https://doi.org/10.56295/1ACEG13

SLOPE HAZARD MANAGEMENT ON THE TOOWOOMBA RANGE RAIL CORRIDOR, QUEENSLAND.

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ABSTRACT

The Toowoomba Range Rail Corridor (TRRC) forms part of the West Moreton Line and runs from Harlaxton to Murphy's Creek. This section of track is approximately 26 km in length and was built circa. 1860's, through the steep terrain and complex geology of the Toowoomba Range. This section of the rail corridor has been subject to historic and ongoing slope instability which has impacted on the operational use of the railway. Over the past five years a programme of routine and emergency site assessments have been conducted to ensure safe operation of the railway. The assessments have been supplemented by UAV-obtained LiDAR and photogrammetry data to create Digital Terrain Models (DTMs). These DTMs have significantly aided in the assessing, planning and managing of slope maintenance activities.

Additionally, automated instrumentation has been installed in high-risk instability zones using GNSS satellite-based movement monitors, track tiltmeters and inclinometers.

The above methodologies have facilitated the development of a comprehensive register of instability events, zones of concern, associated risks and required maintenance works. This register also includes recommendations for further work at all assessed slope sites. This has proven extremely beneficial in assisting the Asset Owner with prioritising and targeting critical locations during the limited Scheduled Corridor Access System closures (SCAS closures) available.

An outline of the remediation works undertaken for one of the larger landslides at Chainage (CH.) 141 km, which reactivated and mobilised following the intense rainfall events in February/March 2022, is also presented.

1 INTRODUCTION

The diverse geological, geomorphological, hydrogeological, vegetation and climatic setting of the TRRC (also known as the Main Range Railway) have posed ongoing challenges for the safe operation of this critical transport link, which is essential for the export of goods from Queensland's interior.

Historically, instability events have impacted cut and fill slopes, structures (retaining walls, culverts, tunnel portals etc) and naturally occurring slopes above and below the rail corridor. To manage the effects of ongoing slope instability, the Asset Owner, has adopted a systematic programme of visual assessments, monitoring and maintenance of the rail corridor, including:

- Emergency and routine visual assessments by qualified engineering geologists.
- The use of UAV for capture of LiDAR and photogrammetric data and its storage in cloud-based software platform that manages and visualises spatial data.
- The installation of track and slope monitoring instrumentation providing cloud-based storage and real time web-based access to the data.
- Regular slope maintenance works including scaling and vegetation removal directed by qualified engineering geologists during SCAS closures.
- Construction of more significant remediation solutions when required.

One of the key challenges with this process has been determining which slopes should be prioritised for remedial works. Because slope instability events along the TRRC are often triggered by periods of elevated rainfall intensity and or changes in vegetation such as root jacking, slope conditions are prone to significant deterioration over relatively short timeframes. The dynamic nature of the processes driving these changes requires a flexible approach to determining where to direct resources to best manage slope risk along the corridor as conditions change over time.

2 PROJECT SETTING

The TRRC is heritage listed and is located directly north-east of the township of Toowoomba, Queensland (Figure 1). The project setting in terms of location, geology/geomorphology and a summary of the history of the site are provided below for context.

Figure 1: Site Location (Qld Gov, 2025)

2.1 SITE DESCRIPTION

The TRRC climbs some 365 m from Murphy's Creek CH. 131.400 km (245 m AHD) at the base of the Great Dividing Range to the summit at Harlaxton CH. 157.790 km (610 m AHD). This is the section of rail corridor described in this paper and has a length of approximately 26.4 km.

The rail line follows the contours of spurs and ridges, with the railway typically set in along ascending hillsides and banks that sit to the north of the track. Responding to the terrain, numerous built features including tunnels, cuttings, culverts, bridges, embankments and stabilising works occur along the extent of the railway.

2.2 GEOLOGY AND GEOMORPHOLOGY

Published geological information (GSQ, 2018) shows the TRRC (Figure 2) to be underlain by:

- Miocene Epoch (22-25 Ma) olivine basalt of the Main Range Volcanic Group at the western end toward Toowoomba.
- Mid-Jurassic Epoch (163-174 Ma) sandstone and siltstones of the Koukandowie Formation from approximately Murphy’s Creek Road intersection to approximately Holmes Yard.
- Early Jurassic Epoch (174-200 Ma) Gatton Sandstone from Holmes Yard toward Murphy’s Creek.

