Quantitative Characterization of Grouting Stones for Drilling with Pre-stressed Concrete Pile Cased Pile

Zhenkun Hou 1,2,3, Mengxiong Tang 1, Hesong Hu 1,*, Zegeng Lin 1, Hang Chen 1, Chunlin Liu 1

1 Guangzhou Institute of Building Science Company Limited, Guangzhou 510440 China
2 Guangzhou Testing Center of Construction Quality & Safety Co., LTD. Guangzhou 510440 China
3 South China University of Technology, Guangzhou 510640, China

*Corresponding author. E-mail: 20122002027@cqu.edu.cn

Abstract. The bearing property of Drilling with pre-stressed concrete pile cased pile is closely related to the grouting effect on the pile side. Based on the 3D scanner, the characteristics of the grouting stone body was quickly obtained with large area and high resolution through high-speed laser scanning measurement technology and extrapolation multi-frequency phase-shift laser grating technology, and the following conclusion was drawn: the quantitative characterization method of grouting rock mass based on the 3D scanner is stable and reliable, its workload is small, data density is large, test process is accurate and fast, and it overcomes the shortcomings of traditional manual measurement; under the condition of same elevation, the thickness of grout decreases as the distance away from the coordinate origin increases, namely in the same horizontal plane, the farther the horizontal distance away from the grout outlet position, the smaller the grout thickness; the greater the elevation, as the horizontal distance away from the grout outlet increases, the larger the decrease rate of grout thickness, the faster the grout thickness decreases; when the horizontal distance away from the grout outlet position is constant, as the elevation increases, the grout thickness gradually decreases.

Keywords: Drilling with pre-stressed concrete pile cased pile; the grouting stone body; 3D scanning; quantitative characterization.

1. Introduction

The unique construction technology of Drilling with pre-stressed concrete pile cased pile [1][2][3][4] causes the borehole diameter to be about 20mm larger than the outer diameter of the PHC pipe pile. After the pile sinking is completed, grouting should be conducted to increase its bearing capacity. Scholars at home and abroad have carried out a lot of studies on the flow and diffusion law of grout in the ground. Zhang Qingsong et al. [5] obtained the relationship between the grouting time of the viscosity modifying liquid and the grouting pressure and the grout diffusion radius through laboratory experiments and theoretical derivation; aiming at the common penetration grouting reinforcement mode of water-rich sands. Wang Hongbo et al. [6] carried out laboratory model tests, theoretical analysis,
numerical simulation, field tests, etc., studied the influence of grouting pressure, sand particle size, grout ratio on the grouting effect, and quantitatively characterized the grouting effect by grouting reinforced strength and permeability coefficient. Sha Fei et al. [7] carried out a set of visual sand-soil medium constant pressure grouting penetration, diffusion and reinforcement simulation test device, analyzed the flow and diffusion characteristics of different grouting materials in sand, and the change law of flow and diffusion distance of different grout under different grouting pressures with time. Wang Qi et al. [8] carried out reinforced physical model tests of grouting materials with different particle sizes and different water-cement ratios to broken surrounding rock grout gap, revealed the grouting reinforcement mechanism of broken surrounding rock grout. Zou Jian et al. [9] carried out physical model tests of post-grouting grout diffusion on the pile end under different grouting conditions in clay soil layers, obtained the concretion shapes under different grouting conditions through excavation, quantitatively characterized the shape and size of grouting bubbles and veins. Saada et al. [10] studied the diffusion and reinforcement mechanism of ultrafine cement grout in the sand layer, and analyzed the influence of water-cement ratio, grouting rate, grouting pressure, and density on the diffusion property of grout.

The physical model test was carried out with the transparent soil, which can realize the visual monitoring of the soil internal deformation and the flow and penetration process of the grout in the soil [11][12]. Wen Lei et al. [13] used transparent materials simulate the pile body, conducted the post-grouting visual model test study of micro steel pipe pile with PIV technology and transparent soil, analyzed the diffusion law of post-grout on the pile side, and carried out the static load test of the micro steel pipe pile, and studied the change law of the soil displacement field around the pile. Gao et al. [14] carried out the visual physical model test study of permeation grouting in saturated sand and revealed the permeation grouting diffusion mechanism of grout in saturated sand. However, transparent soil [15] was mainly formed by mixing, vacuuming and saturating granular materials with a certain gradation and hole liquid with the same refractive index, this is quite different from the real soil, the existence of hole liquid greatly affects the basic physical and mechanical properties of the grout, in addition, transparent soil and natural soil are quite different in the permeability and deformation capacity, the research on using transparent soil carry out post-grouting in pile foundation project still needs to be explored.

