EXCAVATION, STRUCTURAL STABILISATION AND GROUNDWATER MANAGEMENT BY JET GROUTING ON SYDNEY HARBOUR FORESHORE

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ABSTRACT

A former town gasworks site on Sydney Harbour's foreshore has been the subject of site remediation to address residual industrial contamination. Jet Grouting was undertaken under a Design & Construct contract to form a temporary retaining structure behind and under the full length of a 19th Century seawall, thereby facilitating the excavation and ex-situ remediation of contaminated materials at the site and ensuring long-term stability of the seawall. In addition, existing heritage buildings were underpinned with Jet Grouting to ensure the structural stability and integrity of these structures during the excavation phase. The excavation was up to 7m deep and 6m below sea level. Jet Grouting was undertaken under strict settlement and deflection controls, with a target permeability no greater than $1x10^{-7}$m/s. The works were performed by installing over 300 Jet Grout Columns ranging from 1.2m to 2.5m in diameter. Jetting was partially carried out from within the confines of existing heritage structures, while the bulk of the external works was carried out from within an environmental odour control enclosure. The confined nature of the site and its access limitations required the effective co-ordination of Jet Grouting with other site works.

1 INTRODUCTION

The former HMAS Platypus site, located in North Sydney on the waterfront of Neutral Bay has a diverse history as a gasworks, a Naval Base providing torpedo maintenance facilities, and ultimately as the HMAS Platypus submarine base. The site has an area of approximately 1.8ha and includes 11 buildings and structures, some of which are of heritage significance, and it has been off-limits to the public for over 140 years.

The soils, bedrock and groundwater on the site are contaminated, predominantly related to the former gasworks, which operated between 1876 and the late-1930s. Gasworks infrastructure including retorts, tar and liquor tanks, coal stores, gas holders, boiler houses and purifiers are some sources of the contamination at the site, and abandoned underground gasworks infrastructure remains at the site.

Figure 1: The northern part of the site in the early-1900s. (HMAS Platypus 2012)

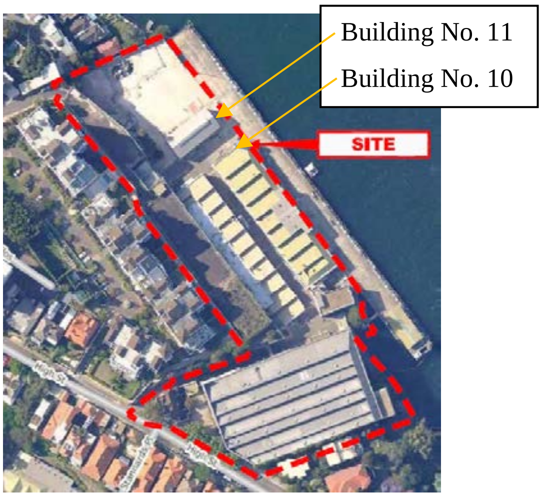


Figure 2: The site in 2010. (HMAS Platypus 2012)

Subsequently, the site became a torpedo maintenance factory and naval maintenance facility (1942-1967), and then the HMAS Platypus submarine base for the Royal Australian Navy (1967-1999). More recent sources of contamination are associated with underground fuel storage tanks.

HMAS Platypus closed as a submarine base in 1999, and in 2005 the site was transferred from the Department of Defence to the Harbour Trust to be remediated and rehabilitated for public use. Funding was provided in 2009 to clean up the site's industrial contamination. Extensive below-ground remediation works have been undertaken at the site since 2010 and treatment of contaminated material was completed in 2012.

The objective of the Platypus Remediation Works was to excavate contaminated soil in controlled conditions inside an odour control enclosure (OCE), and treat the arisings ex-situ by the addition of cement and granular activated carbon. The end use of the stabilised material was either off-site disposal or on-site reinstatement, dependent upon the original concentrations of contaminants.

