BREAKTHROUGH AND BURIAL OF TBMS ON THE BRISBANE AIRPORT LINK PROJECT

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ABSTRACT

The Airport Link Project (APL) was constructed in the Northern Suburbs of Brisbane and connects the Central Business District of Brisbane and the Clem Jones Tunnel to the East-West Arterial Roads leading to the Airport. Construction of the project commenced in November 2008 and was completed in July 2012 with Thiess John Holland (TJH) being appointed to deliver the Design and Construct Contract.

After a total of 15 months the Northern section of the tunnels from Toombul to the Lutwyche Caverns were excavated and both Tunnel Boring Machines (TBMs) buried in September 2011. The Southern section of the tunnels were excavated by Roadheader and met at the Lutwyche Caverns. In total, APL comprised over 15kms of new tunnels. See Fig. 1

This paper describes the methodology used to bury and disassemble both TBMs, actions on breakout and lowering the TBMs. Also discussed is the preparation works involved within the Lutwyche Caverns prior to the TBMs breaking through.

INTRODUCTION

Project Overview

The Northern section of the tunnels were twin 2.2km driven tunnels that were excavated by two 12.48m diameter Earth Pressure Balanced (EPB) TBMs. Being the largest used in Australia at the time, both TBMs were launched from the Toombul site in November 2010 after taking 6 months to construct. Each TBM took a further 7 months to reach the Lutwyche Caverns. Both 11m long TBM Shields were then buried and the remaining backup gantries removed from the tunnel through the Lutwyche Caverns in 2 months. See Fig. 2

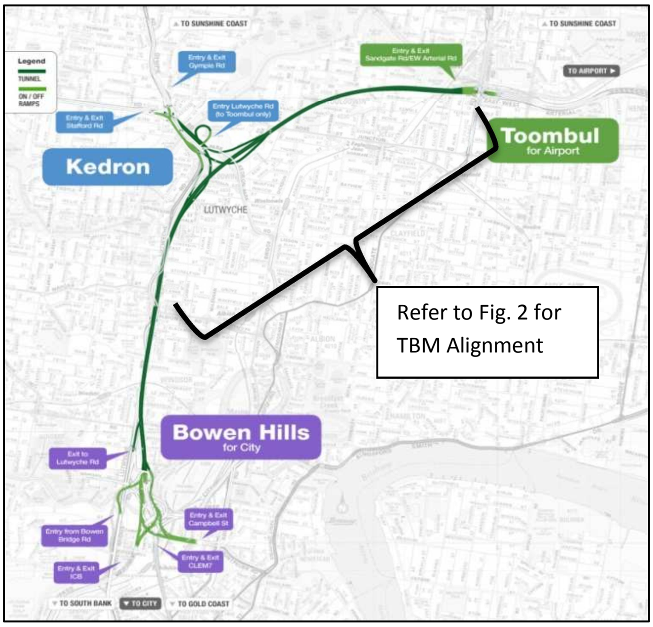

Figure 1 – Airport Link Project

Prior to the TBMs breaking into the Lutwyche Caverns, considerable planning and preparation was required due to changes from the original tender.

After breaking through, the TBMs needed to advance by building a combination of full and partial rings. For the final rings after breakout a restraint beam was installed to allow the TBMs to advance in the Lutwyche Caverns without the risk of losing pressure in the thrust rams.

Four partial rings were then constructed to allow the TBM Shields to advance onto the steelwork, stopping for disassembly from the backup gantries.

The TBMs were then pulled forward onto specially designed steelwork beams and lowered by heavy lift strand jacks. A low strength flowable fill was then used to encase the TBMs, and a capping slab cast to support the removal of the backup gantries.

The TBM backup gantries were then removed from the Lutwyche end of the tunnel. Two 20T and eight 15T electric chain hoists on a series of monorail beams assisted with the dismantling process.