Both the Gatton Sandstone and Koukandowie are part of the Marburg subgroup and form the sedimentary basement rocks which underly the Main Range Volcanics on the Toowoomba Range.

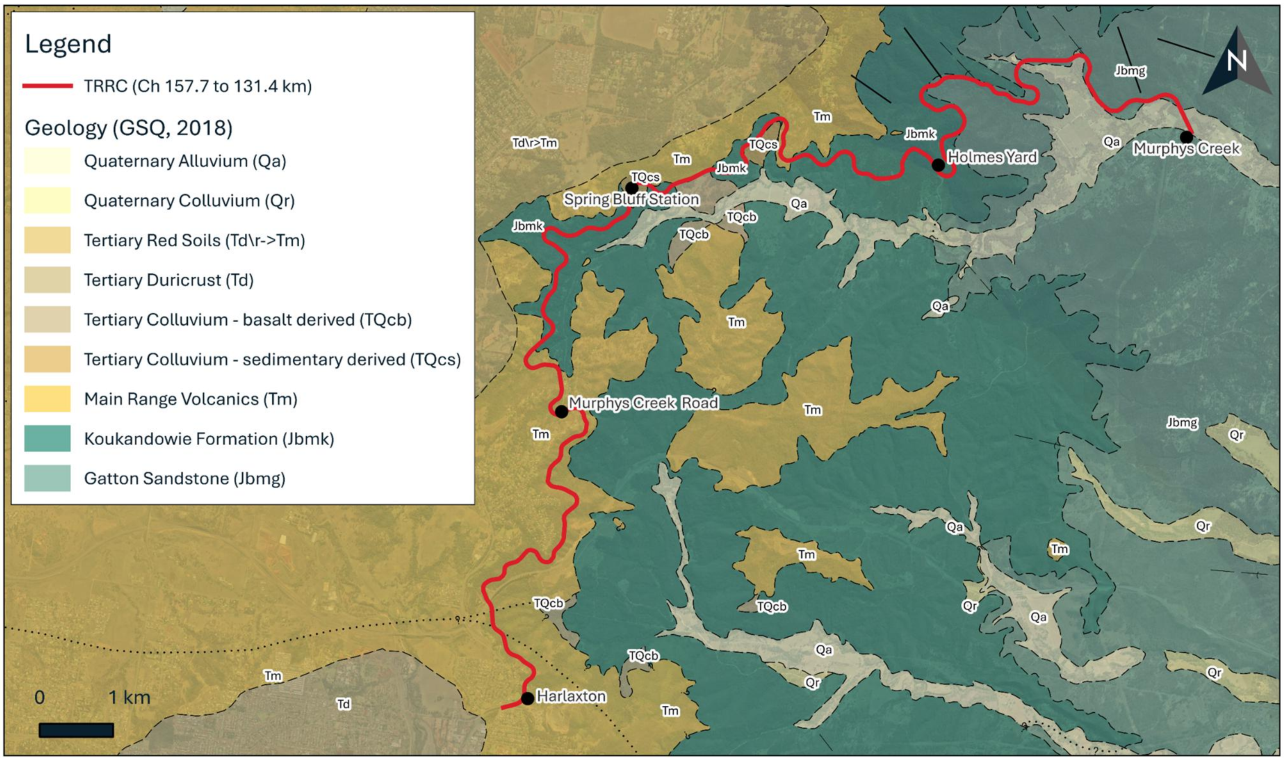

Figure 2: Geological Map (GSQ, 2018)

2.2.1 Main Range Volcanics

The Main Range Volcanics comprise a series of basaltic flows, most just a few metres thick, with discontinuous beds of tuff and agglomerate in some areas. These volcanics occur between Murphy's Creek Road and Harlaxton, with occasional outcrops south of Spring Bluff Station, predominantly along spur ridge lines. Typically, the terrain in this geological unit is steep, with exposed rock outcrops and boulders visible on cleared slopes. Common failure modes include rockfalls, boulder roll, debris slides, and occasional large landslides. Some basaltic flows have an altered upper horizon that has preferentially weathered. In some locations, this has led to undercutting of more competent basalt blocks, increasing their potential for instability. This appears to be a primary failure mechanism in basaltic cuttings, as shown in Figure 3.