Keller Ground Engineering (KGE) was contracted to design and construct the retaining structure to support the heritage seawall and facilitate the safe excavation of contaminated materials to depths of as much as 6m below sea level. In addition, heritage buildings were to be underpinned.

2 GEOLOGICAL SETTING

Hawkesbury Sandstone cliffs form the western side of the site (as can be seen in Figure 1). The fairly flat concreted area from the foot of the cliff to the seawall comprises mainly fill (see Figure 3). The fill deepens progressively towards the seawall, to a maximum depth of about 7m. A thin and variable layer of marine mud occurs between the base of the fill and the sandstone bedrock. Contamination extended through the fill and into the muds.

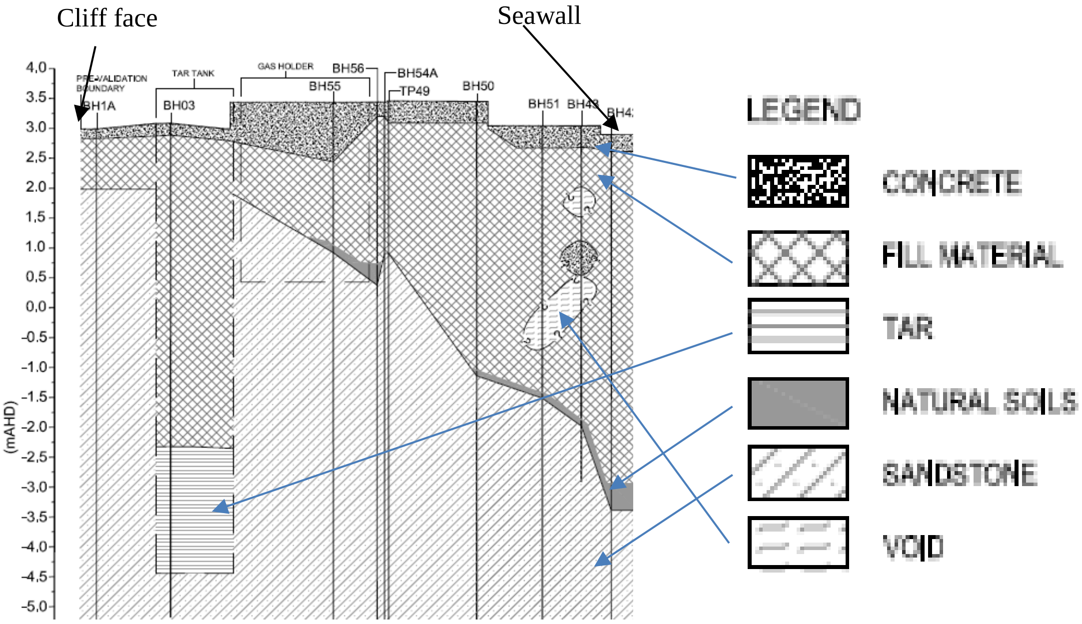


Figure 3: Typical geological cross-section through the northern part of the site. (HMAS Platypus 2012).

Apart from the nature of the fill, being variable industrial waste mixed with excavated materials, of concern was the 100+ year old heritage seawall, which in part was constructed of sandstone blocks, seemingly founded on the former seabed.

3 DESIGN OF SUPPORT SYSTEM

The design principles of the northern section grouting work were to limit hydraulic conductivity and to provide structural support for the existing seawall and a number of heritage buildings. The detailed requirements of the design were to fulfil the following functions (HMAS Platypus 2012):

- Limit the ingress of water during excavation of contaminated fill materials for treatment.
- Act as a retaining wall during excavation to provide a safe and stable working environment, resisting the pressures from the bay water and sediment.
- Provide foundation support for heritage listed Buildings Nos 10 and 11 during excavation (Building 11 is visible on the left hand side of Figure 1, and both are indicated in Figure No. 2).
- Provide long term structural support to the existing seawall, with a design life of 50 years.

