

Seismically induced land damage on Whitewash Head, Christchurch, New Zealand

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ABSTRACT

On 14 February 2016 a M5.7 earthquake, now commonly referred to as the Valentine's Day Earthquake, struck off the coast of Christchurch city causing land damage in the Port Hills. This earthquake follows almost five years after the M6.3 earthquake that struck the city on 22 February 2011 that caused extensive cliff retreat and ground cracking near the cliff edges. Another significant earthquake with a magnitude of 6.3 struck the same year on 13 June. This caused the cliffs at Whitewash Head in the east of the Port Hills to retreat along already mapped tension cracks and created new cracks up to 10m from the cliff edge. Currently, the structures on 'red-zoned' properties on Whitewash Head are being demolished as part of the land clearance works undertaken by Land Information New Zealand. The demolitions are in geotechnically high risk areas and strict monitoring controls are in place. The recent Feb 14 earthquake was the largest since monitoring was installed, thus enabling the engineering geologists to observe how these monitoring systems performed during a significant seismic event. This paper presents the response of the monitoring networks and aerial photograph review following the 2016 Valentine's Day earthquake; discusses possible failure modes and implications of further land deformation in the Port Hills and concludes by providing options for management of future land clearance sites affected by geotechnical hazards.

Keywords: Cliff collapse, Christchurch, Earthquake, Valentine's Day Earthquake, GNS

1 INTRODUCTION

On 14 February 2016 a Magnitude (M) 5.7 earthquake struck 2km off the coast of Christchurch city, New Zealand, approximately 8km deep, causing further land damage in the Port Hills. Cliff collapse was observed at Whitewash Head, Godley Head, Wakefield Avenue and Shag Rock Reserve, (Figure 1). These are areas of present-day or former sea-cliffs (Massey, et al., 2012) with the exception of Wakefield Ave which is an old quarry site. With exception of Godley Head, all areas are currently part of clearance and remedial works undertaken by Land Information New Zealand (LINZ) on 'red-zoned' land. The focus of this paper will be based on two properties at Whitewash Head, where the largest volume of cliff collapse debris fell, herein referred to as 'Property A' and Property B' (Figure 2).

Cliff collapse is referred herein as "rock fall failure characterised by large volumes of debris (thousands of cubic metres). The hazards associated with these cliff collapses included incipient cracking, often with differential vertical displacement and minor extension behind the top of the failed cliff faces, as well as a debris inundation hazard at the base of the cliff face" (Dellow et al. 2011).

On some areas of Whitewash Head there is an immediate risk to life based on modelling by the Institute of Geological and Nuclear Sciences (GNS) (Massey, et al., 2012). The Crown purchased the land and all the buildings and fixtures. 'Red-zoned' means the property is in an area where there is an unacceptable risk to life safety from geotechnical hazards. Demolition of the structures on a 'red-zoned' property begin once it is vacated, settlements are finalised and insurance assessments are complete (New Zealand Government, 2015, 2016a, 2016b). At Whitewash Head, properties A and B were part way through the long process of being demolished when the Valentine's Day Earthquake struck. Fortunately, the event occurred on a Sunday when no site works were being undertaken by the Contractor.

Due to the large amount of land damage caused by the 2010-2011 Christchurch Earthquake Sequence, over five years ago, a monitoring network was installed around 'red-zoned' areas in the Port Hills. Part of this network uses basic techniques that can be accessed on short notice and provide instant results for the Consultant. Tell-tales (point to point measurements that indicate movement)

were installed in areas where cracking in the soil, pavement and structures had occurred and created offsets. These were installed and monitored on a daily basis during the demolition process on Whitewash Head.



Figure 1. Areas where cliff collapse caused by the Valentine's Day Earthquake (GoogleEarth 2016)

2 RESPONSE

2.1 Monitoring Networks

In the days following the earthquake, monitoring controls and detailed field mapping of observed cracking were undertaken by engineering geologists from Aurecon and the Institute GNS. The data collected from Whitewash Head showed movement on existing and additional cracking ranging from 1mm to >150mm horizontally and up to 25mm vertical displacements in the soil, pavement and foundations of Property A and B. Nestled behind the structure on Property B is a 10m high shotcrete wall that is severely cracked.

A Digital Laser Rangefinder provides a relatively fast and reliable way of measuring distance to an object. Baseline distance tell-tale measurements using the rangefinder were established months before the demolitions began and these were compared to daily measurements taken on site, refer to Figure 2. More tell-tales were installed as the demolitions progressed, exposing more cracks that could be monitored. However, as structures became demolished, the monitoring points often had to be relocated or abandoned the number of monitoring points over time.

