Recent Applications of Jet grouting in the Prairies

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ABSTRACT
In situ ground improvement techniques can be applied to solve a lot of challenging conditions during the installation of new buried utilities. This process can modify and stabilize soils below the groundwater table to facilitate hand-mining operations in safe and stable conditions. The modified soils can be excavated to provide suitable access for connection to existing shafts and/or chambers. In most cases, this work cannot be performed in a safe and technically viable manner using conventional techniques. Specialty grouting can be performed to surgically treat and improve the properties of soils within the target zone.

Jet grouting is a process of hydro-dynamically eroding and blending soils in situ with cementitious grout to create soilcrete (soil-cement) matrix. Jet grouting is commonly performed with the double-fluid process. This technique was recently applied to two sites within the Prairies – Winnipeg, Manitoba and Calgary, Alberta.

The jet grouting process was successfully applied to stabilize and modify the soils within the target zones to facilitate hand-mining operations on a project in Winnipeg. At the other site in Calgary, jet grouting was performed to create a bottom seal and perimeter water cut-off wall. This paper provides an overview of the jet grouting process, technical considerations, quality control and case histories of two projects in the Prairies.

RÉSUMÉ
Les techniques d'amélioration des sols in situ peuvent résoudre de nombreuses conditions difficiles lors de l'installation de nouveaux services publics enterrés. Ce processus peut modifier et stabiliser les sols sous la nappe phréatique afin de permettre des opérations d'extraction manuelle dans des conditions sûres et stables. Les sols modifiés peuvent être excavés pour fournir un accès approprié pour la connexion aux puits et / ou chambres existants. Dans la plupart des cas, ce travail ne peut pas être effectué d'une manière sûre et techniquement viable en utilisant des techniques conventionnelles. Un jointoiement spécialisé peut être effectué pour traiter chirurgicalement et améliorer les propriétés des sols dans la zone cible.

Le jet grouting est un processus d'érosion et de mélange hydrodynamique des sols in situ avec du coulis cimentaire pour créer une matrice de béton de sol (sol-ciment). Le jet grouting est généralement effectué en utilisant le procédé à double fluide. Cette technique a récemment été appliquée à deux sites des Prairies.

Le processus de jet grouting a été appliqué avec succès pour stabiliser et modifier les sols dans les zones cibles afin de faciliter les opérations d'extraction manuelle sur place à Winnipeg. Sur l'autre site de Calgary, un jet grouting a été effectué pour créer un joint de fond et une coupure d'eau du périmètre. Ce document donnera un aperçu du processus de jet grouting, des considérations techniques, du contrôle de la qualité et des histoires de cas de deux projets dans les Prairies.

1 INTRODUCTION

Jet grouting is considered as the most versatile soil modification technique. The process entails drilling of a small diameter hole to the target depth and introducing cementitious grout under high pressures via nozzles on a specially designed monitor. The installation process generates soil-cement (soilcrete) elements which can be tailored to meet specified strength and permeability. The grout is introduced to the soil via a hydo-dynamic process with backflow (spoils) being evacuated to the collar of the drilled holes under atmospheric conditions. Jet grouting is commonly performed with the double fluid system where the jet grout stream is being shrouded with compressed air.

Jet grouting was recently performed on two projects in the Prairies Region – Winnipeg, Manitoba and Calgary, Alberta. The technique was applied to treat soil at depth to facilitate excavation under high groundwater conditions. Jet grouted elements were used in both cases to provide adequate water cut-off and stable ground conditions to allow for excavation to be completed in restricted access settings and a dry environment.

The application of jet grouting on the two projects, including challenges, soil conditions, jet grout solution, technical considerations and quality control are presented in this paper.

2. OVERVIEW OF JET GROUTING

Jet grout elements are typically installed from the bottom upwards. A drill string is advanced to the target depth using non-jetting, typically with water flush or a weak grout mix as the flushing medium. The resulting small diameter hole to the bottom of the treatment zone sets the stage for jet grouting by creating a passage (upwards through the annular space between the inside of the borehole wall and the outside of the drill string) for evacuation of excess jet grout backflow.

The double fluid process of jet grouting separately supplies grout and compressed air to the bottom of the drill string via separate, concentric passages within the string. Grout is ejected laterally through specially designed nozzles that focus the grout stream for maximum erosive effect. The compressed air meets the grout slurry on the downstream side of the nozzle, shrouding the grout slurry jet (Figure 1) to further amplify its erosive effect.

