

GEOLOGICAL CHALLENGES OF BRISBANE'S CROSS RIVER RAIL PROJECT

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ABSTRACT

The Cross River Rail project includes a new rail line in Brisbane, comprising surface rail and station upgrades, twin running tunnels and four new underground stations at Boggo Road, Woolloongabba, Albert Street, and Roma Street. This project has provided valuable insights into the geological conditions of the Brisbane CBD through large-scale investigation and construction activities. This paper presents case studies of particularly challenging ground conditions encountered during the project, emphasizing the need to consider geotechnical variability and uncertainty in the design phase, as well as the verification of these conditions during construction. The findings presented may serve as a reference for future ground engineering projects in Brisbane.

1 INTRODUCTION

Cross River Rail (CRR) is a new 10.2 km rail line in Brisbane, Australia. It extends from Dutton Park south of the CBD to Bowen Hills in the north comprising 5.9 km of twin running tunnels and four new underground stations at Boggo Road, Woolloongabba, Albert Street and Roma Street, Figure 1. The Pulse consortium which included the joint venture of CPB Contractors, BAM International Australia, Ghella and UGL (CBGU JV) was awarded the contract to design, construct and maintain the Tunnels, Stations and Development (TSD) works.

The project traversed several geological units, with some adverse and challenging ground conditions encountered. Case studies are presented for selected examples including a major fault zone intersecting Roma Street Station, a low-angle persistent fault at Albert Street Station and a highly variable geological unconformity encountered at the invert of the Boggo Road Station. These case studies demonstrate the importance of considering geotechnical variability and uncertainty in the design phase, along with the verification and flexibility to respond to adverse ground conditions during construction.

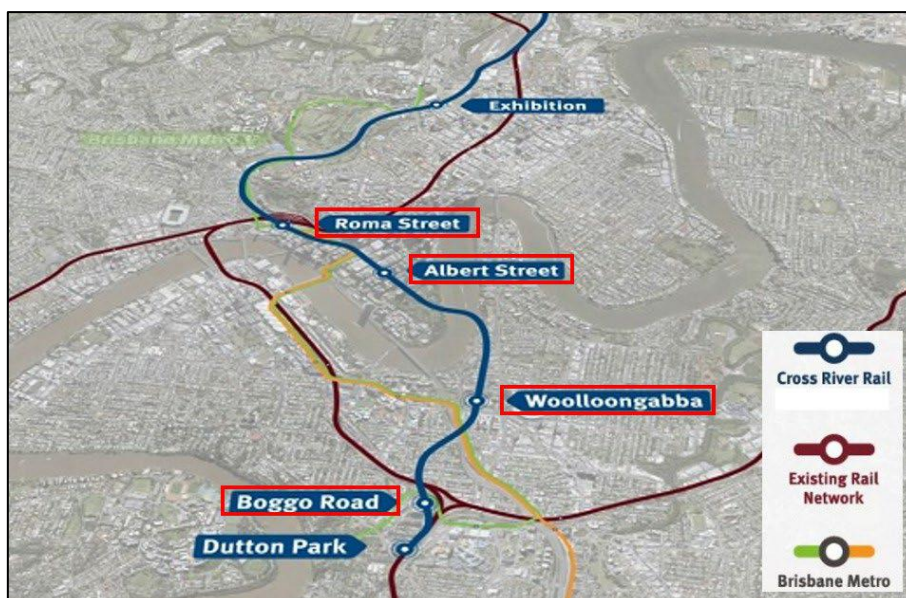


Figure 1: CRR alignment showing the location of the underground stations (www.crossriverrail.qld.gov.au).

2 GEOLOGICAL OVERVIEW

The main geological units encountered at CRR are presented in plan as Figure 2 and described in a stratigraphic column in Table 1. The Neranleigh-Fernvale Beds (NFG) basement rocks are prevalent in the central and northern parts of the project, including the Brisbane CBD. The overlying Brisbane Tuff and Aspley Formation rocks are prevalent in the central and southern parts. Weathering has degraded the rock near the surface to variable depths. Geological unconformities occur between the geological units, which can comprise zones of poor quality sheared or soil strength materials, contrasted with more competent rock above and below. There are multiple significant faults in the Brisbane

CBD, Figure 2. The Normanby Fault Zone (NFZ) strikes northwest to north-northwest through the project area and comprises a wide zone of fault splays, fault gouge and brecciated rock, separated by more competent rock ‘fault blocks’. A detailed description of the rock mass units and structural geology conditions encountered at the CRR project and referred to in this paper is provided in Cammack et. al. (2022). Geotechnical design parameters are also presented in that paper.

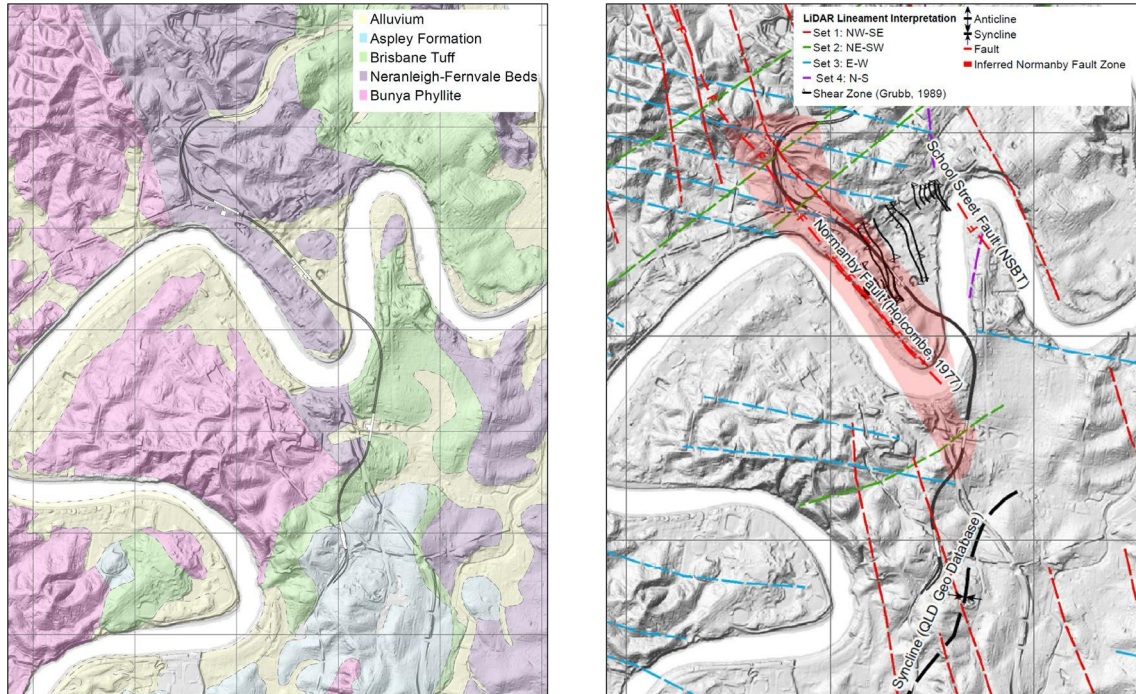


Figure 2: Geological plan and structural geology lineaments showing the CRR alignment.

