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Several Analysis on Influence of Soft Ground to Piled Embankment Reinforced with Geosynthetics

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Abstract— *The main focus of this paper is to present influence of some crucial parameters such as embankment height, soft ground depth, elastic modulus of soft ground and tensile stiffness of geosynthetic to the interacting mechanisms of geosynthetic reinforced pile supported embankment (GRPS). From the analysis results in this study show the influence of pile-soil-geosynthetic interaction to distribution of strain-stress. In addition, the results about efficiency, stress concentration ratio, settlement ratio, tension and axial strain of geosynthetic are intended to provide an insight for designer, who are facing many difficulty and challenge in the design process.*

Keywords— *Embankment, geosynthetic, arching effect, stress concentration ratio, settlement ratio.*

I. ĐẶT VẤN ĐỀ

Pile embankment are increasingly used to construct highways on soft soils due to their rapid construction, low costs, and small total and differential settlement compared to the traditional soft soil improvement methods such as preloading, vertical drains or grounting injection as Magan [1], Shen et.al [2], Ariema and Butler [3]. Geosynthetic reinforcement platform(GRP) has been successfully in corporated with pile foundation as an intergrated system to reduce settlements, minimize yield of the soil above the pile cap, and enhance the efficiency of load transfer (Han and Gabrs [4], Pham et al.,[5], Han and Collin [6], Vegar Mayer and Shao [7]). The integrated system combines vertical piles and horizontally placed geosynthetics to form a relatively stiff platform that transfer embankment load to a deep competent bearing layer. The load from the embankment must be effectively transferred to the piles and to prevent punching of the piles through the embankment fill creating differential settlement at the surface of the embankment. If the piles are placed close enough together, soil arching will occur and the load will be transferred to the piles more effectively.

The scope of this paper is the analysis of geosynthetic reinforced pile supported embankments, installed through soft soil, with a commercially available finite element software and sopil model. And one aim of the paper will focus on studying influence of several factors such as embankment height, soft ground depth, soft ground elastic modulus, and geosynthetic tensile stiffness on efficiency, stress concentration ratio, settlement ratio, tension of geosynthetic, and axial strain of geosynthetic.

II. CALIBRATION OF NUMERICAL MODEL

To ensure reasonableness of the numerical model to be used for the parameter study, a design method of Low.et al. (1994) [8], method of Guido et al. [9], method of BS8006 [10] were selected for the calibration of this numerical model. The details of this calibration can be found in the paper of Han et al. [6], therefore, a brief description of this calibration presented as below.

A. Numerical Model and Theoritical Analysis

A 2D finite element method, incorporated in fast Lagrangian analysis continue (Plaxis) Version 8.5 [7]. was adopted in this study. The numerical model for calibration against this case study is presented in figure 1. Several important factors will be considered in this paper include efficiency, stress concentration ratio, settlement ratio, tension and axial strain of geosynthetic.

Where the "efficiency E" of the pile support is defined as the proportion of the embankment weight carried by the piles. The stress concentration ratio n, which is defined as the ratio of the stress on the pile caps to the soil between the pile caps ($n=\sigma_p/\sigma_s$). The stress concentration ratio n is a global index which incorporates the mechanism of the soil arching, tension membrane or apparent cohesion effect and pile-soil stiffness difference. Settlement ratio that is defined as settlement of original soft ground to settlement of geosynthetic, s/s_0, where $s_0= \sigma_s D/E_c$. (Figure 2)

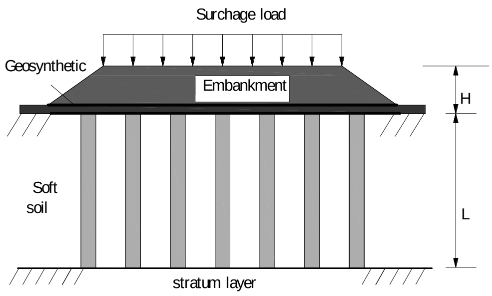

Fig. 1. Cross section of embankment.

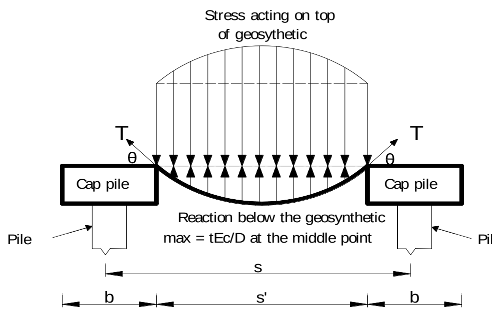

Fig. 2. Idealized stress distribution on geosynthetic.

