1. Introduction

Continuum Alliance (a CPB Contractors and Lendlease Engineering (now Acciona) joint venture in alliance with TfNSW) completed the Blue Mountains Route Clearance (BMRC) project in July 2020. The project enables the New Intercity Fleet (NIF) to operate on a 70km section of the Main Western Line between Springwood and Oakey Park in the Blue Mountains.

The scope ranged from: tunnel lining modifications, track alignment, overhead wiring (OHW) adjustments and track circuit relocations. The team also completed works on 13 heritage-listed stations including platform extensions, coping cutbacks and build-outs as well as station canopy cutbacks.

This entry for the Ken Erikson Award provides details of innovations and achievements on this complex project.

Organisations

- Transport for NSW (Client/Owner & Alliance Partner)
- CPB Contractors Pty Ltd (Joint Venture Contractor & Alliance Partner)
- Lendlease Engineering Pty Ltd (Joint Venture Contractor & Alliance Partner)

Key Individuals:

- John Langford, BMRC Alliance Manager, CPB Contractors (Ph. 0408 426 820)
- Martijn Tiemens, BMRC Alliance Construction Manager, Lendlease Engineering (Ph. 0448 498 869)

Summary Data

Project Name:	**New Intercity Fleet - Blue Mountains Route Clearance**
Location:	Springwood to Oakey Park, Blue Mountains, NSW
Client:	Transport for NSW
Type of Contract:	Alliance
Contract Value:	Not disclosed
Contract Period:	July 2018 - July 2020
No. of Rail Possessions:	8

