SUMMARY

The Pukerua Bay to Paekakariki section of the North Island Main Trunk (NIMT) includes a 3.4km stretch of single line between North and South Junctions which has a steep grade, many tight radius curves and five tunnels. Slopes between the tunnels are up to several hundred metres in height and are inclined at between 40° and 55°.

The North - South Junction section of the line was constructed in the mid to late 1880’s and currently has approximately 50 passenger and freight movements per day. Since completion, and continuing up until the mid 1990’s, there have been a series of large failures from the slopes above the line. These have lead to track outage, occasional train derailment and a number of fatalities. In this period, risk management practices were entirely reactive, and involved either placing speed restrictions, or construction of rockfall catch fences.

In the mid 1990’s, a program of pest and stock control and revegetation was initiated. In the approximately 15 year period since, the frequency of rockfall incidents have significantly decreased and there have been no large scale failures within the last eight years. However, there are still a number of areas where shallow debris/rock falls are continuing to occur, which present a significant risk to the railway line.

KiwiRail are currently investigating options to improve capacity between North and South Junction. Part of this improvement will involve improving permanent speed restrictions which have been historically emplaced.

This paper outlines the geological setting and history of slope failure between North and South Junctions. Additionally, the paper outlines the slope risk rating system that has been recently developed to allow a proactive system of slope risk management. Finally, the paper discusses the risk reduction works that are proposed to reduce the current slope instability risk and improve the current line speed.

1. INTRODUCTION

The North Island Main Trunk (NIMT) is the primary railway line between Auckland and Wellington in the North Island of New Zealand. The Pukerua Bay to Paekakariki section of the NIMT includes a 3.6km stretch of single line between North and South Junctions (31.805km and 34.436km respectively) where double line sections are joined. This section of track has grades as steep as 1:66 and curves as tight as 150m radius.

This section of the NIMT was constructed between 1883 and 1886 by the private Wellington-Manuwaitu Railway Company [1]. There are over 33,000 passenger and freight movements per year through this section of line.

North – South Junction is located at the foot of a steep, high coastal escarpment, which has an average slope of between 35° to 40° and rises to just over 300m above sea level (Figures 1 and 2). The escarpment is an old wave-cut platform [2,3] 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.

Tunnels 3, 4, 5, 6 and 7 are located between North and South Junction as shown on Figure 1. A further Tunnel (12) suffered movement and lining failure soon after construction. The tunnel was abandoned in the early 1900’s and the track deviated in a tight curvature around the outside to form what is now known as Beanpole Corner.

Numerous slope instabilities have occurred from the coastal escarpment between North and South junction in the approximately 125 years since the line was opened. These instabilities have resulted in numerous track outages, train derailments and occasionally, loss of life.
2. GEOLOGICAL SETTING

The bedrock geology between North and South Junction 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 at the southern end of Tunnel 3 to essentially massive sandstone at Tunnel 7. The rock mass has been folded and sheared over several deformation events over the last 250 million years. Bedding in the greywacke rock mass is typically highly sheared, but is generally inclined at between 50° to 80° towards the East.

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’ [2] indicates that the majority of large scale faulting in the Tunnel 3 to Tunnel 6 area is orientated between N-S and NW-SW. Active faults in the area tend to be orientated NE-SW and comprise the following [3]:

- Pukerua Fault: located approximately 1km southwest of the southern end of Tunnel 3 and
- Ohariu Fault: which is located about 2km to the east of the study area
Both faults are indicated [4] to have a maximum moment recurrence interval of between 2000 and 3500 years with intensities of up to 7.4. In addition, the Wellington Fault is located approximately 16km southeast from the North – South Junction escarpment. The Wellington Fault is expected to have a maximum moment event of 7.3 with a recurrence interval of approximately 600 years [4].

The tectonic setting and geological history of the 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 landslide types include rock falls, shallow rock slides, debris flows, scree slides and rock debris avalanches.

3. HISTORICAL SLOPE INSTABILITY HAZARDS

Areas of instability from the coastal escarpment between North and South Junction have caused landslide problems almost since the railway line was constructed approximately 125 years ago. Some of these instabilities were probably initiated by excavations into the base of the slope during construction of the railway line [3], but poor hillslope management practices in the past have contributed significantly to the level of instability. Until the early 1990’s, scrub and grass fires were reasonably common. These were either deliberately lit for vegetation control, but in some cases were accidentally lit by sparks from passing trains (steam trains in particular). Stock grazing occurred on the slopes also until comparatively recently, severely limiting the potential for revegetation.