B. Brief Project Description

A piled embankment is analyzed using the new simple method. The influence of embankment height, soft ground

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depth, soft ground elastic modulus, and geosynthetic tensile stiffness on efficiency, stress concentration ratio, settlement ratio, tension of geosynthetic, and axial strain of geosynthetic is investigated. The geometric of the embankment and design parameters used in the present case study obtained from Chen.et al. (2006). They are as follow: pile cap width = 1.13m, embankment fill-height = 4.52m (assumed), soft ground depth = 25m, Factor of λ =0.8 (assumed). A surcharge of 12kPa is used to simulate the traffic load. In this paper, these values are used throughout unless otherwise specified. No partial factors of safety are applied to the design parameters. The results of present case study are shown in figure 5-24.

TABLE I. Comparison of results from theoretical method and numerical analysis.

Factor	With Geosynthetic			
	Numerical method	Low et al.	BS8006	Guido et al.
Settlement ratio(s/s_0)	0.36	0.41	-	-
Vertical stress on pile (kN/m^2), σ_p	69.30	70.2	71.83	63.05
Vertical stress on geosynthetic (kN/m^2)	15.81	14.49	34.68	20.90
Tension in geosynthetic (kN/m^2)	39.18	34.0	44.4	30.55
Efficiency (%), E	78.08	79.91	51.94	71.04
Stress concentration ratio, n	4.38	4.89	2.07	3.02

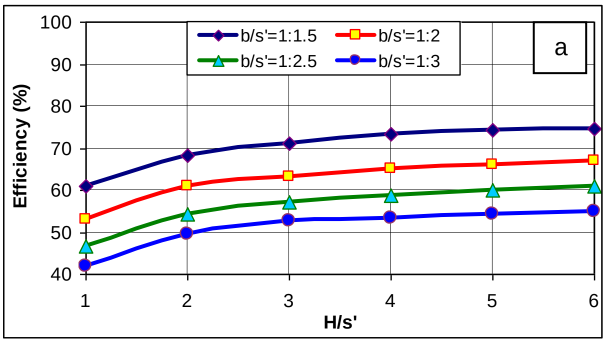
In general, the results from numerical analysis obtained a good match with other methods. Especially, with method of Low.et al. This will be basis for widening to numerical analysis.

III. ANALYSIS OF RESULTS

A. *The Influence of Embankment Height*

Figure 3 shows the influence of embankment fill height on efficiency at different ratio of the pile cap width with to the clear spacing. It can be seen that efficiency increases with increasing area ratio. It can also be seen that the efficiency for the unreinforced case increases with increasing embankment fill height, but it likely to approach a limiting value at a very large height, while that for the reinforced case decreases with increasing embankment fill height at small values of area ratio and increases with increasing embankment fill height at large values of area ratio. The efficiency for reinforced case is higher than that for unreinforced due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps. For the present case study, geosynthetic increases efficiency by 7-75%.

Figure 4 shows the influence of embankment fill height on stress concentration ratio at different ratio of the pile cap width with to the clear spacing. It can be seen that stress concentration ratio increases with increasing area ratio for both the unreinforced case and reinforced case. It can also be seen that the stress concentration ratio for the unreinforced case increases with increasing embankment fill height, but it is likely to approach a limiting value at a very large height, while that for the reinforced case increases with increasing embankment fill height at large values of area ratio, but it is likely to approach a limiting value at a very large height. The stress concentration ratio for reinforced case is higher than that for unreinforced due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps. For present case, geosynthetic increases stress concentration ratio by 35-280%.



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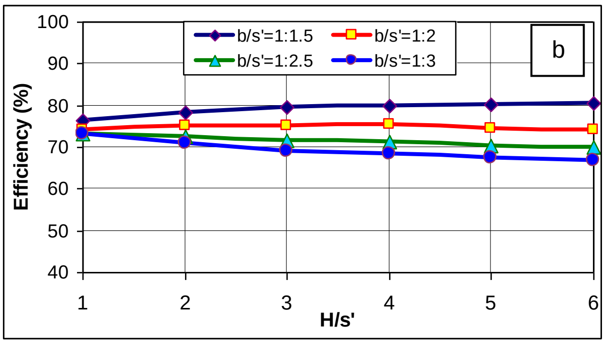

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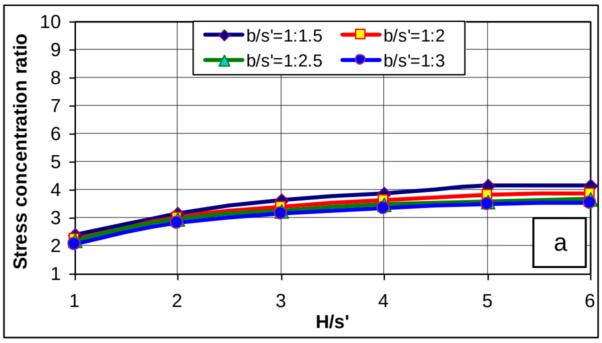
Fig. 3. Effect of embankment height on efficiency (a-without geosyntheic, b-with geosynthetic).



