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Jet Grouting for Mitigating Impact of Secant Pile Wall Installation in Close Proximity to Existing Building

Chu E. HO[a,1] and Aaron EVANS[b,2]
[a] *Arup, USA*
[b] *Nicholson Construction Company, USA*

Abstract. Jet grouting was implemented to protect an existing building against the impact of adjacent secant pile wall installation located 2ft from the building edge. Sixteen vertical jet grout columns, 5ft in diameter and spaced at 47ins intervals, were installed at 1.5ft offset from the external face of the building to form a continuous grout wall to underpin the basement foundations. As the secant pile wall was located in close proximity to the row of underpinning jet grout columns, subsequent casing installation would be problematic having to drill through partially grouted and partially ungrouted soils. The unbalanced drilling would lead to significant pile deviation and cause damage to the completed underpinning jet grout columns. To overcome this, an additional row of jet grout columns was introduced along the secant pile wall line at the primary pile positions to provide full coverage of grouting for the drilling platform. A range of column diameters from 5 to 6.5ft was formed to ensure effective interlock between columns. This innovative scheme provided a stable platform that allowed the secant piles to be installed through consistent material and minimized disturbance to the adjacent building foundation. This paper discusses the design considerations and practical issues associated with the implementation of the jet grouting work.

Keywords. Secant pile walls, jet grouting, underpinning, casing installation.

1. Introduction

Construction of the 96th Street Station on the newly extended Q subway line in New York City included two ancillary buildings located in close proximity to adjacent fragile buildings. These fragile buildings were typically four to five stories high with a single level rubble wall basement supported on timber piles or seated directly on the fill. The buildings were more than 100 years old. Several of the buildings had to be strengthened and underpinned to improve the stability of the structures prior to the new construction [1].

Permanent secant pile walls were adopted as the earth support system for construction of the ancillary buildings. The walls were internally braced by several levels of preloaded steel struts to limit ground displacements caused by the excavation of the basements which ranged from 60 to 70ft deep [2]. At one of the ancillary structures, a jet

[1] 77 Water Street, New York, NY10005, USA.
[2] 8725 West Higgins Road, Suite 820, Chicago, IL 60631, USA.

grouted slab strut and grout wall scheme was implemented to control deep-seated inward wall displacements due to the presence of thick soft soil deposits [3].

While mitigation of excavation-induced ground movements can be controlled by the adoption of a stiff earth retention system, a more problematic issue was the impact of the secant pile wall installation itself on the existing buildings. At Ancillary 1, where the rock head was shallow and close to the excavation bottom, it was possible to protect the building by underpinning with micropiles [4, 5]. The micropiles would also provide relief of the building loads acting on the retained face of the secant pile wall. The situation at Ancillary 2 was more challenging, as it was located in an area of deep rock and a thick bed of soft soils, which would render micropiles ineffective. This paper presents alternate mitigating measures implemented at Ancillary 2.

2. Construction of Ancillary 2 Substructure

Ancillary 2 was located adjacent to a 4-story building. The ground surface was generally level at EL+111 to EL+112ft. The subsurface comprised fill, soft organics, loose to medium dense silty sands and highly sensitive glacial deposits of varved silt and clay that extended to depths greater than 120ft. Figure 1 shows typical soil conditions in the vicinity of the site based on cone penetration test CPT 96-1. As can be seen, the cone tip resistance (Q_t) remained largely unchanged with depth, averaging about 80 to 100tsf below 30ft depth within the silty sands and varved silts/clays. Water table was about 10ft below ground.

