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Numerical investigation of symmetric settlement of piled and geogrid reinforced bridge abutments

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ABSTRACT

One of the major problems in highway and railway bridges is the settlement of the bridge abutments, which its reduction has always been set as the researchers target. Two methods which have been widely used are reinforcing the abutment with geogrid and abutments on piles. However, in terms of performance, these two methods have not been compared accurately. This paper describes the application of a two-dimensional finite element program for comparing the performance of these two methods. The data from an experimented bridge abutment has been used for verification of modeling. The reduction of bridge abutment`s settlement by pile and geogrid have been analysed and compared.

Keywords: bridge abutment, pile, geogrid, settlement, numerical analysis

1 INTRODUCTION

One of the geotechnical problems in highway construction is encountering with soft soils in pavement subgrade and the foundation of bridge abutments. The soft soils can easily cause settlement of bridge and pavement resulting in uneven surface on the roadway. To overcome this problem, a variety of measures have been taken by the engineers worldwide, the optimum solution is subjective. For a long time, piles have been used for transferring the bridge abutment loads to the competent soil in depth or taking that by the friction between the pile surface and surrounding soil. Another method of controlling the settlement of abutment on soft soil is its reinforcement by geosynthetics. A number of studies have been carried out for investigating each method individually Ellis and Springman (2001); Helwany et al. (2003); Hara et al. (2004); Skinner and Rowe (2005); Helwany et al. (2007); Detert and Alexiew (2010). However, their performance in the same conditions for reducing the displacement has not been compared yet.

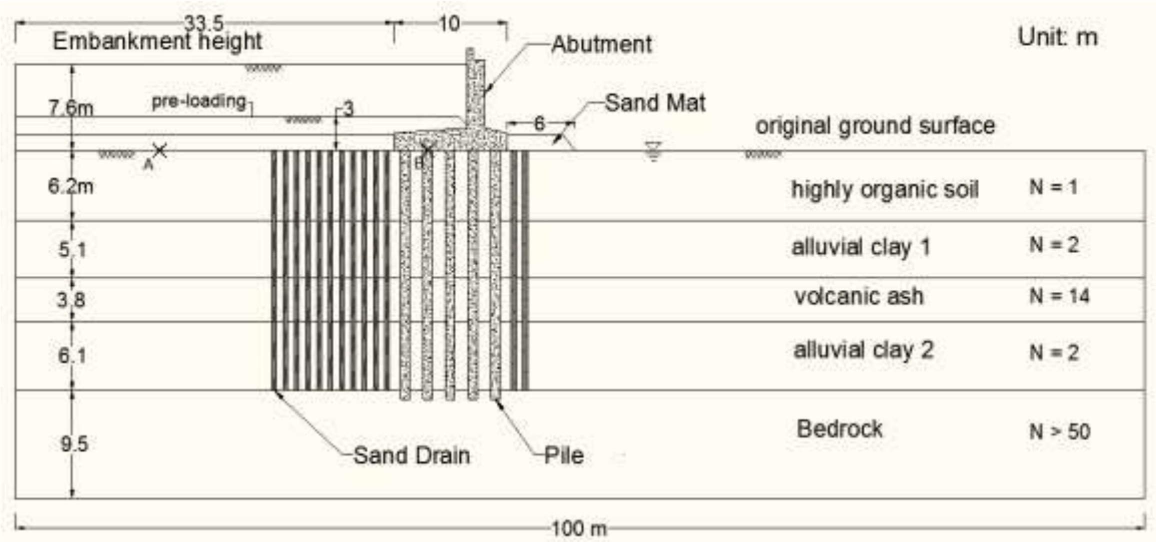
With the objective of comparing the performance of pile and geogrid in reducing the vertical and lateral deformation of a bridge abutment on soft soil, a finite elements analysis using Plaxis 2D V8.5 have been conducted. For verifying the modeling, the data obtained from monitoring the deformations in a real scale piled bridge abutment have been used (Hara et al, 2004). Then, the modeling has been used for the analysis and comparison of two cases of piled bridge abutment, and geogrid reinforced abutment, which are denoted in this paper by PA and GRA, respectively.