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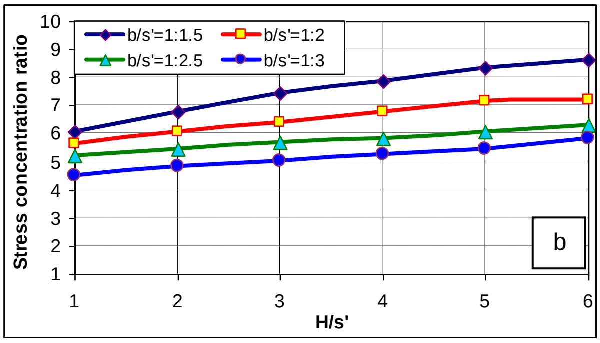


(b)

Fig. 4. Effect of embankment height on stress concentration ratio (a-without geosyntheic, b-with geosynthetic*)*

Figure 5 shows the influence of embankment fill height on settlement ratio (settlement of original soft ground, s/s_0, where $s_0 = \sigma_s D/E_c$) at different ratio of the pile cap width with to the clear spacing. It can be seen that settlement ratio decreases with increasing area ratio. It can also be seen that the settlement ratio decreases with increasing embankment fill height, but it is likely to approach a limiting value at a very large height.

Figure 6 shows the influence of embankment fill height on tension of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that tension of geosynthetic decreases with increasing area ratio. It is also clear that tension of geosynthetic increases with increasing embankment fill height. Tension of geosynthetic become more obvious for small values of area ratio and large values of embankment fill height.

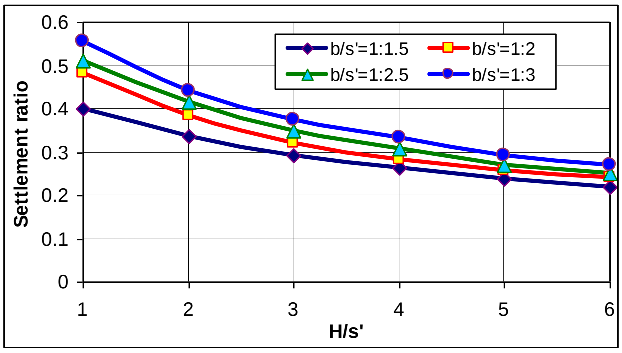


Fig. 5. Effect of embankment height on settlement ratio.

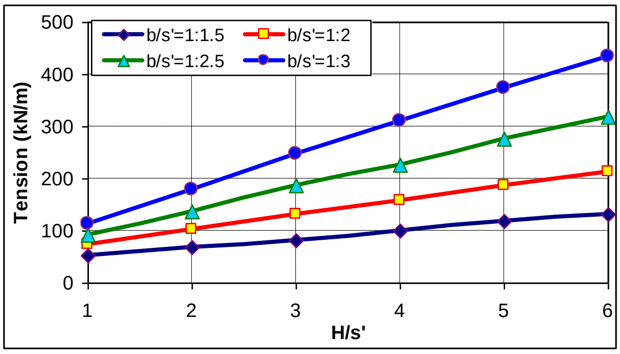


Fig. 6. Effect of embankment height on tension.

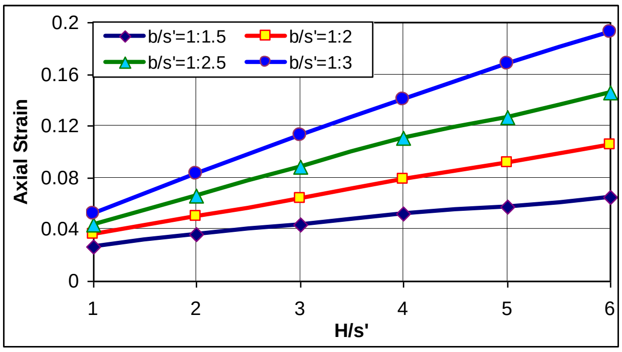


Fig. 7. Effect of embankment height on axial strain.

