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Design and construction challenges for the TBM traverse through Brisbane's partially excavated Albert Street Station cavern

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ABSTRACT: Albert Street Station is one of four underground stations currently under construction as part of Brisbane's Cross River Rail project. The station comprises an underground cavern, entry shafts and a series of adits connecting the entry shafts with the cavern.

The original cavern construction sequence included excavation of the cavern prior to receiving the Tunnel Boring Machines (TBMs) used to excavate the running tunnels. Due to favourable excavation conditions for the TBMs and delays to cavern construction, the TBMs arrived prior to commencement of the cavern bench excavation. Since halting the TBM operation had significant cost and scheduling implications, the construction team opted to continue TBM excavation through the partially excavated cavern.

This paper presents design and construction approaches to address the impact of this changed approach to the stability of the already constructed adits, cavern sidewalls and rock pillar between the cavern and shaft.

These measures resulted in a successful traverse of TBM through the cavern and significant savings to construction time and cost.

1 INTRODUCTION

Cross River Rail (CRR) is a new 10.2 km long metro rail line in Brisbane between Dutton Park in the south and Bowen Hills to the north, which includes 5.9 km long twin tunnels that pass under the Brisbane River and the CBD. A joint venture of CPB Contractors, BAM International Australia, Ghella and UGL (CBGU JV) is building the tunnels.

The Pulse consortium (including the CBGU JV) was awarded the contract to design and construct the Tunnel and Station Development (TSD) works which includes construction of twin Tunnel Boring Machine (TBM) excavated running tunnels and mined running tunnels; four new underground stations at Boggo Road, Woolloongabba, Albert Street and Roma Street; and dive structures at each end of the running tunnels.

Albert Street Station is the central station on the CRR alignment and is connected by twin TBM tunnels to Woolloongabba Station to the south and Roma Street Station to the north. Significant infrastructure including essential utilities and high-rise buildings with deep basements are located within close proximity to the station excavations.

The underground excavations for the station include a 290 m long cavern, two entry shafts, a construction access shaft, seven pedestrian/service/egress adits, an internal services shaft and two temporary access adits (Figure 1).

Five of the seven pedestrian/service/egress adits connect from the two entry shafts into the station cavern at mezzanine level, whereas the other two adits connect the main entry shaft with the cavern via an internal service shaft excavated below the cavern invert (Rogan et al, 2025)

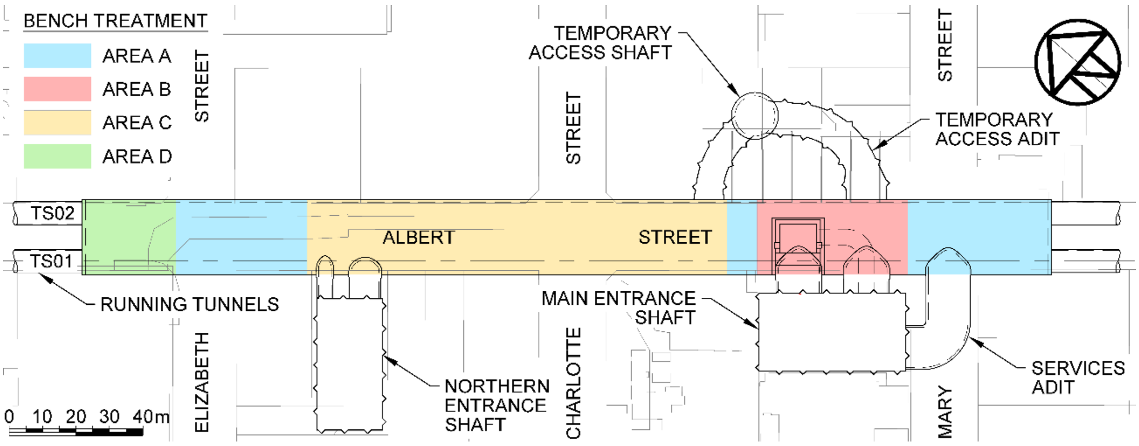


Figure 1. Albert Street Station configuration (Area A to Area D refer to the bench treatment excavation sequence zones discussed in Section 5 and Section 6).