2 REAL-SCALE ABUTMENT MODELING

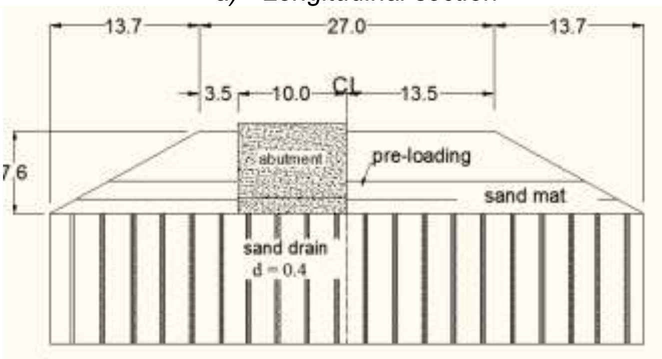
2.1 Modeling the piled bridge abutment (PA)

Figure 1 shows a section of the abutment used in this study. The subgrade soil types, respectively from top to the bottom are as follow: highly organic soil (Ap) with a thickness of 6.2m, Alluvial clay 1 (Ac1) with a thickness of 5.2m, volcanic ash (Av) with a thickness of 3.8m, Alluvial clay 2(Ac2) with a thickness of 6.1 m, and bedrock.

The abutment has been designed with 10m width, 10m length and 9m height, which is supported by a group of 25 (5×5) piles. The piles are made of steel with circular cross section 800mm in diameter, 12mm in thickness and 21m in length. Also in Figure 1, the cross section of the fill and the abutment perpendicular to the bridge axis has been illustrated (Figure 1-b). For reducing the vertical and horizontal displacement of the ground due to filling, a layer of sand with a thickness of 3m have been constructed as pre-loading before construction of the piles and abutment.



a) *Longitudinal section*



b) *Transverse section*

Figure 1: Cross section of abutment: a) Longitudinal section b) Transverse section

Figure 2 shows the process of constructing the fill as follows:

a) After constructing the sand drains, the sand mat was constructed up to the level of 1.3m from the initial ground level, and then laid out for 150 days.

b) For pre-loading, the fill with a height of 1.7m was constructed with a rate of 10cm/day on the sand mat and was laid out for 60 days. Therefore, the total height of the sand mat and the fill for pre-loading from the initial ground level is 3m.

c) A part of the pre-loading layer was removed to construct the abutment and the piles. Then, the fill behind the abutment was constructed again, up to a height of 3m.

d) The filling was continued to the height of 7.6m with a rate of 4cm/day, and then laid out for 400 days.

e) 3meters of the upper part of the fill was removed and the rest laid out for 150 days.

