

# THE APPLICATION OF JET GROUTING FOR THE CONSTRUCTION OF SYDNEY INTERNATIONAL AIRPORT RUNWAY END SAFETY AREA

Babak Hamidi<sup>(1)</sup>, Michal Krzeminski<sup>(1)</sup>, Daniel Berthier<sup>(1)</sup>, Philippe Vincent<sup>(1)</sup>, Murray Yates<sup>(1)</sup>

<sup>(1)</sup>Menard Bachy

## ABSTRACT

The Runway End Safety Area (RESA) is part of the upgrade plan of the Sydney International Airport and adds an extension to the end of the runway. As this area passes a number of existing facilities it will have to be bridged over a heritage listed sewer, an airport perimeter road and the existing highway road.

The area of RESA was previously low lying farming land with major alterations in the ground contours due to previous construction works. The site is on man-made filling up to 4 m thick from earlier dredging works and predominantly marine originated alluvium. Also soft mud deposits are extensively spread over the area, and groundwater level is quite high.

The loads introduced by bridging RESA over existing structures and lowering the road level at the intersection with RESA required specific geotechnical measures.

Jet Grouting has been used successfully in RESA with multiple purposes such as increasing the ground's bearing, retaining the ground and creating impermeable barriers to cut off the flow of water during construction. Multiple requirements and variations in ground conditions required a detailed design with a number of Jet Grout column diameters, lengths and combinations. Design included finite element analyses using Plaxis and later verified by sampling of grout and installing inclinometers to measure ground deformations.

## 1. INTRODUCTION

As part of the upgrade programme of Sydney Airport, the end of Runway 07/25 is being extended for aircraft emergency overrun to achieve compliance with new international safety requirements. The new Runway End Safety Area (RESA) project is being built in a location that collides with the heritage listed Southern and Western Suburbs Ocean Outfall Sewer (SWSOOS), a diverted airport perimeter road and the existing M5 Motorway Tunnel (see Figure 1). As the project location is at the edge of the Cooks River, relocation space is very limited, and it has been understood that the most suitable option for resolving the problem is to construct a 90x90 m<sup>2</sup> concrete area that is bridged over the mentioned facilities.



(a) (b)  
Figure 1: (a) Global view of the project location, (b) RESA location

Levels at the end of the runway are generally around +5 to +6 m RL. Top of SWSOOS is approximately at +6 m RL. The perimeter road is approximately at +1.5 m RL except where it passes under the sewer, at which point it is at -2.6 m RL.

RESA is being constructed on the eastern bank of the Cooks River. This area has been altered several times by SWSOOS construction in the 1950s. It would appear from early aerial photographs that the area of RESA was previously low lying farming land and that it has been extensively filled during the development of the airport, particularly for the 07/25 runway construction. Photographs taken during construction of the SWSOOS seem to confirm that there have been some major alterations in ground contours to the east of SWSOOS and more recently for the underpass, perimeter road and M5 Motorway tunnel construction.

The bridge overrun will consist of a conventional pavement from the end of the runway and then a bridge structure. The structure will span over SWSOOS, the new perimeter road and M5 tunnel.

In addition to the bridge, the project will include lowering and relocating the existing perimeter road so that there is at least a 5 m clearance underneath the proposed aircraft bridge. The minimum design levels shown on the perimeter road longitudinal section indicated that excavation was needed to enable pavement construction to be undertaken.

The first stage of the works comprised of a shallow excavation beneath SWSOOS, whilst it remained supported on its old foundations of driven concrete piles, in order to facilitate the installation of the underpinning prestressed concrete structure. The ground had to provide sufficient bearing to support the formwork of this structure before the load was transferred to four external large bored piles and the old SWSOOS piles were removed. The sewer will be a triple cell reinforced concrete box structure supported on piles which are also required to carry part of the load from the bridge structure.

Temporary works required the construction of a cofferdam system to prevent water ingress and to provide ground retention around the underpass structure.