3.1 Slope Performance 1900 – 1990’s

Since the line was opened in the 1880’s, and continuing up until the mid 1990’s, there have 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.

As examples, a train was derailed on the Paekakariki-Pukerua Bay section of track in June 1896 (Figure 3), caused by landslide debris blocking the line. The driver was injured. A tragic freak accident killed a passenger in February 1911: a boulder dislodged on the hillside above, and crashed into a carriage, killing a young woman [1]. In September 1961, a rock avalanche from ‘Beanpole corner’ (refer Section 3.2) derailed a Wellington-bound good train, almost pushing the locomotive over the bank onto the road approximately 30m below. This avalanche event occurred minutes after the Auckland-bound passenger service had passed. In 1980, a rock avalanche occurred at what is now known as ‘Little Beanpole’ (refer Section 3.3) resulted in a train derailment (Figure 4).

The following is an extract from an email sent to KiwiRail by a rail enthusiast who remembers:

In the 1980's rockfalls and slips were every common, especially between the two tunnels, immediately south of the Beanfence. Units frequently had their trips set off on the hill and the odd pantograph would go bang. In TAIC days, I'm fairly sure a Ganz [an electric multiple unit] got into trouble up there. If you look up the hill from the roadside, above the NE entrance to the tunnel by the Beanpole, you'll see a big slip scar and overhanging rock a fair way up. That I think was one of the slips struck by the Ganz. Loose rocks also used to fall between T3 & T4. Even in the 1980's trains would be pelted with loose rocks from up there, and in between the two following tunnels [Tunnels 5 and 6]
The rockfall and avalanche events experienced on this section of line were typically associated with prolonged periods of heavy rain (several days), with the exception of the 1980 failure at Little Beanpole, which occurred after a week of dry weather [6].

3.1.1 Beanpole Landslide

The Beanpole landslide was located between 34km and 34.5km directly above abandoned Tunnel 12. The landslide was centred on a broad spur that rises moderately steeply (approximately 40°) from sea level. The Beanpole landslide was a notorious spot on the NIMT with instability extending over an approximately 50 year period. In a report in 1981 the New Zealand Geological Survey [6] 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 5.

Increased activity of the slide seems to have occurred during the 1960’s when falls blocked the line on several occasions and on 19 September 1961 when a good train was derailed [6]. Inspection reports from the early 1960s indicate that rockfalls or rock avalanches 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. As a result of the landsliding and rockfalls in this period, the railway was protected by an approximately 4m high rail and sleeper rockfall catch structure (Figure 6). This structure was reasonably effective at protecting the track from the majority of rock falls, however, some detached rock blocks still had sufficient momentum to reach the railway line, either by punching through the netting or bouncing over the top of the fence.

Between November 1966 and November 1979, further movement occurred on the slopes at the head of the slide.

Figure 5 ‘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 [6]

Figure 6. Recent photograph of Beanpole fence. Note the large amount of vegetation behind the wall and the lack of evidence of recent rockfalls

In 1981, the New Zealand Geological Survey (NZGS) observed [6] approximately 20,000 m³ of
material bounded within tensional cracks high on the face above the Beanpole Corner. The slide mass had moved several metres downslope, with 2 to 4m high arcuate tensional cracking extending laterally across the slope 200m [6; refer Figure 5]. The NZGS assessed that the Beanpole Landslide was a shallow translational landslide within colluvial soils and regolith, with the slide base approximately 5 to 6m below ground level (Figure 7). There was no evidence of instability within the underlying greywacke rock mass.

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 rock avalanches 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 [6].

The failure recognised by the NZGS in 1981 was considered to present an extremely high risk to the track below as it had the potential to be the largest single slope failure on the Paekakariki coast [6] and given its large size, would have overwhelmed the rockfall catch structure at the base of the slope.

In 1990, New Zealand Railways made the decision to undertake bulk excavation works to remove the 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. Subsoil drains between 6m and 13m in length were installed on all the bench slopes. The excavation and drainage works were substantially completed by the September 1990.