The excavated span of the cavern is up to 25 m with an excavated height of up to 17 m. The excavated spans of the adits range from 5 m to 14 m and their excavated heights range from 5 m to 10 m. The Main Entrance shaft which provides the main vertical transport access for the station is about 24 m wide and 44 m long with a depth of up to 50 m.

The station is in a highly developed urban environment with a significant number of adjacent multi-storey structures resulting in relatively tight movement tolerances.

2 GROUND CONDITIONS

The ground conditions at Albert Street Station comprise fill, alluvium and residual soils underlain by bedrock of the Neranleigh Fernvale Group (NFG). The total depth from the ground surface to top of the station cavern ranges from 18 m to 21 m. Thickness of competent rock cover above the cavern crown is about 6 m to 14 m.

The NFG comprises weakly metamorphosed sandstone (meta-greywacke and arenite), phyllite and subordinate quartzite and meta-basalt. Meta-greywacke and arenite are typically high strength, while phyllite (metamorphosed mud rocks or argillite) is typically weaker. The NFG rock mass is sub divided into five classes based on rock mass quality, with Class 1 (i.e. NFG1) being the most competent and Class 5 (i.e. NFG5) being the poorest quality (Cammack et al, 2022).

Borehole data in the vicinity of the station shows strongly developed foliation and fabric with a series of moderately dipping fault zones (dipping approximately 50° towards the north-east). In addition, a low-angle contact fault dipping into the cavern was encountered within the rock pillar separating the cavern from the main entry shaft.

The ground level at Albert Street is at approximately RL 4 m and previously comprised swampy terrain. The interpreted groundwater levels prior to tunnelling varied between RL -5 m and RL -9 m.

3 CONSTRUCTION SEQUENCE

The Albert Street cavern excavation commenced from a breakout chamber located at the intersection of the cavern with the temporary access adit on the northern side of the construction access shaft. Once the breakout chamber was completed, excavation of the top heading of the cavern progressed to the north and south using a staggered three heading sequence comprising two side drifts and a central pillar.

A staggered two heading sequence was also adopted in favourable ground conditions with bolted support. The excavation of the station cavern and adits was carried out predominately using road headers with some adits excavated by drill and blast methods. Section 6 describes the cavern bench excavation sequence undertaken with drill and blast methods.

Figure 2. Breakthrough into the segmental lining showing the nominal cover over the crown (16 December, 2021)

The primary (temporary) support for the cavern and adits typically comprises rock bolts and thin shotcrete or a passive thick shotcrete lining at intersections and/or where low rock cover or fault disturbed ground occurs.

The construction sequence for the bolted support was essentially cut, bolt, and spray shotcrete.

The sequence for the passive shotcrete lining adopted the same sequence as the bolted support types for the initial side headings but with full thickness of the passive shotcrete lining constructed in the two side headings prior to excavation of the central heading. The full span passive shotcrete lining was completed as excavation of the central heading was advanced. Structural continuity of the passive shotcrete lining was achieved using a 'Stremaform' sacrificial formwork detail in the longitudinal construction joint between the side headings and the central heading. The 'Stremaform' formwork system implemented in the Albert Street Station cavern is similar to the system described in Shen et al (2022) for the Roma Street station cavern lining.

The adit excavations were generally undertaken as full span headings, and where required, bench excavation was undertaken.

4 TBM TRAVERSE

The original construction program for the TBM traverse through the station was based on sliding the TBM along skids erected on the invert of the fully excavated cavern. However, the excavation rate for the top heading of the cavern was much slower than anticipated due to the extremely high strength massive Metagreywacke rock encountered in the northern section of the cavern (Keating and Swinn, 2023).

Due to favourable excavation conditions for the TBM and the delayed cavern excavation, the TBMs arrived at the station before commencement of the cavern bench excavation.