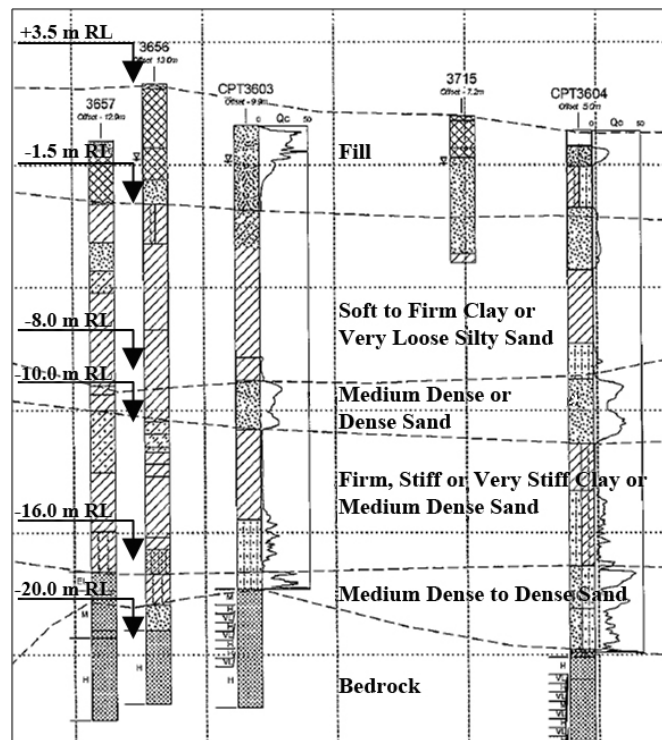


Figure 2: Ground profile at RESA

## 1.1. GROUND CONDITIONS

At the time of the commencement of RESA, the soil strata comprised of up to 4 m of fill, reclaimed during earlier dredging works, followed by predominantly alluvium of marine origin. The subsoil below sea level consisted of soft clay deposits, 8 m thick, overlying 2 m of sand and underlain by stiff residual clay.

A typical section of the ground is shown in Figure 2. Ground surface is from about +3.5 to +1 m RL. Fill layer was composed of a variation of loose to dense sand and silty sand extending down approximately to elevation -1.5 m RL. This layer was followed by soft to firm clay or very loose silty sand down to about -8 m RL. CPT cone resistance,  $q_c$ , of this layer was less than 1 MPa. Sleeve friction ratio,  $f_r$ , was generally about 4% with low and high values of 2% and 6% respectively. The fine layer was underlain by a 2 m thick layer of dense sand that extended down to -10 m RL.  $q_c$  of this layer ranged from 25 to 35 MPa. The soil from -10 to -16 m RL was stiff or very stiff clay. Cone resistance was around 3 to 4 MPa and occasionally higher. Friction ratio was as high as 8%. The soil in between the mentioned layer and bedrock at about -20 m RL was once again dense sand with  $q_c$  in the range of 25 to 35 MPa. In turn bedrock was medium to high strength sandstone.

The available information for this site indicated that groundwater levels were at about RL +1.0 m and fluctuating with the tides of the sea. These levels could have risen during periods of heavy rainfall due to substantial infiltration into the exposed soils between the 07/25 Runway and the International Terminal.

## 1.2. GEOTECHNICAL REQUIREMENTS

In order to span the land bridge over SWSOOS, the M5 Tunnel, and the widened and realigned airport perimeter road it was necessary to identify and implement geotechnical solutions for

- Providing a water cut-off system to allow construction within the working perimeter.
- Allowing construction and excavation under SWSOOS with sufficient head room for positioning equipment under SWSOOS (first excavation to elevation  $\pm 0$  m RL).
- Providing bearing for the formwork and temporary false work props of the new support structure that would replace the piles that were originally supporting SWSOOS.
- Providing sound working platform to build the underpass bottom slab.
- Ensuring full lateral support to the sides of the first and second excavations. The second excavation was at the depth of -3.6 m RL at the bottom slab and -5.5 m RL at drainage facilities. Horizontal movement had to be limited to 10 mm in normal working conditions and 11 mm for accidental failure of the dewatering system and the rise of groundwater level outside the cut-off area from -1 to +1 m RL.
- Providing the temporary wall and foundation system of the new pumping station and drainage lines.
- Stabilising the soft clay ground on the north and south sides of the perimeter wall to facilitate construction of the underpass bottom slab.

