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Southern tunnel works – A case history

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ABSTRACT: Western Harbour Tunnel (WHT) Stage 1, or Southern Tunnel Works (STW) is a complex network of road tunnels, located roughly beneath the suburb of Balmain in Sydney, NSW, Australia. The project was completed on 14 February 2025 with excavation of approximately 8.5 kilometres of mined tunnels undertaken with eight roadheaders and one surface miner. The project had a unique arrangement with all supporting site infrastructure contained underground, which is unprecedented locally. Having the project operate entirely underground reduced the impact of construction on the community and local environment. Given the unique arrangement of STW, a decision was made early in the project to focus on engineering innovative solutions, to ensure program could not only be met, but reduced beyond initial expectations. This paper aims to outline some of the unique challenges & solutions that were managed by the team and how communication and collaboration is key to a successful project delivery as logistically complex as STW.

1 GENERAL OVERVIEW – A UNIQUE TUNNEL PROJECT

STW was awarded to John Holland CPB Joint Venture (JHCPB) as a variation to the WestConnex 3B Rozelle Interchange (RIC) project. RIC required handover and opening completion more than one year before opening completion of STW. This commencement of STW during the commissioning phase of RIC provided an opportunity for a tunnel excavation project with almost nil surface footprint, reducing the impact on the community. It was during the overlap of STW and RIC that the infrastructure was established underground within STW, a process that added a significant interface coordination at a time of commissioning of one of the most complex road infrastructure projects undertaken in Australia. This setup phase would enable STW to operate independently of RIC when the time came for RIC handover.

The project itself contained 8.5km of mined tunnels, starting at WHT Cut & Cover (C&C) located adjacent to a major state road, City West Link, and extending to an underground stub, located at the northern point of Birchgrove, immediately before Sydney Harbour, (see figure 1 below for a general arrangement of STW overlaid with RIC). Excavation volumes for the project was 997,085 bank cubic meters (BCM) of Hawkesbury Sandstone, or to put this in perspective the equivalent weight of 103,697 humpback whales worth of spoil. 100 per cent of this spoil was required to be removed via underground loadout through the WHT C&C to City Westlink.

With the exception of a narrow entry/exit of the WHT C&C, the construction footprint of STW was entirely underground and unseen by the community. To add to the challenges, this approximately 1,000m2 narrow surface footprint, was on a bridge over a drainage canal, connecting the adjacent road City West Link, with the WHT Cut & Cover.

The entry itself into WHT C&C is also limited in height – to a maximum of 5.1m clear height, smaller than the machines that were required to excavate STW.

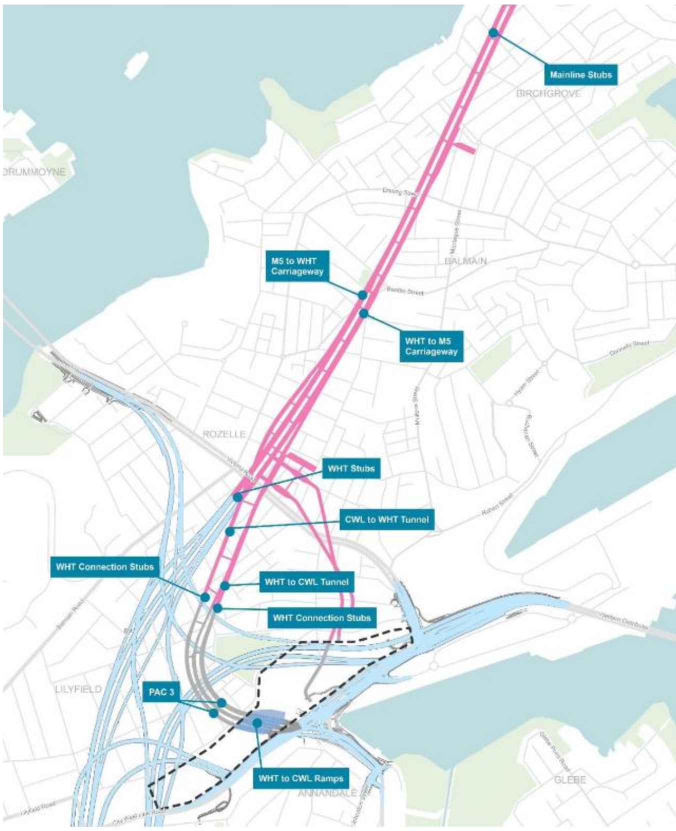

Figure 1. STW General Arrangement (shown in Pink).

