Use of Jet Grouting in
Challenging Infrastructure Renewal Situations
in Hawaii

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ABSTRACT: This paper describes recent strides made in jet grouting in challenging infrastructure renewal situations involving stabilization of flowing ground consisting of coralline sands and gravels with cemented coralline limestone ledges at 30 to 40 m below sea level to form improved ground for ingress and egress of a 84-inch diameter microtunneling machine from and to two 33m deep shafts for two parallel harbor crossing sewer force mains, each 1,828 mm I.D. Jet grouting was also used to provide a stabilized and groundwater cutoff plug at the bottom of the 30 m deep, 10 m diameter jacking and reception shafts. The shafts were installed by the vertical shaft sinking machine. Bidders’ qualifications and construction requirements will be presented and discussed. Applicability of jet grouting in cemented soils and limestone will be discussed.

Jet grouting was also used to install excavation support and groundwater control for 5 to 9 m deep open excavations below sea level within close proximity to existing facilities and utilities, for two projects. The jet grouting parameters and means and methods will be compared and contrasted for projects with different jet grouting performance, such as ground heave lifting buried utilities during jet grouting for one case, and how such problem was avoided by other projects.

INTRODUCTION

In Hawaii, ground improvement by jet grouting methods have been used to provide groundwater control and excavation support in deep excavations since the
1990’s, to sustain the built and natural environment (Kwong and Wanner, 2001; Kwong et. al., 2009). On the island of Oahu, the coastal urban core has low ground elevation and underlain by highly permeable compressible lagoonal and coralline deposits. Infrastructure renewal, such as design and construction of replacement utility pipelines in congested utilities corridors and facilities often require deep excavations below mean sea level in coastal plains on Oahu.

Properly designed and installed jet grouting columns or zones to provide or supplement excavation support and provide positive groundwater control for microtunneling, tunneling and deep open excavations for utility connections into sewer lift or pump stations, often is the only practical and if designed and installed properly reliable method to minimize adverse impact to existing utilities and facilities next to the required deep excavations, to prevent the drawdown of groundwater over 300 to 500 m radius, and to avoid the discharge of dewatering affluent into State waters.

This paper describes some of the key aspects of jet grouting performed to stabilize flowing and cemented ground to assist microtunneling ingress and egress and to achieve ground water control in deep shafts 30 m below sea level. However, despite the mostly successful use of jet grouting methods in the last 20 years, on the island of Oahu for groundwater control and installation of jet grout columns in close proximity to existing utilities, recent problems and issues arose when jet grouting contractors appear to focus solely on productivity over caring for existing utilities in developing jet grouting means and methods. Selected jet grouting parameters and means and methods will be compared and contrasted for projects with different jet grouting performance, such as ground heave lifting buried utilities during jet grouting for one case, and how such problem was avoided by other projects.

STABILIZATION OF DEEP FLOWING AND CEMENTED GROUND

A recent microtunnel project necessitated approximately 850 linear feet (259 meters) of parallel dual sewer force mains to be constructed below a harbor entrance. The harbor entrance mudline was approximately 55 feet (16.8 meters) below mean sea level. To mitigate inadvertent slurry returns to the mudline surface through the very soft sediments during microtunneling, to avoid encountering the deep basaltic lava flow obstructing microtunneling, and to place the microtunnel drive on less soft or loose sediments, the harbor crossing microtunneling profile was set about 30 feet (9.1 meters) below the mudline (Figure 1). The resultant on-land jacking and receiving shafts were approximately 95 feet (29 meters) below ground surface, through geologic units of fill; very loose to loose lagoonal deposits; and medium dense to dense coralline deposits of sand and gravel with cemented coral limestone ledges (Figure 1).

The deep vertical excavations for the two circular jacking/receiving shafts were constructed using a vertical shaft sinking machine (VSM), with cast-in-place
reinforced concrete walls (refer to Figures 2 and 3). Bottom stability and groundwater control was provided by a tremie concrete plug extending an additional 25 feet (7.6 meters) below the shaft bottom.

FIG. 1. Generalized Geologic Profile along Microtunnel Alignment
While this construction method provided for the excavation support and perimeter groundwater control for the deep shafts, deep jet grouting was required to provide groundwater control for the entry and exit ring seals at the jacking/receiving shafts. The groundwater control jet grout stabilized zone was to extend a minimum of 20 feet (6.1 meters) from the outer diameter of the shafts, and a minimum of 16 feet above and below the outer diameter of the 84-inch (2.1 meters) diameter casing pipe. Thus, the jet grout zone would extend between 60 (18.3 meters) to 100 feet (30.5 meters) below ground surface, within the loose to dense coralline sands and gravel, and cemented coralline limestone ledges.