Figure 7 shows the influence of embankment fill height on axial strain of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that axial strain of geosynthetic decreases with increasing area ratio. It is also clear that tension of geosynthetic increases with increasing embankment fill height. Axial strain of geosynthetic become more obvious for small values of area ratio and large values of embankment fill height.

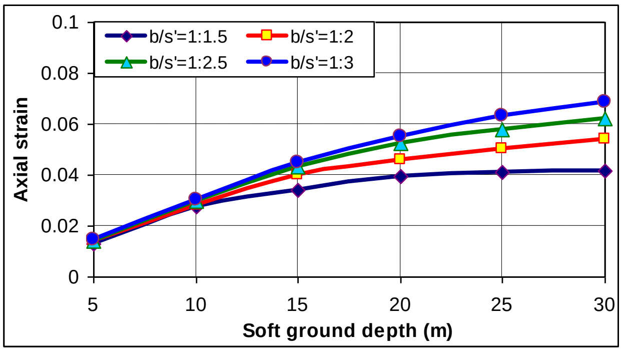
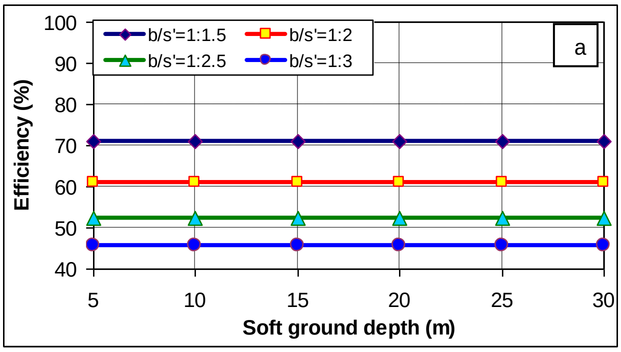


Fig. 8. Effect of soft ground depth on axial strain.

B. The Influence of Soft Ground Depth

Figure 8 shows the influence of soft ground depth on axial strain of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that axial strain of geosynthetic decreases with increasing area ratio. In addition, tension of geosynthetic increases with increasing soft ground depth.



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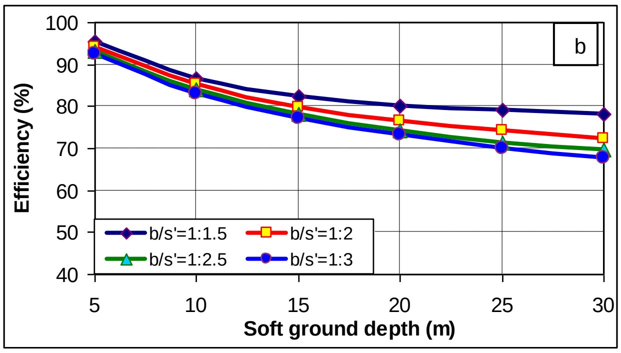

(b)

Fig. 9. Effect of soft ground depth on efficiency (a-without geosyntheic, b-with geosynthetic).

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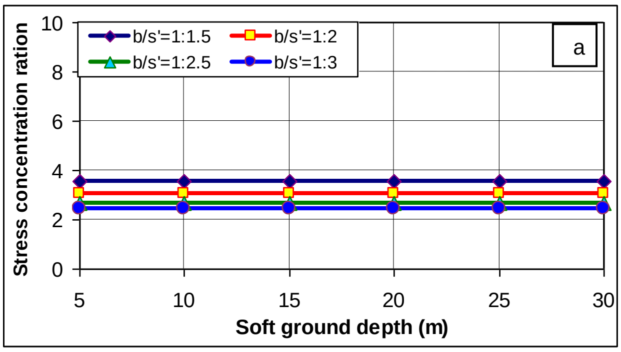
Figure 9 shows the influence of soft ground depth on efficiency at different ratio of the pile cap width with to the clear spacing. It can be seen that efficiency increases with increasing area ratio. As the same time, the efficiency decreases with increasing soft ground depth. The efficiency for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.

Figure 10 shows the influence of soft ground depth on stress concentration ratio at different ratio of the pile ca at different ratio of the pile cap width with to the clear spacing. It can be seen that stress concentration ratio decreases with increasing area ratio. It can also be seen that the stress concentration ratio decreases with increasing soft ground depth. The stress concentration ratio for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.



