ENTRY CONTENTS

1. INTRODUCTION

Including list of key individuals, organisations involved in this entry

Project: The Tweaked Attenuator Barrier with Tail Drapery - A Long-Term Rockfall Protection Measure at Stanwell Park Cutting between 55.100km to 55.400km Illawarra Railway Line

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2. A DESCRIPTION OF THE ENTRY

Project description, problem statement and the solution

2.1 Project Background

Sydney Trains have about few hundreds of railway cuttings which were formed to follow the contour of the land to maintain required vertical alignment for the rail. To meet the high demands for safety and reliability, those cuttings require maintenance as their constituent materials age, weather, dilates and creep with time. These cutting were being managed through the risk-based ‘Fix As You Observe’ approach, e.g., through periodic inspections governed by TMP and targeted localized stabilization.

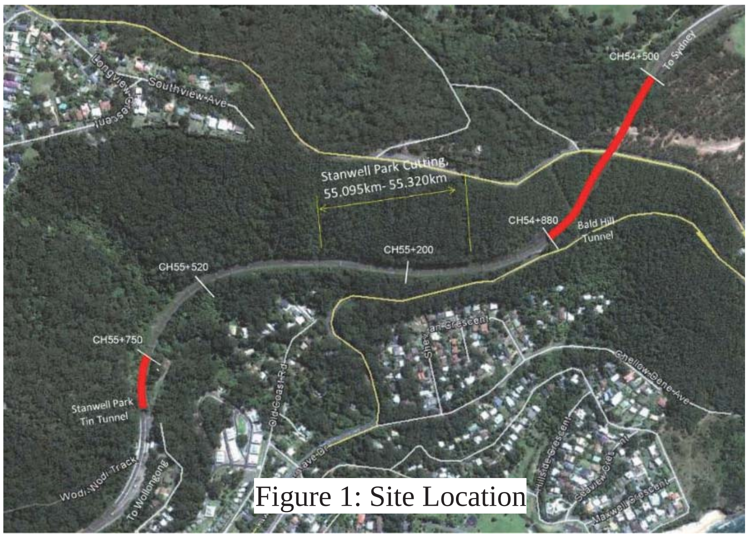


Figure 1: Site Location

Managing geotechnical risk associated with the potential large-scale rockfalls from steep high cuttings is not straight forward. The Stanwell Park cutting which is located between the Bald Hill tunnel and Stanwell Park station present a unique predicament for hazard management on the railway tracks approximately within 55.095km to 55.320km. The cutting lies at the northern end of Stanwell Park, NSW along the Illawarra railway line. It consists of a south facing cutting and slope at the base of the Illawarra escarpment.

The Stanwell Park cutting consists of a rock slope of 55 degrees for a vertical height of approximately 12m, which then gradually transitions back to a natural slope of approximately 40 degrees, higher above. Although the cliff face is extended to about 110m from the track level, based on the past history of rockfalls and analyses of runout and release zones of potential rockfalls using the Digital Terrain Model (DTM) model, the maximum height of the exposed slope is assumed to be 50m. In some regions a 1-2m wide bench is present at the transition area.