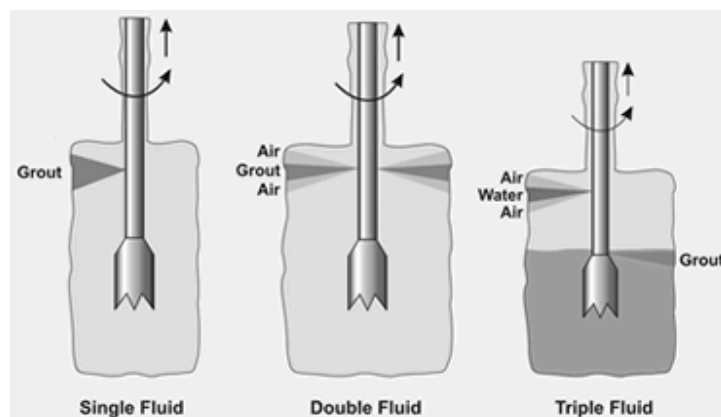


Figure 3: Jet Grouting systems

## 2. SOLUTION: JET GROUTING

Boulderstone, the projects managing contractor, awarded Menard Bachy the specialist geotechnical works to resolve the mentioned problems. Jet Grouting (JG) was proposed and utilized for providing the solution to all the requirements previously stated. As reported by Mitchell (1981) jet grouting was first introduced in Japan (Yahiro and Yoshida, 1973; Miki, 1973; Miki et al., 1980).

Jet grout columns are installed by initially drilling a small hole, typically 100 mm in diameter to the required depth. Then the soil is eroded by a high pressure jet of grout, water, or air-enshrouded grout or water, and the simultaneous injection of cement suspension grout into the disturbed soil by means of a nozzle. The injection pressure can be up to 60 MPa. The drill stem and nozzle are simultaneously raised and rotated so as to combine the grout with a portion of the original soil to form solidified soil mixed material. The end product is cementitious round columns.

There are three major systems for jet grouting; i.e. the single, double and triple fluid systems. In the single fluid system a special hollow drill rod which is equipped with a monitor containing a horizontal jet nozzle at the tip is lowered into the hole. Cement suspension grout is pumped down the drill rod at a very high pressure of up to 60 MPa while the drill rod and monitor are simultaneously rotated and withdrawn. The grout that exits the jet nozzles at high velocity disintegrates the soil and mixes with it to form soilcrete. In the double fluid system the grout is encased within a shroud of compressed air. The air acts as a buffer between the groundwater and the grout, greatly increasing the cutting efficiency. It also creates turbulence in the waste spoil, improving the efficiency of its removal. In this method a special coaxial drill string and jet monitor are used. The triple fluid system requires a triaxial drill stem and monitor with appropriate nozzles. In this system an air-enshrouded jet of water erodes the soil while the grout is simultaneously injected through separate nozzles. The cutting jets are located above the grout supply, which allows a nearly complete replacement of the soil with grout as the monitor is withdrawn. The three grouting systems are shown schematically in Figure 3.

Jet grout columns can be constructed in all soils; however the effective radius and strength depends on the properties of the soil and the jet grouting parameters used. In granular soils jet grout columns can have a strength of about 10 to 15 MPa or more; however the strength of jet grouted columns in clay can be quite less and as low as 1 MPa. Jet grout strength is primarily determined by the soil type; however the amount of cement used per unit volume and the water-cement ratio also have an effect. Typical water-cement grouts have a water-cement ratio in the range of about 0.6 to 1.2 by weight.

For single fluid system jet grouted columns, typically diameters are on the order of 0.4 to 0.6 m in cohesive soils and up to about 1.2 m in granular materials. In two-fluid system column diameters are on the order of 0.8 to 1.2 m in cohesive soils and up to about 1.8 m in granular soils. Implementation of the triple fluid system allows the construction of larger diameter columns whereas in cohesive and granular soils the diameters can be respectively up to 1.5 m and 3.6 m. Typical injection parameters for different jet grouting systems are shown in Table 1.