Figure 3: Rail cutting showing competent basaltic blocks progressively undercut

Volcanic tuff is observed near the rail intersection with Murphy's Creek Road (previously Ballard railway station) where they are seen in layers of 10-15 m in thickness (see Figure 4).

Figure 4: Typical rail cutting in Tuff

2.2.2 Marburg Subgroup

The Koukandowie Formation and Gatton Sandstone form two of the major components of the Marburg subgroup (see Figure 5). This group is typically described as "Fine to coarse-grained, thin- to very thick- bedded, crossbedded, quartzose to lithofeldspathic sandstone, interbedded with polymictic pebble and minor cobble conglomerate, siltstone and claystone; minor coal and basalt, fossil wood ferruginous oolite" (GSQ, 2018). These units are typically found east of Murphy's Creek Road. The Gatton Sandstone typically comprises much thicker beds of sandstone. Areas of instability and/or existing failures are often observed where flat-lying relatively competent sandstone has been undercut by less resistant shales and siltstones. This appears to be a primary mechanism for failure within these cuttings.

Figure 5: Typical rail cuttings in the Koukandowie Formation (left) and Gatton Sandstone (right)

2.3 SITE HISTORY AND SLOPE INSTABILTY

The TRRC was the earliest railway crossing of the Great Dividing Range in Queensland (and in Australia) between Murphy's Creek and Harlaxton. It was built by railway builders Peto, Brassey and Betts between 1865-1867 for the colonial government of Queensland. Along the route, engineering features responded to challenging and variable terrain, as demonstrated in the provision of nine tunnels, numerous culverts, cuttings and embankments, and extensive use of curved track. The line originally included the construction of 47 bridges (mostly timber), but these have been gradually replaced by culverts and embankments.

The regional setting of the TRRC is one of known slope instability, as detailed by W.F Willmott (1984). Historically, slope instability events along the corridor are often triggered by periods of elevated rainfall intensity. This has led the Asset Owner to develop a network of weather stations and rainfall intensity-based triggers which allow pre-defined actions such as closing the rail line and undertaking Emergency Inspections of the corridor prior to re-opening the corridor to rail traffic.

In recent years, major climatic events such as those in January 2011 and 2013 (Ex-Tropical Cyclone Oswald) resulted in significant damage and remediation (e.g. CH. 141.1 km, CH. 153.3 km and CH. 155.6 km) and most recently in January 2022 when much of the line was impacted by superficial slope failures. One notable exception was the reactivation of a previous landslide, which resulted in the loss of an unused access road (see Section 6.2).

3 SLOPE RISK ASSESSMENTS

3.1 HAZARD IDENTIFICATION

In 2019/2020, SMEC was engaged by the Asset Owner to undertake a series of slope risk assessments for the cuttings and embankments along the TRRC. The initial scope was to identify slope hazards with the potential to impact the rail line. Over time the assessments have expanded to consider hazards within the natural terrain above and below the cut and embankment slopes, as well as hazards which could also affect the rail corridor access roads.

A total of one hundred and seven (107) slope sites were assessed. Initial site assessments were carried out on foot, with observations predominantly made from track level, limited access to slope crests was available. Dense vegetation often restricted visual assessments of embankment slopes. For each slope site, an Asset Condition Report was compiled, documenting slope extents, geological conditions, identified hazards including an assessment of likelihood and consequence of each hazard impacting the track. The reports also included recommendations for hazard management and/or mitigation strategies, with indicative time frames in which to conduct the mitigation works.

3.2 RISK ASSESSMENT FRAMEWORK

The risk assessment was qualitative in nature and was undertaken in line with the Asset Owners' risk framework (QR, 2018). The assessment evaluates hazards based on the likelihood of occurrence and potential consequences to the rail track and rail traffic.