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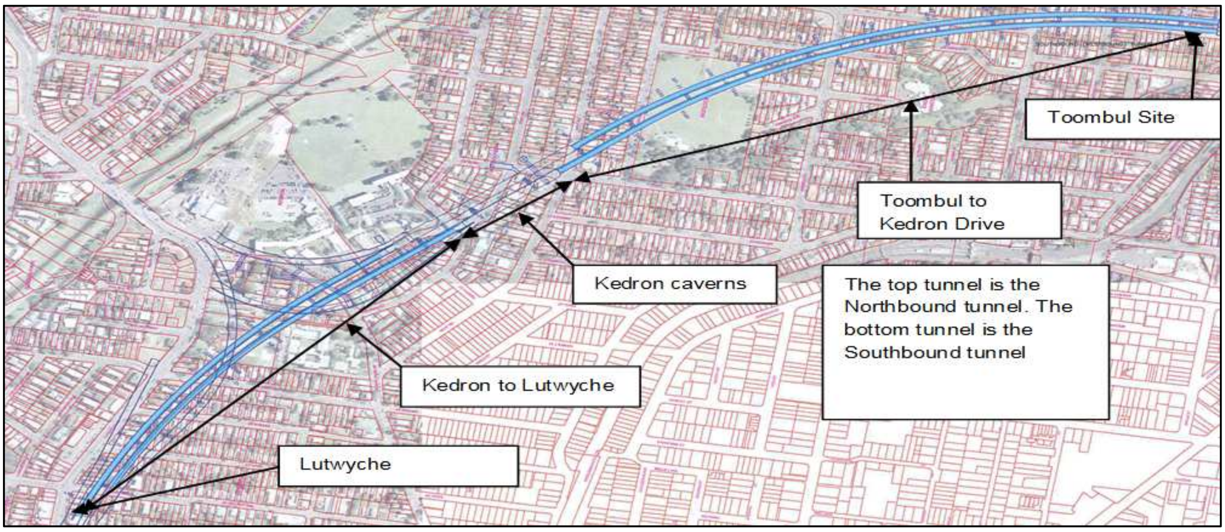

Figure 2 – Toombul to Lutwyche TBM Alignment

Changes from Tender

During the tender phase both TBMs were to be removed via direct extraction at the Lutwyche Caverns and were to be assisted by vertical shafts located at Chalk Street. Due to time constraints, cost, surface disruptions, and the interface required with the Northern Busway Tunnels it was decided after a detailed analysis in early 2010 to lower both TBM Shields into a pre-excavated burial pit on steelwork by heavy lift strand jacks.

Given the sheer complexity, magnitude and being a first of its kind in Australia at the time, a number of alternative concepts were devised to lower the TBM shields to the bottom of the burial pit, these included;

- Fluidisation utilising sand;
- Liquid nitrogen; and
- Controlled demolition.

Planning works required included; correct burial pit sizing and excavation, edge beam design and construction, monorail and electric chain hoist installation, heavy lift studies, support columns, and finally the design and construction of the steelwork structures.

Specialist subcontractor VSL were contracted to design and build the steelwork including the methodologies for TBM Shield lowering.

VSL were also responsible for the procurement and operation of the six heavy lift strand jacks used to lower each TBM Shield.

PREPARATION PRIOR TO BREAKTHROUGH

Burial Pit & Precast Edge Beams

The Northbound and Southbound burial pits were excavated entirely in Brisbane Tuff by drill and blast techniques. Excavation commenced in December 2010 and both burial pits were completed in May 2011.The top heading of the Lutwyche Caverns were excavated by Roadheaders and rock support was in the form of 6m and 4.5m long anchor bolts at 1.5m spacing's. To provide support for the TBMs as they broke through a concrete cradle billet was constructed. See Fig. 3

Burial pit dimensions were 14.5m x 14.5m x 16.5m and rock support was designed to take the approximate 13,500kN load from the TBM Shield as it neared the edge of the pit, the 15T and 20T electric chain hoists suspended from the ceiling and the steelwork. This was confirmed by little movement in the face of the burial pit as the TBM Shield neared the edge.

The burial pits were designed as drained structures, both in the temporary and permanent case.

To relieve groundwater pressures weep holes were incorporated into the final 100-175mm shotcrete lining. Due to the ingress of groundwater into the burial pits, a continuous pumping cycle was utilised during excavation.

The rear precast edge beams were designed for the TBM Shields to traverse across them into the burial pit. The front precast edge beams provided support to the 66T lowering beams as they were lifted and then installed.

The maximum load bearing of the edge beams did not exceed 4000kN and the minimum bearing capacity was 5000kPa. A series of 8m long tie back rock bolts with a 32mm diameter were directly inserted into the rear precast edge beams to provide additional support.

The front and rear edge beam performed well with only minor cracking and deflections observed.

