Mitigating the risk of slope instability and rockfall to railway lines in Wellington, New Zealand

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ABSTRACT

Railways form an integral part of the passenger transport network in the Wellington region, as well as being part of the North-South railway spine of New Zealand. The railway lines in the region pass through very steep hilly topography underlain by highly fractured, deformed and variably weathered bedrock and as a result are susceptible to rockfall and landslide hazards. KiwiRail have inspected the slopes along the Wellington metro area railway corridor and assessed the slope instability hazards, identifying a number of slopes that pose significant risks to the railway lines. We present the results of stabilisation works to mitigate the risk of slope failure and rockfall at three of these sites, being cut slopes above the portals of three tunnels along the North Island Main Trunk line (NIMT) and Johnsonville Line (JVL) in Wellington. The first site, at the southern portal of Tunnel 2 on the NIMT, required stabilisation of a colluvium-infilled paleogully above the railway line. The second site, above the southern portal of Tunnel 2 on the JVL, comprises a large section of over-steepened hillslope in relatively poor quality rock. The third site, at the northern portal of Tunnel 3 on the JVL, comprises a near-vertical cutting in competent bedrock that lies very close to the railway line. The solutions adopted at these sites consisted of a combination of scaling of loose material and installation of ground anchors, drainage measures, erosion control matting and rockfall netting.

Keywords: risk mitigation, slope instability, rock fall hazards, slope stabilisation, Wellington greywacke

1 INTRODUCTION

Slope instability hazards are ubiquitous in the Wellington region due to the very steep hilly topography and highly fractured and deformed bedrock. Railway lines within the Wellington metro area corridor were constructed in the late 1800s through this steep terrain and are susceptible to the slope hazards, with the consequences of slope failures varying from minor track outages to train derailments. KiwiRail have inspected the slopes along the Wellington railway corridor, identifying a number of slopes that pose significant risks to the railway lines (e.g. Justice and Cassidy 2012). This paper presents examples of managing the instability risks of three of these slopes, which are located at or near the portals of tunnels (Figure 1). We present the results of slope assessments and describe the stabilisation measures adopted to mitigate the instability risks to the railway.

The Wellington region is underlain by Triassic to Jurassic greywacke bedrock of the Torlesse terrane, which predominantly consists of indurated, grey, alternating bedded fine grained sandstone and mudstone (Begg and Johnston 2000). The greywacke is generally highly deformed and fractured due to its complex geological history, and sheared zones and faults are common throughout the rock mass. Importantly, lithological changes (i.e. sandstone vs mudstone) are not as important in influencing the intact rock strength as the degree of weathering and the intensity of fracturing. Both of these properties are highly variable both spatially and with depth, and therefore the key priority for assessing the slope risks and designing mitigation works at the tunnel portal sites was to characterise the engineering geological properties of the site materials and assess the instability hazards.

