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APPLICATION RESEARCH OF HIGH PRESSURE JET GROUTING PILE IN AN UNDERGROUND ENGINEERING IN VIETNAM

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High-pressure jet grouting pile is a kind of stratum reinforcement technology developed in recent years. Due to its characteristics of high solid strength, fast construction, low noise, safety and reliability, low cost, controllable reinforcement diameter, strong adaptability to stratum, and good reinforcement effect for soft soil, loose soil and water-rich stratum, high-pressure jet grouting pile technology has been more and more widely used in foundation treatment, water stop, and seepage prevention, tunnel lining and other fields in recent years. As a country with a relatively late development of underground construction engineering, Vietnam has little research on special geotechnical reinforcement technology, especially on special geotechnical reinforcement technology around urban underground construction engineering, especially on its theoretical analysis and practical application. Therefore, this thesis combines the Vietnam Trung Hoa tunnel project as an example, using the theoretical calculation formula and field monitoring measurement comparing the two methods, the high pressure jet grouting pile system research in Vietnam in the underground engineering reinforcement principle and application effect, get to the actual engineering design and construction has a guiding significance to the research, provides the reference for future similar projects. Finally, the application effect of high-pressure jet grouting pile in underground building reinforcement project is evaluated, which proves that high-pressure jet grouting pile has good applicability and economic benefit in underground building reinforcement project in Vietnam.

Keywords: High pressure jet grouting pile, The principle of pile, Deformation of the foundation, Seepage control, Reinforcement effect

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1. INTRODUCTION

High-pressure jet grouting pile is a method that the grouting pipe with special nozzle is placed in the predetermined depth of the soil, and the solidified slurry is mixed with the soil in the form of high-pressure jet to solidify and harden the foundation. If at the same time of spraying, the nozzle rotates and lifts at a certain speed, a cylindrical pile mixed with slurry and soil is formed. Using the drill the grouting pipe with a nozzle to the soil after the desired depth, with 20 ~ 40 Mpa pressure and speed of 100 m/s or water jet from the nozzle, the pulp forming punching failure of the soil, jet when energy is large, fast speed and pulse jet, the dynamic pressure is greater than the soil structural strength, hard peeling off from the soil, soil particle part of fine particles with the size or comes out of the ground water the rest of the soil particles in the jet impact, under the action of centrifugal force and gravity force, and the slurry mixing, and according to certain proportion of slurry soil quality and size, rearrange regularly, slurry after solidification, A consolidation body is formed in the soil layer, and when the jet rotates 360^0, the consolidation body is round [1-6]. The construction equipment of high pressure jet grouting pile mainly includes: air pressure, pressure pump, drill, cement bin, pulp bucket, bucket, mixer and so on. The equipment and construction procedure of high-pressure jet grouting pile are shown in figure 1.

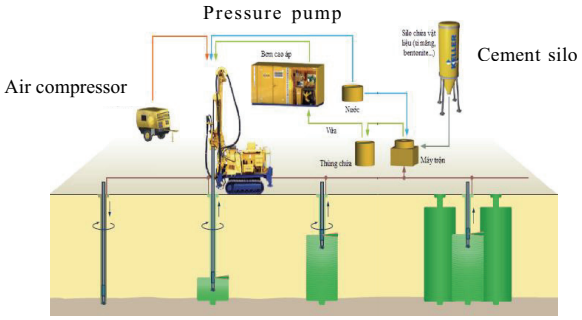

Fig. 1 Schematic diagram of equipment and construction procedure of high pressure jet grouting pile

In the late 1960 s, high-pressure rotary Jet grouting technology for the first time for Japanese foundation reinforcement and seepage control, check water, improve the foundation soil, formed a kind of effect and special foundation reinforcement technology, then called Dry Jet Mixing method (Dry Jet Mixing) [1,2,7]. Then Italy, Germany, Finland and so on have started to apply. In 1980, high pressure Jet grouting pile was developed. Due to the continuous development of science and technology, the method has been gradually improved, and has obtained practical application in many countries [1,2].

