# Geelong Tunnel
## Warrnambool line
Condition Assessment Report

31 January, 2017

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# 1. EXECUTIVE SUMMARY

Following the issue of a Request for quote issued by V/Line on 26 September 2016, SMEC Australia was engaged by V/line Pty Ltd on 19th October 2016 to carry out a special investigation on the Geelong Tunnel located on the Warrnambool railway line at chainage 72.930km, south of the Geelong Station.

The tunnel carries the railway under residential and commercial properties in Geelong and is approximately 425m in length and constructed with a brick base and liner. Geelong Tunnel is protected by a Heritage Overlay, therefore any inspection tasks undertaken had to comply with the corresponding restrictions.

The purpose of the project was to undertake a history review, visual inspection of the tunnel including foundations, brick lining, portals etc. and compare the theoretical design tunnel shape vs. actual tunnel shape using the supplied 3d point cloud (Lidar), to inform the condition assessment task and the process of developing remediation options and work methods.

The field work was undertaken during the daytime on the 19th & 20th of November 2016, utilising the assistance of contractors for labour and geotechnical drilling. The arborist sub consultant attended site prior to SMEC's site inspection and outside of the V/Line occupation on the 31st October.

The findings of the special investigation are summarised as follows:

- Areas of the tunnel wall and roof throughout the tunnel have been successfully repaired in the past, mainly via use of a sprayed concrete liner, which has stopped further deterioration to the bricks and mortar in these areas. The shotcrete sections were found to be generally in new-good condition with some areas showing minor cracking and minor efflorescence, though were not provided with adequate weepholes;
- There appears to be no structural defects or deformation in the tunnel interior lining resulting from vegetation growing above the tunnel. The down end portal has a large amount of Elm tree suckers growing around and also in cracks in the portal. The identified vegetation at either tunnel end should be removed and the soil allowed to stabilise and recover and the cracks repaired, subject to Heritage permit restrictions;
- The tunnel walls and crown are were assessed as being in good condition and require no further action for at least 5 years, provided that V/Line internal operational monitoring identifies no significant degradation in condition. Minor repairs would be consolidated into the major (long term) works recommended for the tunnel base, at whatever timing they ultimately occur;
- The major concern is the Tunnel Drainage, particularly within the tunnel, as it is not functioning correctly and (combined with the soft soils and trapping of water) is causing continual issues with track alignment as the soft soil base allows vertical, differential movements of the structures supporting the track;
- This is a natural result of the location in which the tunnel was built and the nature and standard of original construction, which are inadequate for a modern rail network; the geotechnical investigation and site test pits showed that:
  - There is substantial fall from the Down End to the Up End and a sandy layer beneath the invert at the Down (higher) end allows water to travel subsurface to the Up (lower) end where the sandy layer disappears, leaving the water with nowhere to go. The sandy soils which exist for part of the tunnel length allow the general tunnel area to drain into the soft clay soils, which remain saturated, as there is no apparent functioning subsoil drainage;

- At the failing sections, the Sub base below the invert consists of soft clays with bearing capacities as low as 120 kPa. Being saturated, the brick invert is able to deflect into the understrength foundation under Train loads, which is damaging the bricks;
  - This phenomena also allows the pushing of sleepers into the tunnel invert and survey results have shown variations in track height to confirm this, which also correlates to the track geometry fault data;
  - As a result, the Invert is in poor to marginal condition at the up end from CH0 to CH120 and requires immediate action;
- An additional concern arising from the low-strength clay is the stability of the arch with reduced capacity of the compression strut across the invert;
- SMEC proposes a number of recommendations be implemented to address these issues, including both short and medium/long term actions. It is recognised that some of the actions have lead times which may include determining the availability of sufficient-length occupations for the works and confirming funding, but these are listed in terms of recommended priority without considering such limitations.

### Short Term / Immediate actions

a. **Immediate** (< 3 months): Remove the vegetation at either end of the tunnel and replace with suitable, non-invasive low level shrubs/groundcover, if vegetation is required for aesthetic reasons. Otherwise the vegetation simply could be removed and mulched/stumps ground out and suckers poisoned;

b. **Immediate**: Clean out adequate-condition drainage system elements which are blocked with debris, grout etc. It is noted that the current brick pits are in poor condition, so extreme care should be taken when removing pit lids, with the ability to replace failed/broken items within the same occupation (e.g. replacement Pits/pipes and contractors on standby). This action could be dispensed with for drainage elements outside the tunnel if V/Line enacted item d) below instead, immediately;

c. **Short term** (within 12 months): Design and construct an integrated tunnel base drainage improvement program, comprising the following:
   - i. Hydraulic analysis and design of the system, to confirm sizing. This may require some minor additional survey, service locating/proving and soil tests outside the tunnel;
   - ii. Undertake a detailed Ground Penetrating Radar (GPR) survey of the tunnel base to confirm the extent of the damaged bricks and underlying material, to help identify any risks associated with underboring, such as historical areas with fill;
   - iii. Directionally drill a sufficient diameter pipe (225m diameter minimum, for ease of maintenance) from the Up End to the Down End below the invert to allow water trapped in the sandy layer to drain through the clay layer;
   - iv. Remove a section of the brick invert every 20 m and replace with no-fines concrete to allow connection to the new subsurface drain, to allow in-tunnel drainage;
   - v. Connect the underbored pipe to the repaired/improved external drainage network. If design analysis shows that the piped network grades and system capacity; (including outfall constraints) are not sufficient or at the required level, this may require an alternative such as a wet well with automated pumps at the Up End to take the outfall from the new drains;
   - vi. Connect or replace the terminated existing drain at CH 0 beneath the sleepers to the external drainage and/or new wet well;

vii. Install groundwater bores prior to installing the proposed underbored pipe to both alleviate (or validate) concerns about the location of the groundwater table and monitor any water table movement resulting after the pipe installation. This will better define the tunnel surrounds groundwater conditions for any future design purposes, and to determine if the water ingress is related to surface flow, or groundwater seepage. The indicative scope of the additional groundwater monitoring would include the following:
    i. 3 no. standpipe piezometers with targeted screens across the tunnel profile to a maximum depth of 20m at:
        1. CH 40 (Ryrie St)
        2. CH 80 (Wesley Pl)
        3. CH 150 (Lt. Ryrie St)
    ii. 2 no. post installation visits to monitor the water levels
    iii. Additional visits as required following completion of drainage works

    This recommendation has been provided as indicative information only and should be refined based on a more thorough desktop study and scope planning by a hydrogeologist.

d. **Short term:** Replace or construct required elements of missing or poor condition drainage network located *outside* the tunnel within 1 year. The pits and pipes at the down end of the tunnel should be replaced with equal or larger sized pipes, subject to design and hydraulic analysis checks. Pits 1 to 8 should be replaced with precast concrete pits with grated lids.
e. **Short term:** Install weepholes in the tunnel where missing (e.g. shotcrete section) and clean out non-functioning weepholes;

Immediate and short term actions have preliminary cost estimates shown in **Appendix M**.

