

Post earthquake rockfall protection resilience for a lifeline transmission pylon in Christchurch

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ABSTRACT

Following the 2010 to 2012 Canterbury Earthquake Sequence, a number a lifeline structures were noted to be at risk from damage from rockfall. An electrical transmission pylon, serving as a lifeline to a coastal suburban community of approximately 5000 residents, had been hit by rockfall triggered during the earthquakes. Due to the pylon design, damage had been limited and the structure was fit to remain in operation. The structure was assessed to have a high risk of damage in future rockfall events. Rebuilding of the structure to provide resilience was considered uneconomic. It was therefore decided that to maintain security of supply to the electrical network, rock protection measures would be used instead to safe guard against possible future damage.

The pylon is situated on steeply sloping terrain approximately 75 m above sea level. Outcrops of Port Hills volcanic rocks are located approximately 180 m upslope of the pylon. The slope beneath the rock outcrops comprises predominately loess colluvium (reworked windblown silt) with scattered rock at the near surface along with boulders from previous rockfall events.

This paper describes the process of assessing and designing resilient rock fall protection to a lifeline structure. Work has included:

- Rockfall modelling
- Rockfall protection optioneering
- Removal of source material
- Design of rock fall protection fence

The assessments and modelling resulted in the construction of a rockfall protection fence.

1 INTRODUCTION

The Canterbury Earthquake Sequence (CES), between 2010 and 2012, caused rockfall events on the Port Hills damaging residential properties and infrastructure. While some infrastructure such as roads were closed due to risk to life some structures such as lifeline infrastructure (e.g. overhead power, telecommunications etc.) had to continue to operate. This paper describes the process of providing protection to a lifeline structure to provide resilience against future rockfall events.

1.1 Background

During the CES a transmission pylon on the Heathcote to Barnett Park sub transmission tower line was damaged by multiple rock strikes. This created a significant risk to the electricity supply to Sumner, Redcliffs and the surrounding area.

The pylon is situated on sloping terrain approximately 75 m above sea level, see Figure 1. Outcrops of volcanic rocks from the Lyttleton Volcanic Group are located approximately 180 m upslope of the pylon.

The slope beneath the rock outcrops comprise predominately loess colluvium (reworked windblown silt) with scattered outcrops of exposed rock at the near surface and boulders from previous rockfall events.



Figure 1: Transmission pylon prior to works



Figure 2: Examples of rock damage to pylon

2 INVESTIGATION

2.1 Field Mapping

Field mapping was undertaken by GHD staff to map and quantify; the number, type / size of fallen boulders as well as, potential source boulders from both rock outcrops and the slope around the pylon. Bounce height data at the pylon location was measured from impact marks on the pylon, see Figure 2.

Field mapping, see Figures 3 to 5, identified two types of potential rockfall boulders:

1. Boulders formed by defects in the bluffs (i.e. not yet released);
2. Boulders that had previously released from a bluff onto the slope below and were now supported by soil.



Figure 3: Precarious source rocks identified during walkover



Figure 4: Looking upslope with pylon to the left.

