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Improvement of an existing building shallow foundation using soil nails supported retaining wall: A numerical assessment

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Abstract. In recent years, the need to expand the land area for infrastructure development, such as roads and streets near residential buildings, in urban areas in Vietnam has become more widespread. Such tendency leads to narrowing of the space available for further development thus the ground condition around existing buildings often need improvement. The foundations of existing buildings can no longer bear additional stresses. In such cases the foundation and the ground conditions need engineering solutions to provide geotechnical safety. The present paper presnts a numerical anlyses of soil nailing, to enhance the stability of the foundation of an existing building constructed on firm clay soil. The finite element method was empolyed to compute the stability of the foundation with/without incorporating soil nail reinforcements. Additionally, the analyses concern also the retaining wall construction to assure long-term performance of proposed scenarios. The numerical computation results indicate that the stability of the foundation improved by soil nailing was not enough to meet the ultimate limit state. The combination of a retaining wall supported by soil nails increased the factor of safety to a value considered sufficient. The settlements, as well as the horizontal displacements analyses proved the correctness of proposed solutions.

1 Introduction

Most common infrastructures development all around the world concerns real-estate structures. Land expansion in densely populated areas is a usual practice nowadays. However, in some cases the space is constrained and restricted. Such circumstances result in foundation design challenges [1]. For newly constructed buildings usually deep foundation design is considered. However, for existing structures foundation ground improvement methods are required to be implemented [2]. Placing reinforcing layers in the soil mass beneath a shallow foundation, such as geotextiles and geogrids, is one of the extensively employed conventional improvement approaches. However, these techniques are recommended for embankment type structures [3–5]. The reason is theyare difficult to install within the soil profile beneath the foundation or in a natural soil slope. A construction method

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called soil nailing allows for overcoming such limitations. Geotextiles and geogrids are not considered to be suitable for re-engineering works on new or existing soil slopes as well as for the remedial treatment of unstable natural soil slopes [6, 7]. The procedure involves inserting relatively thin reinforcing elements into the soil, frequently rebar for general use, though there are also specialized solid or hollow-system bars available. Hollow bars can be drilled and grouted by using a sacrificial drill and the grout is injected through the hollow bar as drilling continues. The solid bars, are typically inserted into pre-drilled holes and then grouted into place using a separate grout pipe. Bearing that in mind the paper aims to numerically evaluate the effectiveness of the use of soil nailing technique to improve the ground condition of an existing building constructed on firm clay soil.

2 Presentation of case study

The case study was carried out on a multi-story building located in Bai Chay ward, Ha Long City, next to Ha Long Bay (one of the new 7 natural wonders of the world on 11/11/2011), in Quang Ninh province (located in the North-East of Vietnam). The building's initial height was 9,0 m when it was built in 1999. Later an additional floor was built, making the structure 12,0 m tall. Furthermore, due to the need to enlarge the land area for regional infrastructure developement, the study building's foundation was required to be lowered to 2.5m from its existing level.
More importantly, the surrounding area must be narrowed, thus such demanding conditions lead to the constructing a retaining wall acting as boundary foundation beneath the footings. Figure 1 presents the case-study conditions.

Fig. 1. The study building

2.1 Ground conditions

Two boreholes nearby the building, namely BH1 and BH2, were conducted for soil investigation purposes, to obtained required information for the design and computations of the boundary foundation. The depth of the boreholes was 16.5m from the original ground surface. The distance and location of the two boreholes are shown in Figure 2.
Figure 3 shows the soil profile below the study building. A medium clay soil layer was distinguished of average thickness of 13.1m below the footing. The SPT (standard penetration test) value of the layer is of 6-8. Underneath the medium clay layer is the completely weathered rock deposits which has the RQD (Rock Quality Designation) value less than 10%, the thickness of the layer was about 3.5m.

