Influence of high-strength geotextiles on load distribution in pile systems embedded in soft soil

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ABSTRACT

The application of small cross-sectional concrete piles for ground improvement in soft soil areas - particularly in warehouses and factory buildings - has long been applied in construction practice in Vietnam. The effectiveness of this technique is significantly enhanced by the inclusion of high-strength geotextiles positioned atop the pile heads, facilitating improved load transfer and stress distribution. Despite its practical advantages, a comprehensive understanding of the working mechanism, load-transfer behavior, and optimal design of this combined system remains limited in the current literature. This paper presents a detailed analysis based on existing analytical formulas and employs the finite element method for validation. The results of the study demonstrate that replacing the concrete load transfer platform with a geotextile layer maintains effective stress distribution while achieving a substantial cost reduction of approximately 46%.

1. Introduction

With the rapid pace of urbanization, infrastructure development projects have been extensively implemented across Vietnam. However, due to geological characteristics (particularly in the southern regions), the subsoil in many areas consists predominantly of young alluvial deposits, resulting in relatively weak ground conditions. Constructing structures on such soft soil presents significant challenges, requiring high stability and often incurring substantial costs. Consequently, various ground improvement methods have been studied and applied to enhance bearing capacity and reduce settlement in soft ground conditions. Among these methods, the use of small cross-section piles in combination with high-strength geosynthetic reinforcements has been widely adopted in the construction of factories and warehouses, especially in riverbank areas. One critical aspect of this method is load distribution: ideally, the majority of the structural load should be transferred to the piles, while only a minor portion is borne by the soft subsoil, thereby minimizing settlement.

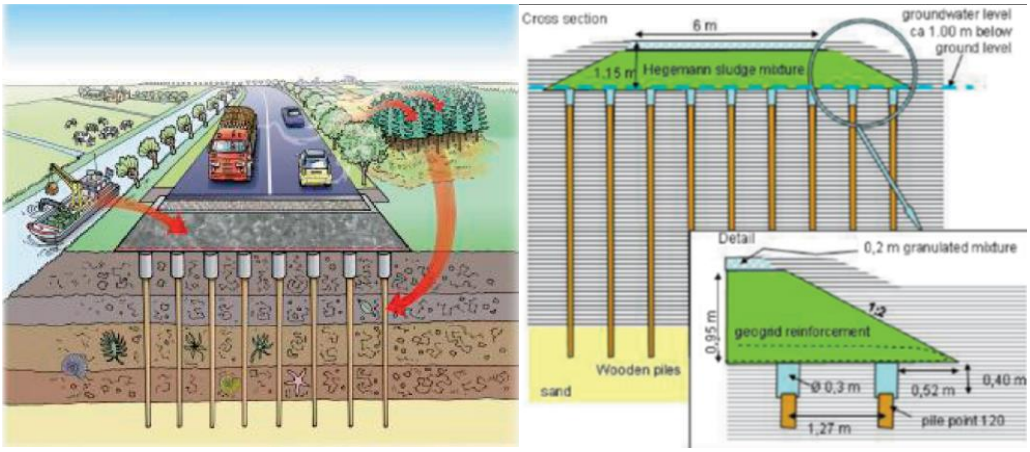
To achieve effective load transfer, a rigid load transfer platform (typically made of concrete) is often required on top of the piles. However, the high cost of such concrete layers necessitates the development of alternative solutions that maintain effective load distribution while reducing overall expenses. One such alternative is the use of high-strength geotextiles, which help distribute loads from the superstructure to the pile system, with the weak soil bearing

only a small portion of the load (Figure 1). When used in combination, an arching effect is generated, enhancing the efficiency of the system.

Nevertheless, the performance of high-strength geotextiles depends on multiple factors, including the tensile strength of the geotextile, the thickness of the cushion layer, the installation depth, the spacing and size of pile caps, and the geotechnical properties of the underlying soil layers. These influencing factors have not yet been fully clarified under current design and construction practices.

