1 Introduction

MWH New Zealand Limited (MWH) is providing geotechnical advice to the Ministry of Education (MoE) regarding the geotechnical hazard presented by the cliffs immediately behind Redcliffs School, located in Sumner, Christchurch.

Since the seismic events of 13th June 2011 a joint decision was made between the MoE and Canterbury Earthquake Recovery Authority (CERA) to withdraw from the site until a detailed assessment of risk could be completed.

Since 2011 the Institute of Geological and Nuclear Sciences (GNS) has been undertaking detailed life safety risk assessments throughout the Port Hills, primarily for the purposes of decision making around re-occupation of residential properties potentially affected by rockfall events. That work has resulted in development of a series of risk contours that can be used to inform decisions around future re-occupation of the school.

This report provides:

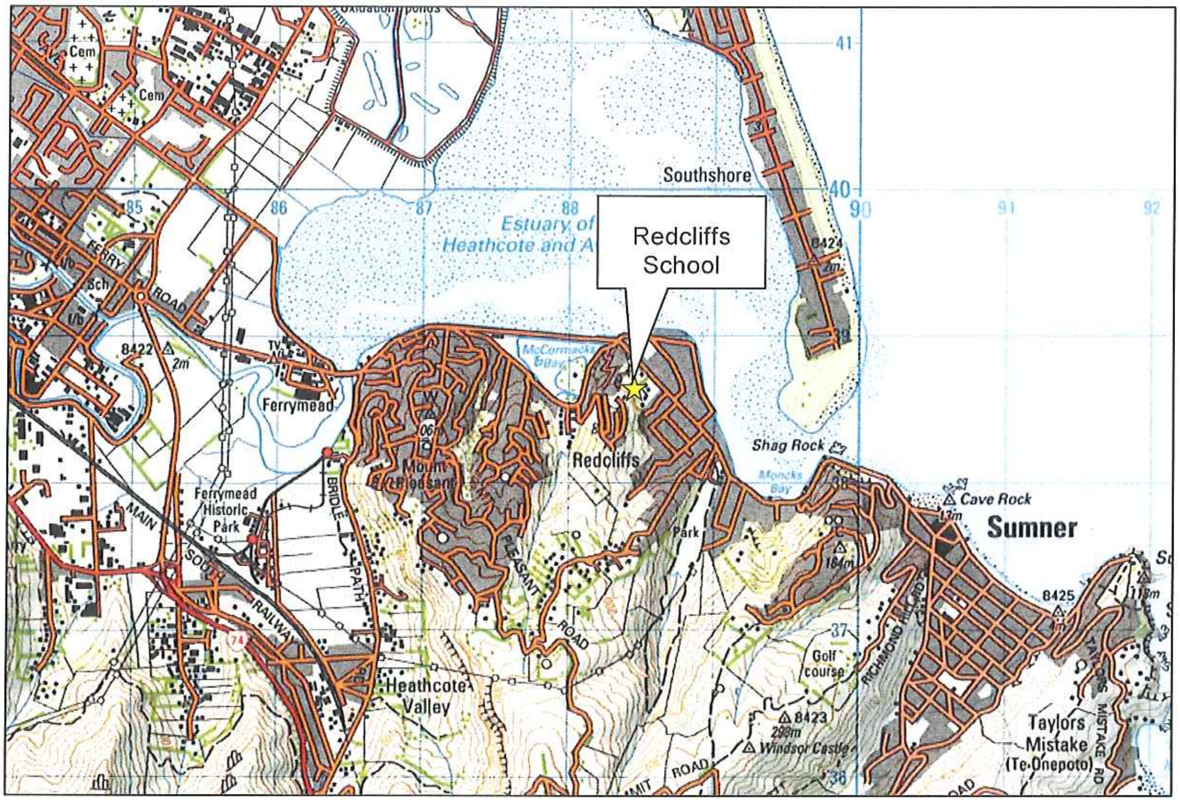
- A discussion of the cliff behaviour to date.
- An overview of modelling work undertaken by MWH to date to quantify rockfall risk to the school.
- A discussion on the risk based assessments undertaken by GNS to date and their applicability to the school.
- Based on the best information available to date an assessment of the remedial works requirements on the school site to address the rockfall risk.

This report should be read in conjunction with the MWH Report dated March 2011 and entitled *Redcliffs School, Mitigation of Rockfall Hazard – Emergency Works.*

2 Site Setting

2.1 Site Location

Redcliffs School is located at Main Road, Sumner in Christchurch. A site location plan is shown in Figure 2-1.