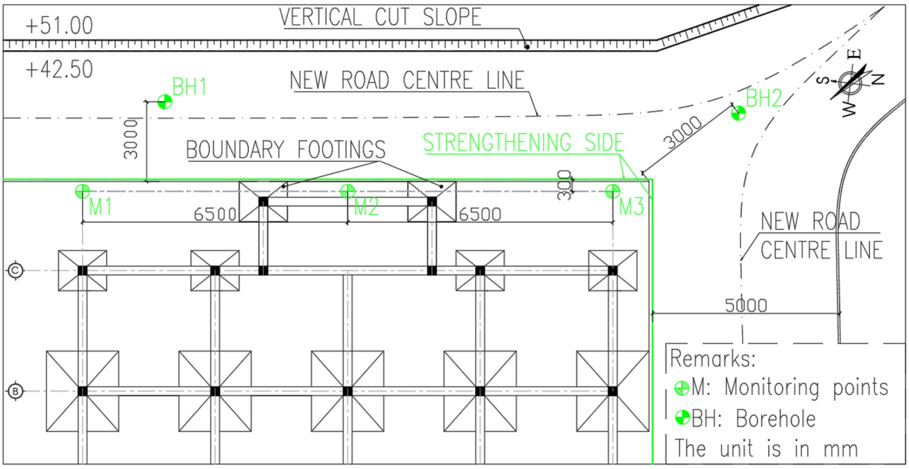


Fig. 2. Plan view of the borehole and total station instrument location

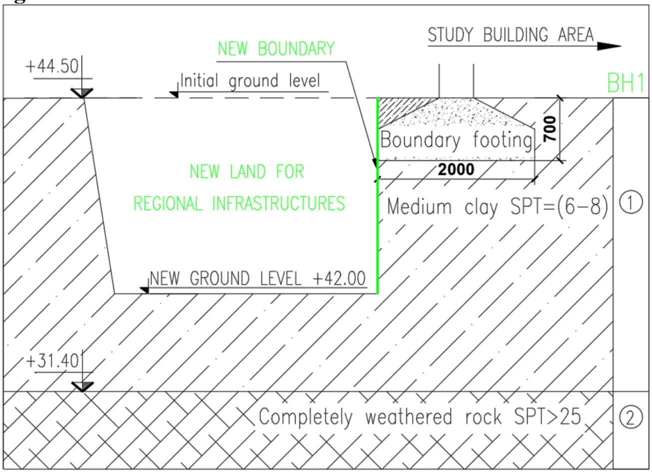


Fig. 3. Cross sectional ground profile

Table 1 summaries the physical and mechanical properties of medium stiff clay soil layer

Table 1. Physical and mechanical properties of medium stiff clay soil

Descriptions	Units	Layer 1
Dry unit weight	kN/m^3	17.5
Saturated unit weight	kN/m^3	18.6
Void ratio	-	0.62
Cohesion	kPa	24.4
Frictional angle	Degree	26.3
Undrained shear strength	kPa	40
SPT_N30	-	6-8
Elastic Modulus	N/mm^2	25

2.2 Strengthening approach and construction methodology

2.2.1 Strengthening approach

One of the major challenges of the present case study was to propose appropriated method to improve the geotechnical safety of the structure, considering the demanding conditions at the site. Due to limited space the improvement methods would include construction of the concrete retaining wall reinforced by the use of two rows of soil nails, in which design diameter of nail elements as well as drilled holes were 25 and 90mm, respectively. The spacing of soil nail elements was 1.0m (in both vertical and longitudinal direction). Details of strengthening elements are presented in Figure 4. This method was aimed to eliminate the potential deformation of the subsoil at the foundation level providing geotechnical safety in terms of ultimate and serviceability limit state. The challenging part however is the execution of the earthworks.

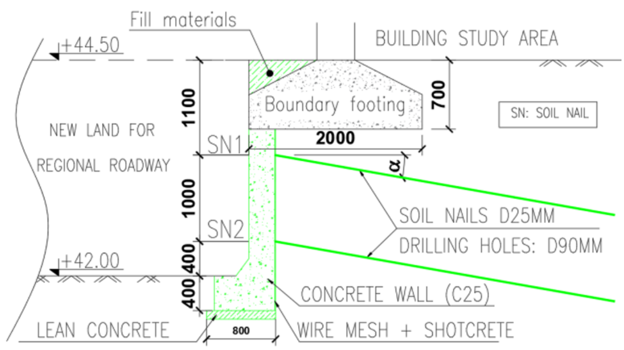


Fig. 4. Strengthening approach for boundary foundation

2.2.2 Construction methodology

As required for a new roadway construction project, the original ground surface was excavated and expanded. This made the boundary of the new road approaching the edge to the foundation of the study building. Thus, to ensure the safety as well as to limit large deformation during the excavation, the construction methodology need to be performed in steps, by excavating the soil layer of maximum 1m thickness, followed by installation of soil nails, at desired depth. Only then the retaining wall can be completed at the designed level of +42.00. Details of construction method is listed as follows:

