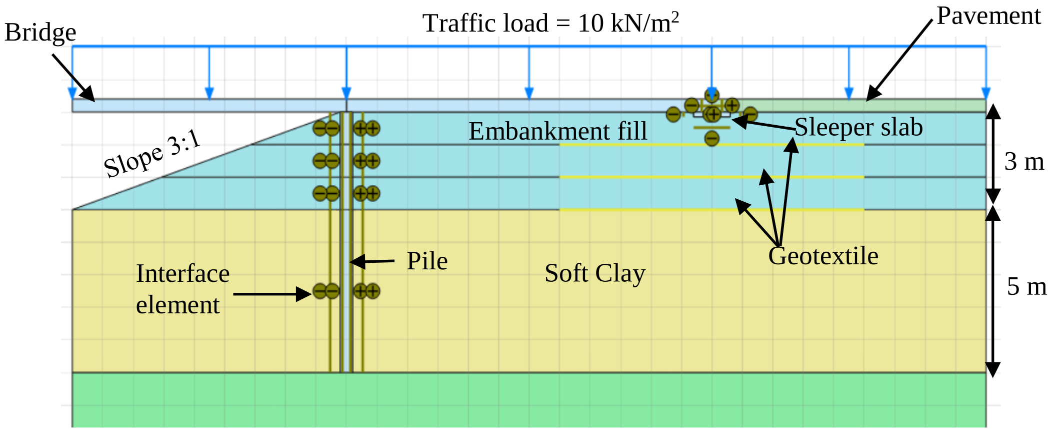

Figure 5: Model for triple layers of geotextile

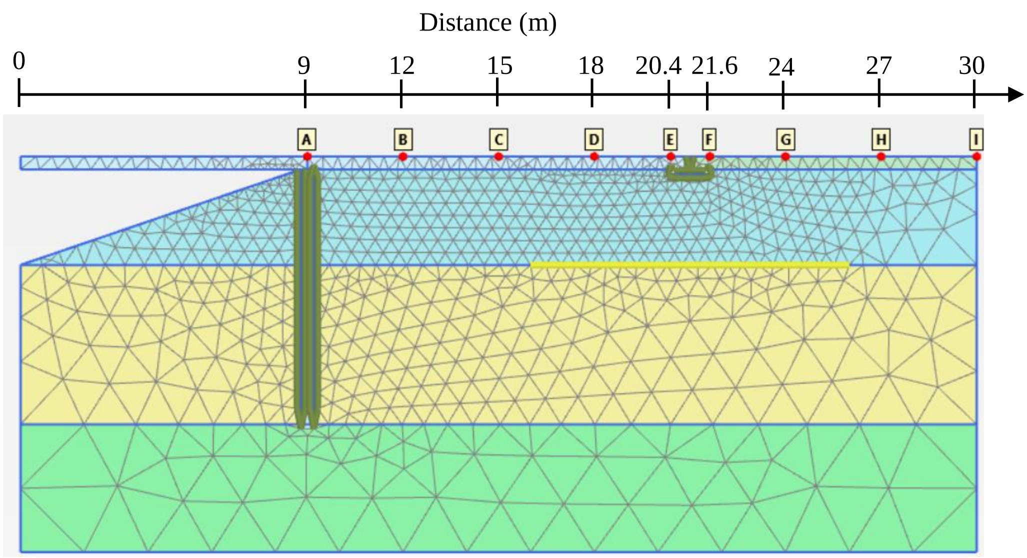

Figure 6: Point interested on settlement

4. Result and Discussion

The difference in displacement from the bridge abutment to the position of the sleeper slab for the model without an approach slab was 23.6 mm, while the difference in displacement was decreased to 22.1 mm with the help of the approach slab and sleeper slab, as shown in Figure 7. The bump level can be reduced by constructing an approach slab and a sleeper slab. The first model simulated a road pavement without an approach slab to access the effect of the approach slab. To access the performance of geotextile layers, four models were compared, which are non-geotextile layer, one layer, two layers, and three-layer geotextile. Installation of one layer of geotextile between the interface of clay and embankment reduced soil settlement by about 16 percent. However, the increase in the geotextile layers led to only a small effect on the settlement improvement as shown in Figure 8. To access the effective length of the geotextile in the reinforcement embankment, three different lengths of 10m, 6m and 18m were installed. Figure 9 shows that the settlement increases with the decrease in the length of the geotextile and vice versa. Lastly, the effective geotextile stiffness performance on soil deformation. Figure 10 shows the displacement decreasing with the increase in geotextile stiffness. Higher geotextile stiffness will have a higher ability to resist tensile forces and reduce the settlement of soil.

