Performance of Rapidjet System JGP Soil Improvement Works in Deep Basement Excavation

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ABSTRACT

This paper presented a case study of Rapidjet system jet grout pile (JGP) ground improvement works performance for deep basement excavation works from design stage to construction and finally the testing and quality control of the JGP are presented. The project site is consisting of clayey silt (F2), underlay with a highlyweathered granite (GIV) to 47 m, and overlying the moderated slightly weathered granite (GII). In view of the close proximity of the proposed deep basement to the existing MRT tunnel and existing novena hospital structures, the project site excavation of 18.0 m in depth was supported with secant bore pile (SBP) of 1.2 m in thickness and 33.1 m in length,three layers of struts were installed, and a 2.4m thick JGP was proposed below final excavation ground level 18m.In this application, JGP was used to form a cross beam of compression member to reduce wall deflection. In addition, the foundation bored pile have been constructed prior JGP work. There is a challenge for carry out JGP after bore pile casted below ground level 18m, because that is a tendency of damage of pile head and significant pile head movement cause by JGP.

Key words：jet grouting; soil improvement; case study

1. INTRODUCTION

This project involved the design and construction to proposed additions and alterations comprising 2 basement medical facilities and ancillary works to existing 14-storey hospital with 2 basements at Mount Elizabeth Novena Hospital. Global Civil Engineering Pte. Ltd (GCE) secured the foundation works project through main contractor Takenaka Corporation Singapore with the support of Sanshin's technology and expertise using Rapidjet system Jet grout pile (JGP) for this job. To minimize the impact on existing structure, the Rapidjet grouting method which consisted of a modified jet nozzle at 1:10 dispersion angle with increased flow rate and grouting pressure maximum of 350 bar was adopted for this project. Work sequencing was carried out to avoid any gap within foundation bored piles. GCE conducted the Rapidjet trial panel for jet grout pile to establish right operation parameter in May 2019. Actual JGP works started in September 2019 and was completed in November 2019. During the course of JGP, there are settlement markers installed in various locations, the readings were consistent and did not breach PDL (Pre-Determined Level). The construction work for deep basement was successfully accomplished.

2. SITE CONDITIONS

The soil conditions of the project site primary consists of clayey silt (F2), underlay with a highly weathered granite (GIV) to 47 m, and overlying the moderated slightly weathered granite (GII) as shown in Figure 1.In view of the close proximity of the proposed deep basement to the existing MRT tunnel and existing Novena Hospital structures, secant bore pile (SBP) with diameter 1.2 m as a retaining wall with 3 layers of horizontal struts for 2 basements excavation at Mount Elizabeth Novena Hospital, final excavation level is about 18.0 m. Below the final excavation level, JGP grout slab with about 2.4 m thickness was construction by Rapidjet jet grout method as shows in Figure 1.In this application, JGP was used to form a cross beam of compression member to reduce wall deflection. Figure-2 as a JGP layout plan of the project, quantity of JGP as shown in Table 1, total quantity of JGP was 281 nos.

Table-1. Quantity of JGP

Type	Diameter, m	Quantity
1	1.0	34
2	1.2	45
3	1.8	64
4	2.2	138
Sum		281

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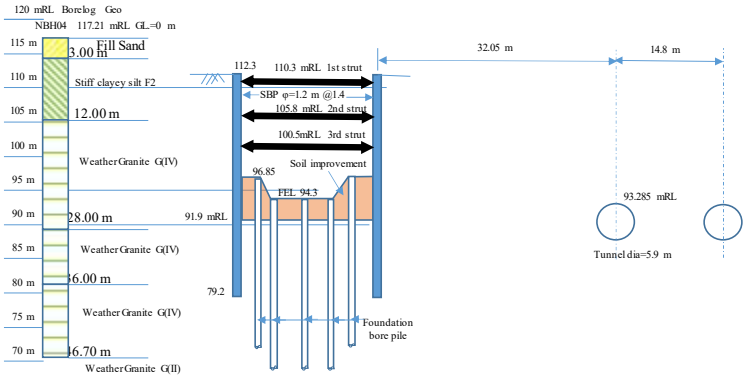