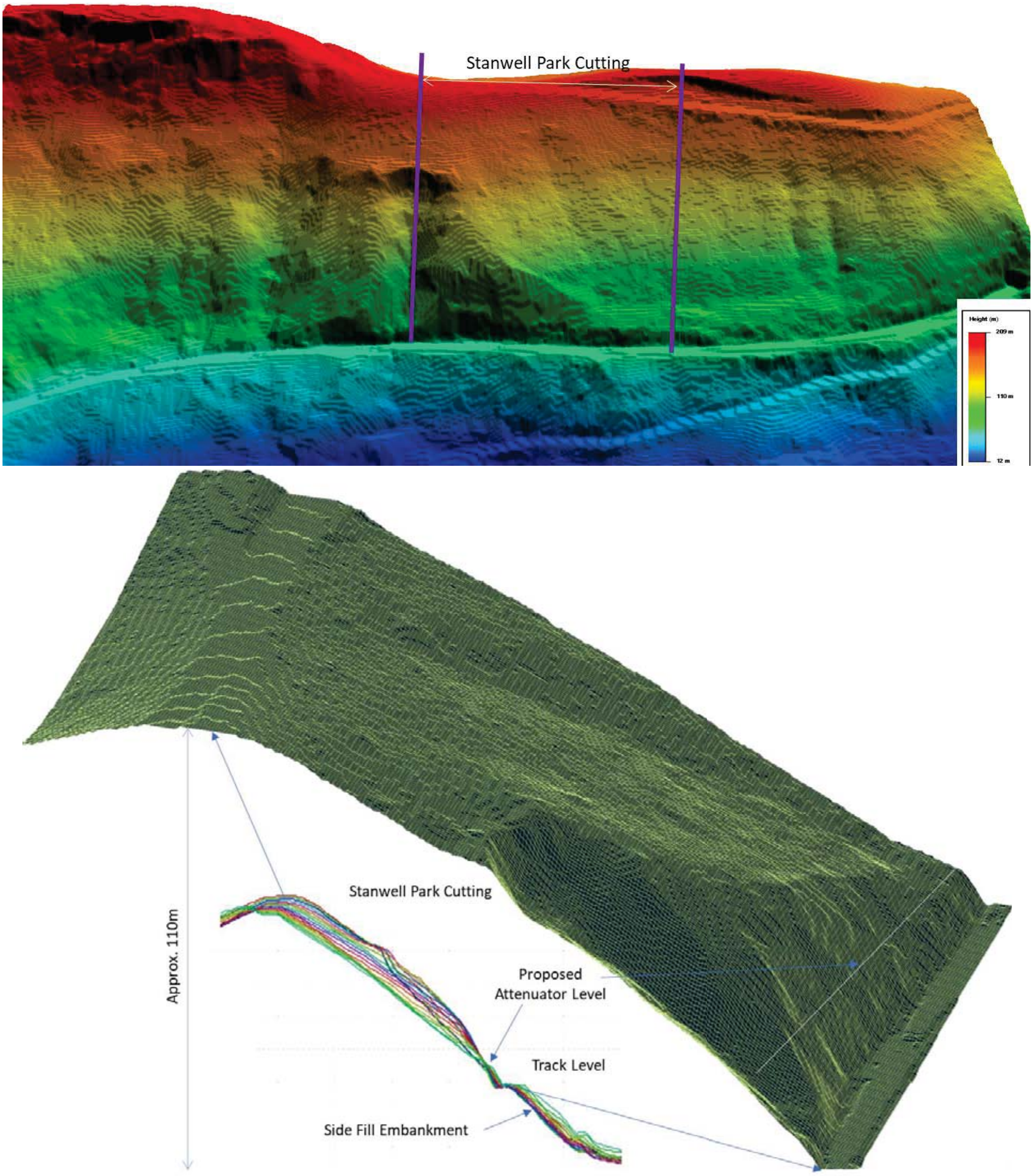


Figure 2: Topographical view of the site

The Stanwell Park cutting was in the high-risk site register since 1988 as the first rockfall reported. Over the past 10 years, the cutting has exhibited almost 1 rockfall incident every year with varying degree of debris volume. Most of the individual rockfall sources were from the up high of the cutting and fallen rock debris landed on the cess or close to the nearest rail. Those rockfall scenarios did not bring any major incidents to the network, although affected the reliability index on few occasions such as in the form of temporary speed restriction of the section of the track. Based on the periodic site inspections and slope feature mapping from 3D topographical orthophoto and DTM using drone based Lidar and photogrammetry scanning, it is envisaged that there is no global stability present for the cutting but a huge number of individual

rockfall instabilities are present on the slope face. Potential failure mechanisms for most of the individual instabilities generally fall under ravelling, toppling and planar failure modes, with an indication of frequent small to moderate scale rockfalls from random locations of the cutting face.

Figure 3: Nature of rockfalls at Stanwell Park Cutting

Limited access, steepness variations of up to 50 degrees and numerous discontinuous lines of sandstone outcrops combined with differential weathering undercutting sandstone layers, vertical fracturing and root-jacking of trees, alternate wet and dry cycles due to climatic changes were the primary triggering factors for the increased fracture densities and dilation of existing fractures for the Stanwell Park cutting. This has rendered the traditional method of stabilization for this cutting being ineffective from both technical and value for money proposition. In fact, the cutting was subjected to frequent rockfalls even though targeted localised stabilisations were periodically carried out in the past.

Some of the FYO-based localised stabilisations considered for the Stanwell Park cutting included devegetation, scaling and targeted rock removal, spot bolting and localised fibrecreting. However, based on the postulation of higher-level type rockfall problems, and extent of existing localised instabilities as well as considering the past history of instabilities and potential weathering rate, rate of appearance of discontinuities and fractured block formations, the usual short to medium term 'Fix As You Observe' (FYO) approach is considered neither economically nor technical viable to address and stabilise the individual defects for this cutting as part of the periodic maintenance. Therefore, the cutting was required to develop a complete solution as the feasible and robust means to eliminate or reduce the geotechnical risks of the cutting not only as

a long-term protection measures (LTO) but also as a short to medium term (FYO) solution.