The two program sequencing options considered by the construction team were either to delay the TBM traverse until completion of the cavern bench or else facilitate TBM tunnelling through the cavern bench and complete the cavern excavation after the TBM traverse.

Since halting the TBM operation until completion of the cavern excavation had significant cost and scheduling implications, the construction team chose to continue TBM tunnelling through the partially excavated cavern (Keating and Swinn, 2023).

The first TBM (TS01) arrived at the southern end of the cavern in the second week of June 2021 and continued traversing towards the northern end while the second TBM (TS02) arrived at in the first week of July 2021. Both TBM's required about four weeks to traverse the length of the cavern.

Survey of the floor levels in the excavated top heading indicated the thickness of rock between the heading floor and top of the TBM segmental lining ranged from about 0.3 m in the northern section to about 0.5 m in the southern section (Figure 2). Rock cover was absent in the central section and the segments were exposed to a depth of up to 0.4 m.

Construction plant exclusion zones were set-up directly above the TBM tunnels due to the minimal rock cover. Operation of construction plant was allowed within the exclusion zone by placing additional backfill material above the segmental linings. The required thickness of backfill material ranged from 0.3 m for general construction plant up to 1.5 m for road headers.

Because the segmental lining within the cavern was only required temporarily, CBGU were able to use segments that were structurally adequate but unsuited for use within the permanent tunnel linings, such as due to minor damage or imperfections.

5 SIDEWALL SUPPORT

5.1 *Sidewall underpinning*

The proposed bench excavation methodology involved blasting over the full depth of the central bench and invert. This resulted in a reduction of the available lateral support to the cavern sidewall due to the loss of confinement provided by the insitu rock and the presence of the excavated TBM tunnels. This mechanism had the potential to compromise the stability of the elephants footing of the passive shotcrete arch lining and also the stability of the narrow rock pillar between the cavern and main entrance shaft.

The risk of deformation or instability to the elephant's footing was addressed by underpinning the footing with additional sidewall bolts installed from the top heading prior to blasting of the central bench. The underpinning sidewall bolts for bench treatment Area C and Area D (Figure 4a) comprised 3 m long rock bolts installed at a nominal inclination of 10° below horizontal and at a longitudinal spacing of 1.5 m, while a reduced spacing of 1.0 m was implemented within bench treatment Area B.

Temporary underpinning bolts were also installed within the rock pillar zone for bench treatment Area B. The temporary underpinning installed on the shaft side of Area B comprises pairs of 40 mm diameter glass-fibre reinforced polymer (GRP) bolts installed at a nominal inclination of 20° to 30° and a longitudinal spacing of 1.2 m.

5.2 *Rock pillar stitching*

One of the design challenges for the TBM traverse through the cavern bench was the potential for excessive ground loads acting on the TBM tunnel segmental lining due to a large-scale rock wedge formed by the contact fault encountered in the rock pillar between the cavern and the main entry shaft excavation. The risk of instability due to the wedge was minimised by installing pillar stich bolts from the already excavated main entry shaft (Figure 3).

The pillar stitch bolts comprise 36 mm diameter high strength threaded GEWI bars installed in 100 mm diameter holes with bolt heads secured using 220 mm wide square anchor plates and dome nuts. The stich bolts were sleeved to provide a 3 m free length while the remaining portion of the stich bolts was grouted to in the bond zone. The net bonded length for the stich bolts installed from the shaft ranged from about 2.7 m to 4.6 m. The pillar stitch bolts were pre-stressed