Table 1: CRR geological units – stratigraphic column and general description

Unit	Period	Age	Rock Type	Description
Aspley Formation (Aspley)	Triassic	200 to 230 Ma	Sedimentary	Conglomerate, sandstone, shale, minor coal. Bedded with orthogonal sub-vertical joint sets and occasional shears and faults. Classified for CRR as either Conglomerate Dominant (CD) or Siltstone Dominant (SD).
Brisbane Tuff (Tuff)			Volcanic/sedimentary	Rhyolitic tuff, ignimbrite, agglomerate, conglomerate, sandstone, shale. Jointed with sub-vertical orthogonal to conjugate sets and sub-horizontal set and occasional shears and faults, often steeply dipping.
Neranleigh-Fernvale Beds (NFG)	Devonian - Carboniferous	300 to 400 Ma	Metamorphic	Phyllite, arenite, meta-greywacke, quartzite derived from a siliceous parentage (chert, jasper), basic metavolcanics, metamorphosed to greenschist facies. Strongly foliated in places (generally dipping to the NE), with frequent foliation partings and foliation parallel shearing. Joint set antithetic to foliation, along with subvertical joints. Significant shears and faults in places.

3 CASE STUDY 1 – FAULT ZONE AT ROMA STREET STATION

3.1 GEOTECHNICAL MODEL

Roma Street Station is located within the NFG geological unit on the northern edge of the Brisbane CBD. Several of the initial investigation boreholes encountered a major fault zone, which was inferred to be associated with the regional NFZ. Additional boreholes were proposed at the design phase to increase confidence in the ground model at critical locations,

including the adit and cavern intersections. However, the boreholes were not able to be completed due to surface constraints including the operating railway station, Inner Northern Busway and other buildings. The location and extent of the fault zone was therefore inferred based on the available information, and was interpreted to intersect the cavern, adits and main shaft Figures 3 and 4. The rock mass was classified into NFG1 to NFG5 (fresh to weathered) units, and fault zone materials including Fault Disturbed Zone (FDZ) and Fault Crush Zone (FCZ). The fault zone materials were assessed to be of significantly lower strength and stiffness compared to the surrounding high strength NFG rocks and were considered to have potential implications for the cavern and shaft stability, ground loading and founding conditions.

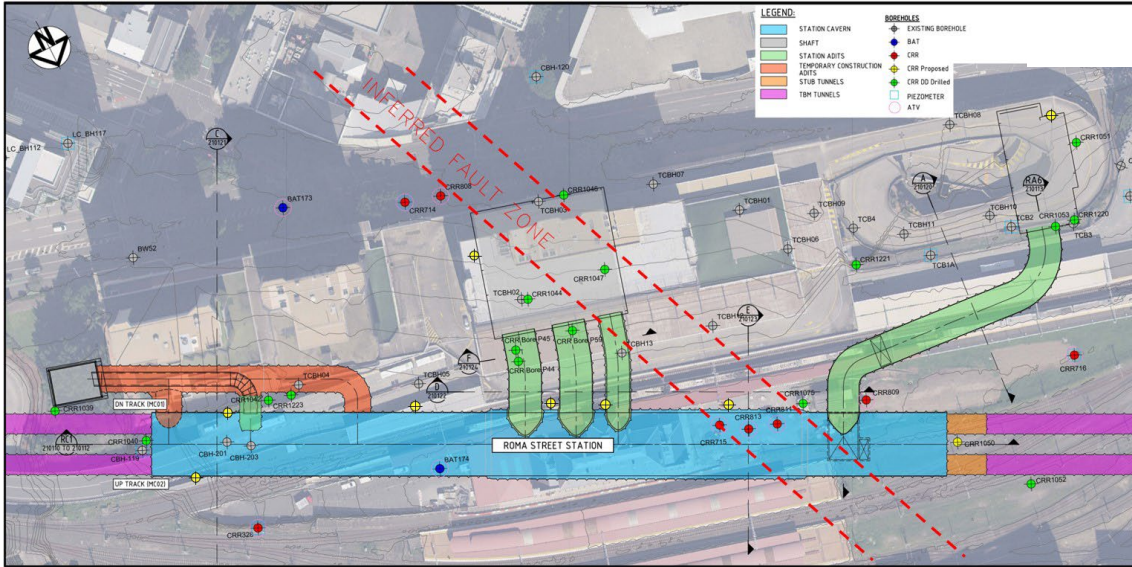


Figure 3: Roma Street Station borehole plan, showing inferred fault zone.