### Medium to Long Term (within 3-5 years)

- The short term drainage improvements listed above are considered interim, and are not expected to fully solve the drainage problems present at the site. It is also considered highly unlikely that the clays can be easily strengthened by grout or lime injection or other subsoil improvement techniques, and to whatever degree they *can* be strengthened, will not deal with the poor subsoil drainage problem present at the clay subgrade section;
- Therefore the recommended long term solution is to reconstruct the invert with either precast units or cast insitu concrete with direct-fixed rail, designed specifically for the application. As this is a major project involving significant cost and train service interruption, it should be 'done once and done fully', anticipating the tunnel geometry changes required by the (probably eventual) conversion of the line to electrification;
- This will require the tunnel base lowering due to the current very tight clearances. Lowering the tunnel invert is a complex process which must anticipate multiple risks;
- Such a project will also have to allow for the resulting transition of the track either side, to accommodate the lower grades through the tunnel, and the cost of this cannot reasonably be estimated *without a fully developed concept design being carried out first*;
- In order to achieve this, some additional investigations/tests are required as part of developing a concept design:

a. Bore holes must be carried out both vertically and horizontally at the base of the tunnel to confirm if any voiding is present, and to better define the subgrade change from sand to clay base. The horizontal bores can also be used to calibrate a Ground Penetrating Radar (GPR) unit to allow detailed scans of the walls and to calculate pull out load capacities for rock bolt designs.
b. Test pits at the intrados arch to invert connection or 'hitch'.

- The long term solution is likely to use rock bolts to secure the base of the arch, allowing the removal of the brick invert and replacing it at a lower level with a concrete invert with a functioning drainage system. Any other cosmetic or structural repairs to the tunnel itself should be incorporated into the long term solution design, but can otherwise wait unless new problems present beforehand;
- It is assumed that the immediate/short term actions would be carried out within 12 months, but that the longer terms works would take a minimum of 3 years to be carried out according to the following indicative timeframe:
  - **Year 1**: Conceptual design including detailed further investigations, cost estimates, project Gantt, Risk assessment and business case development. The estimated cost for these tasks and the additional testing described above is included in **Appendix M**;
  - **Year 2**: Detailed design, cost revision, funding approval, occupation/communications planning and permits;
  - **Year 3**: construction and commissioning.
- The State government capital funding cycle and prioritisation process may cause this to be longer than the practical minimum suggested above, therefore it is recommended that the risk assessment recommended to be carried out in year 1 examines and highlights the potential for eventual failure of the tunnel due to the softening of the subgrade soils under load, to see what remaining life the tunnel has in its current configuration. If this is too complex to reliably estimate, it is recommended that the long term work be completed within 5 years, on the basis of applying the 'precautionary principle' to complex engineering risks.

# 2. ABBREVIATIONS AND ACRONYMS

*Table 2.1 Abbreviations and Acronyms*

| Abbreviation/ Acronym | Description |
|---|---|
| km | Kilometres |
| m | Metres |
| mm | Millimetres |
| RFQ | Request for Quotation |
| TOR | Terms of Reference |

# 3. INTRODUCTION

## 3.1. Background

Following the issue of a Request for quote issued by V/Line which closed on 26th September 2016, SMEC Australia was engaged by V/line Pty Ltd on 19th October 2016 to carry out a special investigation on the Geelong Tunnel, located on the Warrnambool railway line at chainage 72.930km, south of Geelong station.

The tunnel carries the railway under Ryrie St, Little Ryrie St, Myers St and Little Myers St beneath residential and commercial properties. The tunnel is approximately 425m in length and constructed with a brick base and liner. Geelong Tunnel is protected by a Heritage Overlay, therefore any inspection tasks undertaken had to comply with the corresponding restrictions.

All chainages are distances to Flinders Street station in Melbourne.

## 3.2. Scope of Works

In accordance with the Request for Quotation (RFQ) and subsequent agreed scope variations, the key scope items required for this project have been summarised in Table 3.1.

*Table 3.1 Scope of Works*

| Scope Item | Task |
|---|---|
| 1 | Analytical Interpretation of Lidar results |
| 2 | History Review |
| 3 | Site Investigation including geotechnical investigation and additional survey |
| 4 | Proposed Remedial Measures |

## 3.3. Supplied Documentation

Following is the list of supplied documentation from V/Line Pty Ltd;

- DMS Historical drawings;
- Inspection and design standards;
  - NIST-2616
  - NIST-2659
  - NIST-2707
  - NIWI-2707.1
  - SAMG-45
- V/Line report 'TC-ENG-12019, Geelong Tunnel – Excessive Mud Spots Within Tunnel – Preliminary Site Investigation',
- Report titled 'Geelong Tunnel Drainage Infrastructure – Preliminary Observations 3/11/16 – Draft Rev A', which was inclusive of 1961 drainage plans on the vicinity. The report author is not stated but assumed by SMEC to be a V/Line internal document;
- Point cloud data;
  - Unified 0.05m.rcs
- Cross sections of kinematic envelope within the tunnel,

- Track Geometry File;
  - Track Geometry Faults 201609 21.xlsx
- CCTV Video footage from September 2016 for a portion of the external piped drainage network.

# 4. METHODOLOGY

## 4.1. History Review

SMEC accessed and reviewed the V Line, PTC and Victrack historical records, drawings and previous inspection reports, collated the data and developed a historical view of the tunnels condition, defects and past repair works.

