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Design and construction of a deep soil-bentonite groundwater barrier wall at Newcastle, Australia

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ABSTRACT

This paper presents geotechnical and geo-environmental aspects of the design and construction of one of the world's deepest soil bentonite (SB) groundwater barrier wall at the former Steelworks site at Newcastle, Australia. The site is undergoing a $110 million remediation programme, and a critical part of the remediation strategy is the construction of a soil-bentonite wall, nearly 50 m deep and 1.5 km in length. This "up-gradient" cut-off wall was designed to divert groundwater around the most heavily contaminated part of the former steelworks site, known as 'Area 1'.

Topics covered include: geotechnical investigation, slurry trench stability, mix design, laboratory permeability testing, and construction quality assurance. Full-time geotechnical supervision and quality control testing ensured a high standard of key verification and soil-bentonite backfill uniformity, meeting the stringent design criteria. The construction of the wall was successfully completed in 2007.

1 INTRODUCTION

The Mayfield Site is approximately 155 ha within the former Newcastle steel works site on the south bank of the Hunter River. Over a period of 130 years this site has housed copper smelters, steelworks and ancillary operations. Steelworks wastes (slag) have been used to fill much of the site. The most polluted part of the site is an area known as Area 1, and was previously occupied by coke ovens, gas holders, and other processes associated with steelmaking.

On 14 June 2001, under Section 21 of the Contaminated Land Management Act 1997 (CLM Act), the Environment Protection Authority (formerly EPA, now Department of Environment & Conservation - DEC) declared the former Steelworks site to be a remediation site. Under the Declaration, remedial works were required because the DEC considered the site to present a significant risk of harm to human health and the environment. In March 2003, RLMC was created by the NSW Government to manage the former Steelworks site and other crown land in the Lower Hunter Region, including remedial and redevelopment works for the site. RLMC has entered into a Voluntary Remediation Agreement with the DEC, where remediation activities are regulated under Section 26 of the CLM Act, as well as the planning approval under the Environmental Planning and Assessment Act (1979).

2 SITE REMEDIATIONS OPTIONS

A total of 32 options and alternatives were reviewed for this project. Generally, the three main site remediation options are the following:

• Soils remediation *in-situ* (treatment option)	- Permanent solution; High cost; Energy demanding - Excavation of all contaminated material and subsequent processing is difficult to achieve in practice - Obligation to comply with the NEPM 'Air Toxics' guidelines (NEPM, 2003)
• Pump and Treat	- High operational costs - Impact of Ground Water drawdown on other stakeholders
• Containment	- Cost effective solution; Long term effective life - Technical solution endorsed by the EPA - Very low impact on environment and other stakeholders - Low maintenance costs

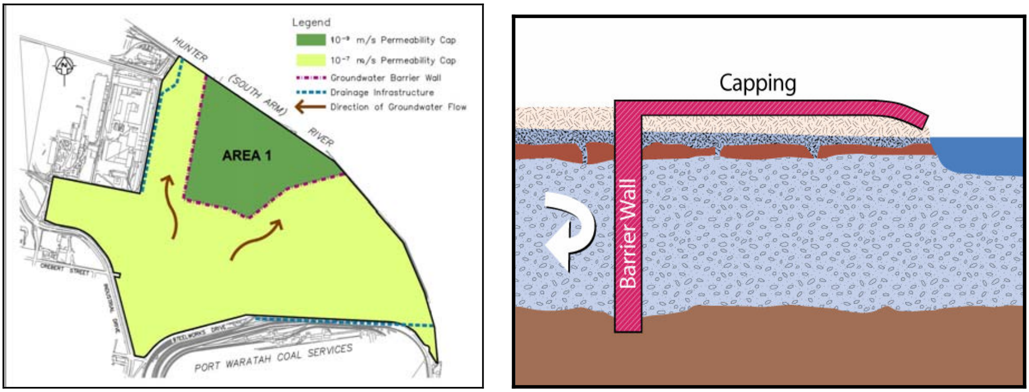

Figure 1: Schematic of Remediation Concept

The strategy finally adopted for the steelworks site is containment and comprises the following key elements as shown on Fig. 1:

- Construction of an upgradient groundwater barrier wall diverting flows away from the most contaminated area of the site (Area 1)
- Sealing the site surface area with an inert capping layer, which both prevents the infiltration of surface water, and provides a physical barrier between contaminated soils and humans on the site.
- Improved drainage infrastructure and contouring of the site, which will contribute to both the reduction of surface water infiltration and the management of possible contaminated surface water run off from the site.