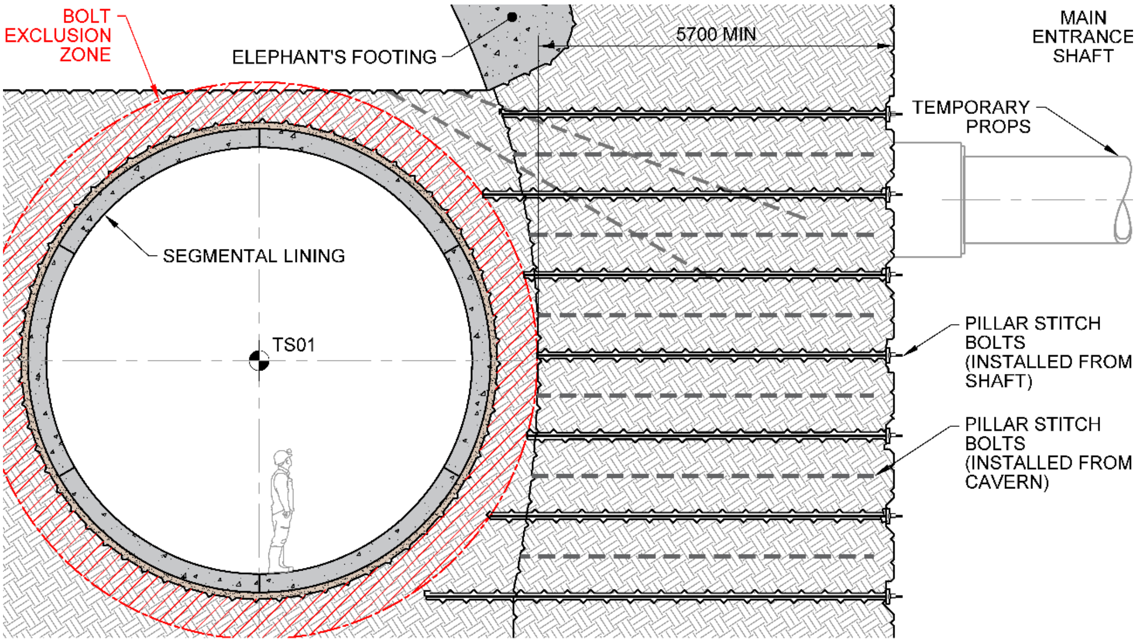


Figure 3. Details of pillar stitch bolts.

to a nominal load of 500 kN to increase the strength of the rock pillar and reduce potential deformation by providing lateral confinement. Complete confinement of the rock pillar between the cavern and the main entry shaft was achieved by installing additional stich bolts of the same specification from the cavern side during cavern bench excavation (Figures 3 and 5b).

5.3 *Shaft temporary props*

The design incorporated a total of 12 large props installed in two rows within the main entry shaft for the purposes of limiting deformation and providing support particularly on the cavern side of the shaft. Six props were installed at cavern crown level and six props were installed near the top level of the cavern bench. The props were installed prior to the TBM traverse and were manually adjusted with hydraulic jacks to provide the required compressive pre-load and limit deformations. The prop loads were controlled with a minimum loading of 10 MN but also a maximum load limit of 15 MN to prevent the props inducing load and deformation into the TBM excavation and cavern during the various excavation and support stages.