In Vietnam, the research and development of the high-pressure rotary jet grouting method was relatively late. High-pressure jet grouting pile method has been applied to the foundation treatment of existing buildings and new construction projects, hydraulic engineering reinforcement, deep foundation pit support and underground engineering, construction of underground waterproof curtains, preventing sand vibration and liquefaction, increasing soil strength and improving settlement of construction projects. High pressure rotary jet pile method is especially suitable for narrow construction site, low clearance, weak upper soil. During construction, production and operation shall not be stopped, traffic shall not be interrupted, public and surrounding environment shall not be harmed, and adjacent buildings shall not be affected [7]. In Vietnam, high-pressure jet grouting pile has been developed as a method for foundation reinforcement, seepage prevention and water control. It has been listed in Vietnam's current national or industry standards, such as TCXDVN 205:1998 pile foundation -- design code; TCXDVN 385:2006 "method of strengthening high pressure rotary jet pile in foundation"; TCCS 05:20 10/VKHTLVN cement-soil column formed by jet grouting method, which improve the soft soil and prevent soil and the internal water seepage; TCVN 9403:2012 the stability of soft soil, cement-soil column method; TCVN 9906:2013 hydraulic structures, the jet grouting method of cement-soil column - soft soil foundation reinforcement design, construction and acceptance of the technical requirements [8-11]. The practical application of high pressure jet grouting pile in Vietnam construction engineering is shown in table 1.

Table 1. Application of high pressure jet grouting pile in construction engineering in Vietnam

Years	Projects	Management institutions	Project scale
2005	Son La hydropower project impervious	Son La hydropower enterprise	Total length of the pile: 2411m; Depth: 15m
2006	Ha Tinh province- Da Bac reservoir impervious	Hong Linh county general affairs division	Total length of the pile: 5125m; Depth: 18m
2008	Foundation reinforcement for tall building no. 6 Ngo Quyen road, Ha Noi city	Vinafood company	Total length of the pile: 1100m; Depth: 20m
2009	Na Zanh reservoir watertight and impermeable	Cao Bang provincial general agricultural service division	Total length of the pile: 3400m; Depth: 29m
2010	Foundation reinforcement of Khe Ngang reservoir	Hue city agricultural general affairs division	Total length of the pile: 32500m
2010	Foundation reinforcement for Tra Linh dam	Water resources II general services division	Total length of the pile: 5600m
2011	Hanoi red river dam modified, foundation reinforced	Hanoi flood prevention department	Total length of the pile: 6000m; Diameter: D800
2013	O Mon sewer	Kien Giang institute for rural development and agriculture	Sewer foundation reinforcement

Continue Table 1. Application of high pressure jet grouting pile in construction engineering in Vietnam

2015	Ho Chi Minh metro line 1 Arriving Shaft reinforcement	Ho Chi Minh city railway authority	Diameter: D3500, D3000; Depth: 31.3m;
2015	Launching Shaft of Ho Chi Minh metro line 1	Ho Chi Minh city railway authority	Diameter: D3500; Depth:17.83m;
2016	Ho Chi Minh metro line 1 Cut & Cover Tunnel	Ho Chi Minh city railway authority	Diameter: D700, D2500, D3000, D3500
2016 2017	Ho Chi Minh metro line 1 Opera house protection	Ho Chi Minh city railway authority	Diameter: D1400, D3000, D3500

（Transcript: Vietnam institute of water science - water engineering institute and Fecon company）

2. THE THEORETICAL ANALYSIS

2.1. PILE-FORMING PRINCIPLE OF HIGH PRESSURE JET GROUTING PILE

The pile-forming principle of high pressure jet grouting pile has three methods: single pipe method (S- construction method), double pipe method (D- construction method) and triple pipe method (T-construction method). **(1) Single pipe method (S- construction method).** Single-pipe method is to use high-pressure mud pump and other devices, at the pressure of 20MPa~30MPa, the slurry from the nozzle jetted out, impact damage to the soil, at the same time with the help of the grouting tube lift and rotation, so that the slurry and the falling soil mixed and stirred, after a certain time of solidification, the formation of cylindrical consolidation body in the soil. The consolidation body formed by the single-pipe method has a smaller diameter of 500mm-800mm, a pile length of 25m, and a grouting speed of 100m/s [12,13]. The single-pipe method (S- construction method) of high-pressure jet grouting pile is shown in figure 2.

