The Flexible Use of Ground Support for the Inner Northern Busway Project, Brisbane

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ABSTRACT
Major excavations within city centres present enormous challenges to the design and construction teams charged with carrying out the work. Effective ground support systems need to be employed in order to reduce the risks of all parties concerned and can reassure stakeholders. This paper presents details of the design of the various ground support types installed for a project in the Brisbane CBD.

RÉSUMÉ
Les travaux d'excavation importants en centre-ville présentent des défis énormes pour les équipes en charge de la conception et de la construction. Des systèmes de soutènement efficaces doivent être employés afin de reduire les risques pour toutes les parties concernées et rassurer les parties prenantes. Cet article présente les détails de la conception d'un tel système pour un projet dans le centre de Brisbane.

1 INTRODUCTION

The Inner Northern Busway (INB), Queen Street to Upper Roma Street Project involved the construction of a dedicated busway between the existing Queen Street Bus Station and the completed section of the INB at Countess Street. The project involved the completion of two bus stations (one within an existing underground car park and the other within an existing railway station complex) as well as 500m of cut-and-cover tunnel within the busy CBD of Brisbane.

The Client for the project was Queensland Transport (QT) and the project was undertaken as an Alliance contract with the member companies being QT, Leighton Contractors Pty Ltd, Maunsell Australia Pty Ltd, Coffey Geotechnics Pty Ltd, Bligh Voller Nield Pty Ltd and EDAW Gillespies Australia.

In 2009, the project received the prestigious Association of Consulting Engineers Australia (ACEA) Project of the Year Award and the Gold Award of Merit in the Transport and Civil Infrastructure category.

This paper will discuss a variety of ground support techniques used during the project over the length of the cut-and-cover tunnel from King George Square to the Brisbane Transit Centre. It does not cover all the permanent and temporary ground support employed during construction but will focus on those which cover a variety of methods and with unique problems.

2 THE SITE

The INB Queen Street to Upper Roma Street Project is located in central Brisbane, and is situated approximately 400m east of the Brisbane River. It is contained within a corridor which joins the existing underground Queen Street Bus Station (QSBS) in the south with the existing INB Section 3 at Countess Street in the west.

The site was divided into four areas:

- Area 10 – QSBS to Ann Street
- Area 20 – Ann Street to Roma Street Transit Centre
- Area 30 – The Roma Street Transit Centre (RSTC) to Countess Street
- Area 40 – Countess Street to Upper Roma Street

The busway was constructed beneath Albert and Adelaide Streets in Area 10, as well as within the existing, below ground, King George Square (KGS) Car Park. In Area 20 a new underground bus station was constructed beneath Ann and Roma Streets with the busway continuing behind the abutment of Turbot Street Bridge before rising to ground level within the Roma Street Forum.

This paper concentrates on the work carried out in Area 20 (Figure 1).

3 SITE GEOLOGY

The geology along the alignment of the project is the slightly metamorphosed rocks of the 400 million year old Neranleigh-Fernvale Beds, overlain (in places) by young (<2 million years old) alluvium. Fill has also been emplaced in varying locations. The Neranleigh-Fernvale Beds are low grade metamorphic rocks (Holcombe, 1977) that occur through a large swath of south east Queensland (eg Cranfield et.al., 1976 and Willmott & Stephens, 1992). Along the INB route corridor, the Neranleigh-Fernvale Beds take the form of either fine or medium grained slightly metamorphosed sedimentary rocks.

A predominant geological feature along the alignment of the project is a pre-existing creek (Grubb, 1988), which generally runs east of the alignment, but cuts across the alignment at Adelaide Street. The bedrock is overlain by fill, alluvium, residual soil and extremely weathered material in varying thickness.

In Area 20 bedrock was typically encountered at approximately 3m below ground level. The residual soil and extremely weathered material above was of the order of 2m thick with the alluvial soils and fill of varying thicknesses making up the upper 1m. A typical geological section is shown on Figure 2.

