



REMEDIAL WORKS FOR THE BURNLEY TUNNEL, MELBOURNE

Background

The Burnley Tunnel in Melbourne is about 3.5km long and passes at a depth of 60m beneath the Yarra River (see Figure 1). In about mid-1999, prior to the tunnel being opened, problems developed with the invert lining within parts of the tunnel. These problems were widely canvassed in the Media and aspects of the remedial works were published in the Melbourne Age. This article deals with technical facets which are in the public domain. It does not deal with matters which were subject to dispute between various parties associated with the tunnel.

Pells Sullivan Meynink Pty Ltd (PSM) was retained by the Contractor, in early 2000, to be responsible for the design of all remedial works.

Tunnel Geometry

Figure 2 shows a cross-section through the final lining of the tunnel (References 1, 2 and 3). The lining is fully tanked by means of a continuous PVC membrane between the Primary Lining (rockbolts, sets and shotcrete) and the unreinforced concrete Secondary Lining.

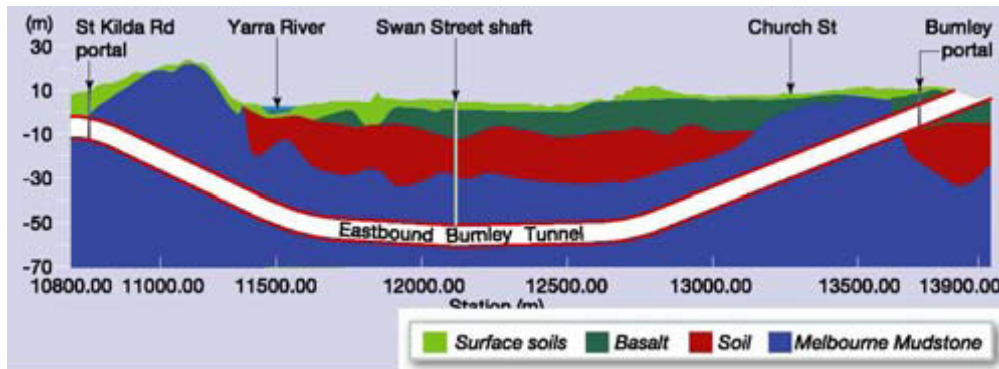


Figure 1 Summary of Geology along the Burnley Tunnel.

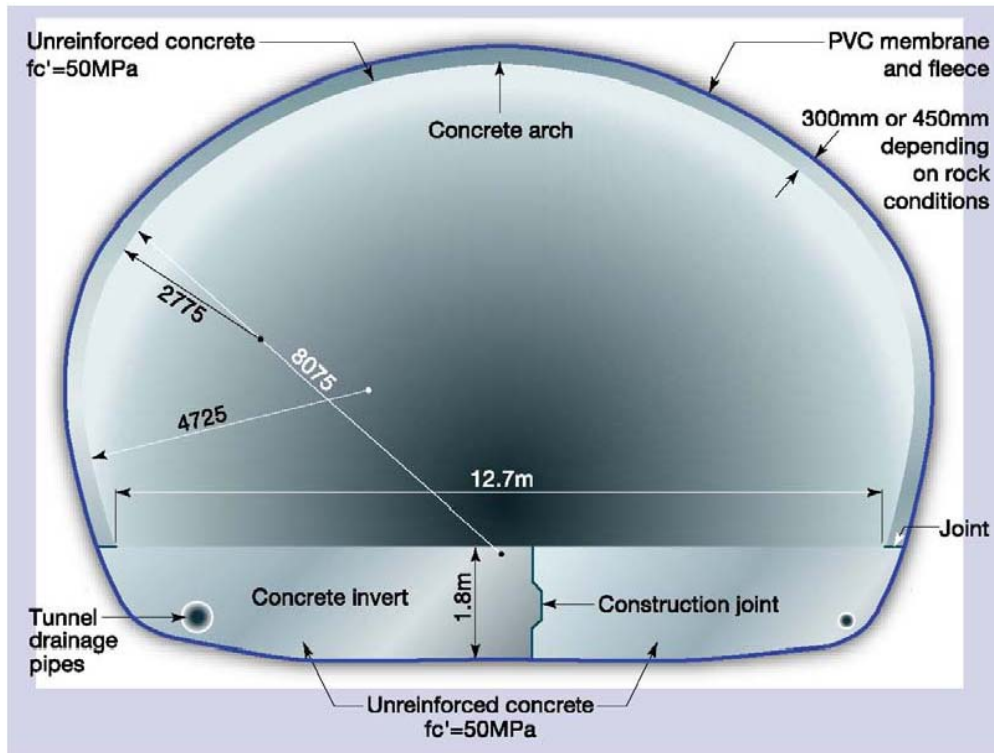


Figure 2 Cross-section through the designed permanent lining of Burnley Tunnel.

