

Research Article

Method Cement Post-grouting to Increase the Load Capacity for Bored Pile

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Abstract: Drilled shafts foundations are used as an indispensable solution for long span bridges in Vietnam. In order to increase the bearing capacity, aside from the increasing of the pile length and diameter, an interested way now is treatment of pile bases after concrete placement. This study is aimed at investigating the defect at the bottom of the bored pile from the sonic test. The injection of high pressure of cement grout to the shaft and tip of the defected bored pile was conducted to increase the bearing capacity of pile. The bearing capacity of defected bored pile is calculated by the TCXD-205:1998 an finite element method. After post-grouting technique done, the soil investigation tests have been carried out to define the properties of treated soils. The analytic method, finite element method an load test also have been applied to determine the bearing capacity of treated bored pile. The results show that the post-grouting to the shaft and tip of pile can increase two times of bearing capacity of defected bored pile and about 20% compared to the normal bored pile.

Keywords: Bored pile, load capacity, post-grouting

INTRODUCTION

Nowadays construction demand is increasing, so the application of new technologies, including the construction of bored pile technology is an inevitable development to the construction industry. Bored pile technology is a ground stabilization measures to handle very high efficiency but great price. To reduce the cost of the pile is a big problem not only for researchers but also for designers, contractors and consultants supervision. So it is necessary to find a measure to increase the load capacity of the pile and reduce the number of pile. Axial load capacity in the land of the bored pile is the sum toe resistance of pile and load capacity around of pile. Normally, component the toe resistance of pile only be mobilized at a very low level. According to some experimental research, the bearing capacity around of bored pile can reach the maximum value at about 0.5-1% of the diameter D of the settlement, while the load capacity of bored pile only be mobilized fully reaching 10-15% of the diameter D of the settlement. The reason is that in the process of construction the ground under the bottom of the pile is disturbed so it needs a large settlement to mobilize the toe resistance of pile. Further more thick humus deposited at the bottom of the pile tip also contributed to this problem. This greatly reduces the bearing capacity of bored pile. The bottom deposit processing plays an important role in improving the bearing capacity of bored pile. In the world, the research into the technologies of handling cleaning the pile bottom and grouting bored pile bottom has been interested and

applied in many countries for along time (such as China, Taiwan, Thailand, etc.). The bored pile bottom can be handled by different methods, including Post-Grouting technology, it has many advantages and has been applied in many countries in the world. TCXD 205-1998 gives the Pile foundation - Design standards (build publisher, Vietnam) (In Vietnamese). TCVN 4787:2001 shows the cement methods of taking and preparing samples. Do *et al.* (2004) have a research of the bottom of the bored piles treatment technology, collection of scientific reports science and technology conference of transport 1999-2004.

TCXDVN 269-2002 study the static compression test experiments method (build publisher, vietnam) institute of science and technology transport : report results of static compression statement bored piles. Dapp *et al.* (2010) study the pos grouting drilled shaft tips principal investigator. Many research results show that Post-Grouting technology is an effectively technology to handle bored pile bottom, requirements for construction equipment are quite simple and construction process as well as quality control is not too complicated. However it needs to continue to conduct experiments to evaluate the increase load capacity of the pile bottom, due to the grouting to the soils as well as specific pressure pump, in order to improve the method of calculating the load capacity of pile handled by this technology. The application of pressure cement grouting solution to increase the load capacity of bored pile of 27 Lang Ha Condominium works is presented in this study.

In order to increase the bearing capacity, aside from the increasing of the pile length and diameter, an interested way now is treatment of pile bases after concrete placement. This study is aimed at investigating the defect at the bottom of the bored pile from the sonic test. The injection of high pressure of cement grout to the shaft and tip of the defected bored pile was conducted to increase the bearing capacity of pile. The bearing capacity of defected bored pile is calculated by the TCXD 205:1998 a finite element method. After post-grouting technique done, the soil investigation tests have been carried out to define the properties of treated soils. The analytic method, finite element method a load test also have been applied to determine the bearing capacity of treated bored pile. The results show that the post – grouting to the shaft and tip of pile can increase two times of bearing capacity of defected bored pile and about 20% compared to the normal bored pile.