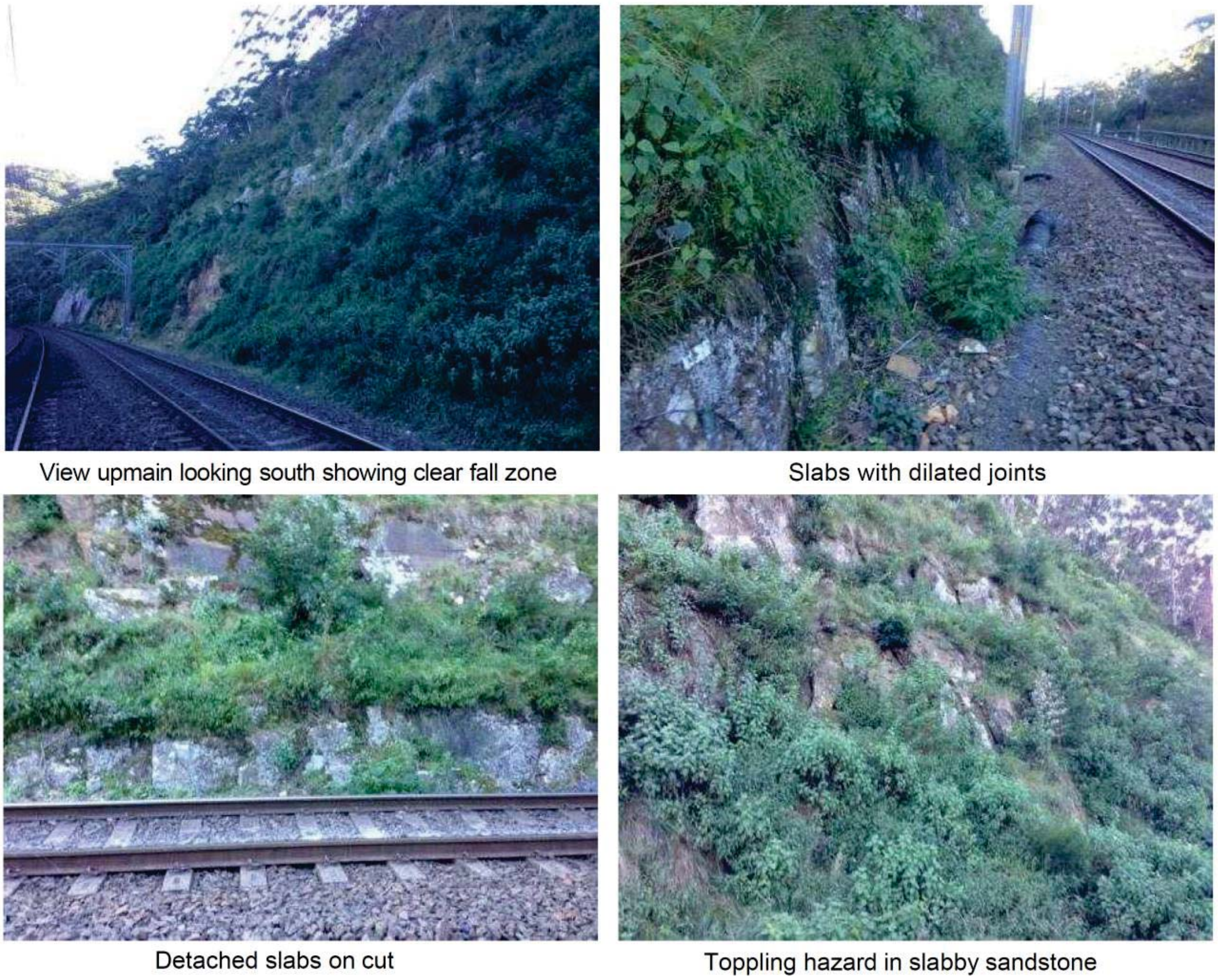


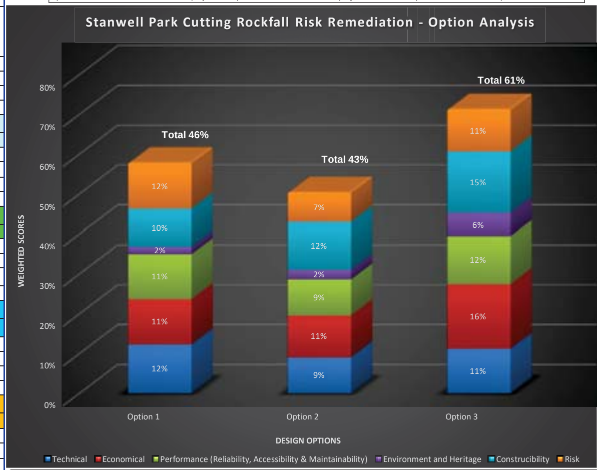
Figure 4: Few localised instability features at lower heights of Stanwell Park Cutting

2.2 Remedial Options for Rockfall Risks

As the Fix As You Observe' (FYO) short to medium term measures at targeted locations are not viable for the Stanwell Park cutting, various long-term remedial solutions were considered at the concept design stage. All options were weighted against their advantages and disadvantages to address the geotechnical challenges present at the cutting mainly arising from rockfall release zones predominantly up to 40m but potentially extended up to 110m from the track level. Other determining critical factors included difficult terrain, limited access, fitting staged construction into 2-day track possessions, unstable downslope steep embankment, environmental footprint, risk reduction or elimination as well as future maintainability consideration and overall construction cost. Various options were considered including full active slope stabilisation using either rockfall mesh anchored to the face or using soil-nail shotcrete, multi-level catch fences and active stabilisation below, full drapery system or a combination of multi-level catch fences and drapery system below, rockfall shelter, rockfall canopy structure etc. Each option was judged against a set criteria and weighting factors after discussion and brain storming session conducted within the Illawarra maintenance team involving geotechnical engineer (myself), asset engineer, civil engineer and construction manager. Among various options considered, the option 3 which is an attenuator solution stood out yielding highest weighted score.

Project Objective	Group Weighting	Key Performance Indicator	Individual Weighting	Option 1 Raw Score	Option 1 Weighted Score	Option 2 Raw Score	Option 2 Weighted Score	Option 3 Raw Score	Option 3 Weighted Score
Stanwell Park Cutting Rockfall Risk Remediation - Option Analysis				**Ranking Scores**					
				Option 1		**Option 2**		**Option 3**	
Technical	20%	Compliance to Standards	4	3	12	3	12	3	12
		Fit for Design criteria	5	5	25	3	15	4	20
		Train operational safety	5	4	20	3	15	4	20
		Maximum Weighted	93%	Σ	57%		42%		52%
		Group Weighted Sub-Total		12%		9%		11%	
Economical	20%	Construction Costs	3	1	3	4	12	4	12
		Procurement Costs	3	3	9	3	9	3	9
		Maintenance Costs	4	3	12	2	8	5	20
		Time Schedule, Track Possession and Power	4	4	16	2	8	4	16
		Maximum Weighted	70%	Σ	40%		37%		57%
		Group Weighted Sub-Total		11%		11%		16%	
Performance (Reliability, Accessibility & Maintainability)	15%	Reliability	4	4	16	3	12	4	16
		Maintainability	4	3	12	3	12	4	16
		Durability	4	4	16	3	12	4	16
		Operational Safety	4	4	16	3	12	4	16
		Maximum Weighted	80%	Σ	60%		48%		64%
		Group Weighted Sub-Total		11%		9%		12%	
Environment and Heritage	10%	Environment impact	4	1	4	2	8	4	12
		Heritage issues	3	3	9	3	9	3	9
									20
		Maximum Weighted	70%	Σ	13%		17%		41%
		Group Weighted Sub-Total		2%		2%		6%	
Construcibility	20%	Construction Time Span	4	1	4	3	12	5	20
		Track Possession Requirement	3	1	3	3	9	4	12
		Construction Complexity	4	4	16	3	12	3	12
		Specialised Contractor	2	4	8	3	6	3	6
		Maximum Weighted	65%	Σ	31%		39%		50%
		Group Weighted Sub-Total		10%		12%		15%	
Risk	15%	Operational	4	4	16	3	12	3	12
		Maintenance	3	4	12	2	6	4	12
		Performance	4	4	16	2	8	4	16
		Construction	2	3	6	3	6	3	6
		Maximum Weighted	65%	Σ	50%		32%		46%
		Group Weighted Sub-Total		12%		7%		11%	
Checksum	**100%**	**Weighted Grand Total**		**46%**		**43%**		**61%**	