- Limit hydraulic connectivity between the reinstated treated fill materials and the waters of Neutral Bay.
- Provide support for the construction of the OCE's structural foundation at predetermined locations.

The following description and figures highlight the main features of the solution adopted by KGE, in accordance with the Client's specification, and are illustrated in Figures 4 to 6 (Keller Ground Engineering 2012):

- Jet Grouting was adopted as the primary treatment option, and the Jet-Grout columns were designed to meet the requirements of the various elements of the project.
- The first row of columns behind the seawall and the columns underpinning the exterior of Building No. 11 were 1.2m diameter, spaced at 0.9m centres.
- A second row of columns 2.2m diameter at 1.8m centres was installed behind the first row in the sections of deepest seawall, adjacent to Building No. 10 and in the area between Building No. 11 and the seawall.
- Columns 2.5m diameter were utilised within Building No. 11 for insitu stabilisation, as the floor in this area was to be retained (see Figure 4).
- Jet-Grout columns were installed using a "Double" jet grouting system (see Figures 7 and 8), utilising either a standard jet grouting rig, or a rig suited to restricted access and/or limited headroom conditions (see Figures 12, 13 and 15).
- Jet-Grout columns were installed to bed-rock level, and the front row columns were constructed to +2.5mRL (nominally 0.5m below existing ground slab level).
- Once Jet-Grout columns were completed, vertical holes were drilled to install tension shear pins, these bores were subject to water testing to determine the permeability of the rock.
- Rock grouting was then conducted on the underlying bedrock based on the water test results.
- The tension shear pins were then installed, with socket depths as per the design requirements (see Figure 5).
- In order to reduce active pressure behind the seawall during and post-installation due to the hydrostatic head of grout, Jet-Grout columns behind the sea-wall and wing-wall retaining walls were installed on a Primary, Secondary, Tertiary 1, Tertiary 2 basis.
- Based on Jet-Grout spoil set time testing conducted during the Field Trials, at least 8h was allowed between each phase of installation.

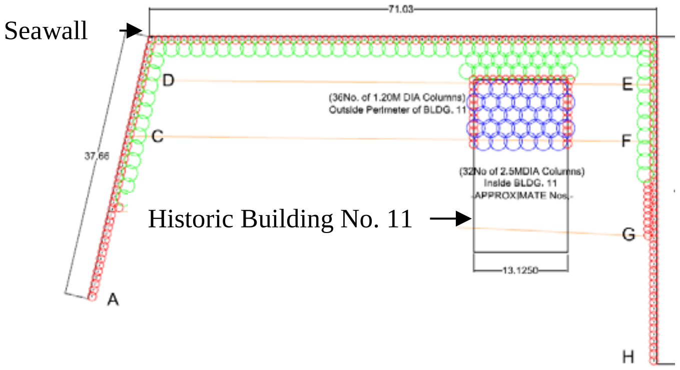


Figure 4: Plan showing Jet Grout column locations.

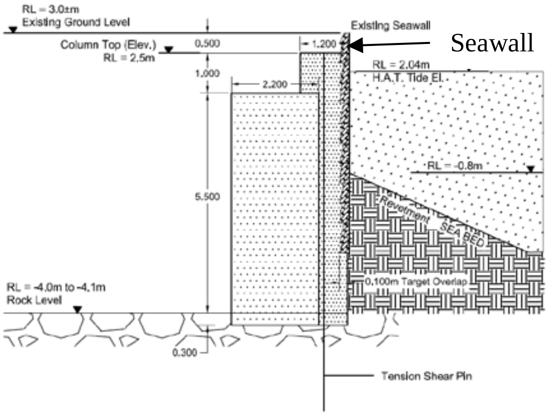


Figure 5: Concept design of seawall support.