3.2.1 Likelihood

The assessment of likelihood considers both the potential for a hazard to mobilise (probability of detachment) and its ability to impact the track (probability of travel). This was based on engineering judgement with consideration given to field based evidence of past events, documented incidents, slope geometry and clear space between the slope and the track. A summary likelihood ratings and descriptors from the asset owners risk framework are presented in Table 1

Table 1: Likelihood Descriptors

Likelihood Term	Likelihood Description
Certain	>100 times/year, Always occurs,
Highly Likely	11 to 100 times/year, regularly occurs
Likely	2 to 10 times/year, periodically occurs
Possible	Once a year, occasionally occurs
Unlikely	Once every 10 years, infrequently occurs
Improbable	Once every 100 years, almost never occurs
Rare	Once every 1000 years, has never occurred

3.2.2 Consequence

In general, to align the risk assessment framework consistently through the assessments the consequence categories were assigned based on service disruption, financial impact and safety concerns. The consequence terms adopted are summarised in Table 2.

Table 2: Consequence Descriptors

Consequence Term	Consequence Description
Catastrophic	>28 days service disruption, multiple fatality
Critical	14 to 28 days service disruption, multiple fatality
Very High	7 to 14 days service disruption, single total permanent disability injury or fatality
High	3 to 7 days service disruption, 1 – 10 major injuries (reportable to WH&S QLD)
Moderate	1 to 3 days service disruption, 1 – 10 serious injuries (lost time injury)
Low	< 1 day service disruption, 1 – 10 minor injuries
Very Low	No disruption, no injury

3.2.3 Risk Assessment

The qualitative risk assessment was conducted for each identified hazard assigning a Risk Rating (e.g., High, Medium, Low) to each. The worst-case scenario determining the overall slope risk rating for each site. Table 3 provides a summary of the derived risk ratings for the initial site assessments in 2020.

Table 3: Summary of risk assessment outcomes for TRRC in 2020

Overall Risk	Cuttings	Embankments	Total
Very Low	0	0	0
Low	5	0	5
Medium	82	7	89
High	8	5	13
Extreme	0	0	0
Total	**95**	**12**	**107**

4 SLOPE PRIORITISATION CHALLENGES

For each site, a Priority Ranking score was assigned based on the Asset Owner's risk framework, with scores derived from likelihood and consequence values within the risk matrix. The ranking aimed to identify which slopes should be prioritised for remedial works.

From the initial risk and priority assessments, the 10 most critical sites were selected for targeted maintenance during future SCAS closures. However, several challenges arose with this prioritisation approach:

- Many hazards fell under the same consequence and likelihood parameters, resulting in identical risk ratings and priority scores for multiple slopes.
- In some cases, hazards of a lower risk rating received higher priority scores to those of a higher risk rating owing to the structure of the risk matrix. For example:
  A Medium-Risk hazard with a ‘Possible’ Likelihood (4) x ‘High’ Consequence (4) = Priority Score 16, while a High-Risk hazard with a ‘Certain’ Likelihood (7) x ‘Low’ Consequence (2) = Priority Score 14.

This rigid approach to a priority framework did not account for temporal changes in environmental triggers for instability, such as wet weather, seasonal vegetation growth, or periods of drying out.

To supplement the slope prioritisation, a schedule of routine site visits was established to visually monitor key hazards for signs of deterioration. These visits were complemented by ad-hoc emergency callouts as and when requested, either following slope instability events, or episodes of wet weather exceeding 50 mm rainfall/24 hrs.

5 ADDITIONAL MONITORING & DATA CAPTURE

Since 2020, additional site data has been routinely collected, allowing for further refinement of the initial risk assessments. The additional data has been obtained by:

- Carrying out detailed slope assessments at individual sites, via roped access during SCAS closures.
- Observing the processes and rates of slope deterioration at individual sites over time.
- Undertaking remedial works at select locations.

In addition to routine and emergency site visits, further site data has been acquired through the installation of slope monitoring devices and the acquisition of a 3D reality capture of the rail corridor using LiDAR and photogrammetry. These enhancements have contributed to establishing a more robust slope risk management along the rail corridor.