Figure-1 Typical soil profile and cross section

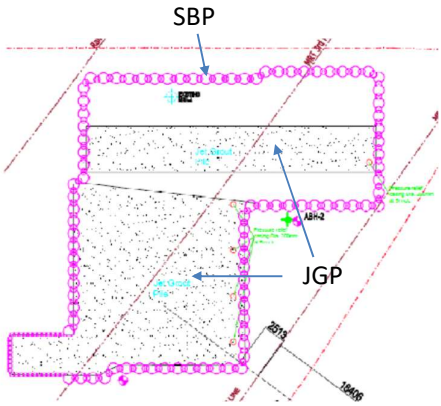

Figure-2 Actual JGP layout plan

3. DESIGN PARAMETER OF JGP

Design parameter of JGP, modulus of elasticity of grouts (E_{50}) Eu=150 MPa and undrain shear strength Cu=300 kPa, total coring recovery (TCR) not less than 85%. Base on the soil bore log report, the following Jet Grouting Pile Parameters are proposed as per Table-2.

Table-2: Jet grouting pile operation parameter

Parameter	1.0 diameter	1.2 diameter	1.8 diameter	2.2 diameter
Lifting Rate min/m	2 ~ 4	2 ~ 5	7 ~ 10	11 ~ 14
Rotation Rpm	5 ~ 7	7 ~ 10	7 ~ 15	7 ~ 15
Pressure Bar	150 ~ 180	230 ~ 280	250~350	300 ~ 350
Flow Rate L/min 18	80~120	180	180	180
Water: Cement Ratio	1.1 ± (0.2)	1.1 ± (0.2)	1.1 ± (0.2)	1.1 ± (0.2)

4. RAPIDJET TRIAL TEST

GCE conducted the Rapidjet trial panel for jet grout pile to establish right operation parameter in May 2019,7 trial piles (T1 ~ T7) of 20.8 m deep drill in this project with pile diameter 1.8 m to 2,2 m as shown in Table-3. Piles diameter was verified later with paint bar during jet grouting, and also did a surface grouting for function test (T8) and confirm the diameter. The overall JGP plan and trial panel trial test plan as shown in Figure-3 & 4. Samples was taken to conduct unconfined compressive strength (UCS) and modulus of elasticity of grouts (E_{50}), total coring recovery (TCR) for each core also be recorded.

Table-3 Summary of trial test

Jet grout pile No	Quantity	Diameter (m)	Design cut off level (m)	Design Toe level(m)	Jet grout length (m)
T1,T2	2	2.2	15.25 (97.45 mRL)	20.8 (91.9 mRL)	5.55
T4,T5,T6	3	1.8	15.25 (97.45 mRL)	20.8 (91.9 mRL)	5.55
T7,T3	2	1.2	15.25 (97.45 mRL)	20.8 (91.9 mRL)	5.55
T8 (Function test)	1	2.2	1.0 (111.7 mRL)	2.0 (109.7 mRL)	1

