Identification, Management and Reduction of Slope Instability Hazards within the Wellington Regional Metro Railway, New Zealand

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ABSTRACT
The Wellington Regional Metro Railway includes around 160km of single and double line track featuring steep grades and many tight radius curves. Natural slopes in some areas are up to several hundred metres high and inclined at between 40° and 60°. Cut slopes adjacent to the tracks can be up to 30m high are typically steeply inclined, and in some cases, close to vertical. The majority of the Wellington Regional Metro Railway was constructed in the mid to late 1880's. Parts of the metro area receive close to 1,000 passenger and freight movements per week. Since completion, and continuing up until the present day, there have been a number of failures from the some of the slopes above and below the line. These have lead to track outage, occasional train derailments and a number of fatalities. Until very recently, risk management practices were entirely reactive, and involved either placing speed restrictions or construction of non-engineered structures (rockfall barriers, retaining walls etc). In 2009, KiwiRail completed the first part of a nationwide study which inspected and rated the cut slopes and embankments within the Wellington metro area. This study highlighted eight sites within the 'North – South Junction' (NSJ) section of the metro area. This 3.5km section of line posed a significant hazard to the safe running of the railway network. In 2010 KiwiRail engaged Aurecon to investigate these sites and to design risk reduction works to reduce the overall risk. This paper outlines the geological setting of the Wellington Metro area and typical slope failures that are a consequence of this. As a practical example, the paper focuses on the NSJ works and the slope risk rating for this area. The paper then discusses the risk reduction strategies that have been adopted by KiwiRail, which are a combination of engineered works, slope monitoring and rainfall alert criteria.

Keywords: slope stability, geo-hazard risk management, railway geotechnics.

1 INTRODUCTION

The Wellington Regional Metro Railway comprises three principal lines, Johnsonville Line (JVL), North Island Main Truck (NIMT) and the Wairarapa Line (WL) as shown on Figure 1. It includes around 160km of single and double line track featuring steep grades and many tight radius curves. Natural slopes in some areas are up to several hundred metres high and inclined at between 40° and 60°. Cut slopes adjacent to the tracks can be up to 30m high are typically steeply inclined, and in some cases, close to vertical.

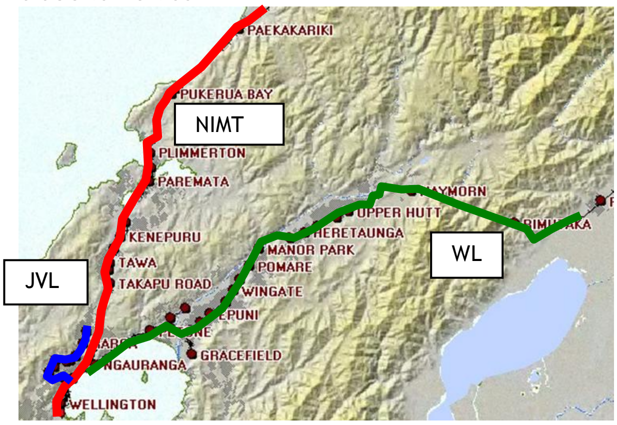

Figure 1. Principal routes within the Wellington Metro area. JVL – Johnsonville Line, NIMT – North Island Main Trunk and WL – Wairarapa Line

2 GEOLOGICAL SETTING

The bedrock geology of the Wellington Metro area comprises interbedded grey to dark grey argillite and sandstone of the Rakia Terrane, which forms part of the Torlesse Supergroup of Jurassic Age (250 million years BP). Commonly termed 'Greywacke', the rock mass is typically slightly to moderately weathered, and ranges from finely interbedded sandstone/argillite to essentially massive sandstone. The rock mass has been folded and sheared over several deformation events over the last 250 million years. Bedding in the rock mass is typically highly sheared. The greywacke bedrock is overlain by a variable thickness (less than 0.5m to over 3m) of colluvium, talus and landslide debris.

