Bakewell Underpass ECI: Innovation and Design and Delivery

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SYNOPSIS

The Bakewell Underpass, the construction of which was completed in early 2008 in Adelaide, South Australia, was an extremely complex engineering project. It involved the replacement of an 80 year old concrete road bridge with a new 4 lane twin deck underpass. The two underpass structures respectively accommodate the main suburban and interstate rail lines from Adelaide’s south and a busy commercial road near the edge of the CBD.

The technical complexity and stakeholder issues led the Principal – the Department for Transport, Energy & Infrastructure – to adopt a previously untried procurement method. The project was one of the first to be delivered by the “ECI” (Early Contractor Involvement) delivery method in Australia. This collaborative approach paid dividends by allowing the many risks to be thoroughly investigated and innovations to be encouraged and realized.

The most unusual feature of the project is the rail bridge deck, which was successfully designed to be launched into place during a four day track occupation, thus minimising disruption to the critical train services. This 3000t deck, which accommodates 6 sets of rail tracks and a shared path, was constructed entirely offline. Preparatory piling and headstock construction was undertaken during short occupations. The deck spans 28m and is comprised of prestressed concrete Super T girders. The foundations consist of 1.35m diameter concrete bored piles, with shotcrete retaining arches between piles. Unusually for this span, the deck acts as a prop, catering for massive forces associated with the long term behaviour of the clay.

A road deck, similarly comprised of prestressed Super T girders, was conventionally constructed parallel to the rail deck, with traffic temporarily diverted around the highly constrained site of the bridge. The approach retaining walls for the underpass, which reach heights of up to 7.5m, consist of soil nailed and shotcrete cut slopes. This extensive use of soil nailing was a first for South Australia.

Many other aspects of this tightly constrained, challenging bridge project will be described in this paper.

Keywords: Underpass, ECI contracting, launched super-tee bridge, soil nail walls, rail bridge, piles
1. INTRODUCTION

The construction of the Bakewell Underpass was completed in early 2008 at Mile End, near the edge of Adelaide’s CBD. The project was a significant and complex undertaking. Many of its features were firsts for South Australia. As one of the first ECI (Early Contractor Involvement) projects in Australia, innovation was part of the project landscape from the start. The technical and program related challenges required innovative approaches to all aspects of the project.

This paper will describe the history of the project and the original structure, the unusual procurement method and will present details of various interesting design elements. These include the 28m span super tee rail bridge, the entire superstructure of which was launched into place over a four day rail shut-down. The paper will also describe the complex and challenging geotechnical conditions and foundation design. Extremely high vertical and horizontal reactions required large 1.35 m diameter bored piles to support the rail bridge. These piles and the headstock they support were constructed during short term partial closures of the suburban train lines. The trough approach retaining walls, reaching 8m in height, are formed from shotcreted, soil nailed slopes.

2. PROJECT DESCRIPTION

History

The original Bakewell Bridge was constructed in 1925 by the Municipal Tramways Trust to provide electric tram and motor vehicle access to the city over train lines and a minor road. Since that time, the minor road has become part of an important freight link and the rail corridor, carrying both suburban and Australian Rail Track Corporation (ARTC) freight trains, is a critical rail link for Adelaide.

The original structure was a significant example of concrete engineering for its time. It comprised 19 spans, varying in length between 9m and 12m, supported by multi-column piles on strip footings. The structure had provided good service during its life, but its deteriorating condition coupled with the sub-standard clearances to both road and rail traffic constituted an unacceptable risk to the bridge’s owner – the Department for Transport, Energy & Infrastructure (DTEI).

