A case study of the improvement of an old building’s shallow foundation resting on sandy clay soil using cement slurry grouting technique

Bui Van Duc[1,2*], *Pham* Duc Tho[1,2], *Nguyen* Duc Chieu[3], *Somjai* Yubonchit[4]

[1]Faculty of Civil Engineering, Hanoi University of Mining and Geology, Hanoi, Vietnam;
[2]Geotechnical Engineering, Construction Materials, and Sustainability Research Group, Hanoi University of Mining and Geology, Hanoi, Vietnam
[3]Transport engineering consultant international joint stock company, Tu Liem South, Hanoi, Vietnam
[4]School of Civil Engineering, Rajamangala University of Technology Isan 744 Sura Narai Road, Muang District, Nakhon Ratchasima 30000 Thailand

Abstract. The need to rebuild and upgrade old structures has grown in recent years, particularly in large urban areas. These renovation and upgrade activities frequently affect the structural load of the building, eventually increasing the loads acting on the foundation. This paper illustrates a case study in which the cement grouting method was used to improve the load-carrying capability of an old structure's foundation. The influence of various key variables of the cement grouting method, such as the diameter, length, and angle of inclination of the mortar pile, was also assessed using the finite element (FE) method, Plaxis 2D. Finally, the optimum parameters for the strengthening method used in the study building were chosen based on the FE analysis results of the improvement of the bearing capacity of the foundation using the cement slurry grouting method.

1 Introduction

Recently, developing countries such as Vietnam have seen a growth in the demand to rebuild and improve existing structures in metropolitan areas, particularly in places with a high level of population density. Building reshaping and remodeling frequently cause the structure load to alter, necessitating the redesign of the foundation structure. Some of the fundamental characteristics of old buildings include limited construction space, decreased structural durability after many years of usage, and a high degree of influence on the stability of nearby structures. Because of these common characteristics, the foundation reinforcement solution must be carefully assessed and implemented. There have been several techniques employed to strengthen the old foundation, such as underpinning methods (all of these methods are based on the same concept of extending the current foundation either lengthwise or widthwise and laying it atop a stronger soil layer), vibro stone columns, use of cement and lime, grouting

* Corresponding author: buivanduc@humg.edu.vn

techniques., etc [1], [2]. Among these methods, grouting methods such as compaction grouting, slurry grouting, and chemical grouting have gained a lot of interest in recent years because of its simplicity of construction, economic rationality, and better geotechnical properties [3], [4]. Despite the fact that chemical grout has changeable gel time, high permeation, and flexibility after solidification, it is not widely used due to its high cost, low solid strength, and low durability [5], additionally, this grouting technique may cause harm to the environment. Compaction grouting is a ground improvement technique that involves injecting low mobility grout into the ground to densify the soil mass, however, throughout liturature review, the compaction grouting has been mainly utilized to lift structures since this grouting technique could induces heaving effects, resulting in threatening the stability of the structural elements of the existing building. Slurry grouting, also known as cement grouting, is a technique that includes injecting neat cement grout in varied amounts into soil or rock to improve the in-situ material's characteristics such as cohesion value [6]. The slurry grouting is widely recognized as one of the most common grouting techniques due to their low cost, diverse raw material sources, and compatibility with the environment [7]. However, research into the impact of various factors on the effectiveness of strengthening the load carrying capacity of reinforced foundations with cement grouting is still limited. This paper delivers a case study on the use of cement slurry grouting techniques to improve bearing capacity of existing shallow foundations resting on sandy clay soil.

2 Case study presentation

The actual case study was conducted on a building with multiple floors located in Ngoc Khanh Street, Ba Dinh district, Hanoi city, Vietnam. The building was constructed more than 20 years ago, and its primary function was to provide workspace for a number of government agencies. However, in order to continue to be used, the building must be strengthened and renovated, which leads to the structural loads acting on the existing foundation to change. According to the scenario described in the new design, the foundation's necessary load capacity rises from 220 kPa to around 260 kPa. The existing foundation of the building employs isolated footings with dimensions of 2x2m, an average distance between footings of 4m, and a depth of around 2m in comparison to natural ground. Figure 1 depicts the actual image of the research building.

Fig. 1. The study building before renovated

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2.1 Ground conditions

Three boreholes inside the building, namely BH1, BH2 and BH3, were conducted for soil investigation. The depth of the boreholes was 20m from ground level. Details of location of boreholes are depicted in figure 2. Based on the boreholes' profile, the subsurface layer in the studied area consists of a sandy clay layer (medium to soft clay), and a stiff to midum clay layer. The average thickness of sandy clay layer from the surface is 10.0m.