The contractor elected not to pre-drill and fragment the cemented soils/coral limestone prior to jet grouting. Example of selected jet grout parameters selected by
the contractor based on their jet grout test program and past experience in jet grouting through similar geologic conditions are presented in Table 1. Due to proprietary jet grout means and methods, not all of Contractor’s jet grout parameters are provided herein. Many of the columns were observed to not have grout returns during jet grouting, due to the porous and very loose lagoonal deposits.

<table>
<thead>
<tr>
<th>Jet Grout Method</th>
<th>Single Fluid System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Rig</td>
<td>Single Head</td>
</tr>
<tr>
<td>Grout Pressure (bars)</td>
<td>400</td>
</tr>
<tr>
<td>Grout Specific Gravity</td>
<td>1.47 to 1.48</td>
</tr>
<tr>
<td>Nozzle Configuration (#)</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Jet Grout Parameters

Six microtunnel drives were performed from the two deep jacking/receiving shafts: two parallel dual lines between the two deep shafts; two parallel dual lines each between the each of the deep shafts and the next shallower shafts along the alignment (refer to Figure 4). To prepare for the microtunneling for six drives, an entry ring with rubber gaskets was mounted on the inside of the shaft wall. While the concrete of the excavation walls were reinforced with steel rebars, the shaft wall at the section where the microtunnel machine was to pass through was instead reinforced with fiberglass rebars. This allowed for the microtunnel machine to tunnel through the wall and the rebars (refer to Figure 5).
Due to the tight work space, chipping into the VSM shaft wall was still required to fit the MTBM between the entry ring and the jacking frame. During the first of the six microtunnel drives, upon removal of the reinforced concrete VSM wall at the launch location, exposing the coral limestone in the zone required to be treated by jet grouting, clear water inflow from portions of the chipped or exposed section was observed, first at approximately 5 gpm, then increasing to approximately 200 gpm as more of the VSM wall was removed at the chipped section exposing coralline limestone with jet grout filled fractures (Figure 6, left photograph). It was suspected the jet grout hole spacing might not allowed jet grout coverage of the annulus space or gap between the VSM wall and the in-situ coral limestone at this location. For subsequent microtunnel drives the contractor chipped less of the shaft walls, but some minor seepage on the order of 5 gpm were still observed through the chipped sections (Figure 6, right photograph).
For each of the six drives, during microtunneling of the first 20 feet (6.1 meters) outside the jacking shafts, spoils consisting of approximately 50% gray grout fragments and 50% coralline sands and gravels were observed in the microtunnel spoils, indicative that jet grout was present within the proposed jet grout stabilized zone. However, the clear water inflow during the first drive, and seepage of water through the chipped zones on the subsequent five microtunnel drives, indicated that in local zones, the jet grouting process, including grout hole spacing used probably did not achieve complete groundwater cutoff at this location. However, it is believed that the jet grouting performed provided the necessary ground stabilization at this location to maintain ground support for the temporary opening outside of the VSM shaft wall under very high hydrostatic pressure.

COMPARISON OF JET GROUTING FOR EXCAVATION SUPPORT AND GROUNDWATER CONTROL FOR TWO CONCURRENT PROJECTS

PROJECT A

Project A required the design and construction of approximately 6m (20 feet) deep open excavations below sea level with full perimeter excavation support and positive groundwater cutoff near the existing wet well, pump station, force main, sewer line, and various near surface utilities as shown in Figure 7 below.

FIG. 7. – Jet grouting layout in close proximity to existing facilities and utilities.

An exploratory boring completed near the proposed deep open excavation during the project’s design phase indicated the subsurface conditions would consist of Fill
with primarily loose to medium dense silty sands, Lagoonal Deposits with primarily very loose to loose silty sands and loose to medium dense silty coralline gravel and Interbedded Coral Reef Limestone and Coralline Detritus.

As required by the contract documents, Contractor A employed a qualified and competent work force who met requirements provided in the projects Bidder’s Statement of Qualification and Jet Grout Specification. A thorough and representative jet grout test program was also performed by Contractor A to develop and verify the jet grouting parameters to be used to install the bottom plugs, primary support columns, and wall support columns for the deep open excavation as required by the contract documents.

Contractor A used a single head drill rig and a single fluid system for production jet grouting. Due to proprietary jet grout means and methods, Contractor A’s jet grout parameters are not provided herein. Typical column spacing for jet grout outside of the pump station facility was observed to be 30-inches on-center. However, within the pump station facility and column spacing was observed to be 24-inches (61 centimeters) to 30-inches (76 centimeters) on-center.

