A case study of effectiveness of large diameter jet grout for soil improvement works in soft marine clay

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ABSTRACT: This paper reports a case study of using the Rapid-Jet system jet grouting for installation of jet grout piles (JGP) in soft marine clay. The use of JGP is part of the ground improvement works for the construction for one of the tunnelling projects that is constructed by China Railway First Group Co. Ltd. Singapore. The tunnel went through a soft marine clay layer which needed to be grouted from below the tunnel to the Old Alluvium (OA) layer. At the project site, there was a 1.8 m outer diameter stormwater pipe crossing the tunnel alignment at 8 m below ground level. The pipe obstructed the installation of JGP piles in marine clay. The Rapid-Jet method was adopted. A field trial programme is conducted to verify the application of the adopted jet grouting parameters. Five trial jet grout columns with sound pipes were carried out. Each panel consisted of a 3 m diameter JGP column to a depth of about 46.6 m in soft marine clay. The nominal diameter of the JGPs was 3.0 m which was verified by the sound detector during jet grouting and excavation after installation. Four coring points were used to obtain cores through the full depth of the grouted block. Nineteen SPT tests also carried out in grout block, 24 samples were taken for unconfined compression tests. The total coring recovery (TCR) for each core were also recorded. The settlements monitored during JGP were consistent and did not breach the alert level. The working parameters were proven to be suitable for the actual JGP works.

1. INTRODUCTION

For the construction of the tunnelling project in Singapore undertaken by China Railway First Group Co. Ltd. Singapore. A tunnel needs to go through a soft marine clay and is required to grout below tunnel until it reaches a very stiff old alluvium layer. Most of the grouting was done by using the deep soil mixing (DSM) method, however, they found a 1.8 m outer diameter storm water pipe crossing the tunnel alignment at 8 m below ground level which was supported by reinforced concrete pile below. With the existence of this pipe, the DSM method could not be carried out, so the conversion of the DSM to a large diameter of grout pile was needed. The grout pile needs to serve two purpose: (1) to improve the ground from tunnel until the old alluvium layer and; (2) to grout to the bottom of the storm water pipe as a support to transfer the load below, as the piles will be cut away when the tunnel boring machine (TBM) is reached. The average grout depth is 37 m, and the average drill depth is 45 m.

2. SITE CONDITIONS

The site and trial panel location is shown in Figure 1. The soil profile along Section F is shown in Figure 2. The 1.8 m outer diameter stormwater pipe at 8 m below the ground is shown in Figure 2. The cross-sections of the two tunnels passing through soft marine clay are also shown in Figure 2.

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The groundwater level was about 1.8 m below the ground level. The soil profile can be divided into five layers: (1) the sand fill layer with an average depth of 14.5 m consisting of fine to coarse-grained sand with gravels. The SPT *N* value ranged from 3 to 16 in this layer; (2) the very soft upper marine clay layer with a depth to 23 m; (3) the stiff fluvial clay layer, F2 with a depth to 28.7 m and SPT *N* value of 8 - 9; (4) the very soft lower marine clay layer with a depth to 44.8 m; and (5) the Old Alluvium (OA) layer consisting of medium-dense to dense cemented clayey sand with a depth to 44.8 m and SPT *N* value of 24 - 36.

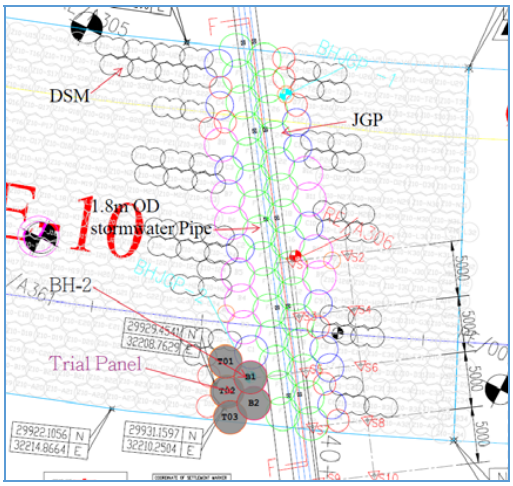

Figure 1. Site and trial panel location

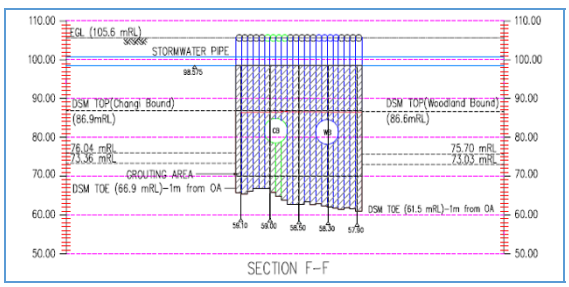

Figure 2. Cross section of F-F

3. RAPID-JET TECHNOLOGY

Similar to the commonly used JSG method, the large diameter jet grouting method (commercially named the Rapid-Jet method) uses a double-tube grouting system with two nozzles on the opposite side of the monitor. The latter also uses air and jet stream to cut and mix the in-situ soil with grout. A larger nozzle diameter of 3 - 4.2 mm is used to allow for a larger grouting rate. The jet grouting parameters of this method are similar to those proposed by Burke (2004) and Lunardi (1997). The grouting parameters used here are as follows: grouting pressure = 30-34 MPa, grouting rate = 120 - 380 *L*/min, and rod rotation and withdrawal rate = 3-10 rpm and 10-12 min/m. Using these grouting parameters that can be rapidly install a grout pile with a diameter up to 2.0-3.5 m at a depth up to 50 m below ground surface. There are two categories in Rapid-Jet system – R1 and R2, in which particular parameters are available as shown in Table 1. Each class involves representative equipment. Water jet test of Rapid-Jet type R2 on site as shown in Figure 3. Typical Rapid-Jet installation procedure as shown in Figure 4, the working procedure as 1) Setting up Rapidjet machine to the required position for drilling. 2) Drilling with Rapidjet monitor directly until designed depth. 3) Carry out the trial test to check the parameters are correct or not. 4) After pre-jetting, raising the double tube rods automatically forming jet grout columns. 5) Removing all rods after jetting work is finished. The acoustic monitoring device is shown in Figure 5; it can be used to detect the quantitative intensity of erosion by jet grout and helps to assess the column diameter (Cheng et al. 2017). This system collects eroding sound at monitoring pipes located on several positions as shown in Figure 5. Sound collectors are synchronized with jet grout depth.

Table 1. Rapid-Jet standard construction specifications

Type	R1	R2
Column Diameter, m	2-3	3-3.5
Drilling method	Direct drilling	Direct drilling
Installation method	Double tube	Double tube
Grout Pressure, MPa	30-34	30-34
Grout Flow Rate, *L*/min	120 - 260	300 - 380
Air Pressure, MPa	0.70 - 1.1	0.70 - 1.1
Air Flow Rate, m^3/min	Over 6	Over 10
1 Step, cm	2.5	2.5
Lift Rate, min/m	10 - 12	10 - 12

Figure 3. Water jet of Rapid-Jet (Type R2)