Jet Grouting within Contaminated Land Fill

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Abstract

The site of the Barangaroo Project forms part of an old Sydney Gas Works and is heavily contaminated with hazardous materials. A perimeter retention wall is to be created with minimum UCS strengths of 5MPa. Construction of this wall involves overlapping jet-grouting columns, performed within negative pressurised tents with all personnel subjected to fully enclosed hazardous PPE and controlled decontamination procedures.

Two fluid jet grouting was considered to be of high risk to personnel due to creating a high level of airborne contaminates within the tent. Single fluid jet grouting utilising a patented optimized monitor enabled the construction of columns up to 1.8m in diameter in typical sandy clays and coal tars.

This paper describes the jet grouting works with focus on hydration of slag base cements within coal tar environments, environmental protection procedures, contamination controls and there overall effectiveness, as well as specific spoil management.

INTRODUCTION

Jet-grouting is one of the most popular techniques for strengthening soils. The principle relies on the use of a liquid jet with high kinetic energy to deconstruct the soil matrix and mix it in place with a binder brought by the jetted liquid itself (Morey – 1995). The device inside which the liquid jet is formed, called monitor, is usually slowly rotated while jetting to build columns.

This concept was originated in the seventies in Japan. During the past decades, developments around jet-grouting have led to three sub-techniques called single, double and triple jet; depending on the number of different fluids simultaneously operated to build columns: Single jet requires a cement grout with high hydrodynamic energy, while double jet operation adds a second jet of compressed air encapsulating the grout jet to increase its erosion capacity. For triple jet, erosion of soil is obtained by a high energy water jet encapsulated by air while grout is added at lower pressure on the toe of the monitor to incorporate the binder in the mixture.

For a given sub-technique and given soil conditions, the jetting energy – pressure, flow-rate and lifting rate - can be adjusted to reach a target column diameter. Jet-grouting is usually operated with small diameter drilling rigs, which can be operated from narrow platforms and/or low-headroom conditions.

More recently, some technical developments were undertaken to increase the erosive power of the jet, leading to the introduction of new jet-grouting equipment on the market amongst which Superjet monitor in Japan or Jetplus monitor in France (Morey et al – 2004), operated for the first time in Australia on Barangaroo site.
BARANGAROO SITE CONDITIONS

Site History:
History of the Barangaroo South area highly influenced the site ground conditions that now dictate the redevelopment plan of the area.
Barangaroo area is located on the western rim of Sydney city, New South Wales, Australia. Substantial amounts of land reclamation in the area took place during the mid to late 19th Century, with various wharves constructed perpendicular to the natural coastline. The Barangaroo South site was part of the Hickson Road Gas Works, constructed in 1840 which included the installation of gasholder tanks excavated into the sandstone. The Gas Works were demolished and backfilled in 1925, followed by the construction of timber wharves and sandstone seawalls by the early 1930’s. From the mid 1960’s containerisation of shipping created a modification of the wharves. A concrete seawall was constructed parallel to the former seawall. A combination of regular end tipping and construction of suspended concrete slabs formed the concrete apron which defines the site today.

The purpose of Barangaroo redevelopment is to convert this former container port into an extension of the Central Business District which will welcome hotels, office blocks, residential buildings as well as public places.
The industrial history of the site has resulted in contamination being found on site such as hydrocarbons from the gas works and asbestos from the land reclamation tipping.
As part of the redevelopment plan of the area remediation works are undertaken that feature a Perimeter Retention Wall, which was constructed in 2016 and is the subject of this paper.

Ground conditions:
The ground of the Perimeter Retention Wall site is mainly composed of:
- Land fill of highly variable thickness,
- Class IV weathered sandstone: 1 meter thick in average, depth ranges from 1.00 meter to 13.50 meters,
- Class III sandstone: depth ranges from 1.80 meter to 14.50 meters.

