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Primary support installation for the Albert Street Station cavern and main station entry shaft intersection, Cross River Rail, Brisbane

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ABSTRACT: As part of the Cross River Rail (CRR) project in Brisbane, the Albert St Station mined cavern was one of the most technically complex underground structures. Constructed beneath the city's central business district (CBD), the cavern featured a critical junction that connected two pedestrian adits and a services adit directly to the main station entry shaft. Excavation and support activities were constrained by limited site access, proximity to adjacent basements, and the requirement to maintain ground stability in challenging geotechnical conditions. This paper outlines the primary ground support design, construction staging and highlights key lessons learnt.

1 INTRODUCTION

Albert St Station was constructed as part of the Cross River Rail (CRR) project, and the station cavern was one of the most technically challenging structures of the underground works. Located beneath Brisbane's CBD, Albert Street Station comprises of a 290m-long cavern with two entrances along its alignment, referred to as the main station entry shaft and northern entry shaft. The cavern is connected to the main station entry shaft by two pedestrian adits (AA5 and AA7) and one services adit (AA4) with as little as 5m of separation between the cavern and the shaft (Figure 1).

The complexity of this 45m long junction lies in its location within low-cover, faulted rock mass conditions and the need for concurrent excavation adjacent to a 45m wide by 50m deep shaft. The interaction of multiple excavation fronts, proximity to high-rise buildings, stringent monitoring requirements, and the presence of a temporary access adit (ATA1) necessitated a highly tailored ground support solution.

This paper outlines the geological context and structural design behind the primary support system, as well as the deviation from the IFC (Issued for Construction) assumptions that occurred during construction. By comparing the original design intent with the actual methodologies adopted on site, and analysing the technical and logistical challenges encountered, this paper aims to share practical insights into managing construction of junctions.

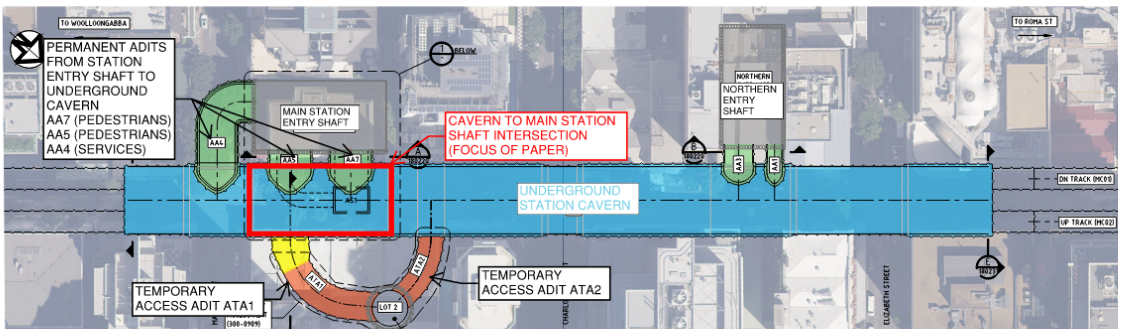

Figure 1. Albert St Station general arrangement

2 DESIGN

2.1 *Geological setting*

The ground at Albert St Station is underlain by rock mass of the Neranleigh-Fernvale Group (NFG) with rock mass units as described in Cammack et al. (2022). The Albert St Station cavern was excavated predominantly within NFG1/2 (typical UCS of 50 MPa) with low rock cover. At the cavern junction, the top heading encountered NFG2, and the geotechnical investigations indicated approximately 2m of NFG2 above the crown, overlain by a south-to-north dipping NFG3 unit between 1 to 3m thick, 1m of NFG4/5, followed by around 10m of alluvium and fill. Borehole data suggested the presence of a significant low angle fault at the location of the junction between the cavern and the main station entry shaft.

2.2 *Primary support design*

The cavern was excavated in a triple heading sequence with the primary support implemented in two stages:
Stage 1 – Initial support comprising of 5.4m long inflatable friction bolts or cement grouted CT bolts and 100mm thick synthetic fiber reinforced shotcrete (SFRS)
Stage 2 –Intersection support comprising an 800mm thick bar and mesh reinforced shotcrete passive shell lining supported on 1800mm wide elephant's footings.