In order to verify the flow law of the grout in the gap between drilling with pre-stressed concrete pile cased pile and soil, the 3D geometric size of the grout was quantitatively characterized by the 3D scanning technology, which can provide theoretical support and technical guidance for improving frictional resistance on the pile side.

2. Grouting Model Test of Drilling with Pre-stressed Concrete Pile Cased Pile

2.1. Test plan
The purpose of this paper is to accurately and quantitatively characterize the distribution of the grout rock mass on the pile side, therefore, a set of experiments were designed in this paper, the grout used in the experiment was the cement paste with 0.5 water-cement ratio, and the grouting pressure is 0.5MPa, the grouting method is single-hole static pressure grouting, and there is no vent hole at the bottom of the pile during the grouting process.

2.2. Experimental equipment and process
Fig.1 is the physical simulation experiment system of the grout flow law on the pile side of drilling with pre-stressed concrete pile cased pile; this system is mainly composed of air compressor, multifunctional grouting box, model pile, protective tube, and model box. The air pressure of air compressor is adjustable (0-2MPa), which can meet the grouting simulation under different grouting pressure conditions, the multi-functional grouting box is composed of 4 grouting outlets, which can meet the needs of single-hole and multi-hole simultaneous grouting.

In this paper, large-diameter PVC pipe (outer diameter 250mm, thickness 15mm) was selected as the model pile, high-strength acrylic pipe (outer diameter 270mm, thickness 8mm) as the casing, and rubber
hose with high compressive strength (outer diameter 25mm, inner diameter 19mm) as grouting pipe, as shown in Fig.1: (1) the grouting pipe was extracted from the bottom of the model pile, and the grouting pipe was blocked at the bottom of the model pile with concrete, the outlet was located on the side wall of the pile bottom; (2) two semi-cylindrical casings were used to clamp the model pile, as a whole, the two were put into the center of the model box, then the gap between the model box and the casing was filled, sandy soil in this experiment, every 15cm was a layer, layered filling and layered compaction were carried out, after the filling was completed, two semi-cylindrical casings were pull out, one 10mm annular columnar gap (the abbreviation is pile-soil gap) is formed between the model pile and the soil around the pile; (3) the grouting pipe was connected with the grouting outlet on the multi-function grouting box, 0.5MPa grouting pressure was provided for pile side grouting through the air compressor, the grouting was stopped and the test ended after the pile top poured grout, (4) after the grouting rock mass was cured for more than 30 days, the grout was excavated, and the remaining sand on the surface of the grouting rock mass was washed with clean water.

![Fig.1](image)

**Fig.1** The grouting physical model test system of drilling with pre-stressed concrete pile cased pile

### 2.3. Analysis of experimental results

As shown in Fig.2, in order to be convenient for the analysis, the position of the grouting outlet as the coordinate origin in this paper, the pile height as the Y axis, and the circular pile circumference was flattened as the X axis. This paper stipulates that the side where the grouting outlet is located is the front side; the side opposite to the grouting outlet is the back side, thus it can be seen:

(1) the grout flows from the grouting outlet on the front side to pile-soil gap upwards under the grouting pressure, the upward-flowing grout flows to both sides under the action of its own weight and grouting pressure;

(2) the grout which flows to both sides converged on the back side to form loop, due to the high grouting pressure, the grout flowed faster, and the vent hole set on the back was closed, and the grout sealed the air in the pile-soil gap at the pile bottom on the back, resulting in the poor grouting effect at the bottom of the pile on the back, it can be seen that it is extremely important to set up vent hole when drilling with pre-stressed concrete pile cased pile conducting grouting on the pile side;

(3) according to visual observation, the grout thickness at the bottom of the pile body is larger than that of the upper part, and the grout thickness on the front pile body is larger than that of the grout on the back; the grout thickness is getting smaller and smaller, if the diameter of the model pile is large enough, it is difficult for a grouting entrance to meet the grouting requirements;

(4) the upper part was close to the ground, the front side was full of grout, and there was almost no grout in the back side, this was because the grout flowed to the ground and flowed out from the upper
gap, the pressure dropped rapidly, causing driving pressure of back grout to be not enough, as a result, it could not be filled, it fully showed that the grouting plate was arranged at the top of the pile to form pressure, which is more conducive to the flow of the back grout.