Jet grouting parameters such as rotation rate, lift rate, injection pressure and mix design are typically proposed based on the contractors' previous experience in similar ground conditions, before being tested in representative conditions, evaluated for performance and conformance, and eventually selected for, or modified prior to, production jet grouting.

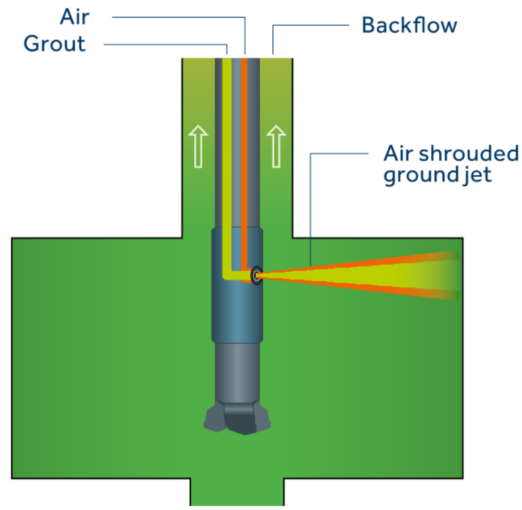

Figure 1: Typical double fluid jet grouting profile

3. TECHNICAL CONSIDERATIONS

Jet grouting is a soil modification process that can be used for underpinning, water control, earth retention, and other geotechnical challenges. Jet grouting is well-suited for sites which are deemed challenging due to restricted access, work being performed below the groundwater table or requiring targeted treatment. It is effective across a wide range of soil types, including granular soils, silts and most clays, making it one of the most versatile grouting techniques (Kirsch and Bell, 2013).

Jet grouting is an erosion-based process with simultaneous blending/partial replacement of existing soils with cementitious grout that can be used to construct a variety of geometries, from thin vertical panels to sector (partial) columns, to full columns of varying diameters. Further, soil-cement properties (i.e. strength, hydraulic conductivity) can be modified by controlling various grouting parameters. Parameters that can be modified include drill rod extraction rate, rotation speed, grout pumping pressures, grout flow, and the specific gravity of the grout. The equipment can be sized to accommodate project needs ranging from low-headroom applications to treatment depths exceeding 30m. This flexibility enables the technique to be tailored to meet the specific project requirements.

The jet grouting process can be used to treat targeted soil strata at depth without disturbing the soils above it. Additionally, because the mixing occurs with fluid and not with a mechanical tool, this allows for treating against, below and around existing structures, such as a bulkhead, shaft wall, or concrete pipe (Kirsch and Bell, 2013). The drill rigs used for jet grouting comes in a range of different sizes; large rigs capable of efficiently treating to depths over 30m and mini-rigs capable of walking through a 0.76 m wide door and working in a basement with only 2m of headroom, making it a perfect technique for improving the foundation of an existing structure.

3.1 Design and Execution Considerations

The jet grouting process uses specialty drill tooling which includes a grouting monitor attached to the end of a multi-chamber drill stem. Typically, the monitor is advanced to the targeted treatment depth, at which time high velocity/energy grout jets typically shrouded with air (and sometimes water) are initiated through nozzles on the side of the monitor. Figure 2 shows a schematic of jet grouting. The jets simultaneously erode and mix the in-situ soil with a cementitious binder as the drill stem and jet grout monitor are rotated and retracted. The process continues until the upper limits of the treatment zone are reached, at which time the tooling is withdrawn, and the hole backfilled with cementitious grout.