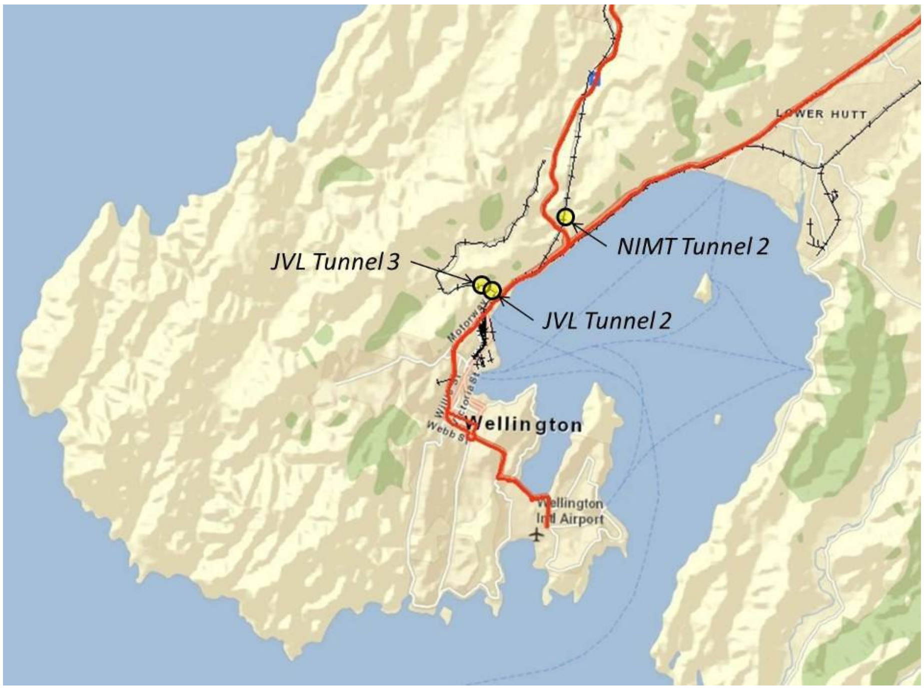

Figure 1. Location map

2 NORTH ISLAND MAIN TRUNK LINE – TUNNEL 2

2.1 Background

Tunnel 2 on the NIMT is located in the Ngauranga Gorge, approximately 6 km north of Wellington city. At the approach to the south portal of the tunnel, the railway line lies at the base of a 130 metre long slope that ranges in height from 12 m to 25 m. This slope was cut for the railway in the late 1800s to early 1900s, and has a history of slope failures. The highest hazard from landslides is a section of slope 25 m long and 15 m high that lies approximately 50 m south of the tunnel portal (Figure 2). This part of the slope has been affected by ongoing instability issues with active/recent slips impacting the railway. Opus International Consultants (Opus) were commissioned to carry out risk assessment, geotechnical investigations, engineering design and construction observation of slope stabilisation works to this part of the slope.

2.2 Engineering Geology

The slope above the railway lies at angles of 45º to 60º. Bedrock outcrops are present at both ends of the site, with the main instability issues posed by a thick infilled gully in the bedrock surface (paleogully). In this paleogully, colluvium of up to 3 m thickness exists over the bedrock. This soil comprises layers of silt, clay and silty gravel over broken rock (coarse gravels and boulders), with competent bedrock beneath. The greywacke bedrock is typically slightly to moderately weathered and moderately strong to strong. Pronounced groundwater seepages emanating from the paleogully area have been observed following prolonged or heavy rainfall.

2.3 Risk Mitigation

The principal mode of instability is soil slips within the colluvium-infilled paleogully, and this part of the slope was therefore the target for slope stabilisation. The physical works were predominantly done by roped access and hand-held drilling equipment. Because of the proximity of the slope to the tracks and overhead cables, the main part of the works was carried out during a Block of Line closure of the railway in December 2010 and January 2011.

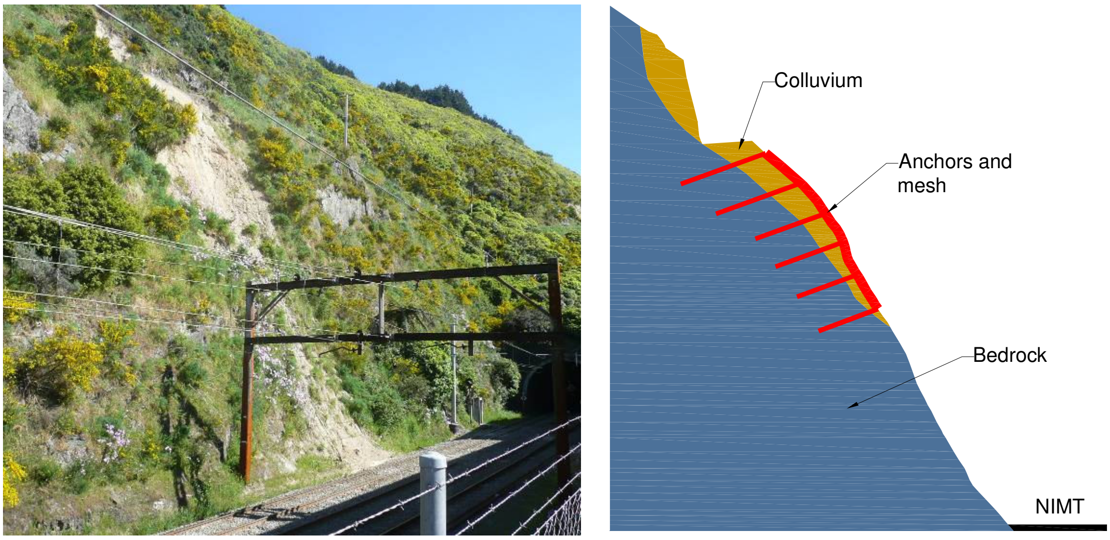

Figure 2. The slope at Tunnel 2 on the NIMT: (a) site photograph and (b) schematic cross section

