168 - Jet-grouting case history: Millennium Water Olympic Village - False Creek, Vancouver, BC, Canada

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ABSTRACT
Jet-Grouting is a well known soil improvement technique which is able to create consolidated elements in the subsoil with different shapes and dimensions and also with good mechanical characteristics and reduced permeability. The technique involves eroding and mixing the insitu soil with water cement grout. The grout mix is jetted, with the aid of special tools, at very high speeds (800-900 km/hrs) created by high pressures (400 to 500 bars = 7,000 to 9,000 psi).

Jet-Grouting was introduced in British Columbia as permanent technique in October 2004, and since then several applications for soil improvement, temporary and permanent, have been carried out in the Lower Mainland.
This paper presents a case history of a Jet-Grouting application used for the shoring of the new residential Millennium Water development in False Creek. This facility will host the athletes for the Vancouver 2010 Olympic Winter Games. More than 1,100 Jet-Grouted Columns were installed, in proximity of the ocean, to create a soil-cement wall with 2 purposes: 1) provision of an impervious cutoff wall and 2) support of streets and other public space improvements constructed adjacent to the site.

Site specific conditions and local installation considerations will be analyzed jointly with the results of the extensive field tests (done to cover the wide area) and laboratory tests done on the soil-cement columns. Both technical and logistical challenges, due to the variable soil conditions and the proximity of the site to a tidal body of water, were resolved in the biggest Jet-Grouting contract completed in Western Canada.

1) INTRODUCTION

The new residential Millennium Water development, that will house the athletes for the Vancouver 2010 XXI Olympic Winter Games, is located in the South area of False Creek-Vancouver and covers an area of approximately 46,000 m2 (328 x 128 meters):photo 1.

Photo 1- False Creek- Vancouver- Location of the project

The area was divided into 10 parcels, 2 of them in close proximity to False Creek, as shown in Fig 1 . The average excavation depth of the parcels in the main lot was 7 m. Parcel 4, located at the northwest of the Olympic Village site and nearest to False Creek was excavated up to 6 m. Parcel 11, at the northeast corner, was excavated only 3 m for a single level of below grade parking, and thus this parcel was not protected with a jet grout wall. The north side of parcel 3 was excavated to as deep as 11 metres to remove potentially contaminated soils and achieve suitable bearing for foundations. The site is bounded by City road right of ways to the West, East and South and a foreshore park to the North. The site was close to level with an elevation of about 4.0 metres (geodetic datum) across the site. Figure 1, below, shows a plan of the Olympic Village site.

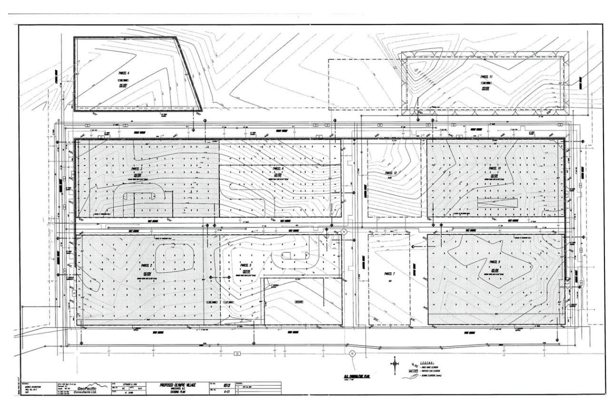

Figure 1: Plan of the area.

This paper will not discuss the details of the Jet-grouting technology since the system is well established in the local Canadian geotechnical community. Should additional information and details be required, the writers would like to refer readers to a paper presented by the same authors with the title: Case History of Jet-Grouting in British Columbia. Underpinning of CN Rail Tunnel in North Vancouver, presented at the 58th CGS Conference- Saskatoon on September '05, or to the authors.