2 SITE OPERATIONS & LOGISTICS - SURFACE VS UNDERGROUND

The infrastructure required to support roadheader excavation is extensive and complex. Traditionally such projects with fewer roadheaders than the eight used at STW, require a large usable surface footprint to accommodate this infrastructure. This typical infrastructure includes items such as site offices and amenities, a soundproofed spoil shed, water treatment plant, materials laydown area and plant maintenance workshops, intertwined with vehicle haul roads with sufficient swept paths for large plant.

A typical surface site of comparable scope was known as ‘Tunnel Site C’ at RIC. Refer to Figures 2 & 3 below, where footprints of Tunnel Site C and STW can be compared. The surface area of Tunnel Site C is approximately 20,000m^2 in area, whereas STW occupied only 1,000m^2 of surface footprint, or about 5% of the size.

Due to these limitations, and the requirement that supporting infrastructure for STW must be entirely independent from RIC - all project infrastructure was located underground, either inside the mined tunnel portals, or within the Cut & Cover. It was only the small site office with amenities which had the opportunity for taking in the view of Sydney Harbour at surface. Significant items of infrastructure that were uniquely placed underground at STW includes:

- Spoil Stockpile; a place for dump trucks to stockpile excavated material, for loadout offsite
- Truck Access Roads; for removal of tunnel spoil, to move trucks to the spoil stockpile, load, and move back offsite with material taken from the stockpile
- Water Treatment Plant (WTP); for treatment of tunnel water prior to discharge or re-use
- Sedimentation pond; to remove large solids from tunnel water prior to treatment in WTP
- Fresh air ventilation fans; to provide a safe and cool environment underground
- Bulkheads & airlocks; to ensure the fresh air fans are isolated from dirty return air
- 30,000 litre water reservoirs; to supply potable water underground and to excavation faces

- Air Compressors & Receiver Tanks; to supply high pressure and safe compressed air underground
- High and low voltage substation and switching gear to provide power to the key items of plant
- Secure communications infrastructure and network to allow efficient communication and safe work environment
- Wheel wash; to clean tires of trucks & other vehicles immediately prior to exiting the site
- Mechanical workshops; to undertake maintenance and repairs to plant
- Bulk diesel supply tanks & fuelling station; to provide plant with fuel
- Bulk accelerator tank; for dosing shotcrete so it can be sprayed effectively

Figure 2. Rozelle Interchange 'Tunnel Site C' Surface Footprint.

Figure 3. STW Surface Footprint

Spoil handling and disposal presented one of the largest challenges while establishing the tunnel project entirely underground. At peak roadheader production, approximately 36,000 tonnes of spoil was excavated from the tunnel face per week. To facilitate continuous excavation, spoil requires removal from the site at the same rate at which it is excavated, or the tunnel would have quickly become inundated, thereby stopping production and progress.

It was critical that the truck movements and spoil handling within the site is smooth and efficient. The internal footprint and alignment of a road tunnel is designed with high radius curves to facilitate safe travels of cars and trucks. This geometry is adverse for efficient spoil handling in comparison to the large open plan spoil sheds erected on the surface. With restrictions on tunnel width, height and turning radius, spoil handling locations needed to be meticulously space-proofed ahead of time. The completion of the tunnel within this footprint also had to be considered, as spoil operations would significantly hinder the ability to complete the remaining follow-on works (e.g. waterproofing, secondary lining and drainage) within the same area.

Given the above, the team elected to house the in-tunnel spoil storage within two of the three carriageway tunnels, as close to the tunnel portal as possible. Truck and dog access and turning was facilitated through an additionally constructed temporary cross passage, for loading via front end loaders. Due to the large radius required for a truck to turn around and exit the tunnel, it was necessary to provide this temporary cross passage. It would not have been possible to turn a truck around without the temporary cross passage, so this was considered a necessary addition.

A loader turning niche was also required to be excavated into the sidewall of one of the existing tunnels, to minimise the need for reversing movements. This niche eliminated the need for reversing within the path of trucks that dump spoil in the area and so was considered highly desirable as it eliminated a potential interaction between loaders and dump trucks. The addition of this cross passage and niche required further tunnel support to be installed within otherwise completed sections of the existing tunnel crown, along with an assessment on the impacts of the already completed RIC tunnels below. Refer to figure 4 below for a general arrangement of the swept paths and spoil removal system adopted.