6 BENCH AND INVERT EXCAVATION

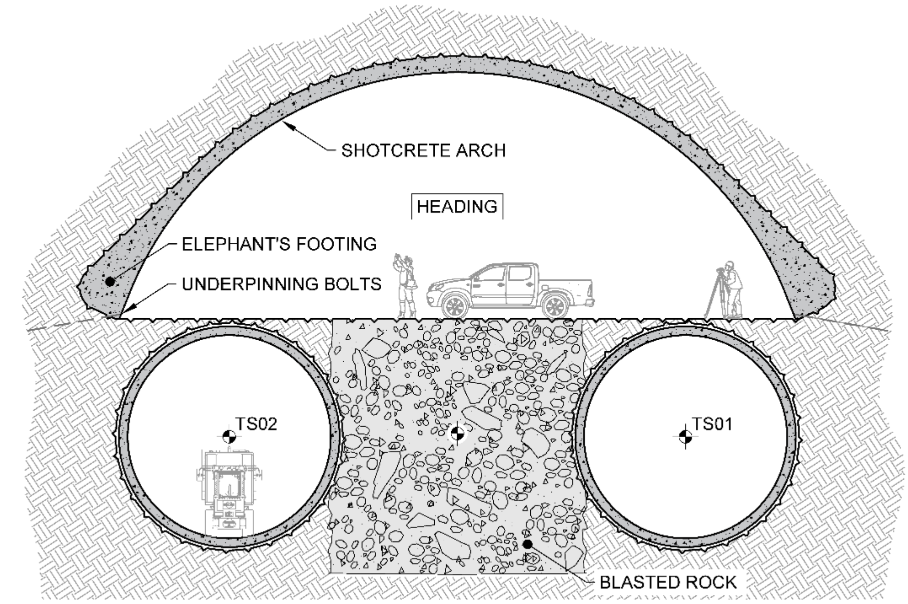
6.1 *Bench treatment zones*

Excavation of the cavern bench and invert was undertaken after completion of the TBM traverse. The original bench excavation sequence was to excavate full width benches while leaving a 1.5 m minimum width temporary buttress immediately beneath the elephant's footing. The buttress was to be excavated in 4 m to 6 m advances and 1 m to 1.5 m lifts with sidewall support installed at each excavation lift.

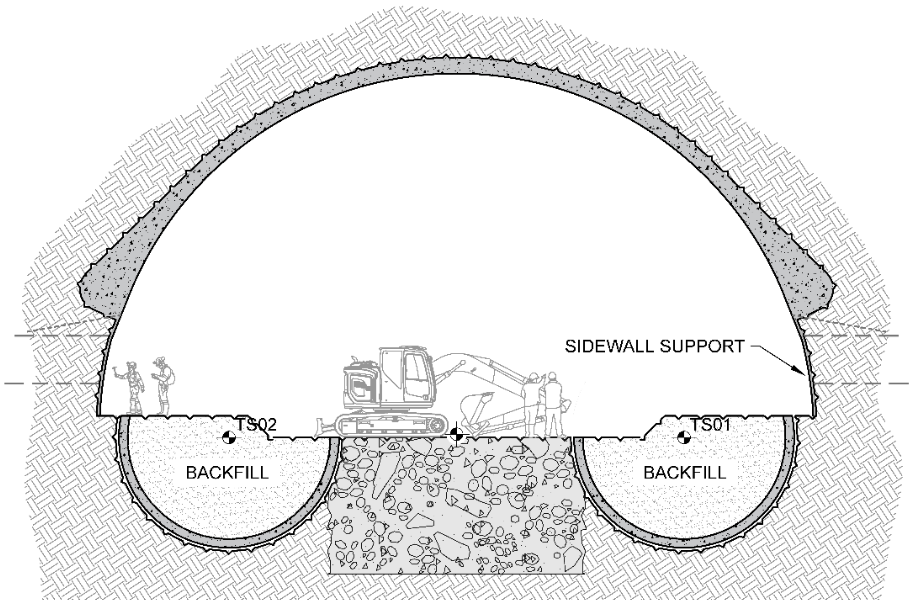
The adopted method of excavation for the changed sequence involved blasting of the central bench between the two TBM tunnels followed by demolition of TBM lining, then trimming of sidewalls and installation of sidewall support.

The bench excavation sequence was grouped into four treatment areas (Figure 1), mainly governed by the cavern sidewall support constraints:

– Area A: Bolted support was implemented in the cavern crown and additional bench treatment was not required.



(a) Blasting over the full depth of bench and invert.