The stabilisation scheme comprised the following:

- 52 grouted anchors, 3 m to 10 m long, to stabilise the slope and protect against deep seated slips. Slope/W was used in the design and specification of the anchors.
- 7 sub-horizontal drain holes to prevent excess groundwater pressure from building up in the soils
- Wire mesh and galvanised wire cables over the stabilisation area to retain any loose blocks
- Erosion protection matting over the bare soil areas to help retain the surface soils

3 JOHNSONVILLE LINE – TUNNEL 2

3.1 Background

Tunnel 2 on the Johnsonville Line is located in Ngaio Gorge near Kaiwharawhara, approximately 3 km north of Wellington. At the southern portal of the tunnel, steep hillslopes rise 40 m above the railway (Figure 3). These slopes were steepened when the approach to the tunnel was excavated, which has resulted in ongoing instability issues as the slope unravels/erodes back to a more stable angle. This has presented an ongoing risk to the railway line of landsliding and small rockfalls.

3.2 Engineering Geology

The site consists of moderately to steeply sloping north-facing hillslopes, vegetated with grass, scrub and occasional trees. The slope angles at the site range from 35° to 60°. The majority of the slope under investigation consists of bedrock exposed at the ground surface, with thin soil cover generally limited to the natural hillslopes above the area of investigation. The soils consist of topsoil and colluvial/residual soil, and are predominantly silty clays with some angular gravel.

Bedrock is generally moderately weathered, moderately strong sandstone and mudstone (locally very weak or strong to very strong), with moderately to very closely spaced defects. However, there is a marked variation over the height of the slope of the degree of rock weathering, the spacing and persistence of defects, and the intact rock strengths. Slightly to moderately weathered and strong to moderately strong rock is exposed at the base of the slope, with the degree of weathering and fracturing of the rock mass increasing up the slope. No groundwater flows or seepages were observed on the slope during the site works (January to October 2011).

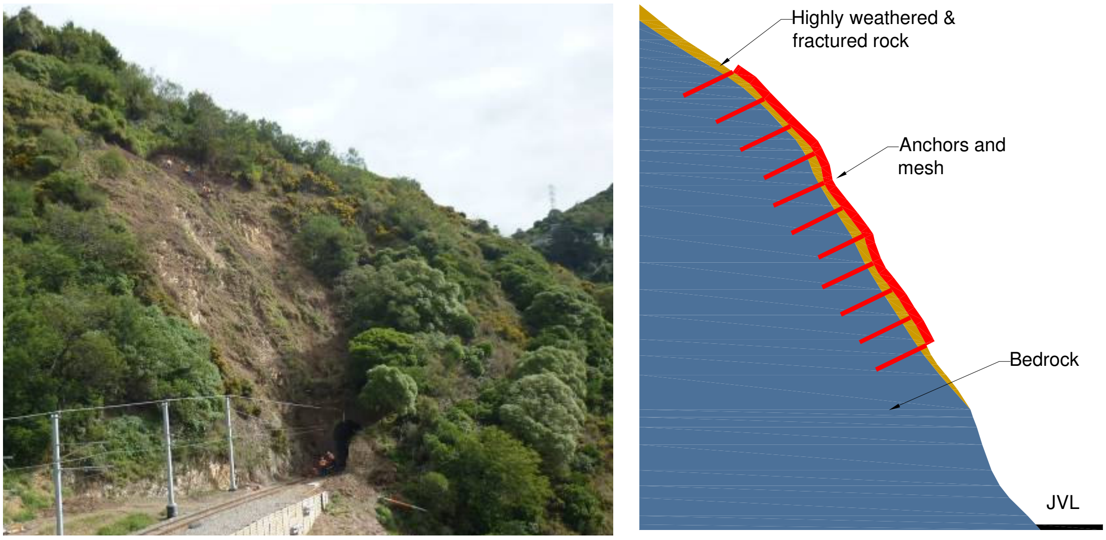

Figure 3. The slope at Tunnel 2 on the JVL: (a) site photograph and (b) schematic cross section

Two main areas of instability are present on the slope. These areas are where the slopes are steepest (steeper than 45°) and consist of exposed soil and highly weathered and fractured rock. Based on inspections and assessment of the ground conditions, the slope was partitioned into zones of failure susceptibility, with the highest susceptibility in the upper part of the slope and a lower susceptibility zone in the lower to middle parts of the slope.