Map from NZMS260 1:50,000, M36 & 37 Lincoln, Edition 2, 1997

Figure 2-1 : Site Location Plan.

2.2 Site Description

Redcliffs School consists of classrooms and buildings located in the centre and southern part of the site, a school hall on the western side of the site, and playing fields to the north and east. The site layout can be seen in drawing C001 which is attached in Appendix A.

Redcliffs School is located directly beneath near vertical cliffs in the order of 70 m high in the district of Sumner. There is clear evidence that loose rocks have historically fallen from the cliffs. Prior to September 2010, the school buildings and playing fields were protected from rockfall hazards by an approximate 2.4 m high protection fence on the southern school boundary, which we understand had proved effective previously. Due to the ongoing rockfall hazard, associated with seismic activity, various additional protection measures were implemented such as a confinement rock bund, placement of shipping containers to form an additional barrier to boulders, installation of a 4 m high mesh catch fence, disuse of the school hall, and relocation of classrooms. These measures are discussed in further detail and in chronological order in Section 3.

2.3 Geological Setting

The rocks forming the hills in the Redcliffs and Sumner areas, are *Lyttelton Volcanics Group* rocks of late Tertiary (Miocene), aged about 10–12 million years old (Brown and Webber, 1992). The steep coastal cliffs around Sumner and Redcliffs areas are remnants of an old (~9,000 years B.P.) sea cliff. These near vertical (~75–85°) cliffs are typically 15 to 30 m high and up to ~70 m high in some places. The old sea cliff has been modified by quarrying in several areas, including major rock quarries located at Redcliffs and Sumner, where basalt was quarried to construct the causeway across McCormack's Bay (GNS, 2 March 2011).

The 70 m high cliff above Redcliffs School comprises a series of volcanic basalt lava flows overlain by welded volcanic ash with a loss and colluvium covering. Over time the rock face has eroded to a near vertical 35 m cliff face above a 35 m deep slope of scree.

The cliff face is predominantly made up of two materials the first being trachy basalt deposited in a lava flow and the second being a tuff material consisting of welded ash materials. The trachy basalt is a very hard, dense material while the tuff is less dense and weaker. Therefore during rockfall events, the trachy basalt generally tends to retain the large size blocks (controlled by joint spacing) on impact while the tuff tends to break up on its journey down slope. This results in the majority of the large blocks at the bottom of the slope comprising trachy basalt, with smaller fragments of tuffaceous material remaining on the talus slope. The intact boulders identified at the toe of the slope, and therefore of importance for this modelling assessment, are basalt blocks.

GNS (Aug 2014) note that crack patterns suggest larger failures than have occurred to date could occur in the future.

3 Cliff Behaviour and Instability Mitigation

3.1 Overview

A series of significant seismic events have occurred in Christchurch and the Canterbury region since September 2010. The first major event occurred on 4th September 2010 where a 7.1 magnitude earthquake was recorded. Numerous aftershocks have continued and on 22nd February 2011 a 6.3 magnitude earthquake struck the Port Hills region of Christchurch. This was followed by another 6.3 magnitude event on 13th June 2011. For the purposes of reporting, these events are described as 4th September, 22nd February and 13th June, respectively, throughout this report.

Following the 4th September and 22nd February earthquakes, rockfalls caused temporary closure of Redcliffs School. MWH provided input into hazard mitigation measures to enable the school to re-open. These mitigation measures, which included an earthworks bund, placement of shipping containers, movement of classrooms and abandonment of part of the school site, are discussed in more detail in the following sections.

Further seismic events on 13th June caused on-going cliff instability throughout the Redcliffs and Sumner area including large scale cliff collapses. Although no known rocks or rock fragments entered the occupied school grounds during this event a joint decision was made by the MoE and CERA that, due to an increased lack of certainty in the ongoing behaviour of the cliffs following the June event, there would be a withdrawal from the site until a robust risk assessment and mitigation process could be completed.

Each of the major seismic events has resulted in some loss of material from the face.

After each event the cliff has been visually inspected with particular attention to:

- the rock fall area at the bottom of the cliff, noting boulder size and geometry,
- a visual assessment of the storage volume remaining behind the rock bund,
- the performance of the rock catch fence, noting evidence of direct hits and mesh deformation,
- walk over survey and mapping of the ground beyond the catch fence looking for any rock fragments that have travelled past the catch fence, and
- inspection of the land at the top of the cliff focussing on the presence of tension cracks.