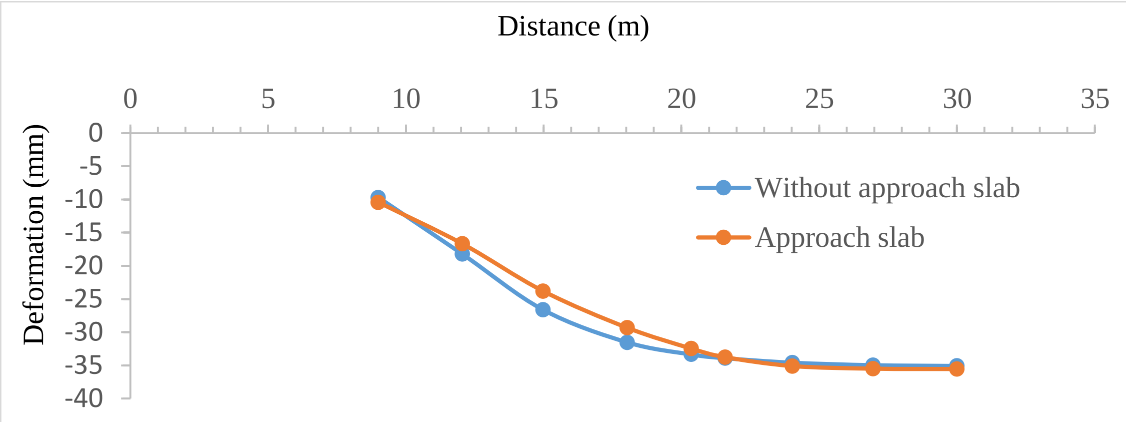

Figure 7: Deformation-distance in the model with and without approach slab

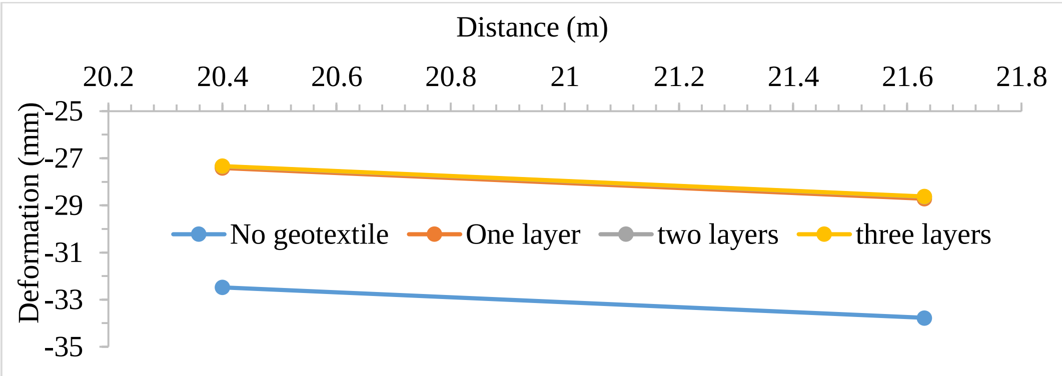

Figure 8: Vertical displacement of different geotextiles layer

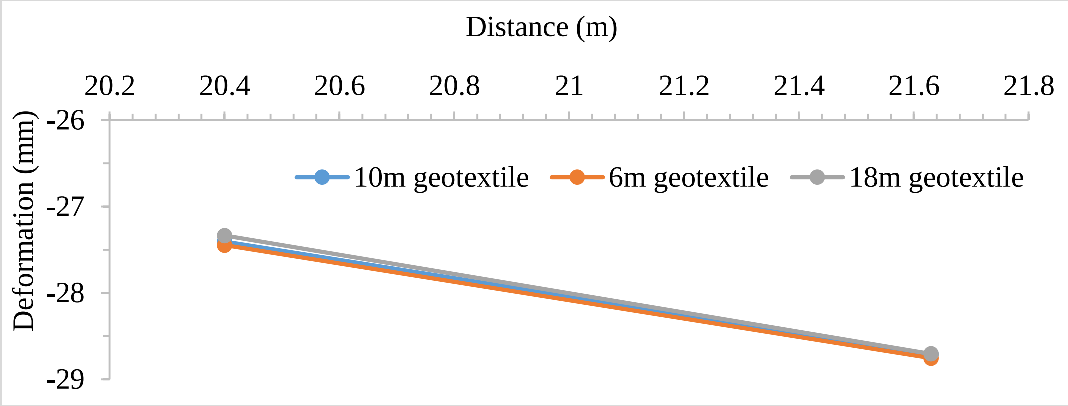

Figure 9: Vertical displacement of different geotextiles length

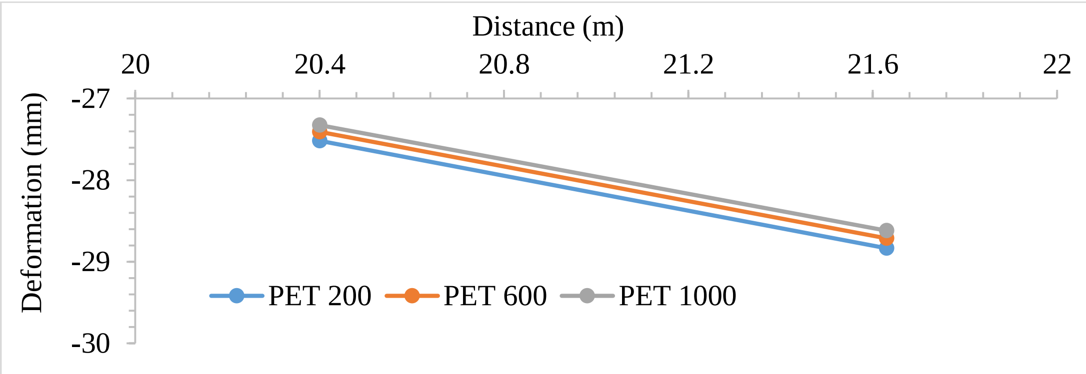

Figure 10: Vertical displacement of different geotextiles stiffness

5. Conclusion

In comparison to unreinforced pavement, the inclusion of a geotextile layer beneath the sleeper resulted in less vertical displacement. The best location to install geotextile is at the interface of two different soil layers. The addition of another layer of geotextile into the embankment does not provide significant improvement. The geotextile's lengthening also assisted in reducing settlement beneath the approach slab. However, there was no substantial difference in displacement when geotextiles with different elastic axial stiffness were employed in the soil layers.

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