

# Innovation During Construction

## Problems and Solutions in Service Tunnel Construction When Under the Water Table

Jonathan Sisovic

### Abstract

The Burrows Road tunnel is a pipe-jacked 87m long 2800mm diameter, water-tight tunnel constructed with to carry electrical conduits beneath Burrows Road, within 100 m of a tidal canal in the Sydney industrial area of Alexandria. The alignment of the base of the tunnel is approximately 5m below the surface and, at that depth, is 4m below the groundwater table. Construction presented some interesting challenges due to the location of the work, soil contaminants and the high groundwater table. Site constraints and project challenges forced the project team to “think outside the box” and draw on experiences outside the immediate context of the project.

This paper describes the construction methodology used to construct the tunnel, project challenges and site constraints that were overcome as a result of the project team’s willingness to brainstorm and create innovative and practical solutions.



## **Introduction**

Burrows Road tunnel was constructed for Ausgrid (previously Energy Australia) to house 6 x 132kV cable circuits to form part of Ausgrid's newly reconfigured network from TransGrid's Beaconsfield South Substation.

The water-tight tunnel was constructed by the trenchless pipe-jack method using an Earth Pressure Balance Machine (EPBM). The Abergeldie-owned EPBM, capable of boring 2100mm diameter in its standard configuration, had to be up-skinned and its cutting heads redesigned and rebuilt to cut the specified diameter of 2800mm.

28 Liner segments, 2800mm in diameter, 410mm thick, and 3000mm long, were pipe-jacked to construct the watertight tunnel. The actual boring process took 10 days at an average rate of 8.4 meters per day.

Launch and receive pits were sunk eight meters into contaminated soil. The scope also included fit-out of the tunnel with cable support brackets, and refitting the pits for later use as tunnel maintenance access points.

The design and construct contract was awarded on 17 March 2010, with a target completion date of 30 September 2010. After client-agreed variations to the project scope and consequent agreed extensions of time and adjustments to the total contract sum, the works were completed to the scope and quality specified on 20 November 2010.

The variations and extensions were largely due to latent site conditions which required redesign of secant piling for the launch and receive pits, the discovery and relocation of a previously unmapped service line, and additional measures to manage and dispose of contaminated soil and ground water.

## **Scope of Work**

There were two phases:

### **Design & Investigation Phase**

1. Detailed geotechnical and environmental investigations.
2. Service identification through pot holing.
3. Detailed design of the proposed shafts and tunnel, including access platforms fixtures and methods of managing seepage and performing ground treatments.
4. Dilapidation surveys of structures in the area.
5. Construction management plans including environmental, water, health & safety, and traffic management.

### **Construction Phase**

6. Site establishment
7. Site survey and monitoring points
8. Ground improvements
9. Construction of launching and receiving shafts
10. Construction of pipe jacked tunnel following excavation by EPBM
11. Modification of the receiving shaft
12. Installation of access platforms and tunnel fixtures

## **Project Management**

The project management approach featured: integrated documentation; frequent fine tolerance measurement to ensure quality outcomes; open communication with multiple stakeholders to build confident cooperation; tight scheduling to integrate work tasks, procurement, deliveries, crange and traffic movements; and team-based problem solving to encourage innovation and draw on experience beyond the immediate project context.

A primary task of the project manager was to drive the process of creative problem solving and innovation, developing new construction and drilling methodologies, re-planning after pre-planning, but always in the context of the specified project outcomes, costs and time.

## **Project Complexities**

The tunnel dimensions, site location, soil conditions and multiple stakeholder interfaces presented extreme technological and management challenges.