## 4.2. Point Cloud Data

SMEC reviewed the point cloud data and historical design drawings to develop an 'original design' 3D tunnel model and actual conditions 3D tunnel model for comparison. SMEC compared the tunnel cross section shape, design vs. actual, and determined the significance of the variances.

## 4.3. Access

Safe access for working within the rail corridor was provided by a safe working level 3 Track Force Protection Coordinator (TFPC), provided by Skilled. SMEC staff David Gardiner, Andrew Hassall and Ashley Robertson and subcontractors Hasan Hamzic, Martin Downey & Brad Hepworth from geotechnical testing subcontractor Geotesta Pty Ltd were inducted to the project JSEA/SWMS and John Holland's site induction/JSEA, V/line contractor induction system and held Rail Industry Worker cards and Level 1 Track Safety training approved by V/Line. SMEC and Geotesta accessed the tunnel via the McKillop St level crossing approximately 100m from the down end portal.

## 4.4. Site Inspection

A site visual inspection was undertaken to assess the current condition of the tunnel, and coordinated with the other site investigation activities. The visual inspection involved the following:

1. Observation of general geometry of the tunnel and any significant deviations or deformities.
2. Assessment of the condition of the bricks (tunnel lining), mortar and bluestone/brick portals, noting defect ratings and overall condition ratings for each 10m section. The inspection template was based on V/Lines documents; NIST-2707 & NIWI-2707.1. As the main focus of the investigation was the tunnel base, the walls, end portals and roof were given less focus than the recent similar inspection at Big Hill Tunnel;
3. Locations of any water ingress and/or soil or sediment ingress and weep holes checked to determine if they were functioning;
4. Stormwater drainage (piped/surface) was reviewed to check condition and function;
5. A review of any previous repairs was carried out;
6. Photographs of all relevant defects and asset component conditions were taken.

The photo log is included with this report as Appendix A.

## 4.5. Exposing Base of tunnel

As mentioned above, a main focus of the investigation was to expose and assess the tunnel base condition and function at regular intervals. John Holland exposed the base of the tunnel at the designated 10m intervals for CH 0 to CH 120 and (approximately) 30m intervals from CH 120 to CH 425 as per item 4.3.2 of the RFQ. John Holland's crews utilised a small excavator, hi-rail dump truck and labourers to clear the ballast in these locations. SMEC inspected and recorded condition of brickwork, survey levels of brickworks, sleepers and rail and took photographs. The work by John Holland also facilitated the geotechnical testing (see item 4.7).

## 4.6. Vegetation Assessment

Sub consultant botanist Land Management Systems Pty Ltd (LMS) undertook the vegetation assessment as per item 4.3.6 of the RFQ. This focused on trees and saplings (within the 10m zone of each portal) which could foul the tunnel, potential root ingress that could structurally deform the brickwork and/or obstruct the drainage.

See Appendix G for report.

## 4.7. Geotechnical investigation

Sub contractor Geotesta undertook the task of drilling, site sampling/tests, laboratory analysis and reporting on geotechnical conditions in the tunnel base. This was not part of the original scope listed in the RFQ, but was added to scope after discussions at the project pre-planning meeting held at V/Lines 'F gate' offices on 28 October 2016. The site sampling and testing was to be carried out at a minimum of 2 and maximum of 4 locations in the tunnel base.

## 4.8. Additional survey

Although a 3D scan of the tunnel was provided, it was agreed at the project pre-planning meeting held at V/Lines 'F gate' offices on 28 October 2016 to have SMEC carry out additional site surveying, aimed at checking the verticality of the tunnel portal walls (as some cracking/bulging had been observed) and also the degree of subsidence of brick base or sleepers below rail created by the foundation conditions and drainage problems under dynamic load. The survey also was aimed at picking up relevant drainage asset details, especially pipe or pit invert levels.

# 5. RESULTS OF INVESTIGATION

## 5.1. History Review

A review of previous inspections and defects documents from V/Line and VicTrack have been consolidated in Appendix E, excluding V/Line's own internal reports (2013, 2016). Most notably recent reports from V/Line indicate that the base of the tunnel is deteriorating rapidly from water infiltration, drainage within the tunnel and outside the tunnel are damaged and/or not operating effectively. Overall findings include bulges in the tunnel lining, voids behind the brickwork and mortar loss. The majority of these areas have been repaired over time. A major repair of the lining was completed in the sections of the tunnel beneath roads. These sections have been strengthened using 'Shotcrete' (sprayed concrete). There are also works orders detailing repointing works in areas of significant mortar loss.

In addition to the V/Line provided data, SMEC was able to access various documents from the Victrack archive, which included;

- Inspection Report, Golder Associates, December 19th 1979;
- Various inspection notes dated from 1979 to 1993;
- P.T.C. & V/Line Repair Works Orders dated from 1981 to 1991;
- Slope Stability Assessment Report, Statewide Geotechnical Services Pty Ltd, 18/06/93;
- Tunnel strengthening design by Kinhill, 1995.

## 5.2. Review of Point Cloud Data

Point Cloud data has been analysed using the software "3d Reshaper" by Technodigit. The original tunnel design section was modelled and compared to the actual tunnel from the point cloud.

Cross sections showing this comparison can be found in Appendix C - Cross Section Comparison.

A "heat map" of deformation and long section of tunnel alignment can be found in Appendix D – Deformation Heat Map Drawings.

## 5.3. Visual Inspection

Chainage 0 has been taken from the UP end portal running through to the DOWN end portal at chainage 425. For complete list of Tunnel Inspection Report notes see Appendix F. Appendix B contains drawings mapping defect locations and extents for mortar loss, brick face loss/erosion and water infiltration with links to photo numbers contained in Appendix A Photo Log.

### *5.3..1. Component overall condition ratings*

Component overall condition ratings (as per NIST-2707, section 8) have been summarised below in their respective 10m segments. Appendix F has further details on defects and comments/inspection site. The tunnel base was only inspected at 10m intervals for the first 120m, and then roughly at 30m intervals thereafter. In keeping with the main focus of the investigation, the tunnel base/invert is described in additional detail in section 5.3.3, per inspection location.