Option 1: A catch fence at 55m high and active stabilisation below using rocfall mesh and anchor grid
Option 2: Multi-level catch fence with drapery - 3 Catch fences at height 12m, 30m and 55m plus drapery mesh from 12m up to the toe at track level
Option 3: Rockfall attenuator with tail drapery - interception zone at 12m and tail drapery mesh from 12m up to the toe at track level)



* Weighting For Individual Criteria		**	Raw Scores for Each Option
4	Issue is of critical importance	5	This option is significantly superior.
3	Issue is important	4	This option is superior for addressing the criteria
2	Issue is of average importance	3	This option satisfies the criteria
1	Issue is of minor importance	2	This option does not adequately address the criteria
		1	This option does not satisfy the criteria

Figure 5: Remedial Option Analysis

Protecting the rail system from the possibility of high risk rockfalls required a measurable solution to absorb the potential high energy impacts, with minimal maintenance, while fitting into the existing rail corridor with its strict space constraints. At the same time, the selected measure was needed to yield good value for money, constructible without much complexity in a possession driven rail corridor and be environmentally sustainable. The recently constructed rockfall attenuator at Stanwell Park cutting meets all these criteria.

2.3 The Attenuator Barrier with Tail Drapery

The attenuator barrier with tail drapery does not stop the rocks at the interception zone, but instead it attenuates or weakens the impact energy then further guide the rocks down to the toe of the slope through a drape tail. The reduction in energy allows the falling rock to be more easily captured at the toe. The top part of the attenuator intercepts rockfall and guides it under the drape. In the middle part of the system, rolling or falling blocks and debris are led down the slope to the safe runout zone. Rock blocks and debris accumulate at the bottom safely and can be cleared with routine periodic maintenance. As the Stanwell Park cutting is a very tall slope with potential for frequent rockfalls, the attenuator barrier with tail drapery is a good candidate for the rockfall protection measures for the site. As the attenuator acts as an intermediate dissipating structure, the design loadings for foundations and anchors are relatively less compared to traditional catch fence which acts as a full interception structure. However, the real challenge is to establish the residual or attenuated energy for the site and configure the system in such a way that it can

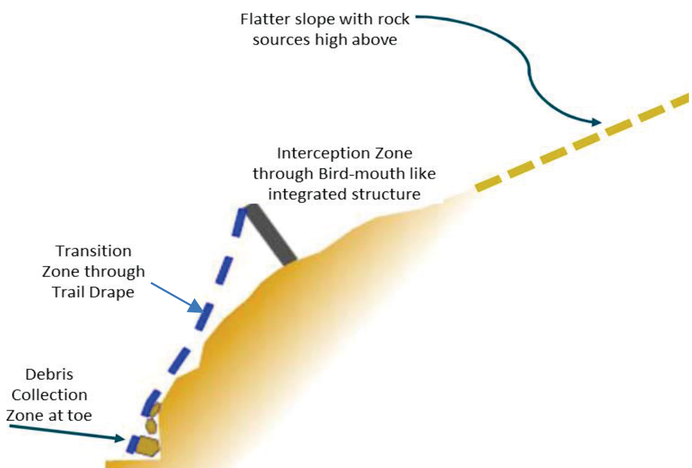


Figure 6: Concept of an Attenuator

withstand the attenuated energy without any breaching of its components and without much deflection of the mesh in a setting of relatively narrow toe catchment and wider kinematic envelop of overhead wire structure and powerline.

2.4 Analysis and Design

2.4.1. Rockfall Modelling

Two-dimensional rockfall modelling for the Stanwell Park cutting was carried out using the software Rocfall (from Rocscience), to evaluate plausible impact velocities and bounce heights, and to determine the appropriate attenuator type and location. The critical interception zone was set to 12m vertical height where the 55 degrees slope transitioning above to 40 degrees natural slope, a total of 3 cross sections were analysed. With a density of 2.4t/m^3, the design block sizes considered were 1m^3, 0.7m^3 and 0.35m^3 and the surface parameters for the analysis were assigned based on a combination of the LiDAR DTM topographical model for the cutting, vegetation cover from drone photogrammetry assessment, idealisation of fracture densities as well as from available geotechnical information. A simulation of 100 rock falls was run for each design block, as well as for each slope cross section. This resulted in a total of 900 rock falls modelled across nine different simulations. Based on the analysis results, a 3m high attenuator system with 500kJ kinetic energy was adopted.