5.1 INSTRUMENTATION

Several types of instrumentation have been utilised along the TRRC for differing purposes at differing times including topographic survey of structures/markers, tiltmeters, standpipe piezometers, and inclinometers for specific sites to support analysis and development of remedial solutions.

One of the most utilised instrumentation types currently is a system patented by Kurloo which is based upon Global Navigation Satellite System (GNSS) and the Internet of Things (IoT) and their cloud computing technology. The basis of the system is that the accuracy of a point in x/y/z determined by GNSS increases with the length of time observation. At one end of the scale a 1 second reading might give 5-10 m uncertainty in location whereas a continuous operation reference station (CORS) may achieve 1-5 mm accuracy. The Kurloo devices are installed at the top of a metal post which can be driven or concreted into the ground, are solar powered and can deliver 0-3 mm accuracy in x/y/z according to the manufacturers. Arrays of these instruments have been installed at several critical sites across the project (see Figure 6). A typical output from the web-based portal which allows customisation for the project and alert triggers to be set is presented in Figure 7.

Figure 6: Kurloo instrumentation embankment monitoring

Figure 7: Typical web-based output

5.2 AERIAL PHOTOGRAMMETRY AND 3D VISUALISATION

To support asset management, the Asset Owner engaged SKAND in 2022 to conduct a topographic survey and host a 3D reality capture of the rail corridor. LiDAR and photogrammetry data were obtained via UAV with the outputs accessible through an online portal hosted by SKAND. The photogrammetry data provides a valuable tool for visualising slopes and identifying key features, including:

- Potentially unstable rock blocks and their dimensions.
- Locations of past remediation zones that may be subject to Cultural & Heritage protections (e.g., old stone pitched walls).
- Critical rail infrastructure such as pressure sensors and greaser devices.

This enables the slope management team to review the assessed hazards, understand site constraints, and identify any assets in the area which may require extra protection measures to be put into place before maintenance works can commence.

While photogrammetry offers detailed surface visualisations, dense vegetation can obscure key slope features. To address this issue, hillshaded DTMs were generated from the LiDAR data. This allows for a clearer visualisation of the ground surface to be achieved in densely vegetated areas. Integrating the hillshades with photogrammetry in the 3D model has proven invaluable for planning slope assessments and maintenance during limited SCAS closures by:

- Assisting the review of initial hazard assessments.
- Identifying key targets for roped access inspections.
- Helping to detect potential instabilities beyond cut slopes within the natural terrain that may require additional inspections.
- Ensuring critical infrastructure (e.g., sensors, greasers) is identified protected before scaling activities, to prevent damage from machinery or falling blocks as they are scaled from the slopes.

Figure 8 illustrates how the combined photogrammetry and hillshade visualisations can be used to highlight visible instabilities in the rock slope and to identify additional zones of concern that may exist within the natural terrain beyond the cut slope crest.