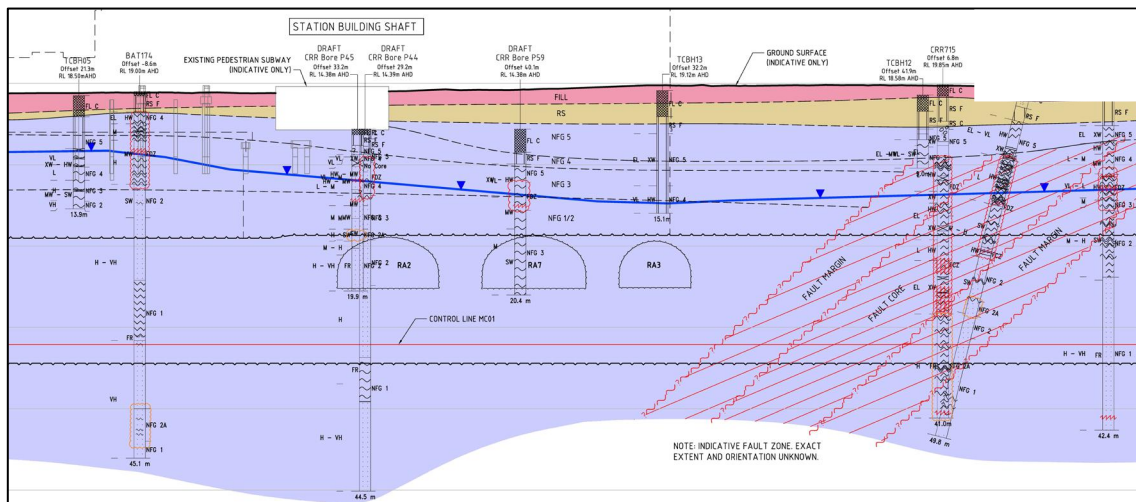


Figure 4: Roma Street Station geotechnical section – showing inferred fault zone intersecting the cavern.

3.2 DESIGN CONSIDERATIONS

Several ground support and ground reinforcement types were included in the Roma Street Station cavern design ‘toolbox’ to cater for the range of expected ground conditions within the fault zone, as described in detail by Shen et. al. (2022) and Cammack et al. (2023). These included:

- A passive shotcrete lining primary cavern crown support type, combined with a three-heading excavation sequence to minimise span width and allow verification of ground conditions in the lead heading, Figure 5.
- A heavily bar reinforced passive shotcrete primary lining support and temporary collar structure if a fault zone was encountered at the intersection of the cavern and adits.

- A widened elephant's foot foundation for the shotcrete arch primary lining, with micropiles and wall support under the footing in the fault zone, Figure 5.
- Removal and concrete replacement of fault zone materials in the cavern invert, Figure 6.
- A permanent concrete lining with thickness and reinforcement which catered for ground loading from the fault zone.

These were assigned during construction via the Permit to Tunnel (PTT) and Hold Point processes based on the encountered conditions. The anticipated ground deformation was also assessed during design, and a series of monitoring trigger levels were defined to alert the designer if the ground was not behaving as expected during construction. Design solutions were also adopted for the main shaft to address these adverse ground conditions however these are not presented in this paper.

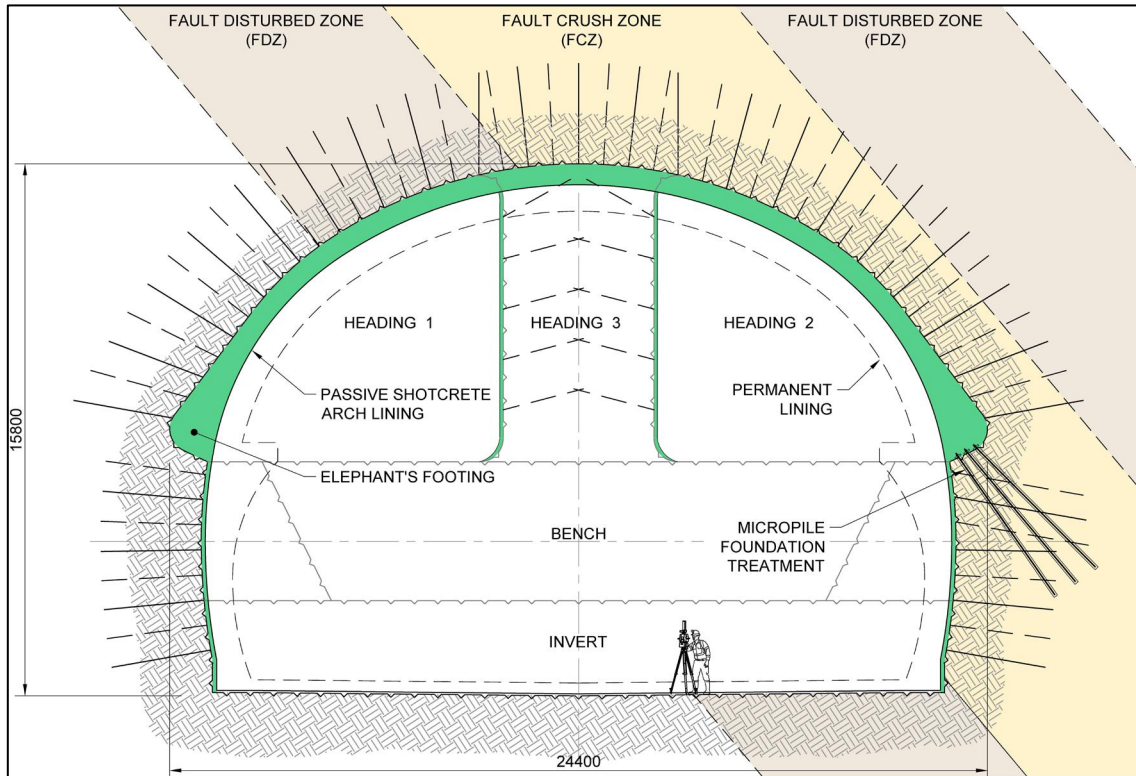


Figure 5: Roma Street Station cavern – showing passive shotcrete arch lining and micropiles at the elephant's footing foundation (Shen et. al. 2022).

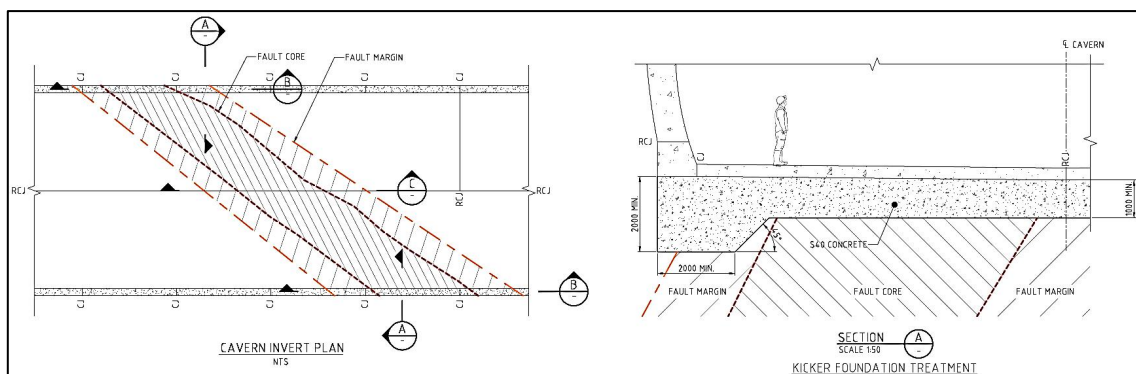


Figure 6: Roma Street Station cavern invert foundation treatment.