Figure 1

Small Cross-Section Piles Combined with Geotextile Reinforcement



Note. The data are from "Analytical model for arching in piled embankments" by S. J. M. Van Eekelen, A. Bezuijen, and A. F. van Tol, 2012, *Geotextiles and Geomembranes, 32*, pp. 11-23. (https://doi.org/10.1016/j.geotexmem. 2011.09.006)

Based on the aforementioned practical context, this paper aims to evaluate the performance of this combination through traditional analytical formulas and compare the results with those obtained from the finite element method as a basis for verification and assessment. At the same time, the study seeks to optimize the parameters of the method, recommendations for a more effective and rational.

2. Literature review

Over the past few decades, numerous studies worldwide have evaluated the effectiveness of small cross-section pile systems combined with geotextiles. Notably, Van Eekelen et al. (2012, 2015) conducted physical model tests in combination with numerical simulations. Their findings highlighted the crucial role of soil arching, emphasizing that the deflection of the high-strength geotextile layer significantly influences stress distribution between the piles and the surrounding soft soil.

Han and Gabr (2002), Mellings and Russel (2004) conducted finite element modeling to evaluate the effects of varying parameters such as the tensile strength of the geotextile layer, the spacing of small cross-section piles, and the height of the embankment load. Their research results indicated that both the strength and the placement of the geotextile layer significantly influence the load distribution behavior of the structure.

In addition, design standards from countries such as BS 8006 (British Standards Institution, 2010) and German Geotechnical Society (EBGEO, 2011) also address load distribution based on force equilibrium theory and the deflection behavior of high-strength

geotextile layers. However, these theoretical approaches remain relatively simplified and require further calibration through experimental studies and alternative numerical methods.

Below are several analytical formulas related to stress distribution:

- Terzaghi's Method (1943):

$$\sigma_s = \sigma_v\big|_{z=h} = \frac{s\gamma}{2K\tan\phi}\left[1-\exp\left(-2K\left(\frac{H}{s}\right)\tan\phi\right)\right]+q$$
$$\sigma_p = \frac{(s+a)(\gamma H+q)-\sigma_s s}{a} \quad (1)$$

- Low's Method (1994):

$$\sigma_s = \alpha\gamma\left\{\frac{(K_p-1)(1-\delta)(s+a)}{2(K_p-2)}+(1-\delta)^{K_p-1}\left[h-\frac{s+a}{2}-\frac{s+a}{2(K_p-2)}\right]+\alpha q\right\}$$
$$\sigma_p = \frac{(s+a)(H\gamma+q)-\sigma_s s}{a} \quad (2)$$

- According to the British design standard BS 8006 (British Standards Institution, 2010):

$$\sigma_s = \frac{(s+a)H\gamma-\sigma_p a}{s}$$
$$\sigma_p = \sigma_v^{'}\left[\frac{C_c a}{H}\right]^2 \quad (3)$$

Where:

$K_p = \frac{1+\sin\varphi}{1-\sin\varphi}$ with φ is the friction angle of the embankment material.

s: pile spacing.

a: pile diameter.

H: height of the embankment above.

$$\delta = \frac{a}{s+a}$$

α is the coefficient of soil pressure distribution on the subsoil = 0.8.

$$\sigma_v^{'} = \left(f_{fs}\gamma H + f_q q\right)$$

C_c: arching coefficient, determined based on tabulated values.

f_q and f_{ms}: partial factor for external loads, obtained from a reference table.

In Vietnam, research on the combination of geotextiles with small cross-section pile systems remains at a general level and continues to face several limitations. Nguyen (2014) and Tran (2016) employed the finite element method using Plaxis software to simulate the behavior of geotextile-reinforced soft soil improved with small-section piles. The results clearly

demonstrated a significant reduction in settlement when this combination was applied, highlighting the effectiveness of load transfer primarily to the piles. However, these studies did not provide a detailed description of the mechanisms by which the subsoil structure interacts with the overlying load components.