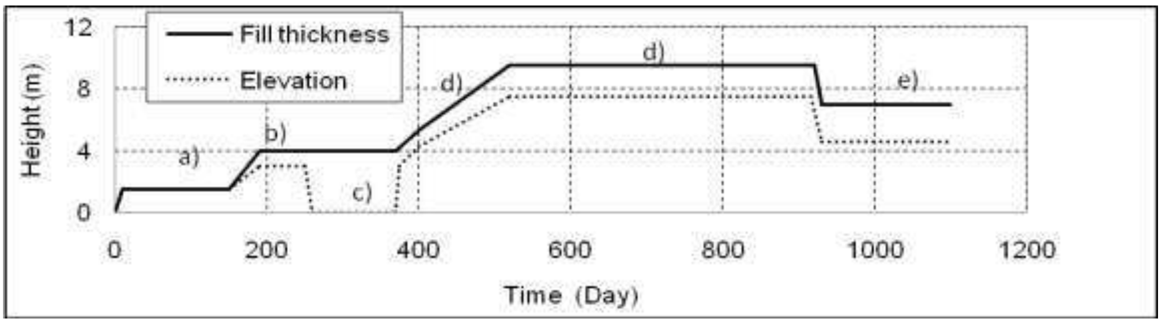


Figure 2: Process of Constructing the filling

The embankments were simulated using the Mohr-Coulomb model. The density of soil was obtained from in situ density tests,γ_{t1}, as shown in Table 1. The cohesion (c) and internal friction of the soil(φ), have been obtained from CD-tests. The abutment material was assumed to be linear and its properties, such as density, elastic modulus and Poisson's ratio was assumed as those for reinforced concrete. In 2 dimensional analysis, a row of piles have been simplified as a wall of plane strain. The arrangement of the piles beneath the abutment can be seen in Figure 3. The plane strain wall has been assumed to be linear in the analysis. Table 1 shows all of the materials properties and their values used in the analysis.

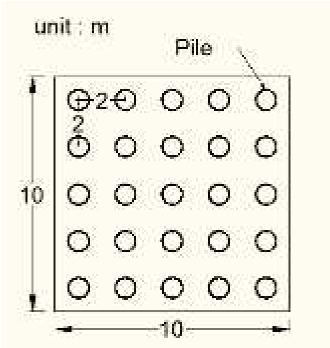


Figure 3: Arrangement of piles beneath the abutment

For the sand drains, instead of their circular cross section, equivalent rectangular section, perpendicular to the bridge axis, have been used. Thus, the flow rate of the two sections, should be equal, and the following equation must be satisfied.

$T_{V1} = T_{V2}$ (1)

T_v = Time factor (in consolidation)

Table 1:Embankment and ground properties

Cam-Clay Materials (Thickness of embankment is 7.6m)							
Material	λ	Κ	e_0	p_c (kN/m^2)	γ (kN/m^3)	K_0	k (m/s)
Ap	0.846	0.169	3.44	52	13	0.8	1E -10
Ac1	0.260	0.052	1.51	135	16	0.5	1E -10
Ac2	0.391	0.078	1.75	137	16	0.5	1E -10
Mohr-Coulomb Materials							
Material	E (kN/m^2)	ϑ	φ (°)	c (kN/m^2)	γ_t (kN/m^3)	k (m/s)	
Sand mat	5000	0.30	30	0	18	1E -04	
Av	15000	0.30	30	50	16	1.7E -06	
Elastic Materials							
Material	E (kN/m^2)	ϑ	γ_t (kN/m^3)	k (m/s)			
abutment	2.5E+07	0.17	24.5	1E -20			
Bed rock	300000	0.30	20	1E -05			
Embankment							
H(m)	γ_t (kN/m^3)	E (kN/m^2)	ϑ	φ (°)	c (kN/m^2)		
0 - 4.0	23	5000	0.30	16.5	55		
4.0 – 6.1	21.5	5000	0.30	16.5	55		
6.1 – 7.6	19.5	5000	0.30	16.5	55		

2.1.1 Analysis of the model

15-nodes triangular elements with 12 guassian points have been used for modeling. For considering the time-dependent dissipation of excess pore pressure, the analysis in all phases has been done using consolidation analysis. Computation of the constructed abutment on pile has been done in 9 consolidation analysis phases, and the whole process of construction and consolidation has lasted 1150 days.

2.2 Geogrid reinforced abutment (GRA)

The geometry of the GRA is the same as that for the PA, as described in previous section, except that, the piles have been omitted and the soil beneath and behind the abutment have been reinforced by geogrid (Figure 4).

The process of constructing the abutment is also the same as that of the PA, except that during filling the embankment, the geogrid layers are placed in 40cm intervals, and 7 layers of geogrid have been used for reinforcing the soil beneath the abutment.

The same behavior and parameters, as used for the case of PA, were used for the case of GRA. In numerical analysis, the geogrid element has been assumed to be elastic. The distance between the geogrids is 0.4 m and their base normal stiffness was assumed to be 500KN/m. However, the analysis was conducted for 3 stiffness values of 1000, 1500 and 2000KN/m.

