Shallow Cover Tunnel Under Heritage Listed Brick Buildings: Brisbane Boggo Road Busway Tunnel

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Introduction

The use of underground space for new transport infrastructure in urban environments has become very common due to space constraints. In built-up areas these tunnels will often pass under sensitive buildings. This article presents a case study on a shallow cover driven busway tunnel under heritage-listed buildings on shallow footings. Phase² (in design), Unwedge and Dips computer software packages were used extensively. The latter two packages were used extensively during tunnel excavation.

Project Description

The Boggo Road Busway and Eastern Busway project is located in the city of Brisbane, Australia. It is a 2km long dedicated public transport link connecting the Eastern and Southern Busway corridors to the University of Queensland via the existing Eleanor Schonell Bridge. The project was delivered through the Boggo Road Busway Alliance, a partnership between Queensland Transport (Owner), Thiess Pty Ltd (Builder), and Sinclair Knight Merz (Designer).

Figure 1: General Arrangement – Plan & Elevation of the Driven Tunnel Section
The alignment required the construction of a 430m long driven tunnel beneath the heritage-listed Boggo Road Jail and Dutton Park, with cut and cover tunnels at both ends. The driven tunnel has a horseshoe-shaped profile with a final excavated width of 15m at the spring line and a height of 8m. The initial 120m of tunnel beneath the jail has a relatively shallow ground cover of 5m to 8m depth to top of crown, when considering the width of the tunnel.

![Figure 2: Typical tunnel profile and tunnel section under the jail](image)

**Geological Setting**

The geological profile of the site comprises 1 to 2m of fill or stiff clay, overlying the Brisbane Tuff Formation. The Brisbane Tuff comprises rhyolitic tuff, conglomerate, breccia and minor sandstone and shale. Underlying the Brisbane Tuff is the Tingalpa Formation, which comprises carbonaceous shale, lithic sandstone, with minor conglomerate and coal. Both formations generally have deeply weathered and variable strength profiles, with many zones of completely weathered rock exhibiting soil-like properties as well as zones of high strength rock.

![Figure 3: Geological Elevation under jail](image)
**Initial Ground Support**

Three distinct temporary ground support regimes were anticipated during the road header top heading excavation.

- Support Type 1 to 3 comprises pattern rock bolts with plain shotcrete of varying thickness.
- Support Type 4 comprises lattice girders encased in plain shotcrete to be used in very poor rock.
- Support Type 5 to be used in low cover tunnel beneath heritage-listed Boggo Road Jail comprises pre-installed canopy tubes and lattice girders with plain shotcrete.

In addition to the above, horizontal fibreglass face dowels are also installed in areas with very low to low strength rock to control face stability.

![Figure 4: Cross Section - Support Type 5](image1)

![Figure 5: Longitudinal Section - Support Type 5](image2)

The final lining consists of an in-situ reinforced concrete arch with a waterproofing membrane. It is essentially a drained tunnel with ‘no fines’ concrete drainage layer under the reinforced concrete road pavement. The final lining will not be discussed in detail as most ground movement already occurred prior to installation of the final concrete lining.
The Boggo Road Jail Buildings

The jail complex directly above the tunnel includes the 6m high perimeter brick wall, a single storey building and two 3-storey high cell block buildings both constructed of brickwork. Most of the brick walls of the buildings are founded on unreinforced concrete strip footings at shallow depth.

![Figure 6: Layout of Boggo Road Jail Complex](image)

Surface Settlement Prediction

The principal method of analysis chosen to assist in predicting the settlement has been a two-dimensional linear elastic Finite Element (FE) Method. The software used for the FE analysis was Phase², a two dimensional commercially available computer package, which has been specifically developed for the analysis of underground facilities.

The Phase² model assembled a scenario of tunnelling under a green-field site. The tunnel support was simulated as a layer of shotcrete liner assuming instantaneous support installation (on the basis that there will be forward installation of canopy tubes ahead of the tunnel excavation). Using the estimated rock mass parameters from the geological model, a set of surface settlement troughs were generated.

![Figure 7: Typical Phase² Model at Shallow Cover Section (Northern Portal)](image)
A range of rock mass moduli in the zone above the tunnel crown and support stiffness were subsequently assessed in a series of sensitivity analyses. The range of settlement results were found to be within a very limited range. The finite element model results gave the upper bound surface settlement of around 7mm at the centreline of tunnel with instantaneous support installation.