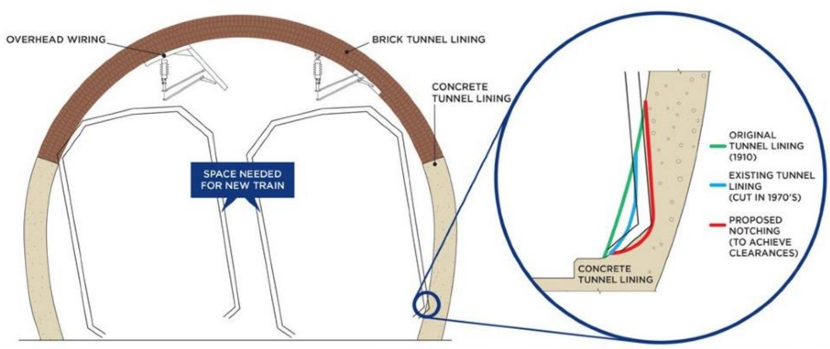

Figure 1 – Tunnel cross-section and Kinematic Envelope (KE) interface with wall

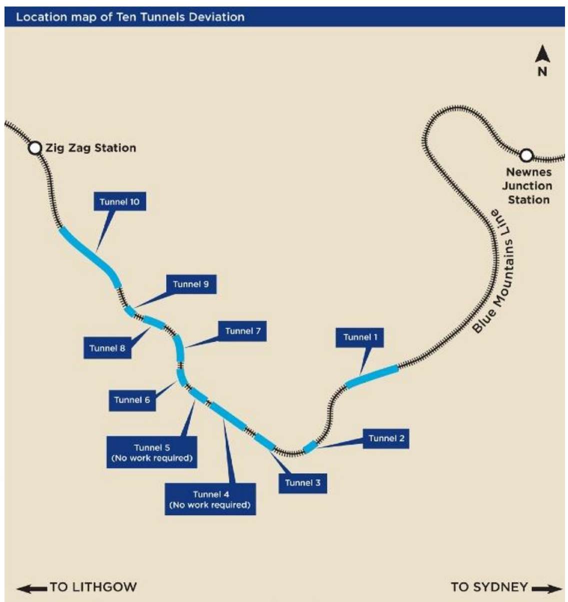

Figure 2 – Location Map

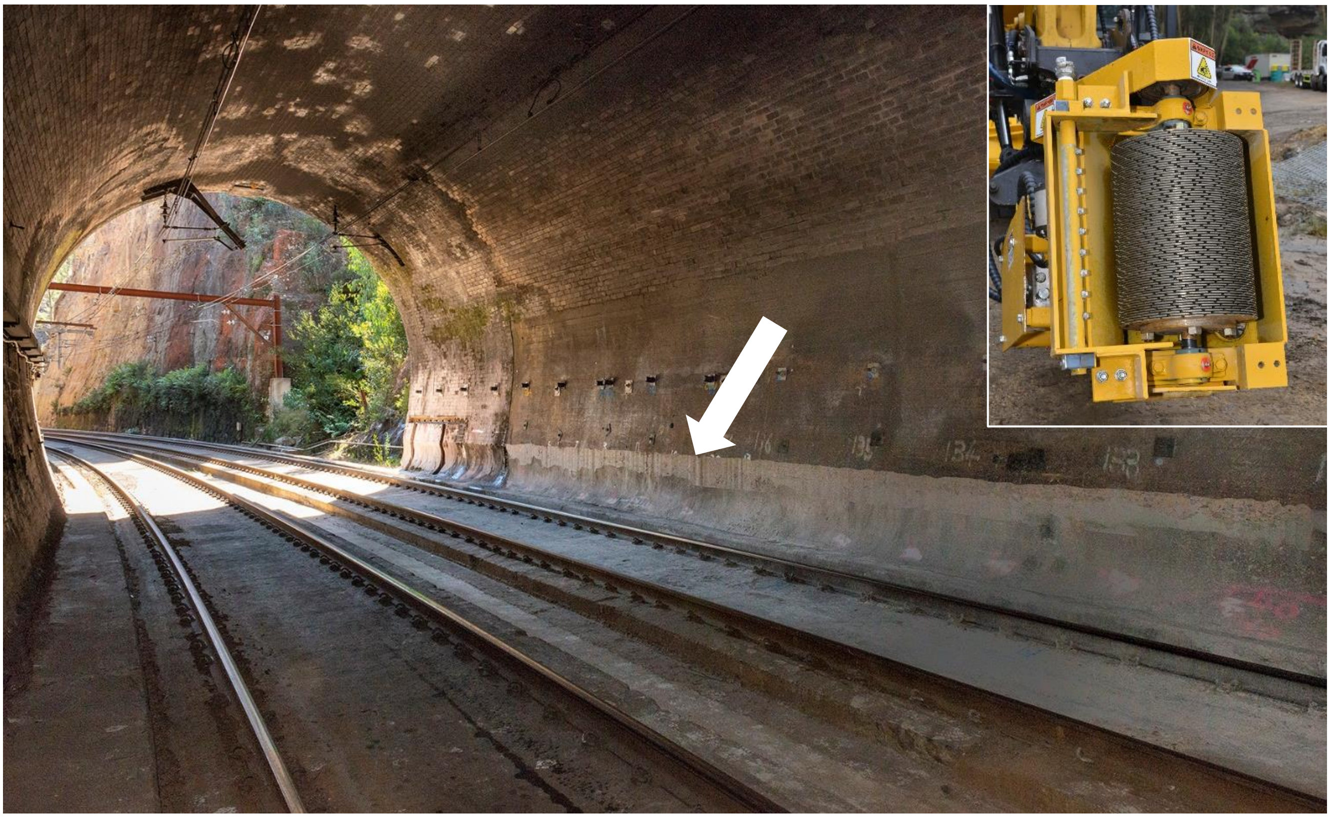

Figure 3 - (Main Picture): General view of tunnel lining after rock bolting and milling of wall.
(Inset): Close-up view of the rotating "Wall Shaver" diamond cutting drum attachment

2. Description of Entry

The NSW Government is delivering the New Intercity Fleet (NIF) to replace existing intercity rolling stock operating throughout the electric rail network. The Main West Line between Springwood and Lithgow Stations is currently only authorised for Narrow KE trains, therefore infrastructure modifications were required to allow the operation of the Medium/Sub-Medium Kinematic Electric NIF rolling stock. In non-prescribed locations (such as ballasted track) the NIF conforms to the Medium KE Standard whereas in prescribed locations such as the Ten Tunnels Deviation (slab track) it also conforms to the Sub-Medium KE Standard.