3. Quantitative Characterization of Grouting Rock Mass

3.1. 3D scanning system
The flow and diffusion law and the distribution law of grout have been qualitatively described in the above, however, the evaluation of grouting effect on the pile side of drilling with pre-stressed concrete pile cased pile requires scientific evaluation, for this reason, it is necessary to find the way to quantitatively characterize the distribution law of grouting rock mass on the pile side. As shown in Fig.3, the 3D scanner is widely used in sheet metal strain measurement, material mechanics test, biomechanics test, deformation measurement and other fields. It can replace traditional strain gauges and displacement sensors and quickly realize the 3D deformation and strain measurement. The 3D scanner can quantitatively characterize the three dimensional geometry of the grouting stone body.
3.2. Quantitative characterization method

As shown in Fig.4, on the basis of the 3D optical surface scanning system, the high-speed laser scanning measurement method was used, the extrapolation multi-frequency phase laser grating technology were used to quickly obtain the point cloud data of the grout with large area and high resolution, thus obtaining the 3D coordinate data and spatial point information of the grout on the pile side, as shown in Fig.4, the grouting rock mass obtained by 3D scanning is composed of countless point clouds, on the basis of the 3D optical surface scanning system, global processing, point cloud fusion processing, and point cloud smoothing were conducted for the collected point cloud, etc., they are saved as PLY format file. In order to contrast the thickness of grout, 3D scanning was carried out on the empty piles without grouting and the test piles with grouting rock mass.

As shown in Fig.5, Geomagic Control 2014 (64bit) professional point cloud processing software was integrated to conduct "coloring, deleting surrounding extra points" on the above empty pile and test pile with grout, etc., the empty pile as the reference pile, and the pipe pile axis and the ground as the reference point, the test pile and the reference pile were aligned, after the above steps were finished, the two were compared in 3D, the thickness and 3D coordinates of the grout at any position can be obtained, cross section model pile is perpendicular to the model pile, the thickness of corresponding grout at different elevations can be derived through the built-in software.

![3D point cloud data of grouting rock mass](image)
3.3. Quantitative characterization of grout thickness

In this paper, elevation 50cm, 80cm, 95cm, and 125cm were taken as examples to analyze the quantitative characterization results of grout based on the 3D scanning system, as shown in Fig.6, the following conclusions can be drawn:

The 3D scanning system is used to quantitatively characterize the thickness of the grout, which is feasible; under the condition of same elevation, the grout thickness decreases as the distance away from the coordinate origin increases, namely in the same horizontal plane, the further the horizontal distance away from the grout outlet position, the smaller the grout thickness; with the increase of the horizontal distance away from the grouting outlet position, the greater the decrease rate of the grout thickness, the faster the grout thickness decreases; when the horizontal distance away from the grout outlet position is constant, the grout thickness gradually decreases as the elevation increases.

![Fig.5](image5.png)

![Fig.6](image6.png)
As shown in Fig.6, the manual measurement results are volatile, the tape is used to record the horizontal coordinates one by one, and the digital-display vernier caliper is used to record the grout thickness one by one, this causes large errors and large reading and recording workload, the workload of accurately cutting grout along different positions is large, and the cutting density cannot be large, the volume of grouting rock mass obtained by calculation is rough, and manual method has many disadvantages. The experimental data obtained by the 3D scanner are relatively smooth, data is relatively stable, data density is large, workload is small, and the test method is accurate and fast, this fully shows that it is feasible and has obvious advantages to quantitatively characterize 3D geometric size of grout based on the 3D scanning system.

In Fig.6, the thickness fitting formula of the grout at 50cm, 80cm, 95cm and 125cm elevation away from the pile bottom grout outlet is shown in formulas (1)-(4), and the thickness of grouting rock mass on the pile side can be predicted based on the formula.

Grout thickness at 50cm elevation:
\[ l_{50} = 20.20269 + 0.202065x - 0.00395x^2 R^2 = 0.94545 \]  \hspace{1cm} (1)

Grout thickness at 80cm elevation:
\[ l_{80} = \begin{cases} 18.9954 - 0.1576x + 0.00223x^2 & (0 \leq x \leq 39.25) \\ 19.3173 + 0.4674x + 0.00256x^2 & (-39.25 \leq x < 0) \end{cases} \quad R^2 = 0.98342 \] (2)

Grout thickness at 95cm elevation:
\[ l_{95} = \begin{cases} 16.2222 - 0.2941x - 0.00145x^2 & (0 \leq x \leq 39.25) \\ 16.9095 + 0.6111x + 0.00458x^2 & (-39.25 \leq x < 0) \end{cases} \quad R^2 = 0.97652 \] (3)

Grout thickness at 125cm elevation:
\[ l_{125} = \begin{cases} 13.0168 - 0.4815x + 0.00352x^2 & (0 \leq x \leq 39.25) \\ 16.9095 + 1.3625 + 0.01404x^2 & (-39.25 \leq x < 0) \end{cases} \quad R^2 = 0.97631 \] (4)

4. Conclusion
It is feasible to adopt the 3D scanning system to quantitatively characterize the 3D geometric dimensions of the grout, the results of manual measurement of grout thickness are volatile, large error and low precision, workload of cutting grout is larger; the experimental data measured by the3D scanner is relatively smooth and stable, data density is large, workload is small, and the testing method is accurate and fast.