A heavy primary support was required due to the concurrent excavation of the adjacent main station entry shaft. An additional design consideration was the interaction with a temporary adit (ATA1), which connects to the cavern at invert level on the eastern side of the cavern. A key constraint was that the ATA1 concrete collar had to achieve a compressive strength of 20MPa before excavation of the heading directly above the access adit could proceed. Figure 2 below shows typical cavern primary lining design cross sections.

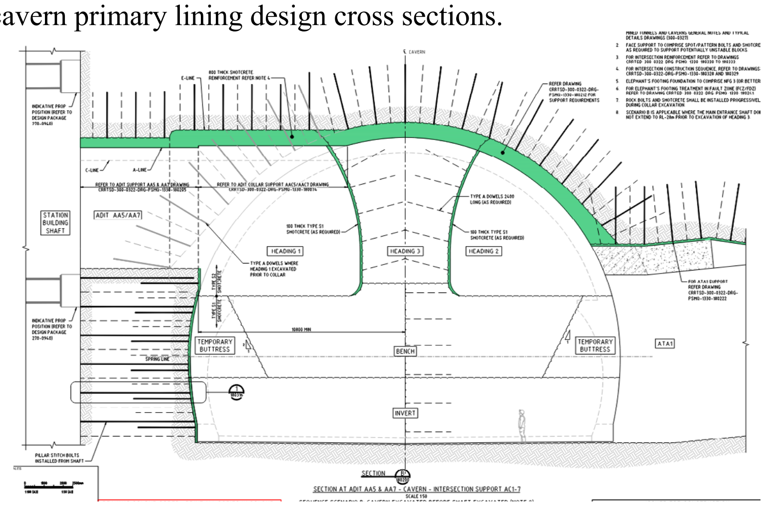

Figure 2. Primary support for cavern junction

2.3 *Other design considerations*

The rock pillar between adits AA5 and AA7 was designed to be excavated out and replaced with mass infill concrete as the rock mass at the pillar was not suitable to be left in place. The rock pillar was excavated as a split heading using rock bolts and 100 mm thick SFRS as temporary support. The design stipulated that the pillar replacement had to be constructed prior to allowing the cavern to be excavated to the full span in the junction area.

Due to the potential presence of a fault dipping through the rock mass between the cavern and station box, stitch bolts were mandated in the design to reinforce this rock pillar. The stitch bolts comprised cement grouted Dywidag WR36 bars stressed to 500kN, installed at 1200mm to 1800mm spacing from the cavern side and shaft side, with recessed anchor plates and a dome nut.

3 CONSTRUCTION

3.1 *Key safety and quality considerations during construction*

Safety measures on site included controlling unsupported ground with signage and barriers to inform personnel of hazardous areas. A typical signage and barrier set up is shown below in Figure 3. Ventilation and dust control were managed using three dust scrubbers in the Albert St cavern, with one servicing the south and two servicing the north. To ensure safe people-plant interaction, dedicated personnel walkways were delineated from tunnel plant using crowd control barriers, and no personnel were allowed in front of the rear jacks of the bolting rig. The delivery team maintained safety through weekly safety task observations and inspections. Quality control measures included rock bolt pull testing and shotcrete testing using cylinders and sprayed panels. A challenge faced was ensuring that the panels remained in an area free of potential damage for at least 24 hours.

Figure 3. Typical signage and barrier set up in cavern

3.2 *Key equipment*

Main equipment utilised to construct the junction primary support was a road header for excavation, Robodrill for installation of rock bolts and a MEYCO Potenza for shotcreting.

3.3 *Design assumed construction methodology*

The assumed construction sequence for the junction triple top heading involved: excavating and supporting top heading 1 (TH1) to full length, followed by the excavation and support of top heading 2 (TH2) to full length. Stage 2 primary support would then be installed in both TH1 and TH2. Once this was completed, the central pillar would be excavated with Stage 1 support installed, followed by the completion of the Stage 2 primary support.

3.4 *Actual construction methodology*

The actual adopted construction method varied considerably from the approach assumed in design as a split heading sequence was approved prior to commencing the junction excavation. The adopted methodology is summarised in Figure 4. The yellow hatch in Figure 4 represents excavation in that stage, grey represents top heading rock to be excavated.

