Management of geotechnical risks for some tunnels in the Wellington Region

David Stewart
Opus International Consultants, Wellington, New Zealand

Keywords: tunnels, risk management, rock fall hazards, tunnel collapse, risk mitigation, Wellington Greywacke

ABSTRACT

Rock falls and lining failures are potential hazards in tunnels. The current paper presents three case histories of the management of tunnel risks in the Wellington Region. Rock fall inspections are required by Land Transport New Zealand in the Orongorongo water supply tunnel to allow use of the access railway through the tunnel. Inspections enable potential rock fall sites to be identified and allow mitigation measures to be recommended if required. Inspections at the Kaitoke water tunnels enable identification of actual or potential rockfall sites that could adversely affect the capacity of these key water supply tunnels. The Carey's Gully stream tunnel runs under Wellington's Southern Landfill. Sections of this tunnel were found to have substandard lining making the tunnel vulnerable to collapse. The risk of blockage with associated potential for overtopping of the landfill during a flood event was considered to be unacceptable. A programme of periodic inspections and drilling investigations has been carried out to facilitate management of the risk. Investigations in the Carey's Gully tunnel found that significant sections of roof concrete lining were inadequate to support long term design loadings. The drilling investigations provided confidence to implement a cost effective retrofit solution involving installation of steel beams to support the roof.

1 INTRODUCTION

Rock falls and roof collapses are potential hazards in tunnels. These can affect the functioning of the tunnel and present safety issues for persons accessing the tunnels.
This paper presents examples of the management of geotechnical risks for three tunnels in the Wellington Region (Figure 1). The tunnels considered are two partially lined water supply tunnels (Orongorongo and Kaitoke Tunnels) which form part of Greater Wellington (Regional Council)'s water supply network, and a fully lined tunnel carrying the Carey's Gully Stream under Wellington City Council's Southern Landfill.

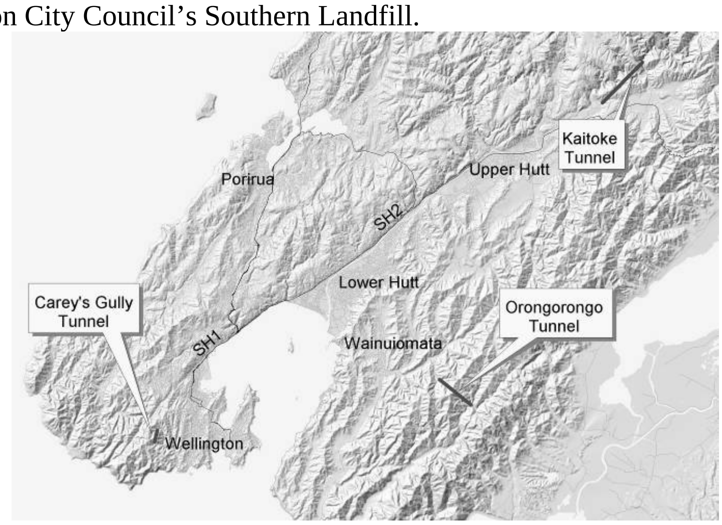

Figure 1 : Location map

Opus has provided risk management advice for each of these tunnels over a number of years, including recommendation and design of stabilisation measures, as required.

The risk assessment and mitigation measures recommended were generally based on the process outlined in AS/NZS 4360: 2003. This process involves assessment of the *Likelihood* of an event (in this case, Rock fall or Collapse) and the *Consequence* to the function (of the tunnel) and safety.

Case histories discussing the management of risk at the three tunnels are given below.

2 ORONGORONGO WATER SUPPLY TUNNEL

2.1 Background

The Orongorongo tunnel is 3.2 km long and carries a 700 mm diameter water supply pipe from the Orongorongo River catchment (Figure 1) to feed into Greater Wellington (GW)'s water distribution system at the Wainuiomata water treatment plant. The tunnel also includes a small gauge railway line to allow GW staff to service the pipeline and access the upstream catchment (Figure 2). The tunnel is approximately 2 m high and partially lined, with approximately 50% of the tunnel left unlined in highly fractured greywacke bedrock.
Inspection of the tunnel is required by Land Transport NZ to ensure safety of the staff using the railway, from rockfall hazards. Inspections by a geotechnical professional from Opus are undertaken at appropriate intervals (currently every 2 years) to assess the risks from rock fall hazards and to recommend any measures to mitigate risks.