### 2.1. DESIGN

A complex system of JG columns were designed with different diameters, spacings, lengths and reinforcement to satisfy the various project requirements from the necessity to provide bearing to creating stable and impervious boundaries. The complex construction drawing of the JG columns under SWSOOS is shown in Figure 4.

Jet Grouting System	Single fluid	Double fluid	Triple fluid
Grout injection rate (l/min)	40-115	70-130	70-130
Grout pressure (MPa)	20-60	30-60	3-17
Air flow (l/min)	-	3700-6000	2700-6000
Air pressure (MPa)	-	0.6-1.2	0.6-1.2
Water flow (l/min)	-	-	70-150
Water pressure (MPa)	-	-	20-50
Rotation (RPM)	10-25	5-10	2-10
Withdrawal rate (cm/min)	10-50	7-30	5-30

**Table 1: Typical injection parameters for different jet grouting systems**



**Figure 4: Complex layout of JG columns under SWSOOS**

Numerical analyses using Plaxis was carried out to verify that stresses within the JG columns and ground deformations would remain within acceptable limits.

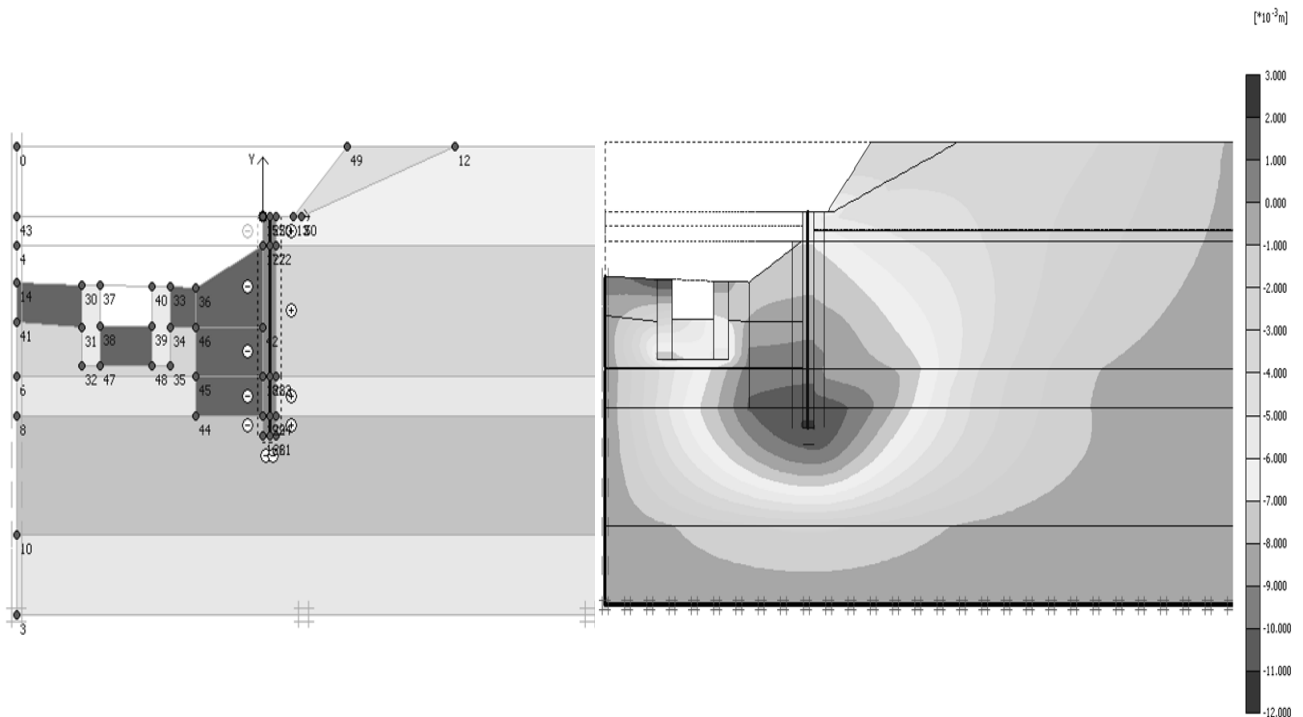
In the calculations multiple groundwater levels had to be assumed. Groundwater level at the periphery of the project was assumed to be reduced by dewatering and pumping to -1 m RL during execution of jet grouting. Inside the perimeter cut-off, water level was assumed to be 1.0m below existing excavation level and at -6.5 m RL when proceeding to final excavation. Also, for the accidental condition of failure of the dewatering system, groundwater level at the periphery was assumed to be +1 m RL.