In summary, 8190 bank cubic meters (BCM) of rock was excavated, approximately 900 bolts were installed and 1600m^3 of shotcrete sprayed to provide the primary support for the junction area. Works were conducted on a 24/7 operation. Overall duration to complete the works associated with the cavern junction was approximately 6 months.

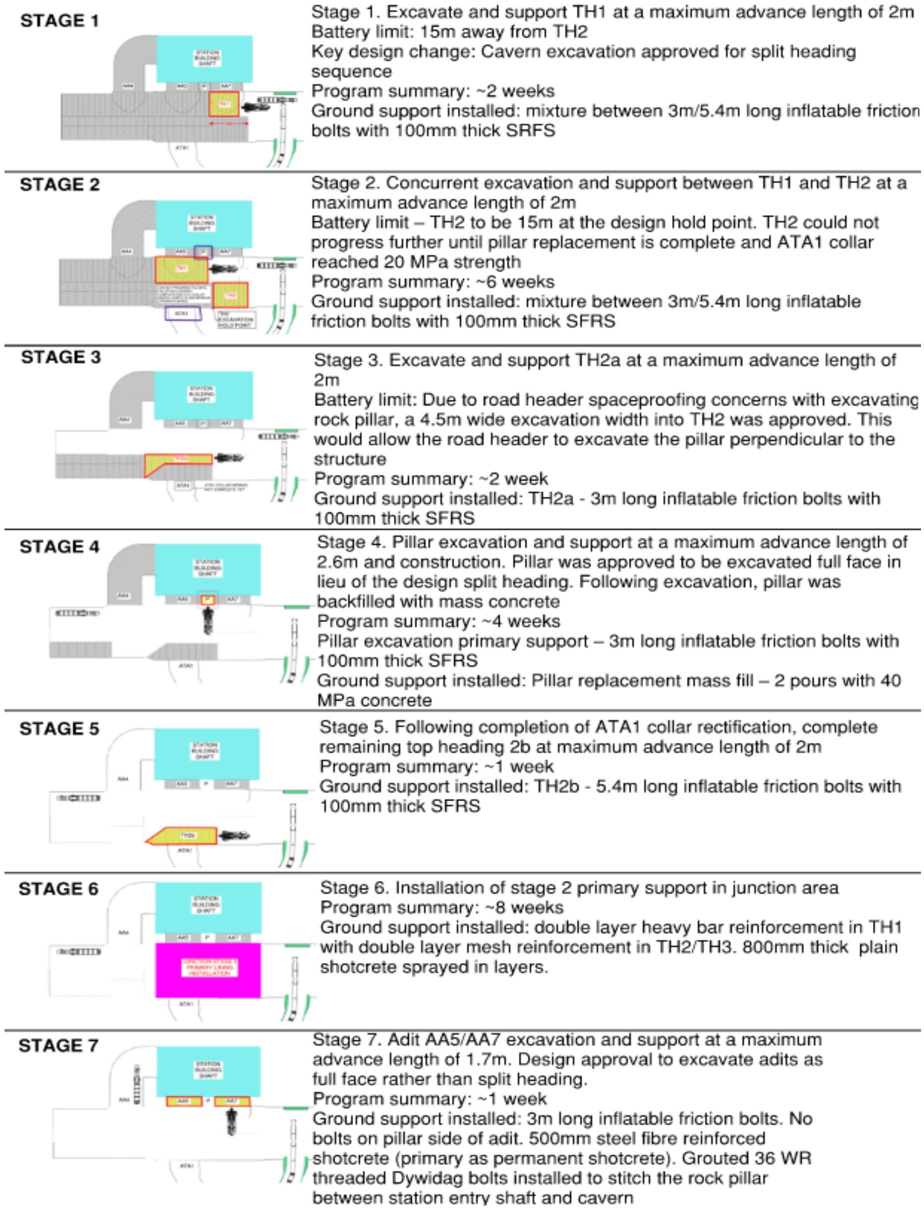

Figure 4. Actual construction methodology for main station entry junction

A photo during construction of the junction top heading is provided in Figure 5 below.