Step 1: *Excavation from ground level to the first soil nail's, says SN1. Install the SN1.*
Step 2: *Excavation of the second layer and install SN2.*
Step 3: *Excavation of the final soil layer; wire mesh installation, application of shotcrete layer.*
Step 4: *Construction of the concrete wall.*

2.3 Finite element evaluation

Plaxis-2D geotechnical finite element (FE) analysis software was used in this study. The model consited of 15-noded a triangular elements allowing to assess the performance and stability of the foundation at the boundary of the building before and after the excavation. The material parameters of structural elements including soil nail, retaining concrete wall (RC wall), footing are summarized in Table 2..

Table 2. Input structural parameter for FEM

Descriptions	Material types	Normal stiffness, EA	Flexural rigidity, EI	Notes
Grout		Compressive strength: 40 MPa		
Soil nail element	*Elastic / Geogrid*	*2.20E+6*	-	
RC wall, t=300mm	*Elastic / Plate*	*9.0E+6*	*6.75E+4*	
Footing	*Elastic / Plate*	*2.5E+7*	*5.5E+5*	
Shotcrete, t=100mm		*2.1E+6*	*1750*	[8]

2.3.1 Performance analysis

According to the design requirements, the allowable bearing capacity of the foundation for the building after restoration must not exceed 300 kPa. To ensure the strengthening method meets this requirement, the load bearing capacity of the foundation was examined using both analytical (based on the well-known theory proposed by Terzaghi [9]) and finite element methods. Firstly, the analytical analysis was employed to estimate the bearing capacity of original foundation, afterwards the FE method was used to compute the bearing capacity of reinforced foundation under different strengthening methods. Details of the computed values are shown in Figure 5. It is shown that after the excavation without strengthening, the load bearing capacity of was significantly lower from its initial value, from 831 kPa it dropped to 46 kPa. However, the bearing capacity was notably increased as the soil nail elements were installed together with RC wall. The final value was 872.5 kPa.

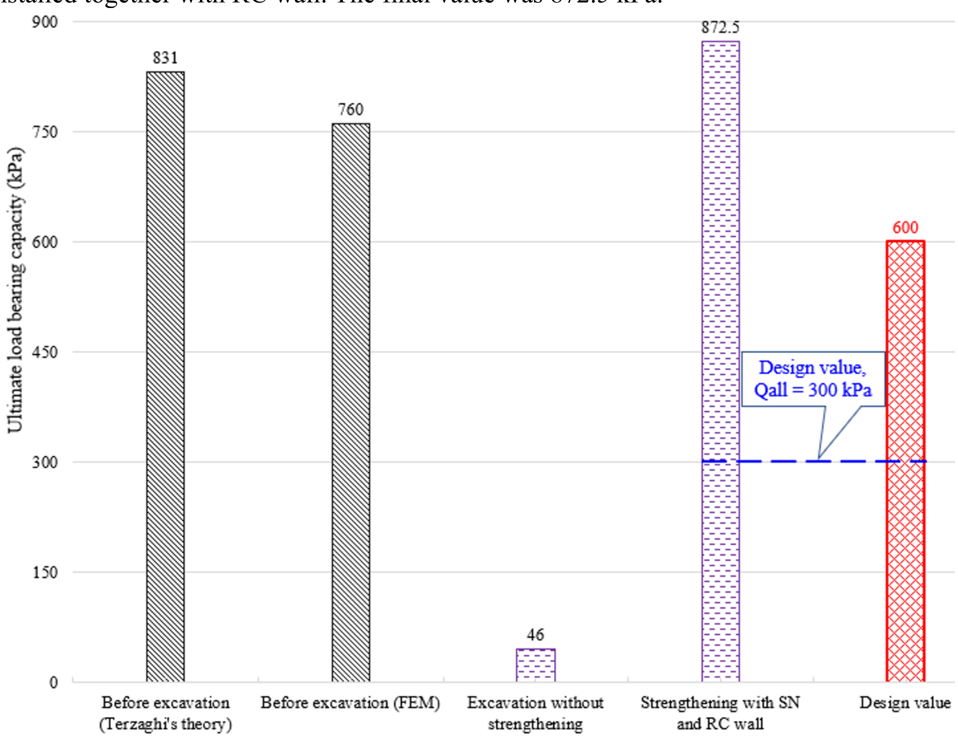
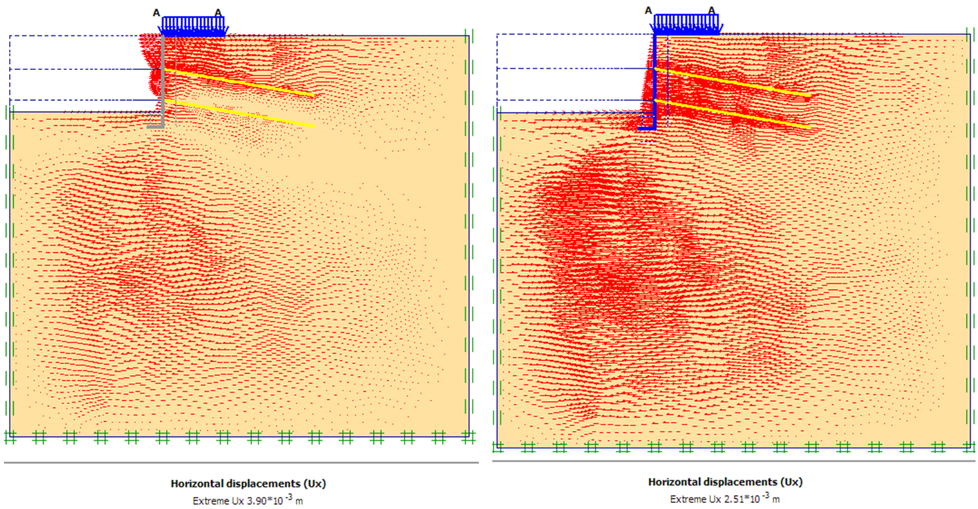


