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Repurposing Roma Street station's temporary access adit as an emergency egress adit

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ABSTRACT: Brisbane's Cross River Rail project includes the excavation and construction of four new underground stations, including the large and geometrically complex underground station beneath the existing railway station at Roma Street. A temporary adit was excavated to provide construction access to the cavern, and was sized for excavation plant, tunnel ventilation, and worker access. Upon the completion of construction, the temporary adit is being repurposed as a permanent emergency egress tunnel for rail passengers. The small permanent tunnel was constructed within the larger temporary adit with the void around the tunnel lining backfilled. Key performance requirements were targeted by the backfill specification, in particular durability, strength and deformation properties. The permanent adits comprise precast concrete units on a cast in situ concrete invert slab. This paper presents the design and construction challenges and unique solutions developed to meet the site constraints and project requirements.

1 INTRODUCTION

Cross River Rail (CRR) is a new 10.2 km long metro rail line in Brisbane extending between Dutton Park in the south and Bowen Hills to the north, which includes 5.9 km long twin tunnels below the Brisbane River and CBD.

The project is being constructed by a joint venture of CPB Contractors, BAM International Australia, Ghella and UGL (CBGU JV) as part of Cross River Rail's Tunnel, Stations and Development (TSD) package.

The TSD component includes construction of twin Tunnel Boring Machine (TBM) excavated 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. The Pulse consortium (including the CBGU JV) was awarded the contract to design and construct the TSD works.

A temporary adit (RTA1) excavated to provide construction access to the Roma Street cavern from the Gallipoli Shaft was subsequently repurposed as a permanent emergency egress adit (Figure 1). Given that the adits's permanent function is limited to passenger evacuation, the required internal envelope was substantially smaller than that of the original RTA1 excavation.

Options considered for the permanent adit included lining the overly large temporary adit or construction of a smaller adit within the temporary adit and backfilling the void around the permanent adit lining. The second option was adopted because it was more cost effective.

2 TEMPORARY CONSTRUCTION ACCESS ADIT RTA1

The temporary adit (RTA1) was required to provide construction access from the Gallipoli shaft to the Roma Street Station cavern, with an overall length of approximately 100 m (Figure 1).

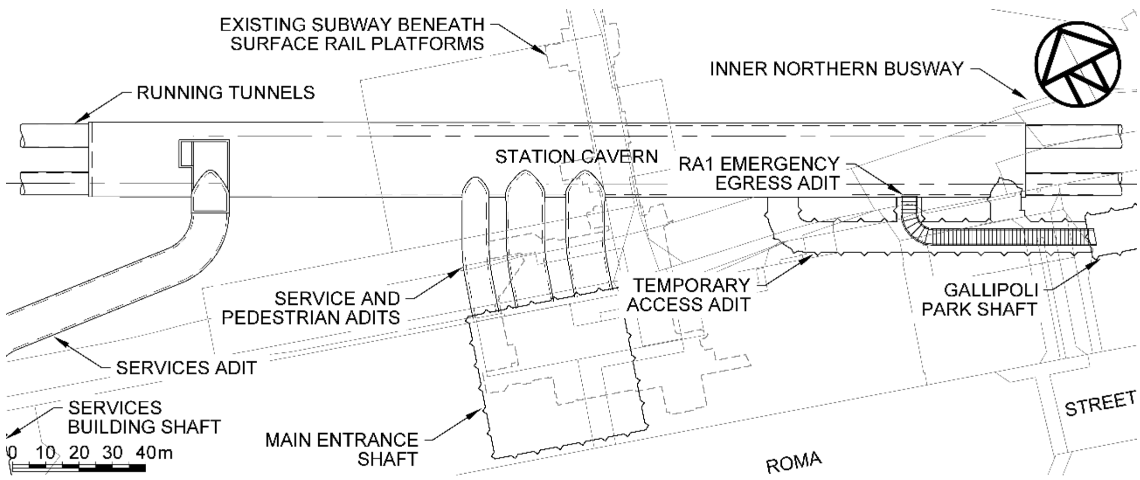


Figure 1. Roma Street station layout showing temporary access adit and emergency egress adit.

The invert level of the temporary access adit drops from RL -3.6 m at the base of the Gallipoli shaft down to RL -14.5 m where it connects to the invert level of the station cavern.

The adit initially provided construction access to the heading level at the east end of the cavern. It was subsequently extended to create access for the permanent adit to the mezzanine level of the cavern and then extended again down to the invert level of the cavern.

The temporary adit was sized for excavation plant, tunnel ventilation ducts, and safe worker access with a span of 9 m and a maximum height of up to 12 m (Figure 2).