THE CEMENT POST-GROUTING TECHNOLOGY INCREASING LOAD CAPACITY BORED PILE

Cement post-grouting technology is put a mixture of liquid grout into pores soil to strengthen the stability and increase load capacity. The grout liquid is cement grout, (mixture of cement and water), cement-soil grout (mixture of cement, soil, water), bentonite grout (mixture of bentonite and water). Cement grout is widely used and with water- cement ratio from 1/10 to 2/1. Cement grout (mixture of cement and water) was used in this construction.

The parameters of the cement spouting grout for post-grouting design: The main parameters of the spouting grout correspond to that criteria are standardized to evaluate and increase spouting grout quality include:

The density of grout: The optimized density grout depends on vibrations of grout at about 1.15-1.30T/m3 and is determined by the hydrometer.

Degree of viscosity: Determining the kinematic viscosity at work by using the 0.5 L conical hopper according to the European standard EN445, the standard of 0.5 L of grout flow speed is about 10-20 seconds, the maximum speed is 25 sec. The viscosity of water flow speed is approximately 13 sec.

Degree of water split: Is the ratio of the deposition of sediment mixture in static conditions after 1-3 h. Measurement method is pouring amount of grout into a glass bottle with carved bar length, for about 1-3 h, measure the height grout material deposited under water (h) and the total height of the grout+water (H). The maximum acceptable water split index (H-h)/H is about 3% to 5%. The water absorption index is the ability to split water after 2 h.

Intensity and setting period time: Grout blocks are gradually agglomerated after at least 3 days and increased intensity to maximum stable status after about 15-30 days. After a certain number of days, grout block will be drilled to obtain grout bar for intensity testing. Minimum grout intensity after 7 days is about 0.25-0.4 kG/cm2.

Selecting the appropriate spouting grout is the first step in the design of spouting grout technology, based on the density mass of grout in the ability to penetrate the grout; it mainly depends on the concentration of grout.

The mixture concentration of water and cement is determined:

$$W / C = \frac{r_w(r_s - r_c)}{r_c(r_w - r_s)} \quad (1)$$

where,

W/C : The concentration of water and cement

r_w : The proportion of water

r_s : The proportion of mixture

r_c : Mass density of cement

The density of cement block is determined:

$$f = \frac{1}{1 + \frac{r_c(W/C)}{r_w}} \quad (2)$$

Theory and the fact show that the ratio W/C = 0.67-: -0.7 corresponding 30% density of cement block, that is optimal concentration, optimal feature and the best filled feature grout.

Post-grouting process is performed by the following stages:

- Constructing bored pile with the nowadays commonly used technology is grout spouting technology
 - Attached to the steel cage at least 2 bottom sealed steel pipe D90, symmetry through the center, along the length of the pile, 10-20cm distance from the bottom of pile
 - The bottom of the pile spouting grout structure; after installing steel cages conducting concrete bored piles
- Drilling the bottom hole of two D90 steel pipes to soil under the pile tip
- Pumping high pressure water with 80-200 bar to wash bottom of the pile until the ejected water is as fresh as pumped water (Fig. 1)

Step post grouting to reinforced the bottom of pile (Fig. 2)

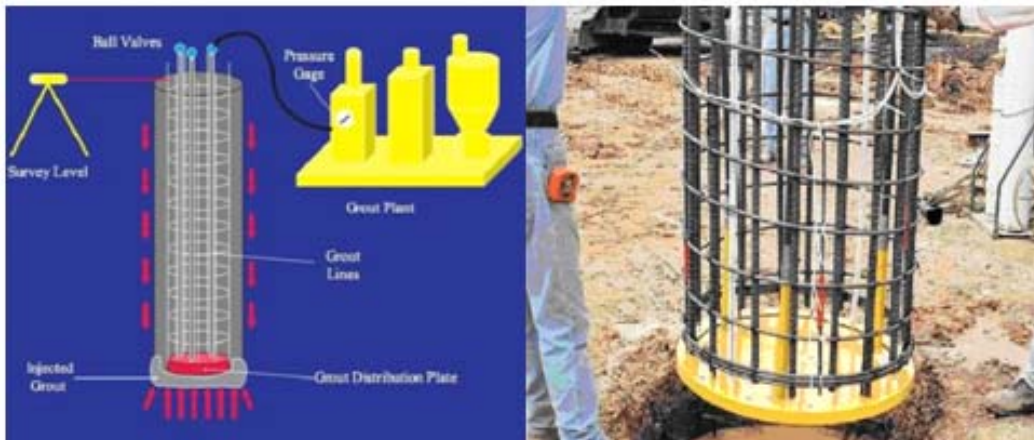


Fig. 1: Diagram of post grouting and installing steel cage with the tubes fixed in the bored pile