Due to the critical nature of the work being performed, full time jet grout observation of Contractor A was provided to document, observe and ensure the accepted work plan was implemented by Contractor A in the construction of the deep open excavation. In general, ground heave, settlement and existing structure or subsurface utility distress was not observed or documented during jet grouting operations within the project area (Figure 8). Listed below are general observations made of Contractor A’s jet grouting means and methods to control ground heave and damage to existing structures and utilities:

a. Use of an oversize drill bit (6-inch (15 centimeters) and 8-inch (20 centimeters)) used to promote drill and material return during drilling and jetting (drill rod OD approximately 4-inches (10 centimeters));
b. Swabbing and reaming of the borehole during both drilling and jetting to recover slurry or grout circulation.
c. Controlled drill and grout slurry with vactor trucks to provide a clean and maintained work area.
d. Driller and Grout Foreman observed drill cuttings and grout returns throughout.
e. Column sequencing was reviewed and modified based on observed drilling and grouting of the open excavation by the driller and grout foreman.
PROJECT B

Project B also had similar Contract requirements as Project A and ground improvement using jet grouting methods was a bid option to provide deep excavations groundwater cutoff and bottom stability for microtunneling shafts and deep utilities construction within facilities that also include existing structures, buildings and subsurface utilities in close proximity to the work area. A boring completed near the proposed deep open excavation during the project’s design phase indicated the subsurface conditions would consist of Fill with primarily soft to very stiff elastic silts, Lagoonal Deposits with primarily very loose to medium dense silty sands, clayey coralline gravel and soft to medium stiff lean clay and Older Alluvium Intercalated with Coralline Detritus with primarily medium stiff to stiff elastic silts, very loose silty sands, and very loose coralline gravel in a silt matrix.

Contractor B submitted a qualified work force for the project’s Bidders Statement of Qualification, however a work force not meeting the Bidders Statement of Qualification requirements was used by Contractor B during production jet grouting. Contractor B did perform a jet grout test program as required by the Contract Documents, however the test program jet grout parameters and equipment was not used during production jet grouting.

In contrast to Project A, excessive ground heave and spoil / grout return was observed and documented during production jet grouting during Project B.

Listed below are general observations made of Contractor B’s jet grouting means and methods:

a. Dual-Head drill rig used during production jet grouting, in contrast to a single head drill rig was used in the test program. No observation of ground heave and excessive slurry / grout returns was documented during the test program.

b. Typical column spacing of 2.835 feet (0.9 meters) was used because the dual-head drill rod configuration was fixed at 5.7 feet (1.7 meters).
c. Undersized drill bits, approximately the same size as the drill rod diameter, were used during production jet grouting, which were observed to not promote slurry and/or grout returns. When Contractor B switched to a 6-inch (15 centimeter) drill bit slurry and grout returns observed increased and a reduction in ground heave and grout return frac-out was also observed.
d. Drill and grout circulation was not re-established when observed to be slow to none. Thus increasing pressures and causing ground heave and spoil and grout frac-outs.
e. Jet grouting sequencing did not follow the Contract Specifications. Project requirements required the excavation support walls to be constructed prior to the installation of the positive groundwater cutoff (aka bottom plug). Jet grouting was done in close proximity of existing facilities and utilities without the full perimeter excavation support acting as a cutoff against uncontrolled spoil escape through existing utilities bedding, etc.
f. Unqualified work force operating the drill rig and grout plant during production jet grouting.
g. Drill rig operator(s) observed to drill to proposed drill depth and press a button to start jetting process. Almost fully automated equipment and procedure reduced the operator’s opportunity to make the necessary adjustments in drilling and grouting to maximize grout spoil return and minimize potential ground heave and uncontrolled grout escape.
h. Grout specialist periodically onsite to monitor jet grout parameters and sequencing.
i. Drill slurry and grout returns not adequately managed thus creating difficult work environment for the jet grout crew.

CONCLUSIONS

Variable interbedded soils and limestone conditions are very difficult to impractical to be thoroughly grouted due to contrasting soil and rock physical properties. Recent project experience confirmed that with an experienced and qualified jet grouting contractor and key personnel, practical ground stabilization and groundwater control can be achieved in deep excavations subjected to high hydrostatic pressure, in variable soil-rock conditions.

Similarly, to sustain and protect the built environment during infrastructure renewal, jet grouting methods performed by a qualified and experienced jet grouting contractor and key personnel was used to support deep excavations and implement groundwater control, in close proximity to adjacent facilities and critical utilities.

Over reliance on automatic jet grouting controls and equipment, and the use of production enhancement jet grouting equipment, such as dual (2) or quad (4) headed drilling rig, was found to be problematic to unacceptable if used near existing utilities.
and facilities prone to damage. Such practice also limits or reduces the key jet grouting personnel, such as the specialist and the rig operator’s ability to for example adjust drilling and grouting procedures to ensure continuous spoil returns and to reduce jet grout holes spacing during production grouting, to tailor the grouting means and methods to changing soil/rock conditions.

The practice of using under-sized jet grout drill/grout bit, such as the same diameter as the drill rod might speed up production drilling of grout holes in variable ground conditions and minimize grout spoil return and therefore handling and disposal costs, but was directly correlated to uncontrollable grout escapes and excessive ground heave over significant distances from the grout rig, particularly when double fluid method was used.

REFERENCES