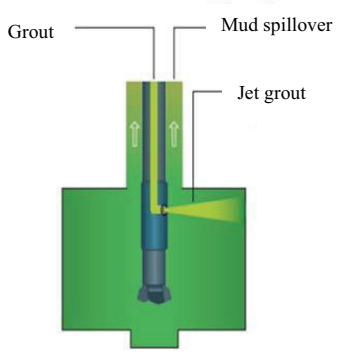

Fig. 2 Single pipe method of high-pressure jet grouting pile (S-construction method)

(2) Double pipe method (D- construction method). D-method is the use of coaxial double grouting pipe conveying two medium at the same time, through the bottom of the tube on the side of a coaxial dual nozzle, at the same time, injection pressure grout (20MPa ~ 30MPa) and air (0.7MPa to 0.8MPa), two medium in high pressure slurry flow and its periphery surrounded airflow under the joint action of impact damage to the soil, destroying the soil a significant increase in energy. The diameter of consolidation body is obviously increased than that of single tube method. The consolidation body formed by the double pipe method has a smaller diameter of 800mm ~ 1500mm, a pile length of 45m, and a grouting speed of 100m/s [12,13]. Double pipe method of high-pressure jet grouting pile (D-construction method) is shown in figure 3.

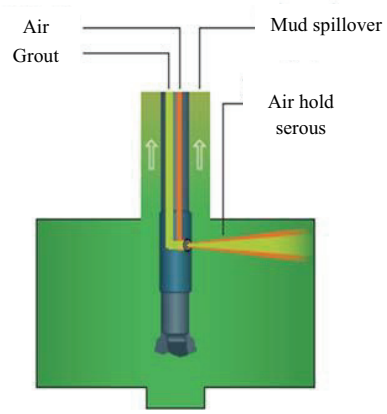

Fig. 3 Double pipe method of high-pressure jet grouting pile (D-construction method)

(3) Triple pipe method (T- construction method). The triple pipe method uses the triple grouting pipe which transports three media, namely gas, water and slurry, respectively. The cylinder air flow around the high-pressure or ultra-high-pressure water jet with pressure of 20MPa ~ 50MPa is around 0.7Mpa. The high-pressure water and air coaxial jet is used to cut the soil to form a larger gap, and the slurry at pressure of 2MPa ~ 5MPa is injected by the mud pump to fill it. When different injection methods are adopted, solidified bodies of various shapes can be formed. The consolidated bodies formed by the triple tube method have a larger diameter of 1000mm ~ 5000mm and a pile length of 60m [12,13]. The triple pipe method (T- construction method) of high-pressure jet grouting pile is shown in figure 4.

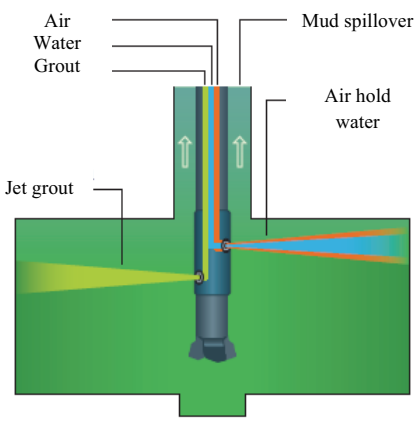

Fig. 4 Triple pipe method of high-pressure jet grouting pile (T-construction method)

2.2. CALCULATION METHOD

This paper adopts two methods of Vietnam (including: based on the calculation method based on natural foundation and pile foundation calculation method) combined with Asia technology A.I.T and local specification DBJ 08-40-94 [14].

3. ENGINEERING APPLICATION AND ANALYSIS

3.1. PROJECT SUMMARY

Hanoi Trung Hoa tunnel project is located in Hanoi capital, Cau Giay district, Trung Hoa square. The scope of the project is Km 3+382.03 to Km 1+328.15 in the direction of Thang Long avenue and Tran Duy Hung road; The scope of the project is Km 22+905.380 to Km 23+634.16 in the direction of Pham Hung road and Khuat Duy Tien road. The engineering building is a two-line tunnel, which adopts the trenchless method. The span of each tunnel is 3.5×3=10.5m, and the length of the tunnel is 691.8m [15]. The section of Hanoi's Trung Hoa tunnel project is shown in figure 5.

The project uses the method of double tube of the high pressure jet grouting pile (calculated in the first stage, L = 20m, B = 14m) to reinforce the foundation and improve the safety of foundation soil for tunnel construction, so as to ensure the stability of the construction of Hanoi metro line 5.