Note: Ground Level=112.7 mRL

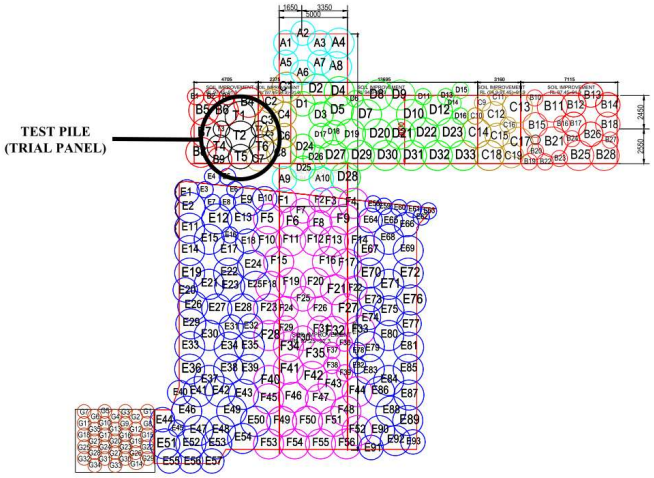

Figure-3 Overall JGP layout plan

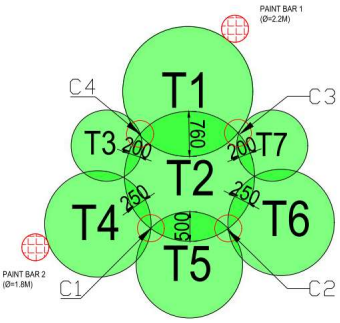

Figure-4 Trial panel layout plan

Test results of trial panel as shown in Table-4, average qu was equal to 2.14 MPa, and Cu = qu/2 = 1.12 MPa, which in line with design parameters Cu=0.3 MPa, average E_{50} was equal to 547 MPa, which also in line with design parameters Eu=150 MPa, only one sample C1-3 showed premature failure due to the defective sample when cutting, the additional 2 samples C1-3A and C1-3B that were subsequently reselected for testing, and the results passed . Average TCR for coring points C1 to C4 were 96%, 96%, 98% and 96% respectively. It was observed that all points have satisfied the minimum requirement 85%. Prior to the JGP trial panel works, an inclinometer has been installed to monitor and detect movements that may have been influenced by the jet grouting works. Figure-5 displays the location of the inclinometer installed. The trial panel JGP started on the 14th of May 2019 and ended on the 18th of May 2019. It shown that the maximum displacement of inclinometer reading during JGP Trail Panel works was only 4.52mm, which proved that the JGP trial panel works had only minimal impact on the movement of the surrounding ground. Based on the predetermined Allowable Limits (31 mm) and Work Stop Limit (44 mm), the results are well within both limits. Therefore, it is safe to conclude that the JGP Trial Panel works had minimal impact on the surrounding ground. Based on the visual observation on the cement stains and paint marking on the paint bar 1 and 2 as per shown in Figure-6, It prove that the trail panel jet grout pile have form the required diameter.

Table-4 Test results of trial panel

Sample No	Depth,mRL (Top of Sample)	Depth,m (Top of sample)	E_{50},Mpa	qu, Mpa
C1-1	97.9	14.8	234	0.715
C1-2	93.9	18.8	1068	4.548
C1-3	92.9	19.8	126	0.398
C1-3A	96.2	16.5	503	1.116
C1-3B	92.7	20.1	492	2.094
C2-1	97.9	14.8	879	2.109
C2-2	95.9	16.8	285	1.480
C2-3	92.9	19.8	1429	5.259
C3-1	96.9	15.8	608	1.909
C3-2	93.9	18.8	423	1.990
C3-3	92.9	19.8	324	1.652
C4-1	97.9	14.8	551	2.811
C4-2	94.9	17.8	182	0.987
C4-3	93.9	18.8	560	1.869

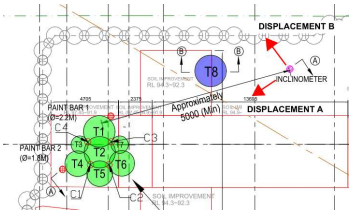

Figure-5 Instrumentation layout plan

Figure-6 Trial test paint bar photo

5. ADVERSE EFFECT OF GROUTING WORK

In addition, the foundation bored pile have been constructed prior JGP work. There is a challenge for carry out JGP after bore pile casted below ground level 18m, because that is a tendency of damage of pile head and significant pile head movement cause by JGP. The grouting pressure was also modelled in Plaxis for the impact assessment with the grouting pressure at nozzle dispersed at 1:10 angle towards SBP wall as shown in Figure-7. The 1:10 dispersion angle is measured from actual field trial of RapidJet. The proposed maximum grouting pressure at nozzle varies from 150-350 bar respectively for 1.0m to 2.2m diameter RapidJet column as shown in Table-5. It is evident from the findings that a smaller nozzle dispersion angle in Rapidjet system would result in a smaller or lighter impact to existing structures. The theoretical values obtained from Plaxis analysis on predicted horizontal displacement of 3.9mm (maximum) and vertical displacement 1.5mm. The Rapidjet full flushing feature with 80% replacement slurry. Hence, the impact to be insignificant to cause on ground heaving. In addition, the foundation bored pile have been constructed prior JGP work. The adverse effect contribute from the grouting is residual soil liquefaction and cement hydration.