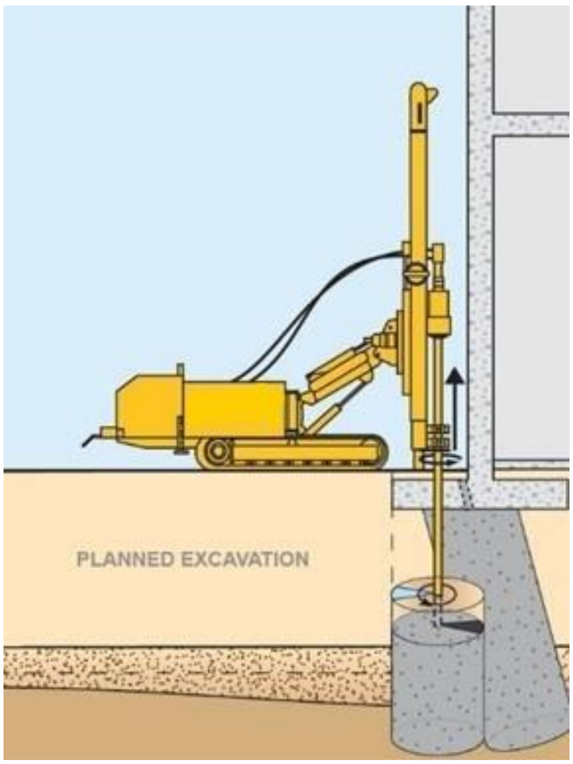

Figure 2: Schematic of jet grouting

Depending on the geometry requirements, the monitor can be rotated continuously in the same direction to create a column or rotated partially back and forth to create any portion of a full 360º circular geometry. The monitor can also be held static as it is withdrawn to create panels in the targeted soil formation. Figure 3 shows typical general arrangement of jet grouting equipment and the installation process.

The diameter of the created soilcrete column is a function of the erosional energy of the jet, erodibility and quantity of the soil. The jetting energy is controlled by the grout flow, grout pressure and tooling lift rate. The grout flow and pressure are adjusted by varying the diameter of the fluid nozzles. The withdrawal rate can also be changed to increase or decrease the diameter of the jet grouted element. In general, the more granular and cohesionless the soils are, the greater the erodibility. Gravels, however, can be difficult to assess. They can be either easily eroded or problematic to erode based on the geologic depositional process in which they were placed.

The strength and hydraulic conductivity of the soil-cement are both functions of the binder content and type of soil treated. The more granular or less cohesive the soils, typically the higher the strength. Higher binder contents can also yield lower hydraulic conductivities in certain soil types. The binder content can be modified by adjusting the specific gravity of the grout used in the jetting process. additionally, Ground Granulated Blast Furnace Slag (GGBFS) can be used as a binder and bentonite as an additive, which will typically provide lower hydraulic conductivities than Portland cement.

Jet grouting can be classified under three categories: single, double and triple fluid. Single fluid involves the injection of cementitious grout only through the nozzles. The double fluid is similar but incorporates an air shroud around the cementitious grout which improves erosion and evacuation of spoils. Triple fluid uses two sets of nozzles, the upper nozzles inject water with a shroud of air to perform the erosion and the lower nozzles inject cementitious grout to replace/blend the eroded soil to create the element.

4 CITY OF WINNIPEG - SIPHON INLET CHAMBER

Jet Grouting is not a common ground improvement technology in the City of Winnipeg or in Southern Manitoba. The soils are not generally conducive to it and there are fewer urban constraints compared with cities like Toronto and Vancouver. The siphon inlet chamber project was a small, surgical type of work that involved the connection between two shafts. An existing shaft and a new shaft positioned only 3.5 metes apart. The shafts needed to be connected by hand mining. In the native soils (stiff clays) this would have been achievable without ground improvement. However, the construction methods of the original shaft resulted in the area around the shaft being backfilled with sands and lose fills. The elevation of the connection was below the water table and located next to the Red River, making hand mining without ground improvement extremely hazardous. Jet grouting was employed to create a solidified block through which hand mining could be safely undertaken and the permanent connection installed. Figure 4 shows a plan view of the shafts and the jet grout columns.