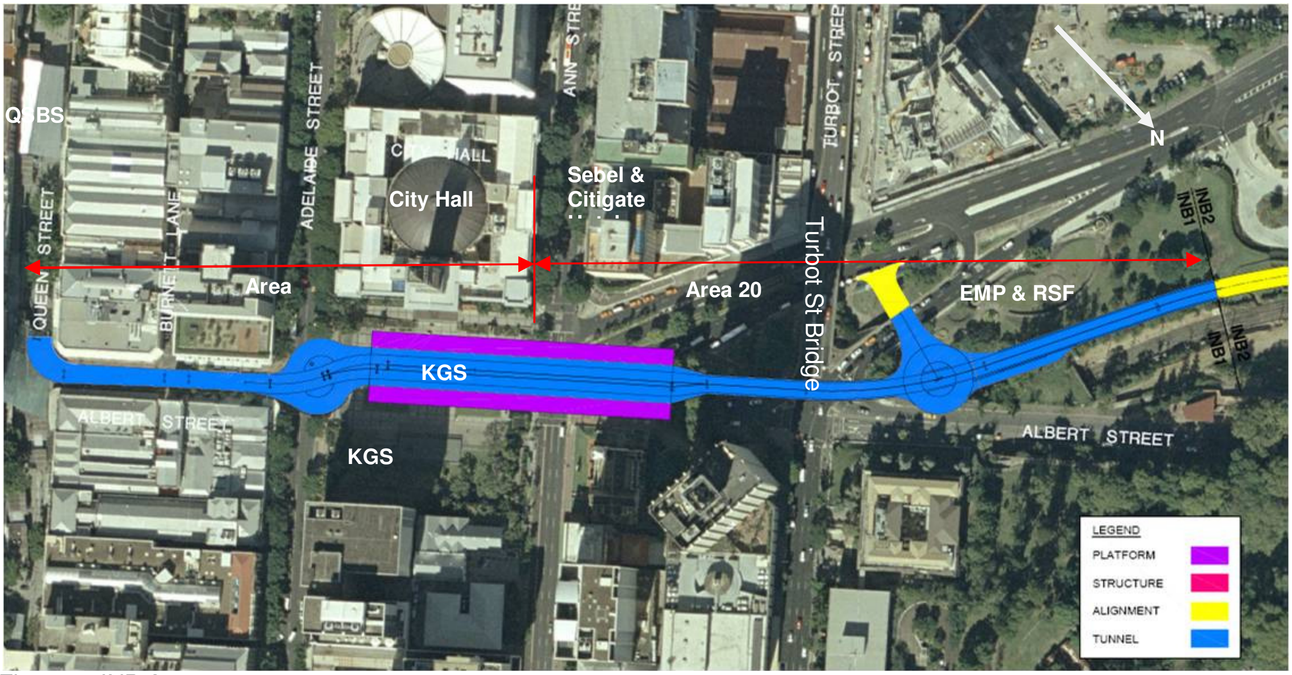

Figure 1. INB Areas 10 & 20

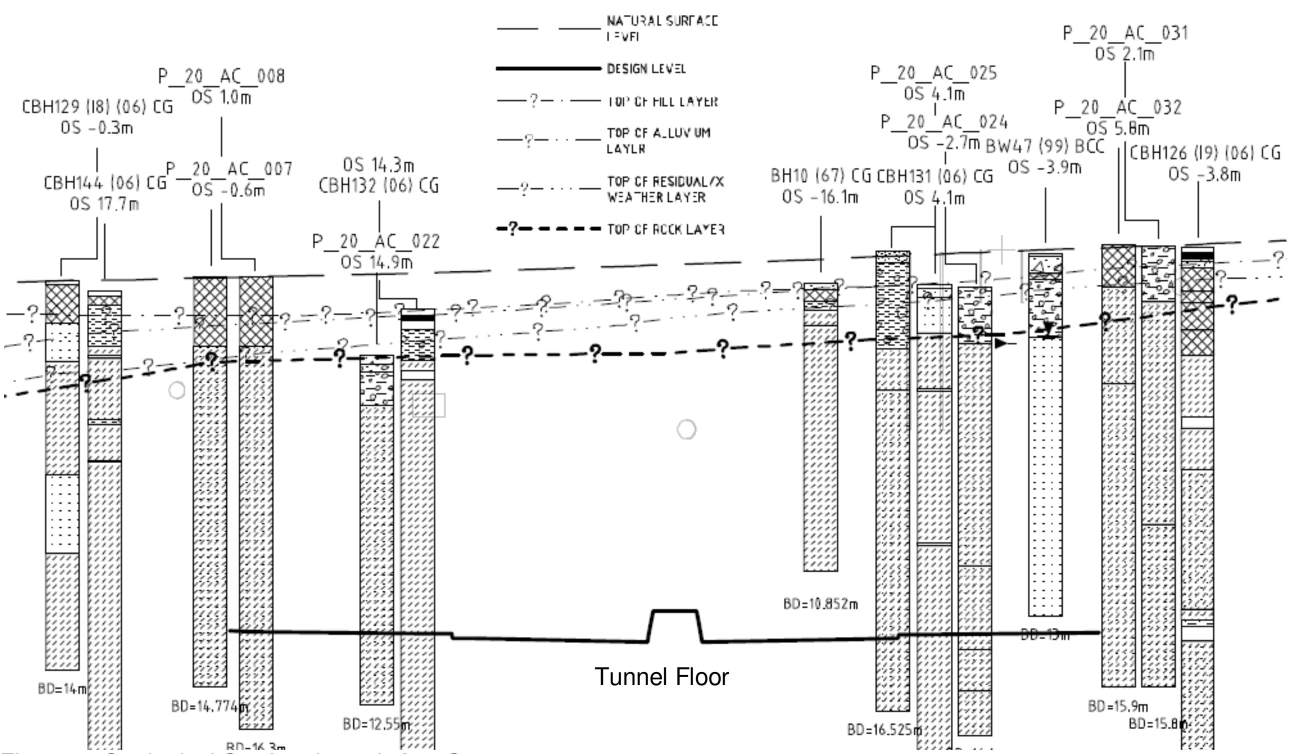

Figure 2. Geological Section through Ann Street

The fill consisted of a matrix of loose clayey gravel with occasional rubble and ash historically placed from local power stations. The alluvial deposits are typically a sandy clay / clayey sand with the fine fraction dominating the engineering behaviour, so that it behaved largely in an 'undrained' manner, over the construction period.

The weathering of the surface of the Neranleigh-Fernvale Beds has produced a weathered zone with residual soil and extremely weathered material identified as stiff to hard gravelly clays. The weathering of the bedrock encountered on the project ranged from highly weathered to fresh. Fresh and slightly weathered rock was typically high or very high strength crystalline material, more weathered rock was typically lower strength. The metamorphic foliation dominated the defect sets, with an additional two sets of joints and some randomly orientated joints also occurring.

4 ROCK STABILITY

The ubiquitous metamorphic foliation created the potential for varying shape and sizes of blocks along the busway. The orientation of the foliation and the busway were such that potential was identified for sliding along foliation partings to occur on the “southeastern” wall of the busway during excavation and construction. In contrast toppling was not considered a significant risk on the “northern” wall of the busway, though this assessment was made with the realisation that careful observation during excavation would be required to confirm this.

5 TYPES OF GROUND SUPPORT

5.1 General

Although much of the ground support was designed prior to construction, site observations combined with a comprehensive instrumentation and monitoring programme offered some flexibility during construction. Where ground conditions were seen to differ from predicted, changes were made to the ground support configuration.

The choice of ground support was determined by a number of factors:

- ground conditions;
- location of services adjacent to the structure; and
- proximity of buildings and other structures.

Ongoing maintenance and access issues meant that stressed ground anchors were only considered for temporary works and not as permanent installations.

The various support systems adopted are discussed below.