The Continuum Alliance was awarded the contract for the detailed design and construction of the project. The Works Brief for the Project generally involved the following works:

- Route clearance works from Springwood to Oakey Park (80.388km to 153.300km) excluding Mount Victoria (126.300km to 127.750km) including track slews, OHW adjustments and track circuit relocations;
- Station modifications from Faulconbridge Station to Newnes Junction Station, excluding Mount Victoria Station, including platform extensions, coping cutbacks and build-outs as well as station canopy cutbacks;
- Modifications to the Ten Tunnels Deviation (inclusive of the slab track section from 145.430km to 150.550km) to allow Sub-Medium KE NIF trains to operate on both the Up and Down Mains (Note: Operationally, the Mediums will be excluded between the crossovers at 145.240km and 150.630km. However, Sub-Medium limits are only applicable to the slab track).

Transport for NSW was a strong supporter for employing innovative solutions on the project and this entry focuses on the modifications to the tunnel lining where a combination of the latest technology and innovation was used to mill/shave the tunnel walls.

3. Judging Criteria

Responses to the seven key criteria follow in this section of our Award Entry.

3-1. Difficulties Overcome

History

The Ten Tunnels Deviation is State Heritage listed and was constructed between 1908 and 1910 to bypass the Great Zig Zag on which trains made their way down from the Blue Mountains to the inland plains. The tunnels were driven through natural rock and were self-supported which means the tunnel lining was supporting itself only. Furthermore, the drill and blast method used to drive the tunnels resulted in varying tunnel lining thicknesses.

In the 1970's, the tracks were lowered by 650mm to accommodate the introduction of V-Set double-deck cars with the ballasted track replaced by a concrete track slab. In addition to the lowering of the tracks, the toe of the tunnel walls were chased/milled as they would have infringed the KE of the V-Sets. Rockbolts were installed to support the tunnel lining during construction and compensate the loss of wall thickness. The chasing/milling was initially undertaken by jackhammers, however, this proved difficult and, in the end, the Alpine Miner used to excavate the floor for the track slab was used to mill the tunnel walls. The resulting finish using this methodology proved to be very coarse and uneven.

Wall thickness

The Sub-Medium KE with a factor of safety of +100mm required up to a further 100mm to be milled from the tunnel walls and generally there was sufficient remaining wall thickness to accommodate this milling. However, in areas that were previously milled for the introduction of the V-Sets, some sections of the tunnel walls had to be replaced (underpinned) and this was the most time consuming and expensive treatment. Other factors determining the effective thickness of the remaining wall thickness were construction tolerance, residual life and any deterioration (durability) of the back of the tunnel lining where it interfaced with the natural rock and was subject to groundwater flows. Only the tolerance of the milling activity could be controlled with over-excavating resulting in the need for underpinning; so it was critical that accuracy was achieved, while at the same time, ensuring the infringements were removed. Refer to Figure 4 below.