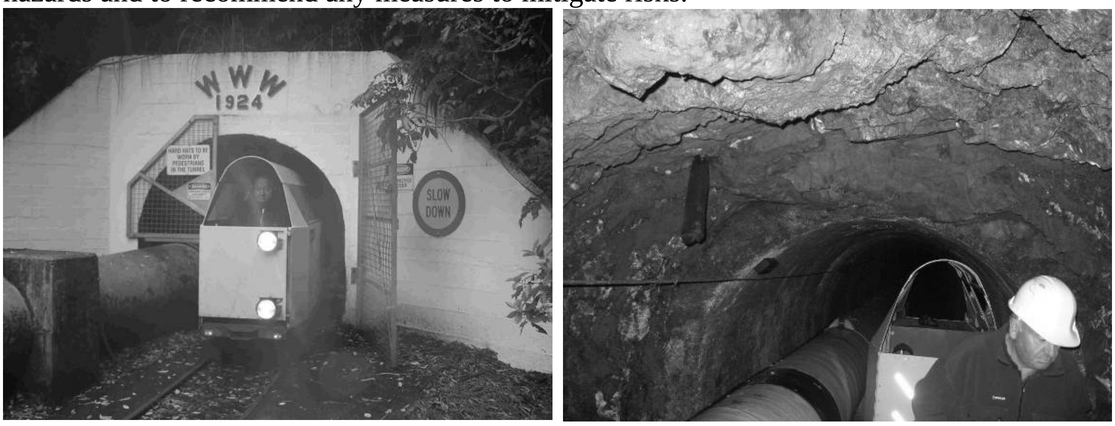

Figure 2: Orongorongo Tunnel, showing (a) railway jigger and water pipeline at portal, and (b) bedrock section of tunnel in foreground with concrete lined section beyond

2.2 Engineering Geology

The tunnel is constructed through Greywacke bedrock, which is typically closely to extremely closely fractured sandstone and siltstone, with block sizes normally less than 300 mm. Sheared seams and thin faults/crushed zones cross the tunnel at intervals with localised minor rock falls common at these points. In many sections the rock surrounding the tunnel is dilated with slight block separation (ie. is 'drummy' when tapped with hammer). Sites of rock falls occurring since the previous inspection are noted during the inspections in consultation with the jigger operator.

2.3 Risk Assessment

The hazards from rock falls include:

- Staff and/or jigger being struck by falling rocks
- Derailment of the jigger from rock fall debris on the railway line
- Damage to the water supply pipeline from rock fall events

Due to the relatively low frequency of staff accessing the tunnel (approx 3 trips/week) the *likelihood* of persons being hit by rock fall is assessed to be very low. The major trigger is considered to be a large earthquake - which has an extremely low probability of occurring when staff are present in the tunnel. The *likelihood* of derailment of the jigger from hitting rock fall debris is much higher but the consequence is lower. The risk of damage to the pipeline is not considered by GW to be a significant issue, partially because alternative water supply sources are available.

2.4 Risk Management

To manage the risk from rock falls, the following procedures are implemented:

- Hardhats and steel cap boots are mandatory for all persons entering the tunnel
- Speed restrictions and vigilance by the jigger operator to ensure that any rock fall debris on the railway line does not cause derailment.
- Localised scaling and/or shotcreting of the most unstable sections. Recent inspections have concluded that such measures are not essential to date due to the relatively low level of rock fall risk. However, rock bolting and shotcreting was carried out in 1996 in a section with adversely oriented widely spaced joints; this took place (during works to slightly widen sections of the tunnel) in order to mitigate the risk of falls of large blocks from the roof.
- Additional inspections are recommended after large earthquakes or if a large volume of rock fall occurs i.e. greater than $1m^3$.

3 KAITOKE WATER SUPPLY TUNNELS

3.1 Background

Two tunnels of 600 m and 2 km length convey water directly from the Hutt River at Kaitoke Regional Park to the Te Marua Treatment plant (Figure 1). These tunnels are partially lined with a semi circular cross section of c. 2.5 m diameter. The tunnels run partially full with water except at planned shutdown maintenance events. Opus has been engaged by GW to carry out rock fall hazard inspections in these tunnels at 5 yearly intervals. Tunnel collapse or rock fall debris in the tunnel will not otherwise be noticed by plant staff, except indirectly by lower flow rates through the tunnel and/or possibly increased rock debris exiting the tunnel. The five yearly inspections allow identification of actual and potential rock fall sites and also assessment of the condition of the concrete lining and amount of gravel bed load in the tunnel.

