Blanket Jet Grouting for Uplift Prevention in Deep Excavations for Bangkok MRT Purple Line Project

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Abstract: The jet grouting method is widely used in deep excavations to control uplift pressure, but challenges often arise in projects such as MRT tunnels with significant depths. At Intervention Shaft 05 (IVS05) of the Purple Line Project (Contract 3: Phan Fa–Memorial Bridge Section) in Bangkok, a 36.2 m deep excavation supported by a 44.3 m diaphragm wall was implemented. Groundwater was encountered at 15 m depth, with the base comprising a 2.5 m sand layer over a 7.5 m stiff clay layer. Jet grouting using 2.8 m diameter columns and the Rapidjet technique was applied to stabilize the base. The factor of safety was 1.6 when frictional resistance was included but dropped to 0.65 without it. Laboratory and field pumping tests validated the design parameters, confirming that Rapidjet grouting improved ground stability, reduced permeability, and achieved significant savings in both construction time and cost.

Keywords:* *Rapidjet method, Blanket jet grouting, Deep excavation.

Introduction

Jet grouting techniques are frequently used to ensure the stability and waterproofing required for constructing high-risk, challenging underground infrastructure (Sakar, et al., 2022; Shakya, et al., 2023; and Yamazaki, et al., 2024). In this paper, we examine a deep excavation project located at Intervention Shaft 05 (IVS05), part of the Purple Line Project, Bangkok, Thailand. A 2.5-meter-thick jet grout column with a diameter of 2.8 m, constructed using the Rapidjet method, was implemented below the base of the excavation level to prevent the risk of uplift in the second stiff clay layer during construction. This paper reviews the uplift design and verifies the effectiveness of the base grouting work. To assess this, field pumping tests with the constant rate method and water recovering method were conducted to measure the permeability of the grout zone at the excavation site. The design parameters for the grouted materials were further verified through laboratory testing of core samples obtained from the site.

Rapidjet Grouting Method

The Rapidjet method utilizes a high-pressure grout slurry to erode and mix the in-situ soil, forming soil-cement mixture columns with diameters of up to approximately 3.5 m. A double-tube grouting system, equipped with two nozzles on opposite sides of the jetting device, enables efficient grouting with large diameters and high-speed construction (Cheng, et al., 2023; Neaupane, et al., 2023).

IVS05 Project Blanket Jet Grouting

The IVS05 project is 26.3 m in length, 16.94 m in width, with an excavation depth of 36.21 m, and is retained by a 44.3 m deep diaphragm wall. The site predominantly consists of soft to stiff clay, with interlayers of sand. A soft clay with fill layers is present within the upper 17 m. The first stiff clay layer is located at depths of 17 to 28.7 m, followed by the first sand layer between 28.7 and 38 m. The second stiff clay layer lies at depths of 38 to 45.5 m, with the second sand layer located below 45.5 m and about 19.5 m thick. A 2.5 m thick jet grout column with a diameter of 2.8 m, constructed using the Rapidjet method, was installed below the base of the excavation level to prevent the risk of uplift in the second stiff clay layer during construction. A total of 92 jet grouting piles were installed.

The uplift factor of safety for considering friction between the diaphragm wall, jet grout, and clay was calculated to be 1.6, which exceeds the minimum required value of 1.5. However, without considering soil/gout to wall friction, the factor of safety is only 0.65, which is less than the generally accepted value of 1.2.

Pumping Tests

The objective of the pumping tests is to verify that the permeability (*k*) during the pumping test is less than 5E-5 cm/s. To verify the effectiveness of the base grouting work, the following stages were conducted: Stage 1:

Pumping and lowering the groundwater inside the shaft down to a level close to the excavation base. Stage 2: Once the groundwater stabilized inside the shaft, a constant rate pumping test was carried out. Stage 3: After completing Stage 2, the pump was shut down, and a recovery test was conducted.

Figure 1 shows the results of the pumping tests. In Stage 1, the groundwater inside the shaft was lowered from a depth of 14 m to 30 m over approximately 46 hours. During this stage, the water level outside the shaft remained almost constant at a depth of around 15 m. In Stage 2, the constant rate permeability test was conducted. The flow rate was controlled at approximately 11 L/min. The seepage flow distance was assumed to be the thickness of the blanket (2.5 m) plus the second clay layer (7.5 m), giving a total distance of 10 m for the calculation. The resulting permeability coefficient ($k_{lowering}$) was 3.95E-5 cm/s. In Stage 3, the recovery permeability test was conducted, with the same seepage flow distance as in Stage 2 (10 m). The resulting permeability coefficient (k_{rising}) was 9.02E-6 cm/s. Both k values calculated from Stages 2 and 3 are less than the required design parameter of k = 5E-5 cm/s.

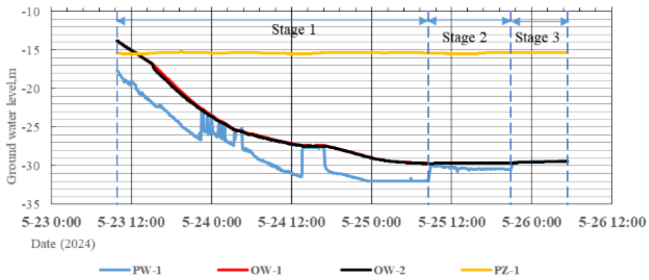

Figure 1, Pumping tests recorded.

Blanket Jet Gout Coring Test Results

The completion of the jet-grouted piles is based on the requirement that the unconfined compressive strength (UCS) of the cement-treated soil columns must reach a minimum design value of 2.0 MPa for the sandy soil layer. The average UCS and E50 values of the core samples are 10.2 and 401.6 MPa, respectively.

Estimation of Jet Grout Diameter

Yamazaki's empirical formula for estimating the diameter of the jet grouting column was utilized to estimate the improvement column diameter for sandy layers (Yamazaki et al., 2024).

$$S = 64.0P_m^{0.271} d_0^{0.325} Q_e^{0.190} N^{0.233} V_{tr}^{-0.025} \quad (1)$$

Where: S = soil eroding distance (cm); P_m = jet injection pressure (MPa); d_0 = nozzle diameter (cm); Q_e =air injection volume (Nm^3/min); V_{tr} = moving speed (cm/s); N= eroding times.

Using the parameter obtained from the IVS05 project, the effective jet grouting diameter was estimated to be equal to 3.81 m using Equation (1). The estimated diameter is much larger than the design diameter of 2.8 m.

Acknowledgements

The authors wish to thank the following organizations for providing valuable construction records for conducting this study: The ITD - NWR MRT Joint Venture, Sanshin Construction (Thailand) Co., Ltd., and ISEKI Engineering (Thailand) Co., Ltd.

Conclusions

The conclusions from this study are provided as follows:

- The calculated FOS for shaft IVS05 was 0.65 without considering the wall-soil/jet grout friction and increased to 1.6 when the friction was considered.
- The $k_{lowering}$ and k_{rising} of pumping tests are 3.95E-5 cm/s and 9.02E-6 cm/s, respectively, which meet the requirement of the design value of 5E-5 cm/s.
- Using Yamazaki's empirical formula, the blanket jet grout diameter was estimated to be 3.81 m, which is much larger than the design diameter of 2.8 m.
- This study demonstrates that the large-diameter jet grouting technique effectively meets the design requirements of the treated materials. Furthermore, the construction time and associated costs were reduced using this technique.

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