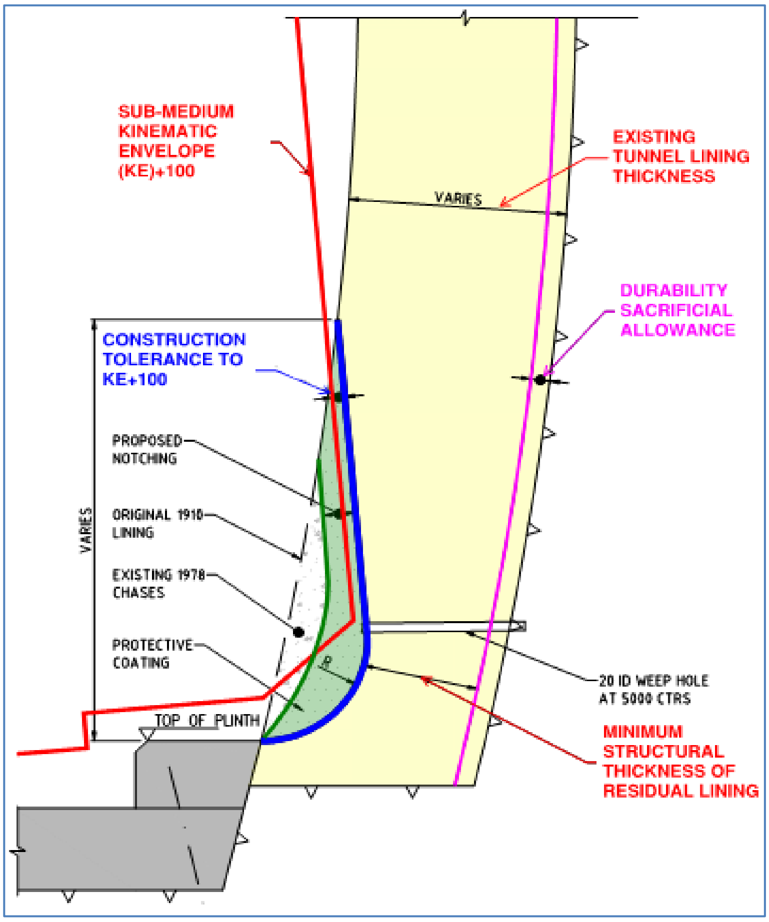

Figure 4 - Residual Lining thickness after treatment

To demonstrate the impact of the construction tolerance, durability and residual life on the volumes of the treatment options, the graph in Figure 5 below was developed during the early design phase showing the relationship between construction tolerance and quantity of underpinning (T3) treatment for three different situations.

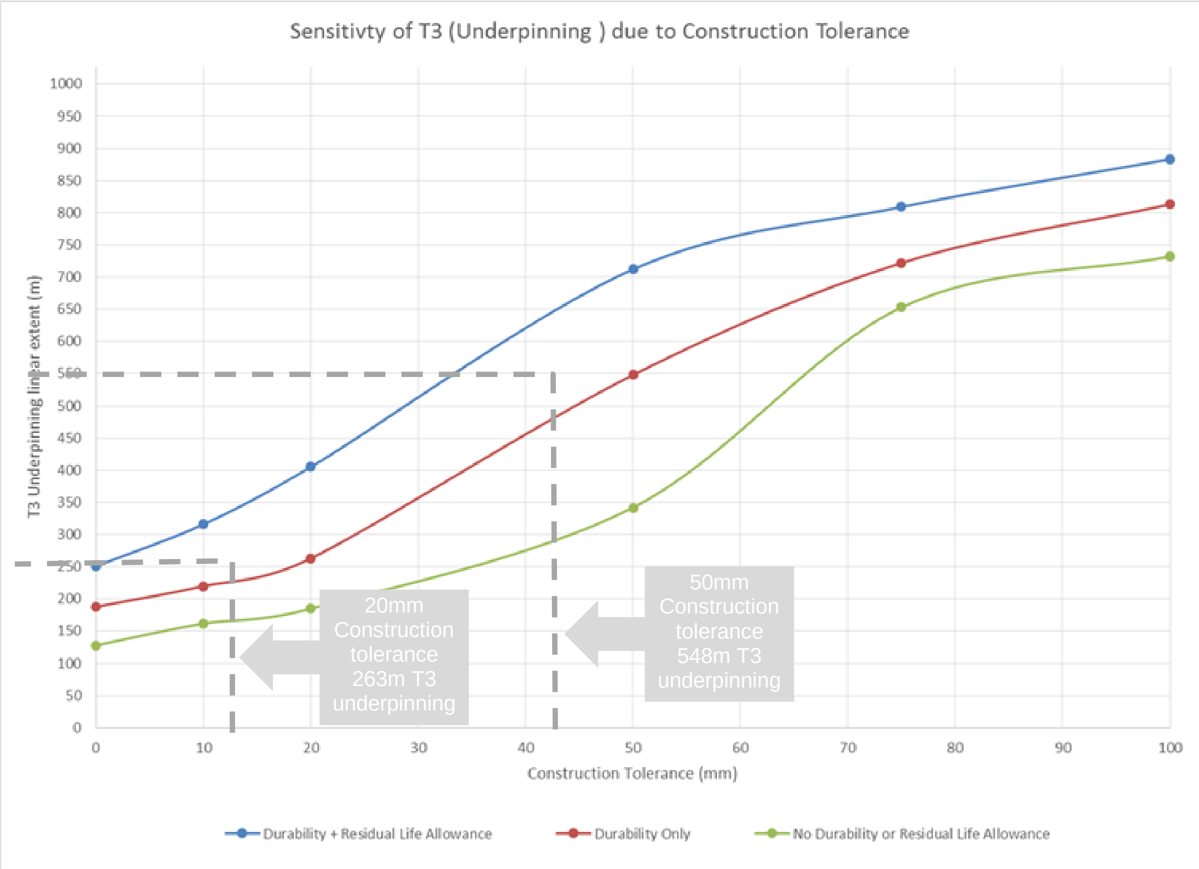

Figure 5 – Impact of construction tolerance on effective wall thickness

As the existing rockbolts installed in the 1970s could not be relied upon, the Alliance installed double-corrosion protection rockbolts in areas to be milled.

