AtkinsRéalis

B8035 - Mull Rockfall
Final Options Report

12 November 2025

B8035 GRIBUN ROCKFALLS - GEOTECHNICAL RISK MANAGEMENT

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Executive Summary

This report presents the final appraisal of geotechnical risks and mitigation options for the B8035 at Gribun, Isle of Mull, following recent rockfall incidents that have impacted the carriageway and posed significant safety risks to road users.

An updated quantitative risk assessment has been presented, further considering the impact of reducing the number of journeys, or reducing the frequency of rockfall events impacting the road. This updated QRA indicates that for a high frequency of events (e.g. 10 blocks per year), journeys would need to be reduced to below 20 journeys per day for single occupancy vehicles to reduce the risk to within the ALARP (As Low As Reasonably Practicable) region, and that for multi-occupancy vehicles the risk remains unacceptably high.

Potential remediation options including operational measures, and engineering interventions have been presented. Full slope engineering interventions are likely to result in the greatest risk reduction, however many of these interventions are likely to be time consuming, and present significant costs and technical challenges.

Targeting interventions to areas that potentially present higher risk, such as sections where sightlines are reduced, or there is potentially a higher frequency of rockfall events depositing on the road may reduce the level of risk to within the ALARP or acceptable levels in a more cost-effective manner.

1. Introduction

This final options report presents the updated results on a geohazard risk assessment carried out along as section of the B8035 at Gribun, Isle of Mull, following on from an interim appraisal published on 10/10/2025.

The assessment was initiated in response to recent rockfall activity affecting the carriageway, posing a risk to road users.

The site is characterised by steep exposure of the Mull Lava Group, comprised of basalt, which exhibit varying degrees of weathering and structural complexity.

The purpose of this report is to present an updated risk assessment and present an appraisal of potential remediation options.

Detail from the initial assessment has not been reproduced in this report. This report should be read in conjunction with the initial hazard evaluation in the B8035 – Mull Rockfall Interim Assessment. As this report has not been written as a standalone document.

2. Updated Hazard & Risk Assessment

Building upon the initial hazard evaluation in the Interim Assessment, this section presents a refined assessment of the risks posed by rockfall events along the B8035 at Gribun. The updated analysis incorporates new data from RAMMS rockfall modelling, and revised assumptions regarding road user exposure and rockfall frequency.

2.1 Methodology

As recommended in CIRIA C810 (Koe, et al., 2023), the following relationship has been used to evaluate the risk posed by rockfall at the site.

$$Rs = P(Hi) \times \Sigma(E \times V \times Ex)$$

Where:

Rs = specific risk due to a particular magnitude of landslide Hi occurring within a specified area over a given period of time.
$P(Hi)$= probability of a particular magnitude of hazard Hi within a specific area and time frame
E = Elements at risk
V = Vulnerability of elements at risk
Ex = Exposure

This assessment considers the detachment of blocks with a maximum dimension of 0.5 m (0.5 x 0.5 x 0.5 m) which represents a common block size observed on site, indicating that this is a frequent event magnitude, to 2 m (2 x 2 x 2 m) which represents larger blocks observed on site which are assumed to be a lower frequency event.

A 1 km section has been selected as a nominal region to allow the risk to be compared between scenarios and to other sites.

This includes assessment of a vehicle collision with a recently fallen block of rock.

2.1.1 P(H) – Likelihood of hazard

P(H) considers the probability of a hazard reaching the area being considered (e.g. how likely is it that a block will detach from the cliff face and reach the road). This can be calculated using the following equation:

$$P(H) = pD \times pT$$

Where:
pD = Probability of detachment
pT = Probability of travel

2.1.1.1 Probability of detachment

While there is limited data on confirmed rockfall events, due to fresh blocks (little to no lichen) being present throughout the site area, and anecdotal data from local road users indicating that material is regularly cleared from the road, values of between 1 and 10 blocks per annum have been considered in this assessment. Engineering interventions including the installation of rockfall fences, and scaling of loose material from the rock face can reduce the frequency of rockfalls reaching the road. Reduced frequencies of 0.1 (10-year return period) and 0.01 (100-year return period) have been considered to demonstrate the impact of reduced frequency on risk levels.

Larger blocks are observed to be present across the site less frequently than smaller blocks, as rockfall frequency typically decreases with increasing magnitude of event. Frequencies of 0.1 (10-year return period) and 0.01 (100-year return period) have been considered within the risk assessment as potential frequencies for higher magnitude events, however it should be noted that the relationship between magnitude and frequency is site dependant and has not been determined at this location due to the limited information available.

Fresh blocks were observed at various locations across the site, both at the location of the 2025 rockfall events, and outwith this area. Larger numbers of blocks can be observed within the central 500 m surrounding the recent rockfall (chainage 700 – 1200 (Figure A-1)) indicating that this area could potentially have a higher frequency of events than other sections or have a greater proportion of blocks depositing adjacent to the road. However, the presence of fresh blocks indicates that the frequency of rockfalls is relatively high across the whole site.

2.1.1.2 pT - Probability of travel

RAMMS rockfall modelling has been undertaken (detailed in Section 2.1.5) to give a greater understanding of potential block runout paths. The results of the modelling have shown that 80% of 0.5 m blocks, and 93% of 2 m blocks reach the B8035, therefore a value of 0.8 has been selected.

Rockfall runout modelling indicates that the likelihood of any detached blocks reaching the road is broadly consistent across the site, with the exception of the channel located at chainage 1250, where 0.5 m blocks are modelled to deposit within the channel, and within a depression adjacent to the channel. 2 m blocks are modelled to reach the road within this area. Within the drone imagery and site photographs many boulders are deposited in these areas, matching the modelling results, as seen in Figure 2-1.