Since the completion of this work, no significant slope instabilities have occurred from the area of the Beanpole Landslide. The excavation scar and face below is now largely revegetated (Figure 9) and there is no evidence of any further instability.

3.1.2 Little Beanpole Landslide

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 (Figure 4). The failure was unusual in that it occurred after a week of dry weather and the area affected had not previously shown any signs of instability [7].

The landslide that led to the train derailment was located on a steep (40-45°) slope of old scree material that had accumulated on a shelf between rocky bluffs [7] and involved a slide mass of approximately 750 m³ of coarse rock debris.

Figure 7. Interpreted cross section of Beanpole Landslide prior to bulk excavation. NZGS [6]
In an effort to protect the track, a rockfall catch structure was constructed adjacent to the track. This structure is essentially the same design as the Beanpole fence (hence the term ‘Little Beanpole’).

Although formed approximately 30 years ago, the scarp from the 1980 failure remains substantially clear of vegetation (Figure 8) and frequent small scale instabilities continue to occur. Periodic rock blocks continue to occur from the scarp, with recent rock blocks observed caught by the catch fence structure.

Figure 8. View downslope of the failure at Little Beanpole (outlined). Little Beanpole fence is located adjacent to the track in the background (arrowed)

3.2 Slope Performance 1990 - 2010

In the early 1990s a focus was put on improving the land’s stability along the Paekakariki escarpment. In a letter the Railways Corporation from the Department of Conservation (DOC) in 1990, it was noted that the land above the railway held high ecological importance in that remnant pockets of native vegetation continued to exist on the slope. The land was at that stage being substantially used for grazing, which was severely affecting the ability of the slope to revegetate.

As a result of the efforts by DOC, in the early 1990’s a local Ecological Group, Nga Uru Ora was granted permission from New Zealand Railways to undertake slope replanting and stock control on the slopes above the railway line. Since this time, Nga Uru Ora have undertaken a program to remove stock and feral animals from the escarpment and have been instrumental in the replanting of native vegetation, using ‘eco-sourced’ seeds.

The net effect of these activities has resulted in far fewer rockfalls or avalanches since 2000. By way of example, five rock fall events have been recorded in KiwiRail’s Incident Reporting System (IRIS) since 2000. This corresponds to 1 rockfall event every two years. In contrast, 11 events were recorded in the four years between 1958 and 1962 (ie approximately 3 events per year).

Significantly, the events recorded since 2000 have tended to be single rock blocks, rather than the debris avalanche events that were frequent during the 1960s to 1980’s.

It is clear that the combined effect of bulk earthworks at Beanpole and the program of stock control and replanting since the early 1990’s has had a significant positive effect on the risk of slope instability between North and South Junction (Figure 9). The likelihood of slope instabilities and track outage from events originating from high on the coastal escarpment has been significantly reduced.

Figure 9. Recent view of area above Beanpole Corner. The slide mass has been removed, and significant vegetation growth has occurred since removal of the slide mass in 1991

However, rockfalls continue to occur occasionally from the slopes adjacent to the railway line. There is still a significant risk of track outage and possible derailment. A program to manage these hazards is currently in the process of being implemented as outlined in the Section 4 following.

3.3 Future Planned Developments

Due to population increase on the coast to the north of this section of line, KiwiRail are currently investigating options to improve capacity between North and South Junction. Part of this improvement will involve improving permanent speed restrictions which have been imposed during previous risk management processes. The planned increases in line speed through this area require that risk reduction works are undertaken in some locations to reduce the current levels of risk. The slope risk ranking system that has recently been developed by KiwiRail has allowed these locations to be identified and assessed in a systematic process.

4 SLOPE RISK RANKING SYSTEM

Recently, KiwiRail have developed a Slope ranking system has been conducted over the
Wellington metropolitan area, including the area between North and South Junction. The benefit of this system to is to allow risk reduction works to be carried out in a systematic 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 where remedial works are required to reduce the current levels of risk.

The overall philosophy of the slope ranking system is to enable slope risks to be assessed using standard criteria and compared against each other on the basis of a points system. The system has been developed substantially in-house by KiwiRail Network, but draws on existing publications, including Network Rail [8], Hoek [9] and AGS [10].