The toes of the JG columns of the perimeter wall were anchored 1 m into the stiff to very stiff clay layer in order to provide water cutt-off. Thus the longest JG columns were 13 m in length.

Jet grout column properties for calculation purposes were determined by preparing a number of different grout mixes in the laboratory for sandy, silty and clayey soil. Based on these tests and by applying a reduction factor of 3 which incorporated the differences between lab and site mixes and long term creep behaviour, Young Modulus of the JG columns was conservatively taken as 1,800 MPa.

In the finite element model, JG columns were represented by a wall with a thickness based on equivalent axial stiffness (Hamidi et al, 2009).

It is noted that the mass improvement of the soil by the short JG columns had a substantial effect on reducing the perimeter wall's horizontal movements to approximately 10 mm at the toe which were below acceptance criterion. The effect of these crucial components of design were taken into account by modifying the ground properties based on the density of the columns, respectively 41 and 75% in different locations.



**Figure 5: Finite element analysis for verification of stresses and deformations**

Structural verification of the perimeter wall jet grout columns was carried out for two main failure modes; i.e. overstressing due to bending moment and failure due to shear. Based on these calculations a steel bars were used for reinforcing the JG columns of the perimeter cut-off wall.

In order to be able to assess the ground conditions during any stage of the works, a typical finite element analysis for any cross section included a number of calculation phases. As an example, the below phases were considered for the eastern section of the wall:

- Initial stage: This phase was modelling the project prior to commencement of any works with groundwater level at +1 m RL.
- Initial excavation stage: At this phase the groundwater level was reduced to -1 m RL and the working platform level was lowered (excavated) to  $\pm 0$  m RL.
- Installing the JG columns: The JG wall was modelled to -11 m RL, and the JG elements were modelled between the perimeter walls. The purpose of the JG mass improvement network was to reduce the perimeter wall movement.
- First excavation stage: In this phase of modelling, the ground water level within the perimeter wall was reduced to -8 m RL. Excavation was modelled to -1.5 m RL. Groundwater flow boundary condition calculations was introduced to the model during this phase. A groundwater flow calculations were carried out in order to model ground water pressures for this phase.
- Second excavation stage: In this phase the excavation was modelled to be at -3.6 m RL.
- Third excavation stage: The sewer pit excavation to -5.5 m RL was modelled in this phase. The model and ground deformations of this phase can be seen in Figure 5.
- Accidental water rise: In this phase the accidental failure of the dewatering system and rising of the groundwater level outside of the perimeter wall to +1 m RL were analysed.



**Figure 5: Implementation of a special mini rig for low head areas**

- Global stability failure calculation:  $c - \phi$  reduction calculation using Plaxis was carried out to check the stability of the excavation. Calculation demonstrated that the factor of safety for the top of the slope (area outside of the perimeter wall) was at least 1.90. The excavation's slip line factor of safety was even higher than this figure.

## 2.2. CONSTRUCTION

Based on the design, a minimum UCS of 4 MPa at 28 days 1,628 JG columns with a total drilling length of 13,761 m, columns length of 6,368 m and volume of 5,134 m<sup>3</sup> were installed using the double fluid system sometimes preceded by pre-cutting to allow larger diameter columns. Of this, approximately 500 JG columns were installed under SWSOOS and in between its supporting piles. JG column diameters were variable from a minimum of 1 m to a maximum value of 2.5 m. Minimum and maximum column lengths were respectively from 2 to 13 m, with perimeter support columns reinforced with one N36 bar in the centres.