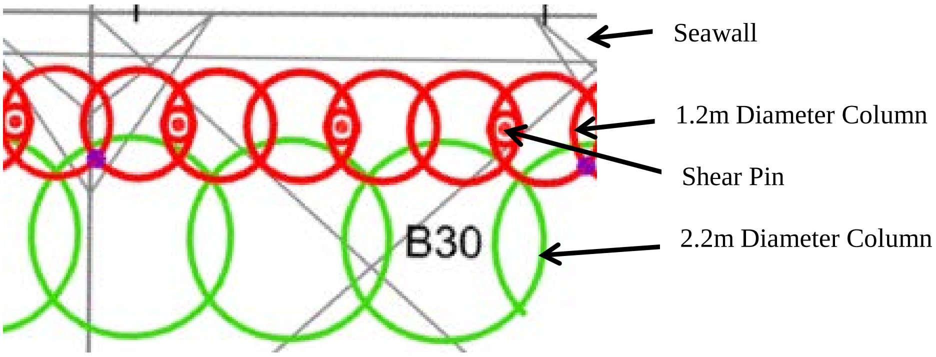


Figure 6: Detail arrangement of Jet Grout columns and shear pins.

4 IMPLEMENTATION OF JET GROUTING

4.1 THE JET GROUTING PROCESS

Jet grouting is a ground treatment method that creates columns or panels of Soilcrete – soil cemented with grout. The method can be used for a wide range of applications, most commonly for underpinning, excavation support and groundwater cut-off. The aim is to create a continuous Soilcrete mass to meet the specific project or design requirements, while maintaining the integrity of supported structures or utilities. Jet grouting uses rotating high velocity cutting jets of water or grout to break up and mix soil. The choice of system is dictated by the application, with Soilcrete permeability and strength dependent upon the grout used and the soil being treated. In this instance a double system was deemed to be the most appropriate, which uses a compressed air shroud around the jet grout nozzle to increase erosion capability (see Figures 7 and 8).

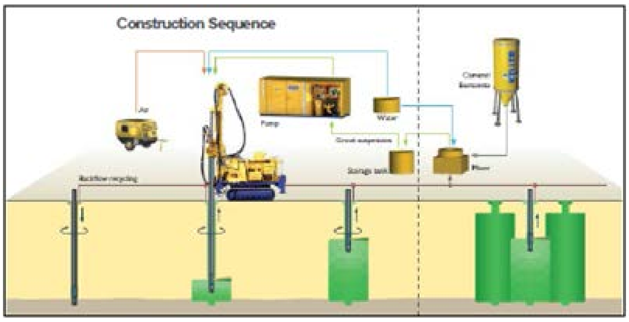
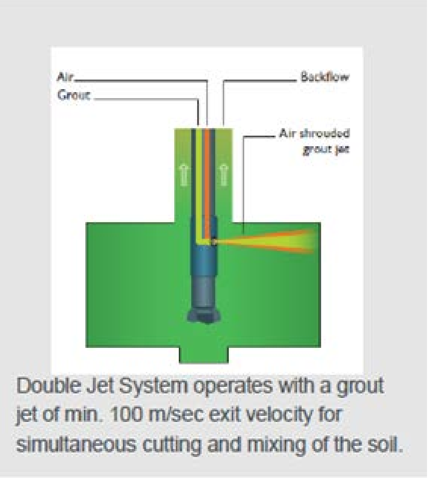


Figure 7: Jet Grouting procedures. (Keller)



Double Jet System operates with a grout jet of min. 100 m/sec exit velocity for simultaneous cutting and mixing of the soil.

Figure 8: Double Jet system. (Keller)

4.2 MOBILISATION AND DELIVERIES TO SITE

Due to residential street access constraints, the very limited space on the site for truck entry and turning, road load restrictions, and limitations on delivery times, most of the plant, equipment and materials were delivered to site by barge, with the Jet Grouting batching area established on the wharf (see Figures 9 to 11).