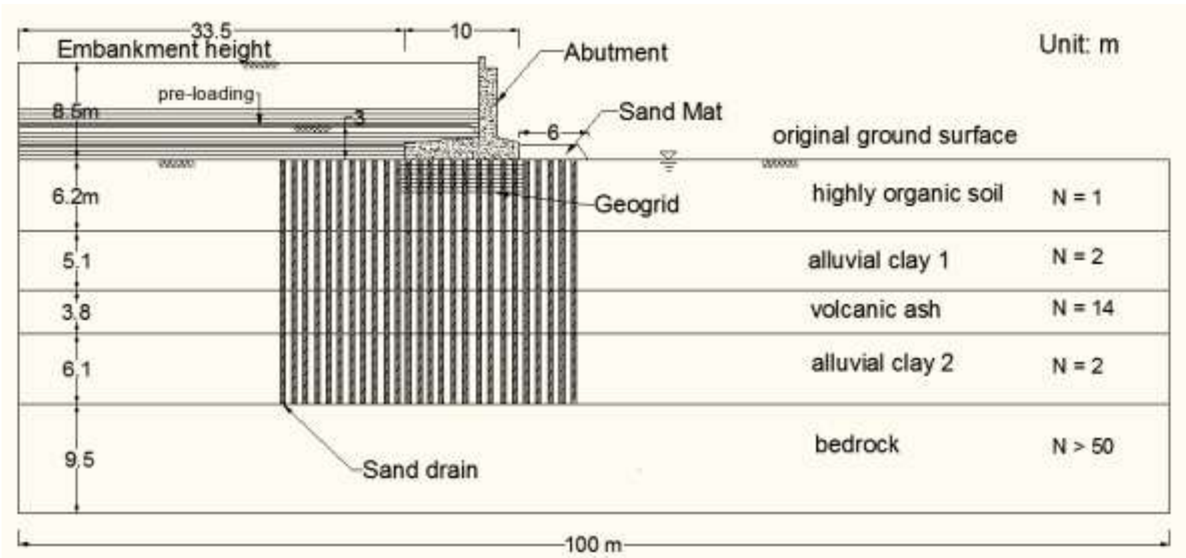
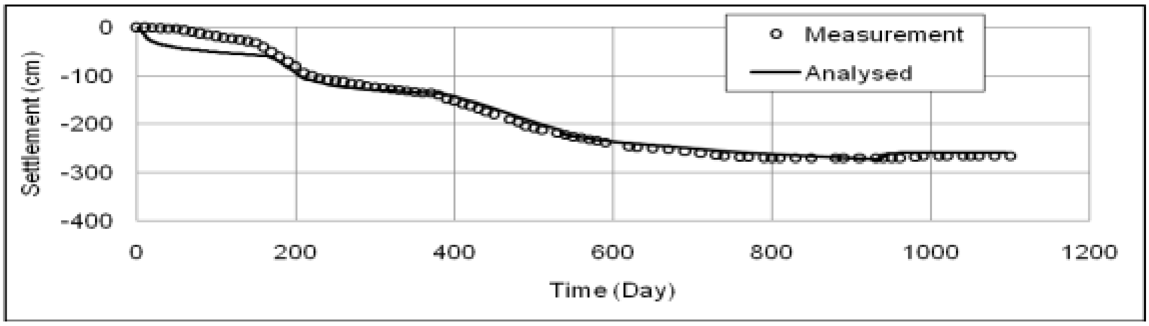