Rock fall Modelling Summary - Impact and Total Kinetic Energy at Barrier location																
Profile	Run	Design Block (m^3)	Mass (kg)	Barrier location*	No of Hits/100	Total Kinetic Energy (kJ)			Translational Velocity (m/s)			Impact Height at Barrier (m)			Min barrier Height (m)
						100%	98%	95%	100%	98%	95%	100%	98%	95%	
1	1	1.15	2,761	Transition from 60 to 40 degrees slope	100	484	475	408	17.24	17.11	15.46	2.37	2.02	1.94	2.9
	2	0.7	1,673		100	271	267	246	16.56	16.36	15.49	2.13	1.90	1.85	2.77
	3	0.38	916		100	174	158	147	17.82	17.4	16.29	1.93	1.90	1.74	2.60
2	4	1.15	2,761		100	495	403	367	17.47	15.32	14.73	1.74	1.66	1.30	1.94
	5	0.7	1,673		100	244	236	227	15.24	15.09	15.0	1.74	1.49	1.18	1.78
	6	0.38	916		100	128	125	118	15.22	14.89	14.4	1.47	1.3	1.10	1.64
3	7	1.15	2,761		100	346	343	328	14.54	14.3	13.91	1.88	1.66	1.58	2
	8	0.7	1,673		100	274	255	234	16.86	15.62	15.2	1.55	1.4	1.39	2.09
	9	0.38	916		100	147	130	123	16.23	14.98	14.76	1.40	1.38	1.22	1.8

Table 1: Rockfall Modelling Results

2.4.2. Product Selection - The Attenuator Barrier with Tail Drapery

Presently, hybrid/attenuator fences do not have a universally accepted standardized crash test such as ETAG27 (now EAD 340059-00-0106) for rock fall catch fences, which is based on a free-falling block of known mass impacting the centre span. The issue with developing a test for hybrids/attenuators is on repeatability and consistency of conducting them, making sure the rocks will be impacting at the same location every time. These are among the reasons why an off-the-shelf attenuator system with specific energy rating is not available in the market. In general, it is generally accepted (e.g., ref. Colorado DOT) that design energy and impact velocity for an attenuator is much less than the traditional flexible catch fence structure. In absence of published standards or guidelines, first challenge for the design of the Stanwell Park attenuator system was

how to design the system. Considering impact of the proposed solution to the rail operations, a more conservative approach was adopted. It was adopted that the attenuator's barrier part to be designed as flexible barrier of 500kJ capacity while its tail drapery part to be design in such a way the mesh product can withstand such kinematic energy without any physical damage or break in the elements. This led to employ the 'momentum transfer' model while considering various other factors including the block shape, expected translation and rotational velocities, as well as the puncturing, and shearing capacity of mesh. Two prominent manufacturers for rockfall protection structures were consulted and a combination of Geobrugg products was chosen to meet the design criteria.

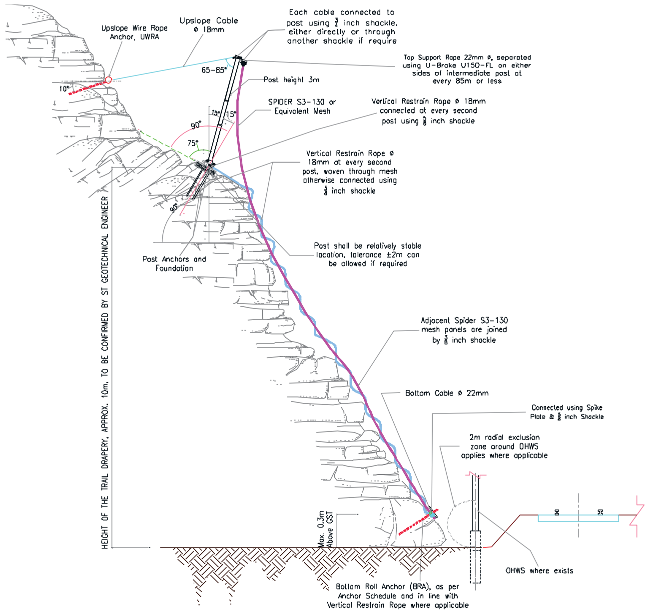


Figure 7: Typical Profile of the Stanwell Park attenuator with tail drapery

The Stanwell Park attenuator with tail drapery consist of Geobrugg 500kJ capacity barrier GBE-500A as the interception structure at 12m high, but mesh for the barrier and tail drapery is replaced with Spider S3-130/4mm mesh instead of usual TECCO G65/3mm mesh. All posts, post foundations, upslope anchors were designed to meet the minimum loadings required for the GBE-500A. The bottom anchors were designed for drapery loading exerted by trapped debris of volume generated by a triangular pyramid of 2m high with base 1m. Factor of safety of all elements were checked and the minimum factor of safety obtained was 4.65. The proposed attenuator system was, in fact, first of its kind that utilizes the momentum to mass transfer model with 500kJ energy rating for all elements.

2.4.3. Tweaking the System - The Vertical Restraint Rope

Given the narrow rail corridor along the Stanwell Park cutting and presence of overhead powerlines and overhead wire structures (OHWS) as well as not having any true vertical slope below the interception zone of the attenuator, it was important to have provision in the design to control the deflection of the highly flexible mesh of the system. This was considered one of the most critical aspects of the attenuator system for potential installation in railway corridor. The 'vertical restraint rope' was then included in the design at each alternate barrier post to limit the potential large deflection. However, after consulting with the manufacturer of the product, it was realised that there was no such provision exist from the off-the-shelf option to the barrier posts to apply any such restraint over the mesh from the post to the bottom support cable. Numerous discussions took place with the Manufacturer Geobrugg who finally agreed to supply custom made posts with additional slots with U-pin to host the proposed