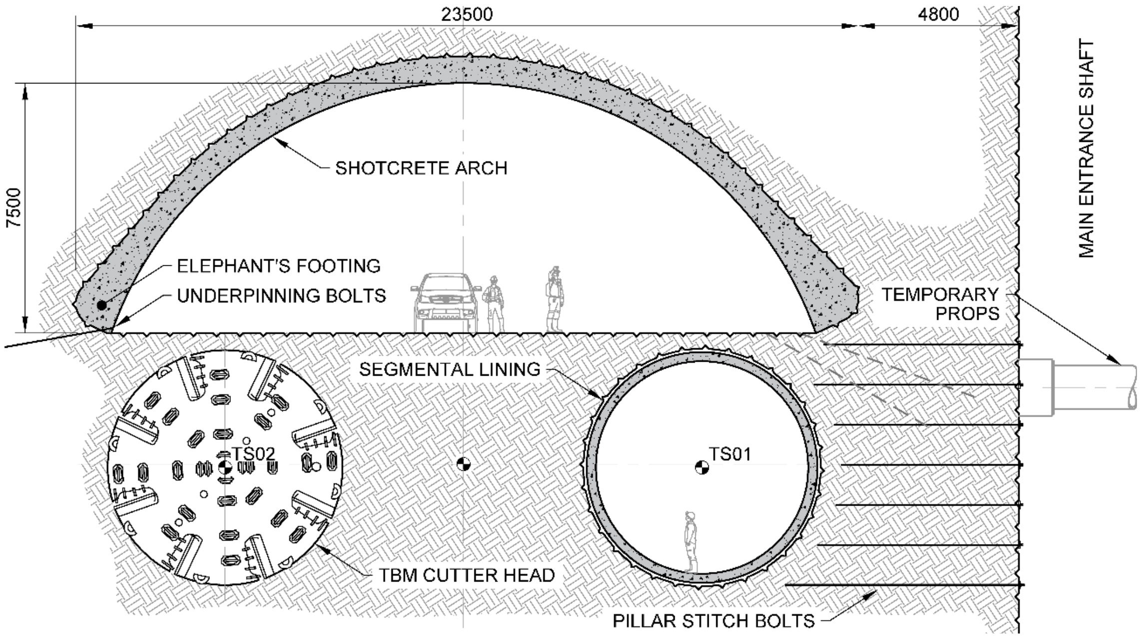
(b) Backfilling of TBM tunnels and installation of sidewall support.

Figure 4. Bench and invert excavation sequence for Areas A, C and D

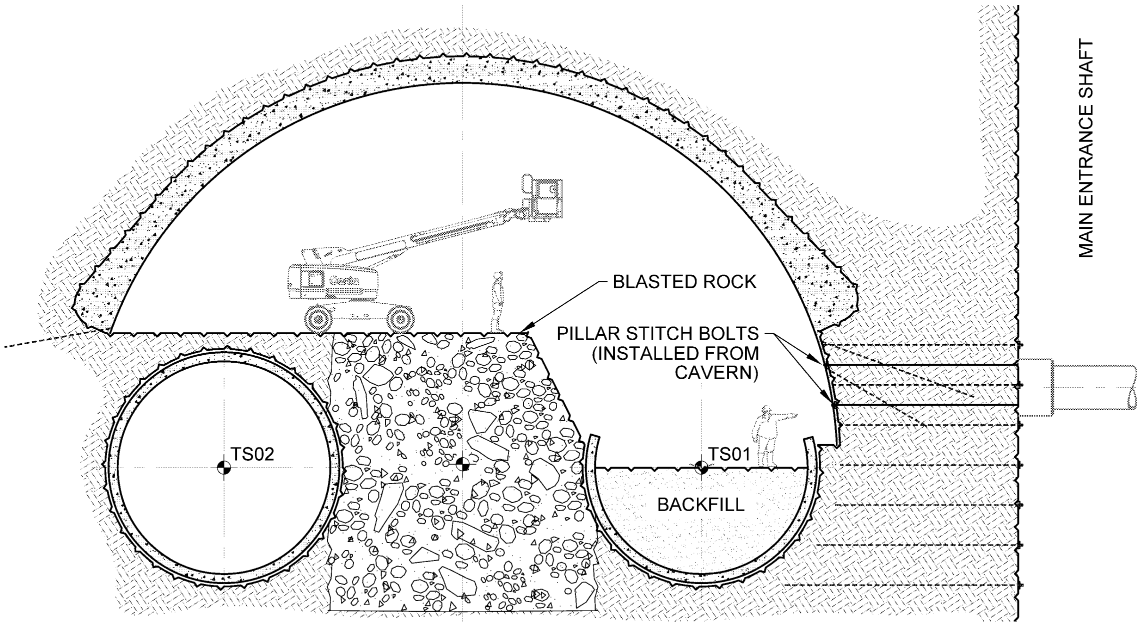
- Area B: Adjacent to the main entry shaft where a passive shotcrete arch lining was constructed to support the cavern crown. This area was the most critical due to the requirement to install pillar stich bolts progressively prior to completion of the bench excavation.
- Area C: Passive shotcrete arch lining was installed in the cavern crown and additional sidewall bolts were required to underpin the elephant's footing.
- Area D: Northern end of the cavern where the cavern top heading was not excavated prior to the TBM traverse. Passive shotcrete arch lining was installed and additional sidewall bolts were required to underpin the elephant's footing . The elephant's footing was constructed at a raised level to provide a minimum rock cover of 1.5 m above the TBM segmental lining.