The barrier wall is 1,510m long, 0.8m wide and has depths ranging from 25m to 49m, keyed into the basal confining layer of clay or weathered rock. The maximum required permeability is 10^{-8}m/s.

3 GEOTECHNICAL AND ENVIRONMENTAL CONDITIONS

The geotechnical investigation comprised 16 test bores, 27 cone penetration tests (CPT) and 20 test pits. The bores and CPTs provided deep stratigraphic information, at an average spacing of 35 m along the wall alignment, allowing the appropriate key-in layer to be determined. The test pits provided information on the fill layer, including depth, composition, excavatability, the nature of obstructions, and the presence of contaminants in the soil or water. The typical subsurface conditions are illustrated in Figure 2, showing a section along part of the wall alignment.

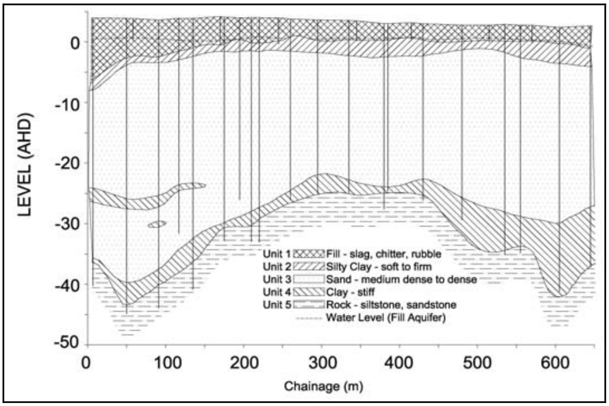

Figure 2: Cross-section Ch 0 to Ch 650

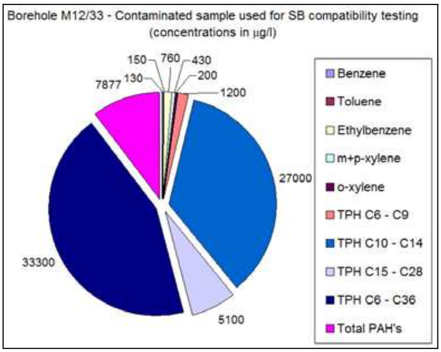

Figure 3: Groundwater contaminants

The geo-environmental testing of fill materials sampled from test pits included chemical analysis for Total Recoverable Hydrocarbons (TRH); Polycyclic Aromatic Hydrocarbons (PAH); Benzene, Toluene, Ethyl Benzene, Xylene (BTEX); Heavy Metals and ammonia. High concentrations were obtained for

PAH, Benzo(a)pyrene (BaP), Chromium (Cr) and Lead (Pb), and these results were consistent with previous testing at the site.

A detailed Environmental Management Plan was prepared to set out suitable procedures for the management of these materials during the pre-trench operations. The pre-trench involved excavation through the fill layer for two main purposes:

- Remove obstructions in the fill prior to deep trenching for wall construction to minimize the risks during the barrier wall construction
- Assess, segregate and stockpile the fill into three categories of contamination.

Figure 3 above shows the main contaminants in groundwater sampled from well M12/33 at 12 m depth. This water was used during the mix design and for long term permeability testing.