3 PERMANENT EMERGENCY EGRESS ADIT RA1

3.1 *Lining geometry*

The RA1 permanent adit was constructed within the RTA1 temporary adit, extending from the Roma Street Station cavern to the Gallipoli Park shaft with an overall length of approximately 65 m (Figure 1). This length included a 90° sweep bend, with a gentle slope of 26.6H:1V in the vertical alignment between the upper horizontal landing near the base of the Gallipoli shaft and the lower landing level at the bend adjacent to the connection to the cavern.

The minimum clear opening (MCO) required for the egress adit comprised a clear span of 4.2 m and a height of 3 m.

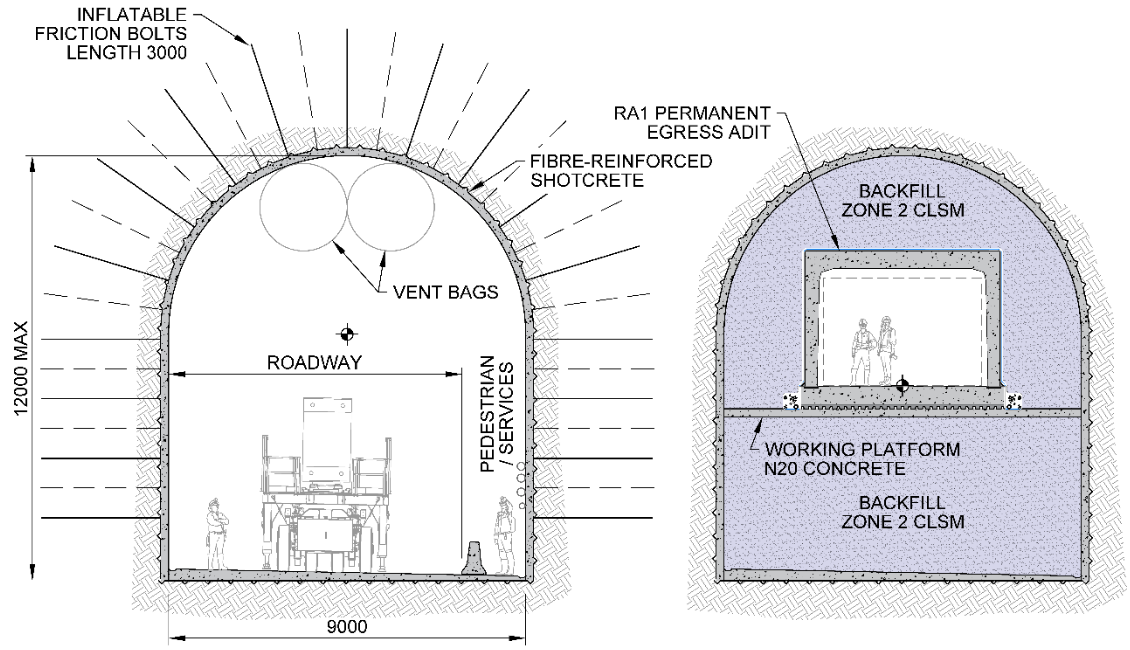
PSM designed the permanent lining for all the underground mined tunnel structures for the CRR project, including the emergency egress adit RA1. As the emergency egress adit was constructed within an existing void, the use of conventional intrados in-situ formwork for the permanent lining was not possible. To address this and improve construction efficiency, the RA1 permanent lining comprised a cast in-situ concrete slab and prefabricated concrete units, offering a more cost- and time-effective solution.

Given that the required MCO was a rectangular envelope, the use of modified precast culvert units - similar to those typically used for road drainage - offered a relatively simple design solution. A standard 1.2 m long precast box culvert in accordance with AS 1597.2 was proposed, as this satisfied the MCO requirements.

The design considered input from CBGU’s preferred precast box culvert supplier to develop the geometrical design of the non-standard units required to accommodate the 90° change in direction and the variation in vertical alignment adjacent to the horizontal landings.

3.2 *Permanent lining design*

Rather than undertaking a full in-house design of the precast units, it was considered more efficient to develop a comprehensive culvert specification that defined the project-specific requirements for geometry, materials, durability, waterproofing, lifting, and fixings. The specification also provided details of the applicable loads and load combinations to be considered.



(a) Temporary construction access adit (b) Permanent emergency egress adit

Figure 2. Cross section of the adit at differing stages of the project.

In addition to the typical ground and groundwater loads relevant to standard drainage culverts, the units were also required to be designed for load cases associated with tunnel permanent lining design, such as blast and fire. The design for these loads was carried out in-house and translated into the minimum unit thickness and concrete cover requirements, making compliance with the blast and fire design requirements straightforward to implement.