The bench excavation sequence adopted in bench treatment Area A, Area C and Area D included (Figure 4):

- Blast the full height of bench and invert (Figure 4a).
- Demolish top segments in both TBM tunnels.
- Backfill both TBM tunnels to create a working platform (Figure 4b).



(a) TBM traverse through bench of cavern.



(b) Blasting of rock between tunnels and installation of pillar stitch bolts.

Figure 5. Bench and invert excavation sequence adjacent to the main entry shaft (Area B).

– Trim the sidewall in 1.5 m lifts and install sidewall support (Figure 4b).
– Demolish the remaining TBM lining and complete invert excavation, trim the sidewalls and install support at each lift.

6.2 *Modified sequence*

Controlling the risk of pillar instability in Area B required the installation of pillar stich bolts from the cavern bench side prior to blasting the bench (Section 5.2). The adopted construction sequence for the excavation of the cavern bench and invert in this area included (Figure 5):
– Demolish top segments in TBM tunnel TS01.
– Backfill TBM tunnel TS01 tunnel to create a working platform (Figure 5b).
– Trim the sidewall in 1.2 m lifts and install pillar stich bolts from the cavern side (Figure 5b).

- Continue to demolish TBM rings, trim sidewalls and install stitch bolts in 1.2 m increments down to the TBM springline level (Figure 5b).
- Blast the full height of the central bench and invert (Figure 5b).
- Demolish top of the segmental lining in TBM tunnel TS02.
- Partially backfill TBM tunnel TS02 tunnel to create a working platform.
- Trim sidewall in 1.0 m lifts and instal sidewall support
- Demolish the remaining TBM lining and complete invert excavation, trim the sidewalls and install support at each lift.

7 CONCLUSIONS

Construction of Brisbane's Cross River Rail project encountered a critical construction program challenge due to early arrival of the tunnel boring machines prior to the completion of the excavation of the Albert Street station cavern.

Cost and program implications from this unforeseen scenario necessitated the TBMs to traverse through the partially excavated cavern. As a result, it was necessary to develop an alternative approach for the excavation of the cavern bench and invert.

The adopted approach involved underpinning the elephant footing, TBM tunnelling through the cavern bench, drill and blast excavation of the central bench, demolition of the TBM tunnel segmental lining, installation of pillar stich bolts, staged trimming of the cavern sidewalls and installation of sidewall support.

Potential risks of deformation and instability of the cavern, adits and main entry shaft due to the changed construction sequence were managed via a coordinated effort between the designers of the cavern primary lining, cavern construction team, main entry shaft construction team, designers of the entry shafts, and designers of the TBM segmental lining.

The adopted design approaches and construction methodology resulted in a successful traverse of the TBM through the cavern with deformations well within acceptable margins and resulted in significant savings to construction time and cost.

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