4 TECHNICAL OPTIONS FOR CONSTRUCTION OF THE GROUNDWATER BARRIER

The main construction methods considered for the project are summarized hereafter:

• Soil Bentonite (SB)	- Most common at waste sites (US EPA 1998 study) - Durability of barrier in presence of contaminants > 30 years - Re-use of excavated materials on site and incorporation in final barrier - Most cost effective solution; Non structural barrier
• Plastic concrete, cement bentonite (CB)	- Frequently used; Comparatively higher cost - For the depth range envisaged on this project, plastic concrete is a more common construction method than CB. - Potential for long term adverse reaction of cement with in-ground contaminants
• Deep soil mixing (wet)	- Difficulty to maintain verticality and hence ensure continuity of the wall to envisaged depths - Difficulty to penetrate through and to incorporate grout in presence of very dense sands - Variability of mixed final product and difficulty in controlling permeability - Relatively few case histories for this application
• HDPE membrane	- Not suitable below 10-15 metres depth - Not suitable alone in dense materials - HDPE panels virtually impervious to water and most contaminants - Difficulty of establishing joints between HDPE panels
• Steel sheetpiles w/ hydrophilic joints	- Structural method - Highest cost - Higher permeability

The soil-bentonite technology was selected on the following basis:

- During the course of tender preparation, both Soil-Bentonite (SB) and Cement-Bentonite (CB) walls were considered suitable for the contaminated site conditions and requirements.
- Tenders were invited from selected contractors for a SB or CB wall which satisfied the design performance requirements.
- The successful Design & Construct specialist contractor accepted by RLMC offered a competitive price for a SB wall, accepted the risks and was able to demonstrate that this methodology was acceptable for this site and all design criteria could be satisfied.

5 PRINCIPLES OF SOIL BENTONITE WALL

Soil bentonite walls are low permeability groundwater barriers constructed by excavating a trench under bentonite slurry. The slurry stabilizes the excavation and prevents it from collapsing, even below the water table, as described in Ryan (2007). The range of permeabilities achievable with this technology is given in Fig. 5 and are a function of the nature of the blended soils and of the percentage of dry bentonite added.

Given the range of depths of excavation, two pieces of equipment working in sequence were used: a backhoe modified to dig to 25 metres to complete the first phase of the trench, and a mechanical clamshell to excavate the deeper material down to the final depths as shown schematically on Fig.4. As the excavation proceeded, the trench was backfilled with a low permeability mixture, consisting of a blend of excavated soil, imported Virgin Excavated Natural Material (VENM) clay and bentonite slurry. Mixing of the constituents generally proceeded along the trench in a linear fashion.

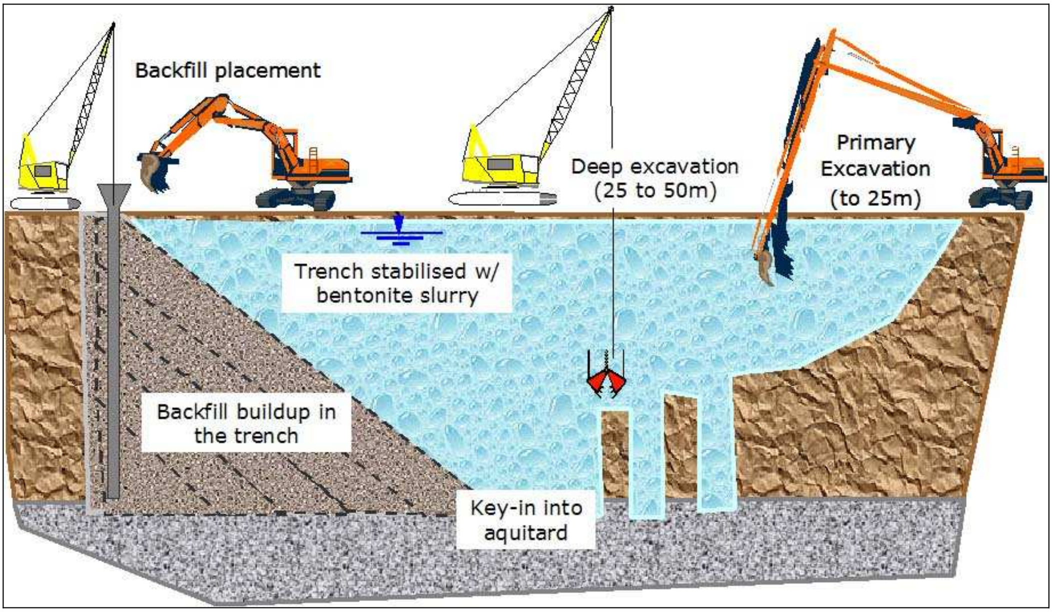

Fig. 4 – Schematic of deep soil-bentonite wall construction process

6 DESIGN, MONITORING AND WALL TESTING

6.1 Mix Design

The main objectives of the mix design were:

- obtain lower and upper limits of fines content and fraction of dry bentonite necessary to achieve the maximum permeability with in situ soil samples,
- carry out permeability testing on in-situ samples using the leachate as a permeant with the objective of assessing any potential detrimental effect of contaminants on long term hydraulic performance of the groundwater barrier
- check any adverse reaction on the bentonite slurry during exposure to site contaminants.