It was recognised that theoretical analyses are prediction tools that have to be supplemented with engineering judgement, local experience and case history data where available. The nearby Brisbane Buranda Busway tunnel completed in 1999 was a relevant case history.

Considerable back analysis of the Buranda tunnel case was made to develop a model with known settlement results that was then related to the Boggo Road tunnel case. The comparison included the geological model, construction methodology, and the rock properties for both sites.

The settlement results from initial finite element analyses at Boggo Road Jail were calibrated against the Buranda back analyses. The final surface settlement above the tunnel centreline at the jail site was estimated to be around 10mm, taking into consideration factors including the differences in tunnel construction methodology, the relative contribution of support types and their timing of installation.

**Monitoring**

A comprehensive instrumentation monitoring program was implemented to monitor the effects of tunnelling on the surface structures. Surface settlement markers were placed on predetermined gridlines on either side of the tunnel centreline. Additional building settlement monitoring was undertaken using electronic tilt beams.

The observed settlements along the tunnel centreline at the jail site during construction ranged from 7mm to 12mm. The difference between the upper and lower values can be attributed to the variance in the geological profile (under the two cell block buildings).

**Tunnel Construction**

The method of tunnel construction under the jail site consisted of heading and bench excavation using an AM105 road header. The initial heading excavation is around 6.5m in height. The chosen initial ground support was to ensure that a very stiff tunnel lining was installed as quickly
as practical at the tunnel face. An admixture was added to the shotcrete at the nozzle to attain high early strengths.

The Permit to Excavate procedure adopted during the tunnel excavation required the builder, designer and geotechnical engineer to review the previous day’s construction, monitoring, and geological data from the face mapping and then agree on the tunnel support and construction methodology to be adopted for the next 24 hours. This process ensured that the settlement trends were reviewed daily and the adopted initial ground support and construction approach was adequate for the geology encountered.

**Face stability**

Face stability was a key factor to limit face loss and its associated surface settlement beneath the jail. The geology beneath the jail was variable with mixed face conditions consisting of low strength breccia in the crown, extremely low strength non-welded tuff (Claystone) in the middle of the tunnel face and an undulating high strength welded tuff (Ignimbrite) in the lower half. The tuff is known for its random jointing, however due to their long persistency and the small tunnel advance rate of 1.0m, joint sets were able to be identified.

Canopy tubes provided the roof support and fibreglass dowels were used to stabilise the tunnel face. The dowels were installed in arrays of between 20 to 35, mostly in the top half of the tunnel face. The dowels work by reducing the outward movement of the face and thus reduce the loosing of the rock mass; they also provide support to key rock wedges, thus reducing face loss which can increase the magnitude of surface settlement.

Daily face and roof mapping provided discontinuity data that was entered into the computer stereographic projection program *Dips* 5.0 and individual discontinuity sets were identified.

![Figure 9: Typical Stereographic Projection by Dips](image-url)
A kinematical stability assessment using *Unwedge* assessed potential failure mechanisms. Typical modes of failure were identified as V shaped wedges, steeply dipping planes and the occasional toppling slab in the claystone tuff and V shaped wedges on undulating firm clay seams in the welded tuff.

![Figure 10: kinematical stability assessment using *Unwedge*](image)

*Unwedge* was able to achieve the fast turnaround times required to analyse the design face pattern of face dowels. *Unwedge* proved to be very useful at predicting unfavourable wedges within the face. This information was then displayed on the Face Map at the Tunnel Portal (tag board) which was an effective tool to communicate to everyone that entered the tunnel.

![Figure 11: Typical Results of *Unwedge* Analysis for the Tunnel Face](image)

**Conclusions**

The predicted settlement at the Boggo Road Jail was 10mm and the observed settlement was 7mm to 12mm with no damage to the heritage structures recorded.

Without a tool such as *Phase*² it would have been much more difficult to predict the settlements with this degree of accuracy.

Combining finite element modelling with case histories data and sound engineering judgement can provide reasonably accurate results in many tunnelling situations.

The two other software packages, *Unwedge* and *Dips* were used successfully throughout the excavation of the tunnel.