3.3 CONSTRUCTION OUTCOMES

Verification of the fault zone was undertaken during construction via geotechnical mapping, endoscopes, piling inspections, plate load testing and monitoring. Mapping of the cavern and adits detailed a 5m to 10m wide fault core comprising variable FCZ (typically 1m to 4m wide) and FDZ (typically 2m to 5m wide), steeply dipping to the northeast. The FCZ materials comprised fault brecciated rock with seams of fault gouge material, ranging from matrix to clast supported and soil to very low rock strength. The FDZ materials comprised highly disturbed and brecciated rock with frequent crush and shear zones, generally clast supported and ranging from very low to medium rock strength. The core was surrounded by a fault margin zone comprising NFG and FDZ materials, around 5m to 10m in thickness either side. A zone of increased rock mass disturbance was observed adjacent to the fault margin in places, characterised by increased jointing, minor warping and folding of foliation and increased weathering of geological structures. Figure 7 presents the fault zone as mapped in the crown of the cavern and adits. The encountered fault zone extent and characteristics were generally consistent with the design assumptions, and the design solutions were implemented without delay or modification. Figure 8 presents a photograph of the fault zone in the cavern heading. Figure 9 presents the removal of the fault zone in the cavern invert. The fault did not occur at the cavern intersection with the adits and therefore the bar reinforced concrete collar was not required.

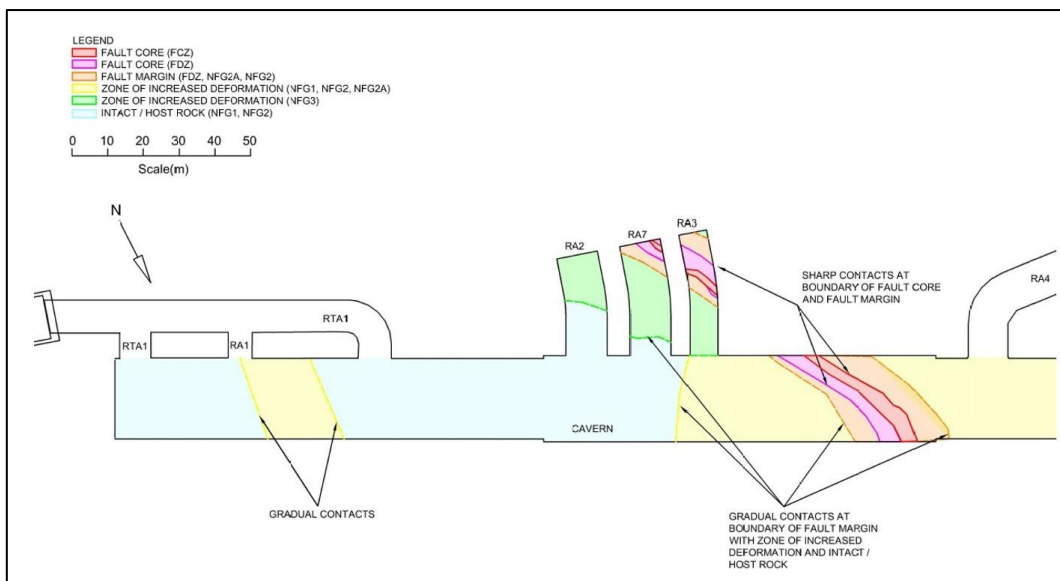


Figure 7: Roma Street Station rock mass units encountered in the cavern and adit crown during construction (Cammack et. al. 2023).



Figure 8: Fault zone encountered in the Roma Street Station cavern heading during construction.

- Three rows of temporary props within the shaft, with continuous load and displacement monitoring and adjustable jacks to maintain the support within defined upper and lower limits during the shaft and cavern excavation. These props were required for other geological conditions as well as the fault (potential large rock wedges along foliation parallel defects in the NFG) and very tight displacement criteria related to the adjacent high-rise buildings.
- Carefully managed excavation and support sequence and extensive deformation monitoring for the cavern, shaft and adjacent existing infrastructure.
- Removal and concrete replacement of fault materials in the cavern invert.
- A thick permanent concrete lining with reinforcement for the cavern to cater for ground loading associated with the fault.
- A robust permanent station building design to consider contrasting stiffness and ground loads.

These were assigned and managed via the PTT, Permit to Excavate (PTE) and Hold Point processes during construction.

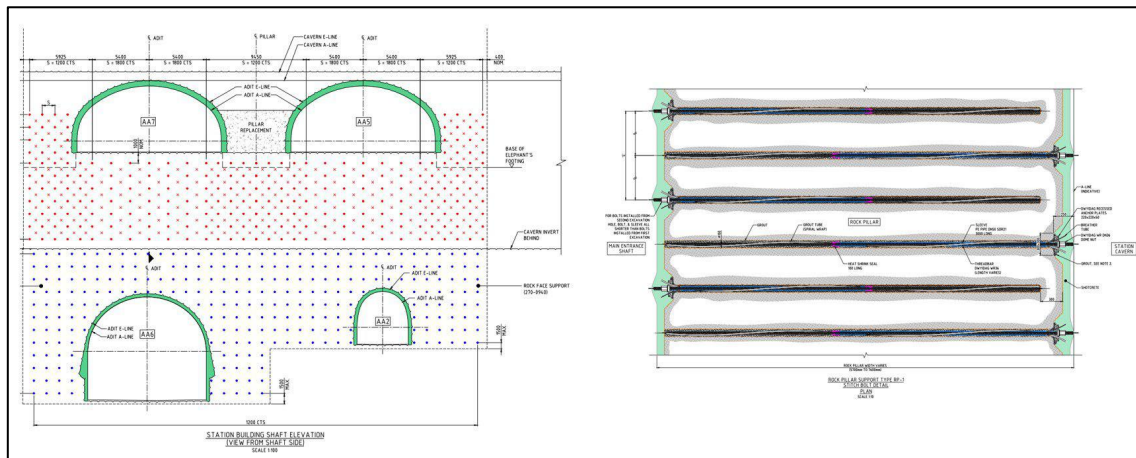


Figure 13: Stitch bolt ground support and concrete replacement of the pillar between the Albert Street Station cavern and the Lot 1 shaft.