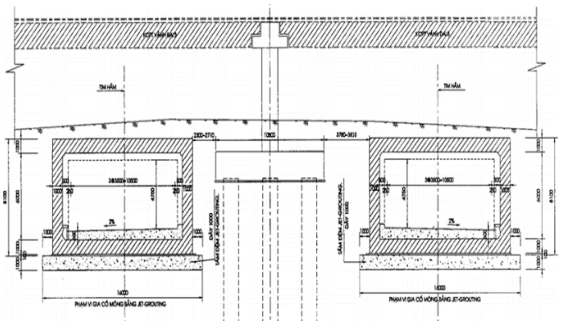

Fig.5 Schematic diagram of the Hanoi Trung Hoa tunnel

Engineering geology and hydrogeological conditions. The Trung Hoa tunnel project in Hanoi is located in Trung Hoa square, Cau Giay district, so it brings with it the geology-hydro-ventral city in the third district, with complicated geological structures and irregular changes. The underground water in Hanoi city is relatively deep, and there is a lot of rainwater capacity in Hanoi during the rain season, which has a great impact on the construction engineering.

According to the survey requirements of the design documents, the geological survey results and the results of the laboratory, the geological axis and mechanism indexes of each subsoil layer are proposed, as shown in figure 6.

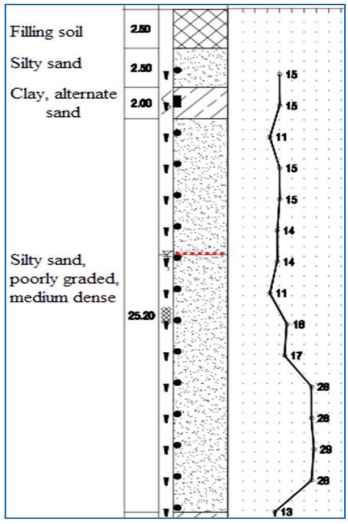

Fig. 6 Schematic Diagram of Typical Geological Axis

According to the typical geological axis, there are four soil layers around the construction. The first soil layer is filling soil, with a thickness of 2.5m. The second soil layer is silty sand with a thickness of 2.5m. The third layer is clay and alternate sand with a thickness of 2.0m. The fourth soil layer is silty sand, poorly graded and medium density, with a thickness of more than 25.2m. The mechanism indexes of each subsoil layer of Trung Hoa tunnel in Hanoi are shown in table 2.

Table 2. Mechanism Index of Foundation Soil Layer

Soil layer	Mean soil thickness (m)	Internal friction angle $\varphi^{(0)}$	Adhesion C (kg/cm^2)	Natural weight γ (T/m^3)	Consistency B
Filling soil	2.5	13°03’	0.103	1.94	0.64
Silty sand	2.5	12°14’	0.115	1.94	0.6
Clay, alternate sand	2.0	10°24’	0.146	1.89	0.58
Silty sand, poorly graded, medium dense	>25	10°45’	0.128	1.88	0.67

3.2. CONSTRUCTION PARAMETERS OF HIGH PRESSURE JET GROUTING PILE

According to the construction requirements, Hanoi Trung Hoa tunnel adopts the double pipe method of high-pressure jet grouting pile to reinforce the foundation, improve the bearing capacity of the foundation, improve the foundation soil and stabilize the foundation pit wall. The diameter of the pile is D800mm and the average length of the pile is L17.2m. The layout of the pile on the plane is a square net, and the span of the pile core is 1000mm. See table 3 for construction parameters.

Table 3. Construction Parameters of High Pressure Jet Grouting Pile

Technical parameters	Symbol	Unit	Calculated value
Cement capacity of $1m^3$	-	Kg/m^3	300
The volume of a pile one meter long	V	m^3	0.5024
Pile one meter long cement capacity	-	Kg	150.72
Cement - water ratio	XM/N	Kg/l	1/1.5
The water content of a pile one meter long	V	l	226.080
Pile one meter long slurry volume	V	l	273.928
Grout jet pressure	P	MPa	17
Grouting flow	Q	l	63±2
Air compressor	-	MPa	0.4±0.2
Lifting speed of drill pipe	-	minutes/m	7
Jet speed of drill pipe	-	ring/minutes	10±20
Grouting time of one meter long pile	T	minutes	4.3

3.3. CORE QUALITY AND TEST RESULTS

After the completion of the construction, in order to evaluate and test the reinforcement effect, the owner entrusted the relevant units to conduct coring test, unconfined compressive strength test and water seepage test, etc. The measured depth of excavation is 1.5m, and the direct measurement and observation show that the rotary jet pile has good perpendicularity, the pile diameter reaches 0.9m, the pile body is of good quality, the cement soil of the pile body is conducive to the bearing capacity of a single pile, and the pile body is well interwoven to ensure water stop and reinforcement. The diameter inspection of pile body is shown in figure 7.