The Land fill is composed of a mixture of sand and gravel, mainly derived from crushed sandstone, with minor quantities of clay. The base of the fill has been interpreted as highly irregular and has often mixed with the upper surface of the underlying natural soil during placement. The fill is observed to contain sandstone cobbles, brick fragments, steel bars and timber. Relics from the former industrial structures such as timber piles, bored piles of various diameters, a number of reinforced concrete slabs, sandstone masonry walls, buried ceramic or concrete services were found along the perimeter of the site.
Class IV sandstone is typically highly weathered, fractured, and has low strength and significant clay seams. Class III sandstone features medium to very high strength and is slightly to moderately weathered. The bedrock profile along the perimeter of the site was heavily influenced by the construction of the wharfs, followed by the construction of the gasholder tank and subsequent buried service installation.
The site is crossed by a near vertical dolerite dyke, between 1.5 m and 3 m wide. It is composed of moderately weathered to slightly weathered dolerite. The dyke is variably weathered across its width, with the margins typically preferentially weathered than the core, and completely weathered to clay in its upper part. It features typically low to medium strength.
The Perimeter Retention Wall crosses a former gas holder tank that was constructed by bulk excavation into the Sandstone. An annulus trench of about 1.8 meter wide and 9.5 meters depth was used to hold residual material of gas operations. The tank was backfilled at the shutting down of the gas works, but this material, particularly Coal Tar, remained in the annulus. More generally, a large portion of the fill has been contaminated by gasworks waste as a result of the previous use of the site as a gas works plant. The variable nature and distribution of fill materials has caused localised variations in groundwater flow and associated contaminant migration, which is further complicated by tidal influences, the dyke and point sources outside the perimeter.

**Design of the Perimeter Retention Wall:**
Soletanche Bachy International – Menard Bachy Joint Venture were engaged by Lend Lease Building to design and construct the Perimeter Retention System for the Block 4 & 5 Remediation Works on the Barangaroo South project. The Scope of Works included the installation of the Perimeter Retention System to allow an ex-situ remediation and land forming works. The Retaining Wall had to achieve minimum UCS (Unconfined Compressive Strength) strength of 5MPa.

The eastern side of the site along Hickson Road was identified to be highly contaminated, particularly in the vicinity of former Gas Works infrastructure and tanks. Main pollutants identified were:
- Separate Phase Gasworks Waste and Tar, namely Coal Tar, containing among others Volatile Organic Compounds such as TPH, PAH (including Benzo(a)pyrene) and BTEX and emitting a strong hydrocarbon odour,
- Contaminants of potential concern, including lead and relatively high concentration of metals (copper and zinc) and ammonia,
- Widespread Asbestos Containing Material.

Within these soil conditions, the construction of the Perimeter wall in this area could not be completed by excavation means such as secant pile wall, contiguous pile wall or slurry wall. Volatile Organic Compound concentration measured in soils along Hickson Road identified concentrations of gas vapour in soil with concentrations up to 90 ppm.

These values, as well as the presence of pedestrian walkways along Hickson Road, required the execution of works within confined and covered areas called Odour Containment Enclosures (OCE) presented later in this paper.

The remaining solution to build all sections of the Perimeter Wall in these contaminated soils was a sequence of overlapping jet grouting columns of 1.5 and 1.6m diameter to provide a structural homogenous wall within the in-situ fill embedded into the top of the weathered rock, as shown on Figure 1. At shallower depths, the temporary anchor was replaced by a second row of inclined columns built behind the vertical columns to form a gravity wall.

This allowed the bulk excavation down to 16 meters depth for remediation works and basement construction.
ENVIRONMENTAL CONTROL ON SITE

The contaminated area presented a significant risk with presence of human carcinogens and substances toxic to aquatic ecosystems. In order to protect the environment as well as health, safety and amenity of workers and members of the public in the vicinity of the site, a Remedial Work Plan was implemented and monitored by an Occupational Hygienist and Environmental Specialists.

All the activities and stages of construction of the Perimeter Retention Wall were adapted to meet specific work procedures which covers the component of works such as Air Quality and Odour Management, Water Treatment, Spoil Management and Occupational Health and Hygiene Management.

Air Quality and Odour Management:
Jet Grouting process involved drilling through the contaminated ground and generating spoil composed of in-situ contaminated material mixed with cement grout. The Jet Grout works were completed inside two tents known as Odour Containment Enclosures (OCEs). These OCEs were mounted on rails and moved up and down the length of the perimeter. These enclosures shown on the Figure 2, were 15 m long x 8.74 m wide x 6.2 m high.

Figure 1: Typical cross section for the Perimeter Wall along Hickson Road

Figure 2: Jet Grouting Mobile OCEs

Figure 3: Jet Grouting set up
The Jet Grouting drilling equipment, tooling and excavation plant had to be located within the OCE to complete the works (Figure 3). A mini drill rig was used, equipped with a short mast and a detachable diesel operated power pack remaining outside of the OCE, in order to significantly reduce heat and diesel particulate matter loads inside the OCE.