Since the June 2011 event there have been continuing rock falls from the cliffs. The volume of rock falling has been small compared to the volumes involved in the February and June 2011 events and no material is known to have reached the school site.

Observations from the earthquakes are presented below along with a summary of the protection works undertaken in response to each of these events.

3.2 Observations of Failure Modes

The modes and mechanisms of failure are not discussed in detail in this report. The re-modelling assessment undertaken for this study is based on a highly conservative approach whereby the hypothesis is for large scale cliff collapse. Therefore failure mechanisms are less important as the modelling is based on this low probability event occurring. Nevertheless, types of failure observed during site walkover investigations are described briefly below and are based on visual observations of surficial material only. A fracture or defect survey of the rock face was not undertaken.

The predominant mechanism of failure in the cliffs behind the school site is block failure. Photo 3-1 shows the cliffs prior to the seismic event of 4th September. Following the September 2010 event, the dominant failure mechanism appears to have been block failure with boulders observed at the base of the cliff and in the talus slope (apparent in Photo 3-2).

Following the event of February 2011, evidence from aerial photographs of the site and a site walkover suggest that there was loss of a surface veneer of weathered rock at the cliff face (Photo 3-3). A large amount of rock material was shaken from the vertical cliff face, infilling the bund (that was formed following the September 2010 event) at the bottom of the slope. As the bund was infilled by large blocks its ability to contain small blocks was reduced and they moved further down the slope, evident by small to medium sized rock fragments that were found to have travelled over the fence (that is located down-slope of the bund) and onto the school property. The failure mode on the 22nd February suggests that blocks toppling out of the cliff face are more likely than a full face failure. This is shown by the relatively small amount of rubble observed after the earthquake.

It appears that following the June 2011 events, more isolated blocks failed as a continuation of the failures that occurred during February. The volume of material that fell in this event has been estimated by laser scanning, the results of which are shown in figure 3-2.

Photo 3-1 – Aerial Photo of Redcliffs School Pre-September 2010 (from Google Maps).

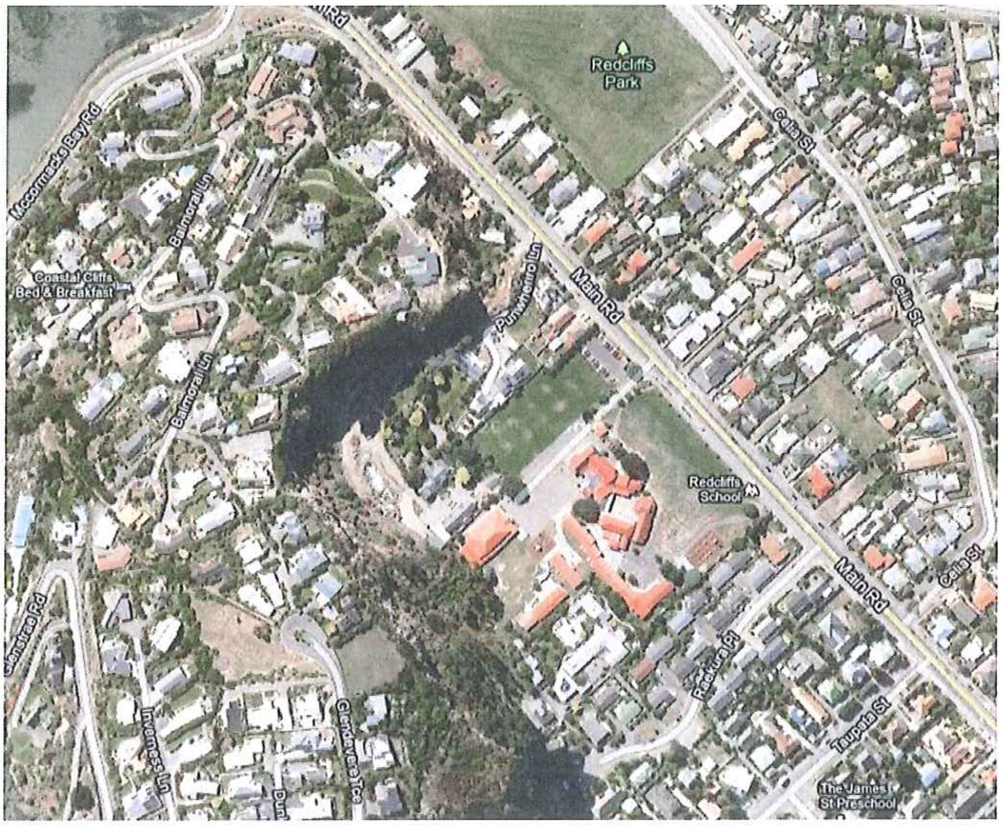
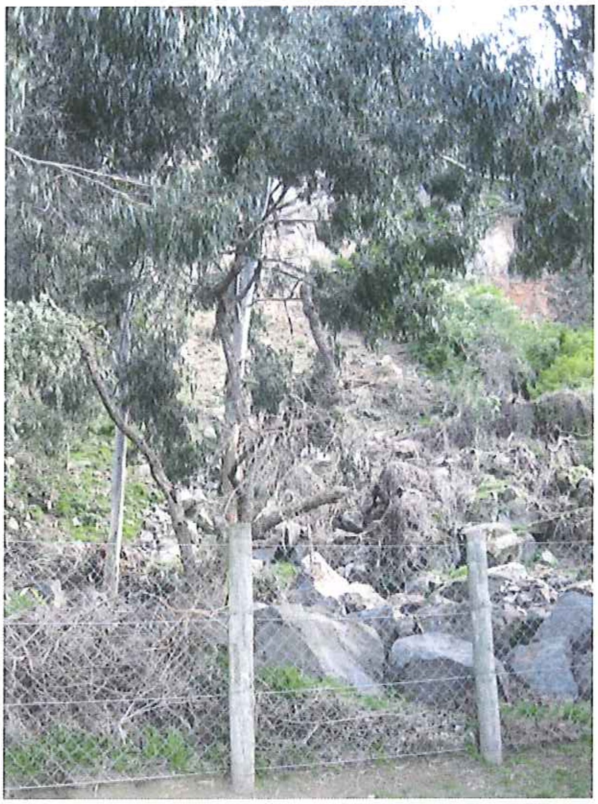