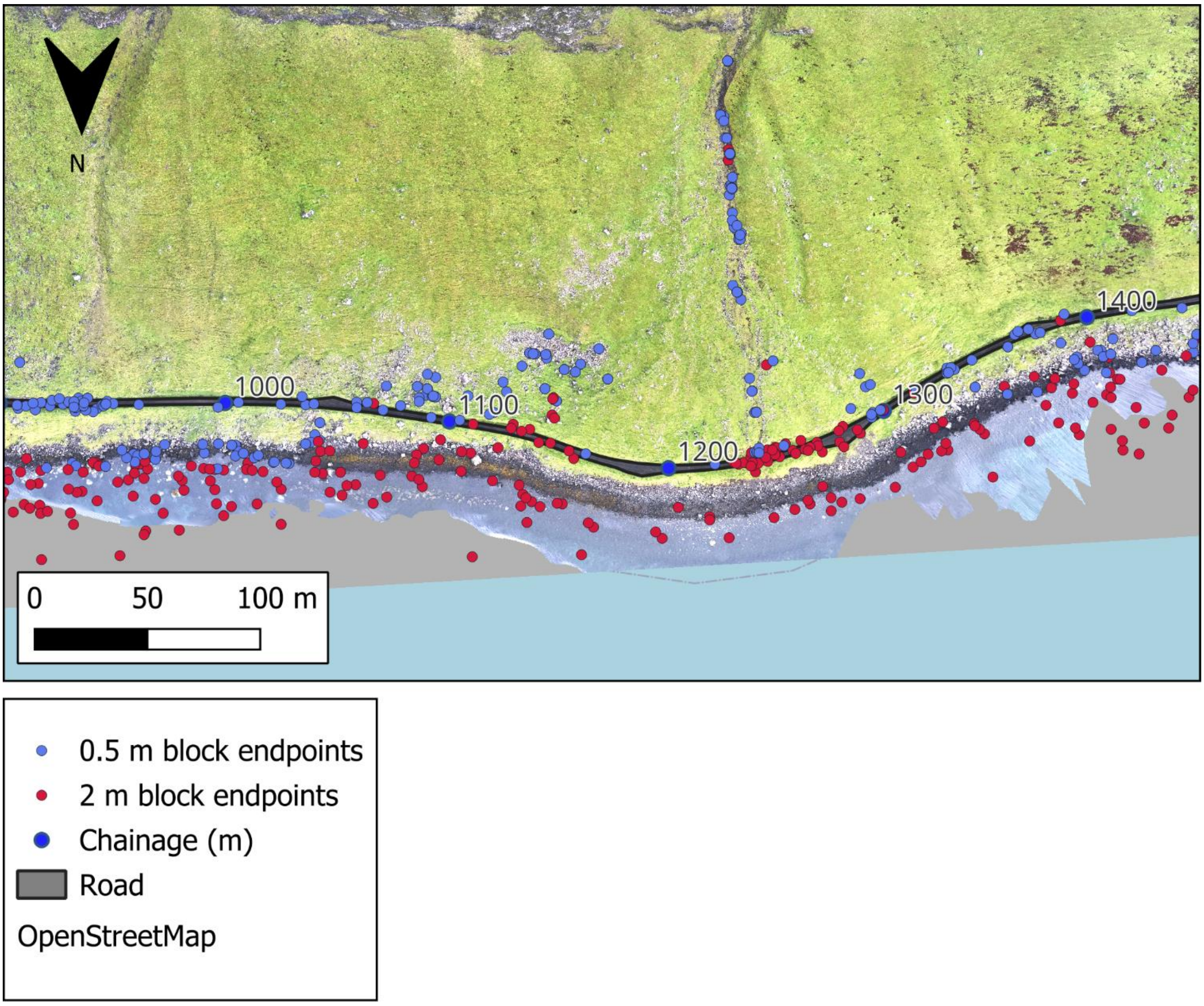

Figure 2-1 - RAMMS rockfall modelling block endpoint locations showing deposition of blocks within a channel in the slope, matching actual blocks visible within the drone imagery

2.1.2 E – Elements at risk

This variable considers the number of elements at risk (i.e. how many people are exposed to the risk). For the considered rockfall scenarios, a single person in a car, and 4 people in a car (e.g. a family on holiday) have been considered.

2.1.3 V – Vulnerability of elements at risk

This variable considers the likelihood of fatality should an element at risk be impacted by or collide with a rockfall in the considered scenarios. As it is assumed that road users will be in a car there is likely a low chance of a fatality occurring, therefore a value of 0.01 has been selected.

Vulnerability is likely to be variable due to a number of factors such as the age and health of road users, the vehicle they are travelling in, and the speed that they are travelling at with elderly people, those in more exposed vehicles such as motorcycles, and those travelling at a greater speed having a higher vulnerability. Walkers and cyclists are expected to have a higher vulnerability to impact from a rockfall. However, as they are not exposed to the risk of collision with rockfall debris, and they are expected to be less common than those in vehicles, their risk is expected to be relatively low.

2.1.4 Ex – Exposure

This variable considers the exposure of an element at risk to the considered rockfall hazard.

This section of the B8035 is designated national speed limit, however due to the width of the road it is likely that vehicles will be moving slower than this. Local road users familiar with the road are likely to be driving significantly faster than tourists unfamiliar with the area.

A speed of 30 mph has been chosen for this scenario. At this speed a standard car will have a stopping distance of 23 m (The AA, 2024) and will cross the 1 km of road being considered in 75 seconds. This results in a spatial probability of 0.023, and a temporal probability of 2.36 x 10^{-6} per year.

Argyle and Bute Council traffic monitoring recorded 330 vehicles using the road daily on average during June 2022. While this likely represents a peak in road usage, at similar vehicle volumes this results in 120450 traffic movements per year.

Further scenarios with 100 journeys per day, and 20 journeys per day have been considered to demonstrate the impact of reducing the number of journeys has on the level of risk.

2.1.5 RAMMS Rockfall Modelling

Three-dimensional rockfall modelling was undertaken using RAMMS:Rockfall software to assess potential rockfall trajectories and better understand the dynamics of rockfall events across the site. This modelling provided detailed outputs on rockfall trajectories, kinetic energy, velocities, and bounce heights, which are critical for informing the design and placement of mitigation measures.

The rockfall model was constructed using the DSM (Digital Surface Model) generated during the drone survey conducted on 30/09/2025 at a resolution of 0.25 m.

A seeder line was drawn along the top of the cliff section, and blocks were released at randomly generated points along this line to give an understanding of runout paths and block velocities across the site. Following this initial model, additional point locations were specified to cover areas of interest within the site (e.g. below a channel within the cliff as boulders released above this were diverted down the channel).

The terrain within the model was categorised into two primary types; the cliff face was assigned the “bedrock” terrain type, while the lower slope was designated as “vegetated talus.” The terrain type dictates how deformable the terrain is when impacted by a block, and the amount of drag force that an impacting block experiences.

At each release location, two blocks were released at 10 randomly generated orientations. A larger and smaller block was selected to give an understanding on the impact of block size on runout, bounce height, and kinetic energy. A block with maximum dimensions of 0.5 m, and a volume of 0.06 m^3 (0.5 x 0.5 x 0.5 m) was selected to represent an average block size observed on site.

A larger block with maximum dimensions of 2 m, and a volume of 4.3 m^3 (2 x 2 x 2 m) was selected to represent the upper end of likely rockfall events. For both blocks, a “real” rock type was selected (Figure 2-2), as this has more irregular faces than standard shape blocks (e.g. cube, sphere) and will result in more realistic behaviour. Equant block shapes were chosen as these have been deemed representative of many of the blocks observed on site, and are likely to have a greater runout, allowing for a more conservative estimate of block behaviour.