External design loads applied to the precast box units included vertical and horizontal ground loads and groundwater pressures (Figure 3). The ground loads applied to the culvert units within the RTA1 temporary adit considered rock loads, backfill weight, and the Brisbane Live future development loads. Brisbane Live comprises a proposed stadium located above the station cavern (Shen *et al*, 2022). For the units within the Gallipoli Park shaft excavation footprint, future development and rock loads were not applicable, though the weight applied by a depth of approximately 15 m of CLSM fill within the shaft was substantial.

Tolerances complied with relevant Australian Standards for standard drainage precast box culverts, as well as the requirements in CBGU's specification for the fabrication of the units. The standards specified a length tolerance of ±15 mm, while the project specification required a verticality tolerance of side and end faces within ±20 mm over the full height, a maximum deviation from straightness of 6 mm when measured with a 1 m straight-edge, and end faces square within ±4 mm. The adoption of these tolerances proved to be problematic and led to gaps between the units larger than 10 mm and alignment issues with station cavern interface (see Section 5).

The permanent adit drainage system included a Cavidrain S60 sheet drainage layer installed beneath the invert slab. This product is manufactured from high density polyethylene and comprises square cuspates of 60 mm depth which, when backfilled with mortar, form a load-bearing layer which is crisscrossed by closely-spaced drainage channels.

Corrugated slotted pipes of 100 mm diameter fitted with filter socks were installed either side of the invert slab. These pipes were embedded within a shallow trench of 20 mm gravel aggregate which abutted the Cavidran (Figure 4). The gravel was wrapped in geotextile fabric and membrane to ensure that it was not clogged during placement of the CLSM backfill.

Drainage was directed towards the station cavern, with the slotted pipes draining into the Cavidrain system near the opening. Flushing-points were provided at the top of the culverts within the Gallipoli shaft structure.

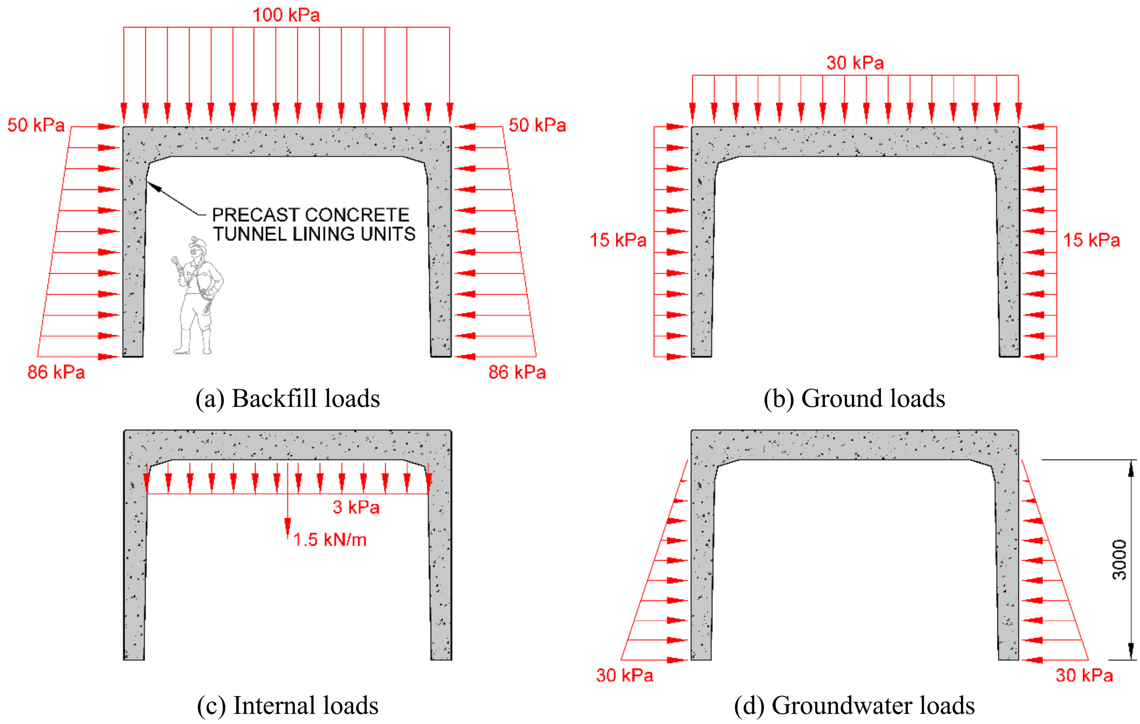


Figure 3. Key design load cases for the precast culvert units.

A waterproofing membrane was installed over the top and sides of the culvert units, with a protective geotextile placed between the units and the membrane. Rearguard PVC waterstops were provided at vulnerable connections located at each end of the culverts.

In addition to the membrane, hydrophilic waterstops were required to be installed at the key joints provided between culvert units. These measures were detailed to satisfy the project's long-term watertightness and durability requirements.