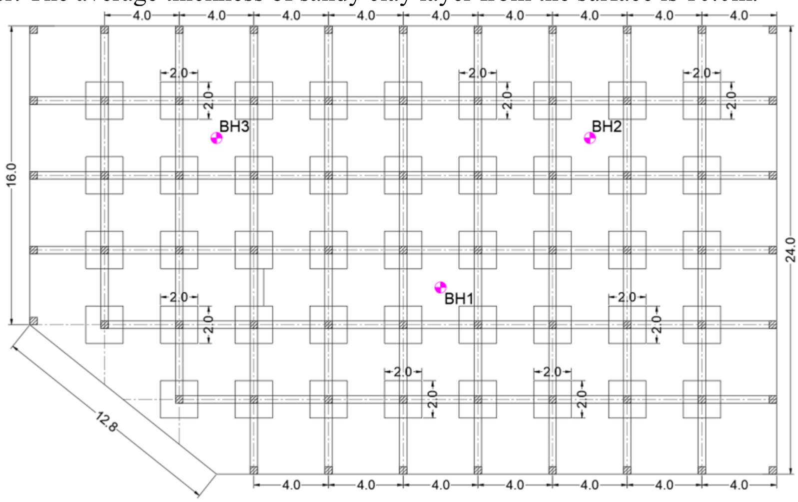


Fig. 2. Plan view of foundation and location of boreholes

The results of soil particle size analyses for sandy clay and clay soil layers are shown in Table 1. Table 2 summarizes of the the physical and mechanical properties of soil layers used in this study. Parameters of the soil layers employed in this study are summarized in Table 2. As shown in tables 1 and 2, the first soil layer contains more than 50% sand particles and has a high void ratio of 1.2, these are considered favorable conditions for using the cement grout method [8]–[10].

Table 1. Particle size of soils

Soil particles	Units	Layer 1 (Sandy clay)	Layer 2 (medium to stiff clay)
Sand (0.075-2.0)	%	51.2	24.3
Silt (0.002-0.075)		21.5	14.4
Clay (<0.002mm)		27.3	61.3

Table 2. Subsurface properties of sandy clay soils

Descriptions	Units	Layer 1 (medium to soft)	Layer 2 (stiff to medium)
Dry unit weight	kN/m^3	12.1	15.4
Saturated unit weight	kN/m^3	17.3	18.9
Void ratio	-	1.2	0.85
Cohesion	kPa	15.2	16.7
Frictional angle	Degree	10.1	18.2
SPT_N30	-	6	10
Modulus of elasticity	MN/m^2	15	25

Figure 3 depicts the ground profile as well as average values of Atterberg Limits, such as limit liquid (LL), plastic limit (PL), and plasticity index (PI) at various depths.

Figure 3 also illustrates the variation in moisture content with depth. Specifically, the soil moisture found to decrease with depth and the moisture in the upper layer (sandy clay soil) was found to be higher than that in the lower one. This ground condition condition has a potential for settlement since the sandy clay layer is placed right below the footing. As a result, improving the existing ground is required to prevent future vertical settlement of the footing.

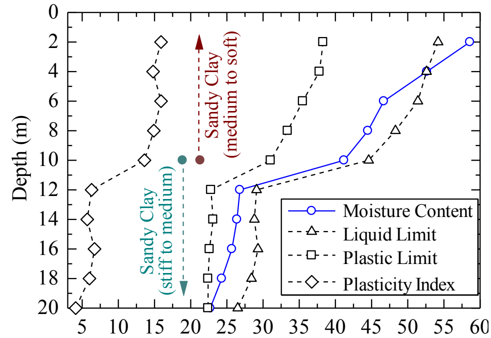


Fig. 3. Cross sectional ground profile

2.2 Improving design concept

Taking crucial conditions of the study building into account, the concept of ground improvement solution was designed based on two main approaches as follows: for the first approach, the construction activities of the design solution must not significantly affect the stability of the existing structures since all the structural elements of the study building were built in a long time ago. For the second approach, the solution needs to be able to enhance the bearing capacity of existing foundation. As mentioned in the Introduction section about the typical characteristics of as well as the advantages of slurry grouting technique, this grouting method could be satisfy those two main approaches.

However, detail of the slurry grouting method used for this study case needs to be examined, especially configuration of grouting system like grouted diameter (D), grouted length (L), inclination of grouted columns (α) as displayed in figure 4.

Regarding the inclination, James Warner (2004) [11] found that the use of inclined grouting could yield a larger horizontal area being projected to the ground surface, consequently causing more heave than vertical one, so as to prevent the existing footings from the negative effect of ground heave induced by heaving the lower values of 20^0 were examined. In addition, the top of the grouted column was set 0.5m lower than the depth of existing footing.