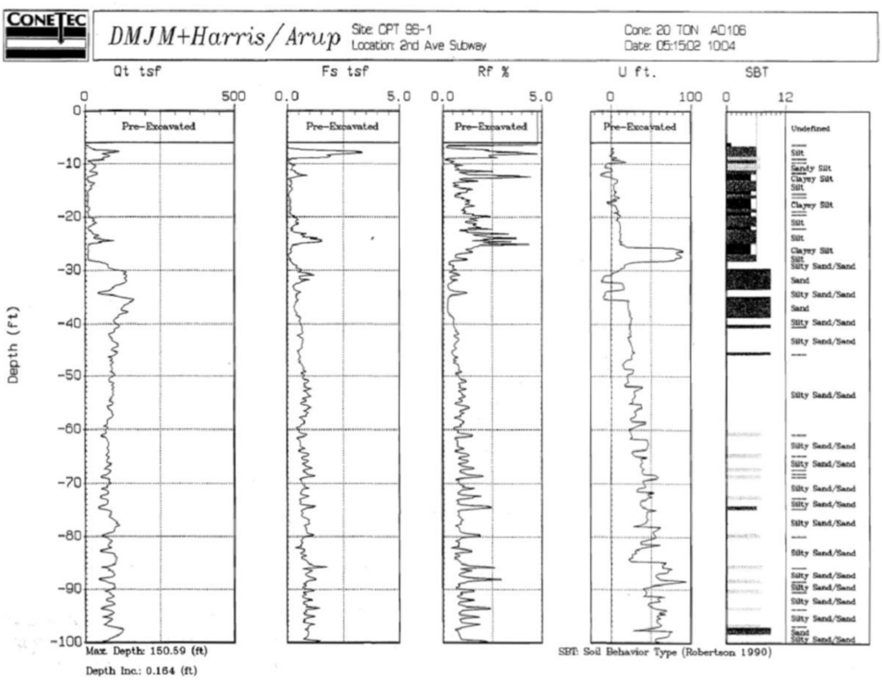

Figure 1. Soil strength profile based on CPT 96-1.

Figure 2 shows the excavation support scheme at Ancillary 2. The secant pile wall consisted of overlapping drilled shafts 34.5ins in diameter and spaced 23.5ft apart. Primary piles were cast with 1000psi plain concrete, whereas secondary piles were cast with 4000psi concrete with a W18x258 lbs/ft structural steel core beam installed at their centers. All primary piles were constructed to EL+27ft (85ft depth). The secondary piles were constructed to between EL-5ft to EL-10ft (117 to 122ft depth). The clear distance between the secant pile wall and the adjacent 4-story building was only 2 feet.

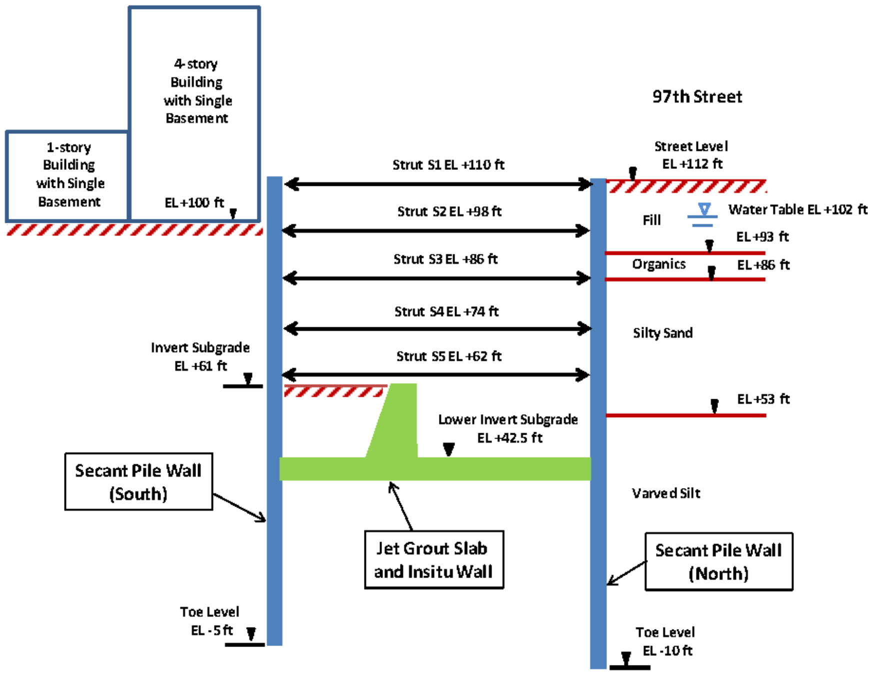

Figure 2. Excavation support system for construction of Ancillary 2.

3. Underpinning Options

Initial test pit investigations along the adjacent 4-story building indicated the foundation wall was made out of stones and typically 18ins thick, with continuous stone footings extending 7 to 11.5ins beyond the external wall face. The footings were between 0.6 and 0.71ft thick with bottom elevations varying from +102.0 to +103.05ft. Groundwater table was found at elevations ranging from +101.15 to +102.12ft within the test pits. The investigations also uncovered 9 to 12ins diameter timber piles in an approximately staggered layout beneath the foundation footings, but the termination depths were unknown. Many piles were in poor condition and several were found disengaged from the footings, suggesting the building loads were essentially carried directly on the ground. Hence, any disturbance to the foundation soils would be potentially detrimental to the stability of the building.