2) SITE CONDITIONS

The site was used previously for industrial purposes, including wood sorting and milling of logs Much of the site was reclaimed from False Creek, and up to 6 metres of variable fill soils were placed over the site. Due to previous site usage, a significant amount of soil and groundwater contamination was identified on the site prior to construction beginning on the site. The City of Vancouver commissioned a design for infrastructure improvements at the site, which included all new roads and utilities, north of 1st Avenue. The intent was to complete all of these works prior to development of building on the site. The City's geotechnical consultant concluded that the existing fills were compressible and could not be used to support future roads and utilities. So prior to installation of any improvements, all of the existing fills were to be removed from the future road right of ways and replaced with compacted engineered fill. The developer negotiated a delay to the installation of improvements in the interior roads to reduce the amount of shoring that would be required and also reduce the potential to which existing works would interfere with construction. Thus only the perimeter of the site was shored and Parcel 4 was shored separately. The position of the shoring wall is shown in Figure 1, above.

The subsurface soil and groundwater conditions were well characterized by the City of Vancouver prior to our involvement in the project. Soil conditions at the location of the shoring wall comprised up to 7 metres of compact to dense clean granular fills over native soils which consisted of loose to compact post glacial marine sediments overlying dense glacial till (a well graded mixture of silt and sand with some gravel and occasional cobbles and boulders) and then sandstone to siltstone bedrock. The thickness of fill generally increased from the south end of the site (as little as 1 metre of fill) towards the north end of the site (where up to 7 metres of fill was identified). The long term static groundwater level was identified at about 0.5 metres geodetic, though a perched transient groundwater condition occurred along the south end of the site, where fills were generally thinner. A typical section across the site is given in Figure 2, below.

3) DESIGN CONSIDERATIONS FOR THE SHORING WALL

As mentioned above the site elevations at the time of construction were close to 4 metres (geodetic datum) and the development required excavation to depths of up to 11 metres (-7 metres geodetic). Furthermore the fills in the road right of ways were sub-excavated and replaced with clean granular fills, which were comparatively permeable, to well below the ambient groundwater level on the site. The developer preferred a simple and reliable envelope treatment, where a drained cavity was installed around all of the building walls to maintain dry basement walls. Jet-grouting was considered the only viable alternative to achieve a high strength and low permeability shoring wall that could also serve as a permanent groundwater cut off. The Jet-grout wall also had the ability to be installed through dense till like soils, through and around boulders and concrete obstructions and thus the elevation of the base of the cut-off wall could be guaranteed.

A decision was made to limit the extent of the cut off wall based on the maximum thickness of granular fills and the likely groundwater conditions. Jet grouting was considered necessary only at the north wall, the Parcel 4 wall and the northern 2/3's of the West and East walls, as shown on Figure 1, above.
A minimum design strength of 6 MPa UCS at 28 days was chosen for structural integrity and impermeability.

Figure 2 shows the typical plan view and section of the Jet-Grouted design. An H beam was installed in alternate columns (every 1.5 metres or 5 feet) for vertical stiffness. A reinforced shotcrete beam, recessed into the jet grout wall, was utilized as a waler.

The knife trimmed jet grout wall provided a smooth surface on which a synthetic drainage material could be placed so that the perimeter walls could be constructed directly against the shoring wall.

The minimum required diameter was 0.9 meter with a 0.75 meter spacing between the columns, to ensure full overlap between columns.

A traditional sheet pile wall was considered. However based on the designers' previous experience, there were concerns with leakage of groundwater at the interlock and at the anchor head. Furthermore, sheet piling could not be relied upon as a permanent cut off close to a marine environment where groundwater was shown to be brackish.