The tunnel invert comprised thick slabs with a slightly arched underside. There is a longitudinal joint near the centerline as shown in Figure 2. The slabs are 12m long along the tunnel, i.e. there are transverse joints at 12m intervals along the invert.

Each 12m long invert slab was given a number. The numbering is shown in Figure 3.

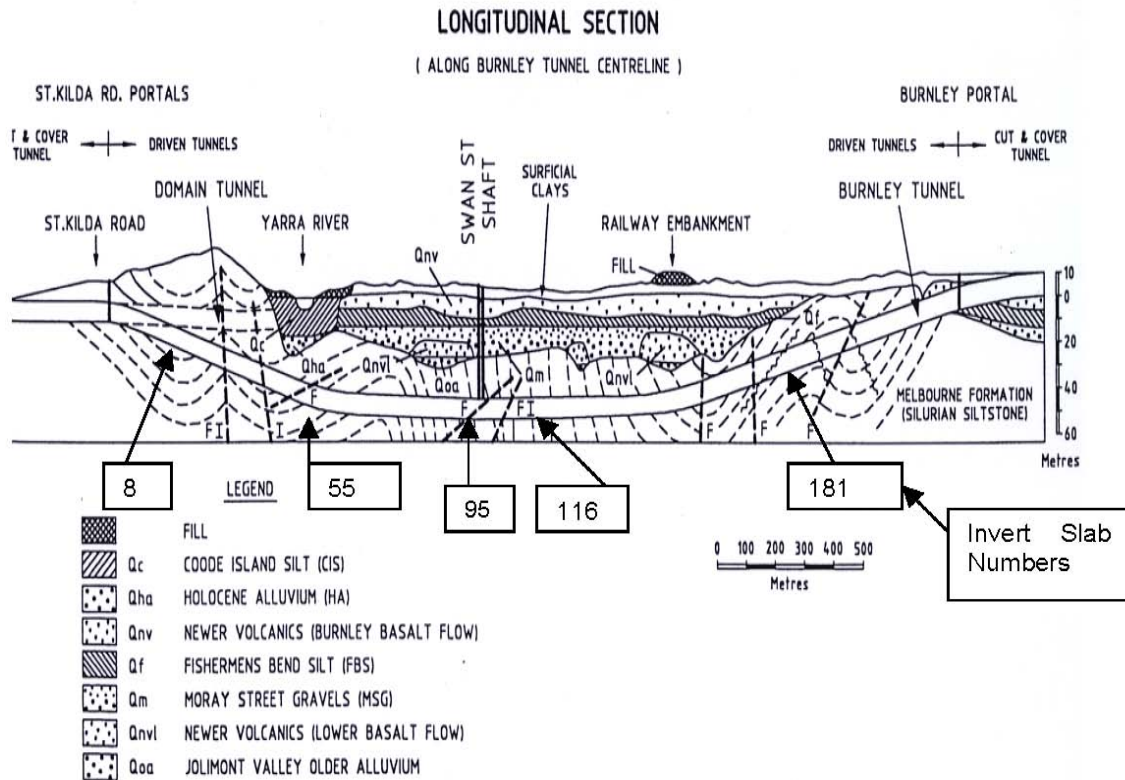


Figure 3 Longitudinal Section Showing Invert Slab Numbers

The hydrostatic pressures in the vicinity of the Swan Street Shaft are 600 kPa (i.e. 60m head of water).

Failure of Certain Invert Slabs

The tunnel was constructed from the two portals, and with headings extending in both directions from the Swan Street shaft. Free drainage of the rock was allowed during construction, and there was substantial drawdown of the groundwater pressures at tunnel level. Surface settlements associated with depressurisation of the Coode Island Silt (a normally consolidated clay) were controlled by an extensive system of reinjection bores.

Closure of the lining and tanking membrane was achieved on Melbourne Cup Day (1st November), 1998. Immediately prior to closure the total inflow into the tunnel was about 40 lit/sec.

Over the following 10 months the groundwater levels slowly recovered, and during this period various grouting works were undertaken to seal

leaks through construction joints, because no membrane tanking is perfect. Total inflows were about 10 to 15 lit/sec. However, the thick floor slabs deflected upwards between about 10mm and 45mm as the groundwater pressures built up.