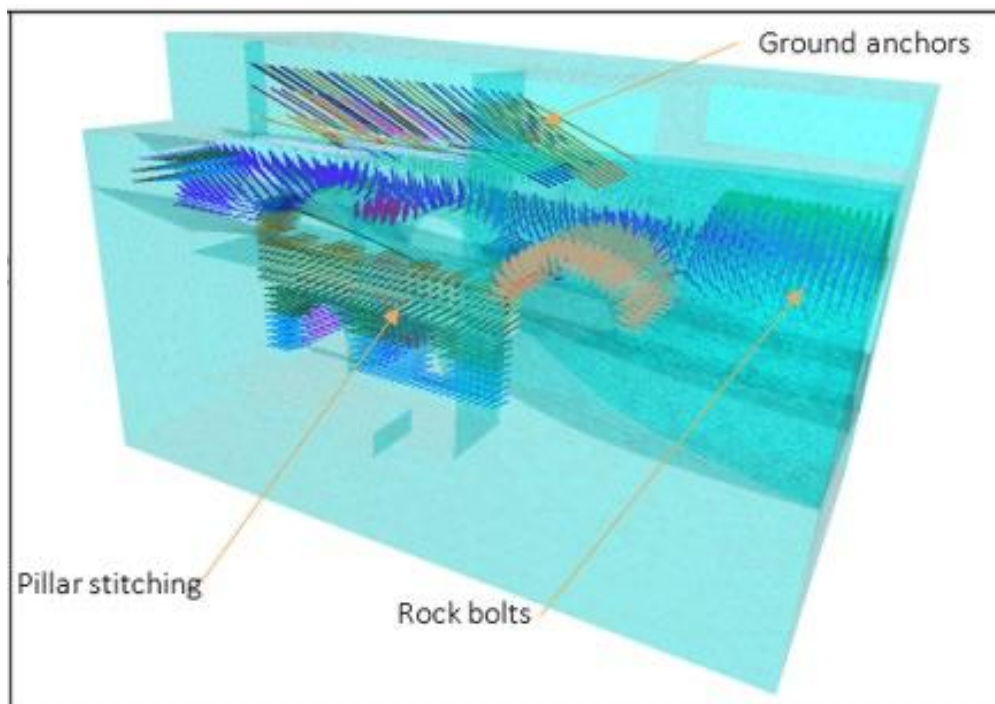


Figure 14: 3D model showing the ground support and pillar stitching elements for the Albert Street Station cavern and the Lot 1 shaft.

4.3 CONSTRUCTION OUTCOMES

Verification of the low-angle fault was undertaken during construction via geotechnical mapping, endoscopes, and monitoring. The fault was persistent as expected and was variable in character along its strike. Figure 15 shows the approximate location of the fault intersecting the Albert Street Station Lot 1 shaft. It varied from a 2m thick zone of FCZ and FDZ, with anastomosing fault splays, Figure 16, to a discrete single fault with around 100mm of brecciated rock infill, Figure 17. The fault was wider than expected in the cavern invert, with a broad crushed zone requiring treatment in the floor, Figure 18. However, in the critical zones (i.e. the shaft walls and pillar) the fault conditions and location were within the design expectations therefore construction was able to continue with no significant delay or design change. This fault is expected to extend into the surrounding properties around the Albert Street Station project site and may need to be considered for future basement excavations or underground works in this area.

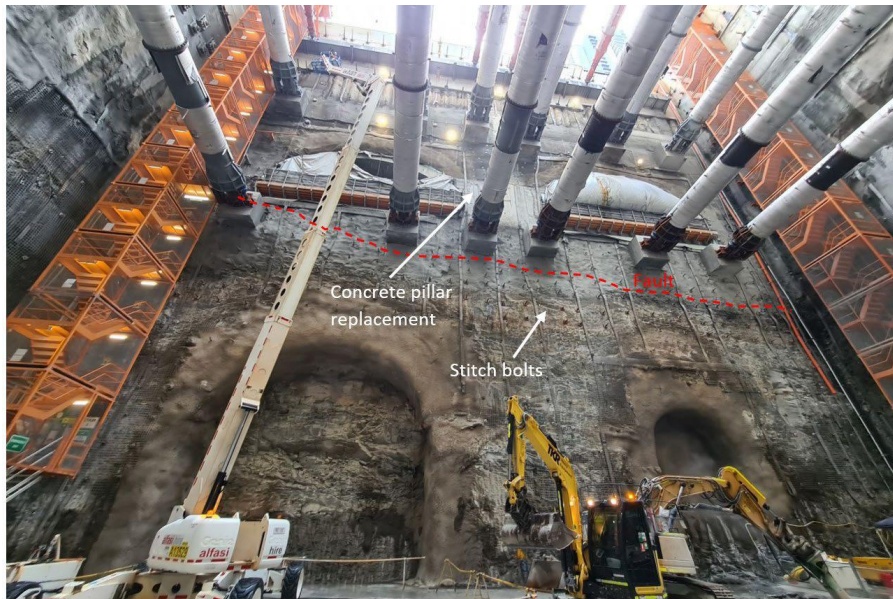


Figure 15: Albert Street Station Lot 1 shaft showing cavern adits, temporary props, stitching bolts, concrete pillar replacement and approximate location of the low-angle fault.