Table 1 lists tell-tales measurements four days prior and three days after the Valentine's Day earthquake (VDE). Since the VDE most tell-tales measurements have remained the same post VDE, however one particular measurement showed a significant change (point 'WWH_M'). This particular tell-tale was set up to measure over a >100mm crack in a stone and concrete patio on Property A (Figure 2). This crack runs sub-parallel to the cliff face and is the closest tell-tale to the cliff edge while just outside of the second cliff collapse event line, see Figure 2.

Measurements from another Tell-tale 'WWH_W', positioned to measure between the concrete block retaining wall and ring foundation on Property A. It too indicated some movement with a 4mm increase in the baseline measurement. This movement vector aligns with the tilted pile in Figure 5(a).

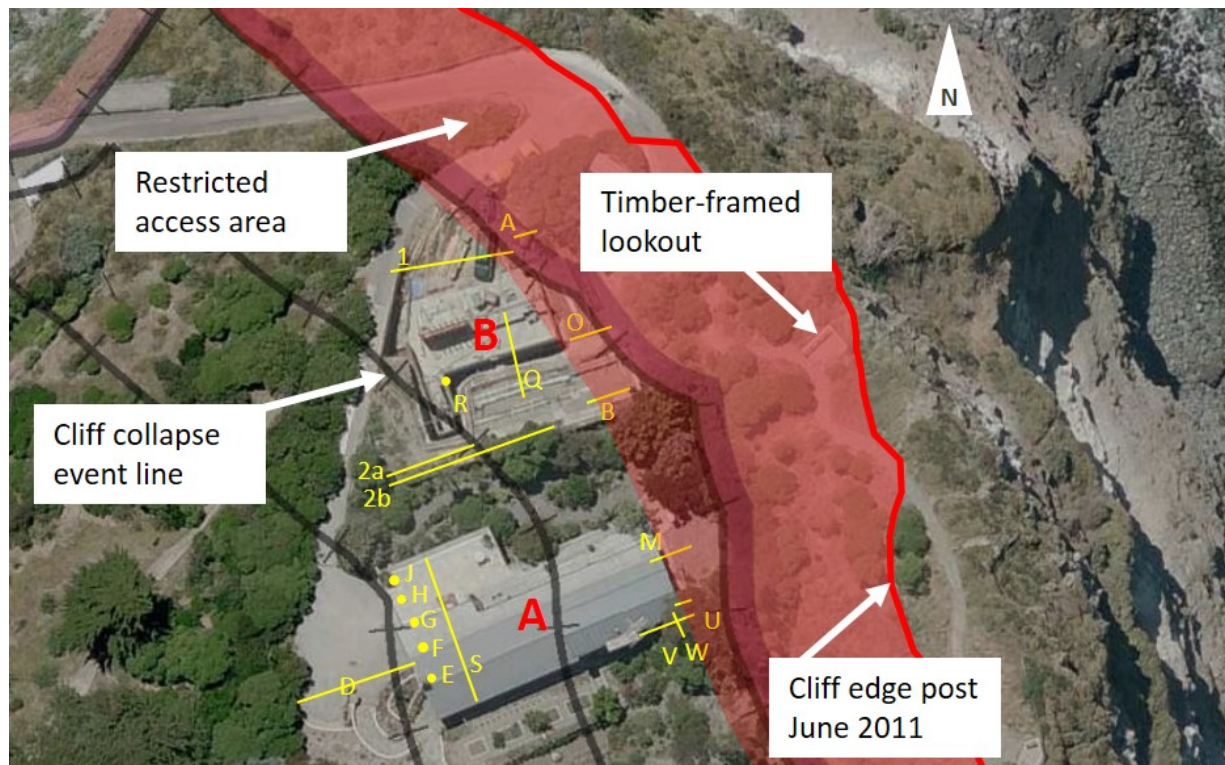


Figure 2. Tell-tale locations at Property A and B. Tell-tales are shown in yellow. The dots are vertical measurements and the lines are horizontal measurements. The 'cliff collapse event line' is defined as the point which the cliff may retreat up to in a significant seismic event. (Aurecon GIS base imagery 2009/2010).