The contaminated spoil was pumped through sealed pipes from the rig location to spoil management areas housed within two larger OCE shown on Figure 4. These enclosures were 20 m long x 21 m wide x 10 m high at the apex, and remained stationary over the spoil management area for the duration of the Jet Grouting works. The spoil management OCEs were fitted with rapid roller doors at each end to allow trucks to enter and exit in a straight line. The OCEs were also fitted with an air curtain to reduce the potential for airborne odours to escape. The air curtain was activated whenever the OCE doors were opened.

All OCEs were operated under negative pressure, the atmosphere within these enclosures being extracted and treated through an Emission Control Systems (ECS) before discharge.

Jet grout enclosures were ventilated by a single mobile ECS servicing both tents with flexible ducting and moved with the enclosures as the Jet Grouting works progressed.

A larger, fixed ECS was used to service the spoil management enclosure with intake ducting extracting air from either side of the enclosure and treating at the ECS.

Both ECSs comprised of particulate filters and Granular Activated Carbon beds to remove dust particles, organic contaminants and odour prior to discharge to the atmosphere.

In addition, all the OCEs were attached to air conditioners and generators.

Baseline monitoring results were in full compliance with the POEO (Protection Of the Environmental Operation Act 1997 NSW).

This approach limited the exposure of contaminated materials to the atmosphere, significantly reducing the potential for generation of odours or volatile organic contaminants.

Water treatment:
A Water Treatment Plant (WTP) was installed on site to treat run off and process water from contaminated areas. This water was collected and pumped directly into storage tanks where it was either reused as part of the Jetting Process or discharged under licence into storm water facilities onsite.
Spoil Management:
Jet Grouting spoil was pumped from its point of generation to spoil management OCEs and then stockpiled in storage bays, where it underwent pre-treatment by drying and curing prior to transfer into trucks for offsite disposal. Total storage within Spoil Management OCEs was 200 m³. Bench scale trials were undertaken with the samples of contaminated material and several grout mixes to select a mix, and to determine the leachability of the contaminants in the resultant spoil. The data was used to apply to the New South Wales Environment Protection Authority for Specific Immobilisation Approval (SIA) for the waste. The SIA was approved, realising significant savings to the project for Hazardous waste disposal.
Material was kept on site long enough to complete the geotechnical and environmental testing required in order to determine the waste classification and allow lawful off-site disposal.

Contamination control:
During execution of works, Coal Tar was encountered within the fill in variable concentrations, often mixed with soil. A relatively high quantity of pure Coal Tar came from the Annulus trench. It was found adhering to the drilling rods and in very dark spoil returns as can be seen on Figures 5 and 6 below.

![Figure 5: Coal Tar attached to drilling rod](image1.png) ![Figure 6: Coal Tar in Spoil returns](image2.png)

While working within OCE tents, workers were highly exposed to hazardous agents. A number of control measures and monitoring were implemented with the help of an Occupational Hygienist to eliminate the risk of unacceptable exposure.
The Site work areas were separated in a “Clean” and a “Red” zone, the Red zone being the exclusion zone where works involving exposure to contamination were carried out. The OCEs were located in the Red zone.
All Jet Grouting personnel entering the Red zone were subjected to pre-entry baseline medicals and the following Personnel Protective Equipment (PPE) requirements, shown on Figure 7:
- Positive air flow full face vapour respirator combined with a hard hat and a communication systems,
- 2 layers of Nitrile inner gloves,
- 1 layer of industrial rubber gloves,
- Chemical/Liquid Tight disposable Coveralls (Category III, Type 3, 4, 5 and 6) with hood on,
- Chemical resistant gum boots,
- Gloves and boots to be taped to the coveralls.
Personnel that entered the Red zone decontaminated themselves within decontamination facilities located between the Red and Clean zones. The process included a succession of precise steps for cleaning, checking, maintaining, storing or disposing gear as per the Occupational Hygienist Plan.

In order to protect workers from exposure, daily monitoring of particulates matter, asbestos fibres, heat stress and noise, were undertaken. It included real time air monitoring of concentration of Volatile Organic Compound, Benzene, Ammonia, as well as area sampling of airborne asbestos fibres and personal sampling using absorption badges. In addition, field odour measurement and monitoring were conducted by a nasal ranger.