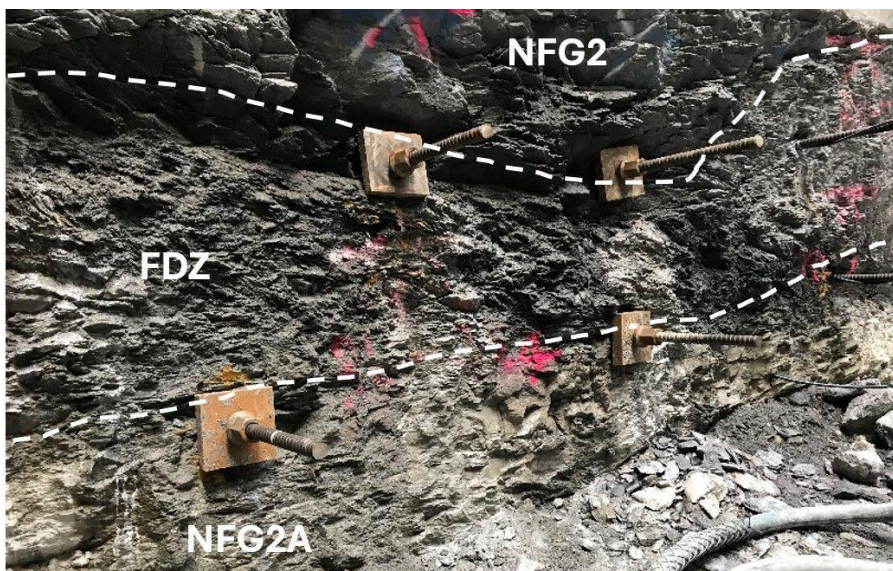


Figure 16: Pillar stitch bolts in low-angle fault at Albert Street Station.

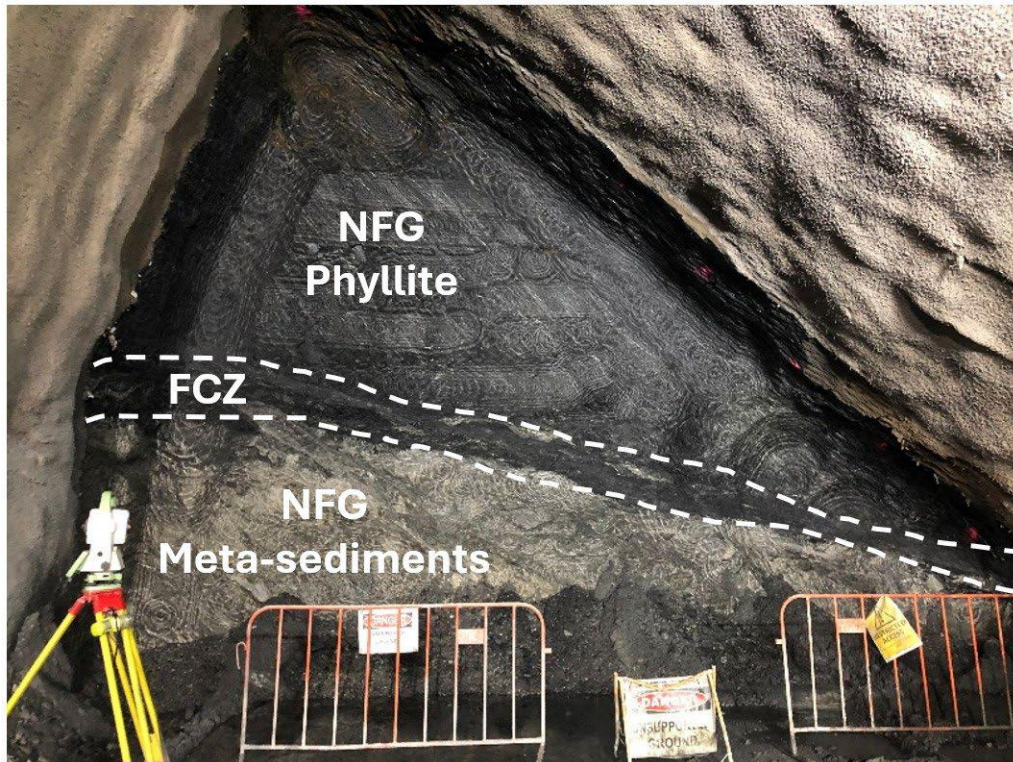


Figure 17: Low-angle fault encountered in the Albert Street Station cavern heading during construction.



Figure 18: Excavation of fault materials for the Albert Street Station cavern invert floor treatment.

5 CASE STUDY 3 – UNCONFORMITY ZONE AT BOGGO ROAD STATION

5.1 GEOTECHNICAL MODEL

Bogga Road Station is located within the Aspley Formation and Brisbane Tuff geological units to the south of the Brisbane CBD. The initial investigation boreholes encountered an Unconformity Zone (UZ) between the overlying Tuff and underlying Aspley units, located close to the invert level of the shaft for the proposed station box building, Figures 19 and 20. The UZ was assessed to be highly variable, ranging from a good quality rock-to-rock contact, to low shear strength and low stiffness brecciated and sheared rock and soil materials up to 1m thick. The UZ was considered to have potential implications for shaft stability, ground loading, founding conditions, and as a potential source of displacement which could impact exiting infrastructure. Additional geotechnical boreholes were drilled from within the shaft excavation during the construction phase to improve understanding of this feature at critical locations where large structural loads or spans were identified in the station box design.

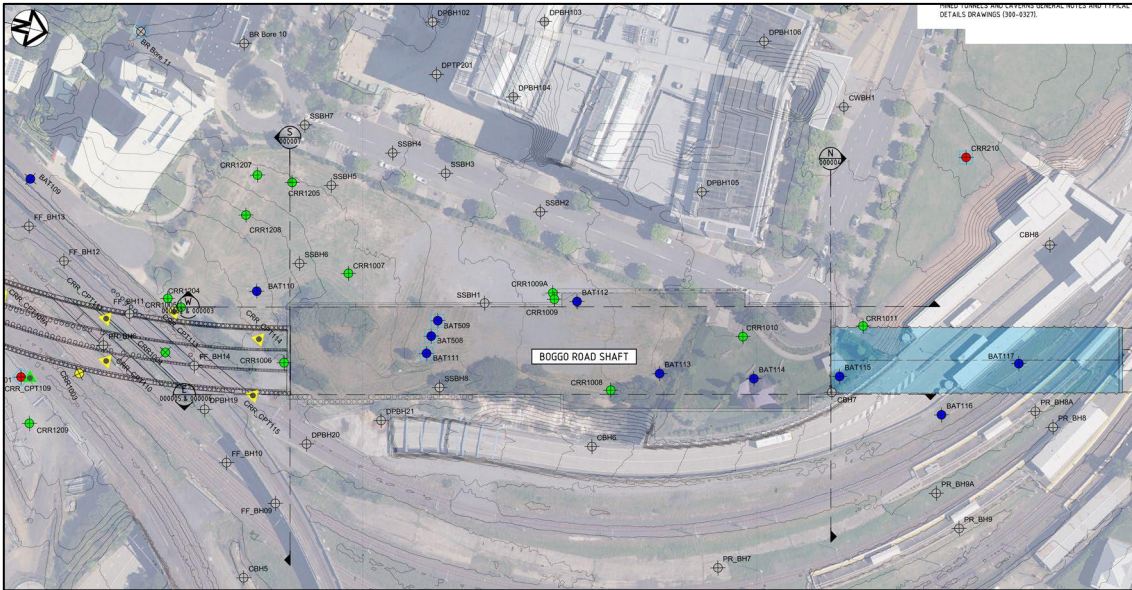


Figure 19: Boggo Road Station borehole plan (refer to Figure 2 for legend).