A significant length of the bitumen road pavement was laid in August 1999 but by October seepage inflows had increased to about 25 lit/sec, parts of the bitumen pavement had lifted, and the groundwater table recovery had stalled at about 40m. There were serious concerns as to achieving full groundwater recovery, and about the performance of the invert under the design loading of 600kPa. To this end the groundwater pressures around successive lengths of the tunnel were increased, by injection, to the design pressure. During this testing several lengths of the invert failed by upward heaving of up to 200mm, and fracturing of the thick, unreinforced concrete.

The original project consultants designed a multi-anchor system for remediation of 21 No. 12m lengths of invert slab near the Swan Street



shaft (see Reference 6). However, concerns remained in regard to the remaining 160 slabs (a length of 1.92km).

It was at this stage that PSM was retained to take responsibility for design of remedial works. Taylor Thomson Whitting acted as specialist sub-consultants in regard to aspects of the concrete works, and Professor Ian Gilbert of University of NSW advised in regard to facets pertaining to concrete creep. Professor Peter Ansourian of University of Sydney conducted some independent analyses of PSM designs. Dr Mike Coulthard provided specialist advice to PSM in regard to UDEC analyses.

Figure 4 shows that these remedial measures comprised:

- Trimming 400mm of the existing invert concrete,
- Installation of sufficient anchors to resist the uplift pressures (typically 96, nominal 100 tonne working load anchors per 12m long by 12.7m wide invert slab),
- Casting of new reinforced concrete capping slab, and
- Stressing of the anchors.

Structural Remediation of the Invert

With some modifications, the multi-anchor design was adopted for slab 55 and for slabs 95 to 116 (see Figure 4).

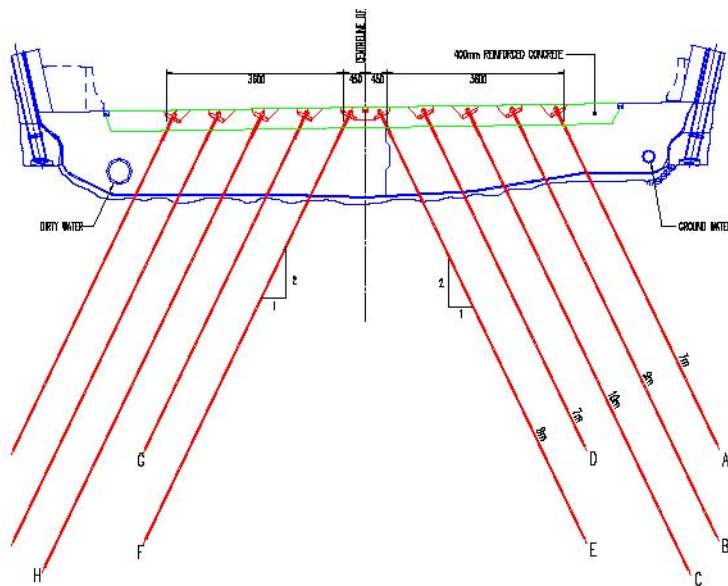


Figure 4 Multi-anchored slabs.

Over the remainder of the tunnel, except for slabs 1 to 12 and 177 to 181, remedial work comprise central twin anchors, at average longitudinal spacing of about 1.2, as shown in Figure 5.

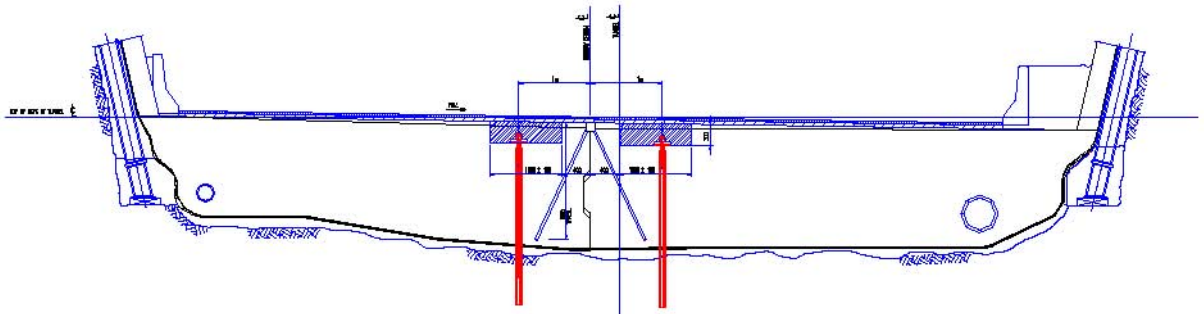


Figure 5 Twin Anchor Design.