Figure 5. Photo during construction of Albert St Station main entry shaft junction

4 KEY CHALLENGES

4.1 *Key challenge 1 – interaction with station building main entry shaft*

Initially, the design assumed that the adjacent main entry shaft excavation would progress further than the cavern, leading to the adoption of a triple heading sequence. However, the triple heading design posed constructability issues, such as the road header's inability to reach the deep elephant's foot profile and clashes with the ventilation ducting. As construction progressed, the cavern's top heading advanced faster than the main station entry shaft excavation, prompting the tunnelling contractor to adopt a split heading sequence with specific constraints, including requiring a minimum rock cover of 3m of NFG2 overlain by 3m of NFG3. The constraint on the adjacent shaft excavation was that the shaft could not progress below RL -12m prior to the cavern junction primary lining reaching a minimum strength gain of 20MPa. Additionally, there was a potential clash between the cavern heading rock bolts and the main station entry shaft pile anchors. Refer to Figure 6 below. Initially, 5.4m bolts were installed in the cavern heading directly adjacent to the shaft, but a clash with the adjacent shaft anchors occurred, leading to a revised bolting arrangement using a combination of 3m and 5.4m long bolts to ensure cavern temporary support was not comprised. To mitigate this issue, the contractor re-bolted a section of the junction with 3m long bolts.

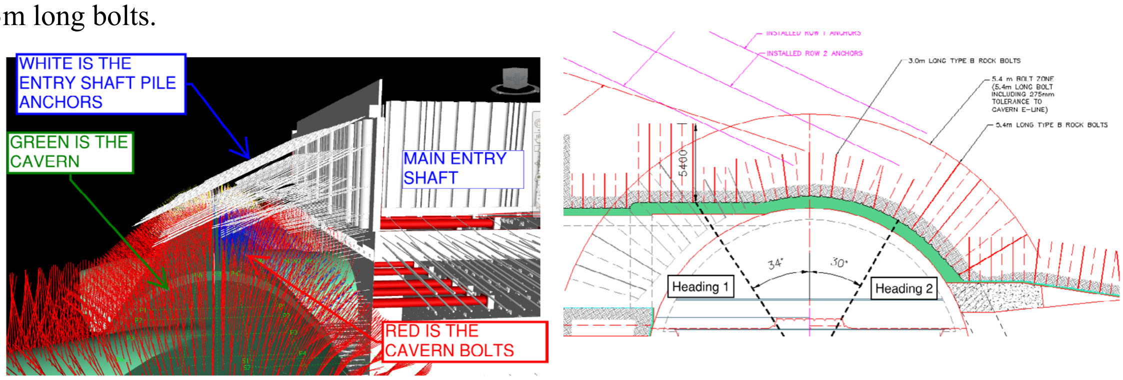

Figure 6. Cavern rock bolt clashes with main station entry shaft anchors

4.2 *Key challenge 2 – strict monitoring requirements during construction*

Due to the location of the Albert St Station cavern, it was determined that a daily permit to tunnel (PTT) would be employed to ensure a comprehensive review of the previous 24 hours of excavation activities. This meeting would assess and interpret ground monitoring data and instrumentation results, confirm alignment with design predictions and allowable limits, and determine and agree on the excavation and ground support for the next 24 hours. Key areas of monitoring included the Albert St footpath between Mary St and Charlotte St for surface settlement, the Sebel Hotel and Festival Towers, which were neighboring high-rise buildings to the junction construction, monitored for displacement and tilt, and in-tunnel monitoring where survey targets were required to be installed in arrays every 10 metres through this junction area as per the design. The design drawings stipulated trigger levels for each type of monitoring instrument depending on location and support type. An example monitoring graphs that were reviewed daily in the PTT are given in Figure 7 below.

If the trigger action levels were breached, a Management Action Team or 'MAT' meeting was called. In total, 40 MAT meetings were held during the full cavern construction program, with 9 occurring during the period of the junction top heading construction. Of these, 3 were due to surface settlement alarms on the Albert St footpath above, with a maximum settlement of 12mm recorded during this time. Tiltmeters on Festival Towers caused a red alarm during this period, but it was concluded that there were no major issues as the tiltmeter sensors were very sensitive to rain events. The construction of the junction top heading took place in summer, a season characterized by frequent rain in Brisbane. In summary, the design predictions on ground, tunnel, and building movement were all within design expectations.