Photo 3-2 – Boulders at the Base of Catch Fence post the September Earthquake.



3.3 Historical Rockfalls

An aerial photograph showing the cliffs behind Redcliffs School prior to the seismic events is shown in Photo 3-1. To our knowledge, there is no aerial survey (LIDAR) data available for the period prior to February 2011 and therefore it is difficult to define historical talus slopes. However, the photograph shows a talus slope is present behind the school hall. The estimated pre September 2010 slope of the cliffs behind the school based on Google Earth Pro is approximately 65° to 70° with the talus slope being approximately 35 to 40°. Figure 3-1 shows a generalised cross section of the cliffs behind the hall.

Prior to the earthquake occurring on 4th September 2010 and subsequent aftershocks, there was evidence for cliff instability behind Redcliffs School. Large boulders (estimated to be up to 1 m^3) were present at the base of the cliff where a scree slope had developed. Rockfalls are prone to occur on steep cliffs as the bulk rock mass properties may have been weakened by weathering or quarrying activities.

Prior to the 2010-11 earthquake inspection school was protected by a mesh fence located on the southern school boundary approximately 2 m to the south of the school hall, at the boundary between the scree slope and Redcliffs School. The Department of Conservation (DoC) erected the fence, which is approximately 2 metres high with an aperture size of approximately 50 mm (wire mesh) (Photo 3-2). We understand that no formal design of the fence was undertaken but that it performed adequately with no known instances of rocks entering the school grounds prior to the September 2010 seismic event.