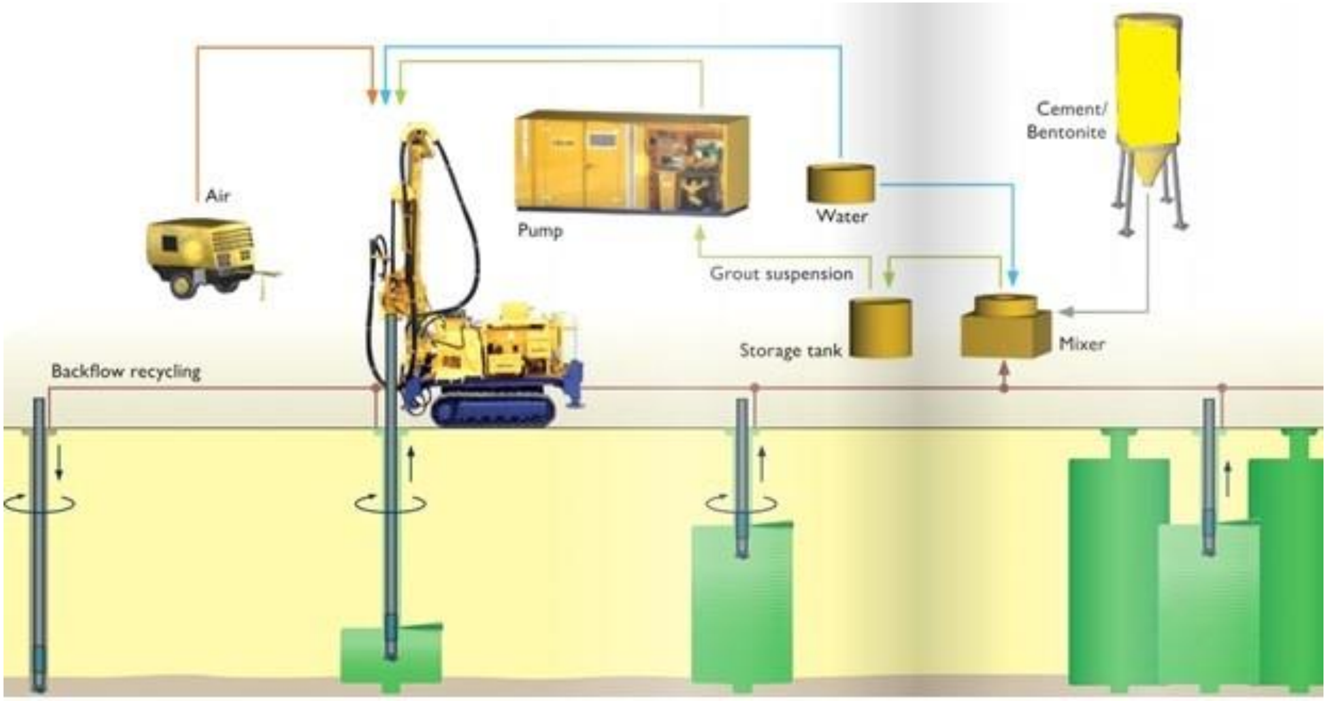

Figure 3: General arrangement of jet grouting equipment and process

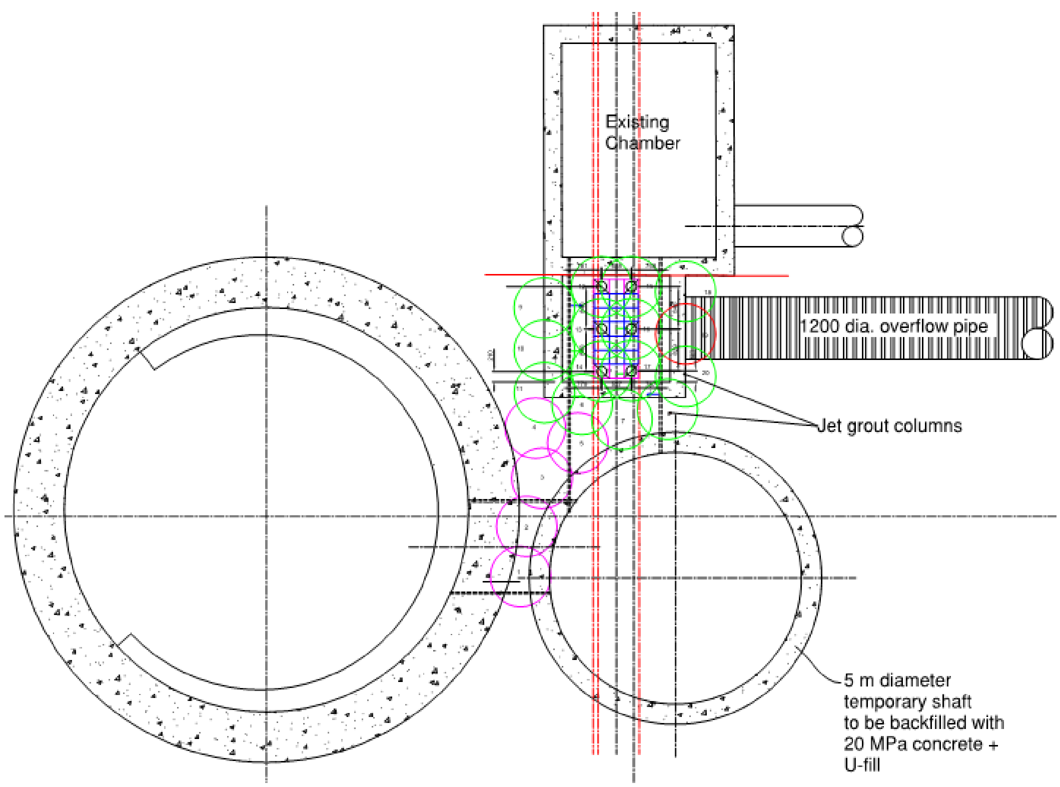

Figure 4: Plan view of shafts and jet grout elements

4.1 Soil Conditions

The native soils conditions in the area are a stiff clay material. Previous construction activity changed the local soil conditions such that saturated sands to silty sands were present. The target jet grout zone was from elevations 218 to 221.5 (grade at 228). The lower end of the treatment zone (about 1 meter thick) consisted of a silt with up to 25% sands and clays. The remaining target zone was predominantly sand with thin silt/clay seams. SPT 'N' values were generally very low.

4.2 Jet Grout Solution

Jet grouting was recommended as the preferred solution for its ability to work with small equipment and with small diameter holes to treat discrete zones at depth. As this project was quite small for a jet grouting operation, efforts were made to ensure the mobilization schedule and cost were controlled. A 'quick hit' jet grout system was employed with included mobilization of the following components:

- Hutte 403 – mini drill rig and tooling
- Trailer mounted automated batch plant and jet grout pump setup
- Horizontal, trailer mount silo.

The grout plant was delivered to site on a standard flatbed truck and was ready to start mixing and pumping grout within 4 hours.

Twenty jet grout columns were installed with the double-fluid process. The 'quick hit' jet grout setup utilizes some smaller pumps than are typical in the full jet grout setup. As such, a pre-cut with water was used to ensure the clay seams were effectively eroded. Two passes in each column was thus performed with the parameters presented in Table 1.