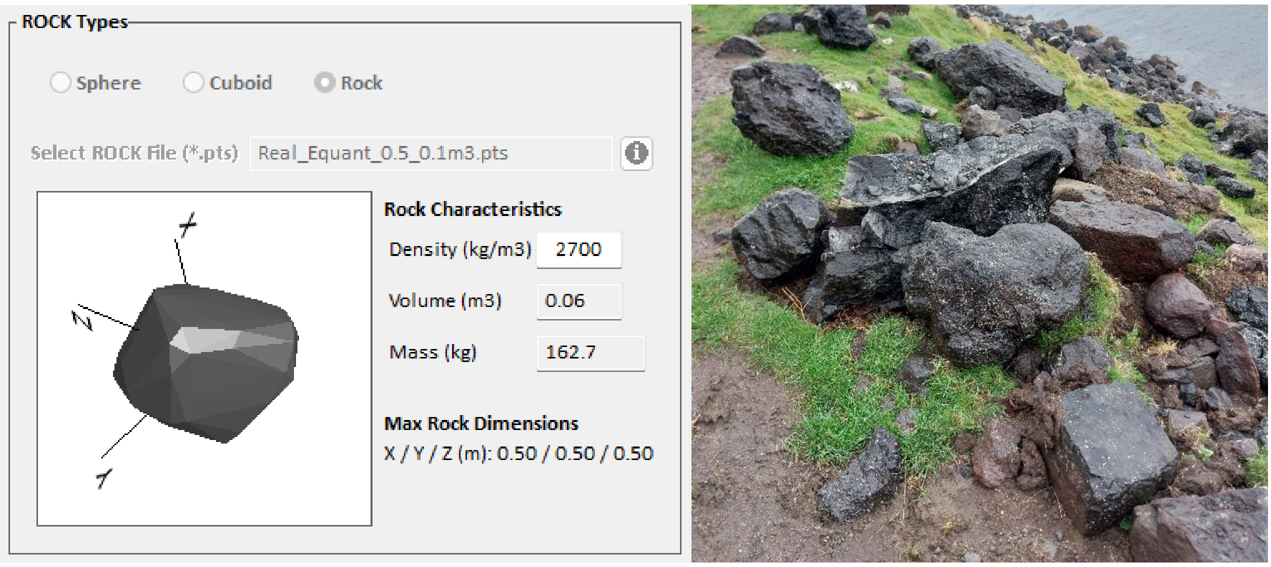

Figure 2-2 - 0.5 m block used during RAMMS rockfall modelling (left), Examples of blocks observed on site (right)

2.1.6 Rockfall Modelling Results

The model results for a 25 m buffer zone upslope of the road were calculated and are shown in Table 2-1 below. This allows the block jump height, velocity, and kinetic energy to be estimated within the vicinity of the road. As the modelling trajectories include an initial free-fall of up to 47 m from the cliff, analysing the results for the whole slope area would result in unrealistically high values. An example block trajectory can be seen in Figure 2-3.

	0.5 m max dimension block	**2 m max dimension block**
Whole Modelling Area		
Mean/Maximum jump height (m)	0.6 / 3.9	2.1 / 10.0
Mean/Maximum block velocity (m/s)	7.2 / 18.2	13.0 / 26.5
Mean/Maximum block kinetic energy (kJ)	5.8 / 28.6	1357.3 / 4714.1
Assumed High Frequency Area (ch. 700 - 1200)		
Mean/Maximum jump height (m)	0.5 / 2.5	2.0 / 6.1
Mean/Maximum block velocity (m/s)	6.2 / 15.7	13.1 / 26.5
Mean/Maximum block kinetic energy (kJ)	4.5 / 22.0	1356.0 / 4714.1

Table 2-1 - RAMMS Rockfall modelling results

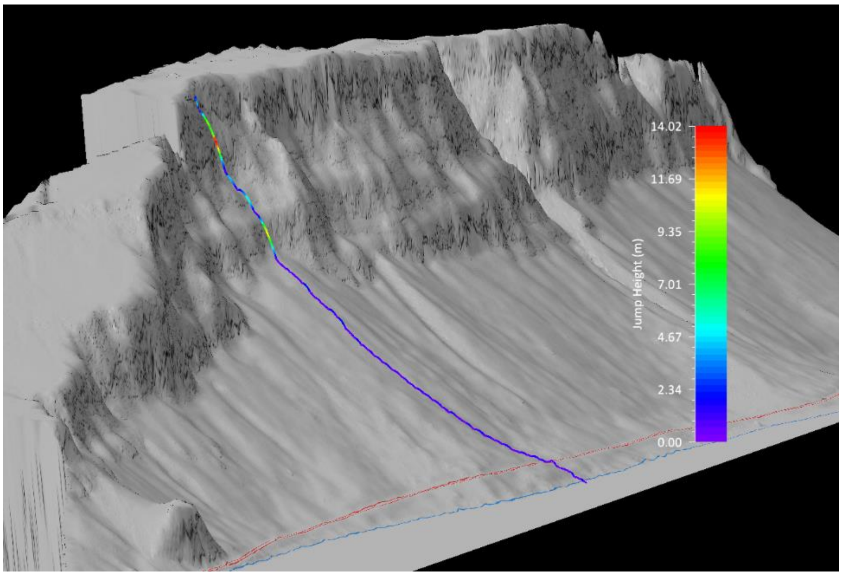

Figure 2-3 - RAMMS rockfall modelling output – 0.5 m block trajectory showing rock jump heights.

2.1.6.1 Rockfall runout distance

Within the modelling area, the vast majority of modelled blocks reach the B8035, as seen in Figure 2-4. 87% of total modelled blocks reach the road with larger blocks being more likely (93%) than smaller blocks (80%).