Fig. 7 Pile diameter inspection (up to 900mm)

It can be seen from the field coring test that the core recovery is high, the pile body is synchronous and complete, and all the indexes meet the design and drawing requirements. The core quality is good, forming a good pile strength, and the core length ranges from 10cm to 140cm. The TCR value of the core can be seen directly with the naked eye to be greater than 85%. The core of the pile is shown in figure 8.

Fig. 8 Field coring test results

The compression strength was obtained through unconfined compressive strength test (core data: core length is 133.1mm, core weight is 888.6gam, and core diameter is 71.5mm), as shown in figure 9. The result of the high pressure Jet Grouting pile of plate loading test for Jet Grouting column as shown in figure 10 [16].

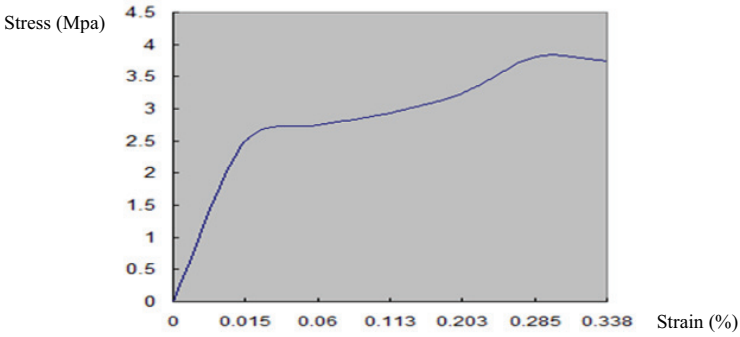

Fig. 9 Unconfined compressive strength test

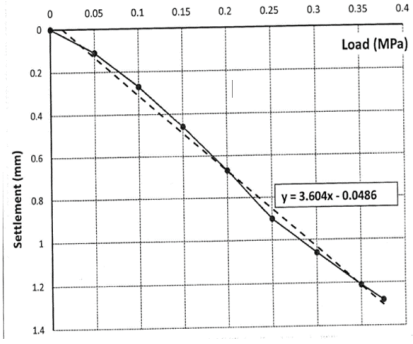

Fig. 10 Field Plate Load Test Results of High Pressure Jet Grouting Pile

3.4. CALCULATION RESULT

3.4.1. CALCULATION MODEL BASED ON PILE FOUNDATION

3.4.1.1. CALCULATION OF ALLOWABLE BEARING CAPACITY OF PILE

(1) The A.I.T. approach of the Asian institute of technology

Allowable bearing capacity of single pile in case of foundation failure:

(3.1) $$Q_s = (\pi d L_c + 2.25\pi d^2) C_u = 61.56(T)$$

Where

Q_s—Allowable bearing capacity of single pile (kN); L_c—Length of pile (m); d—Mean diameter of pile (m); C_u—Shear resistance of pile-range foundation (kg/cm^2).

Allowable bearing capacity of single pile in case of pile failure:

(3.2) $$Q_c = F_c(3.5C_c + 3\sigma_n) = 32.45(T)$$

Where

Q_c—Allowable bearing capacity of single pile (kN); C_c—Adhesion of cement-soil pile; F_c—Mean sectional area of pile (m^2); σ_n— Total transverse pressure of the upper foundation (T/m^2).

Allowable bearing capacity of pile body cement soil (selected safety factor is 1.5) :

(3.3) $$P_{cp} = \frac{Q_c}{1.5} = 21.63(\mathrm{T})$$

(2) China local standard DBJ 08-40-94 method

The allowable bearing capacity of a single pile is based on the pile material:

(3.4) $$P_a = \eta f_{cu} A_p = 0.35 \times 60 \times 0.5024 = 11(\mathrm{T})$$

Where

P_a—Allowable bearing capacity of single pile (kN); η— Pile strength reduction factor, preferable for 0.35; A_p—Staked area (m^2); f_{cu}—The test block of indoor soil-cement (length: 70.7mm) is the same as the test block of pile cement (KPa).

Calculated according to the allowable bearing capacity of pile foundation conditions:

(3.5) $$P_a = \pi d \sum_{i=1}^{n} l_i . q_{si} + A_p . q_p = 223.34(T)$$

Where

P_a—Allowable bearing capacity of single pile (kN); d—Average diameter of pile soil-cement (m); n—The number of soil layers in the project; l_i—Thickness of layer i (m); q_{si}—Determine the allowable frictional resistance (KPa) of the pile layer i according to the Shanghai code for foundation design; q_p—The allowable bearing capacity (KPa) of the pile tip soil shall be in accordance with the Shanghai code for foundation design; A_p—Staked area (m^2).