Table 1: Jet grout parameters – Siphon Inlet

Treatment section: 10.4-6.8m below ground (Jet Grout column diameter 1.2m with overlap 0.3m)	
Precut (Water only)	Jet Grout
2 nozzles at 3.0 and 3.5 mm each	2 nozzles at 3.0 and 3.5 mm each
Flow rate = 200 l/min	Flow rate = 200 l/min
Pressure = 250 bar	Pressure = 330 bar
Lift = 12cm/min	Lift = 12cm/min
Rotation = 5 rpm	Rotation = 5 rpm
Air pressure = 4 bar	Air pressure = 4-6 bar
Air flow: 3000L/min	Air flow: 3000L/min

The jet grout columns were installed in 7 days with productivity primarily controlled by the proximity of the holes in a small area. With the pre-cut, only 2 to 3 columns could be constructed per shift to allow sufficient cure time.

The connection between the two shafts was able to be hand mined successfully with no ground loss or influx of water.

4.3 Quality Control

The quality control program for this work was not specified but satisfied industry standards. All quality control was performed by the contractor. All jet grouting was completed with real time monitoring of each of the parameters illustrated in the above table. These parameters were displayed and recorded for both the pre-cut and jetting phases as shown in Figure 5. Review of these printouts provided verification that each column was constructed over the targeted elevations and with the expected jetting energy.

Quality control is also performed on the neat cement grout throughout the jetting process to ensure the grout mix being delivered is as expected. Specific gravity is taken with a mud balance to ensure accurate w:c ratio and viscosity is measured with a Marsh funnel to ensure consistent viscosity and thus consistent parameters at the jet nozzles.