Despite the clear signage warning of the 4.0m clearance to road traffic, truck collisions with the beams were a regular occurrence. The design team had personal experience of this phenomenon, being based immediately adjacent to site. It was a regular occurrence to witness a truck wedged under the bridge, causing traffic chaos. Horizontal and vertical clearances to rail traffic were also sub-standard. In 1995 a freight train de-railed at the bridge and collided with a pier, causing substantial damage. Fortunately, the ductility of the superstructure meant that its collapse was avoided and no fatalities occurred. The pier was re-built and full service returned. However, it was clear that a replacement structure was necessary.
Following community consultation, DTEI resolved to replace the bridge with an underpass, reversing the existing grade separation. In 2005, the Department invited expressions of interest from consortia interested in undertaking the design and construction of such a structure, comprising two separate underpass decks – one for road and one for rail. Following a workshop focused selection process, the project was awarded to a consortium formed from builders McConnell Dowell and designers CW-DC (a wholly owned subsidiary of Connell Wagner).

3. **“ECI” – EARLY CONTRACTOR INVOLVEMENT**

An interesting aspect of this project is the procurement method. Early Contractor Involvement, universally abbreviated to ECI, is a very common form of delivery in the UK for medium to large sized infrastructure projects. The process to select a preferred proponent and develop a preliminary design is similar to the methodology used for a “pure” Alliance. However, the final contract negotiated is a lump sum contract, rather than the pain/gain sharing arrangement used in Alliances.

Under this arrangement, the Principal, builder and designer work collaboratively from the concept stage, with the minimum of constraints being imposed. A hard money contract is not signed until the design has been well advanced (in Bakewell’s case, to a nominal 80%). It is considered that this process enables all parties to better define risk and encourages innovation. Many of the pitfalls of the Design & Construct type contract are thus avoided.

DTEI decided to procure the Bakewell Underpass as the first ECI project in South Australia and one of the first in the country. From the designers’ perspective at least, this method has proven to be highly successful. The interaction of all relevant parties meant that risks were far better understood by all parties at the time of negotiation of the main contract. The progressive input from the project estimator ensured that effort was not wasted in pursuing cost prohibitive ideas. However, the focus on “value”, as opposed to lowest cost, allowed outcomes that would not necessarily have been achieved under a Design & Construct model.

In the Request for Tender document, DTEI explained that ECI had been selected as the contract strategy for Bakewell because of the following benefits of this procurement method:

- Early involvement of the Principal with the preferred proponent in the development of innovative solutions at the concept phase. Probity prohibits such free information sharing in a traditional competitive tendering environment.
- External project stakeholders only need to deal with a single entity during the design development, not several tenderers as in a D&C or Competitive Alliance.
- Only one Proponent develops a preliminary design, thereby saving unnecessary design costs that would be incurred by unsuccessful tenderers in a D&C or Competitive Alliance.
- Risk: as discussed above, one a design had been well advanced and approved by the Principal, the remaining risks are largely construction related, allowing reasonable pricing by the Proponent.
Co-location is a key element of ECI contracting. From the early days of the project, the designers, builders and client teams came together in a project office, which happened to be immediately adjacent to the site and was owned by DTEI. The daily interaction of all relevant team members proved invaluable.

4. TECHNICAL DETAILS

General Arrangement

An aerial artist’s impression of the finished structure is shown below as Figure 1. The finished underpass carries the busy east-west commuter road Glover Avenue (which changes name to Henley Beach Road on the western approach to the underpass) under the north-south at-grade road and rail corridors. The underpass comprises two traffic lanes in each direction, on-road bike lanes and a 3.2 m wide shared path on the southern side.

![Figure 1: Artist’s aerial impression of finished project](image)

The road and rail decks respectively accommodate James Congdon Drive / East Terrace and five sets of rail tracks, with space for a future, sixth track. Both bridge decks are of prestressed concrete super-tee construction, supported by large concrete bored pile foundations. Precast concrete feature panels are placed in front of these abutments. The approach retaining walls are formed from soil nailed 10:1 slopes, with decorated shotcrete facing.