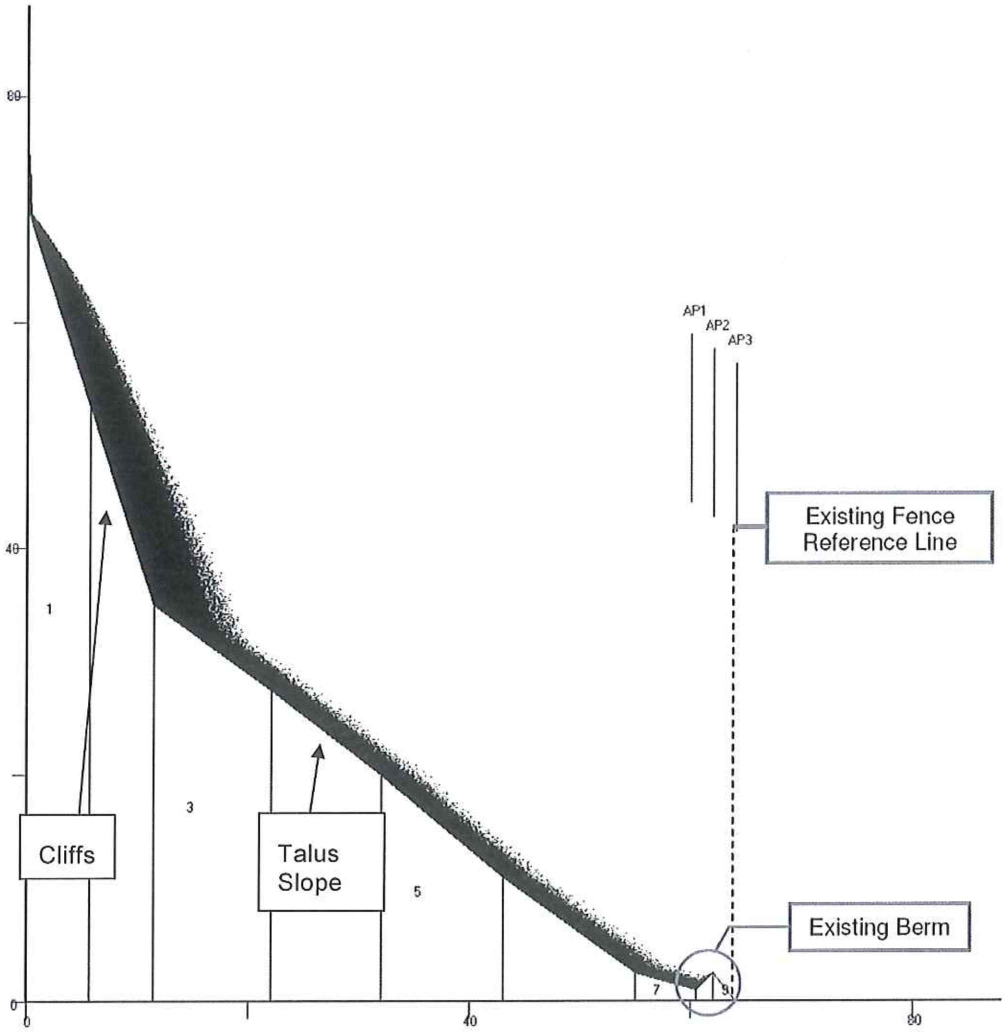


Figure 3-1 : Generalised Cross Section of the Cliffs (Pre February 2011).

3.4 September 2010

Following the seismic events on 4th September, a number of rock fragments fell from the cliffs and a small number struck the school hall, which is the nearest building to the cliffs. The exact sizes of boulders behind the talus slope are unknown as the areas could not be accessed and inspected due to safety reasons; however the boulders are estimated to be up to 1m^3 based on photographs (Photo 3-2). A number of potentially unstable blocks of rock were identified on the cliff face and were removed by a combination of monsoon buckets and physical prying.

A confinement rock bund was constructed at the base of the scree slope (under the direction of Geotech Consulting Limited) creating a catch area between the cliff base and the bund. The bund is approximately 2.5 metres high and formed from large boulders from the toe of the talus slope. The bund is situated behind the school hall to offer further protection to the buildings and potential occupants. The works were completed under the supervision of Geotech Consulting Ltd. MWH observed the works on behalf of the MoE.

3.5 February 2011

The earthquake on 22nd February generated much more intense shaking in Redcliffs than the event on 4th September and resulted in further rockfall from the cliffs. Although the previously installed protection works contained most of the rockfall, a number of rock fragments, cobbles and small boulders struck the school hall and rolled onto the playing fields. Rock fragments were found as far away as classroom 15 and 16, approximately 45.5 metres from the fence, following the 22nd February event. The resulting talus slope extending almost half way up the slope is illustrated in Photo 3-3.

During this event approximately 0. 5m blocks broke through a gate located within the fence line and travelled up to 13 m onto the school playground. There were several points along the fence line where impact marks in the fence show that it successfully protected the school playground from the sizes of material which penetrated the gate. A quantitative assessment of the rock material located on the school ground is contained in the MWH (March 2011) report and is not described in further detail here.