Recently, Le et al. (2020) published a study on ground improvement conditions in the Mekong Delta region, using Plaxis 3D to simulate the problem and subsequently proposing a stress concentration factor specific to this area. Do (2022) also conducted studies on stability when applying geotextiles; however, the research did not clearly address load distribution within the pile system.

In summary, current research in Vietnam still lacks in-depth studies to quantitatively evaluate the correlations between geotextile strength, placement configuration, and the resulting load distribution on soft subsoil and pile systems. Therefore, this paper aims to verify existing analytical formulas and compare them with numerical modeling results to provide a more comprehensive understanding of the behavior of such systems.

3. Methodology

In this section, the author uses the Thanh Luan factory project, located in Hiep Phuoc, Nha Be District, Ho Chi Minh City, as a case study. The finite element method (Plaxis 2D) is applied to evaluate the effectiveness of incorporating a high-strength geotextile layer in the foundation system.

3.1. Project description

The Thanh Luan factory project (Figure 2) was constructed and completed in 2018 in Hiep Phuoc Commune, Nha Be District, Ho Chi Minh City. The foundation soil in this area is weak, consisting of a soft clayey silt layer with a thickness of 30 to 35 meters. To minimize long-term settlement during the operation phase, the adopted foundation solution involved the use of 35-meter-long spun concrete piles with a diameter of 300mm (D300). The piles were installed with a center-to-center spacing of 08 meters and were topped with a 0.3-meter-thick reinforced concrete slab.

Figure 2

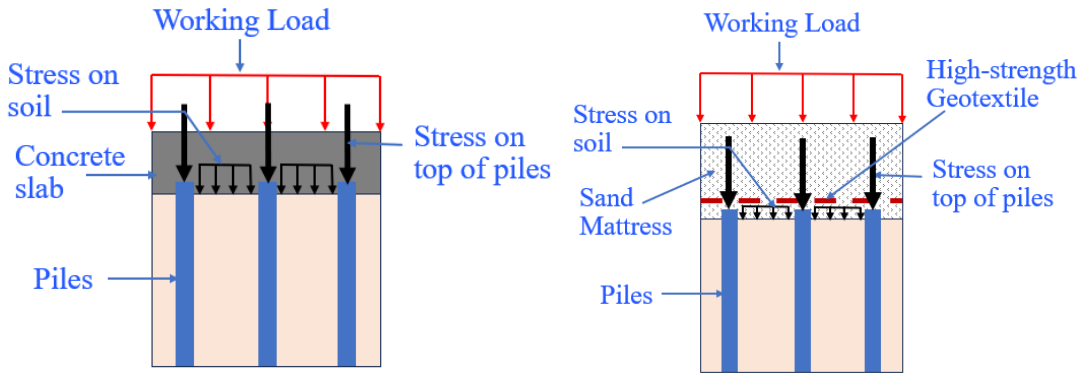
Thanh Luan Factory Project

Note. https://thanhluanco.com/

In this study, the author applies the finite element method using Plaxis 2D to simulate the actual conditions of the Thanh Luan factory project. The input parameters are standardized based on field monitoring data, particularly the measured settlement of the structure. A replacement solution is proposed in which the reinforced concrete surface layer is substituted with a sand cushion combined with a high-strength geotextile. Additionally, using the analytical formulas presented in the previous section, the results will be analyzed and evaluated in detail. Figure 3 below illustrates the two design alternatives examined in this paper.