4 CONTROLLED LOW STRENGTH MATERIAL (CLSM)

4.1 *Overview*

Controlled Low Strength Material (CLSM), or flowable fill, comprises a cementitious fill with flowable consistency at the time of placement and achieves limited compressive strength when fully cured. These characteristics makes it well-suited for backfilling trenches that may require future excavation or complex-geometry voids where its flowability ensures complete filling, while accelerating the construction program, as CLSM can be mixed, transported, and placed using standard ready-mix concrete methods.

The strength of CLSM varies widely, depending on its application, from soil strength up to low strength concrete.

CLSM typically comprises a mixture of cement, water, fine aggregate, and supplementary cementitious materials such as fly ash or slag. The high slump of the CLSM significantly reduced placement time and equipment requirements, leading to lower labour and machinery costs. Its flowable consistency allows it to be placed quickly and uniformly, even in confined or irregular spaces, minimising the risk of voids and potential subsidence.

CLSM was originally intended to be utilised to backfill the totality of the void around the RA1 permanent adit lining. Two distinct CLSM mixes were developed following a review of relevant Australian and international guidelines and technical literature to suit different design and construction purposes.

The first mix (referred as Zone 1 – Backfill) was designed for general backfilling applications, where ease of placement and flowability were the primary considerations.

The second mix (referred as Zone 2 Fill – Structural fill) was specifically designed for placement beneath the permanent invert slab of the RA1 adit and either side of the precast units.

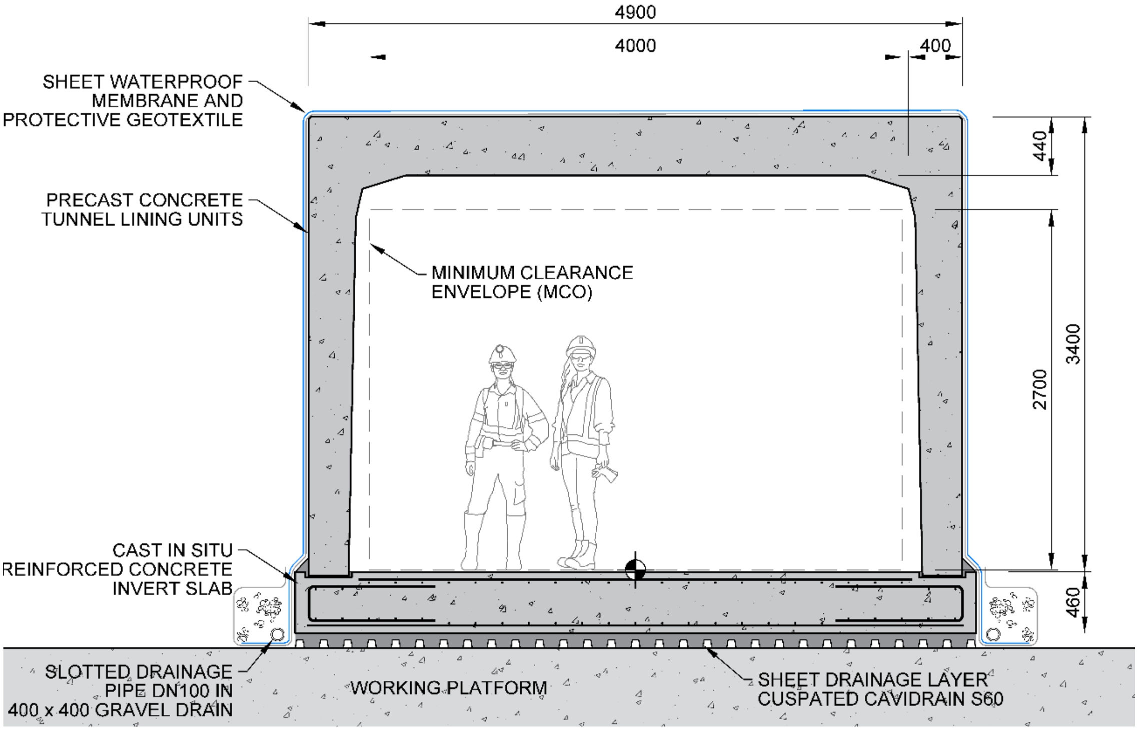


Figure 4. Detailed section of the emergency egress adit.

This mix was subject to stricter performance criteria, the objective being to minimise post-construction settlement and provide an adequate foundation for the invert slab of the permanent adit. Unlike the Zone 1 mix, the function of the Zone 2 mix was that of a controlled engineered fill.

Due to cost and program constraints, the construction team opted to place a 200 mm thick N20 concrete working platform immediately beneath the RA1 invert slab to allow trafficking of the slab at an earlier age than would have been possible with Zone 2 fill.