The key purpose of the underpinning effort was to ensure that the building loads were still supported in the event the foundation soils were disturbed during secant pile installation, in particular within the potentially liquefiable glacial deposits. The rock at this location was deep and there was no competent soil stratum in which to found micropiles. Ground modification was considered a viable alternative. Several grouting techniques were evaluated using field trials on the site. The trials simulated permeation and compensation grouting through inclined injection pipes to be located beneath the adjacent building, as well as vertical compaction grouting columns to be formed directly under the stone footings along the building edge [6, 7]. Although the trials suggest these techniques were potentially effective in controlling ground settlements, there were concerns regarding the interference of existing timber piles with grout pipe installation, as well as the pressurization of the organics which could result in significant displacement of the timber piles due to bulk undrained shearing of the organics. In the final analysis, jet grouting was considered most favorable as the soil surrounding the timber piles would be disintegrated by the erosion process, resulting in the encapsulation of the timber piles by the fluid soil-cement mixture. This could be achieved with minimal disturbance by appropriate selection of jetting parameters.

4. Jet Grout Underpinning Scheme

Figure 3 shows the jet grouting scheme adopted for underpinning the adjacent 4-story building.

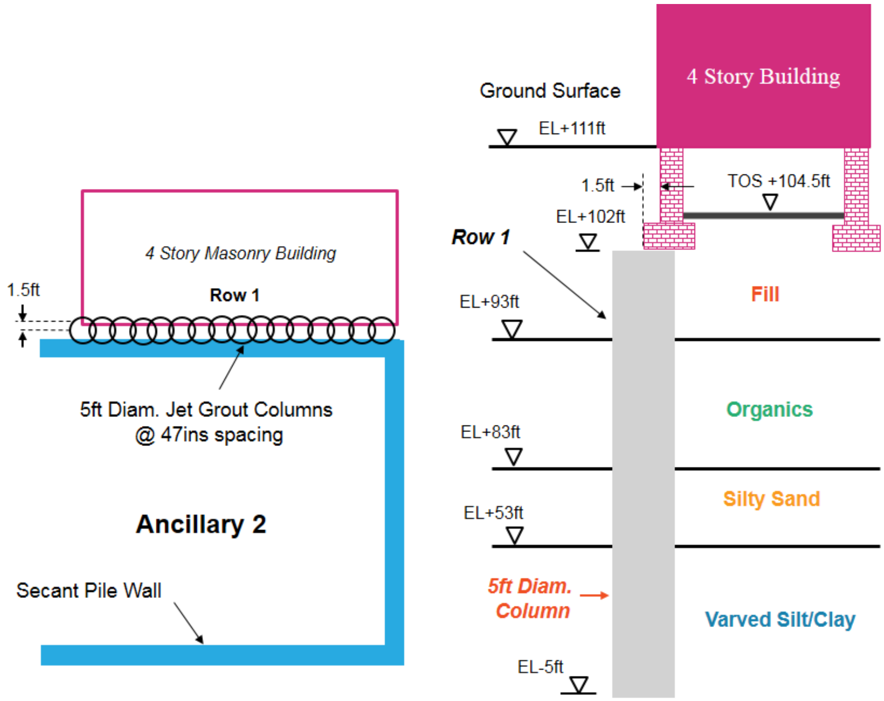

Figure 3. Jet grout underpinning scheme (Row 1).

The proposed underpinning scheme involved installing sixteen vertical overlapping jet grout columns to form a continuous grout wall below the building foundation up to the toe elevation of the secant pile wall at EL-5ft. The jet grout columns were 5ft in diameter and spaced 47ins apart, matching the spacing and position of the adjacent secondary secant piles. In order for the jet grout columns to undergird the footings as much as possible, the column centerlines were set at 18ins offset from the external face of the building. This would result in a theoretical jetting reach of 12ins behind the foundation wall for a 5ft diameter column. Due to uncertainty in the dimensions of the footings, it was conservatively assumed that the footing extended 6ins beyond the outer face of the foundation wall. For this arrangement, a net contact area of 685 square inches between the footing base and jet grout column could be achieved. Based on the total dead and live load of 14.1kips/ft acting at the foundation level, an average bearing stress of 81psi was obtained for the contact area. A 28-day jet grout strength of 400psi was specified for design, giving an allowable bearing pressure of 100psi.