Figure 3: Kaitoke Tunnels showing sections of rock block separation (a) low angle 0.3m thick separated slab crossing roof (dashed line) and (b) site of minor slabbing at the roof (arrowed) with debris on floor

3.2 Engineering Geology

The rock mass comprises typically closely fractured unweathered strong Wellington Greywacke (similar to that in the Orongorongo Tunnel). Block sizes are typically <0.3 m. Sections of slightly dilated ('drummy') rock mass are present along the tunnels; in the most recent (2007) inspection two sites of specific instability were noted – a separated 0.3 m thick slab crossing the roof (Figure 3a) and a small (0.3 m^3) rock fall (Figure 3b).

3.3 Risk Management

Failures of greater than 1-2 m^3 are considered to have a significant effect on the capacity of the tunnel. As the tunnel supplies 45% of the Wellington Region's water, this loss in capacity can be significant. Therefore, indications of likely rock falls of this size are considered to require remedial work (scaling/removal or support by rock bolting) to mitigate the risk of collapses which may affect the tunnel capacity. The latest (2007) assessment recommended allowance for immediate remedial work during the next inspection shutdown at one or both of the sites shown in Figure 3, to be implemented if the inspection indicates conditions have deteriorated; as both sites have the potential for rock fall volumes of greater than 1m^3 .

4 CAREY'S GULLY STREAM TUNNEL

4.1 Background

This tunnel carries the Carey's Gully Stream under the Wellington City Council's (WCC) Southern Landfill (Figure 4). The tunnel was constructed in the mid 1990's to replace a collapsed circular culvert which had been laid prior to landfilling. The tunnel was excavated 530 m through highly fractured greywacke bedrock, and is fully lined with a rectangular (1.8m wide by 1.6 m high) cross section, with a 250 mm diam. leacheate pipe running down the side (Figure 5). Soon after construction, checks revealed sections of substandard concrete lining (very thin concrete) and voids between the roof lining and surrounding greywacke bedrock. At the worst (160m long) section adjoining the downstream portal, the roof was reconstructed with concrete in 1999. Throughout the remaining 370 m of the 1990's tunnel, timber supports were installed at 1100 mm centres (Figure 5a) to support the tunnel roof.

Due to concerns about the structural integrity of the lining and potential for tunnel collapse WCC subsequently engaged Opus to develop options for management of the risks.

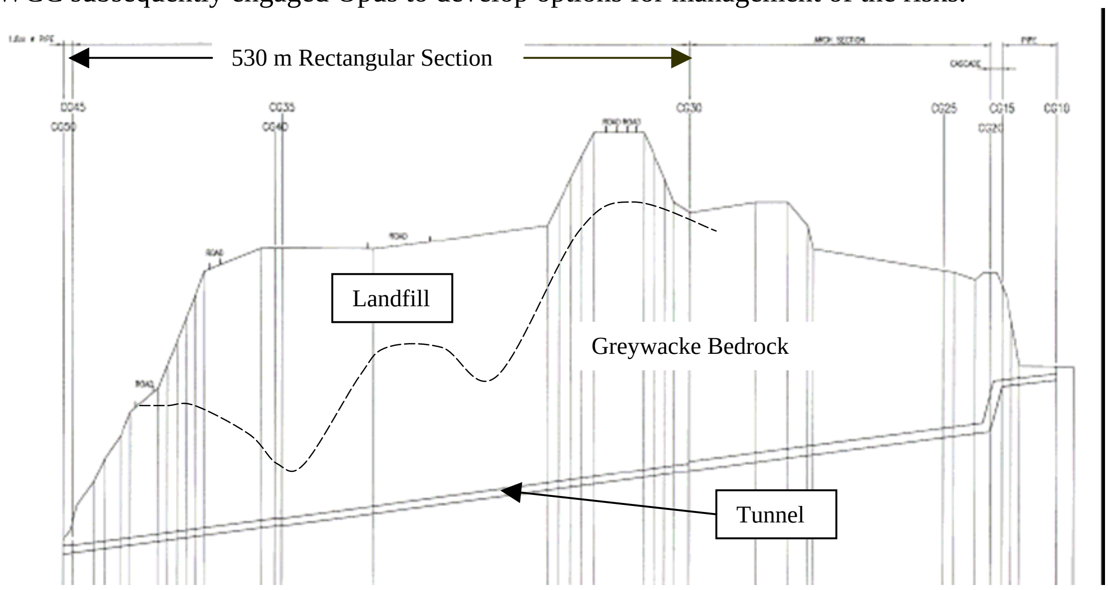

Figure 4 : Carey's Gully stream tunnel profile

Figure 5: Carey's Gully Stream tunnel - (a) rectangular profile showing timber supports, and (b) 2005 drilling investigations in unsupported section near portal

Collapse of the tunnel (in sections of inadequate lining) could result in blockage of the tunnel and backing up of stream flows in high rainfall events, with resultant potential overtopping of the landfill dam. The risk of this occurrence was considered to be unacceptable due to the adverse downstream consequences of overtopping.