- The specification called for the launch pit to be located in the middle of a busy road intersection and the receiving pit within the yard of an operating electricity sub-station. The work methodology was rewritten to reverse the direction of drilling, so that the launch pit, which is the site of most construction activity, would be behind the security fence of the sub-station yard and the receiving pit in the road intersection, thus greatly reducing impact on normal road traffic and inconvenience for local businesses.
- Crange was restricted by the proximity of the Sydney airport runway flight path. The project team had to liaise with Sydney Airport, arranging a long term crane permit, as well as notifying the airport when crane operations began and ceased every day.
- On-site space for storage and preparation of materials and equipment was at a premium, necessitating tight procurement scheduling, taking into account long supply lead times.
- A myriad of existing service lines passed very close to the tunnel boring alignment.
- The soil was rank with two centuries of industrial contaminants and so saturated with ground water that an on-site detention system had to be setup, water samples taken and analysed, and disposal of contaminated water arranged. This was another activity requiring strict monitoring as space restrictions meant that only a limited volume of water could be stored and collection trucks had to be arranged accordingly.
- So soft was the soil that it could hardly support the weight of the tunnelling machine. A new operational control regime had to be developed to increase the number and reduce the tolerance range of positional checks and steering adjustments to maintain boring alignment and prevent the machine and the jacked pipes forming the tunnel from sinking into the mud.
- Innovative measures, using hydrophilic crystals and cement mixed with the normal Bentonite injection, were needed to control leakage of slurry spoil back into the launch pit. Similar measures were needed to prevent flooding of the receiving pit when the boring machine broke through.

Developing these innovative technological solutions required a problem solving process that encouraged lateral thinking, drawing on expertise and experience well beyond the immediate project team to come up with innovative solutions. The problem solving process was time consuming, the technological solutions were experimental and had to be trialed

and proven on site, and their impact on completion time and cost had to be strictly contained.



*Preparing the EPBM, water retention system*



*Excavation of the launch shaft*

## **Project Innovation**

Significant, innovative engineering solutions were developed and implemented in the course of the project to address problems presented by the unstable, water-charged soil conditions. The development, refinement and implementation of these innovations required the project team to initiate and manage a wide-ranging problem solving process, involving the practical application of lateral thinking and networking techniques.

Team members were encouraged to draw on experiences outside the immediate context of the project. The consultative circle was widened to draw on the expertise, experience, ideas and inventiveness of Abergeldie staff working on other projects, Abergeldie's network of materials suppliers and sub-contract services, and (especially) the personal and professional contact networks of individual team members. The outcomes were serendipitous connections that led to innovative, practical solutions.

## **Launch and Receive Pits**

The original tender concept design called for the launching shaft to be located in the intersection of Burrows Rd and Campbell St and the receiving shaft to be located on the site of the future Energy Australia substation. It was foreseen by Abergeldie that the potential for traffic congestion could be reduced if the launch and receiving pit locations were reversed. This cost neutral change greatly simplified traffic management.

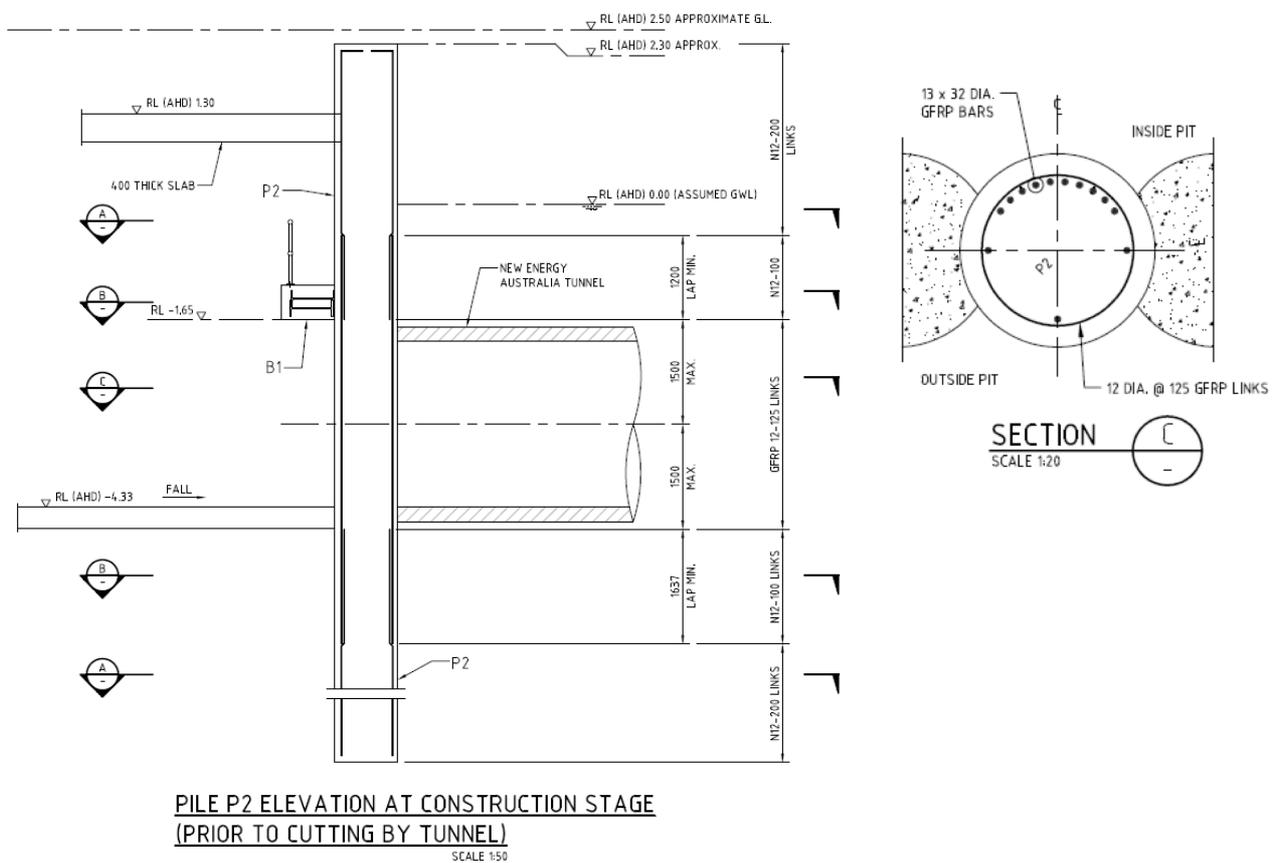
Thorough investigation of the underground services along the tunnel alignment, including position and depths, also prompted change to the initial design. Abergeldie, in consultation with tunnel design consultants Demlakian, changed the size and location of both the launching and receiving shafts to accommodate the existing services found along the tunnel alignment.