Under the condition of the same elevation, the grout thickness decreases with the increase of the distance away from coordinate origin, namely in the same horizontal plane, the further the horizontal distance away from the position of the grouting outlet, the smaller the grout thickness; the greater the elevation, as the horizontal distance away from the grouting outlet position increases, the greater the decrease rate of grout thickness, the faster the decrease of grout thickness; when the horizontal distance away from the grouting outlet position is constant, as the elevation increases, the grout thickness gradually decreases.

If the diameter of the model pile is large enough, it is difficult for one grouting entrance to meet the grouting requirements; when single-hole static pressure grouting, the vent on the side opposite to the grouting entrance is conducive to improve the grouting effect.

Acknowledgements
Fund Projects: Guangdong Basic and Applied Basic Research Foundation (2019A1515110836), Open Research Fund of State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences (grant no. Z019018), China Postdoctoral Science Foundation (grant nos. 2019M662918, 2020M672584), the National Natural Science Foundation of China (nos. 41688103, 51908225, 51678171), the National Key Research and Development Program of China (2018YFC1504903).
References
[1] Tang Mengxiong. The Development and Engineering of Drilling with PHC Pipe Cased Pile [J]. Guangzhou Architecture, 2009(5): 3-7.
[2] Tang Mengxiong, Qi Yuliang, Hu hesong. Influence analysis of drilling with large diameter pipe pile's ferrule on the pile head quality [J]. Building Structure, 2016(S1), 808-811.
[3] Tang Mengxiong, Hu Hesong, Cui Jie, et al. The Vertical Bearing Mechanism of Hybrid Bored Pre-stressed Concrete Cased Piles [J]. International Journal of Civil Engineering, 2020, 18: 293-302.
[4] Yang Xiaosong. Experimental study on vertical compressive bearing capacity and seismic resistance of Drilling with large diameter Pre-stressed Concrete Pile Cased Pile [D]. Guangzhau: Guangzhou University, 2018.
[5] Zhang Qingsong, Zhang Lianzhen, Zhang Xiao, Liu Rentai, Zhu Mingting, Zheng Dongzhu. Grouting Diffusion in a Horizontal Crack Considering Temporal and Spatial Variation of Viscosity [J]. Chinese Journal of Rock Mechanics and Engineering, 2015(06):122-134.
[6] Wang Hongbo. Study on Penetration Reinforcement and Deterioration Mechanism of Grouting in Sand Layer under Seawater Erosion-Seepage and Its Application [D]. Shandong University, 2019.
[7] Sha Fei, Li Shucui, Lin Chunjin, Liu Rentai, Zhang Qingsong, Yang Lei, Li Zhaofeng. Research on penetration grouting diffusion experiment and reinforcement mechanism for sandy soil porous media [J]. Rock and Soil Mechanics, 2019, 40(11): 4259-4270.
[8] Wang Qi, Wang Lei, Liu Bonghong. Study on the void characteristics and mechanical properties of crushed surrounding rock grouting [J]. Journal of China University of Mining and Technology, 2019(6), 218-226.
[9] Zou Jian. Study on Grout Diffusion Theory and Residual Stress on Grouted Drilled Shaft [D]. Zhejiang University, 2010.
[10] Saada Z, Canou J, Dormieux L, et al. Evaluation of elementary filtration properties of a cement grout injected in a sand[J]. Canadian Geotechnical Journal, 2006, 43(12): 1273—1289.
[11] Cao Zhaohu, Kong Gangqiang, Liu Hanlong, et al. Model tests on pipe pile penetration by using transparent soils [J]. Chinese Journal of Geotechnical Engineering, 2014, 36(8): 1564-1568.
[12] Kong G Q, Cao Z H, Zhou H, et al. Analysis of piles under oblique pullout load using transparent-soil models [J]. Geotechnical Testing Journal, 2015, 38(5): 725-738.
[13] Wen Lei, Kong Gangqiang, Zhang Zhendong, Li Qingsong. Study on the Diffusion and Bearing Capacity of Postgrouting Steel Pipe Micropiles in Marine Muddy Soil [J]. Engineering Mechanics, 2019, 036(004):214-220,230.
[14] Gao Y, Sui W H, Liu J Y. Visualization of chemical grout permeation in transparent soil [J]. Geotechnical Testing Journal, 2015, 38(5): 774-786.
[15] Cao Zhaohu, Kong Gangqiang, Liu Hanlong, Zhou Hang. Model tests on pipe pile penetration by using transparent soils [J]. Chinese Journal of Geotechnical Engineering, 2014, 36(8):1564-1569.