A total volume of 5940 m^3 of CLSM was required to backfill around the egress adit within the RTA1 adit (i.e. excluding backfilling of the Gallipoli shaft).

4.2 *Zone 1 Fill – Specification requirements*

The Zone 1 Fill mix was provided as a low-cost backfill material for use in areas where structural performance was not required. It was designed to be self-levelling, with sufficient flowability to fill voids without the need for mechanical compaction.

Key performance requirements included a maximum density of 2000 kg/m^3 to limit loads on the culvert units, and a minimum slump of 200 mm to achieve the required flow characteristics. A nominal minimum compressive strength of 0.5 MPa at 28 days was specified for quality control purposes. No specific limits were imposed on modulus, creep, or bleed, as these properties were not relevant.

Controls on aggregate size, fines content, plasticity, and chloride levels were adopted to promote uniformity and durability of the mix in accordance with the project requirements.

4.3 *Zone 2 Fill – Specification requirements*

The Zone 2 Fill mix was required for use beneath and either side of the culvert units, and thus required structural properties regarding strength, deformation, and durability.

The mix was specified with a maximum density of 2300 kg/m^3, consistent with the higher strength requirements for this application. A maximum slump of 150 mm was adopted to accommodate the formation of the RA1 permanent adit ramp, which has a gradient of approximately 1V:26.6H, while ensuring adequate workability without excessive flow.

Table 1. Adopted CLSM Specification

Properties	Test method	Zone 1 Backfill	Zone 2 Structural fill	Purpose
Compressive strength (3 hrs)	AS 1012.18	-	> 0.1 MPa	Provide worker access
Compressive strength (28 days)	AS 1012.9	> 0.5 MPa	> 2.0 MPa	Long term load capacity
Modulus (28 days)	AS 4133.4.3.2	-	> 4.0 GPa	Control settlement and provide support for cavern sidewall
Slump	AS 1012.3.1	> 200 mm	< 150 mm	Ensure self-levelling (Zone 1) and allow formation of 26.6H:1V slope (Zone 2)
Density	AS 1012.12	< 2000 kg/m^3	< 2300 kg/m^3	Adopted in load assessment
Creep strain (100 years)	Bespoke *	-	< 0.0005	Control settlement
Aggregate size	AS 1141.12	< 19 mm		Facilitate flowability
Fines content (< 75 mm)	AS 1141.12	< 20%		Ensure homogeneity
Plasticity index	AS 1286.3.3.1	< 15%		Ensure homogeneity and limit shrinkage
Chloride content	AS 1012.20.1	< 0.1%		Durability

* Test methodology modified from concept in ASTM C1181-00, with a test period of 3 months with a test stress equivalent to 40% of the required 28-day compressive strength. Refer to Figure 5 and test description in Section 4.3 for further details.

Early age strength requirements included a minimum compressive strength of 0.1 MPa at 3 hours to provide sufficient bearing capacity for early worker access and allow preparation for subsequent lift placements. A minimum 28-day compressive strength of 2.0 MPa was adopted to provide adequate bearing capacity both upon completion of backfilling above the culvert units and when the units were subject to long-term ground loads.

A key property for the specification of the Zone 2 Fill was deformation. The required modulus at 28 days was determined based on the need to provide sufficient stiffness and adequate support to the permanent station cavern sidewalls upon backfilling of the construction adit.

Time-dependent creep behaviour was also a critical design consideration, with the intent of limiting the total post-construction settlement of the adit to less than 10 mm. Creep testing was required to ensure that the proposed CLSM mix was suitable, though selection of the test method was difficult due to the relatively short period of time available to do the testing and the fact that the standard methods were not intended for testing CLSM. The AS 1012.16 method involves the stacking of several cylinders and a test period of one year and was thus deemed unsuitable.

An alternate method, ASTM C1181-00 "Compressive creep of chemical-resistant polymer machinery grouts" was proposed by Boral testing laboratories. This is a clever test configuration, using prestressed springs to apply a constant load over a long period of time. The basic concept was adopted, then modified to suit the CLSM cylinder samples (Figure 5).

A key change to the ASTM method was the use of more flexible springs (k = 159 N/mm), rather than the stiff springs nominated in the ASTM standard (k = 6700 N/mm). The use of the more flexible springs means that the load changes by only 0.2% at the allowable creep deflection of 0.06 mm over 90 days, whereas the use of the stiffer springs results in a theoretical load change of 8.5%.