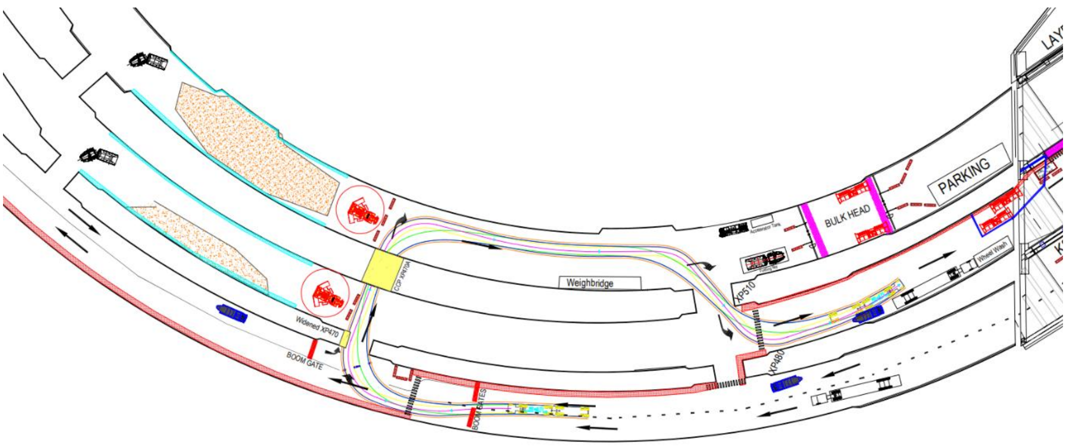

Figure 4. General Arrangement of Underground Spoil Loadout.

3 ENGINEERING INTITIATIVES – ROADHEADER RE-SEQUENCING AND ADDITIONAL CROSS PASSAGES

Upon award of STW, JHCPB began to explore various engineering and optimisation initiatives, in an attempt to shorten & de-risk the overall program beyond initial tender expectations. One of the most beneficial opportunities identified was the planned sequencing of road-header launches and excavation of ventilation tunnels and caverns early. This initiative was based on opening up work areas and getting into the complex excavation as early as possible.

Ventilation tunnels at STW comprised 1,300 linear meters of tunnelling of varying cross-sectional area. This included two tall and large span caverns, which are intended to house large axial fans mounted on a steel structure, in order to provide additional ventilation in the event of fire or poor air quality. Both ventilation caverns are 21 metres wide by 24.5 metres tall, which presents significant complexity in staging the excavation, waterproofing, and potential lateral shearing within the bolted zone.
These caverns were considered a threat to potentially delay the program if any lateral movement and subsequent shearing were to be observed. Shearing has been observed on similar projects in Sydney, as described by Bai et al (2023), and so it was considered critical to ensure this concern could be mitigated, by bringing excavation as far forward in program as possible.