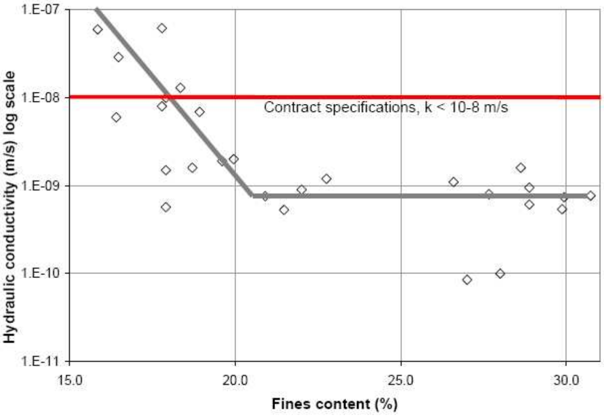

Fig. 5 - Summary of permeability tests results during design phase as a function of fines content

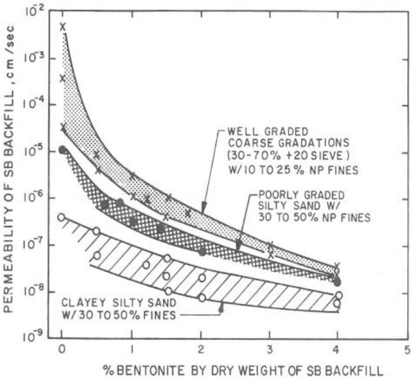

Fig. 6 - Range of permeabilities with SB walls in cm/sec(D'Appolonia, 1974)

The conclusion of the mix design was that the minimum fines content necessary to consistently achieve a permeability of less than 10^{-8} m/s was close to 20%, taking into account the materials available for the project, compared to a 30% lower limit indicated by D'Appolonia (1974) in Fig. 6.

6.2 Geotechnical Design

The trench stability during excavation was assessed using the CPT data which allowed the balance between slurry pressure and lateral earth pressure to be plotted virtually continuously with depth. Global wedge failure was also considered.

The specification also required that the completed wall withstand a differential head of 5 m across the wall. Hydraulic fracture can occur due to settlement and arching of the backfill, which causes a reduction in vertical effective stresses; when these are less than the horizontal effective stresses, and hydraulic pressures are high enough to induce fracturing, the fractures will propagate horizontally and could significantly impair the effectiveness of the wall as a barrier to groundwater flow. The risk of hydraulic fracture was analysed using FLAC (Itasca 2005) and found that this condition was very unlikely for a wall thickness exceeding 0.5m (actual wall thickness was 0.8m).

The surface completion needed to be trafficable to industrial type vehicles, with deflection criteria of 50 mm vertical settlement and 1:50 differential distortion. This comprised compacted granular material (re-used from site), and the expected performance was checked by finite element analysis.

6.3 Environmental Management

Environmental management was achieved through the preparation and implementation of a detailed Contractor Environmental Management Plan (CEMP). The CEMP was reviewed and approved by DEC prior to construction commencing.

Pre-trenching works through the fill horizon were subject to full-time monitoring by an environmental engineer. The excavated fill was categorised into Level 1, 2 and 3 soils based on field sensory screening (visual and olfactory), soil vapour screening using a PID, and reference to previous chemical test results, the level 3 category corresponding to Separate Phase Hydrocarbons with no re-use on site and DEC notification. In addition, a material tracking system was used, linking the material source (chainage and depth) with its destination stockpile (GPS coordinates). Other routine environmental management procedures included screening and treating natural sediments for acid sulphate soil conditions; surface water monitoring; management of noise, dust and asbestos-impacted soil.