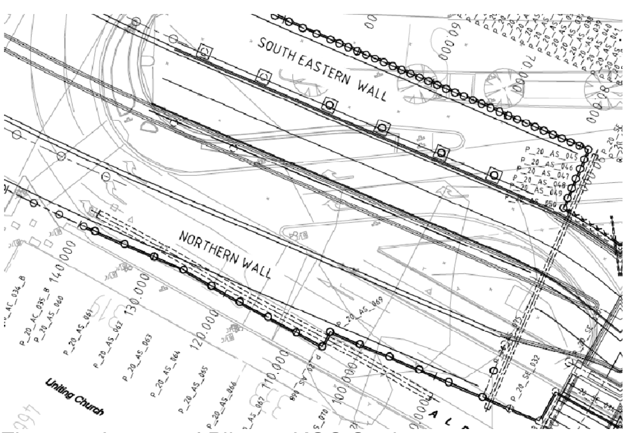

Figure 3. Layout of Piles at KGS Station

5.2 Piles

Piles were used as the primary support method in the tunnel section of the busway. Contiguous piles were employed and at the “southeastern” wall of the excavation in Area 20 where the foliation orientation and the resulting potentially unstable blocks were anticipated. At the “northern” wall of the excavation in Area 20, piles were spaced at up to 4m and were primarily used as support columns for the structure (Figure 3).

In the temporary case many piles were supported through the use of temporary dowels and ground anchors, whereas in the permanent case they were propped by the slabs of the structure.

5.3 Rock Bolts, Dowels and Ground Anchors

While rock bolts, dowels and ground anchors are common types of ground support, their use within the busway was limited, reflecting the ground conditions encountered and the proximity of existing structures. Initial design recommended standard pattern bolting. This was revised to ‘spot bolting’ (observational method) and was subsequently proven to be the correct approach. This involved the inspection and mapping of rock faces as construction progressed and the installation of bolts or dowels as required.

Temporary ground anchors were installed at the base of the KGS car park to support the existing wall of the car park adjacent to City Hall when the supporting slabs within the car park were demolished to make way for the new bus station. Additional ground anchors were used as temporary support for pile walls during excavation prior to construction of the internal structure of the busway.

For a number of reasons the following definitions were derived to enable ease of communication on site:

- dowels – untensioned steel bars, rock bolts and bar anchors; and
- anchors – actively stressed cable and bar anchors.

5.4 Shotcrete

Sprayed concrete, or “shotcrete“, was used on all exposed rock surfaces and some soil faces. A number of shotcrete designs were employed with the three most used being:

- Type B - 225mm thick shotcrete facing with 2 layers of SL82 mesh for soil;
- Type C - 150mm thick shotcrete facing with a single layer of SL82 mesh for rock; and
- Type D - 150mm thick shotcrete facing with a single layer of SL82 mesh placed in an arch between piles.

These are shown on Figures 4 to 6.

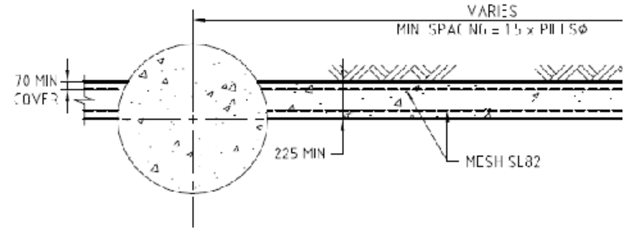

Figure 4. Shotcrete Type B

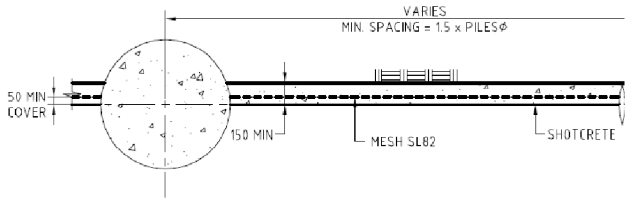

Figure 5. Shotcrete Type C

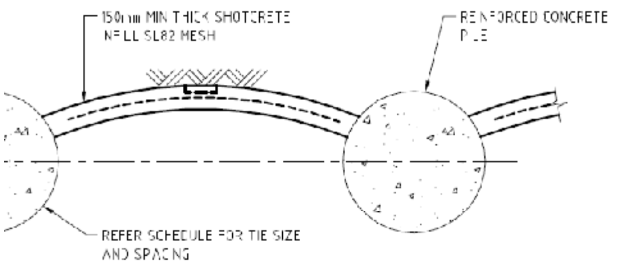

Figure 6. Shotcrete Type D

The arched shotcrete was used where weak rock was observed in the southern face (foliation dipping out of the face) of the busway and the pile spacing allowed it. The primary purpose of the shotcrete was to secure small blocks (<1m^3).