Baseline monitoring and Project Close-Out Medicals showed no adverse Health impacts. Both the Environmental and Health Controls in place ensured compliance to the following: Safe Work Australia Work Place Exposure Standards for Airborne Contaminants 2013; NSW Work Health and Safety Act 2011; NSW Work Health and Safety Regulation 2011; Site Specific Environmental Licence NSW EPA; Protection of the Environment Operational Act 1997 NSW.

THE JETPLUS SYSTEM

Construction of 1.5m and greater diameter columns within these soil conditions would normally require the use of the double jet technique (air and grout). However, due to the presence of volatile compounds as well as toxic vapours within the soils to be treated the risk of creating airborne pollutants meant that the use of air had to be restricted.

The use of JetPlus monitor in single jet on site was a good alternative, as it allows constructing rather large diameter columns with a reasonable energy, which was previously only possible with double jet systems, as illustrated by Figure 8.
On Barangaroo site, the use of a one fluid jet method instead of air jet methods has the following advantages:

- Compressor not required;
- Lighter weight drill string enabling easier manual handling in confined spaces. No drill string annular spaces, meaning less maintenance and blockages;
- Reduced air borne pollutants;
- Reduced risk of soil collapse and soil fracturing via migration or trapped air during jetting;
- Reduced risk of blow-outs hence resulting in a safer work place environment; Improved management of spoil flow.

**JETPLUS PERFORMANCE ANALYSIS**

At the beginning of construction works, several trial columns were installed on site to confirm the jet-grouting production parameters. Trial results enabled the selection of 2 No production parameters (Table 1) to achieve column diameters and establish variable Cement Kg/m3 injection rates pending on concentration of existing tar to be treated.

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<th>Set #1</th>
<th>Set #2</th>
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<tr>
<td>Cement consumption (kg/m3)</td>
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*Table 1: Jetting parameters used on site for both testing and production*

The selected binder consisted of a blend of 60% Ground Granulated Blast Furnace Slag (GGBFS) and 40% Portland cement. GGBFS is a sulphate-resistant product with low hydration heat. The low hydration heat reduced the amount of volatiles exhausted in the OCE environment. GGBFS improved cement hydration and final UCS results when applied in the Coal Tar environment as opposed to test performed using Ordinary Portland Cement (OPC).

The Jet Plus equipment was successful in constructing all the low headroom Jet Grout works within the OCE including columns up to 1.8m in diameter where works had to be performed adjacent or around existing services.

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Jet Grout spoil returns were collected on a daily basis during construction and subjected to 7, 14 and 28 day UCS testing at NATA approved testing facilities. Analysis of these compressive strengths demonstrated the following:

- A gradual evolution of compressive strengths aligned with curing time (Figure 9), illustrates that the presence of chemicals in the soil cement mixture has a relative limited effect on binder hydration process when using GGBFS binders at the correct dosage.

- An acceptable scatter of the unconfined compressive strengths at 28 days, which follows a log-normal distribution curve of 30% (Figure 10). This dispersion is normal, as a variable quantity of coal tar can be encapsulated within a soil-binder matrix (Figure 11),

- Less than 5% of the crushed samples are beyond the target UCS of 5 MPa at 28 days, which is enough to ensure the global and local stability for the retaining wall.

Micropiles were drilled within the Jet Grout walls. Hard material and minimal water ingress were noticed, which confirmed the uniformity of the installed columns, even in the critical Annulus trenches where much Coal Tar was encountered while Jet Grouting (Figure 12).

Core samples were taken from these boreholes (Figure 13) and sent to a NATA accredited laboratory where they got tested. The average UCS obtained on those sample is 7.27 MPa, which is consistent with the results obtained on spoil samples.

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CONCLUSION

Barangaroo has been an exceptionally challenging project that inspired a certain amount of creative and somewhat lateral thinking in order to conform with design requirements, execute the works within confined work spaces, manage labour fatigue due to non-breathable work suits and fully enclosed space type helmets, comply with local environmental regulations and of course complete the works as per allotted programme.

The environmental control measures ensured that atmospheric levels were in line with expectations and deemed safe for the personal and public in proximity of the site.

Results to date have shown that with the right amount of engineering, due diligence in testing, utilisation of correct materials, e.g. cement binder type, ability to be innovative (Trial of Jet Plus System) a positive work force that is engaged in the process and is consciences towards the final outcome, a Jet Grouted retaining structure can be created in even the most challenging soils and working conditions.

ACKNOWLEDGMENTS

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