At-grade works included access roads on the western side, providing partial connection between Glover Avenue and James Congdon Drive. The standard gauge freight line, owned by the Australian Rail Track Corporation (ARTC) was also re-aligned, resulting in a superior track alignment with almost zero disruption to the critical freight network.
Urban Design Initiatives

Achieving a single span for the bridge decks was the single greatest urban design outcome for the project. Given the difficult geotechnical conditions, the cost of a twin span plank deck with central piles was found to be comparable to that of a much heavier single span super-tee alternative, even considering the secondary effects of lowering the vertical alignment. The clear span provides an open sense for all users and is considered to be particularly beneficial for pedestrians, avoiding the perception of an enclosed tunnel.

Feature lighting schemes have been designed to add visual interest to the structure and highlight key elements. Coloured parapet lighting will illuminate the exterior faces of the fluted precast barriers. Downlights at the precast feature wall panels under the bridges will highlight the patterned panels.

Rail Bridge Superstructure

The cross-section consists of 16 No.1800 mm deep super-tee beams nominally 2.0 m wide, the first time super-tees of this depth have been used in South Australia. The deck caters for six railway tracks (refer to Figure 2) – four broad gauge lines for suburban TransAdelaide trains, one standard gauge line shared by ARTC and Great Southern Rail and allowance for an additional standard gauge line to be installed at sometime in the future. In addition, an access path is provided along the eastern edge of the deck to allow passage for pedestrians and council maintenance vehicles across the underpass.

A key feature of the design is the 2.1 m deep by 1.2 m wide diaphragm cast onto the end of the beams. This diaphragm supports the beams through shear friction, and provides the level surface required in order for the deck to be laterally launched into position. Transversely, the vertical bearings are located centrally over the piles, except for the bearings at each end.

Figure 2 – Cross section of the rail bridge superstructure
**Design Development**

Due to the numerous constraints and the complex nature of both the rail and road corridors, six options (plus minor variations) for the rail superstructure were considered in the concept design phase. The original concept design developed by DTEI, which was for a twin span underpass, featured precast concrete planks with an in-situ concrete deck to be constructed conventionally during lengthy track occupations.

During the concept design phase of the ECI process, a single span underpass was identified as the optimal solution. The original preliminary design concept was for a post tensioned concrete through girder deck in order to minimise structural depth, which was to be laterally launched into position during a short duration occupation. This required the substructure to be firstly constructed during short duration occupations. The launched solution enabled track disruptions to be kept to a minimum in comparison with a more conventional in-situ slab on beam construction method.

During the concept design phase, other forms of construction were also considered. These included a steel through-girder bridge, a concrete through-girder bridge and a voided concrete slab deck. The launched super-tee beam structure was recognised as the preferred alternative due to the simpler form of construction, reduced on site activity and reduced cost.

**Headstock**

The rail bridge headstocks were constructed in two halves during three-week duration track possessions of the TransAdelaide suburban rail lines. During the possessions, the ground was excavated down to final headstock level to expose the piles previously installed. In order to meet the tight timeframes associated with the track occupations, precast backwall segments were used in order to reduce the number of in-situ pours required.
The headstocks feature large diameter ligatures at close spacings in order to transfer the propping forces from the headstock to the piles. The large size of both the headstock ligatures and the pile starter bars, coupled with the allowance for out of position pile tolerance, added complexity to the positioning of the precast backwall segments. As such, the precast backwall segments featured blockouts at the pile locations (refer Figure 3) with the ligatures placed loosely in order to allow easier placement of the segments over the piles. Both northern and southern backwalls were divided into four segments, with two being placed per track closure. In-situ stitch pours were undertaken between the adjacent units.

**Launching**

The rail deck was constructed on temporary ground beams in line with the permanent headstocks directly to the east of the final deck alignment. The temporary works and the launching process were designed in conjunction McConnell Dowell. A combination of both vertical and horizontal jacks was used.

