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Prototype Timber Catch Fence

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ABSTRACT

Design engineers often require rockfall protection structures that have relatively low impact energy resistance. Proprietary catch fences are available to the designer, but these can have capacities that greatly exceed the computed demand energy, and therefore may be overly expensive to construct. At a Wellington subdivision site, a simple prototype timber catch fence was constructed, comprising timber posts and timber lagging. The fence was tested by rolling rocks down the steep un-vegetated slope above and into the fence. A rock with an estimated impact energy of 4.5 kJ broke two pieces of the lagging without penetrating the fence. The structure was essentially undamaged by all lower energy impacts. This fence design, with some adjustments, was then used to protect houses within the subdivision. We propose that similar fences could be used for similar sites in future.

1 INTRODUCTION

On developments below steep land, passive rock fall protection structures are often needed to mitigate the effects of falling rocks. In the authors' experience in Wellington greywacke, where the rock typically breaks off into fairly small pieces, the rock fall demand energy can be quite low, such as 5 kJ or less.

There are many types of passive rock fall protection structures, and these are described in detail in MBIE (2016). For low energy demands, the designer is likely to select either a rigid barrier (stiff) or a flexible barrier, in the terminology of MBIE.

If choosing a flexible barrier, the following proprietary catch fences are available to the designer:

- Proprietary flexible systems with EAD (previously known as ETAG) certification. The lowest level of EAD certification is 100 kJ;
- Proprietary systems with capacities lower than 100 kJ – for instance, 10 kJ (Geobrugg 2017) and 35 kJ (Geobrugg 2014) fences are available, although these do not have EAD certification.
- The Roads and Traffic Authority of New South Wales have produced drawings with several different standard rock fall fences, with stated energy absorption capacities as low as 4 kJ (RTA 2007).

All of the above fences comprise steel posts with steel mesh between. Barriers with capacities of 100 kJ or more require a specialist contractor.

In this paper, we describe the testing of a prototype rock fall fence comprising timber posts and timber lagging. The potential benefits of this system included that it:

- Was made from readily available materials
- Could be installed by a non-specialist contractor
- Looked not much different from a typical boundary fence, so might be more acceptable to a resident (or potential purchaser)
- Would, at least, provide a plausible alternative to the steel systems.

In MBIE terminology, this prototype is a structural wall, a subset of rigid barriers.

2 PROJECT BACKGROUND

ENGEO were the geotechnical engineers for a substantial residential development in the hills of Wellington, where cuts of up to about 25 m height into greywacke were required. These cuts were mostly sloped at 45°, which is considered to be typically a safe angle, but we considered that small pieces of rock coming loose from the slopes presented a credible rockfall hazard.

We recommended to our client that a catch fence should be constructed at the base of these cuts to reduce the likelihood of damaging rocks entering the residential properties below. We proposed a trial to establish if this fence would resist the demand energy for the specific site.

The trial had two key purposes:

1. Assess if the prototype fence was sufficiently high and strong enough to stop damaging rocks from entering the properties beyond the fence.
2. Assess a minimum energy rating of the prototype fence such that it could be used within other areas of the proposed subdivision or on similar sites.