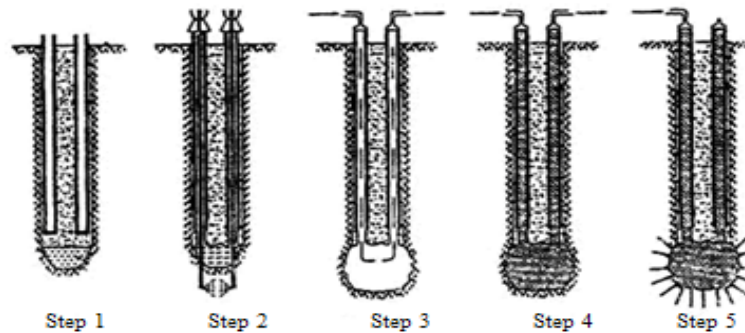


Fig. 2: The process of cement post-grouting to the bottom of pile Step 1: Constructing bored piles with steel pipe in place Step 2: Drilling the bottom of steel pile fixed in the bored pile Step 3: Used high pressure water to wash the bottom of bored pile Step 4: Spouting cement grout to the bottom of bored pile Step 5: Sealed one of the steel pile, continue to pump and hold high pressure

Table 1: Engineering geological characteristic

Layer	Type of soil	Soil Depth (m)	Unit Weight (kN/m ³)	Cohesion C' (kN/m ²)	Angle of friction (degree)	Deformation modulus(kN/m ²)
Layer 1	Levelled sandy	3	18	0	30	
Layer 2	Clay	37	14.4	10	14	13788
Layer 3	Soft clay	3	15.5	10	26	21488
Layer 4	Hard clay	10	15.7	12	26.5	21867
Layer 5	Medium tight sand	18.2	17.5	0	28	22980
Layer 6	Tight sand	very thick	17.5	0	30	38300

Project description and engineering geological characteristic: The cement post-grouting and cleaning bottom of piles was conducted for bored piles in The 27 Lang Ha Condominium, Hanoi, in construction foundation designed used bored piles with piles diameter

D = 1.5m, piles length L = 63m, concrete Rn = 32 Mpa = 320 kg/cm².

The engineering geological characteristic of construction area was 6 layers as follows in Table 1.

CALULATING THE LOAD CAPACITY OF PILES WITHOUT POST-GROUTING

According TCXD 205:1998 standard: For pile with diameter D = 1.5 m, length L = 63 m and the designed load capacity of pile Qa = Qs + Qp (3) Qa = 7375.3 kN

with the toe resistance of pile Qs = 4662.3kN, bearing capacity around of pile Qp = 2712.9kN.

According to the finite element method: Mohr-Coulomb model is used to simulate the traction of undrained clay land layer model and drained sand land layer.

Bored pile be simulated with linear elastic material model. The good quality part of pile has elastic modulus was E = 2.92×10⁷ kN/m².

Pile simulated was 3D in finite element using Plaxis 3D Foundation software, as shown in Fig. 3. The settlement result of the pile is shown in Fig. 4. From which establish the relationship chart between the load capacity and settlement of the disability pile in Fig. 5.

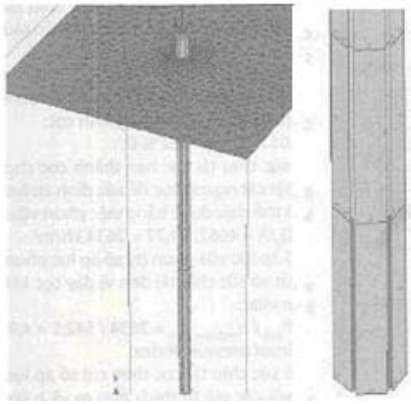


Fig. 3: Pile simulated was 3D in finite element

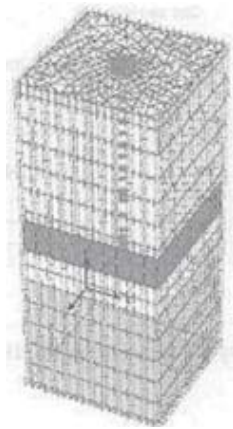


Fig. 4: The settlement $S = 33.65 \times 10^{-3} \text{m}$ with applied load was 14750kN