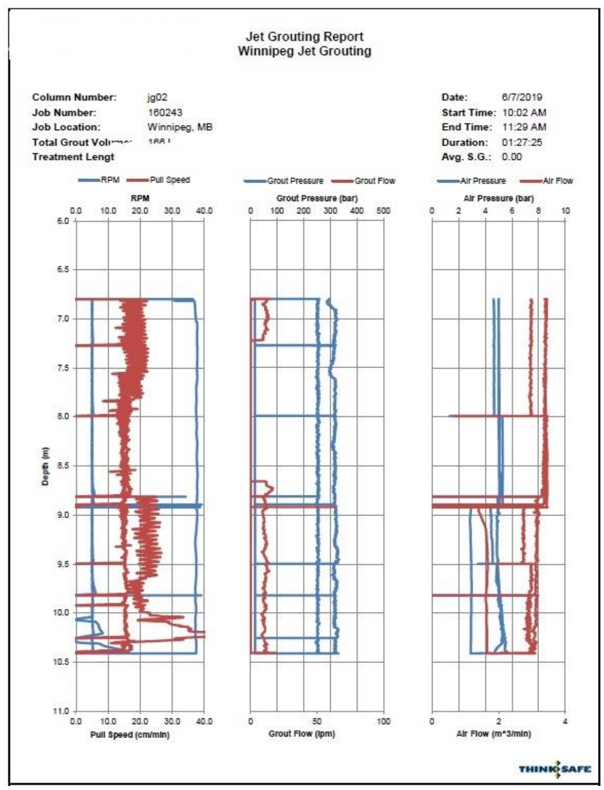

Figure 5: Sample of jet Grout DAQ report

5 CITY OF CALGARY -ELBOW RIVER LAUNCH SHAFT

Later in 2019, a second jet grouting project was performed in the City of Calgary. This project also involved the need for dry access to a shaft near the Elbow River. The General Contractor had sunk an exit shaft and entry shaft on either side of the river and micro tunneled between the two (below the Elbow river). The challenge came when a traditional trench box style excavation was attempted adjacent the entry shaft to allow for the pulling through and connection of an abundance of utilities. The trench box quickly took on soils and water causing the General Contractor to backfill the area and develop a new plan. Jet grouting was recommended by the contractor to create a 3-sided structure with the fourth side being the existing shaft. A bottom plug was then also proposed to create a dry environment for the General Contractor to resume excavation and ultimately utility connections. With the implementation of a bottom seal into the design, medium to large diameter columns are generally required for efficiency in the geometry of the seal

5.1 Soil Conditions

The soil profile over the jetted zone was predominantly sands varying from lose to compact (SPT ‘N’ values of 3 to 50) with some silt lenses. Borehole 19 was very close to the work location and best illustrates the soil conditions. Depth of treatment was from 3.5 to 10 meters for the walls from 7.5 to 10 meters for the base plug. The water table was at 4.5 meters depth but fluctuated with river levels.

5.2 Jet Grouting Solution

The contractor’s design included 19 columns of 1.5-meter to form the 3 walls and 17 columns of 2.1-meter diameter to create the base plug. Figures 6 & 7 shows a plan view and section of the jet grout elements. Double-fluid jet grouting process was used. One test column was installed to confirm the jetting parameters to achieve a 1.5 meter column. A proprietary Acoustic Column Inspector (ACI) tool was used to verify the column diameter in-situ (Figure 8). A purpose-built steel rod is installed in the ground at a set distance from the jet grout borehole. During jetting, an acoustic recording device is used to detect when the jetting action is hitting the acoustic rod. In this manner the parameters can be adjusted to ensure diameter size. One of the 1.5-meter production columns was used as a test column along with the ACI to confirm parameters for the 2.1 meter columns, prior to installing the base plug. Figure 9 illustrates the site set-up for jet grouting operations.