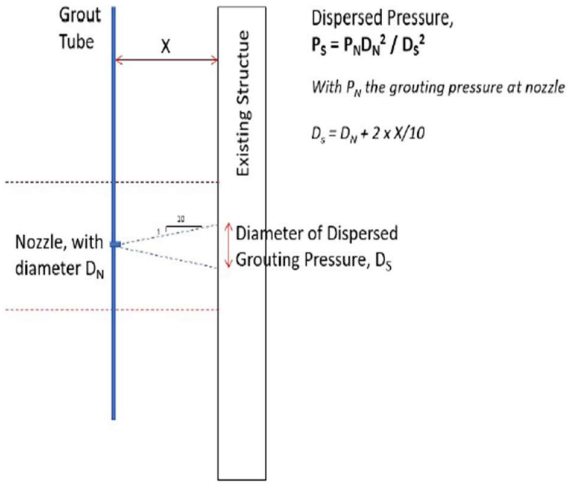

Figure-7 Modelled of grouting in Plaxis

Table-5 Jet grouting piles -parameters

Description	Unit	Diameter (m)			
		1.0	1.2	1.8	2.2
Lifting rate	Min/m	2 ~ 4	2 ~ 5	7 ~ 10	11 ~ 14
Rotation	Rpm	5 ~ 7	7 ~ 10	7 ~ 15	7 ~ 15
Pressure	Bar	150 ~ 180	230 ~ 280	250 ~ 350	300 ~ 350
Flow rate	L/min	80 ~ 120	180	180	180
W/C	Ratio	1.1± (0.2)	1.1± (0.2)	1.1± (0.2)	1.1± (0.2)
Slurry density	g/cm^3	1.45 ~1.52	1.45 ~1.52	1.45 ~1.52	1.45 ~1.52

6. ACTUAL JGP WORKS

Actual JGP works started in September 2019 and was completed in November 2019. Total quantity of JGP as 281 with diameter 1.0 m, 1.2 m, 1.8 m and 2.2 m, maximum drill depth about 20.8 m. There are 24 samples was selected to conduct unconfined compressive strength UCS(qu) and E_{50}, test results as shown in Table-6. Average qu is equal to 14.0 MPa, and Cu= qu/2 = 7.0 MPa, which much higher than the design parameters Cu = 0.3 MPa, average E_{50} is equal to 1721 MPa, which also much higher than design parameters Eu (E_{50})= 150 MPa. Average TCR for coring points also greater than 85%. Variations in qu, E_{50}, and unit weight with depth as shown in Figure-8. In order to minimise the movement and pressure involved in JGP construction toward the foundation bored pile, JGP around the foundation bored pile are constructed in a correspond order which is to balance the pressure towards the foundation pile surface. Figure-9 illustrate the sequence of JGP work around the foundation bored pile. After JGP works completed around the foundation bore pile, the remaining JGP points will only be continued to install. The constructed JGP will be acted as a protective barrier around the foundation bored pile and to prevent the built up pressure which may exerted on the foundation bored pile. During the course of JGP, there are settlement markers installed in various locations, the readings were consistent and did not breach PDL (Pre-Determined Level). One inclinometer was installed close to the existing ERSS sheet pile to monitor and detect movements that may have been influenced by the jet grouting works. Figure-10 displays the location of the inclinometer installed. The eccentricity of existing sheet pile after completed JGP work and inclinometer monitoring results shows that the lateral movement cause by JGP works is very minor.

Table-6 Test results of actual JGP works

JGP No	Sample No	Depth,m	E_{50},MPa	qu, MPa
BH26	S-1	19.8	1679	15.514
	S-2	18.3	1936	15.956
	S-3	15.3	1601	14.249
D7	S-1	20.2	1867	14.253
	S-2	18.9	1780	10.964
	S-3	17.8	1710	14.990
D19	S-1	20.7	1568	15.149
	S-2	19.3	2021	15.053
	S-3	17.8	2118	15.122
B43	S-1	17.0	1976	15.608
	S-2	16.7	2098	16.367
	S-3	15.5	1787	14.118
F5	S-1	20.4	1534	15.771
	S-2	17.0	1059	10.113
	S-3	15.5	1631	13.214
F41	S-1	20.2	1272	10.431
	S-2	18.2	1783	14.444
	S-3	16.2	1384	10.654
G13	S-1	18.5	2134	13.657
	S-2	16.3	1652	15.525
	S-3	9.6	1723	13.993
G15	S-1	18.7	1638	11.730
	S-2	14.8	1991	14.295
	S-3	9.5	1363	13.993