5. Additional Jet Grout Columns for Stabilizing Secant Pile Installation

In the course of developing the underpinning design, the Contractor highlighted possible constructability issues relating to installation of the secant piles alongside the adjacent building. Due to close proximity of the secant piles, the casing shoe would be cutting partially into completed jet grout columns and partially into ungrouted soil. This would cause potential deviation of the casing during installation of the secant piles and may result in damage to pre-installed jet grout columns underpinning the footings. To overcome this, an additional row of jet grout columns was introduced along the proposed secant pile wall line to create a balanced platform (Figure 4).

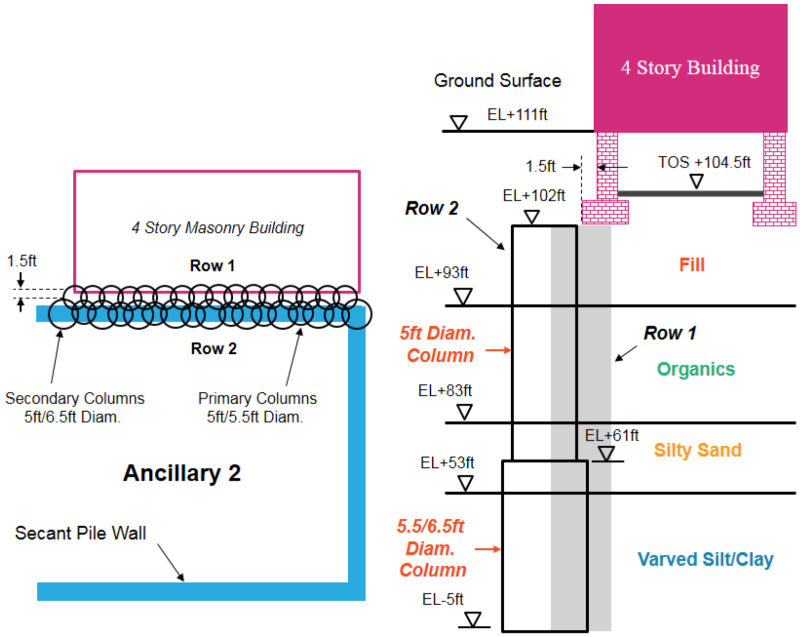

Figure 4. Additional row of jet grout columns (Row 2) for stabilizing secant pile drilling.

Seventeen additional jet grout columns were installed at the designated primary secant pile positions located 47ins apart. Column diameters were nominally 5ft over the upper 41ft, extending from the footing down to the Ancillary 2 excavation level at EL+61ft. Below this level and up to the secant pile toes at EL-5ft, the column sizes alternated between 5.5ft (for primary columns) and 6.5ft (for secondary columns). Smaller grout columns were used in the upper sections to avoid excessive trimming of hardened jet grout within the exposed face of the excavation. The enlarged column sizes at the deeper elevations were necessary to ensure that overlap between jet grout columns was still attainable for an anticipated column deviation of 1%. The respective secondary jet grout columns would be formed after the two adjacent primary columns have been completed. This innovative approach allowed the secant piles to be drilled from a firm platform through consistent material for better verticality control during pile installation.

6. Jet Grout Installation

Jet grouting was performed using a Casagrande C-14 drill rig and Tecniwell TW400/S high pressure triplex pump (Figure 5). An 89mm diameter Jet Plus monitor was used in conjunction with a 114mm diameter drill rod. A 10ins diameter borehole was predrilled and cased to the bottom elevation of the adjacent footing to maintain effective spoil removal during jetting. The drill string was then lowered and progressed using a slightly smaller bit size within the casing and then reamed out, using water as the flushing medium. Jetting parameters were developed based on the results of initial jet grouting field trials on site using CYLJET electric resistivity measurement methodology for evaluation of in situ column dimensions in the various soil strata [8, 9]. Continuous observation of jetting parameters was achieved using a Jean Lutz LT3 monitoring system. Drilling rod inclination was measured using a ShapeAccelArray (SAA) tool.

Figure 5. Jet grouting adjacent to existing building.