Standard design shotcrete for rock consisted of only 1 layer of 200mm square reinforcement (SL82) while the soil design (Type B) incorporated 2 layers at 100mm spacing. Shotcrete installation was monitored with cleaning of the face imperative to allow a strong bond between rock and concrete.

5.5 Drainage

Standpipes and vibrating wire piezometers were installed along the length of the busway tunnel. Subsequent observations have recorded groundwater levels at least 2m below busway level which was reflected in the design process. The busway has been constructed during a period of prolonged drought, consequently, groundwater levels have been observed to be dropping throughout the construction period. While the water table has been considered during the analyses, the level may rise past predicted levels. This should not pose any serious stability issues as the design incorporates a drainage system to reduce potential water pressures.

Drainage of the busway tunnel structure was an integral part of the design. Strip drains were used at regular intervals along the excavated face behind the shotcrete and between piles.

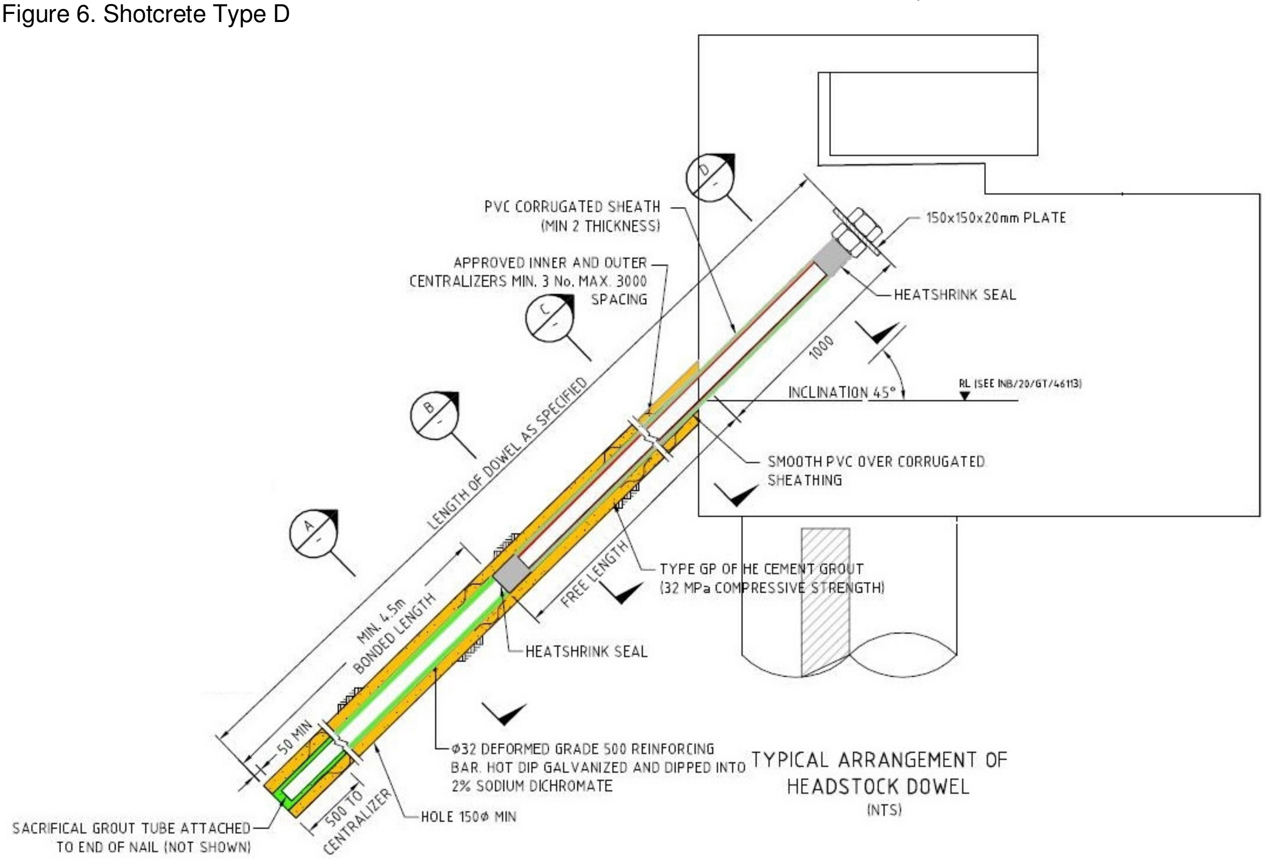

Figure 7. Headstock Dowel (Bar Anchor)