## **Secant Piles**

Secant piles were designed to create waterproof launching and receiving shafts. However, early in the piling process it was discovered that the actual soil conditions were not as indicated in the geotechnical report. The piles that had been designed required a 2 meter

socket into bedrock, but the bedrock was found to be some 5.5 meters deeper than allowed for. This meant that the pile design had to be varied to include temporary steel waler ring beam supports to ensure that the current pile design could be used even with the greater depths required. This design change required more resources and skilled personnel to install the ring beam support in a short timeframe.

Traditional secant pile wall designs would have posed a problem for the tunnel boring machine as the machine would not have been able to bore through the reinforced cages of the hard secant piles. To mitigate this problem Abergeldie replaced sections of the steel reinforcement rods with fiberglass rods at the exact points in the piles where the tunnel boring machine needed to break through. This provided a suitable temporary reinforcement solution for the structural integrity of the secant piles and also provided a “soft-eye” through which to commence boring. The positioning, dimensions and shape of these soft-eye break-through piles had to be extremely precise. The increased depth of the secant piles also meant the pre-fabricated reinforcement cages had to be remade, and the fiberglass reinforcement replaced in the cage at the correct position.



### Leakage Control & Experimentation with Additives

As is normal practice for EPBM boring, Bentonite slurry was injected through the EPBM jacket and through lubrication ports in each section of pipe liner into the bored-out annulus space. This provides lubrication to ease the jacking movement of the pipe sections being installed, and also fills the annulus to prevent the surface of the newly-bored tunnel from collapsing. However on the Burrows Road project, the Bentonite mixed with the water-charged soil formed an unstable, highly fluid sludge that leaked back into the launch pit. The sealing ring which had been installed at the entry point did not effectively staunch the flow.

Inspired by experience using hydrophilic, expanding strips as joint sealers on other “wet” projects of a very different nature, the project team experimented with mixing into the Bentonite slurry a range of different types of hydrophilic crystals. In principal, the hydrophilic crystals should take up some of the water in the Bentonite slurry, expand in size, become sticky, and then be carried on the flow of the leaking slurry to the site of the leaks where they would lodge in the crevices and stop the flow. It took several trials of various kinds of crystals, mixed in various proportions with the Bentonite, to find a formula that worked. Helped by advice from the NSW Area Manager of The Australian Mud Company, the range of products subjected to trials and errors was narrowed down. A mix of Ausplug hydrophilic crystals in a precise proportion with Bentonite did the trick. An innovative application of familiar products created a new, uniquely suitable drilling fluid that delivered effective tunnel sealing and the desired control of seepage.