The 1:250,000 geological map 'Qmap' (Begg and Johnson, 2000) indicates that the majority of active faults in the area tend to be orientated NE-SW and comprise the Wellington, Pukerua and Ohariu faults. The Wellington Fault is expected to have a maximum moment event of M7.3 with a recurrence interval of approximately 600 years. Both the Pukerua and Ohariu faults are indicated to have a maximum moment recurrence interval of between 2000 and 3500 years with intensities of up to M7.4.

3 SLOPE INSTABILITY HAZARDS

Since construction, and continuing up until the present day, there have been a number of failures from the slopes above and below the various lines in the Wellington Metro area. These have led to track outage, occasional train derailments and a number of fatalities. Until very recently, risk management practices were entirely reactive, and involved either placing speed restrictions or construction of non-engineered structures (rockfall barriers, retaining walls etc).

The tectonic setting and geological history of the Wellington area has resulted in the greywacke bedrock now being highly fractured. Due to this closely fractured nature and the overlying colluvial soils, localised instabilities are reasonably common from the steep hillslopes in the Wellington region.

The main geohazards include the following:

3.1 Shallow rock landslides and scree slides (for example, Beanpole Landslide, NIMT 34.0km).

The Beanpole landslide was centred on a broad spur that rises moderately steeply (approximately 45°) from sea level. The Beanpole landslide was a notorious spot on the NIMT with instability extending over a 50+ year period. In a report published in 1981 the New Zealand Geological Survey indicates that the slide could be first identified on aerial photographs flown in the 1940's. Up until the late 1970's the landslide gradually increased in size to the extent shown in Figure 2 below.

Inspection reports from the early 1960s indicate that rockfalls or scree slides were an almost daily occurrence. On 5 May 1962, what was believed to be the biggest slide to have ever blocked the NIMT occurred. Initiated by prolonged heavy rain, the slide mass was estimated at 4000 tonnes and buried the track with 3-4m of material.

Figure 2: 'Beanpole Landslide' prior to excavation in 1990 (RHS) and "Little Beanpole" (LHS). Photograph taken in 1981 and included in the 1981 report by the New Zealand Geological Survey.

The majority of slope instability events at Beanpole in the period from the 1950s until the mid 1980's are interpreted to be a result of movement of the main slide mass and oversteepening of the toe of the landslide. The toe material then failed and evacuated downslope as scree slides to the level of the track below. The growth pattern of the slide since it was first recognised was thought to indicate a progressive upslope migration of the unstable area.

In 1990, New Zealand Railways made the decision to undertake bulk excavation works to remove the main slide mass. This involved the removal of approximately 31,000m3 to form a series of benches approximately 4m wide with batter slopes between 4m and 40m in height.

3.2 Debris/Rock avalanching (for example, Little Beanpole Landslide, NIMT 34.5km)

In November 1980, a rock avalanche occurred approximately 500m north of Beanpole corner. The debris from the rock avalanche evacuated downslope to the level of the track and caused the derailment of a south-bound Electric Unit (EMU). The failure was unusual in that it occurred after a week of dry weather, with no recorded seismic activity and the area affected had not previously shown any signs of instability (NZGS, 1981).

The landslide that led to the train derailment was located on a steep (45-50°) slope of old scree material that had accumulated on a shelf between rocky bluffs (NZGS, 1981) and involved a slide mass of approximately 750 m^3 of coarse rock debris.

Although formed approximately 30 years ago, the scarp from the 1980 failure remains substantially clear of vegetation (Figure 2) and frequent small scale instabilities continue to occur. Periodic rock blocks continue to fall from the scarp, with recent blocks observed being caught by a simple timber catch fence structure.