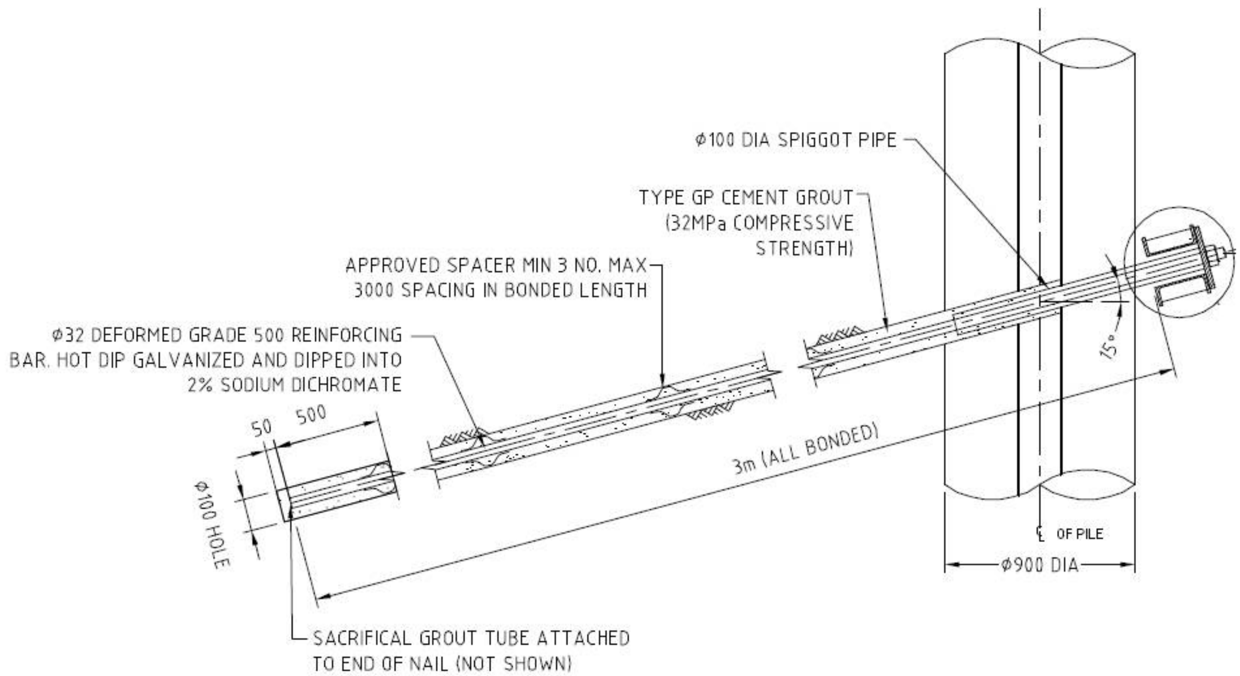

Figure 8. Bar Anchor through Pile

5.6 Soil Nails

Soil nails were proposed during the design for areas where reasonable depths of soil were anticipated. As the excavations proceeded it became evident that the soil cover was less than expected and soil nails were, therefore, not used during construction.

6 GROUND SUPPORT IMPLEMENTATION

6.1 Pile Support during Excavation

During the excavation of KGS station, headstock dowels (Figure 7) and anchor and waler systems (Figure 8) were employed to prevent overturning of the piles. While there was only a relatively shallow depth (<2m) of fill and soil in the area, the excavation was approximately 14m deep and pile sockets were only 2m into rock, providing little support against overturning. While only a small overturning moment was predicted to affect the pile, it was considered necessary to install the dowels to prevent any potential movements and consequently subsidence of the ground below the historic Uniting Church and other adjacent buildings. These elements were to only act temporarily until the roof slab was in place.