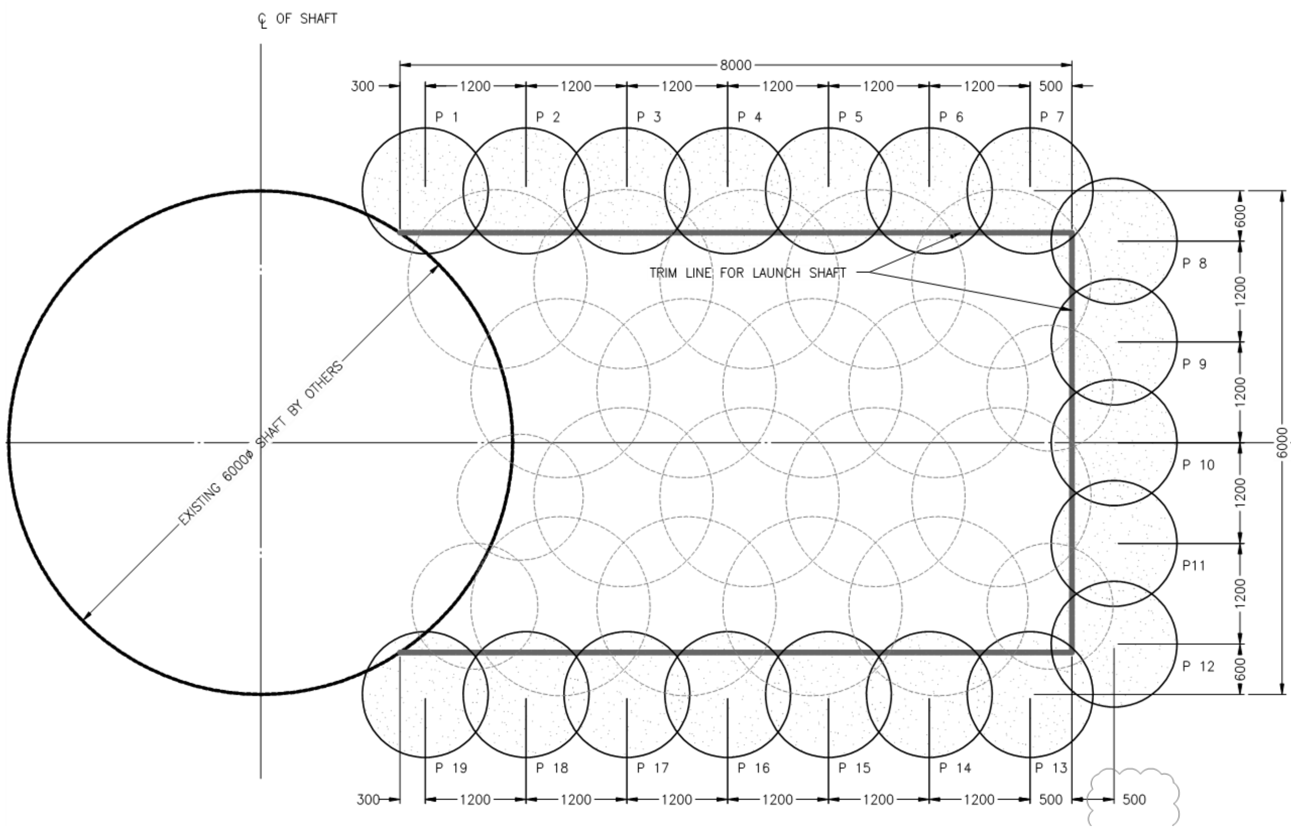

Figure 6: Plan layout of perimeter and bottom seal jet grout columns

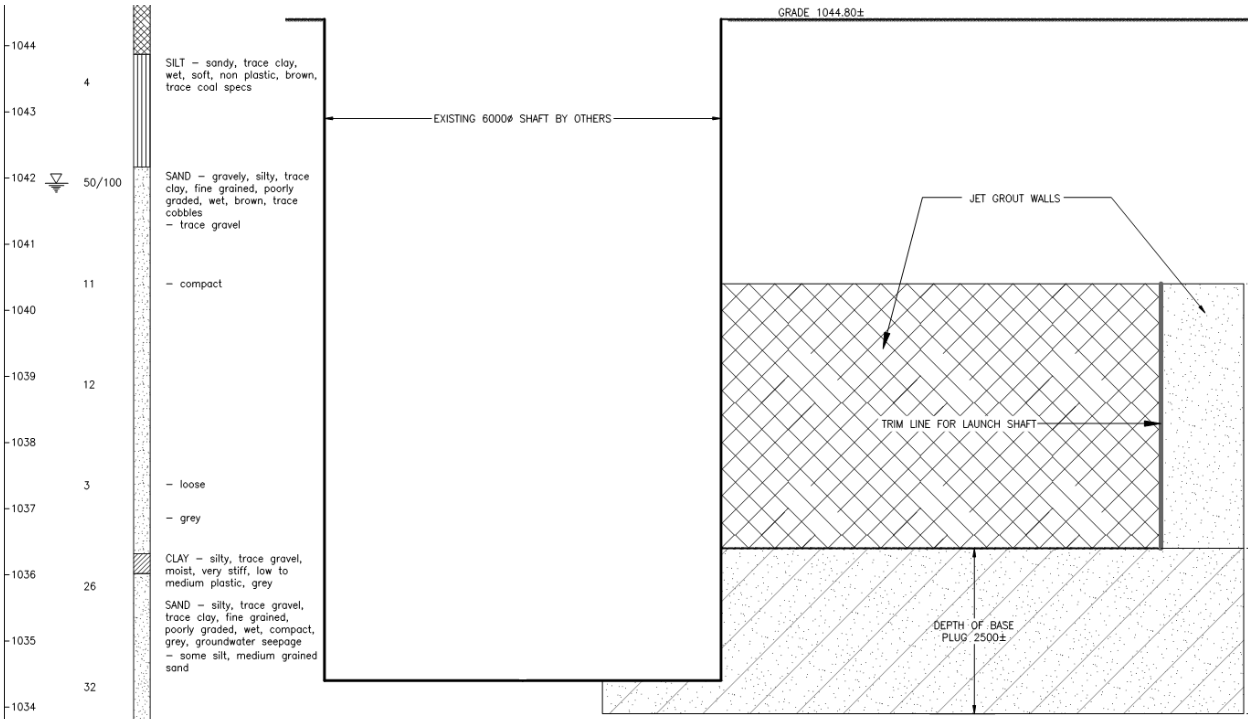

Figure 7: Section through jet grout elements

Figure 8: ACI sensors attached to embedded steel rods

Figure 9: Site arrangement for jet grouting

5.3 Quality Control

Throughout the jet grouting operations, numerous quality control measures were implemented by the contractor to continuously monitor the jet grouting parameters (i.e. lift, flow, rotation, pressure, air flow, etc.). All DAQ reports from each installed column were reviewed to ensure consistency with the site-specific parameters. Samples of grouting spoils being expelled from the collar of the hole were captured at regular intervals and measured for specific gravity. Backflow (spoils) samples were also cast into grout cube molds and sent to an accredited independent testing laboratory for unconfined compressive strength (UCS) testing. Jet grout columns were surveyed, and the SAA data was reviewed and plotted in a timely manner to identify potential gaps in the cut-off and base plug. The SAA (Shape Accel Array) tool is a reel mounted unit with 3 MEMS (micro electromechanical systems) in every segment, spaced at 0.5 m intervals. This unit provides real-time data of the inclination and orientation with a single shot measurement.

6 DISCUSSIONS

A comprehensive quality control program is a key requirement for jet grouting projects. There are several variables in producing a soilcrete product and only experienced personnel can select these parameters which should be verified by a field trial program (Burke, 2009). Throughout the jet grouting process, numerous quality control measures shall be implemented to continuously monitor the jet grouting parameters. The parameters are typically captured by the data acquisition system (i.e. lift, flow, rotation, pressure, air flow, etc.). The DAQ system is also used to control some aspects of the jet grouting process such as lift rate and rotation rate. All DAQ reports from each installed column shall be reviewed to ensure consistency with the site-specific parameters. The as-built location of jet grout elements provides valuable information, especially for water cut-off applications. Jet grout columns shall be surveyed with a SAA or equivalent instrument to check the as-built alignment of the columns. This information can be used to identify potential gaps in the cut-off wall and/or base plug. A 3-D grouting profile shall be developed and updated daily to obstructions, changed site conditions and complexities in achieving the desired column overlap.