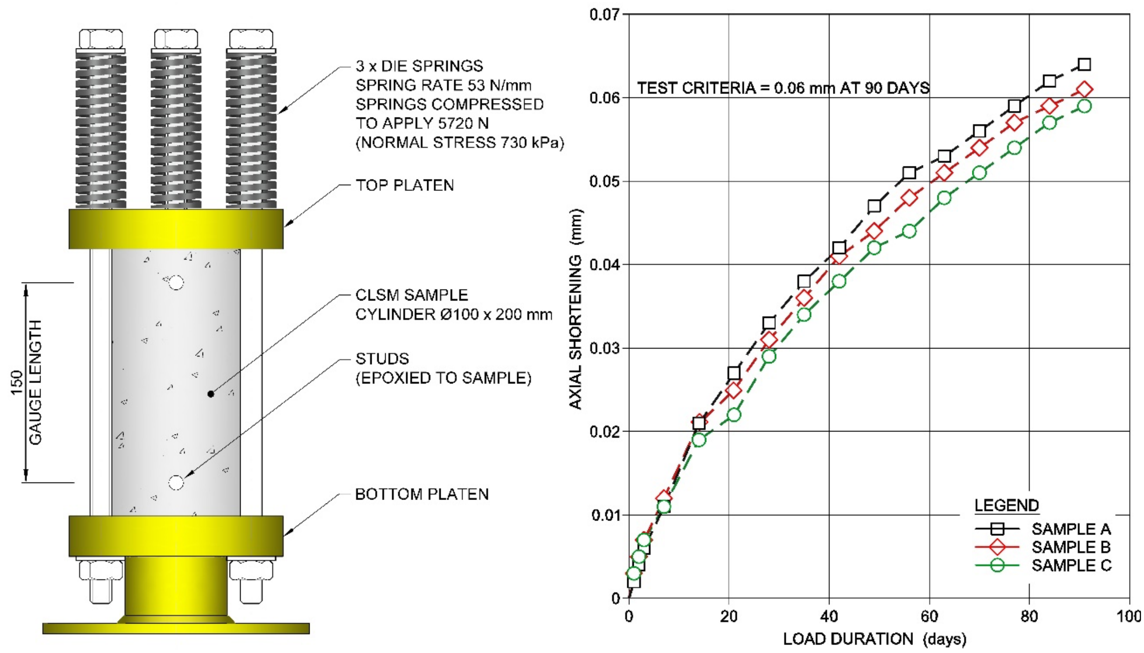


Figure 5. Creep test configuration and test results (After Shen *et al*, 2022) of 0.06 mm over 90 days.

4.4 *Departures from proposed mixes*

The Zone 2 Fill was proposed for the plug at the cavern sidewall opening and for backfilling a large proportion of the temporary adit beneath the RA1 permanent invert slab (Figure 6a), making it well suited for mass backfilling. This led to the decision not to use the lower specification Zone 1 Fill material in the area below the permanent adit.

The design also nominated the use of the non-structural Zone 1 Fill for backfilling above the culvert units and within the Gallipoli Shaft. However, it was found that the cost to supply the Zone 1 Fill was more than that of the higher performance Zone 2 Fill. As a result, only the Zone 2 Fill mix (hereafter referred to as CLSM) was used for backfilling the void around the RA1 permanent lining and the Gallipoli shaft structure (Figure 6b).

The CLSM mix used to backfill above the culverts was modified to achieve a lower density to limit the load applied to the top of the culvert units.

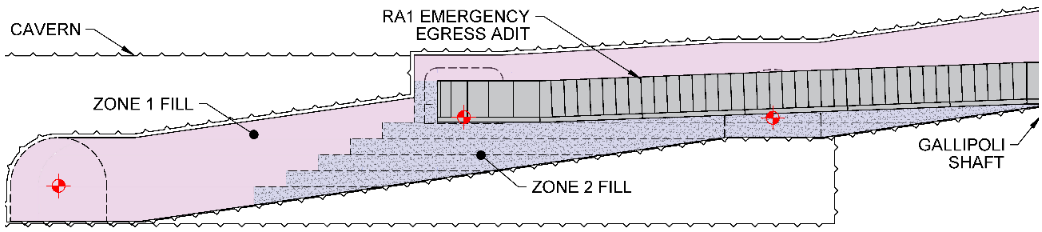
4.5 *CLSM – Test results*

Different testing frequencies and methodologies were nominated for various backfilling areas within the temporary adit to confirm the mix design requirements. An initial intensive testing regime was implemented to confirm the performance of the CLSM mix and establish a reliable correlation between the cylinder and cube compressive strength testing. Due to the high rate of backfilling, the frequency of 28 days compressive strength testing was reduced, while additional 7 day tests were undertaken as early indicators of potential non-compliance. Further production testing, including modulus and creep strain, was specified for the CLSM placed within 5 m beneath the RA1 invert slab to ensure the mix met the performance requirements.