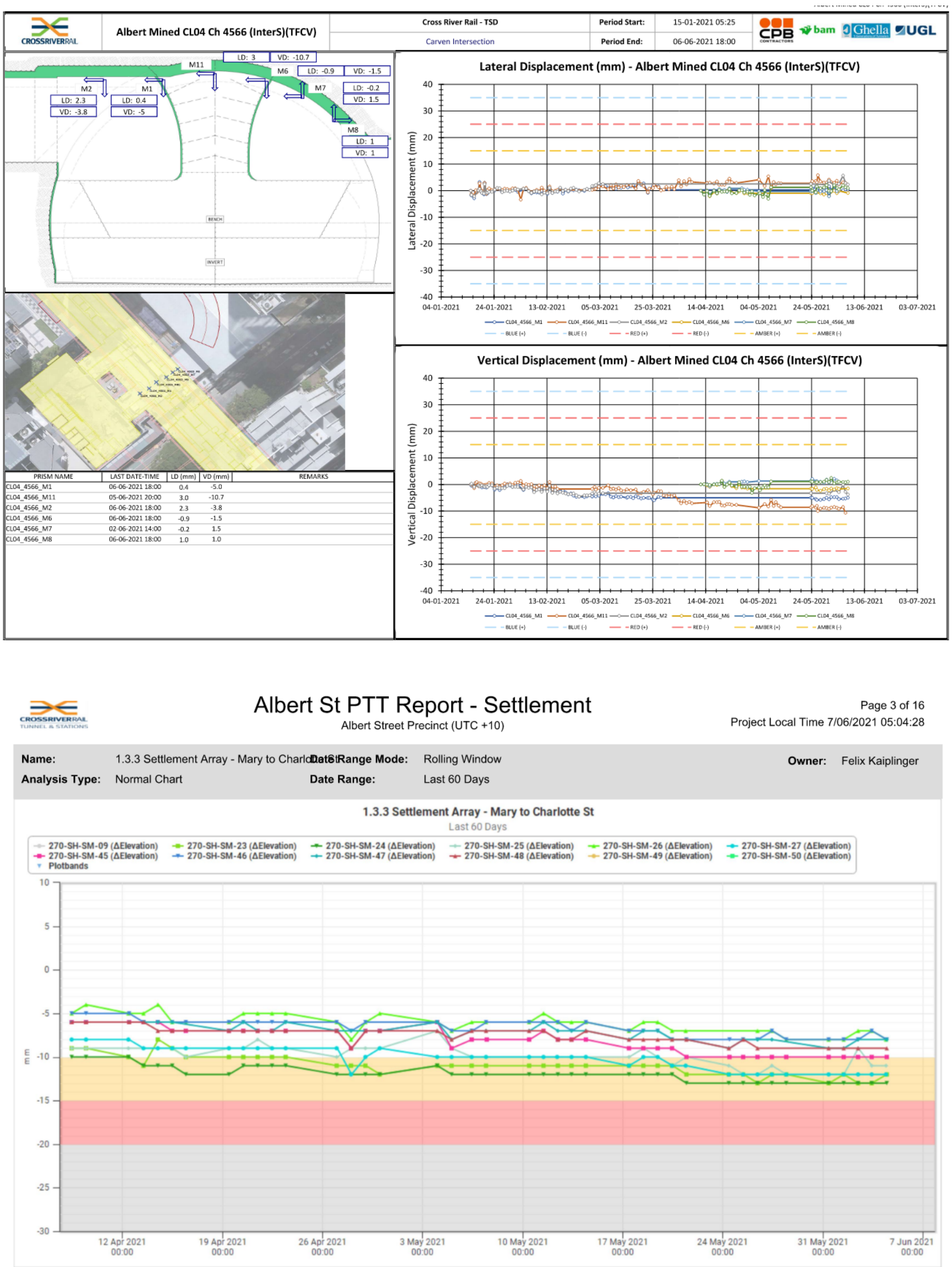

Figure 7. Example monitoring data reviewed during Albert St tunnel permit to tunnel meetings

4.3 *Key challenge 3 – ATA1 collar rectifications*

Following pillar construction, excavation of the final section of the junction was delayed due to an unforeseen construction issue involving the concrete collar constructed at temporary access adit ATA1, associated with Stage 5 of the referenced construction methodology. While the specifics of this issue are beyond the scope of this paper, rectification involved the road header sumping a window into the remaining rock mass (labelled TH2b in the Stage 5 schematic) and drilling from the cavern junction to the ATA1 collar to facilitate grouting of the affected area. Although this issue impacted the junction excavation sequence, the overall effect on cavern progress was minimal, as the road header was able to continue excavation in other areas.