Data acquisition (DAQ) should be an integral part of all jet grouting applications. This is important to capture drilling and installation parameters in a timely manner. The reports should be reviewed to identify and address any anomalies. In additional to DAQ, a full-time Field Engineer or technician should be present on site to conduct QC checks and maintain detailed records of the jet grouting operation. A 3D plot of the as-built jet grout elements based on SAA survey data can provide a better visualization and aid with the identification of potential windows.

The need for remedial and/or supplemental jet grout elements should be reviewed during the execution of the project based on DAQ reports and plots. This alleviate potential remedial work during the excavation stage of the project and savings for addition mobilization of personnel and equipment to the site.

7 SUMMARY

The jet grouting technique was successfully implemented to solve challenging geological settings on two projects in the Prairies Region. The specialty contractor was able to provide input, design considerations and execution of jet grout elements which were tailored to suit the clients' requirements. Both projects were performed with a high level of quality control by the specialty contractor. The specialty equipment was selected based on the scope of the project. A pre-production test program was conducted on both projects to verify the geometric properties of the elements.

Jet grouting is versatile soil modification technique and can be applied to a wide range of soil types. The case histories outlined in this paper highlights potential applications in the Prairies Region. This technique can also be applied for earth retention, environmental containment, ground improvement, groundwater control, seismic/liquefaction mitigation, slope stabilization, underpinning, tunneling and other applications.

ACKNOWLEDGEMENTS

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