Despite loose material falling from the cliff face, little of the sheer part of the face fell. This observation is based on satellite imagery before and 2 days after the earthquake, measurements taken from buildings to the edge of the cliff top, and GNS monitoring the cliff face to pick up cliff instability. A preliminary change model computed between scans observed on 2 March and 6 March indicated there did not appear to be any significant movement between these dates. This period covered the magnitude 4.8 aftershock on Saturday 5th March 2011.

A walkover inspection of the top of the cliff was undertaken to inspect for the presence of tension cracks propagating back from the slope that may indicate cliff instability. A number of tension cracks were identified but these were confirmed from test pitting carried out by Geotech Consulting Ltd, to be located locally within the loess cover and typically less than 2 metres deep. No obvious large scale tension cracks were observed however we understand (pers. Com, Nick Traylen, Geotech Consulting Ltd) that tension cracks within 5 metres of the crest of the cliff and in its face were observed upon more detailed inspection of the cliff face and subsequent abseil access. However, these cracks were discontinuous in extent and were indicative of the outer skin of the rockface coming apart. In peer review with Geotech Consulting Ltd, it was considered that there was no evidence of major global stability issues, just localised cliff face problems. However the likelihood for ongoing blocks to fall from the slope exists.

The perceived level of risk that the cliffs pose to the school increased following the 22nd February event, principally due to the infilling of the storage area behind the previously installed bund making it more likely that boulders could jump the existing fence. More substantial protection works were required before the school could re-open. MWH undertook investigations during February 2011 to determine mitigation works required to protect the school to an acceptable standard before re-opening. A rapid visual inspection was undertaken of the existing bund to estimate slope angles and the extent of infilling behind the existing bund in order to create a cross section of the infilled bund; scree; boulder field and cliff face for use in rock fall hazard modelling. The results of rockfall modelling undertaken following the 22nd February earthquake are discussed in Section 4.1.

Temporary mitigation measures recommended following rockfall modelling and presently in place include (the works put in place can be seen on photo 3-4 and classroom numbering is shown on drawing C001 in Appendix A):

- disuse of the school hall,
- relocation of the classrooms (17, 18 and 19) closest to the cliff,
- the use of shipping containers located 30 m from the existing fence to provide a second barrier to boulders should they bounce over the protection fence and bund,
- a 4 m high mesh fence to provide additional protection from flying rock fragments, and
- part the western playing fields kept out of use to provide a buffer against any rockfall hazards from the more distant cliffs to the west of the school.

Justification for these temporary works are presented in the MWH (March 2011) report.

3.6 June 2011

3.6.1 Redcliffs School

The seismic events of 13th June generated further ground shaking and rockfalls behind Redcliffs School. A visual assessment of the cliff face and review of photographs suggests that the majority of loose material had fallen during the 22nd February event and the cliff profile was not significantly altered following the 13th June event. There is more debris accumulated on the talus slope (refer to the relative level of the talus slope against the 'red' marker horizon in Photos 3-3 and 3-4) but the source area for this material is likely to be boulders on the cliff face itself that were loosened by ground shaking, rather than large scale failures at the cliff edge/top. The block failures appear to be controlled by tension cracking of the softer tuff material and joints associated with the basalt.

GNS undertook terrestrial laser scans of the cliffs behind Redcliffs School on 2, 3 and 6 March 2011, 3 May 2011 and 14 June 2011 (refer Appendix B). The 3D images from the scanning provide an indication of the loss or gain of material from the cliffs between the scan dates. Figure 3-2 is the comparison of scans undertaken on 2 March and 15 June 2011 and shows the volume change between the February and June seismic events. The differences are represented on a colour gradient where blue shows no change and red indicates 3m or more difference. Figure 3-2 shows the majority of the cliff face remains similar between the February and June seismic events, shown by the dark blue colouring. The greatest change in rock volume of the cliffs has occurred in the area above the school hall shown by red colouring.

A site walkover assessment confirmed that the rockfall mitigation measures put forward and adopted following the 22nd February event performed well during the June aftershocks. The pre-February protection works, consisting of a catch fence and bund, contained almost all of the rockfall from the June 2011 event. Whilst some rock fragments passed the pre-February protection works they did not reach the post-February works. Visual observations showed that no boulders reached the container line and no rock fragments reached the fly rock fence.

The behaviour that was experienced in June 2011 is not necessarily the behaviour that would occur in a future event due to on-going degradation of the rock mass.