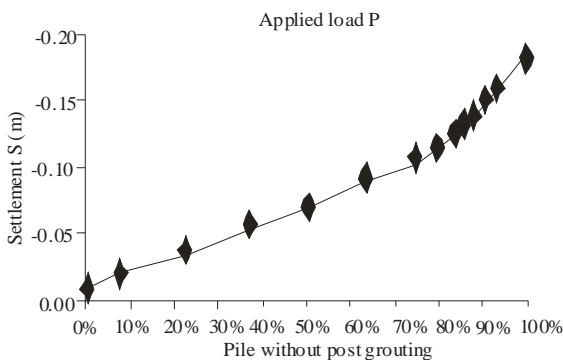


Fig. 5: Applied load-settlement relation pile

With applied load was 14750 kN (by 2 times as applied load designed) the settlement of pile was $33.65 \times 10^{-3} \text{m}$ and when applied load was 7375kN (as applied load designed), the settlement of pile was $11.91 \times 10^{-3} \text{m}$.

CALCULATING THE LOAD CAPACITY OF PILES AFTER POST-GROUTING

Analytic method: After post-grouting, drill to conduct geological survey and determine the land parameters in

processing areas. After high pressure grouting the cohesion of the soil layer reach $C' = 80 \text{kN/m}^2$.

The toe resistance of pile Q_p after post-grouting:

- The load capacity unit of the bottom of pile without grouting, q (% diameter), which must be specified in any settlement, this value will be fully mobilized (typically 5% D):

$$q (\% \text{ diameter}) = Q_p / 5 = 2712.9 / 5 = 542.5 \text{kN} \quad (3)$$

- With given diameter of pile, extreme load bearing capacity around of pile Q_s for the whole depth of pile: $Q_s = 4662.3 \text{kN}$

- The largest settlement allowed as a percentage of the pile diameter: $S = 33.65 \times 10^{-3} \text{m} = 22\% D$
- Divide extreme load bearing capacity around of pile to pile cross-sectional area to determine the maximum pressure the pile can withstand when grout spouted:

$$P_{\text{max}} = Q_s / A = 4662.3 / 1.77 = 2634 \text{kN/m}^2 \quad (4)$$

- Grout pressure index (GPI) (The maximum grout pressure index and the load capacity of bottom pile unit without grout spouted):

$$\text{GPI} = P_{\text{max}} / P (\% \text{ diameter}) = 2634 / 542.5 = 4.9 \quad (5)$$

- Tip Capacity Mulyiplier (TCM) based on the grout pressure index with the appropriate values m and b taken according to soil conditions with the designed settlement and allowed settlement of the pile bottom

$$\text{TCM} = m (\text{GPI}) + b = 1.27 \times 4.9 + 0.63 = 6.853 \quad (6)$$

The according to standard $m = 1.27$; $b = 0.63$

- The grout spouted, toe resistance of pile unit is the product of tip capacity mulyiplier and the load capacity unit of the bottom of pile without grouting.

$$Q_{\text{phun}} = (\text{TCM}) * q (\% \text{ diam}) = 6.853 \times 542.5 = 3717.7 \text{kN} \quad (7)$$

So after post-grouting the pile bottom, the toe resistance of pile Q_p reached

$$Q_p = Q_{\text{phun}} 3717.7 \text{kN}.$$

After spouting grout the pile's surrounding soil considered as soil block with parameters cohesion $C' = 80 \text{kN/m}^2$ and the load capacity around Q_s after post-grouting was $Q_s = 5226.9 \text{kN}$

Table 2: Load capacity of pile (kN)

Test method	Normal pile		Pile after post grouting	
	Applied load P (kN)	Settlement S (mm)	Applied load P (kN)	Settlement S (mm)
Finite Element method	7375	11.91	7375	14
Static compression test experiments method	14750	33.65	14750	38.5
			7345	16.4
			14750	35.6

Table 3: Pile load capacity allows (kN)

Type of pile	Normal pile	Pile after post grouting	Static compression pile after post grouting
Pile load capacity allows (kN)	7375	8944.6	8933.3