Photo 1 shows part of the central section of the tunnel during multi-anchor installation and Photo 2 shows a patch of completed 46mm diameter VLS stressbar anchors within the reinforced capping slab, prior to casting the slab and stressing of the anchors.

Photo 3 shows a typical length of twin-anchor remediated slabs.

In total there were about 2500 anchors in the multi-anchored slabs and a further 2700 anchors in the twin-anchored slabs¹.



Photo 1 Drilling and installation of anchors.

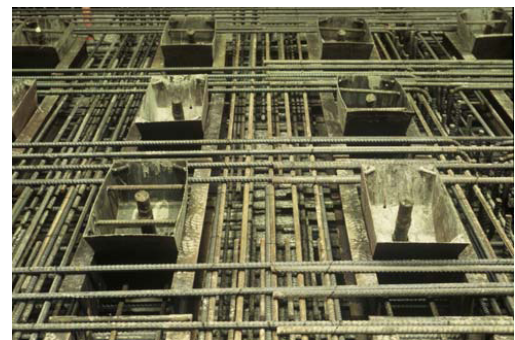


Photo 2



Photo 3

¹ The anchors were installed by two sub-contractors to the Joint Venture, namely Austress-Freyssinet and National/VSL. PSM were responsible for signoff of every anchor. Golder Associates, who were project geotechnical consultants to the JV, assisted with field supervision for anchor installation.



Monitoring of the Invert Slabs During Stressing

As already mentioned, each 12m long central slab was pre-stressed with about 96 anchors, with a combined load of about 10,000 tone (i.e. more than the weight of two Anzac Class Frigates). The key issue was to ensure that the slabs did not settle or twist more than a defined amount during stressing as this could have affected adjacent slabs and/or interaction with the arch lining. The task was to achieve the requisite monitoring accuracy (<2mm in level) and to be able to determine the three dimensional movement of each slab, all in real time.

The system was designed by Mr Neil Street and supplied and managed by Mr John Gertzel, a Melbourne surveyor. It comprised Geodimeter 6000 robotic theodolites mounted on heavy brackets fixed to the concrete sidewall of the tunnel. This system required the use of active prisms which in effect identify themselves to the theodolites. They also have the advantage of a light which flashes when a "hit" is registered and the visual telltale was helpful to supervisory staff casting an eye over the whole process.

Each theodolite could handle about 30 prisms. At the peak of stressing operations there were about 90 prisms, requiring simultaneous operation of three theodolites.



Photo 4

The prisms were mounted on posts which ranged in height from about 1.2m to 2.0m. There were four prisms for each half of an invert slab (a half slab being defined by the near-central longitudinal joint and the 12m-spaced transverse joints). Photo 4 shows the typical post arrangement. Survey distances were typically less than 30m.

Readings from the theodolites were processed and assessed in real time and the stressing sequence of the anchors within a half-slab was managed so that tilt and slab settlement was within the prescribed limits. The system consistently achieved accuracy of relative levels of better than or equal to 1mm.

The structural remedial measures were completed by August 2000 at which time inflows were about 60 lit/sec and there was substantial drawdown of the groundwater system. The task was then to implement a grouting programme to reduce inflows to a target value of <10 lit/sec.

Grouting

An extensive grouting programme was implemented to deal with the damage to the tanking system that occurred due to failure of some of the invert slabs and from installation of about 5200 high capacity anchors through the membrane.

The 60 lit/sec that was entering the tunnel at completion of the structural works was mainly coming through the invert area and from behind the lower sidewalls. Inflows were also entering through transverse joints between arch pours.

To put it mildly it was a difficult grouting project because we were almost working blind and each and every grout hold drilled through the membrane created yet another water path into the tunnel. Fortunately there were excellent mapping records of the geology encountered during tunneling², and in particular shear and fracture zones that were the major paths of water through the folded Silurian siltstones.

² The logging had been done by the Joint Venture's geotechnical group under Bruce Hutchinson, including geologists from Golder Associates.



It was decided that the only way the grouting objective (of <10 lit/sec) could be met was to provide multiple lines of defence. The strategy therefore comprised:

1. Microfine and ultrafine cement grouting of major, highly permeable, features in the rock mass, these being assessed as being prime sources for groundwater;
2. Chemical grouting of water paths at the contact between the rock and the original primary shotcrete and steel set support;
3. Chemical grouting of water paths at the contact between the original primary shotcrete and the geotextile / PVC membrane;
4. Ordinary Portland cement grouting of any voids beneath the invert (i.e. on the rock side of the invert membrane) arising out of uplift movements of the invert slabs; and
5. Chemical grouting to form circumferential cut-off rings at intervals along the tunnel to cut off flow along the tunnel between rock and membrane.