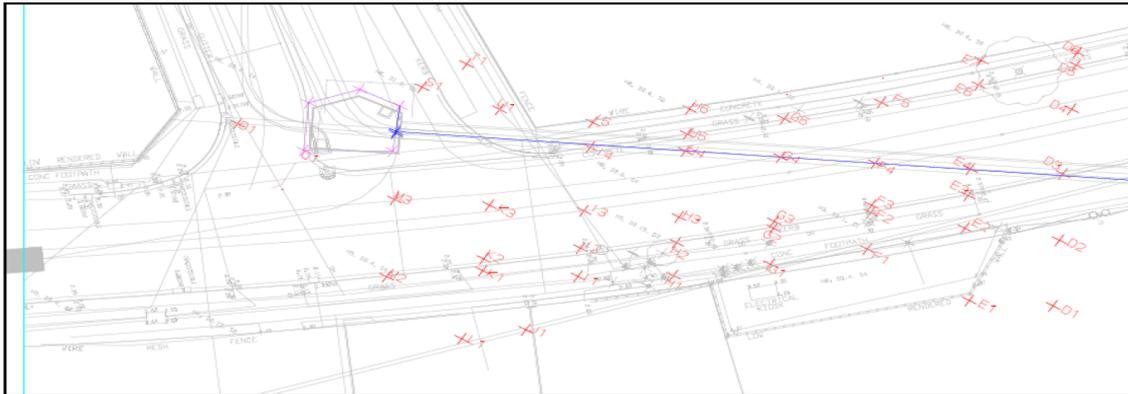
It is also normal practise in tunnel boring to inject Bentonite and detergent together as a “lubricant” to loosen soil at the drill face and hold the soil particles in suspension at a consistency suitable for removable by screw and conveyor. The water-charged soil conditions dictated against this normal drilling practice. Even without the addition of Bentonite, the soil was so wet and soft that the screw had difficulty carrying it away. It was also feared that sludge would pour into the receiving shaft when the EPBM broke through. Further experiments with different mixes of drilling fluids and additives came up with an answer. Drawing on the broader experience of a personal associate of one of the engineering team, a leaf was taken from the book of seismology. Seismologists sometimes use a mix of Bentonite and cement to create a gum-like substance. This substance does not set hard and provides a stable medium into which to insert seismic sensing probes in rock crevices. The engineering team experimented with the Bentonite and cement and it paid off.

The seismologist’s mix of Bentonite and cement, injected at the cutting face, enhanced the effectiveness and steerability of the EPBM as it moved forward and created a seal to prevent the slurry from surging forward into the receiving pit, whilst the innovative combination of Bentonite and hydrophilic Ausplug crystals sealed the slurry in the drilled-out annulus space. When the EPBM broke into the receiving pit it was almost completely dry.