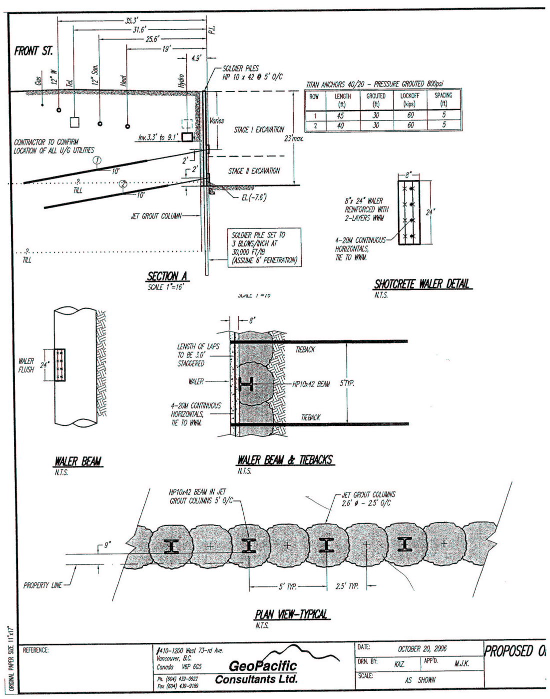

Figure2: Typical section and plan of the jet-grouted wall

4) JET-GROUTING FIELD TESTS

Due to the diversity of the soil at the perimeter of the excavation, which included historic fills, recently placed fill (fine to medium sand placed by the City of Vancouver), several Jet-grouting field trial columns were carried out around the perimeter of the excavation. The tested columns were carried out as part of the final wall and the initial main parameters of the Jet-Grouting (Grout and air pressure and withdraw speed-equivalent to the use of cement), during the tests, were kept initially in the higher range to be prudent.

Some results of the tests:

4.1) West Wall

Photos 2-3 and 4 show the results of the test carried out on the West wall.

Photo 2 shows the complete excavation of the area of the test and photos 3 and 4 two details of some of the columns.

Photo2

Photo 3

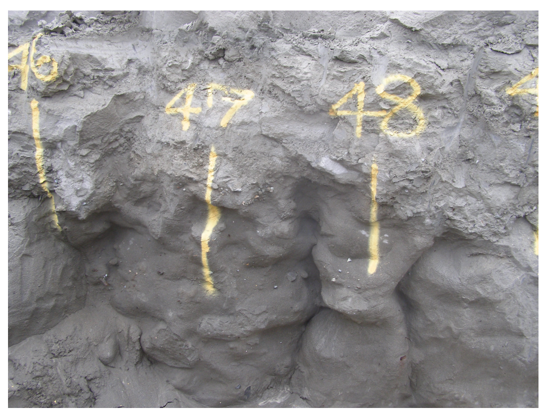

Photo 4

As can be seen on photo 3, columns 53, 55 and 57, constructed prior to columns 54 and 56 (Space Split Method was used), show a diameter of around 1.2 m. The adjacent columns were relatively narrow due to lack of space. The overall effect of the wall was still very acceptable but the result was not considered optimal in terms of homogeneity of the wall and overall consumption of cement. The parameters of Jet-Grouting were modified consequently to obtain a better column diameter consistency.

4.2) North Wall

Photo 5 shows the test done at the North wall. The wall appears quite homogeneous and thus the parameters chosen were adopted for the area.

Photo 5- North Wall

4.3) Parcel 4

Parcel 4 was the most critical area being the closest to the ocean. The result of the test was positive as evident in photo 6.

Photo 6- Parcel 4 North West corner

Photo 7– Parcel 4 detail of Photo 6

From Photo 7 we can clearly observe the inclined excavation plan that indicates the boundary between the historic fill soils and the recent fills (sand placed by the City). Note the extreme flexibility of the Jet-Grouting and in particular the ability to create uniform diameter columns in different soil types. The presence of wood and steel from the historic fills can be seen in the photo. There was no use of imported sand at the north and east walls of parcel 4, which was not anticipated.

Photo 8 shows the presence of boulders, previously detected during exploratory drilling, easily drilled and jet-grouted, on the East wall of parcel 4.

5) DRILLING PARAMETERS

As mentioned above, the jet-grouted columns were embedded 2 meters in the underlying impervious till.

Photo 8 – Parcel 4 East Wall- Boulders

The drill rigs used for the Jet-grouting were equipped with a sophisticated system for Q/C with sensors to record jet-grouting parameters and, additionally, drilling parameters. The computer controlled system used during the execution of Jet-Grouting permits the evaluation in real time of all jet-grouting parameters (depth, pressure, rods withdraw speed and flow), and also the drilling parameters such as: rate of advancement, speed, rotation, torque and thrust.