Figure 3

Design Option (Left) and Proposed Solution (Right)



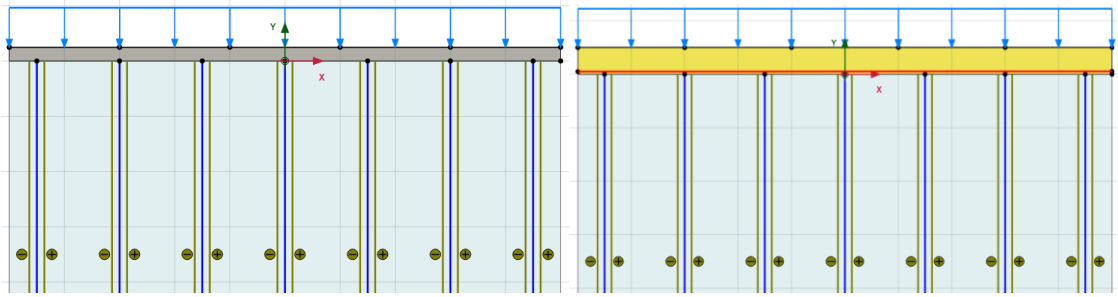
Note. Data analysis results of the research

3.2. Finite element analysis

The structural model was simulated using Plaxis 2D V20 software (Figure 4). The image on the left represents the actual construction scenario with a thick concrete slab placed on top of the pile system. The image on the right shows the simulation of the structure when incorporating a geotextile layer over the pile system.

Figure 4

Plaxis Model: Design Option (Left) and Proposed Solution (Right)



Note. Data analysis results of the research

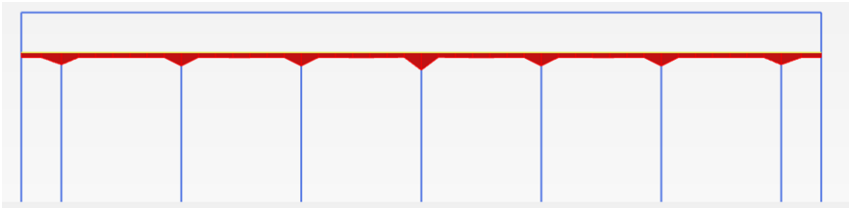
4. Result and discussion

4.1. Result

After calibrating the input parameters in Plaxis by comparing the simulated results of the initial design option with the actual field monitoring data (Figure 5), the author proceeded to simulate two alternative cases: one using a sand cushion to replace the concrete slab (Figure 6) and another using a sand cushion combined with a geotextile layer (Figure 7). The resulting stress distributions acting on the piles and the subsoil are illustrated in the figures below.

Figure 5

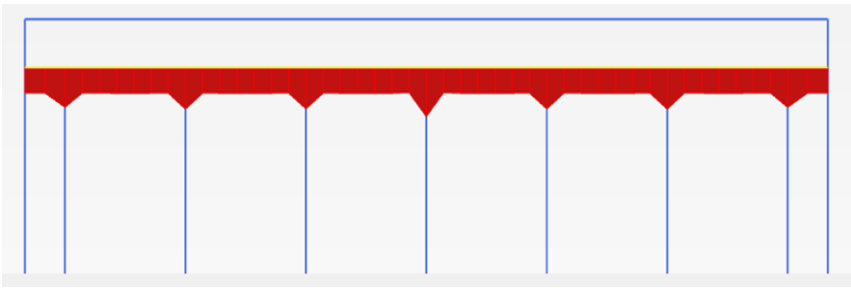
Stress on Piles and Subsoil in the Case of the Original Design with a Concrete Slab



Note. Data analysis results of the research

Figure 6

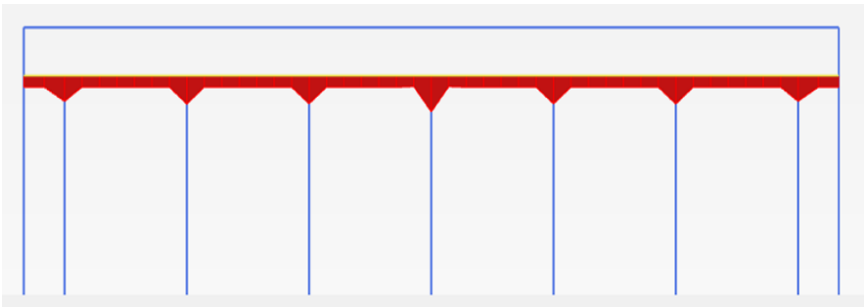
Stress on Piles and Subsoil in the Case Using a Sand Cushion



Note. Data analysis results of the research

Figure 7

Stress on Piles and Subsoil with Sand Cushion and High-Strength Geotextile



Note. Data analysis results of the research

The detailed comparison results from the finite element analysis are presented in Table 1 below.