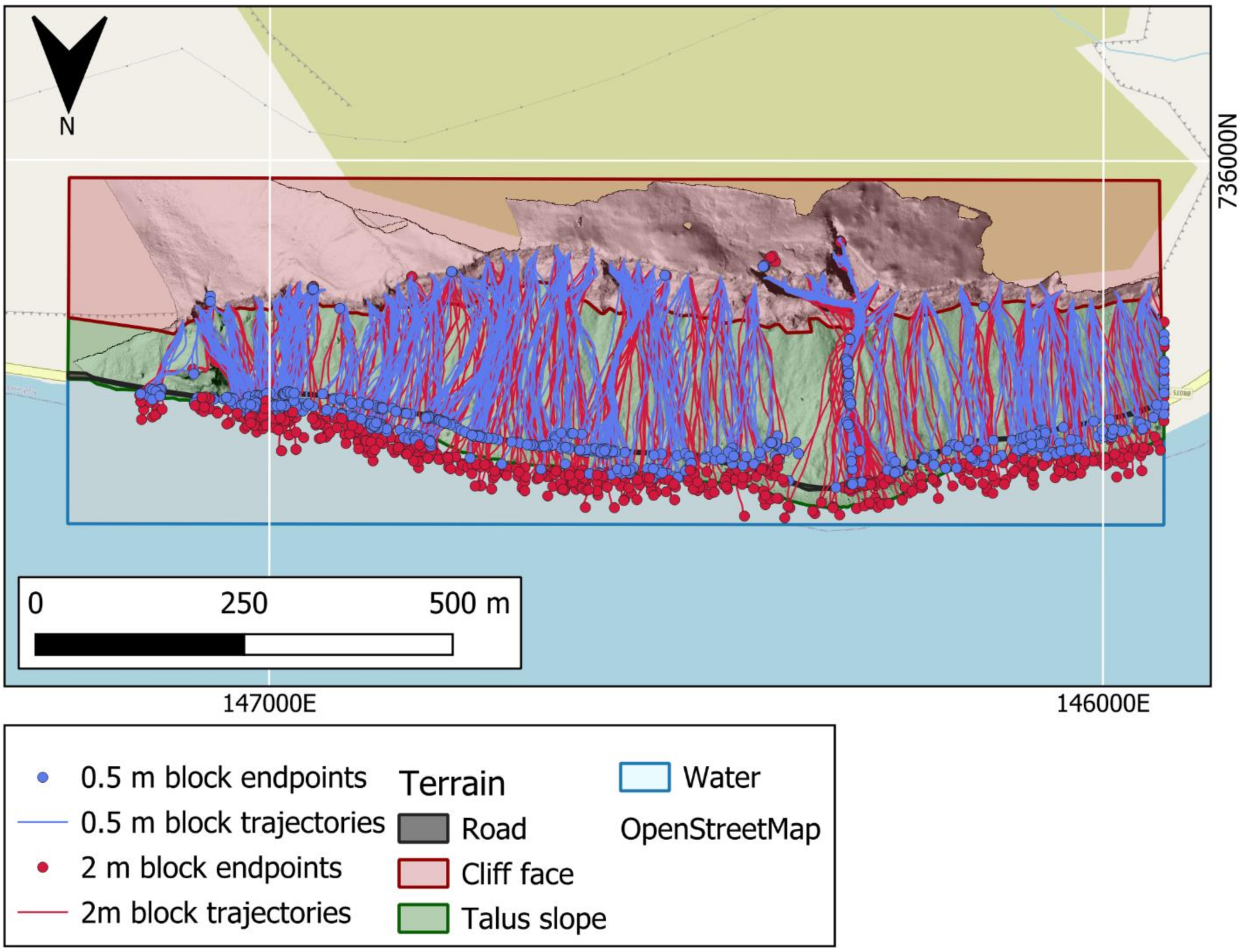

Figure 2-4 - RAMMS rockfall modelling block runout results

2.1.6.2 Rockfall Modelling limitations

The rockfall modelling was focused on the main area of concern surrounding the recent rockfall events, where overhanging blocks adjacent to the 2025 failures that could potentially fail further are located and it is assumed that there could be a higher frequency of rockfall events.

The area east of the modelled area consists of a near-vertical rock face immediately adjacent to the road, indicating that any detached blocks in this area are extremely likely to reach the road in this location by falling directly down, as evidenced by the blocks noted to be present on the verge.

The area south-west of the modelled area has very similar topography to the modelled area. This indicates that detached blocks are likely to behave in a similar manner, reaching the road, as evidenced by the large number of boulders located adjacent to and downslope of the road. While there is the potential for larger magnitude rockfall events in this area, overhanging blocks that are now unsupported due to recent failures were not observed on site.

2.2 Updated Risk Assessment - Results

As seen in Figure 2-5, an annual risk of fatalities below 1 $x10^{-6}$ is considered by the Health and Safety Executive (HSE) to be broadly acceptable for the public and workers. Risk levels between 1 $x10^{-6}$ and $1x10^{-4}$ per annum is considered to be within the ALARP (As Low As Reasonably Practicable) region and can be allowed if it is demonstrated that interventions to reduce the level of risk are likely to be disproportionate to the level of benefit gained. Risk levels above 1 $x10^{-4}$ are considered unacceptable to the public and intervention to lower the risk to a more acceptable level is required.

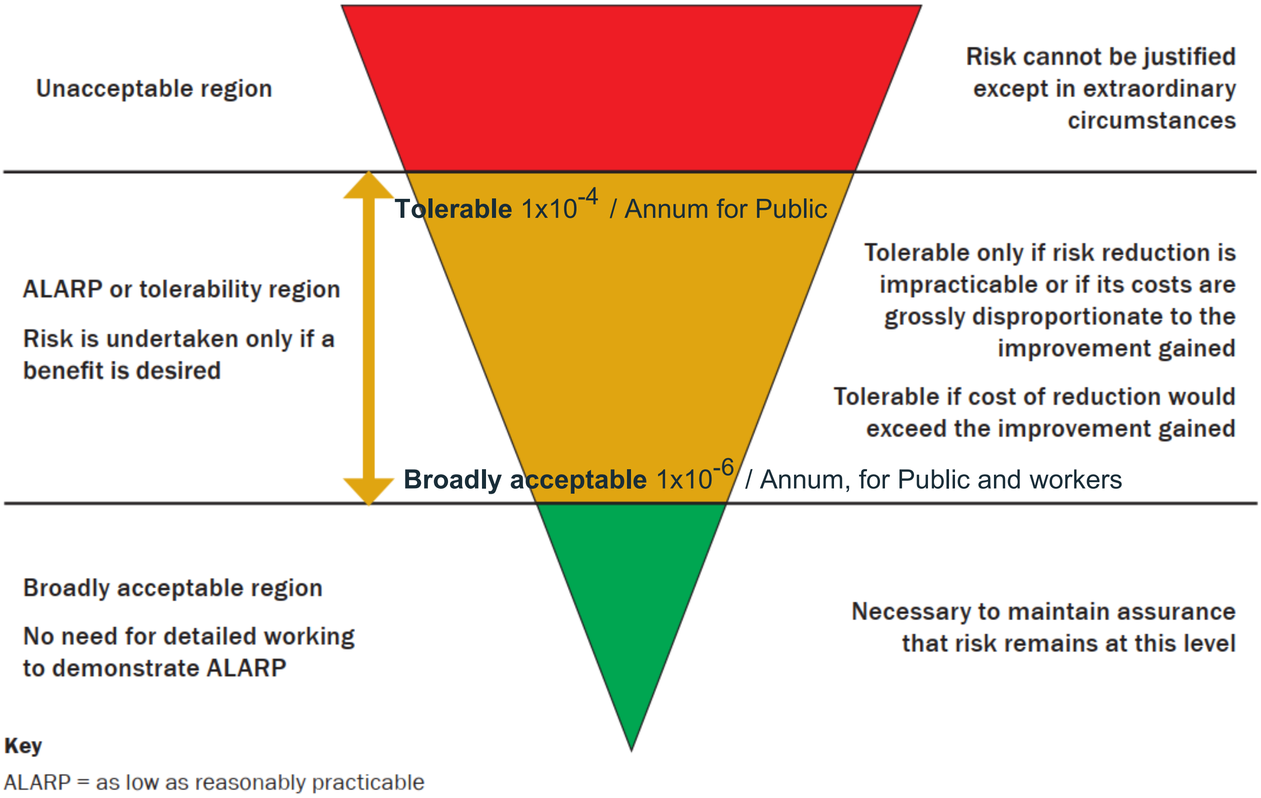

Figure 2-5 - Risk tolerability and the ALARP concept (modified from HSE, 1992)

The updated risk values are presented within Table 2-2, showing the impact of reducing the number of journeys, and reducing the frequency of rockfall events.