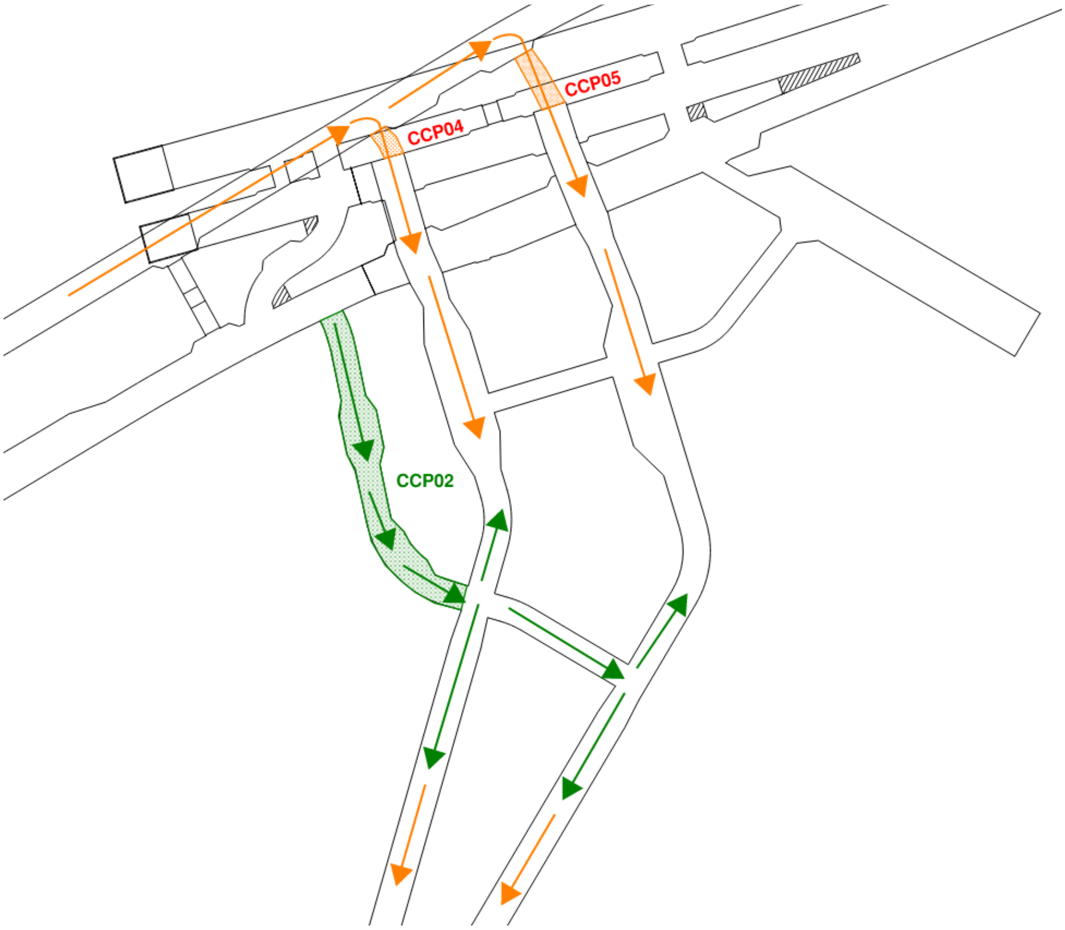

Figure 5. Concept Excavation Sequence (Orange) vs Optimized Excavation Sequence (Green)

Given the complexity involved with tall and large-span caverns and complex geology, it was critical to address program risks associated with these caverns. The concept sequence allowed for two temporary cross passages 'CCP04' and 'CCP05' connecting the main WHT on-ramp to the northern end of ventilation tunnels. In effect – this would mean the entire length of ventilation tunnels would have to be excavated from north to south via these CCPs, with room for only two roadheaders (one in each vent tunnel) to undertake the excavation. CPP04 & CCP05 would also become a bottleneck for spoil and traffic moving in and out of the ventilation tunnels and create interactions with main access ramp to the northern extents of STW.

A program impact and internal cost analysis was undertaken to assess the impact of the introduction of a new temporary cross passage 'CCP02', which would link a less critical access ramp to the ventilation tunnels at a point south of the ventilation caverns. This would result in CCP04 & CCP05 being deleted from the design, as their purpose had become redundant. This change allowed for the number of roadheaders to be doubled to four machines. Two machines to excavate northbound, while another two can excavate southbound back towards RIC. It also allowed for multiple routes of access in and out of ventilation caverns after excavation, whilst also providing flexibility and staging options for waterproofing and secondary lining required to be completed in the ventilation caverns.

The addition of this relatively long cross passage would add additional excavation volume to the project, however the exercise determined that ventilation tunnels could be completed many months earlier through incorporation of this re-sequencing. The largest benefit realized was not only the time saving, but the reduction in overall program risk. In the STW concept program – there was minimal float between completion of ventilation tunnels and overall project critical path. This change moved vent tunnel completion forward significantly, thereby mitigating a significant risk of extending the overall project critical path.

While this exercise added some additional excavation volumes to the project, the net effect was a saving in overall effort, as excavation and tunnel finishing works within ventilation caverns could be completed much sooner, allowing resources to be focused on completing other elements within the project, and thus achieving an overall reduction in time required to project completion.