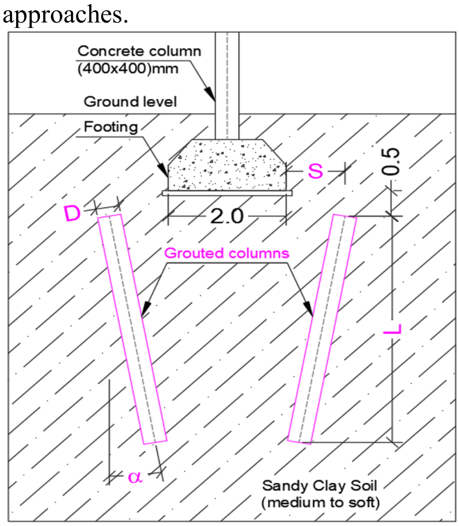
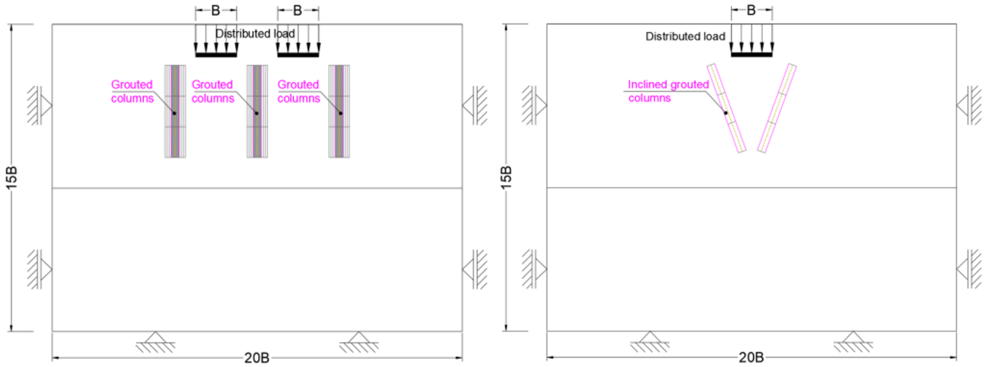


Fig. 4. The studied parameters

2.3 Finite element corroboration and analysis

Plaxis-2D geotechnical finite element (FE) analysis software was used to assess the suitability of the grouting method for enhancing the bearing capacity of the improved foundation as well as the effects of several paramters on the change in the load bearing capacity. The geometry of the standard finite element models used in the analysis is shown in figures 5 a and b. The model's left and right vertical lines are horizontally restricted, and the bottom horizontal boundary remains constrained in both directions as exhibited in figure 5. The material parameters of structural elements including footing, grouted column are summarized in table 3.



(a-vary the diameter and length of grouted column) (b-vary the inclination of grouted column)

Fig. 5. Schematic diagrams for numerical analysis

Acorrding to [6] the minimum value of undrained strength of grout should be no less than 42^0 for a better stability of reinforced ground, thus, the value of 42^0 was taken into consideration during finite element analysis. Typical values of stiffness parameters, such as E and poisson's ratio υ, of grout column were 30 MN/m^2, and 0.25, respectively.

Table 3. Values of the parameters describing the materials used in FEM

Parameters		Unit	Value
Grouting slurry (Grouted column)	W/C (in weight)		1/1
	Viscosity	mPa.s	25
	Unit weight	g/cm^3	1.9
	Uniaxial compressive strength	MPa	6.0
	Modulus of elasticity, E	MN/m^2	30
	Poisson's ratio	-	0.25
Footing	Elastic / Plate		EA=2.5E+7 EI=5.5E+5
	w	kN/m/m	25
	υ	-	0.15

2.3.1 Effect of grouted column diameter

As stated in previous section, the required value of the ultimate bearing capacity of foundation for the renovated building was no less than 260 kPa, however, the value derived through numerical estimation was only about 245 kPa as shown in figure 6.

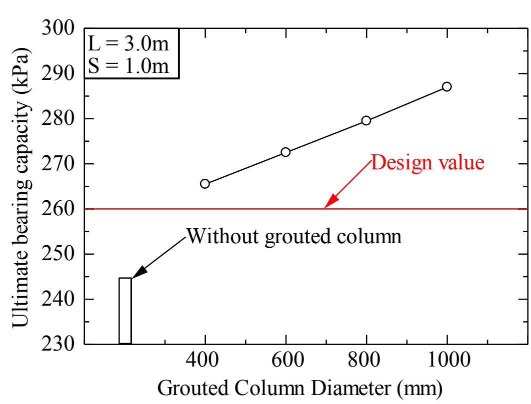


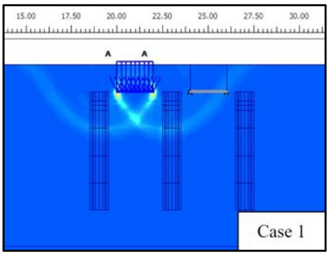
Fig. 6. Effects of grouted column diameter on the bearing capacity

Based on this first assesment result, a series of numerical computations were performed in order to determine the most appropriate solution for improving the foundation utilizing cement grouting. Firstly, the effect of grouted column diameter was examined.