Figure 3 – Construction of Burial Pit showing Rear Edge Beam and the Concrete Cradle Billet

Steelwork Procurement and Assembly

As part of the TBM burial and disassembly works, specially designed steel lowering beams consisting of two plate girders braced together were required to absorb the 13,500kN out of balance TBM Shield loads, provide full access via ladders and walkways and require minimal assembly on site once delivered .

Also manufactured were the 3.5T sliding cradles used to transfer the TBM Shield to the steelwork after the initial breakthrough.

Fabrication of the steelwork commenced early January 2011 in Pingshazhen, China and was delivered to APL during April 2011. Independent testing to British and Australian Standards were carried out and a trial assembly was performed in the factory prior to acceptance and delivery. See Fig. 4

Before the steelwork could be assembled in the Lutwyche Caverns, 15m supporting columns recycled from shoring struts were installed and grouted in place.

Three columns at the front supported the front cross beam which provided a base for four of the heavy lift strand jacks. This front support tied into the front edge beam provided lateral restraint to the front of the Lowering Beam.

Two columns at the rear supported the rear cross beam which provided a base for two of the heavy lift strand jacks. This rear support tied into the rear edge beam provided further lateral restraint to the lowering beam at the rear.

The 66T lowering beams rested on specially designed 25T load skates before being lifted into their final position by a combination of two 20T and four 15T electric chain hoists.

Final assembly of the mid platform, cross beams and the top platform at the front end was then carried out along with checks and survey monitoring.

Figure 4 – Trial assembly of Steelwork in the factory

BREAKTHROUGH AND BURIAL

Detailed TBM Breakout Stages

The Northbound TBM broke through into the Lutwyche Caverns on the 4th July 2011. Two days later the Southbound TBM broke through on the 6th of July 2011.

Both TBMs broke through a full face of Brisbane Tuff of varying strengths from 15 – 100MPa and a 100-200mm shotcrete layer that was pre-cut to limit the possibility of over break and blocky ground. Minimal penetration was needed during the final stages of advance to reduce the risk of early wall failure. To achieve this, the cutter-head and screw conveyor speeds were increased to keep the excavation chamber empty.

To enable the TBMs to progress, 400mm thick and 2m long rings with an internal diameter of 11.30m were installed in a 9 segment + 1 key configuration. Segments were designed with a 40mm double sided Left or Right taper to keep the key segment above the tunnel axis.

Advance and erection of the rings continued with full 2800mm jack extensions to maximize the area of breakout. Timber wedges to prevent ring sagging were installed between segments and the tail-shield below the springline level and were moved forward for each new ring build. Steel channels and straps were installed on the final rings to keep segments tied together and the gaskets compressed. Both measures were taken to compensate for the loss of pressure on the jacks at the breakout.

Normal grouting operations continued through the 4 tail shield ports, and to minimize grout leakage the percentage of sodium silicate in the mix was increased to speed up the gelling time.

Once both TBMs completed the break-out, spoil and material generated from the face was cleaned out and the cutters that would damage the concrete cradle billet were removed. The cutter-head was then returned to a parallel displacement of 100mm. A restraint beam recycled from the Toombul launch frame was then installed across the face of the cutter-head with four 100T anchors either side giving a total of 800T of resistance. Ring building pressures were now reduced to 40 bars for the final rings. See Fig. 5

At this stage the TBM Shield was far enough for a shotcrete layer to be applied to seal the void between the breakout and the shield to prevent grout loss. To prevent shotcrete binding to the TBM Shield, grease and plastic wrapping was applied.

During the final ring builds the restraint beam was released by minor retraction of the cutter-head. The 70mm Macalloy bars were then disconnected and extended before the cutter-head was returned to a 100mm displacement. The TBM was now able to advance 2m. This cycle was repeated for the final four full rings and final four partial rings.

Unlike the previous rings, partial rings were grouted in position by feeding hoses directly from the tailshield ports. Ring roll and excessive movement of the segments was further reduced by installing alignment dowels, bicones and temporary support struts.

The restraint beam was cut and removed once the final partial ring was constructed and the TBM Shield now resting on the sliding cradle passed over the rear edge beam and onto the steelwork. At this stage the sections of the screw conveyor protruding past the tailskin were removed, the erector beam cut and components of the backup gantries disconnected from the TBM Shield. Salvaging of the drive motors, gearboxes and hydraulic oil also commenced.