Access

The Ten Tunnels Deviation lies on an escarpment of the Blue Mountains, winding its way through rock outcrops; therefore, construction access was limited to three access points for road vehicles and the Alliance installed all-weather hi-rail ramps to facilitate access. The initial intent was for the hi-rail ramps to be temporary, only serving the BMRC works, however, Sydney Trains opted to retain the ramps for track slab replacement and Lithgow Yard remodelling works.

Figure 6 - Panoramic view highlighting the limited access and difficult nature of the terrain

Bushfires

In terms of difficulties overcome, it would be wrong not to mention that the works planned in the Ten Tunnels Deviation between Christmas and New Year were cancelled due to the December 2019 bushfires that ravaged the area. Notwithstanding this, the Alliance availed of the possessions arranged for disaster recovery works by Sydney Trains to progress the BMRC works in the tunnels.

3-2. Contribution / Impact to Rail

The rockbolting and chasing/milling works undertaken by the Alliance were not novel as similar works were undertaken for the introduction of the V-Sets in the late 1970s. However, the Alliance deployed the latest technology and innovative equipment to perform the works. These are further described in the Technical Input and Degree of innovation in Rail aspects sections of this submission and can be adopted for similar clearance works in a rail environment.

3-3. Technical Input

The BMRC project was unique when compared to 'standard' infrastructure projects containing significant new/modification works. Typically, the clash detection exercise is a supporting tool/process to ensure collaboration/coordination between engineering disciplines, adequate interfaces with existing infrastructure, and alignment with construction methodologies to avoid issues on site resulting in rework and delays. The clash detection in this case, the transit space infringement assessment, was used to determine the actual project scope and thus inform the number of infringements that require treatment by the relevant engineering discipline.

Amberg Rail

Amberg Rail is a modular system developed to conduct rail clearance surveys. The modular rail survey trolley is comprised of a terrestrial laser scanner, internal track geometry sensors and 3D terrestrial positional system from a robotic total station. The rail survey trolley is supported by proprietary software which is used to combine and process the data from the hardware trolley sensor. The software can interrogate the data and automatically produce exports such as heatmaps and cross sections in a variety of formats which assist in the production of design deliverables

Amberg Rail Clearance software (and hardware – Amberg Rail Trolley) was used to validate that physical infringements have been successfully treated. The AR system:

- produces point cloud survey;
- can import clearance envelopes and permanent way alignments strings;
- provide dimensioned cross sections showing surveyed assets, alignments strings and clearance envelopes (live on site and in the office), and:
- heatmap elevations (graphical representation, using a system of color-coding, showing magnitude of infringements – see Figure 7).

This software combines 3D point cloud, track alignment and relevant clearance envelopes to accurately evaluate spatial clearance.