For the basic underpinning jet grout columns (Row 1), grouting was executed in two stages: Stage 1 from EL+95ft to +EL+102ft (bottom of footing) and Stage 2 from EL-5ft to EL+96ft. The intention of Stage 1 grouting was to tighten up the soils near the ground surface and immediately surrounding the footing in order to limit potential spoil entry into the existing basement, as well as improving stability of the borehole for more effective spoil return during the deeper grouting in Stage 2. A 10ins diameter cased hole would be advanced through the completed Stage 1 grout for subsequent Stage 2 grouting. The 1ft overlap between Stage 1 and Stage 2 was to ensure continuity of the completed columns. Table 1 summarizes the jetting parameters adopted for Row 1. A single 5.5mm diameter nozzle was adopted for grout injection. Compressed air was not used to avoid potential instability of the surrounding soil supporting the footings, particularly when jetting in the organics layer. A water-cement ratio of 1.20 by weight was adopted to produce a grout mix with specific gravity of 1.45. The lift step adopted was 4 cm.

Table 1. Jetting parameters for grouting underneath existing footings (Row 1).

Soil Stratum	Diameter (D)	Elevation (EL)	Grout Pressure (P_g)	Grout Flowrate (Q_g)	Rotational Speed (R_s)	Lift Speed (L_s)
	ft	ft	bars	liters/min	rpm	sec/step
Fill	5.0	+95 to +102	241	260	7.5	16
Organics	5.0	+86 to +96	157	210	4.4	41
Silty Sand	5.0	+52.5 to +86	300	290	8.0	15
Varved Silt/Clay	5.0	-5 to +52.5	365	320	5.3	23

In the case of the outer row of jet grout columns along the secant pile wall (Row 2), a 10ins diameter hole was advanced directly to the toe elevation at EL-5ft and grouting was executed in one continuous up-stage to the footing elevation. Tables 2 and 3 summarize the jetting parameters for the primary and secondary jet grout columns respectively. Jetting was carried out using a single 6.5mm diameter nozzle. Compressed air of 10 to 13 bars was utilized in this case to form the larger columns. A water-cement ratio of 0.86 by weight was adopted to produce a grout mix with specific gravity of 1.58.

Table 2. Jetting parameters for grouting along secant pile wall line (Row 2 - primary columns).

Soil Stratum	Diameter (D)	Elevation (EL)	Grout Pressure (P_g)	Grout Flowrate (Q_g)	Rotational Speed (R_s)	Lift Speed (L_s)
	ft	ft	bars	liters/min	rpm	sec/step
Fill/Organics	5.0	+86 to +102	125	250	18.8	16
Silty Sand	5.0	+61 to +86	179	300	20.0	6
Silty Sand	5.5	+52.5 to +61	179	300	15.0	8
Varved Silt/Clay	5.5	-5 to +52.5	266	365	12.0	10

Table 3. Jetting parameters for grouting along secant pile wall line (Row 2 - secondary columns).

Soil Stratum	Diameter (D)	Elevation (EL)	Grout Pressure (P_g)	Grout Flowrate (Q_g)	Rotational Speed (R_s)	Lift Speed (L_s)
	ft	ft	bars	liters/min	rpm	sec/step
Fill/Organics	5.0	+86 to +102	125	250	18.8	16
Silty Sand	5.0	+61 to +86	179	300	20.0	6
Silty Sand	6.5	+52.5 to +61	179	300	10	12
Varved Silt/Clay	6.5	-5 to +52.5	266	365	7.5	16

Due to the fragile state of the adjacent building, each installed jet grout column was required to gain sufficient strength to achieve positive support for the building before jetting is allowed to commence at an adjacent column. The design guideline specified that no new columns were to be grouted within a clear distance of 15ft (three times the diameter) from any previously installed columns with less than 100psi strength as determined from grab samples. This criteria was considered to be conservative. Discretion was required in the field to avoid jetting into hardened grout that was too strong to cut. Upon completion of each column, grouting was continued above the design top elevation to a sufficient level to ensure that the top of the column did not bleed out. Due to the sensitivity of the existing building, verticality measurements were not performed for Row 1 columns to avoid interruption to the drilling and jetting process.

7. Conclusions

Jet grouting was successfully implemented to provide underpinning support to an adjacent 4-story fragile building for protection against ground displacements caused by installation of a secant pile wall located 2ft away from the building. Vertical jet grout columns were installed from the external face of the building to form a continuous grout wall beneath the existing foundation footings for effective load transfer. Due to the close proximity of the secant pile wall to the completed underpinning jet grout columns, additional jet grouting was required along the centerline of the secant pile wall to ensure subsequent installation of secant piles could be successfully carried out through fully grouted soils. Jet grout column diameters were varied to ensure adequate overlap for seepage control and to avoid excessive trimming of hardened grout during excavation.

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