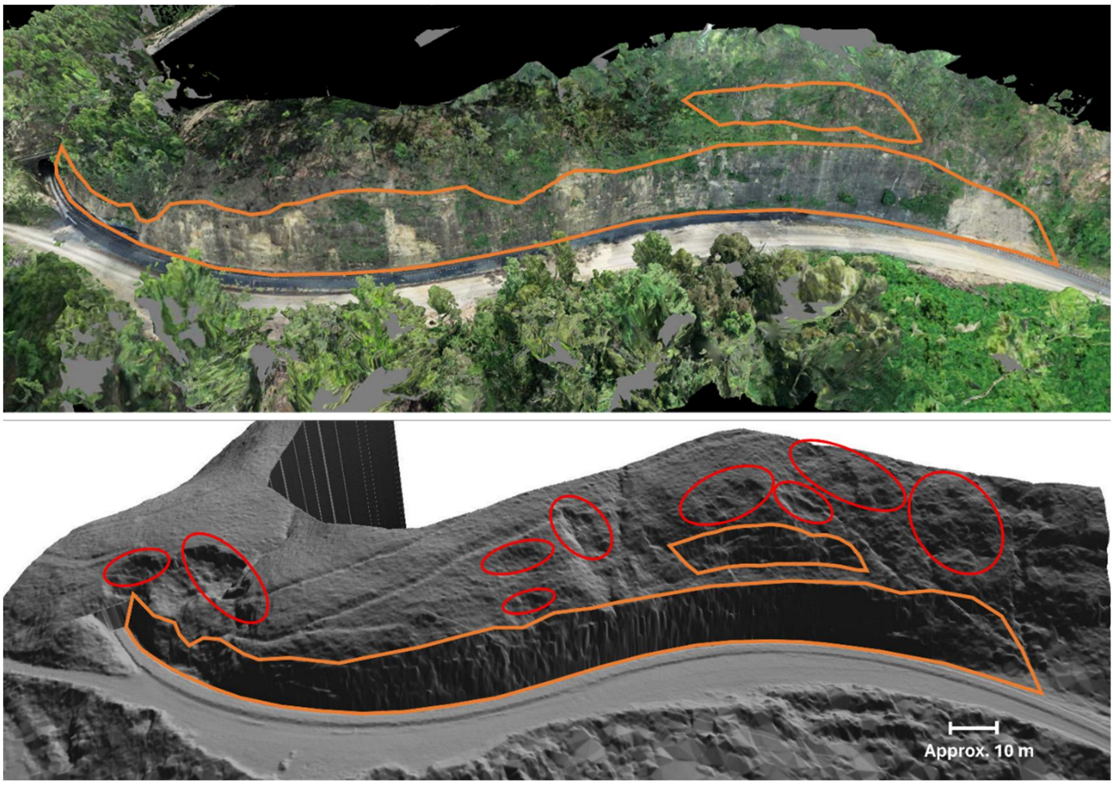

Figure 8: (Top) photogrammetry with rock slope details and extents indicated (orange). (Bottom) 3D hillshade showing additional zones to be assessed located within the vegetated natural terrain above the cutting (red).

Utilising this approach to review site locations when planning future slope maintenance activities has significantly improved efficiency in scaling and inspection campaigns during the limited SCAS closures. Additionally, the 3D visualisations serve as an effective communication tool, helping convey hazard scale and mitigation needs to the Asset Owner.

6 SLOPE MAINTAINANCE REGISTER

Over time, site observations have been compiled to form a recent slope history at each site. These histories document the initial risk assessment observations, recommendations for slope works, recent instability events, and remedial works that may have occurred over time at each site.

The compilation of this data led to the creation of a 'Maintenance Register,' a live document which can be used to track changes in site conditions. It is updated following routine or emergency assessments, scaling works, or as new recommendations and indicative timeframes for remedial works are established. By tracking slopes that have experienced recent deterioration, ongoing instability, or are overdue for inspections, the asset management team can respond dynamically to changing site conditions. This approach is more aligned with the Asset Owner's needs, allowing for flexible and targeted management of slope risks.

6.1 INTEGRATED SYSTEM FOR RISK MANAGEMENT

In 2023, the Asset Owner's risk framework was revised (QR, 2023), triggering an update to the initial risk assessment. This update incorporated the new risk framework, and results of ongoing maintenance works and assessments conducted since the start of the project. Information detailed in the Maintenance Register enabled this task to be streamlined.

As part of the updated assessment, the Maintenance Register was integrated directly into the revised risk assessment document, the intent being to ensure the register is maintained allowing a more data-driven approach to managing slope risks to be adopted moving forward.

6.2 OUTCOMES

At the start of this project, slope assessments and scaling works were typically carried out on a case-by-case basis in response to emergency callouts following rockfalls or landslide events. Over time, routine visits and slope works have been implemented to improve risk management of the corridor slopes.

A key factor driving the regular slope works has been the availability of a clear record of activity at each slope site. Documenting this information in the 'Maintenance Register' provides the asset management team with the data needed to justify and implement a more proactive slope maintenance schedule. This integrated approach has led to a significant reduction in emergency callouts over the past four years.

Between January 2020 to December 2021 a total of 18 emergency callouts occurred associated with instability events. For the period January 2022 to December 2024, a total of 11 emergency callouts were requested associated with instability events, representing a 38% reduction in unplanned track closures.