The superstructure was launched (transverse to the direction of span) into position by cables anchored to the western end of the permanent headstocks, with cables passing through and jacking off the deck end diaphragm. The launching surface comprised a stainless steel plate cast into the underside of the deck diaphragm, with the deck launched over the permanent elastomeric bearings with teflon pads (refer Figure 4). Shear limiter plates were provided on the permanent elastomeric bearings to prevent excessive shear deflection in the direction of movement during the launch.
The deck, including final ballast, track and sleepers, was launched into position during a four day shut down over Easter 2007 with the launching weight of the deck being approximately 3,000 tonnes. During the shutdown, the existing track was removed and the ground level excavated to expose the previously constructed headstocks. Preparatory work for the launching was then undertaken, such as installing and grouting bearings. Following the launch, precast approach slabs were installed, and the ballast and track reinstated on the approaches.

**Road Bridge Superstructure**

The road bridge is a conventional super-tee deck, with the exception being that it also acts as a prop for the piled substructure walls in a similar manner to the rail deck. The deck cross-section (refer Figure 5) consists of 14 No. 1500 mm deep by 2200 mm wide super-tee beams with a 180 mm nominal cast in-situ deck. The road deck carries James Congdon Drive/East Terrace across the underpass, and provides for 4 lanes of traffic and a turning lane, a 4.8 m wide footpath and a 3.6 m wide shared path.
Substructures

Geotechnical Overview

The site of the Bakewell Underpass is somewhat unique in Adelaide. Located on the western edge of the Parklands in close proximity to the Adelaide CBD, the site has never had major development on or near it other than the original bridge. Thus there was little or no pre-existing deep geotechnical data with the nearest deep bore some 600 m from the site. To complicate the matter further, the site is located on the Para Fault line, which is actually a series of parallel north-south oriented fault lines. This area thus has a complicated and high variable soil profile.

The geotechnical investigations carried out prior to the ECI contract phase included thirty nine bores, most to less than 8m, with thirteen extending to about 18 m depth. It became apparent during the concept design phase of the ECI contract that, given the very high pile loads resulting from the 30t rail axle loading in particular, the existing information did not extend deep enough to adequately determine the capacity of the preferred bored pile footings. An additional drilling programme, which included two 40m deep holes, was conducted under the guidance of the geotechnical sub-consultants URS Australia. Unfortunately, due to the presence of the rail lines, deep bores could not be located at the actual bridge abutment and the entire design relied on inferred geotechnical information.

In the end, the geotechnical investigation had over fifty bores and pits in order to cover the site. Also included were a number of tests including shear box tests on gravels, triaxial tests and stress history tests on the clays. The final geotechnical model consisted of five major soil types as shown in Table 1. The depth and soil unit thickness varied over to the site as can be seen in Figure 6.

<table>
<thead>
<tr>
<th>Unit</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fill. Typically a thin layer originally road pavement and rail formation.</td>
</tr>
<tr>
<td>2</td>
<td>Medium to high plasticity red brown clay</td>
</tr>
<tr>
<td>3</td>
<td>Low to medium plasticity brown silty/sandy clay</td>
</tr>
<tr>
<td>4</td>
<td>Sand, silty sand and clayey sand</td>
</tr>
<tr>
<td>5</td>
<td>Gravelly sand and sandy gravel</td>
</tr>
<tr>
<td>Water</td>
<td>Water was consistently found at 16.5 m depth in the gravels</td>
</tr>
</tbody>
</table>

*Table 1 – Geotechnical units*

The geotechnical data was used for the design of various components of the project including soil nail walls, shallow footings for the barriers and approach slab, piled footings to support the abutments, king post walls to retain the soils behind the bridge abutments, a strip footing for the temporary works launching beam and numerous steel post and timber sleeper temporary works retaining walls.
The Approaches

General Layout / Description

The underpass section extends for a total length of 470 metres with a maximum depth of 8.2 m below natural ground level near the middle. The western entry is on level ground whereas the eastern entry is higher and on an upwards slope into the city. The eastern approach is located in the Adelaide City 1 in 100 year flood water detention basin thus requiring a longer approach and higher walls than might have been expected.

The floor of the underpass is located entirely within the unit 3 clays on the eastern approach. Thus the walls needed to retain medium to high plasticity clays. This was of some benefit to construction as these clays could be cut nearly vertical and were essentially self supporting in the short term.