3.3 Isolated Rockfalls.

There are numerous instances of isolated rockfalls around the metro area, especially on the Johnsonville Line and North Island Main Trunk. The main cause of this instability is the pervasively joined rock mass combined with ongoing physical weathering and occasional root action. Such isolated rockfalls are regular in occurrence but generally small in volume (typically less than 10 m^3), often with only a small amount of rock debris actually reaching the tracks. It should be noted, however, that even a small rock boulder of, say, 300mm diameter, on the running rails of the track can cause the emergency braking system to activate on a train.

In 1999 a larger rockfall event occurred on the NIMT at around 36.5kms above the northern portal of Tunnel 7. The tunnel is only around 25m long and passes through a prominent sandstone rock spur with moderately to widely spaced fractures (unlike the siltstone in the area which has very closely spaced fractures). The result was some 120 m^2 of rock debris falling around the tunnel portal but mainly on the State Highway below.

3.4 Shallow slump soil/regolith failures

Failures within soil (wind-blown Loess, alluvium or residually weathered rock or a combination thereof) are reasonably common throughout the Wellington Region. There are two distinct types:

A) Failures from within paleogullies cut into the Greywacke rock. A recent derailment and collision between two EMUs between Plimmerton and Pukerua Bay was the result of concentrated water flow down a paleogully feature and resulting land instability (Figure 3) refer TAIC (2012).

B) Sheet sliding of soil material (including alluvium and colluvium) over rock. This style of failure led to the derailment of a passenger service near Maymorn on the WL (refer TAIC, 2010).

Figure 3: Damaged EMU (left) due to derailment and collision on the NIMT in September 2010 as a result of a slumping failure from a paleogully (outlined on right photograph).

4 SLOPE HAZARD RATING SYSTEM

Recently, KiwiRail have developed a slope ranking system which has been conducted over the Wellington metro area. The benefit of this system is to allow risk reduction works to be carried out in a systematic, transparent and proactive manner, rather than the previous wholly reactive approach. The system has allowed identification of a number of slopes between North and South Junction on the NIMT where remedial works are required to reduce the current levels of risk.

Details of this system are provided in Justice (2012; these proceedings), however in summary, the ranking determined for any one slope is based on an allocation of points and is calculated as follows:

Slope Ranking = (Sum of points contributing to likelihood of failure) x (consequence factors)

Aspects contributing to the likelihood of failure occurring include slope height and angle, material type, water condition, history of failure. Factors contributing to the consequence of failure include line speed and line of sight, traffic volumes and landslide debris runout or embankment crest loss distance.

Over 180 sites were surveyed within the Wellington Regional Metro area and Figure 4 illustrates the highest ranked slopes that were identified. In summary:

- The three highest rated sites are cuttings located on the NIMT
- The fourth highest site is located at Tunnel 2 on the JVL
- Of the 10 highest rated sites:
  - Four are cuttings at tunnel portals
  - Two are embankments
  - The remaining four sites are cuttings above track at locations away from portals
- A total of 15 sites between North and South Junction (NSJ, between 32.7km and 36.5km on the NIMT) are within the top 50 sites in the Wellington Area, including eight sites within the top 20. The highest ranked sites between North and South Junction are typically located adjacent to tunnel portals and involve steep rock slopes above the tracks.

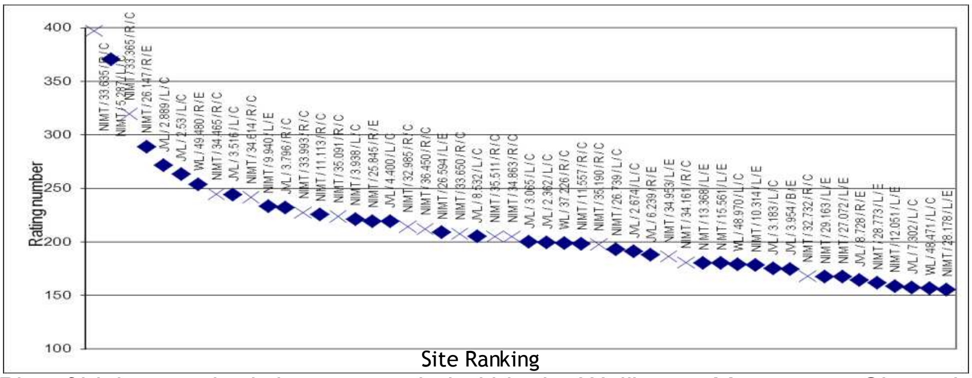

Figure 4. Plot of highest ranked slopes recorded within the Wellington Metro area. Slopes between North and South Junction are indicated by a cross.