Table 1

Results of Applied Stresses in The Evaluated Scenarios

	Piles + Concrete Slab (kN/m²)	**Piles + Sand Cushion (kN/m²)**	**Piles + Sand Cushion + High-Strength Geotextile (kN/m²)**
Stress on piles	75.2	43.7	68.1
Stress on the subsoil	12.3	32.5	20.2

Note. Data analysis results of the research

In addition, the author conducted a preliminary cost analysis comparing the original design option and the proposed solution. Details are presented in Table 2.

Table 2

Results of Cost Comparison

Work Item Description	*Unit*	*D300 Concrete Piles + High-Strength Geotextile*			*D300 Concrete Piles + Concrete Slab*		
		Quantity	*Unit Price (VND)*	*Total cost (million VND)*	*Quantity*	*Unit Price*	*Total cost (million VND)*
Thickness of sand cushion/concrete slab	m	1			0.5		
Volume of sand cushion/concrete slab	m^3	20,000	300,000	6,000	10,000	1,200,000	12,000
Geotextile	m^2	20,000	22,000	440			
Total Cost				**6,440**			**12,000**

Note. Data analysis results of the research

4.2. Discussion

- The stress concentration factor for the original design option is **6.11**. This value is relatively high compared to previous studies, which typically report factors ranging from 2 to 4. This indicates that the original design option is highly effective at reducing residual settlement during the operational phase.

- The stress concentration factor for the proposed option is **3.37**. Although this value is lower than that of the original design, it still falls within the range recommended by earlier research.

- The stress concentration factors for the sand cushion option with and without geotextile are **3.37** and **1.34**, respectively.

- The cost difference between the original design and the proposed research option amounts to 5,560,000,000VND, representing a reduction of 46.3%.

5. Conclusions and recommendations

The key findings derived from this research are summarized as follows:

- The original design option, which incorporates a rigid reinforced concrete slab on a pile foundation, proves to be quite effective in reducing residual settlement during operation, as indicated by a stress concentration factor of 6.11.

- Although the proposed research option is less effective than the original design in this regard, it still ensures structural safety. It meets the residual settlement requirements with a stress concentration factor of 3.37. Moreover, a significant advantage of the proposed option is its considerable cost savings compared to the original design, highlighting the optimization achieved by the proposed method.

- The effectiveness of the high-strength geotextile layer in stress distribution is clearly demonstrated by comparing cases with and without the geotextile. Therefore, it is recommended to apply a high-strength geotextile layer in similar cases to enhance the efficiency of the foundation system.

- Future research directions may include comparing different geotextile placement configurations and investigating the use of multiple geotextile layers further to improve the effectiveness of the combined foundation method.

SCIENTIFIC CONTRIBUTION

The manuscript clearly identifies a research gap; the manuscript extends or refines existing theories; the manuscript introduces or improves research methods; the manuscript presents statistically and practically significant findings; the manuscript opens new directions for further research.

AUTHOR CONTRIBUTIONS

CRediT: **Vo Nguyen Phu Huan**: Conceptualization, Methodology, Validation, Formal Analysis, Resources, Data Curation, Writing - Original Draft, Supervision, Project Administration; **Phan Tran Thanh An**: Software, Validation, Formal Analysis, Data Curation, Writing - Review & Editing; **Hoang Van Dung**: Software, Validation, Formal Analysis, Data Curation, Writing - Review & Editing; **Bui Thi Hong Phuoc**: Software, Validation, Formal Analysis, Data Curation, Writing - Review & Editing; **Luu Quang Cong**: Software, Validation, Formal Analysis, Data Curation, Writing - Review & Editing.

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NO CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

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