Anchor and waler systems were used below Turbot St and along the “southeastern” wall face of the KGS station excavation. A steel I-beam was secured to the front of the piles and tensioned anchors were used to apply a restraining load to the piles.

In the “southeastern” wall face of the KGS station the presence of up to 4m of fill and loads on the piles from an adjacent tower crane foundation at the western end of the station necessitated their use.

6.2 Ground Support for Emma Miller Place Fountain

The fountain situated in Emma Miller Place (EMP) prior to construction of the busway was to be reinstated as part of the works. Previously, the fountain consisted of large, rounded blocks of rock stacked on top of each other and concreted together. A large amount of vegetation including grass and small shrubs adorned the façade of the structure with their roots penetrating the voids. During construction of the busway all the loose blocks were removed, leaving several large blocks cemented in place. The design of the new foundation consisted of a concrete block of staged pools, approximately 4m high as seen in Figure 9.

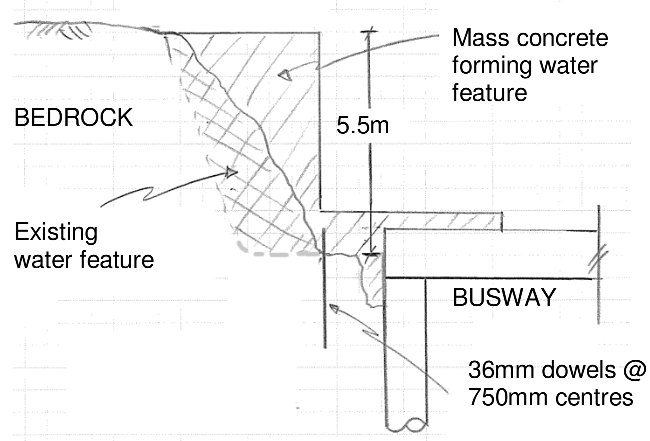

Figure 9. New water feature

The main issue concerning the construction of the fountain was securing the concrete block against sliding. Several designs were proposed with a row of steel anchors acting as a shear key adopted. As some movement is required for the strength of the anchors to mobilise, a 100mm thick Styrofoam layer was placed against the headstock of the busway to allow some movement without transferring the weight of the block onto the busway structure.

The dowels were 36mm 500N grade steel with a 0.75 m spacing set back approximately 1.5 m from the headstock with 1.5 m embedment.

6.3 Wedge Support below a Cantilevered Walkway

Adjacent to the waterfall the footpath of Albert Street was removed as part of the excavation. The reinstatement solution was a cantilever walkway out over the busway excavation, placing large moments on the rock. Two rows of 7m long dowels were installed below the walkway (see Figures 10 & 11). These dowels were 50mm diameter bars, installed at 20° below the horizontal as a preventative measure.