Periodic risk assessment was carried out by Opus following inspections of the tunnel carried out in 2002, 2004 and 2005. The inspections were to identify any areas of cracking or deformation that might be indicative of potential collapse areas. Drilling investigations were carried out in 2005 to enable a better assessment of the condition of the tunnel lining and surrounding ground along the full 530m long rectangular section of tunnel.

4.2 Investigations

Drilling investigations carried out in 2005 (Figure 5b) involved 21 cored holes (50 and 80 mm diameter) through the concrete lining (13 in the roof and 8 in the walls) which enabled:

- Determination of thicknesses of lining
- Compressive strength testing of concrete lining cores
- Rotary coring of bedrock surrounding the tunnel (in 40% of holes)
- CCTV viewing of the voids and cored bedrock drillholes around the tunnel

The investigations were carried out in difficult conditions, with risks from (explosive) methane gas and potential leacheate seepages (both from the overlying Landfill), cramped confined space conditions and flooding in heavy rain events. Due to the hazardous nature of the site and difficulties in communication, measures included: forced ventilation, continuous monitoring with gas detectors, intrinsically safe equipment and a large safety team to support those working in the tunnel.

Investigation findings indicated that the wall lining was largely adequate (>150 mm thick concrete), however the roof lining was 'thin and unreinforced' in a number of sections. The concrete quality was found to be satisfactory. Roof cavity heights were indicated to be generally small (<0.8 m).

Structural assessment of rock fall debris loadings on the roof lining indicated that where the concrete roof lining is less than about 100 mm thick the unreinforced lining is inadequate to support debris loadings from potential roof rock falls. In addition, the timber supports installed in 1999 were a 'stopgap' option and were assessed to be inadequate to support potential rock fall debris loads on the roof lining; also the life of the timber supports is not sufficient.

4.3 Risk Mitigation Options

Options to mitigate the tunnel collapse risks included:

- Installation of a new circular pipe throughout the substandard (rectangular) section
- Formation of a new concrete arch along the roof of the tunnel,
- Grouting of the void between the concrete lining and the surrounding rock
- Construction of a new tunnel over the substandard section
- Installing beams to support the roof lining

The tunnel is required to be functional to enable the security of the landfill. Due to the high cost of the first four options (above), short term interim measures such as installation of wooden roof beams to support the roof were also considered – to give WCC the option of delaying the expensive rehabilitation works.

The final solution, developed in conjunction with WCC, involved installation of replaceable galvanised steel roof beams supported on brackets attached with stainless steel bolts to the concrete wall lining. This option is significantly cheaper than the other options, is sufficiently robust to maintain the tunnel integrity under possible loadings from rock fall debris on the roof lining, maintains full access to the leacheate pipe within the tunnel and also maintains the same hydraulic capacity as the existing tunnel. Proof drilling at close intervals was carried out in 2007 to verify the lining thicknesses assumed in the design. The retrofit work was carried out between February and April 2008 (Figure 6).

Figure 6: Carey's Gully Stream Tunnel - Risk management solution involved removal of the timber supports (visible in walls and roof) and installation of steel beams supported on steel brackets bolted into the upper wall (see numbered steel beam)

5 CONCLUSIONS

Rock fall and/or lining collapse in tunnels can affect the functioning of the tunnel and pose safety hazards to staff using the tunnels. Management of risk involves understanding the function and context of the tunnel so that appropriate risk mitigation measures can be implemented. Geotechnical inspection of tunnels is required to assess the risks of rock fall/collapse and recommend appropriate risk management procedures. In some cases further drilling etc investigations may be required to better understand the risk. Such investigations can also better define the condition of the tunnel lining and/or surrounding ground so that a cost effective solution can be developed and implemented.

6 ACKNOWLEDGEMENTS

The author acknowledges the permission from Wellington City Council and Greater Wellington (Regional Council) to publish the paper and also their inputs into the tunnel assessment. The contributions of Greg Saul, Brian Newsome, Ed Sainsbury and P. Brabhaharan in the risk assessments for the various tunnels are also acknowledged.