Considering 1 person per vehicle:			
Frequency	**330 Journeys per day**	**100 Journeys per day**	**20 Journeys per day**
10 rocks per year	5.2×10^{-4}	1.6×10^{-4}	3.2×10^{-5}
1 rock per year	5.2×10^{-5}	1.6×10^{-5}	3.2×10^{-6}
Considering 4 people per vehicle:			
Frequency	**330 Journeys per day**	**100 Journeys per day**	**20 Journeys per day**
10 rocks per year	2.1×10^{-3}	6.4×10^{-4}	1.3×10^{-4}
1 rock per year	2.1×10^{-4}	6.4×10^{-5}	1.3×10^{-5}

Table 2-2 - Updated quantitative risk assessment results

At higher levels of rockfall frequency (between 1 and 10 blocks per year), the level of risk is still unacceptable or within the ALARP region for both single, and multiple occupancy vehicles, even when the number of journeys through the considered area is reduced to an average of 20 journeys per day throughout a given year.

This shows that the number of journeys through the site area would need to be significantly reduced to lower the risk to ALARP or acceptable levels or there would need to be a significant reduction of the frequency of rockfall events reaching the B8035 through the installation of mitigation measures.

2.2.1 Limitations for this Preliminary Risk Assessment

This preliminary risk assessment considers the risk per annum and therefore does not take into account daily and seasonal variations that affect risk levels. The number of vehicles using the road does change seasonally and daily. This has not been taken into account for this assessment. The data provided is based on vehicles using an adjacent road during the summer and is likely to incorporate a significant amount of tourist traffic. Over the winter months traffic levels are likely to decrease, and the number of journeys is likely to vary between 20 and 100.

Storm events are usually a main cause of rockfall events in the UK. These typically occur during the winter months and while this would increase the risk, the number of vehicles using the road is expected to be less.

It is likely that the risk level overnight decreases significantly as the number of vehicles using the road decreases.

Climate modelling by the Met Office (UKCP18 - (Met Office, 2022)) very generally indicates warmer winters with prolonged rainfall events, and hotter summers with shorter intense rainfall events. The effects of climate change will vary locally, and this assessment has not taken these into account, but the risk will change with changing conditions.

This risk assessment does not take into account any measures a driver may take to avoid a falling block. It is likely that if a block is seen it may be avoided either by breaking or swerving out of the way if possible. As a result, the risk may be lower than shown. As this is a preliminary risk assessment this level of detail has not been included.

Taking the above factors into account, it is considered that the level of risk sits predominantly in the boundary between unacceptable and tolerable but under certain conditions it is likely to move into unacceptable levels of risk. It should be noted that the level of risk is only considered tolerable if methods of risk reduction are considered impractical or if the cost is grossly disproportionate to the level of improvement gained. Some potential options to reduce the risk are discussed below with high level estimated budget costs.

3. Options Development & Appraisal

In response to the identified rockfall hazards along the B8035 corridor, a range of mitigation strategies have been developed and appraised to reduce the risk to road users. This section outlines the engineering and operational options considered, including physical interventions such as rockfall barriers and stabilisation netting, as well as traffic management measures like road closures and enhanced signage. Each option has been evaluated based on its effectiveness in reducing risk, estimated cost, long-term maintainability, and implementation timescale.

The costs presented in this report are approximate estimates to assist in helping to identify likely remedial options that are not disproportionate in terms of cost to the benefit gained. The costs will change subject to market conditions, availability of materials and resources, and will also vary with the design approach, hence they should not be relied upon for setting budgets. We recommend that the costs be revised at each stage of the design process. Should an accurate estimate for budgeting purposes be required, a suitable cost exercise should be undertaken by an appropriately qualified quantity surveyor/estimator.

3.1 Road closure except for local access

Restricting access to the B8035 corridor to local traffic only is expected to reduce the overall risk to road users by limiting the number of journeys through the identified rockfall hazard zone. As demonstrated in the updated risk assessment, this reduction in exposure correlates with a lower probability of fatality; however, at the upper end of the assumed rockfall frequency (i.e. 10 rockfall events per year), the residual risk remains unacceptable for vehicles carrying four occupants and falls within the ALARP zone for single-occupant vehicles.

Installation of gates to allow for local access while preventing access to the public would be required.

Following closure of the road, it would need to be ensured that adequate information on the remaining risks to local road users is communicated to allow for informed decision making on usage of the road.

3.2 Road closure during high rainfall events

Closing the road during storm or high rainfall events where rockfall events are potentially more likely to occur would reduce the risk to road users by ensuring that they are not within the at-risk area during a rockfall and allowing for the road to be inspected before opening, reducing the likelihood of vehicles colliding with rockfall debris.

Due to the lack of information on the timing of rockfalls beyond the known events in summer 2025, the correlation between rockfall events and high rainfall cannot be confirmed.

The known 2025 events show limited correlation with high rainfall values.

Data from a SEPA rainfall gauge located in Tobermory (19 km away - North), and gauges managed by Argyll and Bute Council located in Dervaig (16 km away - North), and Lochdonhead (26 km away - East) is shown in Figure 3-1.

During the initial rockfall event on 02/07/2025 values between 0.1 and 7.0 mm were recorded. Rainfall values of up to 25.6 mm were recorded in the preceding days indicating that rainfall may have contributed to this event.

During the second rockfall on 06/08/2025 values between 6.0 and 15.3 mm were recorded. This rockfall event showed slightly increased rainfall (up to 31.1mm) in the preceding days. However, these values were recorded at the Lochdonhead gauge which is furthest from the site location.

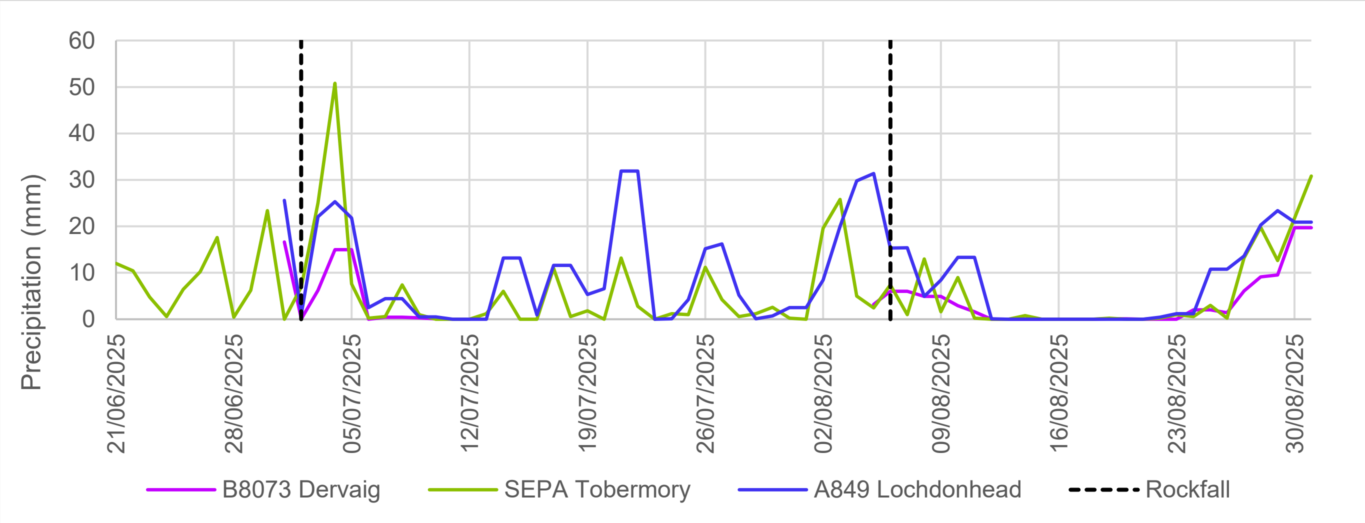

Figure 3-1 - Precipitation data during July/August 2025. Note SEPA gauges record daily data from 9am to 9am, and the Argyll and Bute Council gauges record data from 6am to 6am, therefore rainfall between these times may show on different days.