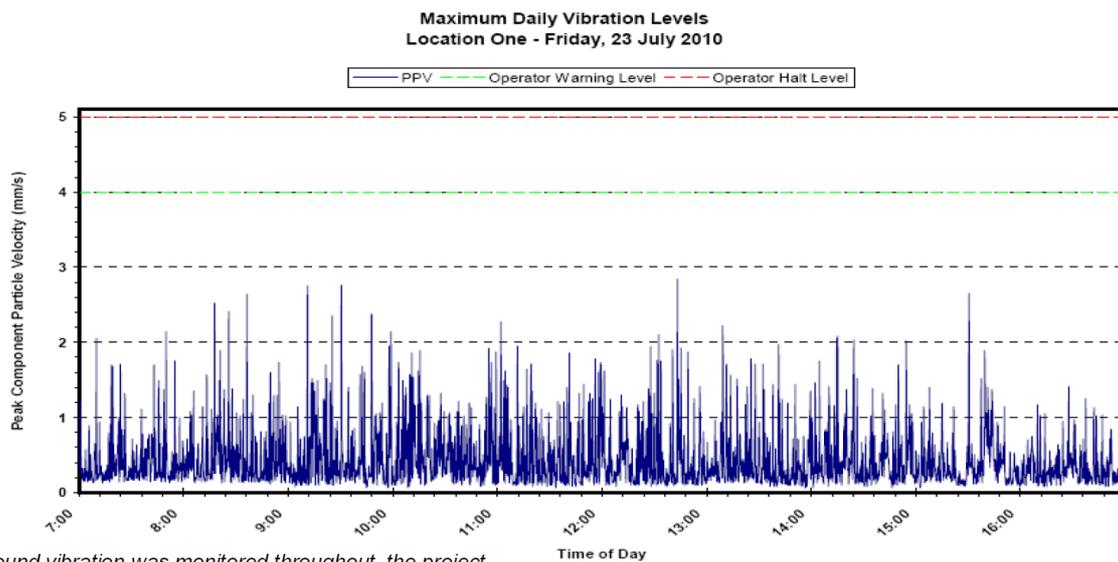
## **Environment**

The environmental management plan developed for Burrows Road included a contaminated waste capture/storage/removal plan, legislative and regulatory compliance checklists, incident management and emergency response procedures, site water capture pits, and limitation of the dimensions of the ground area to be disturbed by construction. All potential environmental risks were contained and managed within the immediate areas of the launch and receiving pits.

Throughout the tunnelling process, information was continuously collected to monitor vibration levels as a result of tunnelling. Noise was monitored to ensure it stayed within acceptably safe levels, and the surrounding ground was monitored for settlement to ensure that the road and underground services would not be put under stress due to tunnelling activities.



Several settlement monitoring points were established along Burrows Road and around the tunnel shafts



Ground vibration was monitored throughout the project

To mitigate risks posed by contaminated soil and ground water, seepage was collected and stored in a dedicated reservoir in the launch pit, from which it was periodically pumped out into an above ground detention system, with tankers organised to take it away as contaminated water. Similarly, excavated tunnelling spoil was stockpiled on site, treated with lime to make it more manageable and carted off site as contaminated material.

Limited space also meant that only six sections of tunnel lining could be kept on site. Manufacturing of each section took three months, and they had to be delivered to the site by road from Melbourne, requiring two days' notice. The number of pipe sections to be used each day had to be gauged accurately in advance. Order too few pipes and work would have to stop to await delivery of more. Order too many, and there would be nowhere to store them.

## Conclusion

A primary task of the project team was to drive the process of creative problem solving and innovation, developing new construction and drilling methodologies, re-planning after pre-planning, but always in the context of the specified project outcomes, costs and time.

The strength of such stringent, integrated pre-planning is that it provides a firm basis from which to respond to unanticipated difficulties. By integrating the various elements of project control (OHS, environment, safety, traffic management, community liaison, procurement scheduling, staff training, etc.), the ripple-through effects of changes in any one element of the plan become readily apparent for other areas of operational control. Coordinated responses can be thought through by the collective management team, documented, integrated and implemented.

On the Burrows Road project, planning documents were kept under constant review and updated continually as unanticipated issues emerged. Without the sound basis provided by the initial integrated management plans, the tight project control needed for such a demanding project would have been impossible.

At Burrows Road, the client's prime requirement was for a fully hydrostatic tunnel. This was vital; given that the purpose of the tunnel is to carry electrical cables and that the full length of its alignment is below the water table.

The finished alignment of the bore and tunnel had to be within 20mm, horizontal and vertical, of specified points. Because of the extremely soft ground conditions which made it very difficult to steer the boring machine accurately, the project team increased the frequency of laser positional checks and reduced the misalignment tolerance point beyond which delicate steering adjustments were made. When the EPBM broke through the receiving pit, the machine was bone dry, and the consequent frequent and minute steering adjustments resulted in a finished tunnel alignment within 7mm of target.



**About the author:**

JONATHAN SISOVIC

B.E. (Civil Engineering), BSc (Physics)

Email: [jsisovic@abergeldie.com](mailto:jsisovic@abergeldie.com)

Jonathan Sisovic graduated from the University of Sydney in 2008, with his final year thesis investigating costs estimation practices in the construction industry being published in The Engineering Economist (Liu, Lu., Wehbe, George. and Sisovic, Jonathan (2010) "The Accuracy of Hybrid Estimating Approaches: A Case Study of an Australian State Road & Traffic Authority". The Engineering Economist, Volume 55: Issue 3, 225-245).

Jonathan is currently working as a Senior Project Engineer for an infrastructure construction company, Abergeldie Complex Infrastructure. His interests include Project Management, playing the piano and the cello, cycling, and indie music. He currently resides in Sydney Australia