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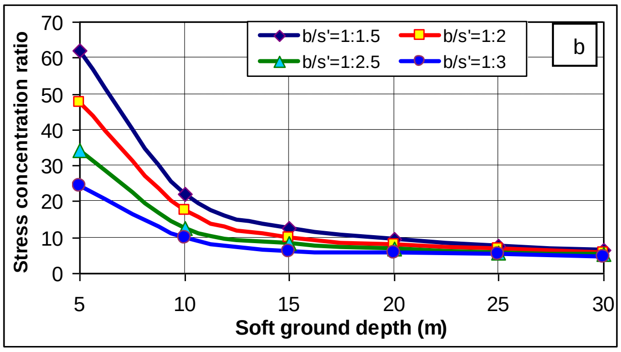


(b)

Fig. 10. Effect of soft ground depth on stress concentration ratio (a-without geosyntheic, b-with geosynthetic).

Figure 11 shows the influence of soft ground depth on settlement ratio at different ratio of the pile cap width with to the clear spacing. It can be seen that settlement ratio decreases with increasing area ratio. It can also be seen that the settlement ratio decreases with increasing soft ground depth.

Figure 12 shows the influence of soft ground depth on tension of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that tension of geosynthetic decreases with increasing area ratio. In addition, tension of geosynthetic increases with increasing soft ground depth.

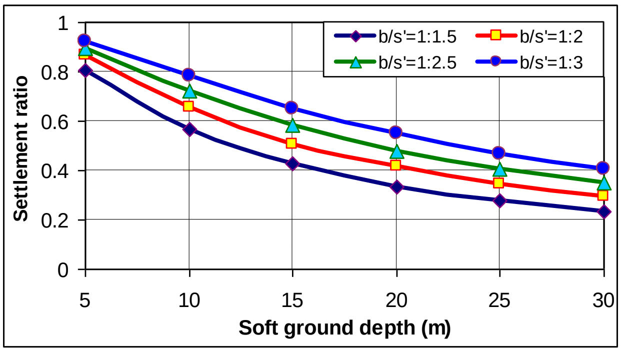


Fig. 11. Effect of soft ground depth on settlement ratio.

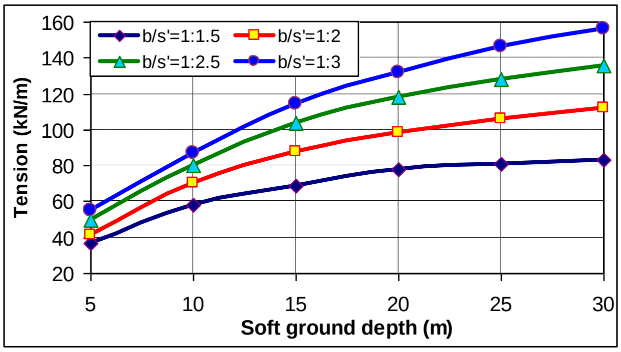
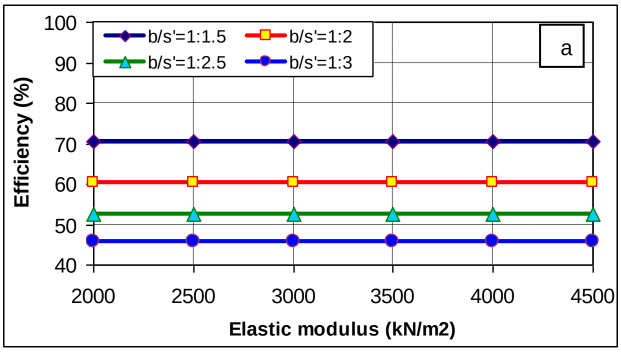


Fig. 12. Effect of soft ground depth on tension.



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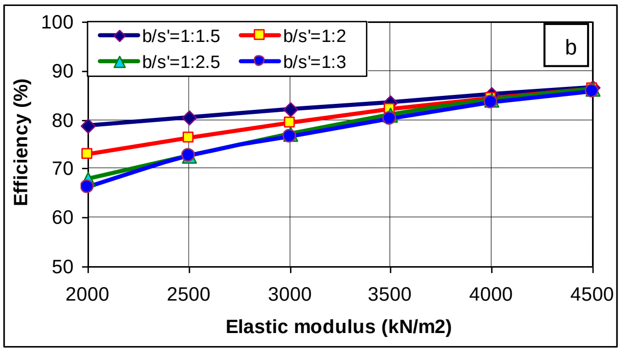

(b)

Fig. 13. Effect of soft ground elastic modulus on efficiency (a-without geosyntheic, b-with geosynthetic).