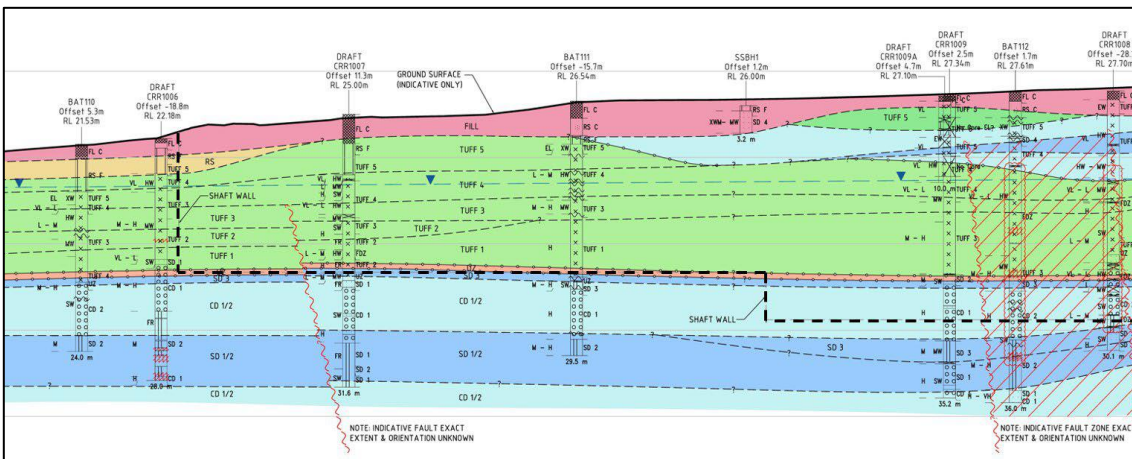


Figure 20: Boggo Road Station geotechnical section – showing inferred Unconformity Zone (orange unit) at shaft invert level between Brisbane Tuff (green units) and Aspley Formation (blue units).

5.2 DESIGN CONSIDERATIONS

The design solutions developed to cater for the UZ at the Boggo Road Station shaft included:

- Heavier primary ground support for the shaft walls where the UZ daylights.
- Underpinning or deepening of shaft piles where they are founded within or close to the UZ.
- A review of additional construction phase investigations, Figure 21, ground-structure interaction assessments and geotechnical loading and settlement inputs into the permanent station box structural design to cater for the UZ materials. The design solutions introduced for the station box included:
 - Removal and concrete replacement of adverse UZ materials where close to the shaft invert, or
 - Inclusion of additional reinforcement in the station box slab and walls to span across or enable transfer load around zones of lower stiffness in the foundation associated with the UZ.
- Carefully managed excavation and support sequence and deformation monitoring of the shaft and adjacent existing infrastructure.
- Staged construction of the station-box structure to manage deformations.

These were assigned and managed via the PTE, Hold Point and Request for Information (RFI) processes during construction.