It is not the intent of this paper to provide a full outline of the slope ranking system, however in summary, the ranking determined for any one slope is based on an allocation of points and is calculated as follows:

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\text{Slope Ranking} = (\text{Sum of points contributing to likelihood of failure}) \times (\text{consequence factors})
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Aspects contributing to the likelihood of failure occurring include:

- Whether the site would be subject to a fall onto the track or subsidence below the track,
- Slope height and angle;
- Subsurface materials,
- Distance of the track from the toe or crest of the slope,
- History of failure of the subject slope;
- Evidence of active or incipient failure; and
- Local drainage patterns and existing drainage measures.

Factors contributing to the consequence of failure include:

- Line speed and available sightline
- Landslide debris runout or embankment crest loss distance, and
- The number of train movements over time.

The maximum ranking that a slope could theoretically have is 487. The minimum is zero. The highest rated slopes are those that on the balance of probability will be the most likely to fail and have the highest consequence of failure.

4.1 Wellington Metro Area Pilot Study

As part of the development of the slope rating system, a pilot study has been conducted within the Wellington metro area. Lines within this area include the Johnsonville Line, part of the Wairarapa Line and the NIMT, including the section between North and South Junctions. The total length of track included in the pilot study is approximately 100km.

![Figure 10. Plot of highest ranked slopes recorded within the Wellington Metro area. Slopes between North and South Junction are indicated by a cross.](image-url)
Over 180 sites were surveyed within the area of the pilot study. Figure 10 above provides a summary of the highest ranked slopes that were identified. In summary, a total of 11 sites between North and South Junction are within the top 50 sites in the Wellington Area, including nine sites within the top 20. The highest ranked sites between North and South Junction are typically located adjacent to tunnel portals (as shown in Figure 11).

**Figure 11. Slope Conditions at End 2 of Tunnel 4 showing evidence of recent rockfall. This area is the second highest rated slope within the Wellington Metro Area and the highest rated slope between North and South Junction.**

5 PROPOSED SLOPE MAINTENANCE PHILOSOPHY

The slope maintenance philosophy that KiwiRail are in the process of adopting for the future management of the North-South Junction Escarpment can be outlined as follows:

1. Proposed higher line speeds between North and South Junction require that risk reduction works are undertaken at those slopes adjacent to the railway which have been assessed to have a high rating.

2. Continued promotion of vegetation growth on the higher levels of the escarpment above the railway line by selective replanting and stock/pest control.

5.1 Risk Reduction Works Adjacent to Railway

A program of risk reduction works is currently underway at the identified slopes between North and South Junction. The intent of the works proposed is to maintain or reduce the likelihood of slope instability affecting the track from major rainfall events (of up to 100 year period, say). Stabilisation of the slopes against seismic induced instabilities (in particular, major rupture of the Wellington Fault) is not considered to be economically possible. Proposed risk reduction works comprise either the implementation of a comprehensive monitoring system to provide an early warning of debris falls or rock falls onto the track, or more likely, the construction of suitable risk reduction works. These works would likely comprise:

- Anchored rockfall netting (Figure 12)
- Anchored sprayed concrete walls where tight clearances exist adjacent to the track (Figure 13),
- Toe fences to prevent fretted material from the rock slopes near track level accumulating in cess drains, and
- reconstruction and/or replacement of the existing fences at Beanpole and Little Beanpole.

**Figure 12. Rockfall netting under construction on the Johnsonville Line in Wellington. Similar measures are proposed for some of the identified high risk slopes between North and South Junction.**
6 CONCLUSIONS

The 3.5km long section of the NIMT between North and South Junction has had a long history of instability leading to track outage, derailment and in some instances, loss of life. Poor slope management practices during the majority of last century significantly exacerbated the frequency and size of slope instabilities along this section of the line.

Removal of the highest risk area of landsliding at Beanpole Corner and a more proactive programme of stock/pest control and revegetation on the escarpment since the early 1990’s above the railway line has led to a significant decrease in the frequency and size of slope events.

KiwiRail are currently investigating options to improve capacity between North and South Junction. Part of this improvement will involve improving permanent speed restrictions which will entail installation of a number of risk reduction measures at slopes considered to pose a risk to the track. A process of systematic slope rating recently developed by KiwiRail has assisted with the identification of key areas and selecting appropriate remedial measures.

7 REFERENCES