C. The Influence of Soft Ground Elastic Modulus

Figure 13 shows the influence of soft ground elastic modulus on efficiency at different ratio of the pile cap width with to the clear spacing. It can be seen that efficiency

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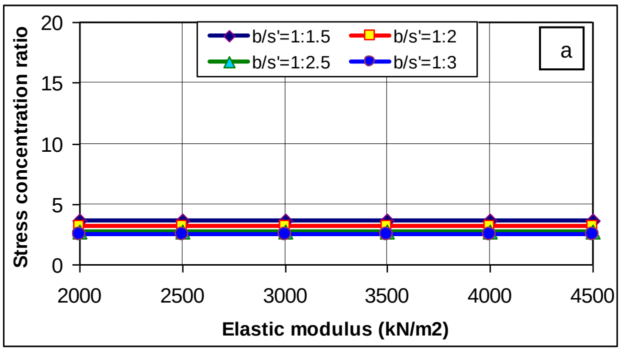
increases with increasing area ratio. It can also be seen that the efficiency increases with increasing soft ground elastic modulus. The efficiency for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.

Figure 14 shows the influence of soft ground elastic modulus on stress concentration ratio at different ratio of the pile ca at different ratio of the pile cap width with to the clear spacing. It can be seen that stress concentration ratio decreases with increasing area ratio. It can also be seen that the stress concentration ratio increases with increasing soft ground elastic modulus. The stress concentration ratio for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.



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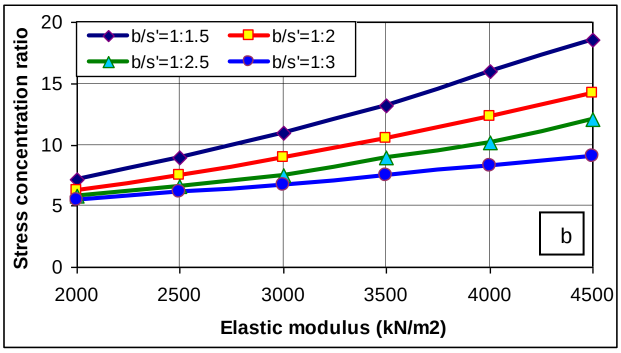

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Fig. 14. Effect of ground elastic modulus on stress concentration ratio(a-without geosyntheic,b-with geosynthetic).

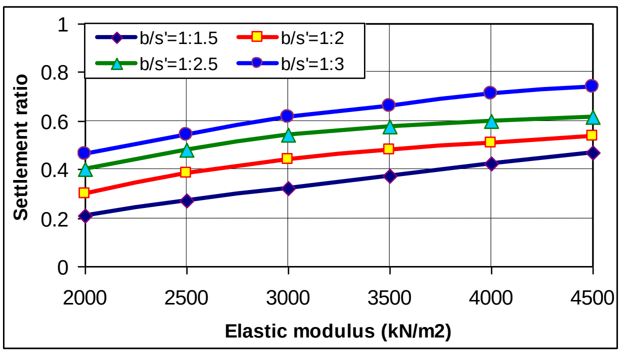


Fig. 15. Effect of elastic modulus on settlement ratio.

Figure 15 shows the influence of soft ground elastic modulus on settlement ratio at different ratio of the pile cap width with to the clear spacing. It can be seen that settlement ratio decreases with increasing area ratio. It can also be seen that the settlement ratio increases with increasing soft ground elastic modulus.

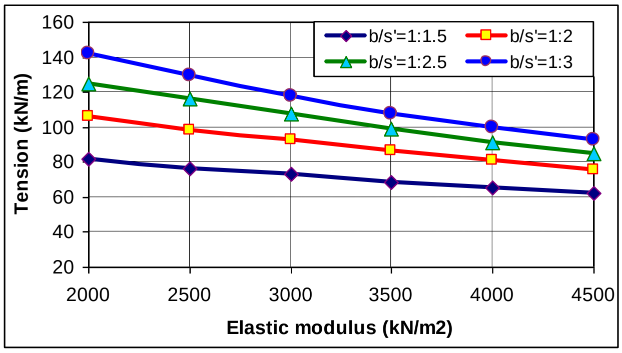


Fig. 16. Effect of ground elastic modulus on tension.

Figure 16 shows the influence of soft ground elastic modulus on tension of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that tension of geosynthetic decreases with increasing area ratio. In addition, tension of geosynthetic decreases with increasing soft ground elastic modulus.