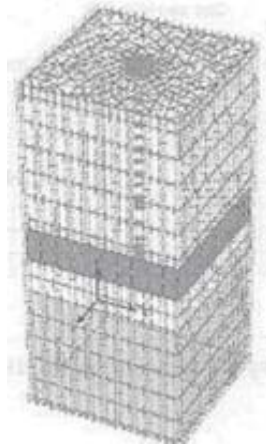


Fig. 6: The settlement $S = 38.5 \times 10^{-3} \text{m}$ with applied load was 14750kN

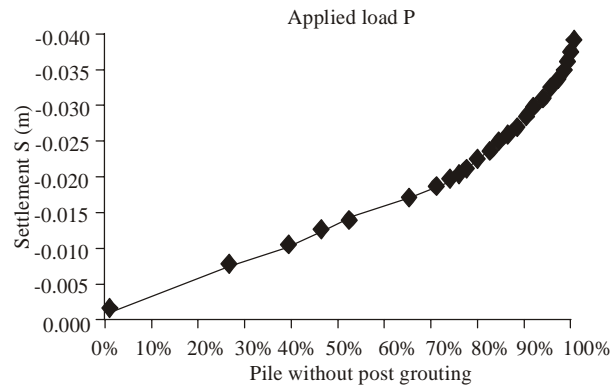


Fig. 7: Applied load-settlement relation pile

The allowed load capacity of pile after post-grouting: $Q_a = Q_s + Q_p = 5226.9 + 3717.7 = 8944.6$ (kN).

It shown that: After post-grouting to processe pile and pile bottom the load capacity increase 20% ($Q_a = 8944.6 - 7375.3 = 1569.3 = 20\% Q_a$) compared with the load capacity of the original designed pile.

Finite element method: From the experimental actual data using Plaxis 3D Foundation software pile simulated the pile that the bottom land processed by cement post-grouting to analyze the bearing capacity of pile. Pile simulated was 3D in finite element is shown as:

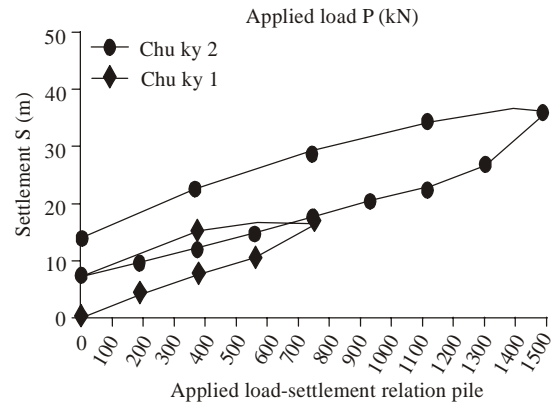


Fig. 8: The results static compression test experiments method of pile after post grouting

Fig. 3. The settlement result of the pile is shown in Fig. 6. Since that charting the relationship between the applied load and the settlement of the pile after processed in Fig. 7. With applied load was 14750KN (by 2 times as applied load designed), the pile settled $38.5 \times 10^{-3} \text{m}$ and the applied load was 7375kN (as applied load designed), the pile settled $14 \times 10^{-3} \text{m}$.

The results shown in the table Table 2.

Static compression test experiments method: After finishing pile tip post grouting conducted the static compression site experiments according TCXDVN 269-2002. The results are shown in Fig. 8 about the relation of settlement and applied load. The largest applied load obtained 14750 kN corresponding to two times as applied load designed. From the graph (Fig. 8) the allowed load capacity determined $Q_a = 13400/1.5 = 8933.3 \text{kN}$ (safety equal to 1.5). The result of the normal piles load capacity and the load capacity piles after processed by cement post grouting with the different calculation methods and site experiments are summarized in Table 2. And the allowed load capacity of piles is presented in Table 3.

CONCLUSION

The following conclusions are based on the research results:

- The causes affect to the load capacity of bored piles is mainly due to uncleanly washing the pile bottom that leads the drilling mud mix with concrete reduce the toe resistance of pile
- The pile tip processing solution is cement post-grouting to pile surrounding to increase the friction of piles and directly cement post-grouting into the pile tip to increase the toe resistance of piles
- In Hanoi the geological conditions is soft ground, if cement post-grouting technology bored pile is strictly applied it can increase 20% of the pile load capacity as normal, so it can reduce a large price of project
- Using finite element method (Plaxis 3D Foundation Software) is a fast and effective tool to calculate for many cases of the pile, from which estimate the load capacity, the settlement of normal piles and processed piles. Results calculated by the

finite element method is relatively accurate compared with the field static compression results.

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