- **Up end Portal**

Component overall condition ratings are presented in Table 5.1:

*Table 5.1, Up end Portal*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Acceptable | Elm trees/suckers growing in and creating cracks in masonry |
| Mortar | Acceptable | Elm trees/suckers growing in and creating cracks in masonry |
| Bluestone | Acceptable | |

- **Chainage 0-10**

Component overall condition ratings are presented in Table 5.2:

*Table 5.2, Chainage 0-10*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Poor to Marginal | See section 5.3.3 |

- **Chainage 10-20**

Component overall condition ratings are presented in Table 5.3:

*Table 5.3, Chainage 10-20*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Marginal | See section 5.3.3 |

- **Chainage 20-30**

Component overall condition ratings are presented in Table 5.4:

*Table 5.4, Chainage 20-30*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Marginal | See section 5.3.3 |

- **Chainage 30-40**

Component overall condition ratings are presented in Table 5.5:

*Table 5.5, Chainage 30-40*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH34) | Good | |

| | | |
|---|---|---|
| Base | Marginal | See section 5.3.3 |

- **Chainage 40-50**

Component overall condition ratings are presented in Table 5.6:

*Table 5.6, Chainage 40-50*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Marginal | See section 5.3.3 |

- **Chainage 50-60**

Component overall condition ratings are presented in Table 5.7:

*Table 5.7, Chainage 50-60*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Marginal to Poor | See section 5.3.3 |

- **Chainage 60-70**

Component overall condition ratings are presented in Table 5.8:

*Table 5.8, Chainage 60-70*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH65) | Good | |
| Base (CH70) | Poor | See section 5.3.3 |

- **Chainage 70-80**

Component overall condition ratings are presented in Table 5.9:

*Table 5.9, Chainage 70-80*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Poor to Marginal | See section 5.3.3 |

- **Chainage 80-90**

Component overall condition ratings are presented in Table 5.10:

*Table 5.10, Chainage 80-90*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Marginal | See section 5.3.3 |

- **Chainage 90-100**

Component overall condition ratings are presented in Table 5.11:

*Table 5.11, Chainage 90-100*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH95) | Good | |
| Base | Marginal | See section 5.3.3 |

- **Chainage 100-110**

Component overall condition ratings are presented in Table 5.12:

*Table 5.12, Chainage 100-110*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Marginal to Acceptable | See section 5.3.3 |

- **Chainage 110-120**

Component overall condition ratings are presented in Table 5.13:

*Table 5.13, Chainage 110-120*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Acceptable to Good | See section 5.3.3 |

- **Chainage 120-130**

Component overall condition ratings are presented in Table 5.14:

*Table 5.14, Chainage 120-130*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 130-140**

Component overall condition ratings are presented in Table 5.15:

*Table 5.15, Chainage 130-140*

| Component | Condition Rating | Description |
|---|---|---|

| | | |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Shotcrete | New/Good | |
| Man Hole/Safe Zone (CH130) | Good | |
| Base | Not assessed | |

- **Chainage 140-150**

Component overall condition ratings are presented in Table 5.16:

*Table 5.16, Chainage 140-150*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base (CH150) | Good | See section 5.3.3 |

- **Chainage 150-160**

Component overall condition ratings are presented in Table 5.17:

*Table 5.17, Chainage 150-160*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH150) | Good | See section 5.3.3 |

- **Chainage 160-170**

Component overall condition ratings are presented in Table 5.18:

*Table 5.18, Chainage 160-170*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH162.5) | Acceptable | Minor spalling and water ingress |
| Base | Not assessed | |

- **Chainage 170-180**

Component overall condition ratings are presented in Table 5.19:

*Table 5.19, Chainage 170-180*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |

| | | |
|---|---|---|
| Base (CH180) | Good | See section 5.3.3 |

- **Chainage 180-190**

Component overall condition ratings are presented in Table 5.20:

*Table 5.20, Chainage 180-190*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH180) | Good | See section 5.3.3 |

- **Chainage 190-200**

Component overall condition ratings are presented in Table 5.21:

*Table 5.21, Chainage 190-200*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH195) | Good | |
| Base | Not assessed | |

- **Chainage 200-210**

Component overall condition ratings are presented in Table 5.22:

*Table 5.22, Chainage 200-210*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH209) | Good | See section 5.3.3 |

- **Chainage 210-220**

Component overall condition ratings are presented in Table 5.23:

*Table 5.23, Chainage 210-220*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 220-230**

Component overall condition ratings are presented in Table 5.24:

*Table 5.24, Chainage 220-230*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |

| | | |
|---|---|---|
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH227) | Good | |
| Base | Not assessed | |

- **Chainage 230-240**

Component overall condition ratings are presented in Table 5.25:

*Table 5.25, Chainage 230-240*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH238) | Good | See section 5.3.3 |

- **Chainage 240-250**

Component overall condition ratings are presented in Table 5.26:

*Table 5.26, Chainage 240-250*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 250-260**

Component overall condition ratings are presented in Table 5.27:

*Table 5.27, Chainage 250-260*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 260-270**

Component overall condition ratings are presented in Table 5.28:

*Table 5.28, Chainage 260-270*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH260) | Good | |
| Base (CH267) | Good | See section 5.3.3 |

- **Chainage 270-280**

Component overall condition ratings are presented in Table 5.29:

*Table 5.29, Chainage 270-280*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 280-290**

Component overall condition ratings are presented in Table 5.30:

*Table 5.30, Chainage 280-290*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 290-300**

Component overall condition ratings are presented in Table 5.31:

*Table 5.31, Chainage 290-300*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH294) | Good | |
| Base (CH296) | Acceptable | See section 5.3.3 |

- **Chainage 300-310**

Component overall condition ratings are presented in Table 5.32:

*Table 5.32, Chainage 300-310*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 310-320**

Component overall condition ratings are presented in Table 5.33:

*Table 5.33, Chainage 310-320*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 320-330**

Component overall condition ratings are presented in Table 5.34:

*Table 5.34, Chainage 320-330*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH326) | Good | See section 5.3.3 |

- **Chainage 330-340**

Component overall condition ratings are presented in Table 5.35:

*Table 5.35, Chainage 330-340*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Acceptable | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 340-350**

Component overall condition ratings are presented in Table 5.36:

*Table 5.36, Chainage 340-350*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 350-360**

Component overall condition ratings are presented in Table 5.37:

*Table 5.37, Chainage 350-360*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH358) | Acceptable | |
| Base (CH356) | Good | See section 5.3.3 |