The following section provides an outline of the risk reduction works that have been undertaken at the NSJ site as a result of this slope hazard rating system.

5 NORTH – SOUTH JUNCTION (NSJ) IMPROVEMENT PROJECT

5.1 Background

The Pukerua Bay to Paekakariki section of the NIMT includes a 3.6km stretch of single line between North and South Junctions where double line sections are joined. This section of track has grades as steep as 1:66 and curves as tight as 150m radius. There are over 33,000 passenger and freight movements per year through this section of line.

NSJ is located at the foot of a steep, high coastal escarpment, which has an average slope of between 35° to 50° and rises to just over 300m above sea level (Figures 5 and 6). The escarpment is an old wave-cut platform and is now covered in grass and regenerating bush. The railway is constructed on a cut bench which rises from approximately 6m above sea level at the northern end of the section to about 60m near South Junction.

Since the line was opened in the 1880's, and continuing up until the mid 1990's, there were been a series of large failures from the slopes above the line. Failures of up to about 5000 cubic metres periodically occurred, leading to track outage, occasional train derailment and a number of fatalities.
Some of these instabilities were probably initiated by excavations into the base of the slope during construction of the railway line, but poor hillslope management practices in the past have contributed significantly to the level of instability.

5.2 Geological and Geotechnical Investigations

In May 2010 KiwiRail engaged Aurecon NZ Ltd to investigate the high risk sites identified in the slope hazard rating pilot study and to design slope stabilisation and improvement works to enable train speeds to be increased and risk to human life to be more effectively managed. The geotechnical component of this project was part of a suite of services Aurecon provided the project including track geometry alignment, drainage and tunnel clearance.

The field investigations concentrated on geological rock mapping of the cut slopes above track level and borehole investigations to provide depth to rock information below track level. Kinematic analysis of the rock face mapping was completed and indicated some sites were prone to wedge and toppling failure which was supported by field observations. Borehole data suggested the depth to rock varied along the route and in some locations the depth to insitu greywacke was over 12m beneath track level.

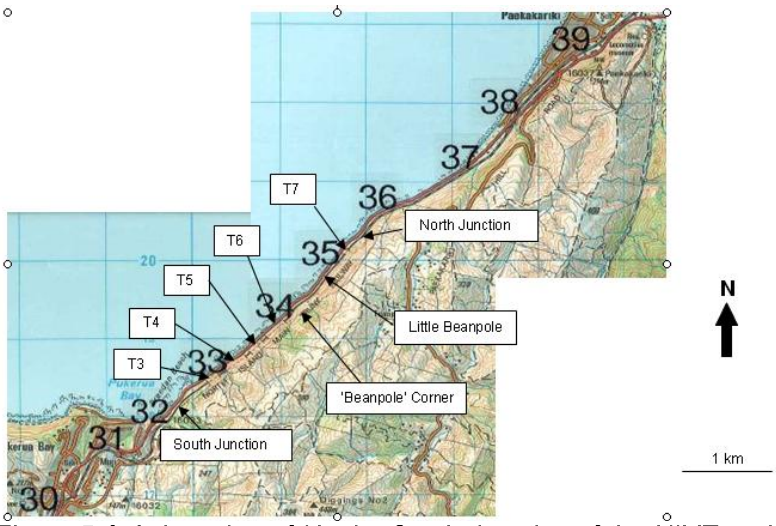

Figure 5 & 6: Location of North –South Junction of the NIMT and Key features (T – Tunnel). Location of track indicated by white arrows.