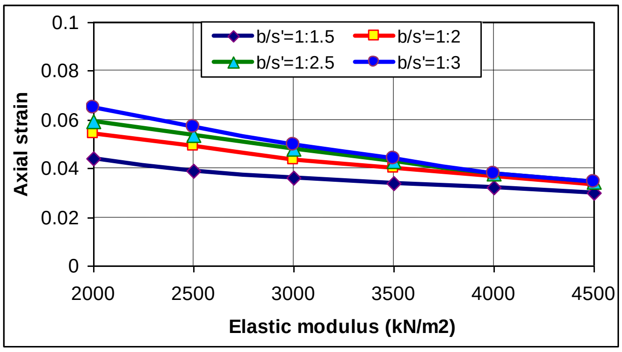


Fig. 17. Effect of elastic modulus on axial strain.

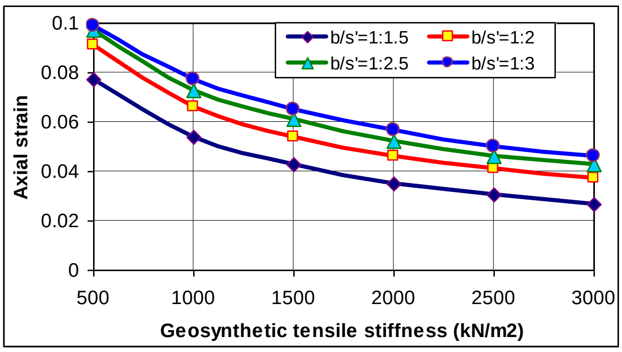


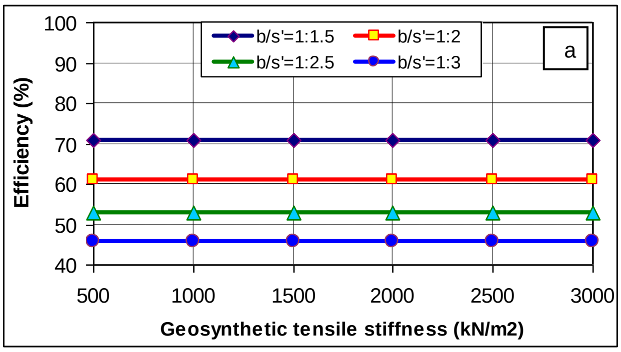
Fig. 18. Effect of geo tensile stiffness on axial strain.

Figure 17 shows the influence of soft ground elastic modulus on axial strain of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that axial strain of geosynthetic decreases with increasing area ratio. It is also clear that tension of geosynthetic decreases with increasing soft ground elastic modulus.

D. The Influence of Geosynthetic Tensile Stiffness

Figure 18 shows the influence of geosynthetic tensile stiffness on axial strain of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that axial strain of geosynthetic decreases with increasing area ratio. It is also clear that tension of geosynthetic decreases with increasing geosynthetic tensile stiffness.

Figure 19 shows the influence of geosynthetic tensile stiffness on efficiency at different ratio of the pile cap width with to the clear spacing. It can be seen that efficiency increases with increasing area ratio. It can also be seen that the efficiency decreases gradually with increasing geosynthetic tensile stiffness. The efficiency for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.



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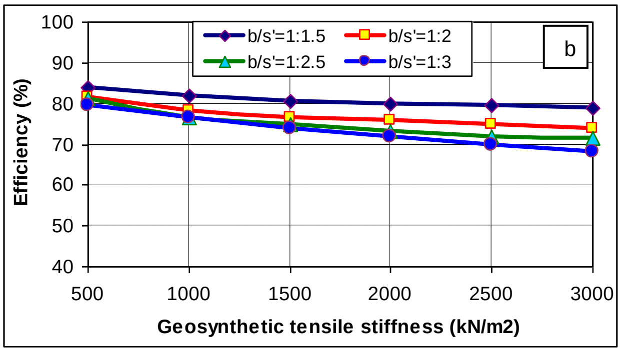
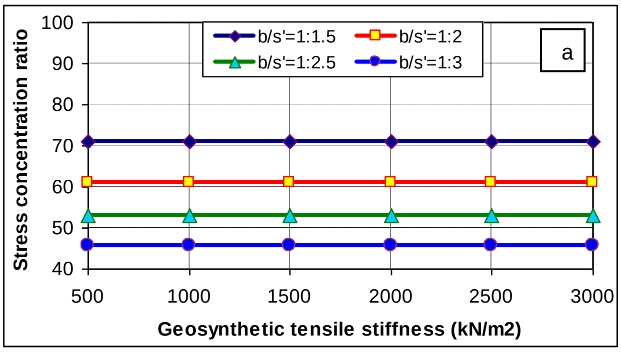


(b)

Fig. 19. Effect of geosynthetic tensile stiffness on efficiency (a-without geosyntheic, b-with geosynthetic).