Concept Design

The concept design of the underpass walls proposed a fairly traditional system of bored piles, with shotcrete arch panels, cantilevering above a concrete base slab located at the floor of the underpass with a finished surface of precast concrete panels. The actual cantilever length of the pile, being up to over 7.5m, required closely spaced heavily reinforced piles up to 1200mm in diameter. Similarly the propping forces in the base slab lead to a substantial thickness of reinforced concrete. It was clear that an alternative construction method was required in order to achieve the target budget for the overall project.
Final Design - Soil Nails

Using experience gained on Victorian projects such as the Martha Cove underpass and the Narre Warren – Cranborne Road, CW-DC investigated and adopted soil nailed walls as the final design solution for the walls as shown in Figure 7. This consists of a grid of passively reinforced soil nails installed into the wall face and anchored into a shotcrete facing. The nails create a reinforced soil mass which is sized to act as a gravity wall and resist slip circle failure. A concrete propping slab at the floor of the underpass is not required and was replaced by a typical flexible pavement.

Substantial cost savings were achieved by adopting this wall construction in lieu of the contiguous pile arrangement.

The soil nailing on this project was constructed in the following manner:

1. A layer approximately 1.5 m deep is excavated and the wall surfaced trimmed by detail excavation
2. Holes are drilled at about 1.5 m spacing along the wall. The hole depth, spacing and inclination is determined by design.
3. A reinforcing bar inserted and the hole filled with grout. The 100 year design life for the soil nails was achieved by providing 50mm grout cover to galvanised bars and a corrosion allowance when selecting the bar size.
4. The reinforcement for the facing is installed and then shotcreting carried out
5. Steps 1 to 4 are repeated down the height of the wall to the floor of the underpass

The Bakewell Underpass project represents the first major application of soil nail walls in South Australia. The lack of experience in the local soils represented a challenge for both the geotechnical engineers and CW-DC’s soil nail designer. The design was undertaken using the SlopeW wall analysis software and allowances were made to account for the expansive nature of the clays in the wall structure.
Due to the nature of the construction method and the shotcrete facing, the soil nail walls are laid back at 1 horizontal to 10 vertical although the clays have been found to stand up when cut vertically. Significant attention has been paid to the surface finish of the shotcrete facing in order to diminish the visual impact of the construction joints, shrinkage cracking, general surface unevenness, blandness of the large expanse of concrete and to provide some level of graffiti resistance.

**Bridge Substructures**

**General Layout / Description**

The design concept and detailing of the substructure of both the road and rail bridge is essentially the same. The bridges are supported by concrete headstocks on bored cast-in place concrete piles. The piles also act as lateral soil retaining elements and have shotcrete arches between them above the floor of the underpass. In order to keep the piles to a reasonable size they span between the soil at the underpass floor, which provides support by passive resistance, and the bridge superstructure, which props the top of the pile as shown in Figure 8.

![Figure 8 – Rail bridge long section showing abutment and deck detail](image)

**Geotechnical Overview**

As discussed earlier, the geotechnical conditions at the site are variable and difficult with lenses of soft clay in the foundation gravels. In order to establish a viable footing system, five 750 mm trial holes were bored and the stability of the excavations assessed. This programme confirmed that the sand and gravel soils were reasonably stable above the watertable and that it was not practical to consider bored piles below this. The water was reasonably free flowing and the excavations collapsed readily below watertable level. Based on the trial drilling and the preliminary boreholes, it was decided that the maximum practical depth for a bored pile was about 1m above the watertable - a depth of 15 m.
Rail Bridge Substructure

The initial construction methodology for the rail bridge proposed that the bored piles be constructed during night time rail closures, within windows of activity of about eight hours. To remove the need for track-works the piles were laid out between tracks with a typical spacing of 4.5 m and a maximum diameter of 1500 mm. The risk of not completing a pile of this size within eight hours was very high, and leaving an open hole adjacent to an operating rail track was considered unacceptable.