(3) According to Vietnam standard method (using Meyerhof formula)

The safety factor of the selected pile tip is 3, and the safety factor of the bearing capacity around the pile body is 2:

(3.6) $$P_{gh} = \frac{1}{2}\pi d\sum_{i=1}^{n} L_c f_{si} + \frac{1}{3} q_m . F_c = 48.22(T)$$

Allowable bearing capacity of single pile (selected safety factor is 1.4):

(3.7) $$P_{cp} = \frac{P_{gh}}{1.4} = \frac{48.22}{1.4} = 34.44(\mathrm{T})$$

Where

P_{gh}—Allowable bearing capacity of single pile (kN); d—Average diameter of pile soil-cement (m); n—The number of soil layers in the project; L_c—Length of pile (m); f_{si}—Allowable frictional resistance of soil layer i (KPa); F_c—Mean sectional area of pile (m^2); q_m—Allowable bearing capacity of pile tip soil (KPa).

3.4.1.2. FOUNDATION DEFORMATION CALCULATION

The calculation of foundation deformation (settlement deformation) is shown in Fig. 11

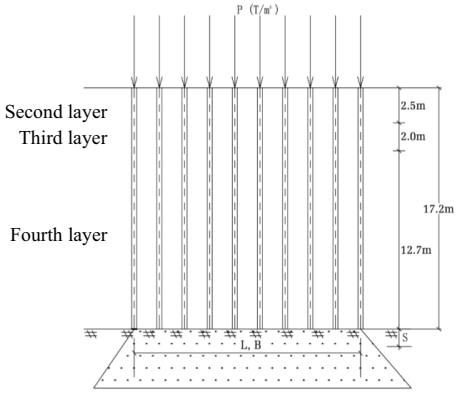

Fig. 11 Schematic Diagram of Foundation Deformation Calculation

As for the method based on the calculation model of pile foundation, the strength of the strengthened area of high-pressure rotary jet pile is very great, while the deformation of the pile is very small, so only the deformation of the foundation below the pile tip (that is, the compression amount of the underlying layer in the strengthened area) can be calculated. The compression amount of the underlying layer in the reinforcement area is calculated by the method of layered summation, and the calculation formula is as follows.

(3.8) $$S = \frac{0.8\sum \sigma_{zi}^{gl} . h_i}{E_i} \quad (E_i=293.36\ kg/cm^2; \sigma_{zi}^{gl} = k_i \sigma_0)$$

(3.9) $$\sigma_0 = (\frac{N_0 + N_{qu} + N_x}{F_{qu}}) = 66.05(T/m^2)$$

Where

S—Compression of the underlying layer in the reinforcement area (mm); σ_{zi}^{gl} — Settlement stress at the center of soil layer i (T/m^2); σ_0 — Stress at the bottom of the specified foundation block (T/m^2); N_0—load, N_0 = p.F (T); F_{qu}—Average area of the statute foundation block (m^2)； N_{qu}—Weight of the statute foundation block (T); N_x—Weight of cement (T).

Stress at zi depth according to Vietnam standards $\sigma_{zi}^{gl} \le 0,2\sigma_{zi}^{bt}$

(3.10) $$\sigma_0^{bt} = 1.94 \times 2.5 + 1.89 \times 2 + 1.88 \times 12.7 = 32.506(T)$$

The compression amount of the underlying layer in the foundation reinforcement area (the thickness of the layer is Z=1m) is calculated by the layered summation method as follows:

Table 4. Calculation of Underlying Layer (Pile Tip) Stress in Foundation Reinforcement Area

z (m)	2z/b	k_i Look at the standard (Page 43)	$\sigma_{zi}^{gl} = k_i \sigma_0$ (T/m^2)	$\sigma_{zi}^{bt} = \sigma_0^{bt} + \gamma_i z$ (T/m^2)
1	0.14	0.90	59.45	34.38
2	0.28	0.89	58.78	36.26
3	0.42	0.88	58.12	38.15
4	0.60	0.87	57.46	40.03
5	0.71	0.84	55.48	41.91
6	0.86	0.75	49.50	43.78
7	1.00	0.72	47.56	45.67
8	1.14	0.69	45.60	47.55
9	1.29	0.61	40.29	49.43