- **Chainage 360-370**

Component overall condition ratings are presented in Table 5.38:

*Table 5.38, Chainage 360-370*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |
| Mortar | Good | |

| | | |
|---|---|---|
| Weephole | Acceptable | |
| Shotcrete | New/Good | |
| Base | Not assessed | |

- **Chainage 370-380**

Component overall condition ratings are presented in Table 5.39:

*Table 5.39, Chainage 370-380*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 380-390**

Component overall condition ratings are presented in Table 5.40:

*Table 5.40, Chainage 380-390*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Man Hole/Safe Zone (CH390) | Good | |
| Base (CH387) | Good | See section 5.3.3 |

- **Chainage 390-400**

Component overall condition ratings are presented in Table 5.41:

*Table 5.41, Chainage 390-400*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 400-410**

Component overall condition ratings are presented in Table 5.42:

*Table 5.42, Chainage 400-410*

| Component | Condition Rating | Description |
|---|---|---|
| Shotcrete | New/Good | |
| Brick | Good | |
| Mortar | Good | |
| Weephole | Acceptable | |
| Base | Not assessed | |

- **Chainage 410-425**

Component overall condition ratings are presented in Table 5.43:

*Table 5.43, Chainage 410-425*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Good | |

| | | |
|---|---|---|
| Mortar | Good | |
| Weephole | Acceptable | |
| Base (CH416) | Good | See section 5.3.3 |

- **Down end Portal**

Component overall condition ratings are presented in Table 5.44:

*Table 5.44, Down end Portal*

| Component | Condition Rating | Description |
|---|---|---|
| Brick | Acceptable | Some cracks with trees growing through |
| Mortar | Acceptable | |
| Bluestone | Good | |

#### *5.3..2. Component defect ratings*

Defects found included brick face loss/spalling/brick erosion, mortar loss, efflorescence and water ingress, assessed as per Appendix H. For a complete list of all defects refer to Appendix F, for maps of defect locations refer Appendix B.

No Category 5 or 6 defects were found during the course of the inspection. Category 4 Defects are summarised in Table 5.45:

*Table 5.45, Category 4 Defects*

| Chainage | Location | Description |
|---|---|---|
| 0 | Base | Wet with poor drainage and damaged brick at edges. Refer photos 1-3 |
| 10 | Base | Inadequate drainage |
| 20 | Base | Very wet and muddy, non functioning geofabic wrapped drain. Refer Photos 12-15 |
| 30 | Base | Very wet and muddy, non functioning geofabic wrapped drain. Refer Photos 17-19 |
| 40 | Base | Very wet and muddy, non functioning geofabic wrapped drain. Refer Photos 26-28 |
| 50 | Base | Inadequate drainage. Refer photos 41-44 |
| 60 | Base | Very wet and muddy, sunken sleeper. Refer Photos 46-51 |
| 70 | Base | Very wet and muddy, sunken sleepers, broken bricks and drain. Refer Photos 55-60 |
| 80 | Base | Inadequate drainage, bricks softening, Refer Photos 64-68 |
| 90 | Base | Muddy and submerged |
| 100 | Base | Submerged in water |
| 110 | Base | Damp – drainage inadequate. Refer photos 75-76 |

Overall the tunnel can be described as being in good condition, albeit there are deformations and various minor defects.  Most defects were category 2, with a few category 3. The exception to the general good condition is the tunnel base, which is in marginal to poor condition at the 0-100m chainage and acceptable to good for the remainder.

### *5.3..3. Exposing of Tunnel Invert*

As there was a high degree of focus on the function and condition of the tunnel base or invert, this information is presented here, by chainage, to expand upon the general condition information presented above. The associated defects are listed in Appendix F.

- **Chainage 0**

Findings are presented in Table 5.46:

*Table 5.46, Exposing of Base, Ch 0*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet |
| Drainage | Poor | No drain |

- **Chainage 10**

Findings are presented in Table 5.47:

*Table 5.47, Exposing of Base, Ch 10*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet, Geo fabric over base |
| Drainage | Marginal | |

- **Chainage 20**

Findings are presented in Table 5.48:

*Table 5.48, Exposing of Base, Ch 20*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet, very muddy, geo fabric over base |
| Drainage | Marginal | Drain broken |

- **Chainage 30**

Findings are presented in Table 5.49:

*Table 5.49, Exposing of Base, Ch 30*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Saturated, Geo fabric over base |
| Drainage | Marginal | |

- **Chainage 40**

Findings are presented in Table 5.50:

*Table 5.50, Exposing of Base, Ch 40*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet, Geo fabric over base |
| Drainage | Marginal | |

- **Chainage 50**

Findings are presented in Table 5.51:

*Table 5.51, Exposing of Base, Ch 50*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet, Geo fabric over base |
| Drainage | Marginal | |

- **Chainage 60**

Findings are presented in Table 5.52:

*Table 5.52, Exposing of Base, Ch 60*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Poor | Submerged |
| Drainage | Poor | |

- **Chainage 70**

Findings are presented in Table 5.53:

*Table 5.53, Exposing of Base, Ch 70*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Poor | Muddy, Saturated, broken bricks |
| Drainage | Poor | |

- **Chainage 80**

Findings are presented in Table 5.54:

*Table 5.54, Exposing of Base, Ch 80*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Wet, Geo fabric over base |
| Drainage | Marginal | |

- **Chainage 90**

Findings are presented in Table 5.55:

*Table 5.55, Exposing of Base, Ch 90*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Muddy, submerged |
| Drainage | Marginal | |

- **Chainage 100**

Findings are presented in Table 5.56:

*Table 5.56, Exposing of Base, Ch 100*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Marginal | Submerged |
| Drainage | Marginal | |

- **Chainage 110**

Findings are presented in Table 5.57:

*Table 5.57, Exposing of Base, Ch 110*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Acceptable | Damp, Geo fabric over base |
| Drainage | Acceptable | |

- **Chainage 120**

Findings are presented in Table 5.58:

*Table 5.58, Exposing of Base, Ch 120*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 150**

Findings are presented in Table 5.59:

*Table 5.59, Exposing of Base, Ch 150*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Dry |
| Drainage | Good | |

- **Chainage 180**

Findings are presented in Table 5.60:

*Table 5.60, Exposing of Base, Ch 180*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Acceptable | Drain torn |