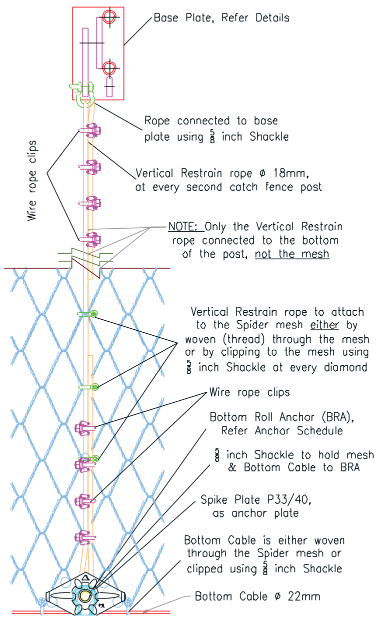


Figure 8: Vertical restrain rope connection detail

vertical restraint cable. The base plate for the post was also needed to be enlarged from its usual size to accommodate modified post size and post anchors.

2.4.4. Exclusion Zone around OHWS – Additional Safety in Design Element

Although the all rockfall mesh elements are not conducive to electrical current (Source: Geobrugg internal memo) and anchors were directed attached to the ground as well as provision for vertical restraint rope was made, additional electrical safety element was considered into the design - mainly to deal with any remote possibility of stray current in a scenario of touching the OHWS using one hand and touching any of the attenuator elements using other hand. An exclusion was enforced in the design to rule out any such possibility and a design detail was provided for cutting and joining the Spider mesh with appropriate set of anchor arrangement.

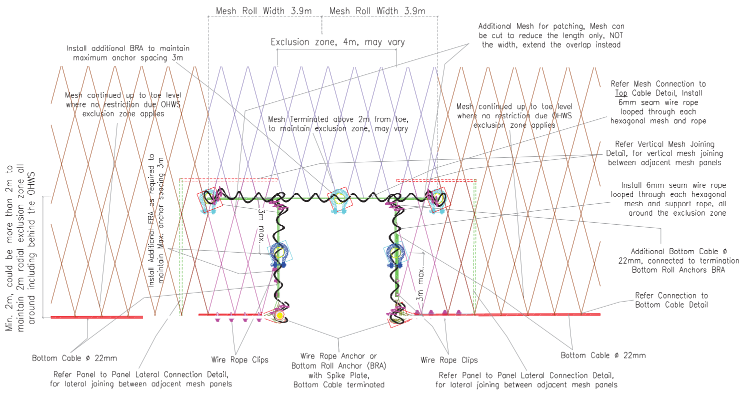


Figure 9: Typical exclusion zone configuration

2.4.5. Post Alignment – Another Design Challenge in Difficult Terrain

Setting out appropriate post locations for the attenuator barrier at the interception zone was quite challenging. This was mainly due to the topography of the slope, significant RL variations along the line of interception zone exceeding permissible tolerance for deviation of post alignment, track and thus the cut slope being on a curvature, nonexistence of narrow bench along the whole interception line etc. Another design criterion for the post alignment was to achieve the effective barrier height of 3m along the whole length while maintaining a nice aesthetic look. Considering all factors, the elevations for all post base plates were fitted into a 2nd order polynomial and RL values for each post was provided in the construction drawing set.

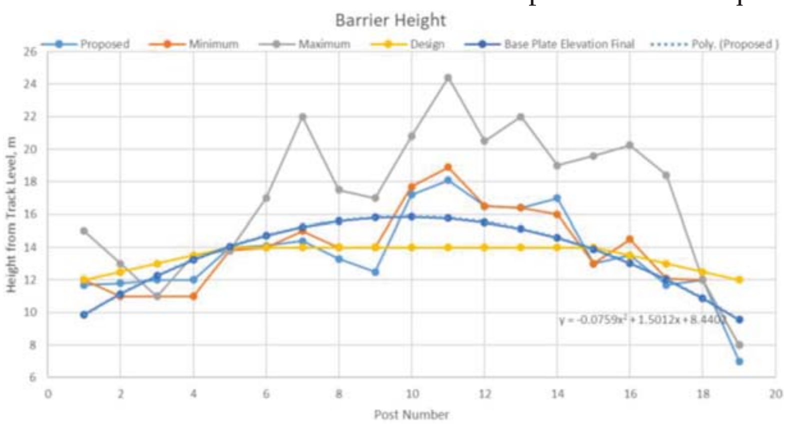


Figure 10: Iterations for Post Alignment

2.5. Construction Challenges

Although the construction was awarded one of the experience contractors, a significant challenge encountered during the construction phase was setting up the post alignment up high about 12m from track level. Some modifications to the design post elevation were unavoidable to facilitate convenient elevated work platform for drilling and post installation as well as suitable local ground conditions at post locations. In fact, this led to a highly variable undulating alignment for the top of the posts deviating significantly from the original design intent. A poor choice of work