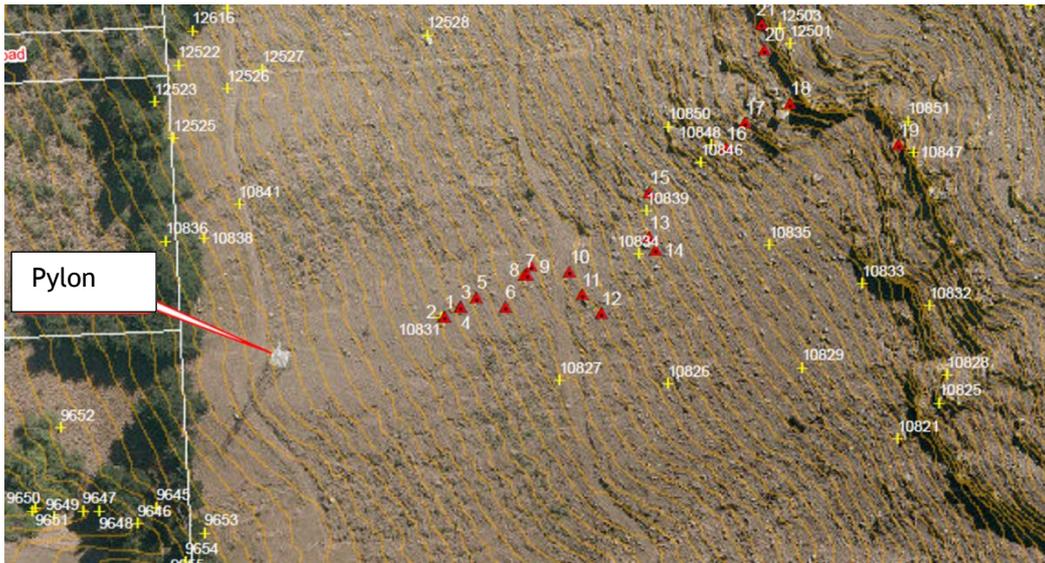


Figure 5: Mapped precarious boulders

3 RISK ASSESSMENT

3.1 Rockfall Modelling

Existing rockfall data collected by GNS Sciences (GNS) and the Port Hills Geotechnical Group (PHGG) following the earthquakes of the CES was obtained from Christchurch City Council (CCC). This data comprised the details and locations of mapped boulders that had moved in the CES and several attributes logged during field mapping of fallen boulders. Volumes of individual boulders were calculated by using a volume reduction factor of 30% to take into account the boulders shape. The mass was calculated using a boulder unit weight of 27 kN/m^3 as per GNS Science Consultancy Report CR2011/311.

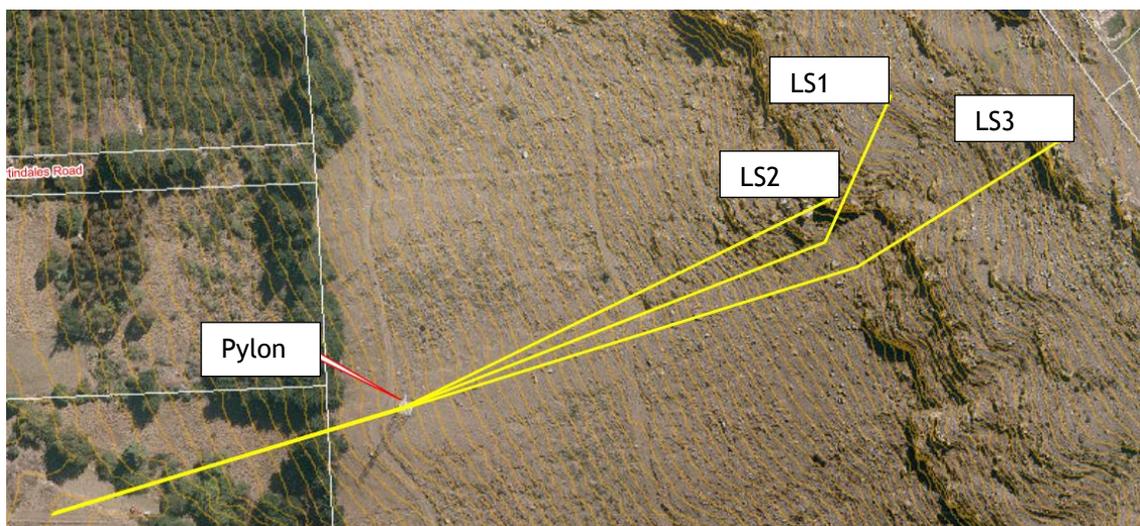


Figure 6: Boulder Runouts For Selected Sources

2-Dimensional rockfall modelling was undertaken using the rockfall modelling software RocFallTM (by Rocscience).

The rockfall modelling process, project settings and initial material parameters, were undertaken / selected in accordance with Appendix F (Rockfall Modelling Methodology for Field Verification) of GNS Science Consultancy Report CR2011/311.