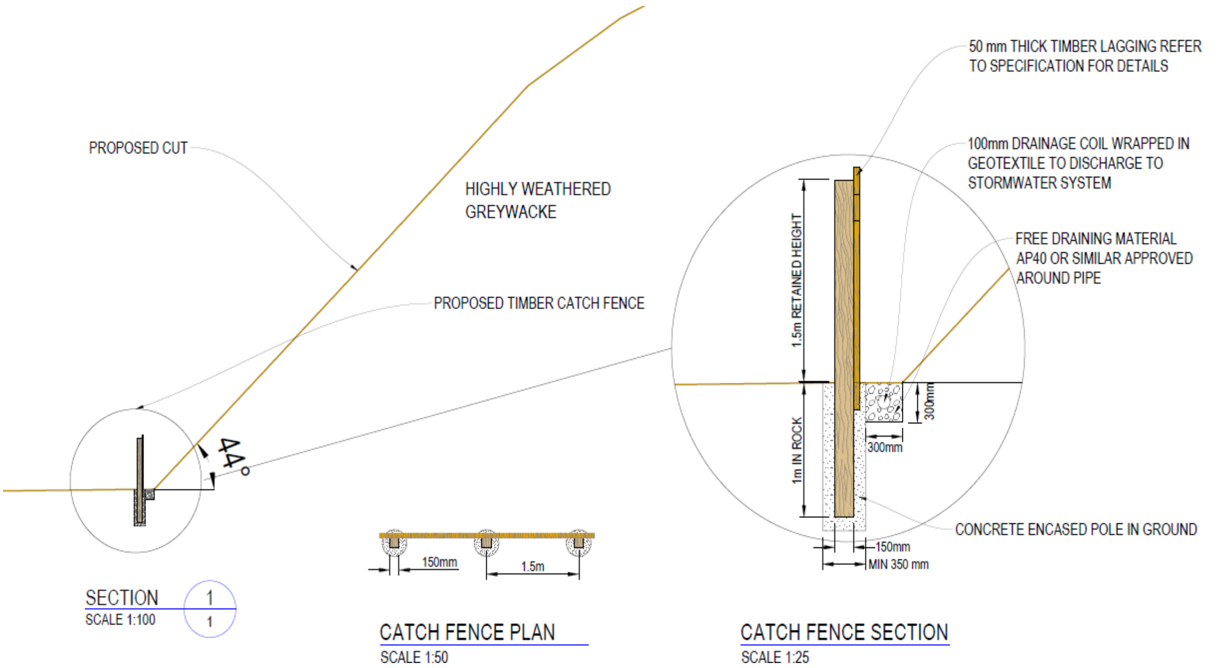

Figure 1: Prototype catch fence design

3 PROTOTYPE FENCE DESIGN

The prototype fence was designed by ENGEO and constructed by Keith Bullock Contracting - the design is shown in Figure 1.

The as-built fence differed in some minor respects to the design. The as-built details were as follows:

- The fence was about 16.5 m long and comprised 12 square posts with lagging between posts.
- It was 1.5 m high to the top of the lagging. The base of the lagging sat 50 mm off the ground, and there were seven lagging boards with a total height of 1.45 m – an average board height of just over 200 mm.
- The lagging was 55 mm thick. The five bays of the southern end of the fence had a double thickness of lagging; the remaining six bays at the northern end had a single thickness of lagging.
- The posts were 155 mm square timber.
- The centre-to-centre spacing of the posts varied from 1.33 m to 1.70 m, with an average of 1.51 m. The average spacing of the double-lagging section was 1.49 m; of the single-lagging section 1.52 m.
- The angle of the slope immediately above the fence varied from 43° above horizontal at the southern end to 35° at the northern end.

It is estimated that the construction cost of this prototype fence was roughly $300 per linear metre – the fence was constructed in 2018.

4 ROCK SELECTION

The lower parts of the cut batters on the subdivision mostly exposed highly to moderately weathered greywacke. In general, the approach for cut batters on the subdivision was to cut the slopes shallow enough that medium or large scale slips, those in the order of several cubic metres, were unlikely to occur. With this design, it would still be possible for small rocks to dislodge from the completed cut batters.

The intention of the catch fence was to stop such small rocks. We therefore selected rocks in the trial that were as large as we, or the contractor, could find on site. We reasoned that if larger rocks were not readily available in a working earthworks site with many existing cuts, then they were unlikely to come loose from the batters.

5 THE TRIAL

The rocks were carried by hand to the top of the slope above the prototype fence, as it was not possible to drive machinery to the top of the slope. The trial was divided into a series of "Runs", which were groups of two to eight rocks that were dropped down the slope. Two different launch positions were chosen, as shown in Figure 2 below. The higher launch position (green circle), used for Runs 1 to 5, was located about 23 m vertically above the fence and the lower launch position (red circle), used for Runs 6 to 9, was located about 15 m vertically above the fence.