4 DESIGN MANAGEMENT - AN OBSERVATIONAL APPROACH TO TUNNEL GEOMETRY

Observational approaches to tunnel support and groundwater control systems, as decribed by Salcher et al (2023) and Brown et al (2020) respectively, are relatively common across recent mined tunnel projects in Sydney. This is an approach well defined by Nicholson et al (1999), but to be put more simply is where a ‘toolbox’ of options are presented within the design, and a strict system of ongoing site observations and review is undertaken, allowing for an option from the ‘toolbox’ to be selected and applied on site in response to observed conditions. This is a highly flexible, and generally favoured approach.

STW adopted this same approach, however expanded the observational approach to tunnel geometry & set-out in select circumstances. This was most notably implemented in a tall and wide span ventilation cavern, located adjacent to the Great Sydney Dyke (GSD) which was projected to run sub-parallel to the alignment of the ventilation cavern, somewhere within 10 metres to 30 metres of the closest sidewall. This observational approach would allow a significant improvement in overall tunnel stability and safety during construction. At the initial design phase, the confidence on the projection of the GSD was relatively low as there was limited surface site investigation data available in the area. It was identified that further in-tunnel investigation results should be incorporated as part of the tunnel selection criteria.

The ventilation cavern support nominated mandatory probing towards the GSD on the nearest sidewall (prior to benching to full height), as validation to ensure the dyke was not located within 10 metres of the sidewall. If the dyke were to be discovered – a regime of stitch bolting, with 13.5 metre long cable bolts at 1 metre centers, across the sidewall would be required as part of a special support type designed to pin the sidewall, a solution that was not pallatable.

The design proposed two options for ventilation cavern geometry to address the potential risk of the GSD. Option 1 provided the regular cavern geometry, with a 4 metre widening on both sides of the cavern. Option 2 provided an alternate geometry, with an 8 metre widening on the far side of the cavern only. Option 2 was effectively a horizontal offset of the cavern, moving the critical sidewall 4 meters away from the dyke if necessary.