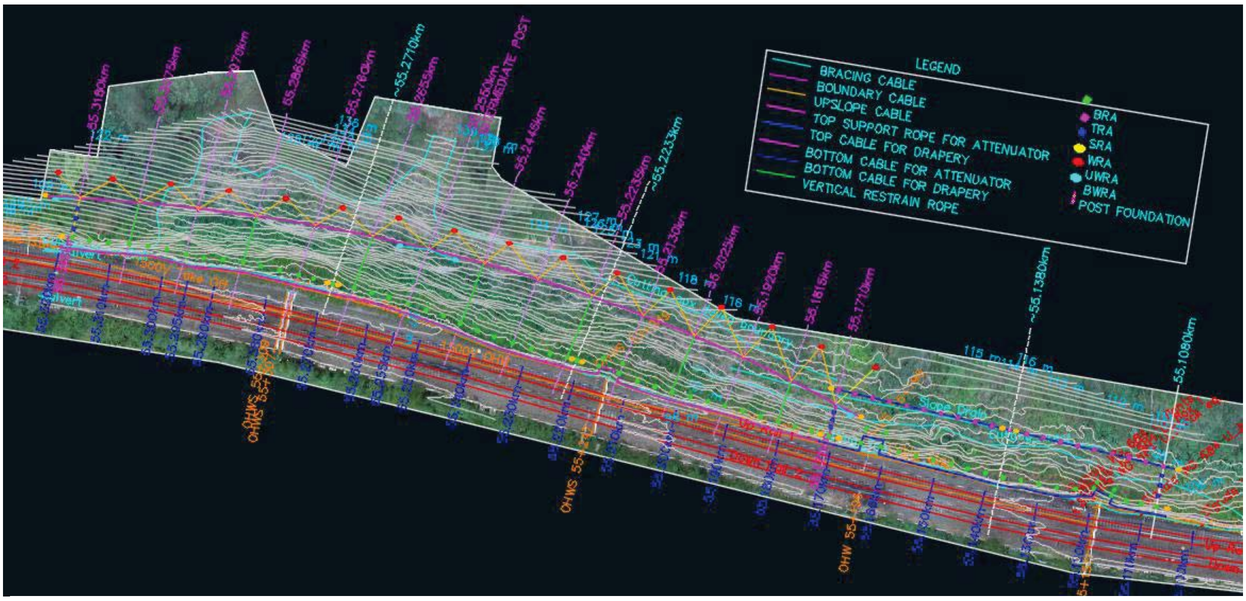


Figure 11: Plan view of Stanwell Park attenuator with tail drapery

methodology by the contractor played a significant role in this undesirable outcome. To address this variability, however, each post height was recalculated to achieve the same elevation for the top of the barrier and custom height posts were sourced by the contractor from the post manufacturer Geobrugg.

Figure 12: Construction in progress for Stanwell Park attenuator with tail drapery

2.6. Benefits of the Attenuator Barrier with Tail Drapery

The attenuator rockfall protection system at Stanwell Park cutting offers a number of significant advantages over the traditional solutions. It offers optimisation of initial and overall life-cycle cost to a large extent, as the design is based on principle of attenuation or weakening the dynamic rockfall energy rather than constructing the absolute energy resistant structure such as the traditional catch fence. The attenuator system has less maintenance requirement as the rockfall

debris does not need to be cleaned up from the interception zone at height, instead debris are collected from the bottom of the drapery. The system has also small environment footprint as the devegetation of the entire 60m high cutting and beyond is not necessary. The attenuator system challenges traditional rockfall solutions through the implementation of a hybrid approach which takes into consideration of the complex terrain of the rail corridor and future-proofing accessibility concerns for ongoing routine maintenance. The construction took four 2-day weekend track possessions and the installation of the whole attenuator system over the 225m section was completed in August 2020. The overall construction cost for the project was 1.6 million. With the construction of the attenuator system, the geotechnical risk rank for the section of the Stanwell Park cutting is now reduced to a tolerable level of residual risk C- from B-P1 (as per ASA Standard T HR CI 12100).

Figure 13: The Stanwell Park attenuator with tail construction completed in August 2020

2.7. Outlook

Designing a site-specific attenuator system is more challenging especially in a railway corridor with difficult terrain and limited access. In fact, the rockfall attenuator system at Stanwell Park cutting is first of its kind in AU/NZ region that utilizes the concept of dynamic rockfall momentum transfer model for translating a targeted initial impact energy to a much lower impact energy at the receiving toe of the cutting. During the design process, a few tweaking elements were considered into the system to make it viable in Sydney Trains railway corridor that has live overhead power system running along.

The attenuator solution at Stanwell Park cutting is a long-term solution for protecting the track from high risk rockfalls and is a good solution for tolerable risk-based design for very high cutting in a difficult topographical setting. By applying a cost-effective and robust approach to the significant safety problem, Sydney Trains now has a resilient geotechnical solution that will help

ensure the reliability of the rail network within the area. The solution can be easily adapted and has high potential for application to few other high-risk cuttings not only in Sydney Trains railway corridor but also in road corridor across the Transport for NSW.

The design, development and installation of the Stanwell Park attenuator with tail drapery is a significant milestone in the adoption and development of long-term rockfall protection systems in Sydney Trains railway corridor. The system is an excellent example of building network resilience, being innovative, adapting to natural hazards and environmental constraints, adopting new and emerging technologies and developing practical construction methodologies in difficult settings. As the attenuator system was installed successfully for the first time in Sydney Trains rail network, it enables constant opportunities for improvement of geotechnical risk mitigation strategy to be more effective in line with the So Far As Is Reasonably Practicable (SFAIRP) framework, as well as providing ample confidence in the future design and adoption of similar rockfall protection systems across the Transport for NSW.