10	1.43	0.55	36.32	51.30
11	1.57	0.53	35.00	53.18
12	1.72	0.45	29.72	55.06
13	1.86	0.40	26.42	56.94
14	2.00	0.38	25.09	58.82
15	2.14	0.33	21.79	60.70
16	2.29	0.32	21.13	62.58
17	2.43	0.29	19.15	64.50
18	2.60	0.26	17.10	66.34
19	2.72	0.23	15.19	68.22
20	2.90	0.21	13.87	70.10

See table 4 for the allowable settlement in the 20 soil layer $\sigma_{z20}^{gl} = 13.87 \le 0.2\sigma_{z20}^{ht} = 14.02(\mathrm{T/m^2})$

(3.11)
$$S = \frac{0.8 \times 1(59.45 \times 0.5 + \sum_{i=2}^{19} \sigma_{zi}^{gh} + 13.87 \times 0.5)}{293.36 \times 10} = 0.19(\mathrm{m})$$

3.4.2. BASED ON NATURAL FOUNDATION CALCULATION MODEL

3.4.2.1. CALCULATION OF BEARING CAPACITY OF FOUNDATION

According to the results of pile soil-cement experiment: C_c=1(kg/cm^2); $\varphi_c = 30^0$; E_c=1566 (kg/cm^2) $\varphi_{td} = 21^007$ according to the standard 205-1998 [17,18] choose A = 0.56; B = 3.24; D = 5.85; m_1 = 1.1; m_2 = 1.0; K_{tc} = 1.0.

The calculated strength on the surface of the foundation:

(3.12)
$$p = \frac{m_1 m_2 (Ab\gamma_{II} + Bh\gamma'_{II} + Dc_{II})}{K_{tc}} = 135.9(T/m^2)$$

Distributed stress of pile body: $P_c = \mu \times p = 217.4(T/m^2)$

Where

μ —Stress concentration factor

Single pile commitment bearing capacity: $P_{gh} = P_c \times F_c = 109.25(\mathrm{T/m^2})$

Bearing capacity of foundation (selected safety factor is 1.5):

(3.13)
$$\mathrm{P_{cp}} = \frac{\mathrm{P_{gh}}}{1.5} = \frac{109.25}{1.5} = 72.83(\mathrm{T})$$

3.4.2.2. FOUNDATION DEFORMATION CALCULATION

For the method based on the natural foundation calculation model, the foundation deformation includes: (1) the compression amount of the reinforced area of high-pressure jet grouting pile is S_1; (2) the compression amount of lying down in the foundation reinforcement area of high-pressure jet grouting pile (Natural foundation area compression) is S_2. Thus, the total settlement S of the foundation under load can be expressed as the sum of the two parts as follows (see figure 12).

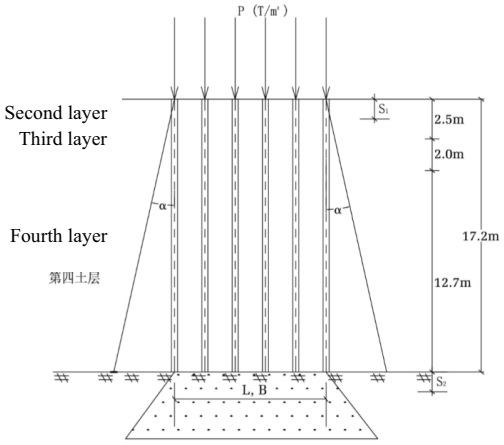

Fig. 12 Schematic Diagram of Foundation Deformation Calculation

Formula for calculating foundation deformation (total settlement):

(3.14) $$S = S1 + S2$$

(3.15) $$S_1 = \frac{q \times L_c}{E_{td}} = 0.066(\text{m})$$

(3.16) $$S_2 = \frac{0.8\sum \sigma_{zi}^{gl} . h_i}{E_i}$$

(3.17) $$\sigma_{zi}^{gl} = k_i \sigma_0$$

Settlement stress at the bottom of high-pressure jet grouting pile (at a depth of 17.2m)

(3.18) $$\sigma_{z17}^{gl} = k_{17} \times \sigma_0 = 11.67(\text{T/m}^2)$$

According to Vietnamese standard: stress at zi depth $\sigma_{zi}^{gl} \leq 0,2\sigma_{zi}^{bt}$

(3.19) $$\sigma_0^{bt} = 1.94 \times 2.5 + 1.89 \times 2 + 1.88 \times 12.7 = 32.506(T)$$

The compression amount of the underlying layer in the foundation reinforcement area (the thickness of the layer is Z=1m) is calculated by the layered summation method as follows.