With these parameters it is possible to evaluate the specific energy used during drilling that can be evaluated with the following formula:

e = F/A + 2*pi*R*T/A/v (KJ/m3)

where:

F= Thrust (kN) (force that is applied onto the drill rod)
A= Area of the hole (m2)
R= rotation (r per sec)
T= Torque (kN*m)
V= penetration rate (m/sec)

Figure 3 shows the graphic obtained by the computer data acquisition system, including the graphic of the specific energy correlated with the depth. The evaluation of the specific energy does not permit the evaluation of the soil but does give an idea of the consistency/density of the soil and can be considered as an equivalent of SPT. Test and evaluation are still under development

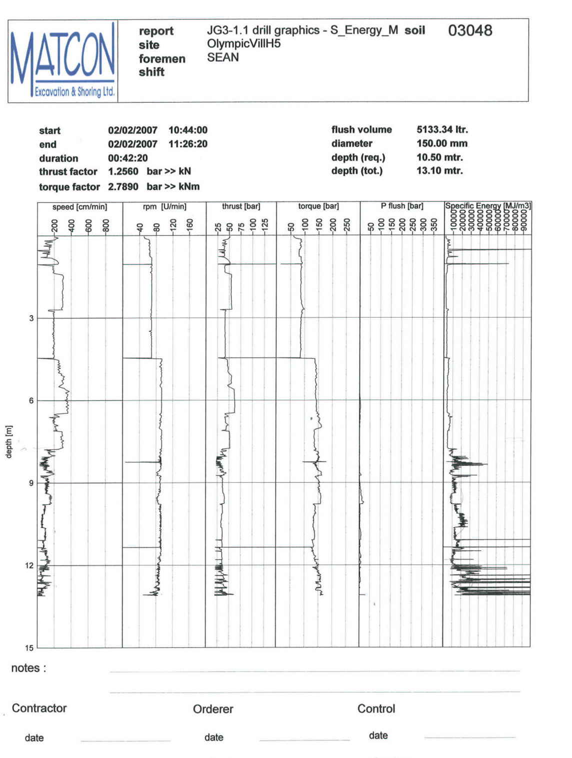

Figure 3- Specific energy during drilling

From Figure 3 it is clear to see the change in specific energy at approx 8 meters and 12 meters depth, which corresponds to the location of the lower impermeable till layer. This monitoring permits the evaluation of geotechnical data in a more continuous way.

6) QUANTITIES

2 jet grouting groups were used for the execution of 1,050 columns, with a total of 10,500 meters of jetting, from February until August 2007.
The surface excavated was approx 100,000 m2.
Double system Jet-grouting was used.

7) RESULTS

Five cored holes, with triple core barrel, were carried out for the purpose of obtaining samples and evaluating the characteristics of the soil/cement wall.
Photos 9 and 10 show an example of the cored columns and samples.

Photo 9- Coring of Jet-Grouted columns

Photo 10- Samples

Average UCS was 8.5 MPa in 11 tests and permeability was 5.2* 10^{-8} m/s (average) in the 4 lab tests done.

The entire wall was exposed during excavation and it was easy to directly observe the results. No major defects were detected and the excavation was completed without any problem of water seepage or instability. See photo 11 and 12 with the details of the wall excavated.

8) CONCLUSIONS

The Olympic Village Jet-Grouting project confirmed the flexibility and suitability of the jet-grouting system in variable ground conditions where a high strength and low permeability structural wall is required. The system was able to be installed in the vicinity of existing utilities and fixtures with low vibration levels and generally low impacts to the surrounding lands. Removal of the upper portion of the walls was straightforward once shoring was complete and servicing was required for the various parcels. The work was able to proceed regardless of the discovery of unexpected soils, including wood waste, steel and concrete, boulders and other materials that would have impeded the installation of other systems

Photo 11- Excavated and trimmed jet-grouted wall

Photo 12- Excavated and trimmed jet-grouted wall