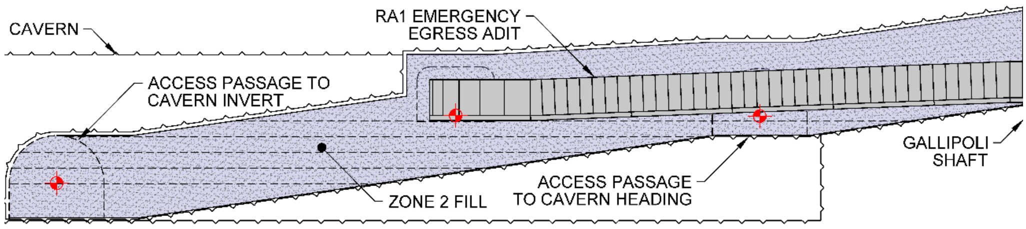
5 CONSTRUCTION

5.1 *Sequence*

Once the RTA1 temporary adit was no longer required for construction access to the cavern, the sidewall opening in the cavern lining was closed. Formwork was erected on the cavern side to create a pour face for the CLSM to be pumped into the temporary adit to complete the plug and backfill. After formwork removal, a protective geotextile and PVC waterproof membrane was installed and integrated with the cavern waterproofing.



(a) Originally proposed application of the CLSM mixes.



(b) As-built extent of CLSM.

Figure 6. Long section through the RTA1 temporary adit and RA1 permanent egress adit.

The structural fill was placed using a line pump and hoses, which were moved manually or with a Dieci telehandler to implement the backfilling sequence. Care was required during the placement of the CLSM at the cavern plug and near the crown of RTA1 to avoid air entrapment.

The last layer of CLSM beneath the culvert invert slab in the original design was replaced with a 200 mm thick working platform, with the finished surface screeded to support the Cavidrain system. N20 concrete mix was used instead of the CLSM mix to achieve faster strength gain, allowing earlier access for the 12 tonne Dieci telehandler used for steel and material delivery required for the invert slab works. The design of the working platform's thickness and characteristic strength accounted for two key scenarios: during the early age when the platform was loaded by the telehandler, and after the platform had attained its full strength, when the RA1 permanent invert slab was constructed and the culvert transporter, carrying the heaviest precast box culvert unit, trafficked on the invert slab.

A total of fifty-two precast box culvert units, ranging in weight from 10.8 tonnes to 22.3 tonnes, were lifted by gantry crane to the base of the Gallipoli shaft, then rotated and placed onto a self-propelled modular transporter (SPMT). The SPMT is of modular construction, with the one used to move the culverts comprising 16 wheels arranged on four axle lines, with each axle line rated at 40 tonnes. Wheels are grouped in pairs, with the direction, speed, and height of each pair remotely controlled by the plant operator to provide precise movement control in every direction. A power pack containing the engine and hydraulic pumps hangs from the back of the SPMT.

The transporter has a nominal bed level of 1.5 m above ground level, with a movement range of ±0.3 m, and thus required addition of a support frame to enable it to reach up to the underside of the culvert units (Figure 7). The transporter then moved the precast units to their final positions, the first unit being placed adjacent to the cavern and progressing eastward towards the shaft.

CLSM was placed adjacent to the culvert legs in 300 mm to 500 mm thick layers to maintain safe worker access to the precast units.

5.2 *Productivity*

Prior to commencing the backfilling of the adit, a series of trials were undertaken to improve the construction team's understanding of the CLSM material, particularly key differences with concrete.

The relationship between slump and strength and flowability was investigated to ensure that the CLSM could be placed efficiently without compromising the specified engineering properties. The trials were also important for the batch plant so that they could become familiar with the production of the mix. The capacity of the agitators delivering the mix to site as well as the achievable pumping rates were established to permit accurate scheduling of the works program.

Table 2. Summary of available test results performed on Zone 2 Fill

Property	Number of tests	Unit	Measured Values		
			Min.	Median	Max
Compressive strength (7 days)	37 (25)	MPa	1.4 (1.9)	1.6 (2.3)	2.5 (3.1)
Compressive strength (28 days)	106 (88)	MPa	1.5 (2.2)	4.6 (6.0)	8.3 (11)
Modulus (28 days)	2	GPa	13.3	13.5	13.7
Density (28 days)	106 (88)	kg/m³	1920 (1940)	2040 (2050)	2160 (2260)
Creep deflection (91 days)	3	mm	0.059	0.061	0.064

* Values in brackets represent results from tests conducted on cube samples.

The placement rate of CLSM within the temporary adit varied depending on the proximity to RA1 culvert units and the RTA1 crown. During mass backfilling of open areas, placement progressed at approximately 30 m³/h. However, this rate was significantly less when backfilling adjacent to the culvert units to prevent unbalanced lateral loads.

5.3 *Lessons learnt*

The main lessons learnt were related to the varying geometric tolerances of the cavern lining, culvert units, and permanent egress structure within the Gallipoli shaft.