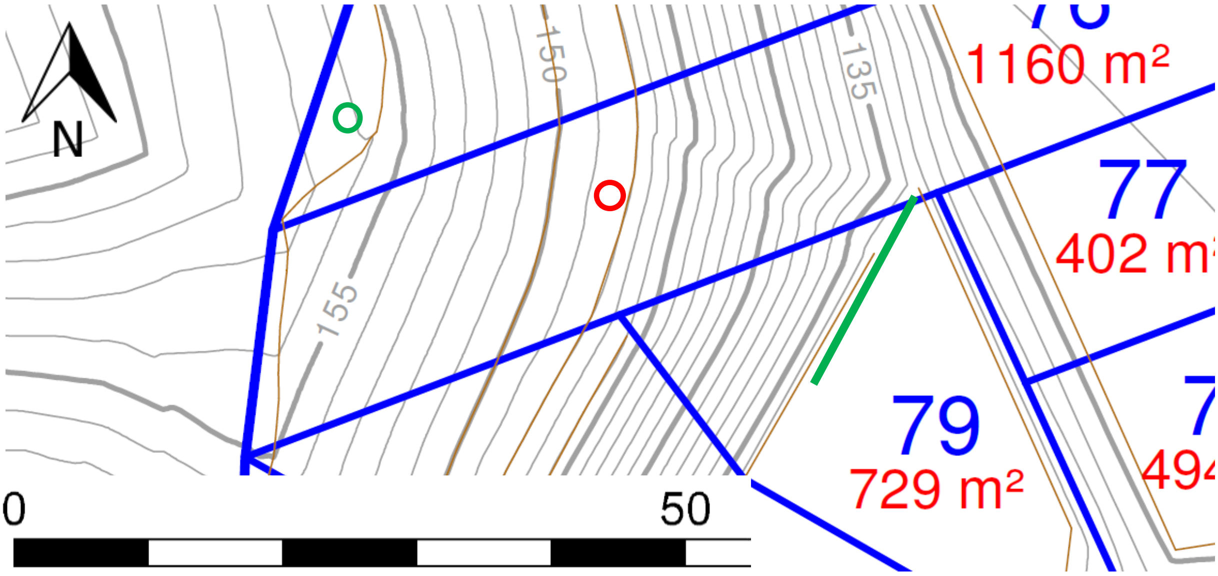

Figure 2 - Site Plan. The green line is the fence, the green circle is the higher rock launch position and the red circle the lower rock launch position. Contours shown are at 1 m vertical intervals.

For the higher launch position, the horizontal distance from the rock launch point to the fence was about 38 m. The average gradient of the trajectory was about 30°, varying from about 20° at the top of the slope to a maximum of about 43° at the base. The horizontal distance from the second launch position to the fence was about 19 m, with a vertical drop of about 15 m, and an approximate average trajectory of 38°.

The trial was filmed by a camera located near the southern end of the fence for Runs 1 to 5, and by cameras at both ends for Runs 6 to 9. Markings were made with spray paint on the slope indicating 4 m from the fence. By watching the films in slow-motion, we estimated the time for the rocks to travel the final 4 m before impact, and hence were able to estimate their velocity at impact. The two cameras used were both GoPro cameras, one with a frame rate of 30 frames per second, and the other 60 frames per second.

After a rock had struck the fence, the rock would be removed from the behind the fence and its impact point noted. Any pieces that had clearly fractured from the rock during impact were also collected. The rock, and any associated fragments, was weighed, using digital bathroom scales, after striking the fence. This method is conservative, as the rock may have weighed more at impact than we measured. However, based on the films, few rocks lost significant weight during impact with the fence.

Unfortunately, the prototype fence was located below an area of slightly convex slope. This resulted in many rocks missing the fence to the sides, in particular from the higher launch position. The run-out distances of these rocks past the fence were measured. Moving the launch position to the lower position for the later runs increased the proportion of rocks that struck the fence without any noticeable reduction in mean impact velocity.

6 TRIAL RESULTS

6.1 Fence Impact Results

We rolled 51 rocks that either struck the fence or travelled over it. Of these, we were able to record data for 55 impacts with the fence. We observed 10 to 11 rocks or fragments that travelled over the fence – these were from six rolled rocks.