Figure 10. Installing dowels below Albert Street

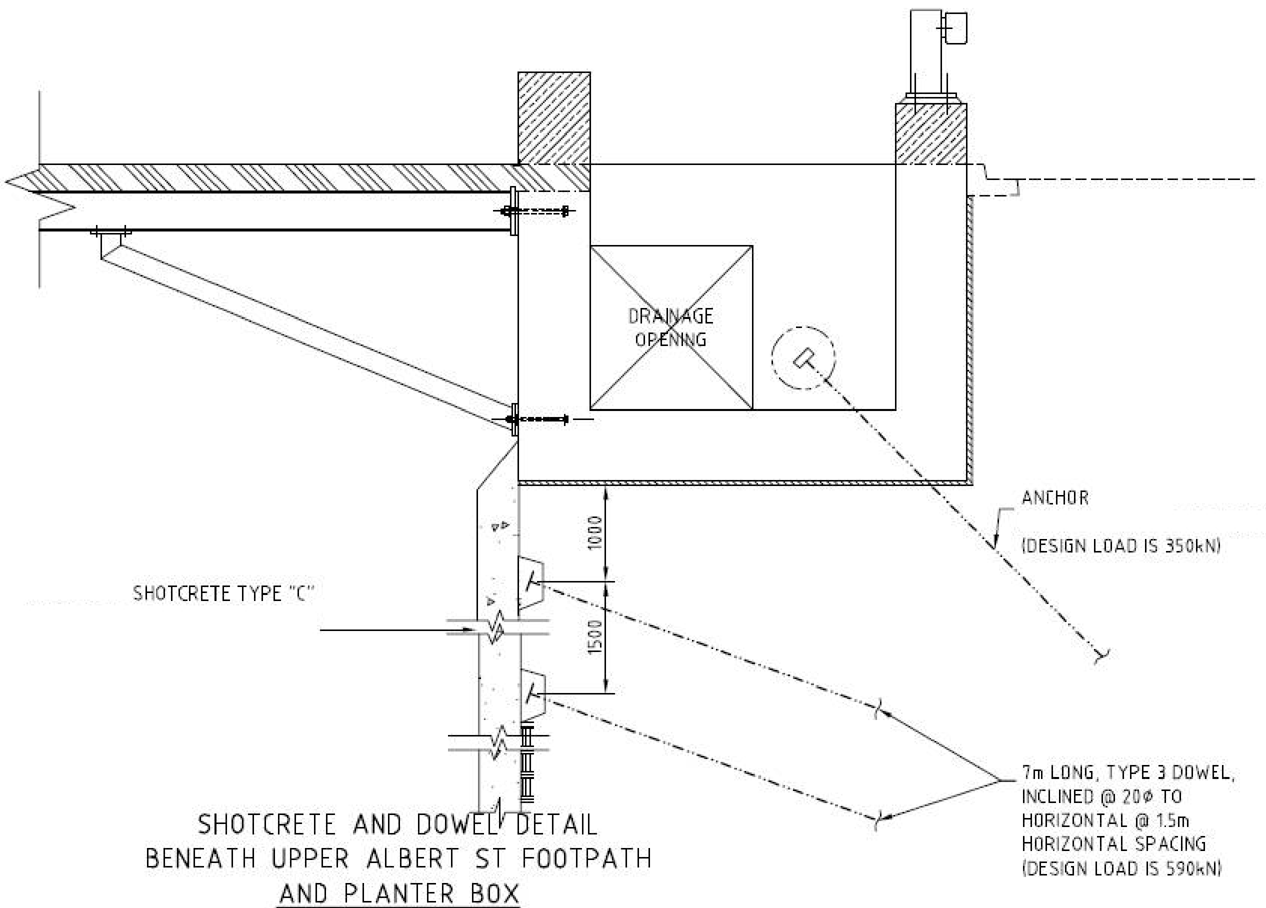

Figure 11. Layout of dowels below Albert Street

6.4 Turbot St Bridge Abutment

The construction of the busway passed close to the existing northern abutment of the Turbot Street Bridge. As discussed in Section 4, in the southern face of the excavation it was possible for sliding on discontinuities along the metamorphic foliation. It was possible that if a rock wedge existed, it would have the raked piles of the abutment sitting on it. This scenario prompted a more conservative approach for this short length of busway. The design assumed that a wedge did in fact exist with discontinuity parameters of c'= 0kPa and ϕ' = 20 ° with a surcharge equal to the allowable bearing capacity of the Turbot Street piles (as per the as-built drawings obtained). The solution was to provide high strength "rock dowels" to support such a wedge. The rock dowels selected were 50mm diameter 500/550 N/mm^2 steel bars.

7 CONCLUSION

The Inner Northern Busway Project incorporated a variety of ground support methods. The requirements of a project constructed in a confined urban environment provided significant challenges in designing appropriate support while satisfying community and construction needs.

This paper presents some of the challenges and unique limitations imposed by such a project. Many of these challenges were met in an innovative and dynamic way. Through the endeavours of the whole construction team, the ground support works allowed the project to proceed unhindered with the project to finishing ahead of time and on budget.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the contribution of all members of the Alliance for establishing and maintaining a positive and cooperative set of behaviours enabling an observational approach to be adopted.

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