- **Chainage 209**

Findings are presented in Table 5.61:

*Table 5.61, Exposing of Base, Ch 209*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 238**

Findings are presented in Table 5.62:

*Table 5.62, Exposing of Base, Ch 238*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Acceptable | Drain torn |

- **Chainage 267**

Findings are presented in Table 5.63:

*Table 5.63, Exposing of Base, Ch 267*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 296**

Findings are presented in Table 5.64:

*Table 5.64, Exposing of Base, Ch 296*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Dry |
| Drainage | - | Drain unknown, concrete in base |

- **Chainage 326**

Findings are presented in Table 5.65:

*Table 5.65, Exposing of Base, Ch 326*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 356**

Findings are presented in Table 5.66:

*Table 5.66, Exposing of Base, Ch 356*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 387**

Findings are presented in Table 5.67:

*Table 5.67, Exposing of Base, Ch 387*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Mostly dry |
| Drainage | Good | |

- **Chainage 416**

Findings are presented in Table 5.68:

*Table 5.68, Exposing of Base, Ch 416*

| Component | Condition Rating | Description |
|---|---|---|
| Brick Base / Invert | Good | Dry |
| Drainage | Good | |

#### *5.3..4. Vegetation*

Key findings from Arborists report are outlined below. Refer Appendix G for full report.

The arborists report detailed 7 species of trees in the 10m zone of the up portal and 3 species at the down end portal. These trees have potential to foul the tunnel, and create potential root ingress that could structurally deform the tunnel lining and/or obstruct the drainage.

At the Up end portal there are numerous trees and shrubs, it is recommended to remove or treat vegetation growing directly above the portal, prune low hanging branches on the eastern embankment and remove the peppercorn tree on the western embankment.

The down end portal is dominated with Elm trees and Elm tree suckers are growing through cracks in the tunnels portal and around the portal. It is recommended to chemically treat and/or remove Elm tree suckers growing above the portal and around the brickwork.

It is understood that no permit would be required for the removal of the vegetation listed above. The arborist's report advises that removal of the native 'Kangaroo Apple' will not require a permit under the exemption listed in Clause 52.17-7 (Planning and Environment Act) which states that no permit is required to remove, destroy or lop native vegetation to the minimum extent necessary "*to maintain the safe and efficient function of an existing railway*" etc. V/Line's environment officer should confirm this assumption before removal works are undertaken.

#### *5.3..5. Drainage*

The rail falls from the McKillop St Level crossing about 100m from the Down-Portal to past the Up-Portal near Geelong station. Drainage within the tunnel consists of a centrally located geo-fabric wrapped slotted plastic drain pipe sitting on the invert of the tunnel base. The size of the drain is approximately 300x25mm from the point observed at CH 416 – CH 110. At CH296 there was rough concrete in the base and the drain was not observed at this location and was possibly removed when the concrete invert was installed. From CH 100-10 the drain was observed to be 150x25mm, however there was no drain at CH 0 and no obvious connection of the sections observed with the external drainage network.

External drainage at the down end consists of grated pits on either side of the rail shoulder. The pits on the western side are connected under the rail to pits opposite on the eastern side and discharging to the south. It is noted that the majority of these pits had substantial water in them indicating that many of the pipes in the system are blocked.

External drainage at the up end of the tunnel consists of open swale drains on both sides of the track connecting to brick pits and piped to the discharge point north of the Gordon Library building. This piped network appears to be functioning correctly although doesn't appear to be effectively connected to the tunnel drainage.

The majority of weepholes through the tunnel don't appear to be functioning properly, as evidence by them appearing to be dry and surrounding areas of brickwork showing water infiltration. The water infiltration observed is not evidence that the water table is above the tunnel invert, as it is usual for surface water to migrate through soil layers down to areas where it is trapped, and/or down to the water table. The Geotesta report from 2013 (GE2029-13) records groundwater wells that were installed to 6m deep within the four foot of the tunnel at approximate CH 25 (BH1) and Ch75 (BH2). These locations were apparently selected based on observations of significant water presence within the tunnel. At the time of monitoring by Geotesta, the wells showed:

a. BH1 groundwater depth 0.25m

b. BH2 groundwater depth 0m

It is noted that the wells were constructed with full depth screen including into the ballast layer. SMEC considers that this is not the ideal well construction methodology as it leads to the opportunity for surface water to enter the standpipe rather than exclusively collecting water from subsurface profiles. However as the purpose of the Geotesta groundwater bores was to sample and determine the source of the water (e.g. stormwater vs sewer leaks), this may partly explain the choice of method used. This issue is discussed further in sections 5.3.7 and 6.3.

Some areas of shotcrete contain no weepholes.

Drainage can be summarised as being poor to non-functioning within the tunnel, and functioning or in poor condition outside the tunnel, with inadequate to no connections between the in/outside tunnel systems. Tunnel drainage problems are exacerbated by the nature of the soils around and below the tunnel – refer section 5.3.7 below.

#### *5.3..6. Signs*

Signage consists of several sign attached to the portals at either end, indicating speed restrictions and reflective hazard indicators, there are also reflective numbered plaques approximately 200x200mm through the tunnel on the left wall indicating chainage every 10m.

External signage is generally in relatively good condition. The chainage plaques within the tunnel are legible and in reasonable condition although many of these plaques are semi covered in light render overspray and the majority have limited retro reflectivity.

#### *5.3..7. Geotechnical investigation*

Key findings from the Geotechnical report are outlined below.

Sub-contractor Geotesta under took the drilling of four boreholes to depths of 3 metres. Borehole locations were decided on site during the occupation and are as follows;

- BH 1, CH240
- BH 2, CH120
- BH 3, CH70
- BH 4, CH30

Bore Holes 1 & 2 contained a sandy layer allowing water to pass through although Bore Holes 3 & 4 encountered only clay. Water seepage was evident through the tunnel indicating water in the soil surrounding the tunnel. Poor site drainage along with the low permeability of the clay is consioderd to be causing the water ponding in the upper section of the tunnel. The clay is also considered by SMEC to be of insufficient bearing capacity to form an adequate base for the tunnel dynamic train loads, which leads to the subsidence problems and resulting track geometry faults. This low bearing strength is exacerbated by the tunnel base being constructed of bricks (which are segmented, unreinforced and subject to crushing, softening and dislodgement), of the construction being very old and by the tunnel base being constantly wet in the 0-110m chainage section due to the inadequate drainage issues.