The highest hazard from slope instability is posed by a layer of openly jointed, moderately to highly weathered greywacke of about 2 m to 4 m thick in the upper part of the slope. This material is actively eroding by a combination of fretting/spalling of loose blocks and shallow-seated slumps of weak material.

The lower part of the slope comprises more competent and intact bedrock than the upper slope, and instability controlled by persistent structural discontinuities within this slightly to moderately weathered bedrock presents a lower slope failure hazard.

3.3 Risk Mitigation

The hillslope forms a broad "bowl" above the railway and material falling down the slope is channelled down a narrow section onto the tracks immediately adjacent the tunnel portal. The tunnel goes through a right hand bend along its length, and the portal is not visible to trains travelling southwards until they are very close to it; consequently the trains have very little time to stop should there be any slip debris on the tracks at the portal. To mitigate this risk, Opus developed a stabilisation scheme which was implemented between April and September 2011. This scheme comprised the following:

- 114 grouted rock anchors, 4 m long, to protect against failures developing in the unstable near-surface zone of weak rock. Slope/W was used in the assessment and design of the anchors.
- 5 sub-horizontal drain holes at the top of the site to reduce groundwater infiltration from the hillslope above.
- Wire mesh and galvanised wire cables over the entire stabilisation area, with erosion protection matting over selected areas, to reinforce the surface materials and retain any loose or unstable blocks.

There were several important physical constraints at this site that strongly influenced the design and construction methodology of the slope stabilisation measures. The zone of actively eroding, open/dilated and weathered rock was the primary target for stabilisation, and required self-drilling anchors because of the potential for drill holes to collapse. Access to the site was poor, and the works were required to be carried out entirely by roped access and hand drilling techniques. Consequently, the method for accessing and moving around the site required careful consideration and planning. Temporary anchors and safety lines were required along the access track and at the top of the slope before any works on the slope could begin. Similarly, the ongoing operation of the railway could not be compromised by the work, and the timing of operations on the slope was carefully managed. Scaling of loose material was ongoing throughout the project, and temporary catch fences were installed on the slope and alongside the tracks to retain any falling debris. Night working and Block of Line closures of the railway were utilised for operations that impacted the tracks, such as emptying and clearing debris from the catch fences.

4 JOHNSONVILLE LINE – TUNNEL 3

4.1 Background

Tunnel 3 on the JVL is located approximately 300 m up the line from Tunnel 2. To the west of the tunnel the railway lies within a box cutting. The slope on the southern side of the tracks consists of a 10 to 15 metre high and 50 m long cutting that lies at an average angle of 70° to 80º, with some overhanging areas (Figure 4). The railway lines are particularly exposed to the slope failure hazards at this site, as the slope is prone to rockfall and the tracks lie 1 to 3 m from the toe of the slope.