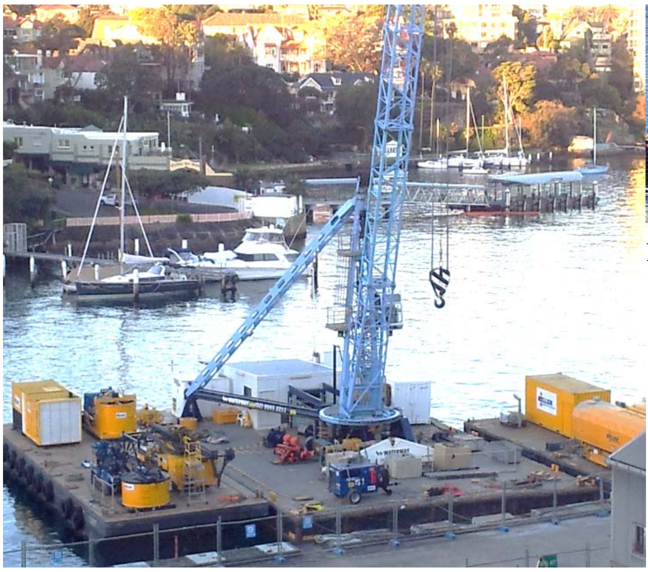


Figure 9: Most KGE plant and equipment was transported to/from site by barge and craned onto/off the wharf.

Figure 10: Cement supplies arrived daily by barge.

Figure 11: Jet Grouting support plant on the wharf.

4.3 JET GROUTING TRIALS

A series of trials was undertaken throughout the project to determine the key parameters to be adopted for the range of jet grout column diameters required for the works. The key parameters were:

- Grout flow rate
- Grout pressure
- Air flow rate
- Air pressure
- Jet grout nozzle size and number
- Grout density and strength
- Rotation speed
- Lift rate

The trials involved the installation, monitoring and excavation of a number of jet grout columns at three locations across the site. An assessment of column diameter over depth was undertaken along with continuity of treatment, permeability and strength of the Soilcrete.

4.4 PRODUCTION JET GROUTING

The trials and early works in the northern section of the site commenced prior to erection of the OCE. Figures 12 and 13 illustrate the works at this stage of the project. Works in the southern section of the site were conducted in restricted access conditions either within existing buildings or in small isolated work areas. The spoil generated by the jet grouting process was pumped to above ground storage lagoons, located in the northern part of the site, where it was allowed to set over a period of 1-2 days before being stockpiled for disposal off site.

Figure 12: Jet Grouting on the seawall after initial trials.

Figure 13: Jet Grout underpinning of Building No.11.

4.5 WORKING INSIDE THE ODOUR CONTROL ENCLOSURE

Once the dome had been erected and remedial works commenced, the environmental and occupational health aspects dictated stringent precautions for operating personnel. Figures 14 and 15 give an idea of the working conditions during this phase of the project.

Figure 14: The OCE under construction (over the top of Bulding No. 11).

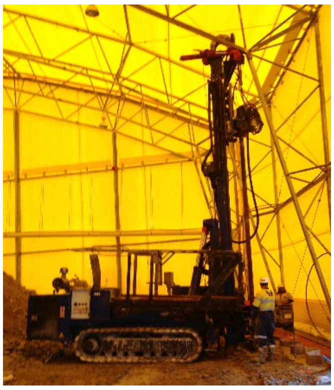


Figure 15: Jet Grouting inside the OCE.

4.6 PROPPING

Protection of the heritage seawall was a primary objective, and after the assessment of its stability in the temporary case, it became necessary to prop the entire seawall and continuously monitor it for movement during the works. The majority of the propping was installed in restricted access below the wharf structure, as can be seen in Figure 16 below.

Figure 16: Propping of the seawall beneath the wharf.

5 TESTING AND VALIDATION

A comprehensive programme of testing was undertaken in order to validate the design and performance requirements of the works.