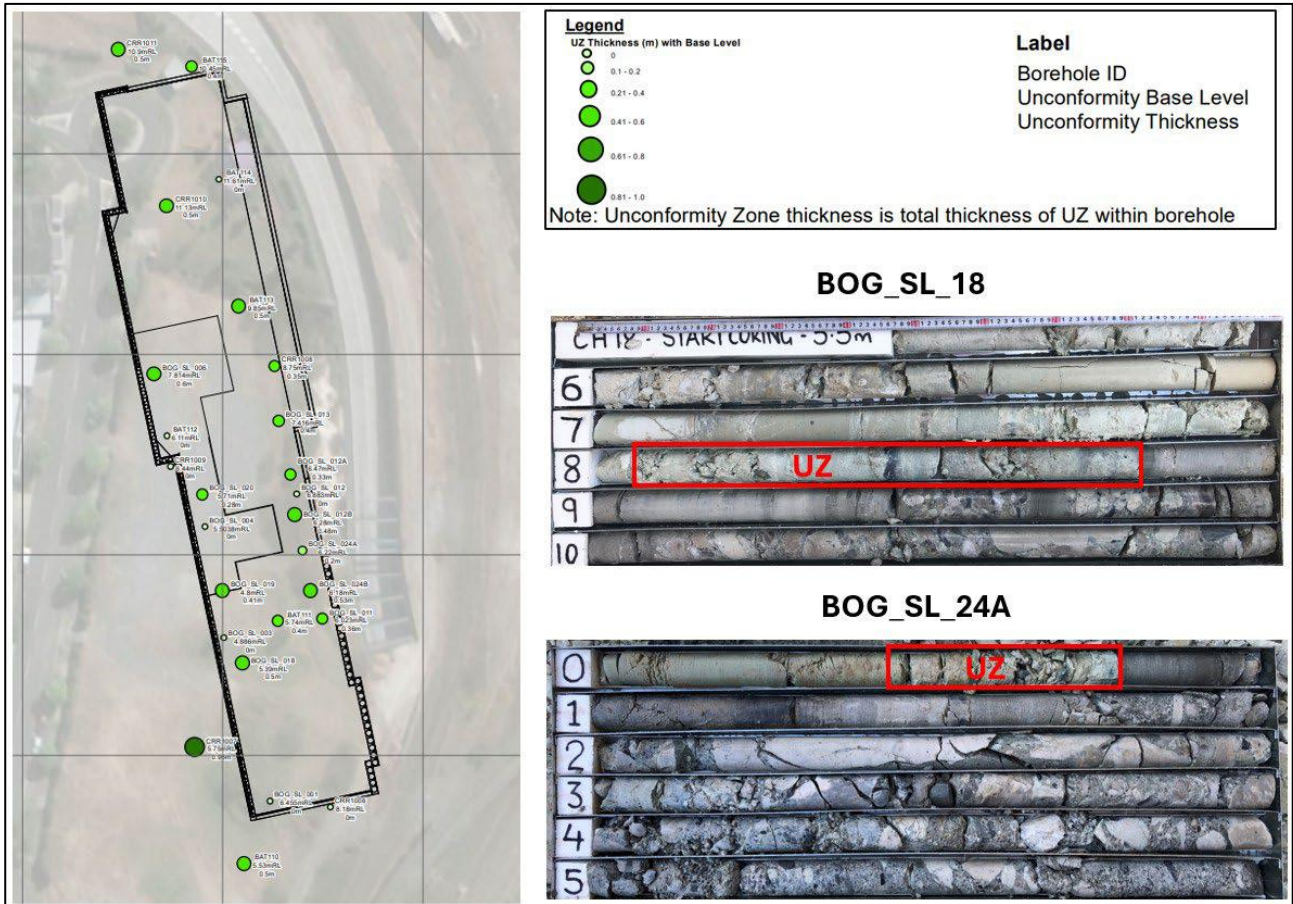


Figure 21: Construction phase geotechnical boreholes to investigate the relative level, thickness and character of the Unconformity Zone below the Boggo Road Station shaft invert. Typical core photographs are shown.

5.3 CONSTRUCTION OUTCOMES

Verification of the UZ was undertaken during construction via additional boreholes with televiewer imaging, geotechnical mapping, endoscopes, piling inspections and monitoring. The UZ was persistent and observed to be undulating in shape over short distances, inferred to be associated with the paleo-erosion surface prior to deposition of the overlying volcanic tuff materials. It was variable in character along its strike, ranging from a clean rock-to-rock contact to a 1m thick zone of clast or matrix supported brecciated rock with zones of soil, including high plasticity clay, up to 0.5m thick, Figure 22. Slickensides and other signs of shearing were observed in places. Significant groundwater seepage occurred at some locations. Removal and replacement of the UZ materials was undertaken in the Boggo Road Station shaft invert, Figure 23.

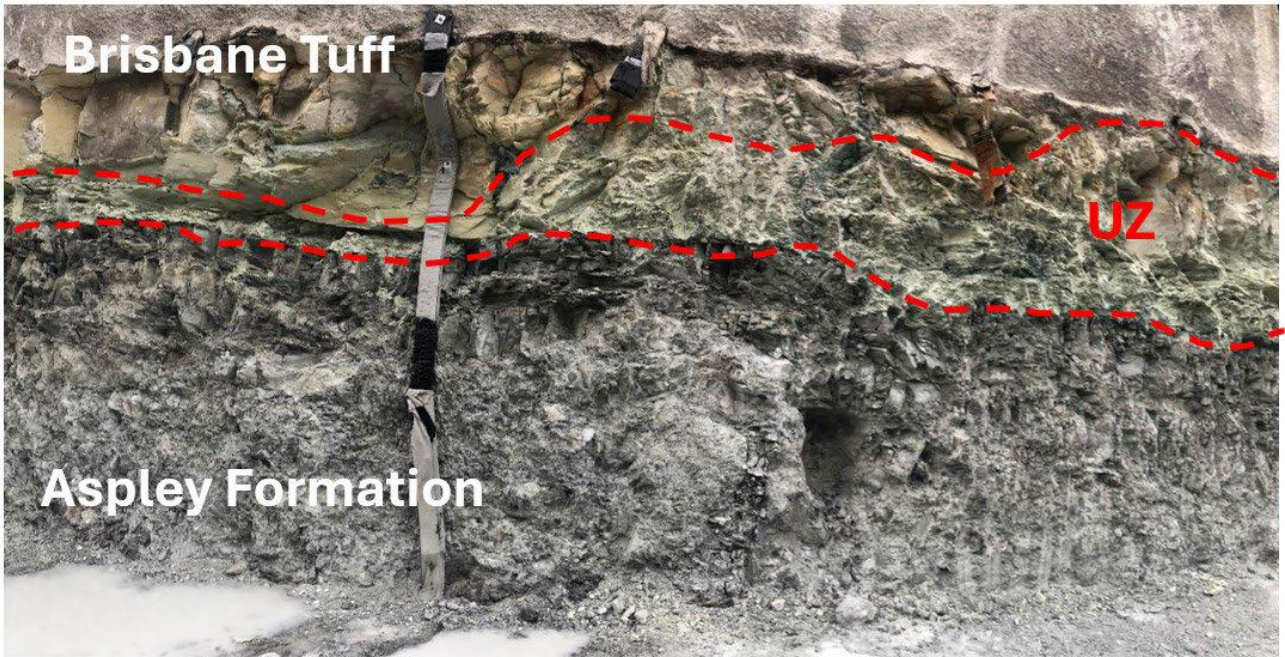


Figure 22: Unconformity Zone between the overlying Brisbane Tuff and underlying Aspley Formation geological units encountered in the Boggo Road Station shaft excavation during construction.



Figure 23: Excavation of Unconformity Zone materials for the Boggo Road Station invert floor treatment.

6 CONCLUSIONS

A range of challenging geological conditions were considered and managed during the design and construction of CRR. Adverse conditions associated with the Normanby Fault Zone were contended with in several locations, including major fault zones up to 15m in width, and persistent discrete faults up to 2m in width. A similar range of conditions, including potentially wider fault zones, are expected elsewhere in the Normanby Fault Zone within the Brisbane CBD. Highly variable conditions were observed at geological unconformities between the Brisbane Tuff, Aspley Formation and NFG units. These were encountered at several locations at CRR to the south of the Brisbane CBD including the southern dive structure, mined tunnels and Boggo Road and Woolloongabba Stations.

Case studies for three selected examples are presented in this paper, which demonstrate the importance of appropriate site investigations, understanding the level of confidence in geotechnical models, allowing for geotechnical variability in design, and the verification and monitoring of ground conditions and performance during construction. These examples comprised zones of significantly lower strength and stiffness materials bounded by high strength rock. This contrast in geotechnical properties can present issues related to ground loads on tunnel and shaft linings and ground support, kinematic stability mechanisms, ground deformation, founding conditions and load transfer, arching & bridging actions for reinforced concrete structures.

The project has provided information to better understand a variety of adverse ground conditions in Brisbane and it is hoped this may be useful for future ground-engineering projects.

7 ACKNOWLEDGMENTS

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