Table 5. Calculation of Underlying Layer (Pile Tip) Stress in Foundation Reinforcement Area

z (m)	2z/b	k_i Look at the standard (Page 43)	$\sigma_{zi}^{gl} = k_i \sigma_{17}^{gh}$ (T/m^2)	$\sigma_{zi}^{bt} = \sigma_0^{bt} + \gamma_i z$ (T/m^2)
1	0.14	0.90	10.50	34.38
2	0.28	0.89	10.38	36.26
3	0.42	0.88	10.26	38.15
4	0.60	0.87	10.15	40.03
5	0.71	0.84	9.80	41.91
6	0.86	0.75	8.75	43.78

See table 5 for the allowable settlement in the 6 soil layer $\sigma_{z6}^{gl} = 8.75 \le 0.2\sigma_{z6}^{bt} = 8.76(T/m^2)$

(3.20) $$S_2 = \frac{0.8 \times 1(10.5 \times 0.5 + \sum_{i=2}^{5} \sigma_{zi}^{gh} + 8.75 \times 0.5)}{293.36 \times 10} = 0.012(m)$$

Foundation deformation (settlement deformation):

(3.21) $$S = S1 + S2 = 0.066 + 0.012 = 0.078 \text{ (m)}$$

3.5. COMPARISON OF CALCULATION RESULTS

According to the theoretical calculation formula, it can be seen that: (1) for the calculation of allowable bearing capacity of a single pile, the calculation model based on the pile foundation is: ① the calculation result of A.I.T method of Asian institute of technology is 21.63T, ② the calculation result of DBJ 08-40-94 method is 223.34T, ③ the calculation result of Vietnam standard (using Meyerhof formula) is 34.44T; Based on the natural foundation calculation model, the calculation result is 72.83T. By comparing the above calculation results with the field test results (37.50T), it can be seen that the results calculated by Vietnam standard (using Meyerhof formula) are the closest to the field test results. (2) for foundation deformation calculation (settlement deformation), the

calculation result based on the pile foundation calculation model is 0.19m (foundation settlement deformation), and the calculation result based on the natural foundation calculation model is 0.078m, which is less than 0.19m (foundation calculation model).

Comparing the calculated results and experimental results indicate the Hanoi area geological conditions, the allowable bearing capacity of single pile and the high pressure jet grouting pile foundation deformation calculation should be combined with the above two kinds of calculation model, form integrated computation model, namely the allowable bearing capacity calculation of the single pile with pile foundation calculation model of the same (by Meyerhof formula), is calculated using the same as the natural foundation of foundation deformation calculation model.

4. CONCLUSION

In this paper, the application of high pressure jet grouting pile in an underground project in Vietnam is studied, and Trung Hoa tunnel in Hanoi is selected as the project case. Based on the construction requirements, theoretical calculation results, field measurement and test results, the following conclusions and results are obtained.

(1) By summing up the geological and hydrological conditions of the project, the foundation treatment measures are done according to the geological survey results and the practical situation of the project, and the calculation model of allowable bearing capacity of single pile and foundation deformation is established, which can provide reference for the design and construction of similar projects in the future.

(2) The project adopts the double tube method, the high pressure jet grouting pile test parameters of the high pressure jet grouting pile is adopted to improve the high pressure jet grouting pile construction, and stop water heavy curtain reinforcement effect better, improve the foundation soil, meet the needs of the tunnel excavation, and settlement of foundation pit is almost small (0.078m), ensure the overall stability of retaining structure. This method will be fully applied in the tunnel excavation and the later construction of Hanoi Metro Line 5.

(3) Based on the construction process of Trung Hoa tunnel in Hanoi, this paper conducts theoretical calculation in reference to the construction data, compares and analyzes the calculated results with the test results, and searches for the optimal results by referring to the Vietnamese standard. On this basis, a comprehensive calculation model for the geological conditions of high pressure rotary jet pile in Hanoi is proposed, that is, the calculation model for the allowable bearing capacity of single pile

is the same as that for pile foundation (using the Meyerhof formula), and the calculation model for foundation deformation is the same as that for natural foundation.

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LIST OF FIGURES AND TABLES:

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