#### *5.3..8. Additional survey*

Additional survey undertaken by SMEC included checking the verticality of the portal walls and survey of the rail level through the tunnel. At each site where the base had been exposed levels were taken on top of sleepers on the outside edge, corresponding brick level at that edge as well as central drain obvert levels.

The tunnels portals are close to vertical and show only very minor signs of leaning or tilting, both portals have tilted by approximately 20mm from the base to the top of the tunnel arch. The cracking concerns of V/Line at the down end portal are probably due to the invasive action of the trees present, which if removed may be stabilised and repaired, though should continue to be monitored. There is no evidence that the wall itself is failing and overturning.

The track rail levels taken show deviations in the rail height corresponding to the track geometry fault data provided as well as the 3d point cloud provided, though these faults occur between chainages 0 to 120 only, with the remainder of the track in good condition. There was no evidence of additional subsidence or heave between the October 2016 point cloud survey and the November 2016 additional site engineering survey.

Generally the base sections were consistent, in that the sleepers were resting on the brick base on the outside edges. The major area of concern is around CH70 where the brick base is breaking up, and where the survey determined that the rail level has a dip between CH60 – CH80 and the base has also heaved in the order of 60mm, resulting in the top of sleeper (~120mm thick) approximately the same level as top of brick. The depth of punching in these locations are as follows; CH60 – no punching, CH70 – 90-130mm depth of punching & CH80 – no punching. CH 70 was the only location where brick punching was observed, no other instances were observed. Refer detailed sections in Appendix O for more information.

The external drainage at both ends of the tunnel was also surveyed, pipe invert levels, diameters, pit invert levels and pit sizes were recorded where possible. Due to the condition of the drainage pits at the down end of the tunnel, grated pit lids were unable to be removed due to concern of the brick pits collapsing. Pit invert levels were taken as an estimated substitute for pipe invert levels. Drainage plans are included in Appendix K.

# 6. DISCUSSION

## 6.1. Point Cloud Data Review

Point Cloud data has been analysed using the software “3d Reshaper” by Technodigit. The original tunnel design section was modelled and compared to the actual tunnel from the point cloud.

Generally the cross section shape follows that of the original design drawings, there are some sections of deformation although these areas are adjacent sections that have been treated with shotcrete. A “heat map” of this deformation can also be found in Appendix D.

See Appendix C - Cross Section Comparison.

Surveyed points of tunnel portals were compared with the point cloud data and line up reasonably well, there is no major variations between them.

## 6.2. Site Inspection Findings

From the past historical records and inspection reports it is evident that the areas of the tunnel wall and roof throughout the tunnel that were of worsening condition have been treated with shotcrete, and this has stopped further deterioration to the bricks and mortar in these areas. The shotcrete sections were found to be generally in new-good condition with some areas showing minor cracking and minor efflorescence, and were not provided with adequate weepholes.

There appears to be no structural defects or deformation in the tunnel lining resulting from vegetation growing above the tunnel. The down end portal has a large amount of Elm tree suckers growing around and also in cracks in the portal. These should be removed and the soil allowed to stabilise and recover and the cracks repaired, subject to Heritage permit restrictions.

The major concern is the Tunnel Drainage, particularly within the tunnel, as it is not functioning correctly and (combined with the soft soils and trapping of water) is causing continual issues with track alignment as the soft soil base allows vertical, differential movements of the structures supporting the track.

This is a natural result of the location in which the tunnel was built and the nature and standard of construction. No doubt the techniques in 1862 were considered appropriate at that time, but given the prevailing geological conditions, are manifestly inadequate for a modern rail network.

## 6.3. Recommendation/Remedial works

The tunnel walls and crown are in good condition and require no further action for at least 5 years, provided that V/Line internal operation monitoring identifies no significant degradation in condition.

The Invert is in poor condition at the up end from CH0 to CH120 and requires immediate action. The Sub base to 1 m below the invert consists of soft clays with bearing capacities as low as 120 kPa. Being saturated, the brick invert is able to deflect under Train loads, which is damaging the bricks as can be seen from the brick rubble in some of the inspection photos. This allows the pushing of sleepers into the invert and survey results have shown variations in track height to confirm this.

The issue of the invert crushing is not the main concern, as it could be continually fixed via maintenance interventions (including the option of grouting the entire failed invert section base/ballast with a material such as listed in Appendix N), albeit these are not cost effective in the long term, delay the inevitable and the rail system reliability will always suffer interruptions to service reliability. The main concern is the stability of the arch with reduced capacity of the compression strut across the invert. There is an approx. 8 m fall from the Down End to the Up End and a sandy layer beneath the invert at the Down End allows water to travel subsurface to the Up

End where the sandy layer disappears, leaving the water with nowhere to go. The following recommendations are made with reference to the Sketches and schematic plans provided in Appendices K & L. It is recognised that some of the actions have lead times which may include availability of sufficient-length occupations for the works and funding, but are listed in terms of priority without considering such limitations.

- **Short Term / Immediate (< 12 months)**

a. **Immediate (< 3 months):** Remove the vegetation at either end of the tunnel and replace with suitable, non-invasive low level shrubs/groundcover, if vegetation is required for aesthetic reasons. Otherwise the vegetation simply could be removed and mulched/stumps ground out and suckers poisoned. This action could be done immediately

b. **Immediate (< 3 months)**: Clean out adequate-condition drainage system elements which are blocked with debris, grout etc. It is noted that the current brick pits are in poor condition, so extreme care should be taken when removing pit lids, with the ability to replace failed/broken items within the same occupation (e.g. replacement Pits/pipes and contractors on standby). This action could be dispensed with for drainage elements outside the tunnel if V/Line enacted item d) below instead, immediately;

c. **Short term (within 12 months):** Design and construct an integrated tunnel base drainage improvement program, comprising the following:

   i. Hydraulic analysis and design of the system, to confirm sizing. This may require some minor additional survey, service locating/proving and soil tests outside the tunnel;
   ii. Undertake a detailed Ground Penetrating Radar (GPR) survey of the tunnel base to confirm the extent of the damaged bricks and underlying material, to help identify any risks associated with underboring, such as historical areas with fill;
   iii. Directionally drill a sufficient diameter pipe (225m diameter minimum, for ease of maintenance) from the Up End to the Down End below the invert to allow water trapped in the sandy layer to drain through the clay layer;
   iv. Remove a section of the brick invert every 20 m and replace with no-fines concrete to allow connection to the new subsurface drain, to allow in-tunnel drainage;
   v. Connect the underbored pipe to the repaired/improved external drainage network. If design analysis shows that the piped network grades and system capacity; (including outfall constraints) are not sufficient or at the required level, this may require an alternative such as a wet well with automated pumps at the Up End to take the outfall from the new drains;
   vi. Connect or replace the terminated existing drain at CH 0 beneath the sleepers to the external drainage and/or new wet well;
   vii. It may also be appropriate to install groundwater bores prior to installing the proposed underbored pipe to both alleviate or validate concerns about the location of the groundwater table and monitor any water table movement resulting after the pipe installation. To better define the tunnel surrounds groundwater conditions for any future design purposes, and to determine if the water ingress is related to surface flow, or groundwater seepage, a series of groundwater investigations and associated monitoring regime is recommended. In light of the observations during the site inspection an indicative scope of groundwater monitoring would include the following:
      - 3 no. standpipe piezometers with targeted screens across the tunnel profile to a maximum depth of 20m at:
         - CH 40 (Ryrie St)
         - CH 80 (Wesley Pl)

    - CH 150 (Lt. Ryrie St)
  - 2 no. post installation visits to monitor the water levels
  - Additional visits as required following completion of drainage works

  This recommendation has been provided as indicative information only and should be refined based on a more thorough desktop study and scope planning by a hydrogeologist.

d. **Short term:** Replace or construct required elements of missing or poor condition drainage network located *outside* the tunnel within 1 year. The pits and pipes at the down end of the tunnel should be replaced with equal or larger sized pipes, subject to design and hydraulic analysis checks. Pits 1 to 8 should be replaced with precast concrete pits with grated lids.

**e. Short term:** Install weepholes in the tunnel where missing (e.g. shotcrete section) and clean out non functioning weepholes**;**

Immediate and short term actions have preliminary cost estimates shown in **Appendix M**.

- **Long Term (3-5 years)**

The drainage improvements listed above are considered interim, are not expected to fully solve the drainage problems at the site, and cannot solve the understrength clay subgrade issue. It is also considered highly unlikely that the clays can be easily strengthened by grout or lime injection or other subsoil improvement techniques (which can create problems as well, such as grout lifting the bricks differentially), and to whatever degree they *can* be strengthened, will not deal with the poor subsoil drainage problem.

Therefore the recommended long term solution for this complex suite of problems is to reconstruct the invert with either precast unit or cast insitu concrete with direct-fix rail. As this is a major project involving significant cost and train service interruption, it should be 'done once and done fully', anticipating the conversion of the line to electrification. This will require the tunnel base lowering (by perhaps 300-400mm) due to the current very tight clearances. Lowering the tunnel invert is a complex process which must anticipate the risks associated with the subsequent undermining of the base of the tunnel side walls, the heritage nature of the brick tunnel, and the inherent risks in the original tunnel construction and subsequent events.

Such a project will also have to allow for the resulting transition of the track either side, to accommodate the lower grades through the tunnel, and the cost of this cannot reasonably be estimated without a fully developed concept design being carried out first.

In order to achieve this, some additional investigations are required as part of developing a concept design.

- Bore holes must be carried out both vertically and horizontally at the base of the tunnel to confirm if any voiding is present, and to better define the subgrade change from sand to clay base. The horizontal bores can also be used to calibrate a Ground Penetrating Radar (GPR) unit to allow detailed scans of the walls and to calculate pull out load capacities for rock bolt designs.
- Test pits at the intrados arch to invert connection or 'hitch'.

The long term solution is likely to use rock bolts to secure the base of the arch (refer **Appendix L**), allowing the removal of the brick invert and replacing it at a lower level with a concrete invert with a functioning drainage system. Any other cosmetic or structural repairs to the tunnel itself should be incorporated into the long term solution design, but can otherwise wait unless new problems present beforehand.

It is assumed that the immediate/short term actions would be carried out within 12 months, but that the longer terms works would take a *minimum of 3 years to be carried out*:

- **Year 1**: Conceptual design including detailed further investigations, cost estimates, project Gantt, Risk assessment and business case development;
- **Year 2**: Detailed design, cost revision, funding approval, occupation/communications planning and permits;
- **Year 3**: Construction and commissioning.

The State government capital funding cycle and prioritisation process may cause this to be longer than the practical minimum suggested above, therefore it is recommended that the risk assessment recommended to be carried out in year 1 examines and highlights the potential for eventual failure of the tunnel due to the softening of the subgrade soils under load, to see what remaining life the tunnel has in its current configuration. If this is too complex to reliably estimate, *it is recommended that the long term work be completed within 5 years, on the basis of applying the 'precautionary principle' to complex engineering risks*. It is not possible without detailed analysis to model the timing or likelihood of sudden failure of the compression strut at the failed invert section of the tunnel.

# APPENDIX A PHOTO LOG

# APPENDIX B DRAWINGS OF DEFECT LOCATIONS

# APPENDIX C CROSS SECTION COMPARISON

# APPENDIX D DEFORMATION HEAT MAP DRAWINGS

# APPENDIX E PREVIOUS INSPECTION HISTORY

# APPENDIX F TUNNEL INSPECTION REPORT NOTES

# APPENDIX G VEGETATION ASSESSMENT REPORT

# APPENDIX H V/LINE CONDITION AND DEFECTS RATINGS

# APPENDIX I DMS HISTORICAL DRAWINGS

# APPENDIX J GEOTECHNICAL INVESTIGATION REPORT

# APPENDIX K SCHEMATIC LAYOUT OF DRAINAGE IMPROVEMENTS

# APPENDIX L DRAINAGE IMPROVEMENT CROSS SECTION SKETCHES

# APPENDIX M PRELIMINARY COST ESTIMATES

# APPENDIX N DATA SHEET – BLUEY 'BLUE CEM HE80 AG'

# APPENDIX O DETAILED CROSS SECTIONS (CH 60-80)