Following the risk framework update, the revised 2024 risk assessment is summarised in Table 4.

Table 4: Summary of Revised Risk Assessment Outcomes for TRRC IN 2024

Overall Risk	Cuttings	Embankments	Total
Low	31	0	31
Medium	64	9	73
High	2	4	6
Extreme	0	0	0
Total	97	13	110*

Note: *Three sites were added in 2024 as these sites were not accessible for initial 2020 assessments.

7 REMEDIATION MEASURES

As part of the slope risk assessment process, recommendations for remedial measures have been made to better manage slope risks along the corridor. In the short term, prescriptive measures such as routine scaling and roped access assessments are commonly adopted. For more long-term solutions, permanent designs have been developed to the concept stage, with detailed design and construction completed for one site to date.

7.1 PRESCRIPTIVE MAINTENANCE

Prescriptive maintenance measures adopted along the TRRC have included roped access inspections, scaling activities, and vegetation management. These efforts typically aim to reduce the likelihood of future rockfalls and mitigate slope deterioration due to root jacking (Figure 9 & Figure 10). While these measures are lower cost compared to permanent solutions, they require repeat visits to address ongoing slope deterioration.

Figure 9: (Left) Rockfalls induced by root jacking, trimming and poisoning of critical vegetation is often utilised. (Right) Roped access assessment and the use of air bags to remove large localised blocks from the slope face.

Figure 10: (Left) Extensive scaling via roped access and the use of hand tools. (Right) Mechanical scaling of larger zones of problematic rock mass via long reach excavator.

7.2 PERMANENT REMEDIATION (CH. 141 KM EMBANKMENT STABILISATION)

The embankment below the rail line is positioned on a historical landslide area, which was reported to have occurred following a rainfall triggering event in 2012. The landslide was reactivated following extreme rainfall event in February 2022 where approximately 450 mm was recorded over a four-day period. A landslide scarp of approximately 80 m long developed with up to 6 m of downwards displacement. The landslide continued slow displacement predominately associated with each rainfall event. A detailed design was undertaken to support the upper access track and mitigate the slope instability.

Remediation works were undertaken between July 2023 and October 2023 comprising:

- Soil nails and shotcrete to upper access track: to aid long-term stability of the slope by mitigating potential erosion issues, assisting drainage control and decreasing the risk of global slope instability.
- Site-wide drainage: to mitigate potential scour/erosion from the site and to mitigate water infiltration into the slope. The drainage system aimed to slow the flow velocity at the pipe exits of existing culverts (using a pit), down the chute (by added bevels/steps), and along the slope (using a rock mattress/gabion) and to collecting the water and convey it away from the slope.
- Regrading the slope: to flatten the slope steepness, which results in a reduction of shear stress acting on the soil, hence creating more stable slope conditions.
- Vegetation: was added to the slope surface. The roots of the vegetation hold the soil in place and reduce the effects of erosion.

Figure 11 shows the condition of the landslide prior to and following the remediation works.

Figure 11: (Top) Reactivation of an existing failure at CH. 141.1 km resulted in the mid-slope access road experiencing 6 m downwards displacement. (Bottom) Post construction condition of the slope following remedial works undertaken in 2023.

8 CONCLUSIONS AND ACKNOWLEDGEMENTS

Information regarding the frequency of instability events, particularly in sparsely populated areas, is often poorly documented (Shipway & Cooper, 2019). This has considerable impact on the risk assessment process when determining the likelihood of a hazard occurring. Clearly documenting any instability events, recommendations for remedial works with suggested timeframes for completion, and any maintenance works undertaken at each slope site, provides an important knowledge framework for successfully assessing and managing risks to the rail operation both now and in the future.

The Maintenance Register implemented on this project has proven invaluable to the asset management team to efficiently identify and prioritise critical slopes for remedial works during limited SCAS closures, ensuring a proactive and organised approach to slope maintenance is achieved.

The authors gratefully acknowledge the Asset Owner for providing historical information and data to facilitate this study. Further, acknowledgement is extended to Kurloo and SKAND for their specialist equipment and technology.

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