5.3 Risk Reduction Solutions

The information obtained from the geological and geotechnical investigations informed the geotechnical design of a series of risk reduction solutions, including the following:

Shotcrete & anchor walls were chosen at track level, where steep excavations were made into the rock slopes and/or where there was a perceived risk of small rock falls/wedge failures onto the track immediately below. The main benefit of this solution is the low maintenance during the design life of the wall and the ability to provide additional lateral space at track level for improved drainage systems.

Anchored rockfall netting was used on the upper slopes where rock fall risks were identified. First the areas were inspected and scaled of loose rock, soil and vegetation debris before being netted in place. For economic reasons a balance of risk versus cost was reviewed and two anchoring systems were chosen for use. Firstly an 'active' system comprising a grid of anchors at regular spacings was used where the rock mass was particularly aggressive in terms of fracture dilation or abundance of discontinuities. Secondly a 'passive' drapery system was used where the potential rock block sizes were considered small enough to allow only two or three rows of anchors to be used. This system was used extensively where small blocks of rock weather insitu and roll down the steep slopes onto the tracks – occasionally tripping the trains emergency brake system that is located at wheel level.

A timber pole retaining wall with catch fence was installed at the infamous Beanpole Corner where the new rail alignment saw the track cut the toe of the existing slope. Given the historical slope instability at this location, it was agreed to design a two tier solution. First a timber pole cantilever retaining wall was designed to retain the steep cut of up to 3m at the toe of the slope, which comprised large diameter, treated timber poles set into a reinforced concrete base pad for ease and speed of construction. Within the same concrete base pad were steel circular hollow sections used as catch fence posts, rising 1.5m above the top of the timber retaining wall. Rockfall netting with top and bottom wire ropes was used to complete the catch fence (illustrated in Figure 5 below).

Figure 5. Completed timber pole wall with catch fence (left) and driven steel soldier pile wall (right).

A driven steel soldier pile wall was installed to support the track and formation at a location immediately south of Beanpole corner where the new rail alignment saw the track move out away from the current slope platform, towards the sea. Borehole information at this location indicated the depth to rock was in excess of 12m so the wall was designed to act effectively in cantilever without the need for tie backs which would have added time and cost to the tight construction programme. Utilising large UC sections, top driven by crawler crane mounted equipment, this wall was designed to maintain its strength and integrity even if some of the soil material in front of the wall is lost during a seismic event, therefore creating a relatively low maintenance solution (illustrated in Figure 5 above).

6 CONCLUSIONS

The understanding and management of Geo-Hazards within the railway network of New Zealand is a relatively new phenomena, having been primarily a reactive system prior to 2010. The slope hazard rating system provides a robust and transparent system on which KiwiRail can review risk data collected in the field and make informed decisions on where to prioritise annual budget and effort in remediation works and risk reduction.

Construction projects within an active railway corridor presents a number of unique and challenging working conditions including limited access for investigation teams and equipment, reduced hours of construction shift work and the requirement to maintain a safe train service within site works. Working at height (such as the rockfall netting) with a spotter at track level was particularly efficient as works could be undertaken almost 24 hours a day. Drilling and installing rock anchors at track level, however, took perhaps twice as long when compared to other sites with no restrictions. All of these challenges need to be borne in mind and planned/coordinated in good time at the start of a project.

Conducting geotechnical risk reduction and value engineering workshops on difficult projects can add significant value to the overall project team performance in terms of understanding the key risk items and associated 'costs' required to reduce/control them. Often programme and/or budget constraints result in a desire to amend or reduce the scope of planned works which needs to be carefully considered and the risks fully understood before decisions to change are made. Project programme and budgets should be openly discussed at the front end of complex projects where the key focus is to effectively reduce risk.

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