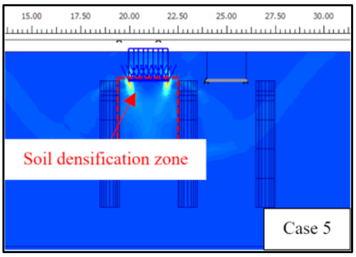
For this stage, five study scenarios were established, in which the diameter of grouted column was varied from a value of 400 mm to 1000 mm, whereas the other parameters such as length of grouted column, and the distance between grouted pile to the edge of footing were kept constant. Details of study scenarios are illustrated in table 4. The bearing capacity of the footing soil system is observed to increase as the grouted column increases. This is due to the placement of grouted columns along either side of loaded footing, specifically, constructing column beside the loaded footing reduces the subsequent tensile strain in the soil, and its primary role is to lower the distortion rate in the sheared zone and the ultimate shear stress generated in the shear zone. As a result, it facilitates the ability to enhance the bearing capacity of the footing soil system [12]. In addition, as the grouted column installed the lateral movement of the soil particles below the footing was restricted and the confining effect was created as clearly seen in figures 7 a, b.

Table 4. Study scenarios of effect of grouted column diameter

Contents	Descriptions	Remarks
Case 1	Without grouted column installed	
Case 2	Grouted column D400mm	L=3.0m S=1.0m *(S: distance from center of grouted column to edge of footing)*
Case 3	Grouted column D600mm	
Case 4	Grouted column D800mm	
Case 5	Grouted column D1000mm	



(a-without grouted column installed)



(b-with grouted column installed)

Fig. 6. Distribution of shear strains shading view

Figure 7 shows the distribution of plastic points. The result reveals that there are few plastic points between confined zone and they are mostly concentrated below the footing, implying that shear failure will occur outside the confined zone. Based on this finding, it is possible to conclude that both the confining formation and the grouted column can function as a single unit, with the bearing capacity failure plane induced at the uppermost point of this block.

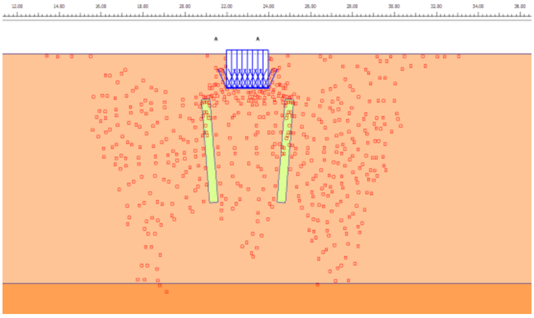


Fig. 7. Distribution of plastic points

2.3.2 Effect of grouted column length

To achieve the most benefit of the soil confinement effect, the depth of the grouted column should be sufficient to reach below the failure plane of the footing soil system. Figure 8 illustrates the relationship between L/B ratios and bearing capacity of improved footing soil system. Results obtained from different numerical computations shows that at L/B > 1.5 the magnitudes of the bearing capacity were found to be nearly identical. This finding proves that the use of short grouted columns provides only partial confinement to the soil.

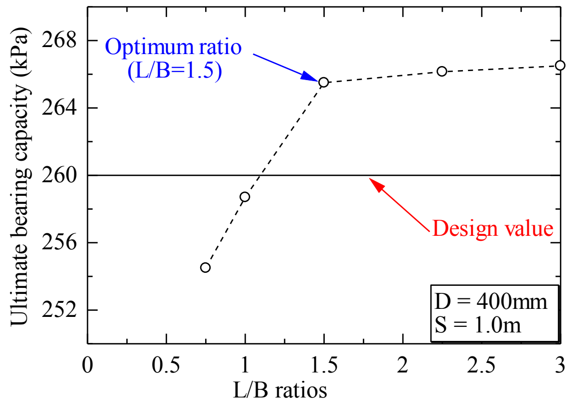


Fig. 8. Effect of length of grouted column

2.3.3 Effect of grouted column inclinations

Figure 9 presents the calculation results of bearing capacity of improved footing soil system at various values of grouted column inclinations. The maximum value of 20 degrees was taken into account as suggested by James Warner (2004) [11]. The results reveal that using angled grouted columns could result in a higher bearing capacity. This finding is similar to that found by [13]. In particular, for a weak ground, including soft soil, where the punching shear failure occurs, it is advisable to consider simply utilized the cross installation.