Figure 20 shows the influence of geosynthetic tensile stiffness on stress concentration ratio at different ratio of the pile ca at different ratio of the pile cap width with to the clear spacing. It can be seen that stress concentration ratio decreases with increasing area ratio. It can also be seen that the stress concentration ratio decreases with increasing geosynthetic tensile stiffness, but it is likely to approach a limiting value at a very large geosynthetic tensile stiffness. The stress concentration ratio for reinforced case is higher than that for unreinforced case due to that the geosynthetic enhances the load transfer from the soft soil to the pile caps.



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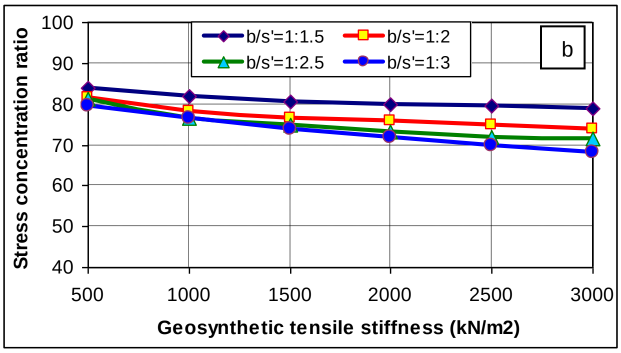

(b)

Fig. 20. Effect of geos. tensile stiffness on stress concentration ratio(a-without geosyntheic, b-with geosynthetic).

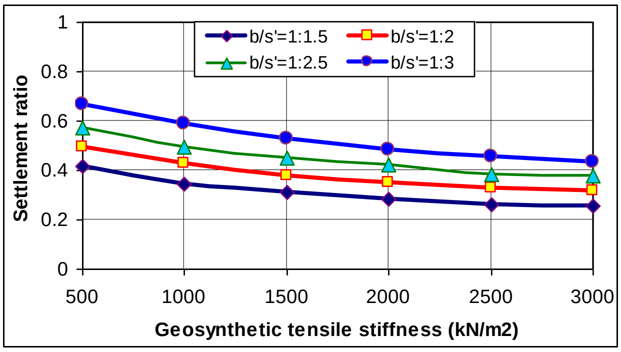

Fig. 21. Effect of geo. tensile stiffness on settlement ratio.

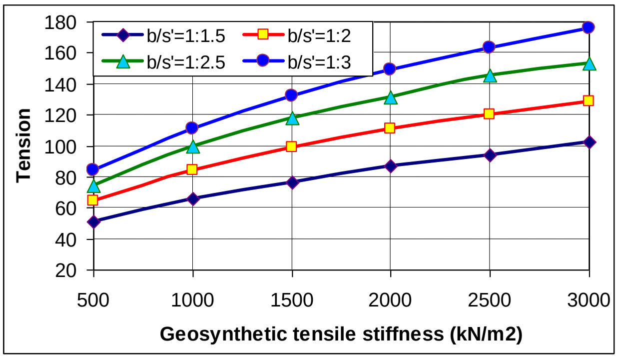

Fig. 22. Effect of geo. tensile stiffness on tension.

Figure 21 shows the influence of geosynthetic tensile stiffness on settlement ratio at different ratio of the pile cap width with to the clear spacing. It can be seen that settlement ratio decreases with increasing area ratio. It can also be seen that the settlement ratio decreases with increasing geosynthetic tensile stiffness.

Figure 22 shows the influence of geosynthetic tensile stiffness on tension of geosynthetic at different ratios of the pile cap width to the clear spacing. It is clear that tension of geosynthetic decreases with increasing area ratio. It is also clear that tension of geosynthetic increases with increasing geosynthetic tensile stiffness.

E. Comment

The working stress of the geotexile depends on complex interaction of fill properties, soft groiund properties, and geotexile properties.

The geosynthetic is more effective when soft soil is very compressible, because the axial force in the geosynthetic increases with increasing the settlement of soft ground.

The settlement decreases with increasing the soft ground elastic modulus and geosynthetic tensile stiffness, and increases with increasing the embankment fill height and soft soil depth as expected. The fill load carried by piles decreases with increasing the soft ground depth and geosynthetic tensile stiffness, and increases with increasing the embankment height and soft ground elastic modulus, because the reaction of soft ground on geosynthetic decreases with increasing the soft ground depth and geosynthetic tensile stiffness, and increases with increasing the embankment height and soft ground elastic modulus.

As a result the net stress acting on the geotextile increases with the soft ground depth and geosynthetic tensile stiffness, and increases with the embankment height and soft ground elastic modulus.

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