Test Piles

Increasing the pile diameter meant track-works and even longer construction windows. Deeper bored piles meant drilling below the watertable and very expensive liners. CFA (continuous flight auger) piles of the required diameter could not be constructed and the depth to rock was estimated as being over 100 m. To resolve this impasse, it was decided to construct a test pile and load it statically and dynamically in order to get a better understanding of the performance of the founding soils under load.

It was not practical to construct 1500 mm diameter test piles since an appropriate dynamic hammer is not available in Australia. The pile testing was therefore undertaken on two 600 mm diameter bored piles founded at 15m depth in a clay layer in the gravels. In order to mimic excavation of the underpass, and hence removal of skin friction in the excavated depth, the top 8m of pile was sleeved. Both piles were dynamically loaded using an 8 tonne hammer and analysed using PDA and CAPWAP analysis. One pile was then statically loaded.
Pile vertical design

The results of the pile testing were extremely encouraging and showed that the actual bearing capacity and skin friction were much higher than estimated. The gravels were not as loose as expected, and the skin friction in the clays, sands and gravels was higher than expected. The testing results for the 600mm diameter were extrapolated to larger diameter piles, using conventional pile capacity methods to back-calculate soil parameters.

Meanwhile, McConnell Dowell abandoned the idea of constructing bored piles in nightly track possessions due to the high risk involved. Instead, they negotiated extra time in the extended track possessions in order to construct the bored piles and headstocks. This enabled the pile spacing to be reduced to a nominal 3.2 m, which also slightly reduced the load on the piles. The final pile design indicated that a 1350 mm diameter pile would be adequate to carry the vertical load.

Pile lateral design

Although provided primarily for vertical support of the bridges, the bored piles also retain the soils behind them. The floor of the underpass at the deepest point is approximately 6.5 m below the bridge beams soffit and nearly 8.2 m below ground level. It is not practical to cantilever a pile this far, particularly without a propping base slab, so the bridge superstructure is used to prop the top of the piles. This is achieved by installing a thrust pad between the deck (as low as possible) and the backwall of the headstock. The resulting structural system was bored piles at 3.2 m centres with a shotcrete arch between the piles and integral headstock and backwall.

The clay soils behind the retaining wall were subjected to testing in order to determine the ‘at rest’ earth pressure coefficient and their consolidation state. The results gave a \( k_0 \) value of 1.5 but the soils are very heavily over consolidated. Based on this and the advice in the manual for the software WALLAP, it was deemed appropriate to model the resetting of \( k_0 \) in these clays in order to account for a potential build-up of earth pressure over the 100 year design life. Many models and scenarios were run to account for variations in construction sequence; undrained and drained soil parameters; shrinkage and creep in the propping deck; cracked and uncracked pile section; creep; thermal expansion and contraction of the propping deck at many stages during the life of the structure; variation in the soil profile and long term pressure build-up of the clays.

The result of this complicated modelling was that a 1350 mm diameter pile with a concentration of reinforcement in the road side face was deemed adequate. Serviceability design based on stress limits in the reinforcement in accordance with AS5100 was dominant and the ultimate strength was well in excess of the required capacity.
5. SUMMARY

The Bakewell Underpass Project has produced numerous firsts for South Australia and utilised a number of innovative design solutions. The construction methodology and staging was developed by CW-DC and McConnell Dowell and included the launching of the entire 3000t rail bridge in a single operation.

The complexity of the project requirements and site called for an innovative approach to the project delivery method. By adopting the Early Contractor Involvement (ECI) method, DTEI assembled a team that collaborated effectively with the Department to develop an approved design from concept design stage, that was then delivered under a conventional Design and Construct contract. This method has proved to be most successful in delivering the required infrastructure asset within budget and on time. Under this arrangement innovation was successfully nurtured and risk better understood and priced by the Proponent. The outcome speaks for itself – apart from achieving extremely tight deadlines and budget, the project has since been successful in winning major state and national awards from Engineers Australia, Australian Institute of Project Management and the Civil Contractors Federation.

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