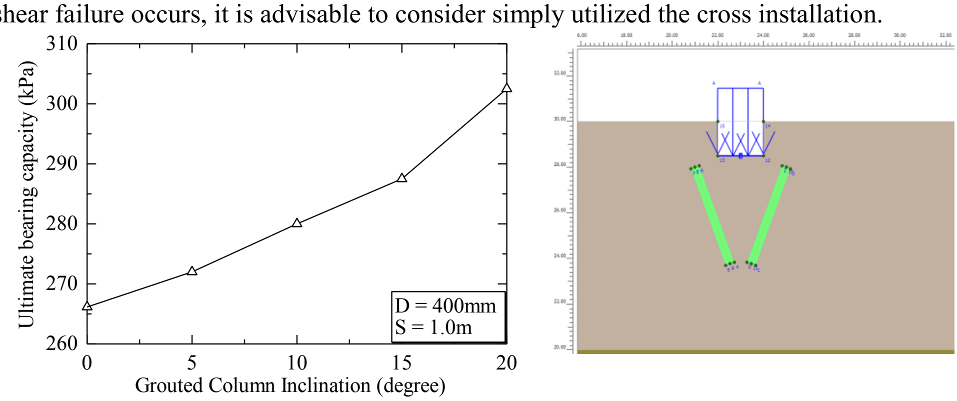


Fig. 9. Influence of grouted column inclinations on the bearing capacity of improved foundation

2.4 Construction methodology

Figure 10 illustrates the construction methodology for grouting. To specific, the final length of grouted column was devided into three equal parts (L/3). Grout injection was carried out at L/3m intervals between design depths, and then conducting progressively upward from the bottom. The grouting time used for the first and the second steps was set to be same value, say 10 mins. For the last part was longer, says 15 mins. There was a 10 to 15 minute break between each step for grout pipe raising. Details of grouting time as well as grouting pressure used for each step exhibits in figure 10. The lowest value of grouting pressure, 0.5 MPa, was used for the last part, this aim to prevent the footing from being affected by grouting pressure which could induce uplift force.

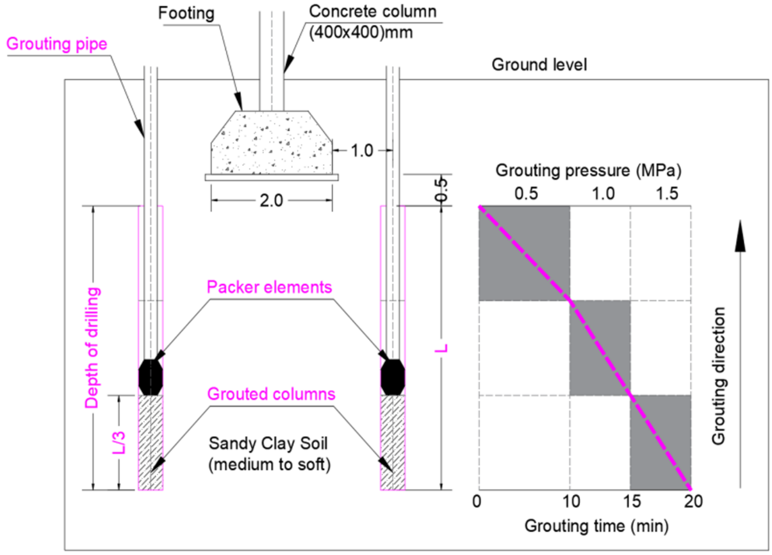


Fig. 10. Construction methodology for cement grouting

Figure 11 presents several photos that showing the grouting construction activities as well as some equipments used to improve the existing foundation of the study building.

(a) drilling the grouting hole

(b) packer element

(c) Portland cement

(d) grout mixing and pumping machine

Fig. 11. Applying the improving design method in the study building

3 Conclusions

The paper presents an actual case study on the use of cement grouting technique for enhancing bearing capacity of an existing footing soil system. The numerical analysis results show that the grouting approach is helpful in enhancing the load carrying capability of the foundation. Several aspects affecting the mechanical reactions of improved foundations, such as the diameter, length, and inclination of grouted columns, were investigated throughout this work. More study, including field monitoring and field assessment, is needed to enhance the findings on the efficiency of the cement grouting technique.

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