Figure 4:The geometry of GRA

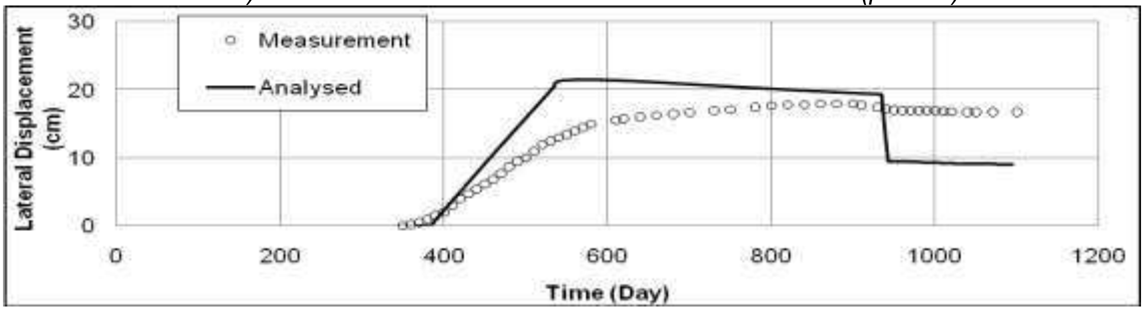
3 RESULTS OF ANALYSIS

3.1 Piled bridge abutment (PA)

Figure 5-a shows the history of the maximum settlement of ground from its initial level. As can be seen, the measured and calculated values are well consistent, this settlement has been occurred at point A which is specified in Figure 1a. Figure 5-b shows the maximum horizontal displacement of the pile head at ground level which is specified by point B in Figure 1a. Displacements of these two points have been monitored in a real piled bridge abutment. As can be seen in the figure, there is a slight discrepancy between the measured and calculated values, which is more noticeable after removing the 3 meter of the upper part of the abutment. As can be seen, the maximum horizontal displacement under the abutment, has been calculated to be 21cm, while the real measured value is 17cm. This discrepancy is attributed to the modeling assumptions and that the 3-dimensional interaction mechanisms between the soil and piles has not been well simulated by the 2-dimensional modeling in this analysis. In general, before removing the upper part, the horizontal displacement of the piles head, calculated by the model, is reliable and is not accurate after that.



a) The maximum vertical settlement beneath the fill (point A)



b) The maximum lateral displacement of pile head (point B)

Figure 5: the comparison of measured and calculated values of a) the maximum vertical settlement beneath the fill(point A) and b) the maximum lateral displacement of pile head (point B)

3.2 Geogrid reinforced abutment (GRA)

Figure 6 shows the maximum settlement of the embankment on the same soil reinforced by a geogrid with two different stiffnesses of 500KN/m and 1500KN/m. It can be seen that increasing in the stiffness of geogrid does not influence the settlement.

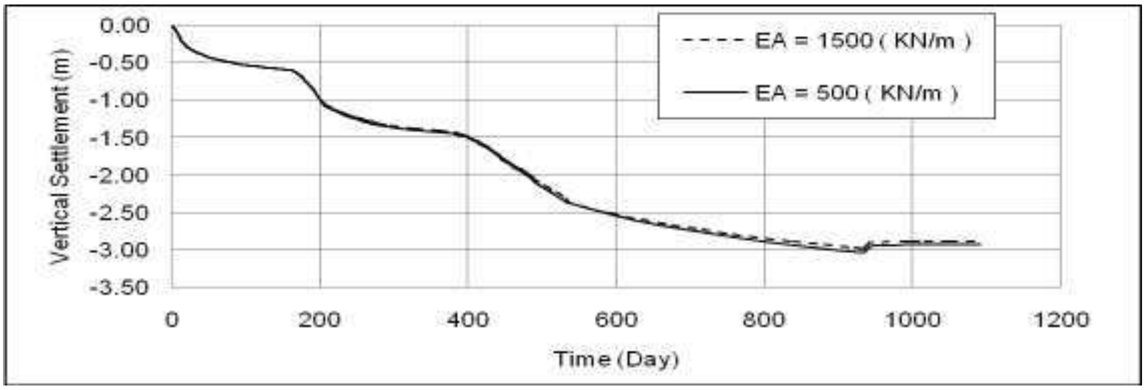


Figure 6: The maximum settlement of the abutment on soil reinforced by geogrid with two different stiffness values

3.3 Comparison of PA and GRA

Figure 7 shows the vertical settlement of the PA and GRA. As can be seen, in equal conditions, the maximum vertical settlement of the PA is less than that of the GRA. The figure shows that, after constructing the pile, the vertical settlement of the PA does not increase anymore.