While increased rainfall is likely to increase the risk of rockfall, it is not possible to establish a direct relationship with the currently available information on rockfall frequency. Freeze-thaw effects on the cliff face are likely to be another significant triggering factor for rockfall and would need to be considered, likely resulting in significant closures over winter.

Climate modelling indicates that Scotland is projected to experience an increase in rainfall during the winter and decrease during the summer. Summer precipitation is projected to decrease overall. However, heavy rainfall events are expected to increase in intensity, with extreme events indicated to increase in frequency. The convective (summer storm) season is projected to extend into autumn, giving an increase in heavy hourly rainfall events into the autumn (Rivington & Jabloun, 2022). These higher intensity rainfall events may have an increased risk of rockfall events occurring.

This option would likely have minimal installation costs; however, it would require monitoring of predicted rainfall events, and personnel to attend site to close the road and conduct an inspection of the road prior to opening. A rainfall monitoring gauge would be required to be installed on site to improve the accuracy of precipitation data as the closest available data is located within Dervaig, 16 km from the site. A rockfall management plan would be required to be developed to confirm the weather thresholds needed to trigger closure of the road.

3.3 Earthwork Bund

Given the energy levels of the falling blocks, indicated by the rockfall modelling presented in Section 2.1.5, it is likely that a substantial earthwork bund would require a height between 4 to 8 m in height. The practicality of constructing this at the toe of the slope is likely to be problematic. There would also be a requirement to import a substantial amount of material to form the bund, which could be a significant cost. As a result, this option has not been considered further.

3.4 Rockfall Barriers

The installation of rockfall catch fences across the site would significantly reduce the risk of rockfalls reaching the road by intercepting and containing falling debris.

To cover the total site area, approximately 1800 m of fencing would be required, as fences are not suitable in areas where the rockface is immediately adjacent to the road. Overlap of individual fences would be required to provide full coverage of the road so the exact length of fencing required would be determined during detailed design. Assuming a cost of £2000 per m of fence, this would result in an estimated cost of £3.6 million, not accounting for mobilisation costs.

A reduced fence length of 500 m, focused on the central section of the site near the 2025 rockfall location, would target the area with the highest observed concentration of boulders adjacent to the road. This targeted approach is estimated to cost approximately £1 million.

The installation of catch fences would result in ongoing inspection and maintenance costs. Manufacturers such as Geobrugg recommend annual inspections under normal environmental conditions, with additional inspections following any reported rockfall events. Automated systems which can alert asset owners of rockfall impacts to fences are available with associated additional installation and monitoring costs.

As holding rockfall material will reduce the potential capacity of installed rockfall fences, removal of material would be required following larger rockfall events. Several components of rockfall fences are designed to extend during rockfall impact to absorb energy and these components are likely to need replacement following rockfalls. Due to the sites coastal location, it is likely that an installed rockfall fence will experience an increased rate of corrosion, therefore increased maintenance, or corrosion resistant material, will be required.

Design and installation of 500 m of rockfall fences would be typically expected to take approximately 6 months to complete.

Should the targeted length of rockfall fences be chosen, scaling works would be required to remove loose material across the rest of the site area to reduce the likelihood of a rockfall event occurring, particularly within areas where lines of sight are reduced around corners, as the risk is likely to remain high within these areas

It is also likely that inspection and scaling of any loose material would be required within the fenced area to reduce the risk to workers during construction.

3.5 Rock Stabilisation Netting

The installation of stabilisation netting across the rock face would significantly reduce the risk of rockfalls impacting the adjacent road by limiting the frequency and volume of material reaching the carriageway. A stabilisation system or system with a closed base would be required as opposed to an open draped system as it is likely that blocks reaching the base of a draped system would roll down the slope and reach the road.

To cover the entire site area an estimated 160 000 m^2 of netting would be required. Based on an indicative unit cost of approximately £400 per m^2, would be estimated to cost around £65 million. However, this figure could be reduced by adopting a targeted approach, focusing on high-risk areas identified during detailed design and geotechnical assessment.

Installing netting to the central 500 m with an assumed higher frequency would require approximately 50 000 m^2 of netting, at an approximate cost of £20 million.

Should the targeted length of rock stabilisation netting be chosen it is likely that scaling works would be required to remove loose material across the rest of the site area. It is also likely that inspection and scaling of any loose material would be required within the netting area to reduce the risk to workers during construction.

3.6 Inspection and Scaling

Regular inspection of the rock face and scaling to remove loose material would reduce the risk to the road by reducing the potential number of rocks reaching the road. The level of risk from the reduction in rockfall frequency can be seen in Table 3-1 below.

Considering 1 person per vehicle:			
Frequency	**330 Journeys per day**	**100 Journeys per day**	**20 Journeys per day**
0.1 rocks per year (every 10 years)	5.2×10^{-6}	1.6×10^{-6}	3.2×10^{-7}
0.01 rocks per year (every 100 years)	5.2×10^{-7}	1.6×10^{-7}	3.2×10^{-8}
Considering 4 people per vehicle:			
Frequency	**330 Journeys per day**	**100 Journeys per day**	**20 Journeys per day**
0.1 rocks per year (every 10 years)	2.1×10^{-5}	6.4×10^{-6}	1.3×10^{-6}
0.01 rocks per year (every 100 years)	2.1×10^{-6}	6.4×10^{-7}	1.3×10^{-7}

Table 3-1 - Updated quantitative risk assessment results

A reduction in the frequency of events to below 0.1 per year would result in the level of risk being acceptable or within the ALARP region for all considered number of journeys for both single and multiple occupancy vehicles.

Given the extensive area of exposed rock within the site, the initial scaling works are anticipated to be a major undertaking. The scale of the task is such that it is likely to represent one of the largest rock scaling projects undertaken in the UK. The process is expected to be slow and logistically complex due to the limited available workforce and difficulty of access to much of the rock face.

A preliminary estimate suggests that the initial scaling programme could extend over a period exceeding 12 months. Based on an assumed unit cost of approximately £10 per square metre for light scaling using hand tools, the total cost to scale the entire rock face is estimated at approximately £2 million. This does not account for heavy scaling which requires the use of machinery such as jacks or expanding grout, which is expected to cost approximately £300 per m^2.

Regular scaling is expected to be required to maintain the stability of the rock face. Initially an intensive, and higher cost, programme of scaling would be required to inspect the whole site area and remove any high-risk material. The intensity, and cost, of scaling required would then decrease as unstable material is removed. Ongoing weathering processes would then contribute to areas of instability meaning that periodic intensive, and higher cost, intervention would be required. This process would be a repeat cycle.