Fig. 5. Change in bearing capacity of boundary foundation under different scenarios

The significant improvement of load bearing capacity when soil nail elements were installed together with RC wall, could be related to the “confining effect” [10and9]. The construction of RC wall near to the boundary footing could contribute to better confinement of the soil beneath the footing, so the horizontal displacement of soil is restricted thereby the load carry capacity enhances and deformations decreases, what is presented in terms of lateral displacement in Figure 6. Analysis with those two scenarios (without and with RC wall), the maximum lateral movements of soil along the boundary wall when subjected to the same value of distributed load of 50 kN/m^2 , were 3.9 mm, and 2.51 mm, respectively.



(a) only soil nail elements installed *(b) soil nail elements with RC wall*

Fig. 6. Lateral movement of soil along the boundary wall

2.3.2 Stability analysis

Safety analysis in Plaxis, called Phi-c reduction method, was employed to examine the stability of boundary foundation. As per design requirements, there were two values of factor of safety (FOS), one was used for the construction stage, value of 1.2, and the other applied for the each structural element of the building required FOS no less than 2.0.

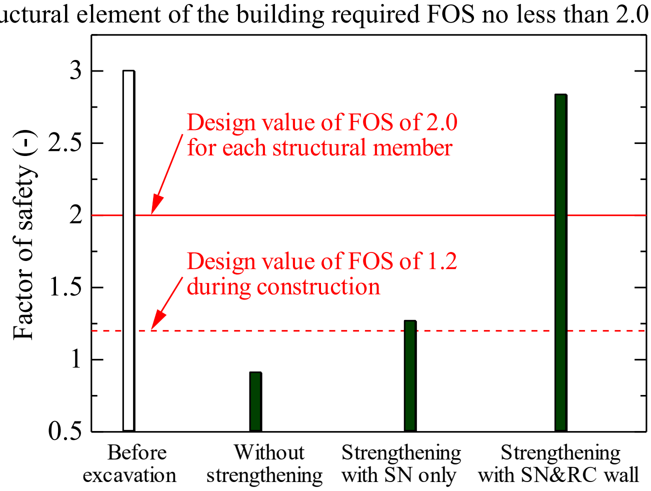


Fig. 7. Stability analysis results of the boundary foundation of the study building

The numerical results shown in Figure 7 indicate that the FOS significantly decreases after the soil around the study building is narrowed, from its initial value of 3.0 to 0.89, thus the foundation needs strengthening. As the soil nail elements installed during excavation, the FOS was larger than the required value. Performing safety analysis for another strengthening scenario, in which the soil nail element was installed together with RC wall. The numerical computation results show that the FOS obtained from this strengthening method was 2.9, which is larger than the design value of 2.0.