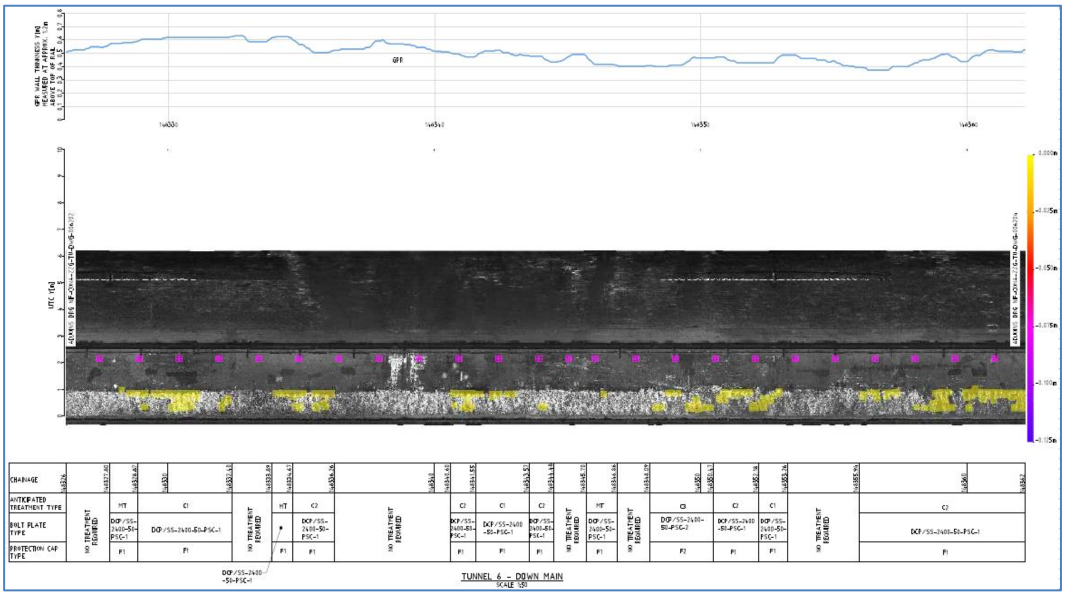

Figure 7 - Heatmap of tunnel wall showing rockbolts and milling areas

Amberg Rail is a mobile surveying solution, that is 'portable' in the strictest sense of the word. Amberg Rail allows measurements to be made in real-time during construction to confirm that infringements have been cleared appropriately without the need to return to the office for further processing. At the same time the laser scan supports the process to update drawings to an as-built status. Up to five kilometres of track can be surveyed per hour (walking speed).

Figure 8 - Amberg Trolley identifying infringement in tunnel lining

Machine Guidance

Machine guidance uses a total station, single prism for a 'direct' measurement at the shaving drum or twin-header and a dual-axis level sensor that corrects for tilts of the working to up to +-30 degrees from horizontal.

Design strings describing the KE (using the known track alignment) are loaded into the machine and the machine then calculates the distance from the cutting head to the edge of the KE using the known location of the total stations and relative distance to the KE. The operator interface is a simple screen displaying the cutting head and distance to the KE. Refer to Figures 9 and 10 below.

Figure 9 – Operator's view of machine guidance controls

Figure 10 - Machine guidance prism fitted to cutting drum

Figure 11 – Tunnel lining milling with dust suppression and machine guidance

This system provided a number of benefits related to productivity:

A. Minimal set-out and checking works were required. A survey team checked the set-up and accuracy of the system at the start of a section and then performed occasional checks;
B. The excavation process benefited from real-time feedback of the positioning of the cutting tool, it took the guesswork out of the process as a distance to the KE was provided everywhere and not at intermittent points when using traditional survey;
C. By virtue of having the design strings loaded into the system, the system provided a check on survey set-out information; and
D. The increased accuracy allowed construction tolerances in the design to be reduced, minimising the amount of material removed and lessening the impact to the heritage fabric.

From a safety point of view, the system provided the following benefits:

A. Eliminated the need for surveyors to enter the plant operating zone and the area beneath the crown of the tunnel subject to vibration and potential falling bricks; and
B. The system reduced the risk of over-cutting and potential destabilisation of the tunnel walls.

3-4. Degree of Innovation in Rail Aspects

Diamond cutting drum (Wall Shaver)

To undertake the milling of the tunnel walls, the Alliance in consultation with Lendlease Engineering's Plant Manager, first explored mounting tungsten carbide cutting heads and a power pack on a rail trolley, towed by a light engine or hi-rail vehicle. The Alliance also commenced discussions with a supplier who proposed a bespoke solution of stacking diamond cutting blades together to form a drum in the profile of the KE and mounting it on a rail trolley. This was attractive to the Alliance as it was likely that the diamond cutting drum would cause less vibration than traditional tungsten carbide cutting heads and there was uncertainty around the impact the milling works would have on the integrity of the tunnel walls and crown.