Targeted areas of scaling to reduce risk could be undertaken, for example, the initial section of the rock face adjacent to the road, between chainages 0–200, where the road alignment includes tight bends and reduced stopping distances, presents a higher risk and could be prioritised. Scaling in this area is estimated to cost approximately £50 000. Scaling of the 500 m assumed higher frequency area would cost approximately £500 000.

Additional scaling would likely be required for other proposed interventions where workers are likely to be present during construction.

3.7 Reopen the road with additional signage

Reopening the road with additional signage warning road users of the high rockfall risk and to proceed at their own risk has been considered. If drivers are aware, they may be more prepared to take appropriate actions (if possible) to avoid falling and fallen blocks, however this is hard to quantify. It is assumed that additional signage is unlikely to reduce the liability to Argyll and Bute Council should there be a serious injury or fatality due to rockfall.

Should Argyll and Bute Council wish to pursue this option, it is recommended that additional measures such as scaling of cliffs next to the road should also be included to reduce the risk. It is also recommended that the potential legal implications and liabilities associated with road user safety be reviewed in consultation with Argyll and Bute's legal team.

3.8 Options Summary

Mitigation Option	Effectiveness	Estimated Cost	Long-term Maintainability	Estimated Timescale
Reopening with additional signage	Low – unlikely to reduce risk and liability	Cost of sign installation	Limited maintenance required	Weeks - months
Road closure with local access	Removes the risk to the public accessing the site within vehicles. Risk remains to those accessing on foot or cycling; however, this risk is expected to be lower	Cost of permanent barrier installation and legal process to close the road	No maintenance costs.	3 months + dependant on legal process
Road closure during rainfall events	Low without further rockfall monitoring to increase understanding of rainfall relationship	Costs for developing a rockfall management plan and installing a barrier. Staffing costs for monitoring and closing the barrier.	Limited maintenance required. Ongoing monitoring and staffing required to close the barrier	Weeks - months
Earthwork Bund	Not considered further due to constructability issues			
Rockfall Fences - Whole slope	High – reduces likelihood detached rocks from reaching the road	£3.6 million	Regular inspections and maintenance following rockfall events	1-2 years
Rockfall Fences – Targeted (example 500m)	Moderate – reduces likelihood detached rocks from reaching the road within the assumed higher frequency area	£1 million	Regular inspections and maintenance following rockfall events	6-8 months

Mitigation Option	Effectiveness	Estimated Cost	Long-term Maintainability	Estimated Timescale
Rock Stabilisation Netting – Whole slope	High – prevents detached rocks from reaching the road	£65 million	Regular inspections and maintenance following rockfall events	1-2 years
Rock Stabilisation Netting – Targeted (example 500m)	Moderate - prevents detached rocks from reaching the road	£20 million	Regular inspections and maintenance following rockfall events	6-12 months
Scaling – full slope	High – reduces the number of detached rocks, reducing risk	£2 million (£10/m^2 light scaling, increases with any required heavy scaling)	High cost of initial scaling. Required further work at regular intervals however this will be significantly lower than initial costs	1-2 years for initial inspection and scaling
Scaling – Targeted (example 500m)	Moderate - reduces the number of detached rocks, reducing risk within assumed higher risk areas	£500 000	High cost of initial scaling. Required further work at regular intervals however this will be significantly lower than initial costs	6-12 months

Table 3-2 - Risk reduction options summary

4. Conclusion

This final options report presents an updated assessment of the geohazard risks posed to users of the B8035. The updated hazard modelling, incorporating RAMMS rockfall modelling and site-specific observations, confirms that the likely frequency of rockfall events pose a risk level that is probably on the boundary of Tolerable / Unacceptable regions but under certain conditions / circumstances is likely to move into the Unacceptable level of risk, especially in areas that may have higher rockfall frequency, or where the cliff face is directly adjacent to the carriageway with reduced lines of sight.

The Quantitative risk assessment is preliminary and there are a number of factors that have been simplified, such as annual rockfall frequency and some factors such as drivers reaction to break or avoid fallen rocks that have not been taken into account.

Mitigation options which are likely to reduce the level of risk to an acceptable or ALARP level have been presented in Table 3-2. To take the project onto the next stage we recommend that Argyll and Bute Council undertake a review and determine the most appropriate two remedial options or combined options (e.g. signage and scaling of specific areas) that manage their risks at a tolerable level. These two options could then be progressed further to enable a budget to be set for the project, and detailed consultation with appropriate stakeholders. The most beneficial option, in terms of cost, programme, and risk reduction could then be taken forward to the next stages of implementation.