The increase in the factor of safety as soil nail elements and RC wall installed is due to the improvement of the ground conditions, the stresses are transferred to structural elements. As can be seen from figure 8 by installing both the soil nails and RC wall, the shear plane extends and although shear strength resisting forces are mobilized along it. Consequently a higher stability is gained since the FOS is the ratio of shear strength to actual shear stress.

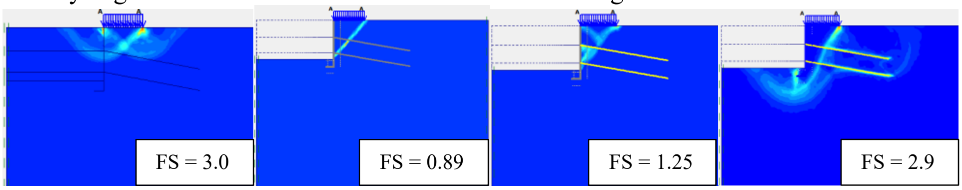


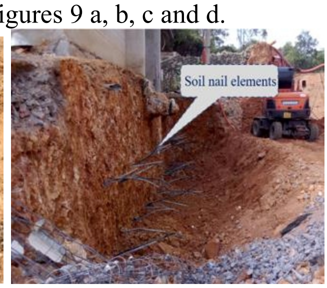
Fig. 8. The change in failure shear plans for different analysis scenarios

2.4 Applying the strengthening approach in the study building

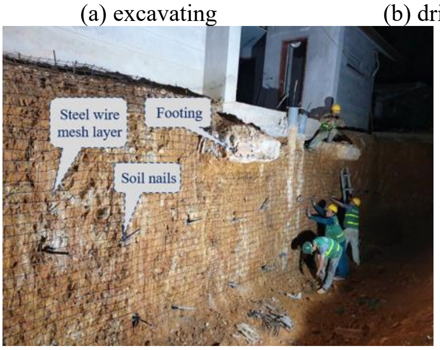
Based on the numerical evaluation of the strengthening method, the strengthening design was applied to the study building in the field as shown in figures 9 a, b, c and d.

(a) excavating

(b) drilling and grouting



(c) soil nail installation



(d) steel wire mesh

(e) the build was stable after foundation lowered and narrowed

Fig. 9. Applying the strengthening design method in the study building

To evaluate stability of the building after its original ground was excavated, three total stations were were installed at the top of the wall to record absolute the settlement of the wall as shown in figure 2. The monitoring activity was executed after all the temporary support structures including soil nail element, wire mesh, and shotcrete layer were completely placed. The equipment used in for settlement measurement was the precision leveling machine, namely Leica NAK2 Automatic Level. Figure 10 presents the 2-week settlement monitoring results obtained from 3 points, they were M1, M2, and M3. The results shows that the settlement of the foundation was significantly decreased after 3 days of RC construction, the maximum value of setlement was found at the point M2. The recorded monitoring data also indicated the effect of rainy event on the settlement, to wit, the settlement was found to be increased during two rainy days.

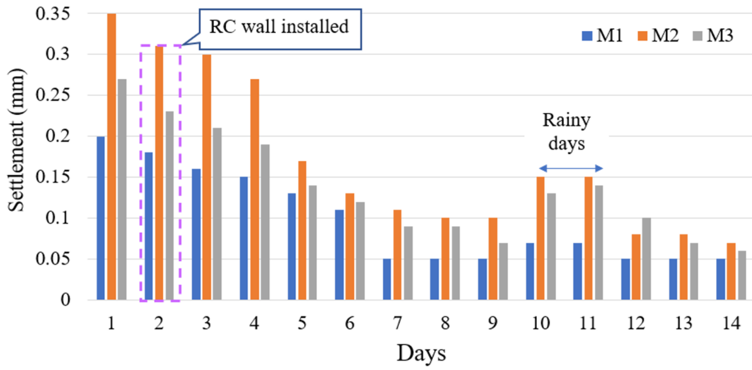


Fig. 10. 2-week settlement monitoring results

3 Conclusions

The paper presents an actual case study on the use of soil nailing technique for strengthening a boundary foundation of existing building placing on the firm stiff clay soil. Results obtained from both numerical analysis and monitoring data indicate the effectiveness of the soil nails and RC in improving the stability as well as in enhancing the load carrying capacity of foundation.

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