5.1 PERMEABILITY

5.1.1 In-Situ Permeability Testing of the Jet Grout Wall

In-situ testing to determine the permeability of the jet grout wall was undertaken by means of Lugeon tests with interpretation of the results based on the methods proposed by AC Houlsby (Houlsby 2011). The tests were undertaken within vertical boreholes located at the overlap between adjacent jet grout columns, a zone within the wall likely to exhibit the highest permeability. A target permeability of $1x10^{-7}$m/s was identified within the specification (HMAS Platypus 2012), and a Lugeon value of 1 was accepted as being equivalent to the target permeability.

In total 15 in-situ permeability tests were carried out within the jet grout wall to validate the works; all the tests recorded a Lugeon value of 1, hence meeting the specification requirement of 90% of permeability tests having a permeability of not greater than $1x10^{-7}$m/s.

A further requirement of the specification was that borehole CCTV camera surveys were undertaken within each test borehole. The results of these camera surveys provided continuous footage of the borehole and confirmed the continuity of treatment over the full depth on each occasion. The surveys also confirmed the presence of large sandstone boulders and brick rubble within the fill material.

5.1.2 Laboratory Permeability Testing of the Jet Grout Material

In addition to the in-situ permeability testing required by the specification, four samples were submitted for laboratory testing. The test samples were formed within U100 tubes from slurry spoil returns collected during the jet grouting process. Permeability testing was carried out in accordance with AS 1289.6.7.3 with the results at 90 days ranging from $1.0x10^{-9}$m/s to $6.0x10^{-9}$m/s. The difference between the in-situ and laboratory test results of at least one order of magnitude appears to be consistent with data from other jet grouting (and soil mixing) projects, and this is the subject of further internal review within the Keller Group.

5.1.3 In-situ Permeability Testing of the Bedrock

Lugeon tests, as detailed above, were carried out during the rock grouting works to determine the permeability of the rock mass and to validate the effectiveness of the rock grouting treatment. In the instances that Lugeon values in excess of 1 were recorded, repeat grout injections were carried out until an acceptable permeability was achieved.

5.1.4 Observation of the Excavated Works

The excavation works to remove and treat the contaminated fill were carried out sequentially across the site. Observations of the jet grout wall and base of the excavation were made during this process in regard to water ingress – seepages were not measurable and appeared to come mainly from the land side. The works were carried out in what were essentially dry conditions (see Figure 17).

Figure 17: Panorama during excavation – centre facing the rear of the seawall (approx. 7m excavation depth and up to 6m below sea level), to the right is the underpinned Building No. 11.

5.2 SOILCRETE AND GROUT

5.2.1 Daily QA/QC Testing

Daily QA/QC testing was carried out in accordance with the project specification and quality plan to ensure that the various grouts utilised for jet grouting, rock grouting and shear pin installation met the targeted parameters for Specific Gravity, Viscosity and Gel Time.

5.2.2 Unconfined Compressive Strength

Unconfined Compressive Strength (UCS) testing was conducted throughout the project on representative samples of jet grout slurry returns (Soilcrete); grout from the jet grout batch plant (neat grout); shear pin installation grout (homing grout) and the grout used for rock grouting. The information relating to Soilcrete, neat grout and homing grout is summarised in Table 1 and demonstrates compliance with both the project specification and the KGE design requirements. Figure 18 shows the increase in UCS over time for the Soilcrete and neat grout samples.