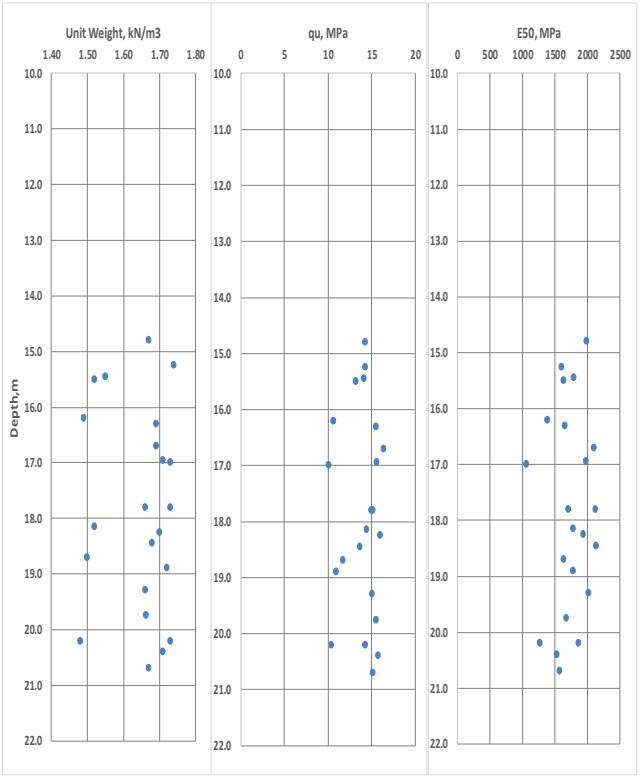

Figure-8 Variations in qu, E_{50}, and unit weight with depth for actual JGP works

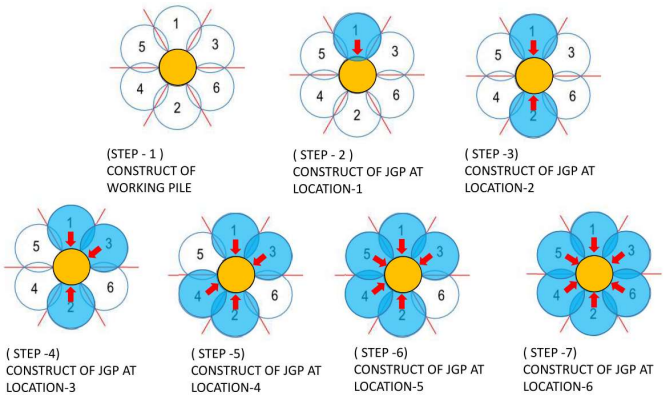

Figure-9 JGP construction sequence around the foundation bored pile

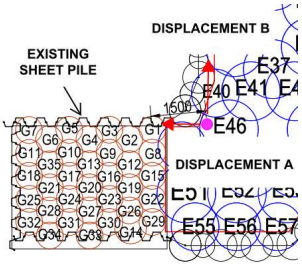

Figure-10 Instrumentation layout plan

7. CONCLUSIONS

GCE conducted the Rapidjet trial panel for jet grout pile to establish right operation parameter in May 2019, 7 Rapidjet jet trial piles of 21 m deep drilled in this project, all grout piles are expected to have a nominal diameter of 1.2 to 2.2 m, which was verified later with paint bar during jet grouting, and also did a surface grouting and confirm the diameter. Samples was taken to conduct unconfined compressive strength (UCS) and modulus of elasticity of grouts (E_{50}), total coring recovery (TCR) for each core also be recorded. Actual JGP works started in September 2019 and was completed in November 2019. During the course of JGP, there are settlement markers installed in

various locations, the readings were consistent and did not breach PDL (Pre-Determined Level). The as built eccentricity of foundation bored pile results also prove that the movement of pile head is minor even though JGP works is after the installation of foundation bored pile. It shown that, there are no significant lateral movement to existing sensitive structures during and after JGP works. The construction work for deep basement was successfully accomplished.

8. ACKNOWLEDGEMENTS

The Authors are indebted to the following organizations: Global Civil Engineering Pte. Ltd (GCE) secured the foundation works project through main contractor Takenaka Corporation Singapore with the support of Sanshin's technology and expertise using Rapidjet system Jet grout pile (JGP) for this job

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