With the February 2019 closedown approaching, the Alliance was keen to trial the diamond cutting drum. They decided to engage Lendlease Engineering's local plant yard rather than the international supplier considered previously to fabricate a cutting head as an attachment to an excavator arm. The diamond cutting drum attachment was fabricated and combined with a power pack and industrial wet-vacuum mounted on a hi-rail trolley in time for the February 2019 closedown. The drum performed well on vertical sections of the tunnel walls, however, the shroud around the cutting drum for the vacuum and dust suppression prevented the drum from milling the lower sections as it clashed with the concrete plinth at the base of the walls. Modifications were made to the shroud and further trials were carried out at Lendlease Engineering's Plant Yard and again in the tunnels during the May 2019 closedown.

The diamond cutting drum generated less vibration than the twin-header attachments, with both below baseline

(vibration generated by passing train) and DIN 4150 criteria. Maximum measurements during trials were:

a. 0.19mm/s at 90Hz (peak) at 2.8 – 4.4m from source for the wall shaver; and

b. 2.4mm/s at >100Hz at 2.8 – 3.8m from source for twin-header.

While improvements in vibration generated, surface finish and accuracy were achieved with the diamond cutting drum, production rates were lower than expected, placing additional pressure on the program. Also, hi-rail excavators with a twin-header had to mill the base of the walls in the same areas where the diamond cutting drum had already milled the vertical sections of the walls, which was inefficient. Finally, as the existing surface was irregular as a result of chasing works undertaken in the 1970s and the surface finish using traditional twin-header attachments was of similar quality, the twin-header attachments were used to complete the works. Refer to Figures 12 and 13.

Figures 12 and 13 - Bottom section notched using twin-header; top section treated using diamond cutting drum (large undulations indicate sections notched in the 1970s)

3-5. Contribution to Safety

As described previously, using machine guidance provided the following safety benefits:

A. Eliminated the need for surveyors to enter the plant operating zone and the area beneath the crown of the tunnel subject to vibration and potential falling bricks; and
B. The system reduced the risk of over-cutting and potential destabilisation of the tunnel walls.

The diamond cutting drum with its shroud and wet vacuum eliminated dust generated by milling activities. It should be noted that maintaining a safe exclusion zone around mobile plant and providing dust suppression were challenges in the tunnels when using twin-header attachments. The Alliance worked with the plant supplier to develop a mist sprayer attached to the cutting head attachments of the excavators, eliminating the need for a worker to be in the plant operating zone with a high-pressure water washer to suppress dust.

3-6. Systems Assurance

TfNSW worked collaboratively with key stakeholders to define the route clearance works and produce a reference design. The Alliance continued the collaboration with key stakeholders to produce a Transit Space Clearance Assessment Report which formed the basis of the detailed design. These culminated in the NIF Clearance Certificate that certified that the route was clear for Medium KE and Sub-Medium KE rolling stock.

Having consistent software from the start to finish of the project provided confidence that route clearance had been achieved. Amberg Rail was used to scan the tunnels:

a. At the start of the project to inform design;

b. To inform construction of depth to mill;

c. To confirm to construction teams that adequate depth of milling had been achieved; and

d. At the end of the works to verify clearance had been achieved and produce an as-built point cloud.

The data from the as-built scan also provides Sydney Trains with an accurate record of the tunnels for future reference.

3-7. Commercial Benefits

Amberg Rail

The benefit of using a mobile trolley to scan and identify infringements in real-time and capture data was speed, avoiding the need for multiple survey crews to scan and capture the same amount of data in the same amount of time using traditional survey instruments. This was of importance given all work in the Ten Tunnels Deviation was undertaken during rail track possessions.

Machine Guidance

Once again, the benefit of machine guidance was its speed; and the fact that it enabled the cutting heads to continuously mill the tunnel lining without having to stop and start for check measurements as would have been required if traditional survey methods were used. Additionally, improved tolerance was able to be achieved, thus reducing the amount of material removed and full lining replacement required.

Wall Shaver

Unfortunately, following several trials, the diamond cutting drum attachment did not achieve the desired productivity and the Alliance ceased using it for milling works. However, valuable lessons were learned by the Plant Yard and construction team for future reference and innovations

The technology and equipment adopted for the project enhanced the accuracy and production, which contributed to the work in the tunnels being delivered on time and under budget.

References: SD Duncan – Tunnels and Tunnelling, May, 1980