Potable water and marine grade cement were used in the JG columns. A total of 5,104 tons of cement was used to produce the columns.

The works were carried out using 3 rigs in two working shifts. As shown in Figure 6, one of these rigs was a specially designed machine capable of working underneath SWSOOS with a limited head room of only 2.7 m. An interval in jet grouting operations was allowed during the construction of RESA to allow for the first excavation, construction of the SWSOOS frame support and cutting SWSOOS' redundant piles.

In order to ensure minimum effect of jet grouting on the piles of SWSOOS, a clearance distance of 500 mm and 800 mm were respectively considered for the short and long JG columns.

Due to the sensitivity of the project, variations in ground levels, and head and toe elevations of JG columns it was necessary to implement a very stringent surveying method on site that would minimize errors. Thus, the installation point of each JG column and actual ground levels was identified using a GPS system that was capable of reporting all three coordinates of the points.

Both drilling and jetting were monitored by digital recording hardware. During drilling, depth, advance speed, rotary speed and thrust pressure were recorded. Grout pressure, grout flow, grout volume, stationary time, air pressure, air flow, uplift speed and rotation speed were monitored during the jetting phase. The start and stop time for each columns was also recorded. Furthermore, the grout density and viscosity were measured during each working shift.

Special sequences were applied to the columns to allow sufficient setting time of the grout as needed.

In addition to collecting spoil samples, 0.5% of the columns were cored between the overlapping interface of two columns and samples collected for testing. The tests demonstrated that the minimum required UCS of 4MPa had been achieved.



**Figure 6: Excavation and construction of SWSOOS support structure after jet grouting**

Actual measurements during construction confirmed that horizontal deformations were at most 2 mm at the top of the JG perimeter wall which was well below the acceptance limit. Settlement of the frame support was measured to be 8 mm which was very close to the calculated value of 9 mm.

These highly demanding jet grouting works, tightly nested with other construction activities, were carried out in two main stages; namely before and after installation of SWSOOS supporting structure. Figure 6 shows the excavation and retainment of the ground and construction of SWSOOS' support structure after jet grouting.

### **3. CONCLUSION**

RESA has been a high performance design and construction feat in ground improvement. This project has demonstrated the successful application of jet grouting for multiple purposes and functions. Stringent requirements, limited movements in the sensitive SWSOOS structure and the piles supporting it to a few millimetres, complex staging, difficult ground conditions and a number of site constraints dictated a very comprehensive design supported by finite element analyses. Using jet grouting technology it has possible to create an impervious barrier to allow excavation under groundwater level. The same barrier was also designed as a wall to retain the soil from entering the work area. Also, JG columns were able to improve the ground soil as a mass in order to minimize wall deformations. JG columns also provided bearing for loads and formed the foundation of SWSOOS' frame support.

### **4. REFERENCES**

- HAMIDI, B., NIKRAZ, H. & VARAKSIN, S. (2009) Arching in Ground Improvement. *Australian Geomechanics Journal*, 44, 4 (December), 99-108.
- MIKI, G. (1973) Chemical Stabilization of Sandy Soils by Grouting in Japan. *8th International Conference on Soil Mechanics and Foundation Engineering*, 395.
- MIKI, G., NAKANISHI, W., IIZUKA, T., ICHINO, Y. & IMAMISHI, H. (1980) Grout Jetting Method Applied to Excavation of Soft Ground.
- MITCHELL, J. K. (1981) Soil Improvement State-of-the-Art Report. *10th International Conference on Soil Mechanics and Foundation Engineering*, 4, Stockholm, 509-565.
- YAHIRO, T. & YOSHIDA, H. (1973) Induction Grouting Method Utilizing High Speed Water Jet. *8th International Conference on Soil Mechanics and Foundation Engineering*, Moscow, 402-404-404 also 359-362.