Figure 5 - Restraint Beam was installed shortly after breakthrough

Pulling the TBM Forward

Due to the uncertainty surrounding the exact distribution of the load, the manufacturer of the TBMs, Herrenknecht estimated that the shield weight with a centre of gravity at 3.3m to be approximately 13,500kN. This force was to then distribute through the stiff portions of the TBM Shield and transfer to the sliding cradles which moved along on low friction Nylatron pads.

Both TBMs were pulled forward into their final position by 70mm Macalloy bars and a hydraulic pulling system. Friction was reduced to a co-efficient of 0.1 between the sliding cradles and the steelwork by applying a layer of dishwashing detergent for each 1.5m stroke. This was confirmed by the hydraulic pulling system measuring a pulling force of 1,400kN for the 13,500kN TBM Shield. See Fig. 6

Once the TBM Shield was in its final position, six heavy lift strand jacks were then installed by VSL on the front and rear cross beams. Final disassembly and salvaging works prior to lowering were carried out in the TBM Shield during this stage.

Figure 6 - Pulling the TBM Shield forward on the Steelwork

Lowering the TBM

The front and rear cross beams installed provided a base for the heavy lift strand jacks. VLS was responsible for the lowering operation with assistance provided by TJH. Four strand jacks were located at the front and two were placed at the rear.

Each strand jack consisted of thirty-one 15mm seven wire strands, weighed over 2T, measured 3m high and had a lifting capacity of 3224kN. All six strand jacks were powered by four 22kW hydraulic pumps with operating pressures upwards of 450 Bars each.

Lifting and levelling was performed by operating the front strand jacks in groups of two and the rear two strand jacks independently. During lowering operations all six strand jacks with a stroke of 500mm were operated in groups of two. See Fig. 7

The entire operation to lower each TBM Shield took approximately seven hours.

Figure 7 - Lowering the TBM Shield

Survey Monitoring and Control

An extensive survey and monitoring regime was established as both TBMs approached the rear edge beam of the burial pit and moved onto the steelwork. Deflections in the two lowering beams for each burial pit were monitored for every 1m advance from the TBM Shields as they were pulled forward. As a precaution, results were reviewed before pulling the TBM Shields any further.

As the TBM Shield loads were transferred to the sliding cradles which moved along the steelwork, minor 10mm deflections in each of the lowering beams were observed. After an extensive review these minor deflections were concluded to be from the splices in the steelwork opening up. Trigger levels were revised and monitoring of the lowering beams continued. Maximum deflections in the lowering beams reached up to 28mm.

Final Burial and Disassembly

A 24 hour operation was undertaken utilising two concrete pumps and a 10MPa flowable fill to completely encase the TBM Shields within the burial pit. In total 2,500m3 of flowable fill was used for each burial pit. Due to the consistency and viscosity of the fill there was no need for additional hosing as the fill flowed into all areas of the TBM Shield. See Fig. 8

Once completed a 40MPa reinforced capping slab was cast to provide support for the removal of the backup gantry components as they were pulled forward and disassembled. Over 3000T of steel and 200m of backup gantry was successfully disassembled and removed ahead of schedule.

Figure 8 - Final burial with the top of the TBM Shield visible

CONCLUSION

Due to the initial changes from tender considerable planning and preparation was required to allow both TBMs to break through into the Lutwyche Caverns during the planned July 2011 date without any delays to the programme. Key elements involved in the successful and timely breakthrough and burial of both TBMs were:

- A detailed risk assessment for all works.
- Early engagement with subcontractors.
- The design and construction of the Lutwyche Caverns and TBM burial pits including ground support.
- The design, procurement and installation of the steelwork, edge beams and the electric chain hoists.
- Detailed lifting studies, breakout procedures, lowering and disassembly methodologies.
- A strict survey and monitoring regime including alert trigger levels.
- Tunnelling parameters to limit over excavation during breakthrough.
- Identifying recyclable and existing materials on APL that could be used.
- Experienced tunnel crews, supervisors and engineers.
- Communication and coordination between TJH and VSL.

The burial of both TBMs was a complex undertaking, being the first in Australia at the time a number of methods and techniques in underground construction were developed. As a result each 1,300T TBM Shield was removed from the tunnel with no surface disruptions and had minimal impacts on the community and environment.

ACKNOWLEDGEMENTS

The author would like to thank the Thiess-John Holland Project Tunnel team under the leadership of David Hake for the unique and challenging experience. Special thanks to Southbound Tunnel Manager, Andrew Shepherd who provided assistance in writing this paper.