Construction of the collar around the RA1 opening in the cavern sidewall was subject to the adopted tunnel lining tolerances for the project, which included a generous -0 mm/+150 mm excavation tolerance for the extrados surface. The culvert units were required to butt up against the collar, though these tolerances permitted the collar surface to vary significantly from vertical, such that an additional lightly reinforced concrete collar section was required to be built to provide a better-matching planar surface.

As noted in Section 3.2, the culvert design adopted the standard drainage culvert geometric specification. The culverts had been constructed then stored outside for about a year prior to being

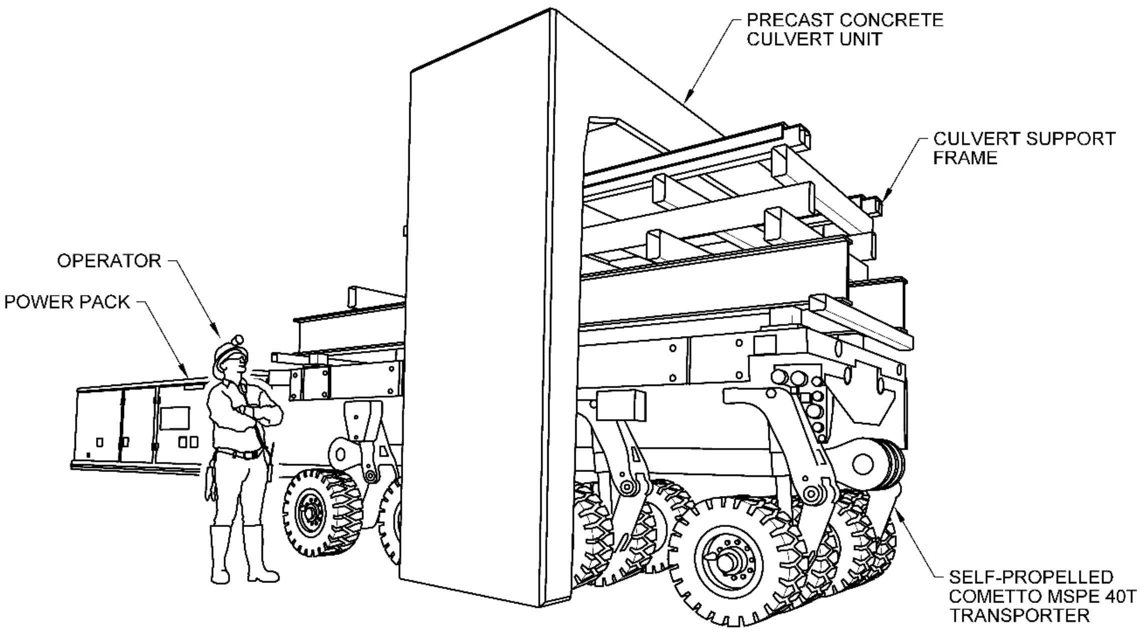


Figure 7. Cometto four axle self-propelled modular transporter used to place culvert units.

installed. They were found to be bowed/distorted such that the crown of the adjoining culvert faces were not square/aligned resulting in gaps of up to 15 mm. This wider gap had the potential to compromise the effectiveness of the hydrophilic waterstop. In some locations it proved necessary to repack the bases to decrease the gap and maintain the design crown alignment. In locations where the gap was greater than 10 mm the waterproof membrane was reinforced by a second layer at the joint location.

A further challenge was the exposed edge risks due to the necessity to work from the top of the culverts. This resulted in changes to the staging of waterproofing, drainage and backfilling around the culverts. When backfilling either side of the adit the waterproofing layers on the top were initially left off to avoid damage. The crown waterproofing was subsequently installed then protected by a 100 mm to 200 mm layer of CLSM.

The final challenge was connecting the culverts to the egress shaft structure. Due to the inability to adjust the overall length of the culverts the final culvert could not be positioned at the nominated design interface location with the shaft, and this resulted in modification to the shaft structure.

Some of the challenges with the culvert tolerances may have been managed by further changes to the standard culvert joint detail. A stepped/lapped detail such as employed in spigot and socketed concrete pipes could have provided the means to adjust the position of the culvert units.

6 CONCLUSIONS

The construction of the RA1 permanent emergency egress adit within the existing RTA1 temporary access adit provided an efficient and cost-effective solution to repurpose the excavation. Bespoke precast culvert units, designed to meet stringent project-specific requirements, ensured the required structural performance and durability, despite the challenges posed by dimensional tolerances and structural interfaces.

The application of CLSM for backfilling the void around the permanent lining proved advantageous, as its flowability made it easier to place in complex areas and helped maintain the construction schedule.

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