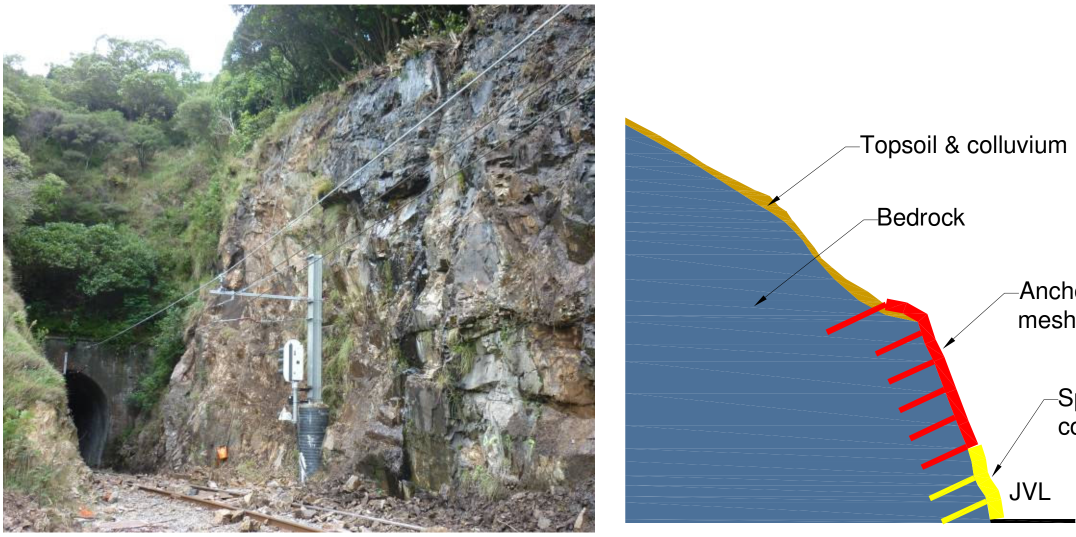

Figure 4. The slope at Tunnel 3 on the JVL: (a) site photograph and (b) schematic cross section.
** Anchoring and sprayed concrete proposed to be carried out at Christmas 2012*

4.2 Engineering Geology

The cutting at the site exposes slightly weathered and very strong sandstone, with occasional thin mudstone beds. The rock mass is generally competent and blocky, with persistent closely to widely spaced defects.

The dominant modes of slope failure are fretting, spalling, and shallow planar and wedge failures/dropouts. The rock exposed in the cut face appears slightly relaxed and dilated along steeply dipping joints (c. 80°) that are sub parallel to the cut face. This is presumed to be due to gradual relaxation of the surficial rock mass towards the railway line since the slope was cut in the late 19th Century. Large scale planar or wedge shaped failures are not considered to present a significant risk to the railway under static conditions.

4.3 Risk Mitigation

The slope presents a significant hazard to the railway operation due to the high likelihood of rockfall and the proximity of the tracks to the slope. Opus and KiwiRail developed a stabilisation scheme to reduce the risk to the railway. This site is severely constrained due to the proximity of the tracks and overhead power lines to the face, and no drilling work was able to be carried out on the face except when the lines were closed to trains. Therefore the form and extent of the stabilisation scheme was influenced in a large part by timing and logistical constraints.

The scheme was divided into two parts, each of which was self-contained to be constructed within two week-long Block of Line closures. The first phase of stabilisation targeted instability and rockfall in the top part of the slope, and comprised the following:

- Scaling of loose and unstable rock.
- 55 grouted rock bolts and pins, 3 to 4 m long, to protect against planar and wedge failures. Rocplane and Swedge were used in the slope assessment and rock bolt design.
- Rockfall netting to protect the railway from debris smaller failures.
- Sub-horizontal drain holes on the face and subsoil drainage measures on the hillslope above and the face.

This phase of work commenced at Christmas 2011, and at the time of writing was scheduled to be completed in summer/autumn 2012. The second phase of stabilisation is to target the lower part of the slope. This is planned to be carried out at Christmas 2012, and is to comprise the following:

- Grouted rock bolts to retain any unstable blocks and protect against wedge failures.
- Sprayed concrete over the base of the slope to protect the railway from rockfall. Sprayed concrete is preferred over netting to avoid the risk of bulges in the netting should any failures occur.

5 CONCLUSIONS

Slope instability and rockfall are particular hazards in the Wellington region. Railway lines are susceptible to these hazards where the tracks lie in close proximity to steep slopes, such as at tunnel portals. Mitigation of the risks requires understanding of the engineering geological issues, which are often complex and highly variable in Wellington greywacke terrain. The risk mitigation measures implemented at the three sites described above were developed by careful consideration of the ground conditions and the logistical and physical constraints of working on slopes close to the railway. The slope at the southern portal of Tunnel 2 on the North Island Main Trunk line is susceptible to shallow landslides in greywacke-derived colluvium that has infilled a gully in the bedrock surface. The hillslope above the southern portal of Tunnel 2 on the Johnsonville Line is eroding and unravelling by fretting/spalling of loose blocks with shallow-seated slumps of weathered and weak rock. Slope stabilisation measures at these two sites comprised grouted anchors, drainage measures, wire mesh and erosion protection matting. The steep cut at the western portal of Tunnel 3 on the Johnsonville Line is susceptible to rockfall and defect-controlled planar/wedge failures in unweathered, competent rock. Stabilisation measures comprised scaling, grouted rock bolts, drainage measures, and rockfall netting, with further stabilisation works (rock bolts and sprayed concrete) planned for 2012/2013.

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