Three transects (LS1 to LS3) were run downslope from the bluffs through the pylon, see Figure 6. Two boulder sizes were considered for the modelling of potential rockfall risk:

1. The 95 percentile boulder from the data collected during GHD’s field assessment was 85,000 kg. This was revised to 7,300 kg following boulder deconstruction works undertaken subsequent to the field mapping.
2. The GNS Port Hills 95 percentile boulder size of 8,250 kg.

The GNS Port Hills 95 percentile boulder size was used for the modelling. This was considered the most conservative boulder size and removes any potential bias created by a limited field survey.

Through back analysis, the GNS guideline material parameters were modified to achieve similar bounce heights to those observed on the pylon. Run out distances from the modified parameters ran further than the furthest boulder recorded in the GNS dataset. However this boulder and all other boulders in the area appear to have been stopped prematurely by vegetation. From field mapping of potential boulders, a Super Ellipse⁴ (5:6) boulder shape was used in the modelling due to the somewhat tabular nature of the boulders.

The rockfall modelling results are provided in Table 1.

Table 1: Rockfall model input parameters and results

Layout	Transect 1	Transect 2	Transect 4
Boulder Mass (kg)	8250	8250	8250
Pylon Location on Section (m)	235	186	283
No. Boulders Past Pylon	191	561	248
Max Runout Distance (m past Pylon)	77	86	95
Bounce Height at Pylon (m)	1.11	0.7	1.1
Total Kinetic Energy at Pylon (kJ)	646	516	584

The results were in line with observed data captured during the field inspection.

4 MITIGATION OPTIONS DISCUSSION

A variety of mitigation options to reduce the rockfall risk were considered with different advantages and disadvantages and cost implications and are discussed in the following sections.

4.1 Deconstruction and scaling of potential boulders

Deconstruction and scaling of individual boulders can be used as a targeted approach to eliminate high risk boulders. As the quantity of potential boulders increases this method becomes less economical. The method can be used to target specific large boulders and those that have a higher probability of detachment. This option results in a solution that does not produce a fixed asset that requires maintenance but would require ongoing re-assessment. In this case, it was considered uneconomical to deconstruct all potential boulders and completely remove the hazards. In addition, the incorrect deconstruction of boulders could trigger further weathering, instability and rockfall. Boulder No. 16 was identified as needing deconstruction immediately, as it posed an immediate significant risk. It was estimated that a further five large boulders (>24,000 kg) and several smaller boulders would require varying degrees of source treatment at some stage in the

future, as the soil support may erode and cause instability. This work was subsequently carried out by Solutions 2 Access Ltd.

4.2 Rock bolting of potential boulders

Rock bolting can be used as a targeted approach to reduce the probability of detachment of high risk boulders. This method is only suitable where boulders are supported by near surface bedrock for rock bolt installation, which was not the case in this situation. In addition rock bolts would become an asset with a limited lifespan and would require ongoing maintenance.

4.3 Reinforced concrete support/buttress of potential boulders

A reinforced concrete support or buttress of the boulder can be used as a targeted approach to reduce the probability of detachment of high risk boulders. However, this method can become uneconomical to treat many potential boulders and completely reduce the hazard. In this instance it was not suitable for all boulders due to the steep underlying terrain. Also it would become an asset with a limited lifespan that will require ongoing checking and maintenance.

4.4 Rockfall netting mesh/drapery system

A rockfall netting of mesh or a drapery system can cover large areas with suitable anchor points typically installed in rock. This method arrests boulder fall and prevents roll and bounce of boulders hitting the structure. The netting becomes an asset with a limited lifespan that requires maintenance and removal of rocks that fall within the mesh. It was not considered suitable due to the sheer scale of the area requiring cover.

4.5 Earth or Rock Embankment

Earth embankments are able to divert and catch large volumes of rock and can absorb impacts from boulders with large energies. This technique is also relatively easily repaired and cleared out after each large event. It can also be 'greened' to reduce the visual effect. However, it requires significant earthworks which can destabilise the slope if not undertaken carefully.