4.4 *Key challenge 4 – Stage 2 junction primary lining*

Due to the major design constraint of the adjacent main station entry shaft, after completing the cavern top heading excavation and Stage 1 primary support, it was necessary to install extrados and intrados layers of reinforcement, with shotcrete layers applied to encapsulate the reinforcement. Rebar was utilised in TH1 with top and bottom mesh to be installed in TH2 and in the central heading. Stremaform (a stay-in-place formwork) was installed at the intersection of the headings to create a construction joint. The sequence of works to complete the junction reinforcement followed these steps: preparing the scaffold area, erecting the scaffold, installing anchors for dummy bars, setting dummy bars, installing and tying extrados reinforcement, removing the scaffold and storing it underground, applying shotcrete to the passive lining, re-erecting the scaffold, installing and tying intrados reinforcement, removing the scaffold, and finally, shotcreting the remaining passive lining. The main purpose of utilizing a scaffold instead of scissor lifts for the rebar installation was due to several reasons: it enabled a stable working platform, productivity was assumed to be quicker than with a scissor lift, and it minimised the potential for slips and trips. Refer to Figure 8 for as built photo of the scaffold. Interface management was crucial during this stage, as the adjacent AA4 adit was to be excavated simultaneously with the reinforcement installation. Therefore, the scaffold structure had to be protected from plant interaction, which was achieved by using pinned-down concrete barriers directly next to the scaffold structure.

Figure 8. Scaffold erection in constrained top heading

4.5 *Key challenge 5 – shotcrete voids*

Following completion of the stage 2 junction primary lining, shotcrete inspections were undertaken to investigate potential voids in the junction primary lining. This included hammer tests, coring work and endoscope inspections. The inspections identified an extensive number of voids within various locations across the junction as shown in the “heat map” presented in Figure 9.

The methodology adopted for the lining remediation involved pressure grouting via injection. The grouting was conducted from south to north, focusing on voids around the adit collars before moving out towards the center of the cavern crown. The process began with setting up a grout pump and securing the work area, followed by installing inlet plates and pressure gauges. Grout was batched at a specified water-cement ratio, tested for fluidity, and pumped through inlet valves with breather valves open. Once grout was visible at breather holes, they were sealed, and pumping resumed until a maximum pressure of 50kPa was reached. The pressure was held and monitored; if stable, the line was shut and bled. Grout samples were collected, and the injected section was left to cure. The process was repeated for each void, and once grout reached 2MPa strength, secondary inspection holes were cored and examined via endoscopes with the CPS team. Remediation of the junction lining became critical as bench blasting and excavation could not continue until the lining remediation was completed.

Figure 9. Identified shotcrete voids in junction area

5 LESSONS LEARNT

5.1 *Location of temporary access adit*

A key lesson learnt is to avoid locating a temporary access adit at an already complex junction area in future projects. The presence of ATA1 introduced significant construction constraints, including delays to Stage 2 primary support works in the junction. Specifically, excavation of the top heading above ATA1 could not proceed until the concrete collar had achieved 20MPa strength. Early planning should carefully consider adit location to avoid interference with major structural elements and staging of primary support works.

5.2 *Reinforced primary lining*

The primary lining on the adit side of the top heading comprised two layers of N32 bars and 800mm thick shotcrete. Given the bar size, spacing and two layers of the reinforcement, application of shotcrete proved to be more difficult than anticipated. Remediation of the voids in the lining necessitated an extensive injection grouting campaign, which in turn constrained subsequent bench blasting activities. The following alternatives were considered:

- Hand spraying: This was considered to not be feasible due to the large volume of shotcrete required (1400m3).
- Cable bolt support: This was considered but deemed unviable due to low rock cover, risk of clashes with adjacent shaft anchors and also due to the loading from the main station building shaft.

An additional key lesson was the importance of thoroughly reviewing shotcrete mix designs during the planning phase. An alternate mix may have reduced the risk of void formation.

6 REFERENCES

Cammack, R., Bertuzzi, R., Smith, A. and Brehaut, R. 2022. Rock Mass Parameters for the Brisbane CBD. Australian Geomechanics, Vol. 57: No. 4, pp. 47 – 72.