5. References

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APPENDICES

Appendix A. Road chainage

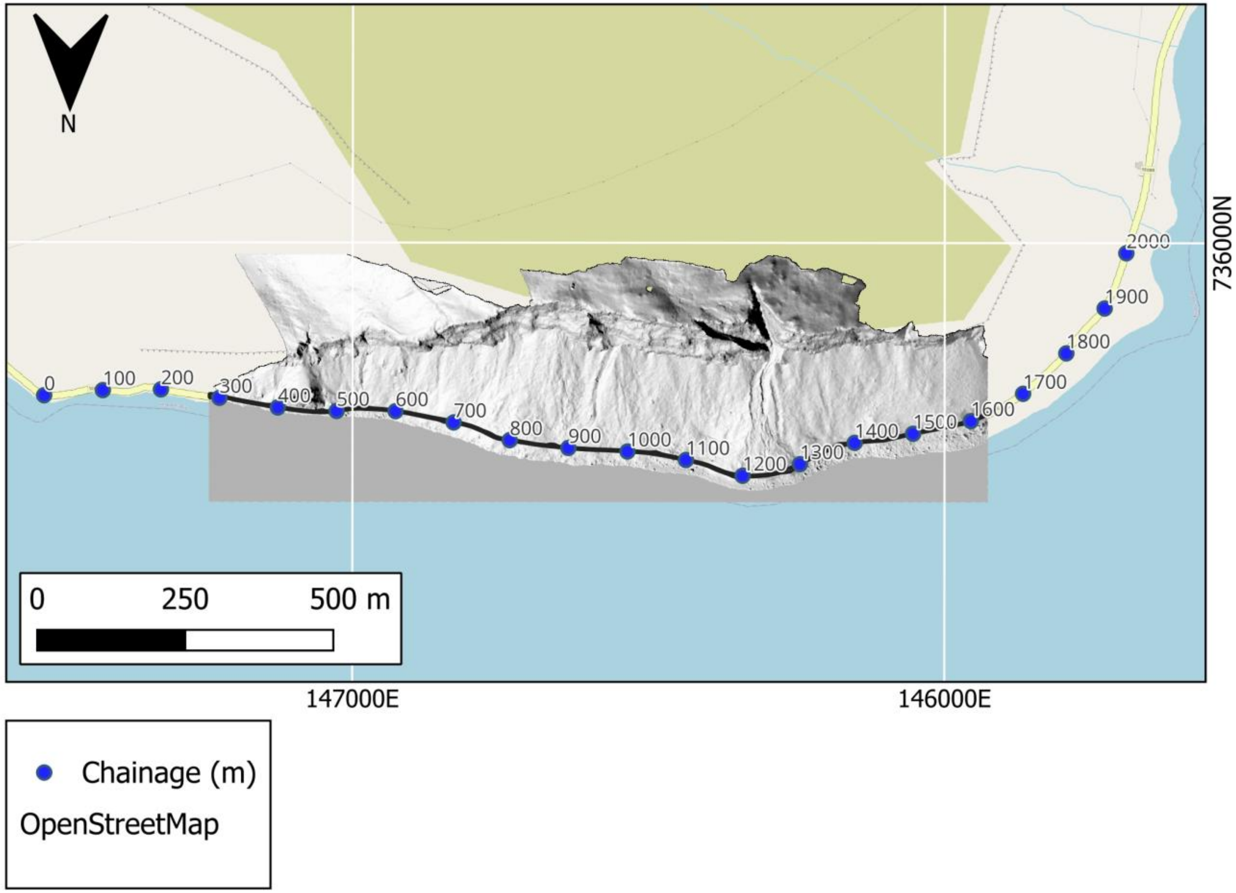

Figure A-1 - Road chainage

Appendix B. Geotechnical Risk Register

A Geotechnical Risk Register has been created to identify geotechnical hazards and establish a method for their management for the B8035 Gribun rockfall.

Risk is a function of probability that a hazard may occur and its potential impact. The Risk Register reflects the current level of understanding of the geotechnical aspects of the scheme and will be subject to revision as the project progresses when further information becomes available.

The risk rating used in the risk register follows the principle;

Risk Rating (RR) = Likelihood (L) x Severity (S)

Likelihood		**Severity**				
		1	2	3	4	5
		Minor	Moderate	Serious	Major	Catastrophic
1	Extremely unlikely	1	2	3	4	5
2	Unlikely	2	4	6	8	10
3	Likely	3	6	9	12	15
4	Extremely Likely	4	8	12	16	20
5	Almost Certain	5	10	15	20	25

Potential severity of harm occurring		
1	Minor	Minor damage or loss – (no human injury)
2	Moderate	Moderate damage or loss – (slight injury or illness)
3	Serious	Substantial damage or loss – (serious injury or illness)
4	Major	Major damage or loss – (fatal injury)
5	Catastrophic	Catastrophic damage or loss – (multiple fatalities)

Risk Classification	
Low (1-8)	Ensure assumed control measures are maintained and reviewed as necessary.
Medium (9-19)	Additional control measures needed to reduce risk rating to a level that is tolerable.
High (20-25)	Activity not permitted. Hazard to be avoided or risk to be reduced to tolerable level.

No.	Location	Hazard	Consequence	Before Control			Design Measures to Eliminate Hazards	Design Measures to Reduce risk	Residual Risk		
				L	S	RR			L	S	RR
Natural Terrain Hazards											
1	Whole scheme	Rockfall from crags and exposures.	Blocked public access. Damage to B8035 Road. Road closures resulting in emergency response, traffic flow disruptions, ongoing maintenance and long diversions. Unstable ground caused by landslide / rockfall events. Delays to programmes and additional cost Injury/death of public and/or workers.	5	5	**25**	It is not possible to eliminate the identified hazard.	Refer to report Section 3.	4	2	**8**
2	Whole scheme	Landslides from slope above B8035.	Blocked public access. Damage to B8035 Road. Road closures resulting in emergency response, traffic flow disruptions, ongoing maintenance and long diversions. Unstable ground caused by landslide / rockfall events. Delays to programmes and additional cost Injury/death of public and/or workers.	3	3	**9**	It is not possible to eliminate the identified hazard.	Detailed geohazard assessment considering possible failure locations, volumes of material and travel velocities. Installation of rockfall fences to protect the road and users from rockfall. Installation of rock stabilisation netting to capture rockfall at source locations. Ongoing monitoring of slope for further deterioration and increased instability. Ensure level of residual risk is understood by all parties. Constructability review with input from contractors as required.	3	2	**6**
3	Whole scheme	Challenging terrain and complex topography	Complex topography requiring complicated earthworks designs, structures and foundations as well as significant temporary works, with slope stabilisation required during construction. Injury/death of workers. Additional costs for plant delivery or large-scale enabling works	5	4	**20**	It is not possible to eliminate the identified hazard.	Early contractor involvement. Detailed geohazard assessment considering possible failure locations, volumes of material and travel velocities. Detailed drone surveys at regular intervals to provided high resolution data to contractor and inform understanding of topographical changes with time.	5	3	**15**
4	Whole scheme	Unstable ground created from landslide, debris flow or site works upslope.	Debris reaching the route and impacting the road and construction operations. Road closures resulting in emergency response, disruption in traffic flows, ongoing maintenance and lengthy diversions. Damage to existing road and proposed resilience measures. Damage/erosion of hillside downslope of B8035.	3	5	**15**	It is not possible to eliminate the identified hazard.	Design of slope stabilisation measures and protection measures, as required. Ensure level of residual risk is understood by all parties. Constructability review with input from contractors as required.	2	4	**8**

No.	Location	Hazard	Consequence	Before Control			Design Measures to Eliminate Hazards	Design Measures to Reduce risk	Residual Risk		
				L	S	RR			L	S	RR
Geotechnical risks											
5	Whole scheme	Unforeseen ground conditions	Ground unsuitable for earthworks or structure foundations. Delays to programme and additional cost.	3	3	**9**	Identify areas where more information is required. Provide representative ground investigation coverage across the site, based on an understanding of the geomorphological processes that have influenced the geology of the route. Ground investigation undertaken (where needed), testing and walkovers to confirm ground conditions across the study area.	Ongoing site walkovers and drone surveys to identify any areas of change.	2	3	**6**
6	Whole scheme	Variable/uncertain depth to rockhead	Delays to programme and additional cost for breaking out / over dig and mobilisation of suitable equipment.	4	4	**16**	Ground investigation undertaken to confirm depth to bedrock including surface geophysical surveys and exploratory holes with adequate coring to confirm weathered horizons and potential boulders. It is not possible to eliminate the identified hazard.	Sensitivity assessment for foundation and slope designs to account for rockhead variation. Detailed excavatability assessments as required. Design for observational approach to slope stabilisation and foundation requirements.	2	3	**6**
7	Whole scheme	Steep slope gradients	Difficult access for construction.	5	4	**20**	It is not possible to eliminate the identified hazard.	Constructability review with input from contractors as required.	2	4	**8**
8	Whole scheme	Site conditions corrosive to steel and/or concrete	Shortened lifespan of buried steel and/or concrete elements, leading to increased maintenance costs. Corrosion of steel components due to coastal location	3	2	**6**	It is not possible to eliminate the identified hazard.	Use of corrosion resistant materials Perform GI to confirm ground conditions. Undertake geochemical testing and appropriate concrete class design. Employ appropriate mitigation measures during design.	2	2	**4**

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