Table 1. Summary of UCS Test Data (28-day strengths)

Material	*Specification*	*KGE Design*	*Result Range*	*Mean Result*
Soilcrete	n/a	>2MPa	4.1-20.5MPa	10.5MPa
Neat Grout	90% >5MPa	n/a	7.4-38.5MPa	26.4MPa
Homing Grout	n/a	≥ 40MPa	44.0-92.5MPa	67.6MPa

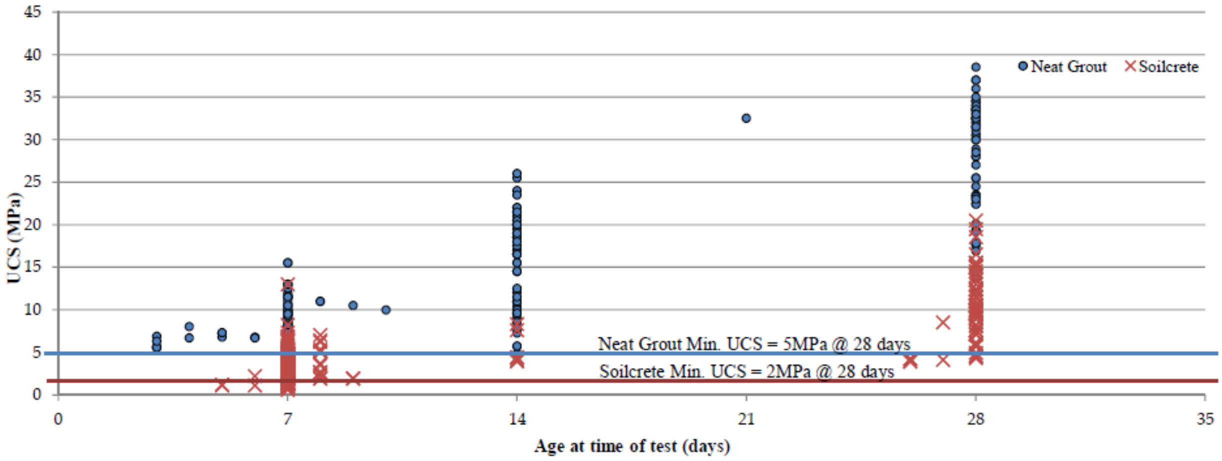


Figure 18: Soilcrete and neat grout Unconfined Compressive Strength test results.

5.2.3 Young's Modulus

Deformation testing to determine the Young's Modulus of the Soilcrete and neat grout was undertaken as part of the testing and validation programme; the results are summarised in Table 2 below and display compliance with the requirements of the project specification.

Table 2. Summary of Young's Modulus Test Data

Material	*Specification*	*KGE Design*	*Result Range*	*Mean Result*
Soilcrete	n/a	n/a	2.6-8.0GPa	4.9GPa
Neat Grout	90% >500MPa	n/a	5.2-8.1GPa	7.3GPa

5.3 SHEAR PINS

Vertical shear pins were incorporated into the jet grout retaining structure to provide flexural capacity to the jet grout block and were extended into the underlying sandstone to provide stability against seawater uplift forces (Keller Ground Engineering 2012). The design and verification of the shear pins was carried out in accordance with U.S. Department of Transport Circular No. 7 (2003).

Two test shear pins were installed in order to verify the parameters used in the design:

- Test No. 1: Distal test with the bonded length entirely within sandstone. The upper section of the reinforcing bar was de-bonded within the jet grout Soilcrete using a PVC sleeve.
- Test No. 2: Proximal test with the bonded length entirely within Soilcrete. Again, a PVC sleeve was used to de-bond the upper section of the reinforcing bar above the top of the Jet Grout column (refer to Figure 19 below).

The tests were performed to confirm the bond stress between the shear pin and the ground, and the shear pins were subjected to pull-out loads of up to 200% of the design working load, F_w, with a 60 minute creep test at 150% F_w. Both tests achieved the maximum test load of 200% F_w, met the creep test parameters and as such complied with the acceptance criteria detailed in the above-referenced document. The result for Test No. 2 are presented in graphical form in Figure 20 below. In addition, Test No. 2 was further loaded to determine the ultimate bond between the homing grout and the ground (jet grout) – a load of 500% F_w was imposed without failure being observed and the test was halted due to deformation of the base material below the bearing plate.