6.4 Quality Control - Geotechnical Monitoring

Quality control of bentonite slurry properties is important to identify any anomaly immediately to ensure trench stability, but is not specific to soil-bentonite walls and includes tests such as viscosity and filter press.

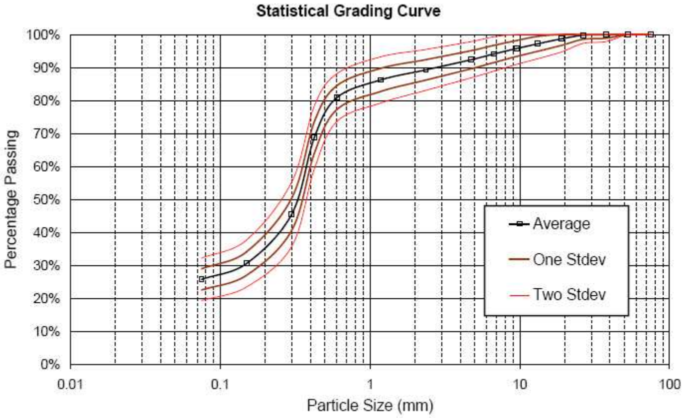

Fig. 7 - Monitoring of fines content during SBW construction (220 samples nos. taken from mixing bays)

Fig. 8 - CPTu testing on top of barrier wall

Specific on-site testing on blended backfill material was performed daily before incorporation in the trench. It included daily fines content to verify that the minimum 20% fines (75μm sieve) criteria was respected, as shown on Fig. 7 which is a statistical analysis based on 220 gradations tests), slumps to check consistence and densities. In addition, mud-balance densities of in-trench backfill was monitored from samples taken at different depths (including 2m from the bottom) to check that backfill remained heavier than in-trench slurry by at least 0.25g/cm^3.

Twice daily monitoring of the backfill slope indicated a gradient of between 1:5 and 1:11 (V:H) over the course of the works.

6.5 Acceptance testing of wall construction

A total of 108 permeability tests, including 37 at the design stage, were carried out, with hydraulic conductivities of between 9x10^{-11}m/s and 3x10^{-9}m/s during production. A summary graph of production tests values can be found in Ryan (2007).

As a further check of backfill uniformity and base key, 20 piezocone (CPTu) tests were carried out through the narrow width of the SB wall to the base (about 40 m), as shown in Fig 8, requiring great care to maintain verticality of the cone. This was successful and only a few tests struck the side wall of the trench. It is noted that care is required interpreting such tests because if the cone hits lumps of clay or other inclusions, it can falsely give a signature similar to a sand layer.

7 CONCLUSIONS

The design & construction of a deep SB groundwater barrier wall was completed at Mayfield, NSW. The success of the ground barrier was demonstrated through a thorough quality control program implemented during each phase of the project and which satisfied the design criteria.

Long term settlement of the wall is being monitored through a one year program to verify less than 50 mm total settlement, with measured values as of March 2007 less than 10mm in total.

The long term performance of the wall will be closely monitored by RLMC, including via a system of groundwater monitoring wells fitted with automatic water level loggers located both inside and outside of the barrier wall.

REFERENCES

D'Appolonia, D. J. (1980). "Soil–bentonite slurry trench cutoffs." J. Geotech. Eng., 106(4), 399–417

Itasca Consulting Group Inc (2005) *Fast Lagrangian Analysis of Continua (FLAC) Version 5.0*

Liausu,P & Spaulding,C (2007) 'Construction d'une paroi etanche en sol-bentonite sur le site de l'ancienne acierie de Newcastle' *Revue Travaux*, no. 836, pp. 75-79

NEPM (2003). *Impact Statement for the National Environment Protection (Air Toxics) Measure* 2003, National Environment Protection Council, NSW Australia

Ryan,C & Spaulding,C. (2007) 'Vertical groundwater barriers for contaminated site reclamation' *proceedings of the 10th Australia New Zealand Conference on Geomechanics 2007*, Brisbane

US EPA (1998), '*Evaluation of Subsurface Engineered Barriers at Waste Sites*' EPA-542-R-98-005, July 1998