Table 1 presents the ranges of estimated impact velocities, recorded impact heights, measured masses and calculated impact energies. Where the impacts were recorded by multiple cameras, we typically used the camera closest to the impact to record the velocities and impact heights. Where rocks broke into several smaller pieces during their descent, and where the individual pieces could be clearly seen in the video, then individual impacts were recorded. Kinetic energy was calculated for each impact using Equation 1.

$$E_r = 0.5 \times m \times v^2 \quad (1)$$

where E_r= Kinetic Energy; m = Mass of Rock; and v = Velocity at Impact

Table 1: Summary of Rock Impact Data

Impacts	Velocity at Impact (m/s)	Impact Height (m)	Mass (kg)	Kinetic Energy (J)
55	5.7 – 15.4	0.1 – 1.6	0.5 - 54	8 - 4495

The fence withstood all of the impacts in Table 1 without significant damage, with the exception of Run 7, Impact #6, which broke the lowest two pieces of lagging at the northern end of the wall, where the wall was single lagged. This impact had the largest energy of all of the rocks, approximately 4500 J, and camera footage from this impact is shown in Figure 3. The lowest piece of lagging permanently deformed outwards by about 80 mm, and the second lowest piece by 30 mm. The rock, which weighed 54 kg, did not penetrate the wall, although had there been a subsequent similar impact at the same location, it may have penetrated the wall. The details of the 54kg impact, along with the three other largest impacts, are provided in Table 2. Other impacts noticeably indented the back of the lagging in several places, but did not loosen or break any timber.

Table 2: Details of Four Rocks with Highest Energy

Impact No.	Velocity at Impact (m/s)	Impact Height (m)	Mass (kg)	Kinetic Energy (J)
Run 7 #2	12.1	0.5	25	1837
Run 7 #3	11.8	1.0	21	1453
Run 7 #6	12.9	0.4	54	4495
Run 9 #2	13.3	0.8	19	1689

Figure 3: Trial fence, shown just before impact of 54 kg rock that broke some lagging. The researcher who rolled the rock can just be seen top right of picture.

6.2 Rocks that travelled over the fence

Several rocks passed over the fence during the trial. The details of these rocks are recorded in Table 3. In all cases the rocks that passed over the fence were associated with larger rocks that struck the fence. The rocks that passed over the fence had separated from the main rock, either on impact with the slope, or on impact with the fence.

Table 3: Overtopping Rock Data

Mass Category	Number of Rocks in Category	Height Passing Over Fence (m)	Distance Travelled Past Fence (m)
Less than 100 g	3	0.2 - 0.8	13.5 – 19.5
About 100 g	6 - 7	0.1 – 0.2	Up to 10
5 kg	1	0.4	4.5

6.3 Rocks that missed the fence

Several rocks missed the fence to the side. This situation mostly occurred in the runs when the rocks were launched from a higher location on the slope. Rocks missing the fence on the southern end travelled up to 12.5 m past the fence, with the heaviest being a 4 kg rock which travelled 12 m into the flat building platform. Rocks missing the fence on the northern end travelled down a 2.5 m high, approximately 45° slope shortly below the fence and then onto a flat building platform. The maximum runout distance was 34 m past the fence, by the heaviest rock, which weighed 11.5 kg.

7 TRIAL ANALYSIS

7.1 Energy

The catch fence ultimately achieved its purpose of no rocks breaking through. There was one rock that broke two of the lagging boards but the intention of the fence was still fulfilled.

This largest impact struck near the bottom of the fence. There were some 1200 J to 1400 J impacts nearer the top of the fence (one example is shown in Table 2), which suggests that the fence has some strength near its top, although there were no impacts near the top of the fence approaching 4500 J. Our qualitative assessment is that a 4500 J impact at the top of the fence would likely break lagging, but that the vertical posts would be unbroken because the fence is more flexible at the top and hence deflects more, producing less force, and the breaking of the lagging will absorb energy.

We used the impact data to assess the fence's capacity in terms of MBIE, which defines a Maximum Energy Level (MEL) approach and a Service Energy Level (SEL) approach. We assessed the fence using both approaches.

At MEL, a barrier should be designed to withstand one impact with the design energy, and it is expected that the barrier will have to be repaired or replaced following impact. Following a 4500 J impact, the fence suffered some broken lagging, and needed repair. But the rock did not penetrate the fence, so we considered that the fence had demonstrated a MEL capacity of at least 4500 J.