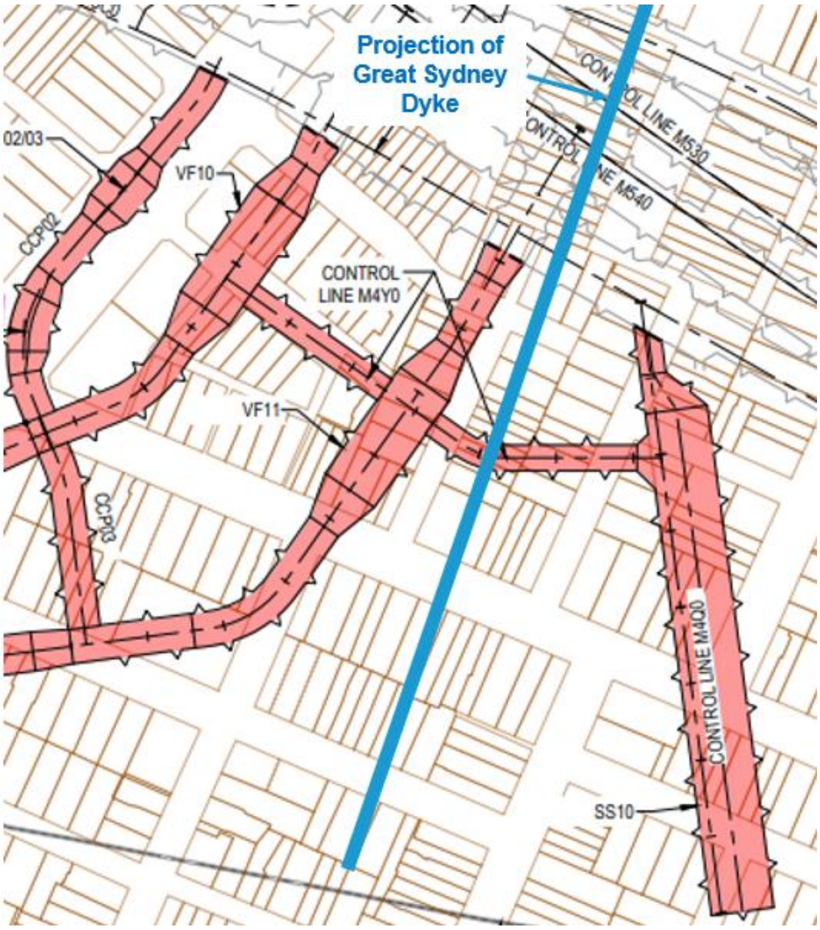

Figure 6. STW Ancillary Tunnels with projection of Great Sydney Dyke

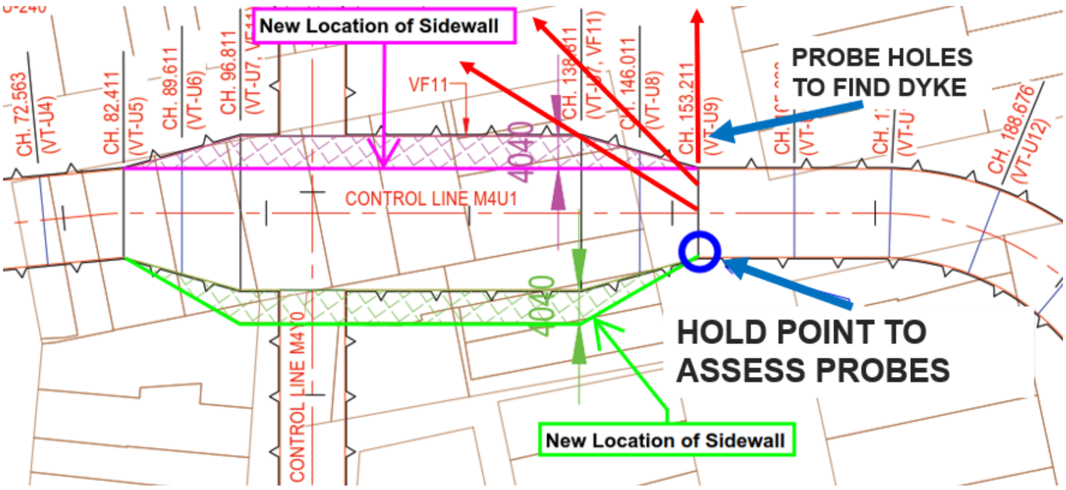

Figure 7. Probing Plan & Option for Alternative Ventilation Cavern Geometry

In order to inform, validate and ensure any impacts of this change were captured – a Hold Point was nominated in the design excavation sequence, immediately prior to entry into the cavern widening. This Hold Point nominated probing at the face and sidewall towards the GSD, in order to find and measure the actual location of dyke relative to cavern sidewall. An informed decision on the relocation of the sidewall away from the dyke could then be made. In order to release the Hold Point – the construction team provided geological probing results, along with the nomination of which geometry was proposed, to JHCPBs Design Manager who acted as the release authority for the hold point.

The construction team undertook this probing, and elected to proceed with the alternate geometry. The approach was successful, with no stitch bolting or adverse support types required throughout the cavern.

This flexibility was made possible, as the options were carefully planned not to have any impact on tunnel space-proofing, alignment, or accessibility and maintainability requirements. This approach was only applied to ventilation tunnels and service passages, and was not permitted for road tunnels, as spaceproofing requirements are considerably more flexible when traffic and road geometry considerations are not applicable.

This concept was found to be highly effective in optimizing tunnelling activities, improving safety and overall efficiency and would be worth exploring in further detail on future projects. It is noted that strong cooperation and an open flow of dialogue between construction and design teams is key to ensuring this process operates smoothly and succesfully.

5 DISCUSSION

The delivery of STW higlights how the integration and balance between program, excavation quantities, intelligent engineering solutions and proactive design management processess are key to successful delivery of such complex infrastructure. In the authors opinion, the importance of involving staff who are both technically minded, and experts in delivery is critical, as an understanding of the reasons *why* specific design requirements exist is key, so engineering solutions can be safely, efficiently and pragmatically implemented. The benefit of having experienced and expert staff on board meant that complex time and cost judgements could be undertaken and implemented at relatively short notice, allowing for implementation of signficantly optimized and innovative engineering solutions.

6 REFERENCES

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7 CONCLUSIONS

Southern Tunnel Works was considered a successful project, delivered ahead of time, with reduced disturbance to the community and local environment. This was due to excellent collaboration between Transport for NSW and contractor John Holland CPB Joint Venture.

The decision to focus on unique, innovative solutions and engineering initiatives across the project worked tremendously to minimize impacts and optimize outcomes for all stakeholders.

Transport for NSW and JHCPB have proven with this project that it is possible to shift a traditional tunnel site underground, with minimal disruption to tunnelling activities, and with less impact on the wider community.