4.6 Concrete Deflection Barrier

Concrete deflection barriers are able to divert and catch large volumes of rock and withstand multiple boulder strikes. However they require deep embedment into the slope and may act as a dam, causing detrimental effect to water flows. This type of barrier in such a location was also considered to not to be aesthetically pleasing. It would require greater excavation and earthworks, and thus have greater environmental impact than a rockfall protection fence.

4.7 Rockfall Catch Fence/ Barrier System

A rockfall fence does not require significant earthworks and the structure can be small and targeted. These fences can withstand over two strikes from boulders. A fence will have to be emptied following boulder strike and will require ongoing maintenance.

5 SELECTED SOLUTION - PROTECTION TO STRUCTURE

5.1 Design Approach

Installation of a rockfall catch fence was recommended in conjunction with source treatment. A catch fence is considered an appropriate protection structure as total kinetic energies are within the limits of rockfall catch fence design and bounce heights are relatively low (~1 m) at the pylon. A rockfall catch fence required the least amount of earthworks and the modelled total kinetic energy (at the pylon) for the 95 percentile boulder is within its capability. Modelled bounce heights and observed bounce heights are approximately 1 m above ground level, indicating a 2 m

high rockfall catch fence is a realistic and feasible height. As the source treatment had been undertaken on the larger boulders, this significantly reduced the demand on the rockfall catch fence. In addition, construction of a rockfall catch fence directly upslope of the pylon minimised the length of the fence required.

The design approach needed to include consideration of the planning and consent process. As the pylon is located on land owned by the CCC, consultation was necessary to determine a mutually agreeable design.

5.2 Investigation

A 15 m deep machine borehole was drilled by McMillan Drilling to understand the depth of Loess and volcanic rock, and to provide soil and rock parameters for the design of the rockfall barrier anchoring and foundations. The investigation found up to 15 m of stiff Loess, with no bedrock encountered.

5.3 Detailed Design

The total kinetic energy of 95th percentile boulder strike was in the range of 600 to 800 KJ. Using a factor of safety of two, a catch fence with a maximum impact energy level of 1500KJ was identified as the most appropriate protection structure for this project. The proposed fence was designed to be 30 m wide, with post spacings of 10 m and with post heights of 4 m. The post height of 4 m was chosen to account for a conservative bounce height of 2 m, with a factor of safety of two. The embedment of the piles / anchors was based on the presence of weak loess soils and in consultation with Geofabrics. Allowing for a factor of safety of two the anchors are adequate for an 800 KJ boulder strike. The anchor type and length were specifically designed for the site.

6 CONSTRUCTION

The rockfall protection fence was constructed by Solutions 2 Access Ltd with a rockfall protection fence provided by Geofabrics. Figure 7 shows the site during construction. Figure 8 shows the completed fence.



Figure 7: Construction



Figure 8: Completed fence

7 CONCLUSIONS

A transmission power pylon had been struck by multiple boulder rolls following earthquakes of the Canterbury Earthquake Sequence (2010 -2012).

A field assessment of the area upslope of the pylon identified many potential boulders which could present future risk to the pylon (a lifeline structure). The potential boulders varied in both size and risk posed to the pylon. From this data set, a 95th percentile boulder was able to be determined and applied to 2-Dimensional rockfall modelling. The modelling was undertaken to determine parameters for the design of potential rockfall mitigation techniques. The modelling results indicated the bounce height to be low (<2 m), which agrees with observations of previous boulder strikes on the pylon. The calculated total kinetic energy of a 95th percentile boulder strike was in the range of 600 to 800 kJ.

There are a variety of rockfall protection techniques that could broadly be classified into two types; source treatment and protection structures. These were considered and a combined approach using both source treatment of the larger boulders as well as construction of a rockfall protection structure. The construction of the rockfall protection fence reduces the risk of boulder strike to the pylon. To date a small amount of rock has been caught by the fence, see Figure 8.

8 ACKNOWLEDGEMENTS

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Rocscience Version 5, RocFallTM