At SEL, a barrier should be designed to withstand two impacts with the design energy with no repairs allowed after the first drop. We should disregard the 4500 J, which caused damage, and consider the next two highest energies (see Table 2) of 1689 and 1837 J, and hence the SEL is at least 1689 J.

As the energy rating for a fence should be the minimum of MEL and 3 x SEL, the rating for the fence is assessed as at least 4500 J. As the fence was only slightly damaged during the test, it maybe that the rating of the fence is much larger than this.

Although we are not suggesting that our testing is equivalent to EAD testing, we do note that the maximum velocity in subject test was 15.4 m/s, below the 25 m/s in an EAD test regime (EOTA 2018). Therefore, we suggest that the 4500 J rating is only appropriate for impact velocities up to about 15 m/s.

7.2 Rock Height

From the trial we calculated a 95th percentile bounce height, consistent with MBIE (2016). This was achieved by considering a total of 61 bounce heights, after all measurable split off segments of the 51 rocks rolled were taken into account. The 95th percentile of 61 data points is the 58th lowest, which is the 4th highest. As fragments from six rocks travelled over, the 4th highest bounce height must be higher than the fence, and was 1.7 m above the ground surface.

7.3 Comparison to Previous Modelling

Our physical testing suggested that the 95th percentile bounce height is 1.7 m, whereas the computer modelling indicated a bounce height of 2.8 m, suggesting that the computer modelling overestimated the bounce height by 1.1 m, a relatively large distance.
Computer modelling suggested a 95th percentile energy demand of 1.7 to 2.5 kJ for the various analysed cross sections within the subdivision. The 95th percentile of the impact energies calculated during testing was 1680 J (1.7 kJ), suggesting that the computer modelling was reasonable.

7.4 Runout Distances

Runout distances for rocks outflanking the fence were substantial, up to 34 m. New houses were planned to be within a few metres of the base of the cuts. Grant et al (2018) suggest that rock blocks with impact kinetic energies of 2 kJ to 5 kJ are unlikely to penetrate more than about 0.2 m – 0.3 m into a typical dwelling (which is only slightly further than a typical wall thickness). However, given the fairly small sample sizes of Grant et al’s research, and ours, we considered that it would be imprudent to rely on the new houses to resist the rock impact. Further, it was likely that at least some of the houses would be laid out with patio doors or other large glazed areas facing gardens at the base of the slope. In these cases, a 2 kJ – 5 kJ impact might penetrate an unacceptable distance into the house, emphasising the need for the catch fence on this site and in other similar scenarios.

8 CONCLUSIONS

8.1 Trial Findings

We considered that the prototype fence was generally acceptable for the remainder of the base of the cut slope on site. As the runout distances recorded were so large, we considered that it is impractical to have a no-build zone for houses. Therefore, we considered that a catch fence was the most practical and sensible measure. A similar fence, single lagged, was eventually constructed for the remaining lots beneath the cut, but at a height of 1.7 m, as that was the 95th percentile bounce height in the physical testing.

8.2 Recommendations for Industry Standards

The prototype fence described in this document appears to be capable of resisting impact energies of around 4.5 kJ, and possibly more, at impact velocities up to about 15 m/s. We consider that this it is sensible to use this type of fence for future design situations with low calculated design energies. We would encourage others to design, test and document other similar fences.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

EOTA 2018. EAD 340059-00-0106 Falling Rock Protection Kits

Geobrugg 2014. Standard Drawing – T35 Roadside Rockfall Barrier

Geobrugg 2017. Standard Drawing – T10 Roadside Rockfall Barrier

Grant, A., Wartman, J., Massey, C. et al. 2018. The impact of rockfalls on dwellings during the 2011 Christchurch, New Zealand, earthquakes. *Landslides* 15, 31-42 2018.

Ministry of Business, Innovation and Employment (MBIE) 2016. Rockfall: Design considerations for passive protection structures.

Roads and Traffic Authority of NSW 2007. Rockfall Fence Type 1 – Sheet A. Rigid Pipe Post Fence (Light Duty)