A full description of the grouting works is outside the scope of this short technical history. The work too 5 months, commencing in mid-July 2000. Throughout this period it was very difficult to measure whether we were being successful because water introduced into the tunnel for drilling, and other construction processes, made it impossible to measure the natural inflows (see Figure 6).

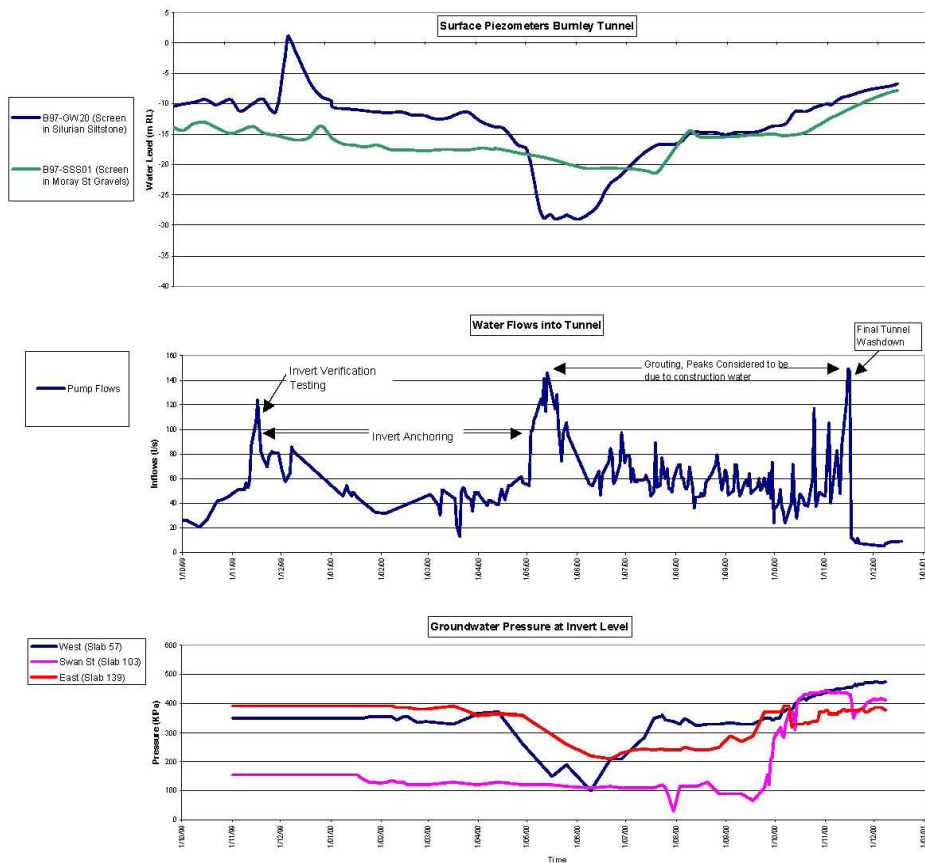


Figure 6 Inflows and Groundwater Pressures.



By mid-December 2000, almost exactly a year after PSM commenced work on the project, rock mass cement grouting of 5604 holes had been completed, and 6482 holes had been drilled and grouted with polyurethane and acrylate grouts.³ By the 11th November 2000 all tunnel electrical and mechanical facilities had been tested and the tunnel was ready for traffic. Between 14 and 16 November, final washdown occurred with discharge from the tunnel peaking at 150 lit/sec. We held our collective breaths, and a few days later the inflow was measured at 7.6 lit/sec. Over the following months the groundwater table recovered to about 55m head and inflows were about 9.4 lit/sec. By Christmas 2000 the Melbourne public were happily using their new tunnel.

Acknowledgements

PSM acknowledge the extraordinary work from construction personnel of the Transfield Obyashi JV during the remedial works. Naming individuals is always invidious, but when it was cold, wet, dark and depressing the efforts and dogged enthusiasm of Ross Herbert, Ray Verratti, Matthew Gault and Gary Griffioen were wonderful. PSM particularly acknowledges the support of Claudio di Berardino who was Project Director for the remedial works, and thanks Malcolm Short and Ed Taylor for all the information they provided in regard to design and construction work that had occurred in the years prior to PSM's involvement.

References

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6. Benson ND, Haberfield C and Paul D (2005). Geotechnical Design and Construction of Invert Anchors. Australian Tunneling Conference, Brisbane.

³ The cement grouting was performed by National Contracting / VSL and the chemical grouting by Eptec Pty Ltd.