Figure 14: The Stanwell Park attenuator with tail drapery protecting the track from rockfalls

Attachments

Project Information Video:
https://drive.google.com/file/d/10XFbSfjyGJjLR8HnxtYetQ0WZZWsVwS4/view?usp=sharing

JUDGING CRITERIA

Addressing judging criteria

3.1. Difficulties Overcome

- *Technically viable and practically constructible with limited budget:* The Stanwell Park cutting needed a long-term solution that is technically possible for essentially a 110m rock slope subjected to frequent rockfalls in random trajectories, yet the solution had to be cost-effective to be able to fit into the regular maintenance (RM) program, constructible in a 2-day possession driven railway corridor. Being located between two tunnels and along a creeping side-fill steep embankment along the downside of the track, the design also needed to consider the construction staging as well as the mobilization and accessibility aspects required for the plants through a single narrow access gate. The attenuator barrier with tail drapery is the only solution that meets all the construction constraints, limited track possessions and monetary allowances, while yielding a technically attractive long-term rockfall protection system compared to other hard solutions such as rock shelter or tunnel. Overall cost for the project was 1.6 million which was completed just in five 2-day weekend track possessions, yielding an average cost of just $66/m2 for a 220m by 110m difficult terrain slope in a highly space constraint railway environment. Refer Sections 2.1 and 2.2 for the procedures adopted for the project.
- *Design challenge – fitting the solution into space constraints railway corridor:* Few unorthodox tweaking elements, as described briefly in Sections 2.4.2, 2.4.3 and 2.4.4, were added to the system to ensure safety and reliability of the system are maintained throughout the design life of the solution and residual risks are maintained at a tolerable level. Setting up the attenuator post alignment in actual terrain to meet the modelling conditions as well as curvature of the track was the most challenging task, which was resolved through DTM modelling at the design phase and later adjusting the post height during the construction phase. Another critical challenge was how to control the deflection of the highly flexible free mesh of the attenuator in a space constraint environment with electrical overhead powerlines. Traditionally, attenuator-type solutions are employed on remote areas where space is not a concern, but this is not the case for the Stanwell Park cutting. Therefore, a new idea must be developed to include the 'vertical restraint rope' which, according to the manufacturer Geobrugg, has never been accommodated in any attenuator-type solutions. This led to some modifications of post base plate and post from the off-the-shelf elements.

3.2. Contribution / Impact to Rail

Recently installed attenuator with tail drapery at Stanwell Park is a significant milestone in deriving a long-term rockfall protection system in the space constraint Sydney Trains rail corridor. The attenuator system was tweaked in order to make it fit for purpose while yielding an excellent level of cost optimisation. Without this tweaked attenuator with tail drapery, virtually there is no practicable long-term remedial measure plausible for the Stanwell Park cutting without spending too much under a special capital expenditure

(CAPEx) program and without any extended track closure period. The tweaked attenuator barrier with tail drapery as constructed at Stanwell Park cutting virtually ends the long-ongoing debate of 'impossible' rockfall protection solution for any challenging terrain and access setting and offers an attractive long-term solution with extremely low maintenance (limited to debris collection from toe) requirement. The solution can be easily adapted and has high potential for application to few other high-risk cuttings not only in Sydney Trains railway corridor but also in road corridor across the Transport for NSW.

3.3. Technical Input

Designing the attenuator system to meet the difficult site conditions present at Stanwell Park cutting was quite challenging. It involved an extensive level of research, rigorous consultation with the rockfall mesh product suppliers and internal stakeholders consultations. Before putting into final construction drawings, the design idea was revisited numerous times based on the geotechnical risk assessment of the site, slope rockfall feature mapping, drone scanning, digital terrain modelling, rockfall modelling as well as rigorous cost benefit analysis.

3.4. Degree of Innovation in Rail Aspects

The tweaked attenuator barrier with tail drapery at Stanwell Park cutting is a resilient rockfall protection system with extremely low environmental footprint. The attenuator system challenges traditional rockfall solutions through the implementation of a hybrid approach which takes into consideration of the complex terrain of the rail corridor and future-proofing accessibility concerns for ongoing routine maintenance. A few unorthodox tweaking was considered into the system to ensure the system is fit for purpose while economically attractive and practically constructible. Some of the innovative ideas built into the system include:

- Utilising 'momentum transfer model' to design the attenuator barrier as well as its tail drapery – giving it a theoretical energy rating of 500kJ, a first of its kind ever constructed in AS/NZ.
- Addition of the 'vertical restraint rope' to limit potential large deflection of the attenuator's free and flexible mesh to make the system fit for purpose in a space constraint railway corridor with overhead powerlines.
- Developing a load transfer mechanism for designing anchor forces and cable tensions around the exclusion zones of overhead wire structure (OHWS) – a necessary safety in design element to prevent the spread of stray current in an extremely remote scenario.
- An algorithm to transfer bounce heights from rockfall modelling into an easily identifiable post elevation to match the topographical setting and aesthetically pleasing solution.

3.5. Contribution to Safety

The developed attenuator barrier with tail drapery is designed to manage the geotechnical risk of a high cutting in a reasonably practicable measure. It provides effective protection

from rockfalls to ensure safety and reliability of the rail network for normal train operations. The developed solution addressed a safety significant problem of the network which has been ongoing since 1990. With the completion of construction of the attenuator system, the geotechnical risk rank for the Stanwell Park cutting is now reduced to a tolerable level of residual risk (C-) from the high risk (B-P1).

3.6. Systems Assurance

Because there is no specific standard exists for designing a complete attenuator system, various applicable standards were followed for different elements. The attenuator capacity was governed by ETAG27 (now EAD 340059-00-0106) European guidelines, where anchor designs were governed by AS 4671 and RMS R64. System certificates from the manufacturer of the system components were also sought and Geobrugg has carried out the system safety check after the completion of the construction to ensure system meets the standard benchmark. Various of ITP checks also established by the construction team to ensure construction meets design intent.

3.7. Commercial benefits

The developed tweaked attenuator barrier with tail drapery at Stanwell Park is a practically constructible rockfall protection solution for very high cuttings in a difficult topographical setting. It is cost effective and relatively easy to install. The system has a great prospective especially for the very high cuttings in difficult terrains where other protection measures are too complex and impracticable or too costly to construct. The solution can be easily adapted and has high potential for application to other high risk cuttings in rail and railway corridors.