Figure 8 shows the maximum horizontal displacement of the PA and GRA with different stiffness values of geogrid. As can be seen, increasing the stiffness of the geogrid decreases the horizontal displacement. The horizontal displacement of the abutment decreases by 82%, as the stiffness increases from 500KN/m to 2000KN/m. In this figure, it can also be seen that, the horizontal displacement of the abutment on soil reinforced by a geogrid with a stiffness of 500KN/m is higher than that of the PA. However, as the stiffness increases to 1500 and 2000KN/m, the maximum horizontal displacement reduces to a value equal and less than that of the PA, respectively.

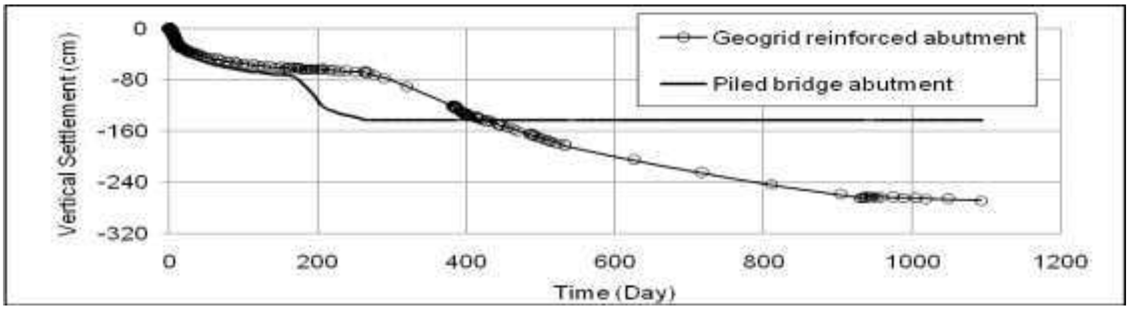


Figure 7: The maximum settlement of the abutment in PA and GRA

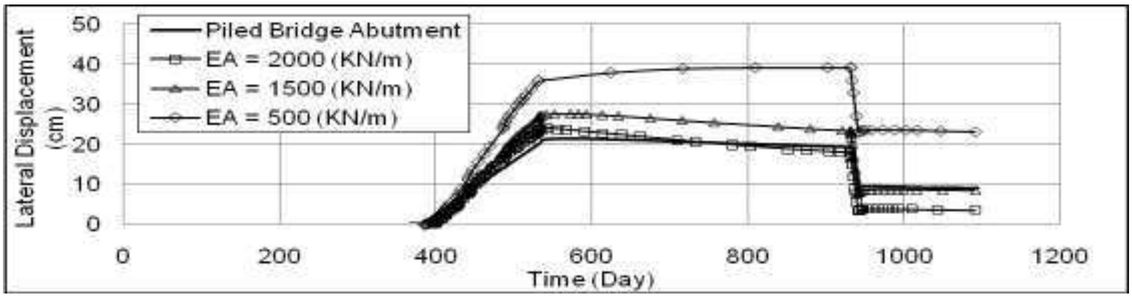


Figure 8: the maximum lateral displacement of the PA and GRA

4 CONCLUSIONS

The following conclusions can be drawn from this paper;

- Verification of the modeling showed that it can well predict the measured vertical settlement, all over the process, however, the lateral displacement of the pile, after removing the upper part of fill, can not be accurately predicted.
- In equal conditions, the vertical settlement of the PA is less than that of the GRA.
- The vertical settlement of the GRA is not affected by the stiffness of geogrid.
- The horizontal displacement of the GRA, is influenced by the stiffness of geogrid, where the horizontal displacement decreases with increasing the stiffness.
- Although, the vertical settlement of the GRA is higher than that of PA, and is independent of the stiffness of geogrid, the horizontal displacement of the GRA can be less than that of the abutment on pile, when stiffer geogrid is used for reinforcement.
- As the vertical displacement of the bridge abutment is more important than the horizontal displacement for highway ride quality, it is suggested that piles be used for constructing the abutments on soft soils.

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