Proof tests were performed on three production shear pins to confirm that the production nails could withstand the design loads without excessive movement or long term creep over the service life, the shear pins were successfully subjected to a test load of 150% F_w including a 60 minute creep test at maximum load.

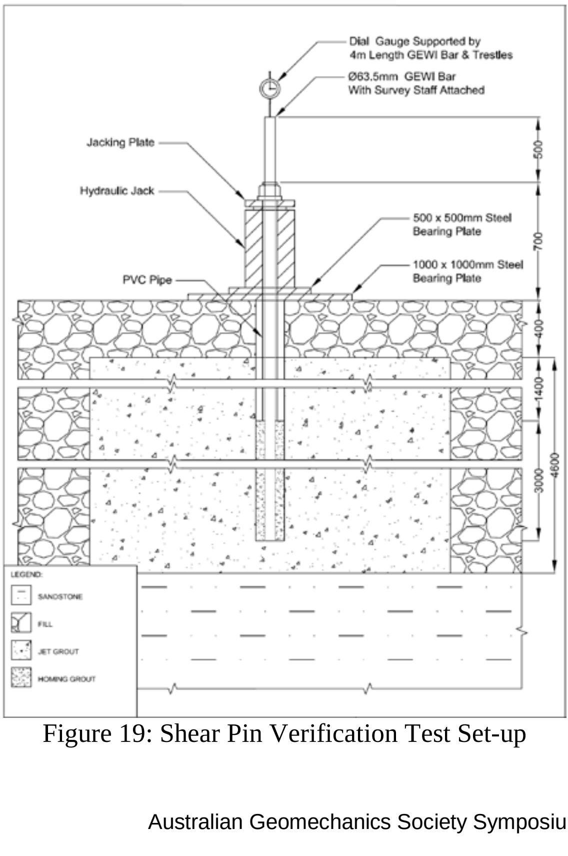


Figure 19: Shear Pin Verification Test Set-up

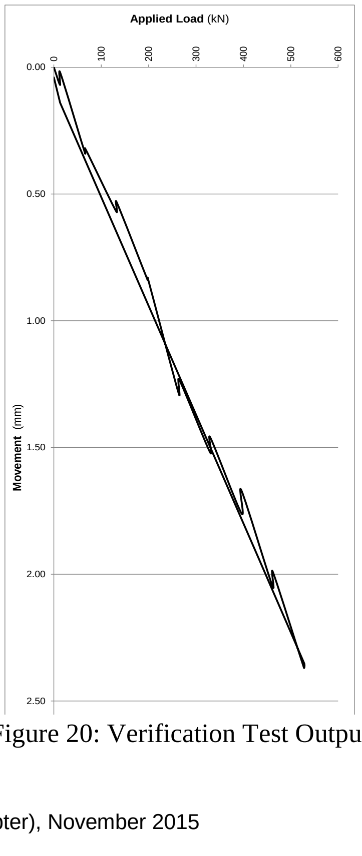


Figure 20: Verification Test Output

(Test No. 2).

(Test No. 2).

6 CONCLUSIONS

The remediation of historic contamination at a site on Sydney Harbour's foreshore was aided by the provision of stabilisation and underpinning of the heritage seawall and structures. Jet Grouting was the technique adopted for the primary works, accompanied by rock grouting and the installation of tension shear pins. Excavations to depths of 7m, up to 6m below sea level, remained essentially free from any measurable seepage. Quality Control procedures resulted in the desired end product, with the provision of a stable excavation and a safe working environment. The performance of the Jet-Grouted seawall exceeded requirements and expectations. Ex-situ remediation was completed and the excavation backfilled. The works were carried out in a confined site with access constraints and several simultaneous operations, which required close cooperation between the various parties. Works are now in progress to complete the capping of the site and return it to public use for the first time in over 140 years.

7 ACKNOWLEDGEMENTS

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