Table 1. Tell-tale measurements (mm) taken before and after the Valentine's Day aftershock.

| Location ID | Baseline Readings (mm) | 04/02/2016 | | 09/02/2016 | 10/02/2016 | | 17/02/2016 |
|-------------|------------------------|------------|---------|------------|------------|---------|------------|
| | | 0800hrs | 1200hrs | 1015hrs | 0800hrs | 1530hrs | 1030hrs |
| WWH_A | 1546 | 1546 | 1547 | 1574 | 1546 | 1547 | 1547 |
| WH_1 | 12347 | – | – | 12348 | 12346 | 12348 | 12346 |
| WH_2a | 7802 | 7803 | 7804 | 7803 | 7802 | 7803 | 7803 |
| WH_2b | 16836 | 16835 | 16835 | 16834 | 16834 | 16833 | 16834 |
| WWH_B | 3325 | 3328 | 3328 | 3327 | 3327 | 3329 | 3331 |
| WWH_O | 3784 | 3785 | 3785 | 3785 | 3784 | 3785 | 3785 |
| WWH_D | 12977 | 12974 | – | 12973 | 12973 | 12974 | 12975 |
| WWH_E | 3566 | 3563 | 3565 | 3565 | 3563 | 3566 | 3565 |
| WWH_F | 3569 | 3567 | 3568 | 3568 | 3567 | 3570 | 3568 |
| WWH_G | 3573 | 2570 | 3572 | 3573 | 3570 | 3574 | 3572 |
| WWH_H | 3570 | 3569 | 3569 | 3571 | 3568 | 3571 | 3570 |
| WWH_J | 3574 | 3574 | 3574 | 3574 | 3572 | 3575 | 3574 |
| WH_4 | 3901 | 3902 | 3904 | 3903 | 3900 | 3903 | 3901 |
| WWH_M | 6530 | 6528 | 6528 | 6527 | 6527 | 6527 | 6535 |
| WWH_3a | 4731 | 4733 | 4732 | 4732 | 4732 | 4732 | 4733 |
| WWH_P | 2821 | 2821 | 2822 | 2822 | 2821 | 2820 | 2822 |
| WWH_Q | 8580 | 8580 | 8581 | 8582 | 8580 | 8582 | 8583 |
| WWH_R | 3349 | 3349 | 3350 | 3349 | 3348 | 3345 | 3349 |
| WWH_S | 9014 | 9013 | 9014 | 9014 | 9013 | 9014 | 9014 |
| WWH_U | 6363 | 6363 | 6362 | 6363 | 6362 | 6363 | 6361 |
| WWH_V | 1923 | 1924 | 1922 | 1925 | 1922 | 1922 | 1926 |
| WWH_W | 4444 | 4445 | 4445 | 4446 | 4446 | 4446 | 4449 |
| WWH_X | 7815 | – | – | 7815 | 7815 | 7815 | 7815 |
| WWH_Y | 7011 | 7010 | 7011 | 7011 | 7010 | 7010 | 7011 |
| WWH_Z | 2706 | 2707 | 2707 | 2708 | 2707 | 2707 | 2707 |

2.2 Photo Review

Hours after the 14 February 2016 earthquake, members of the LINZ Rapid Response Team comprising of geotechnical experts from Aurecon, and the demolition contractor surveyed the cliffs at Whitewash Head from a helicopter refer to Figure 3(a) and (b). Following this, further inspections were conducted using an unmanned aerial vehicle (UAV). The use of the UAV meant additional aerial reconnaissance could take place on multiple days at a fraction of the cost and allow a closer look at the cliff. The Gimbal-stabilised camera allowed high resolution photos to be taken in close proximity to assess land damage where parts of the cliff had cracked or collapsed while keeping personal out of high geotechnical risk areas.

Figures 3(a) and (b), taken before and after the 14 February 2016 aftershock, show how the cliff face below Property A and B has further retreated. The majority of material has fallen from the upper third of the cliff and it has accumulated down the bottom, see Figure 4. This same area of the cliff retreated in the February and June 2011 events.

A UAV was flown on the 17 and 18 February 2016 to assess the land damage in an area where, as described by Kupec (2016) “4 to 8m of cliff was lost (during the VDE), with cracking occurring in Property A and in the reinforced foundations of Property B. Although the cracking appears to be about 25m from the current cliff edge we need to consider that in February 2011 about 15 to 20m fell off and in June 2011 about 25m of cliff edge retreated (at different areas along the cliff). Hence the cracking does provide a credible scenario for upcoming cliff edge retreat.” One landmark, a timber-framed viewing platform perched on an overhanging section of the cliff, was lost over the edge. During the earthquake a pair of surfers were floating in the water below Whitewash Head, they observed boulders as large as cars falling into the sea from the cliff and a large dust cloud was seen from as far away as New Brighton, over 2km away.



Figure 3(a). 65 – 85 m high sea cliff below Property A and B Whitewash Head, Scarborough. Note: timber framed lookout (24/09/2016 Aurecon).



Figure 3(b). 65 – 85 m high sea cliff below A and B Whitewash Head, Scarborough. Note: missing timber-framed lookout, vegetation, and visible crack sub-parallel to cliff face (14/06/2016 Aurecon).

Further inspection with a UAV showed large (>1m³) size rocks precariously perched on the cliff with daylight showing between them and the cliff, see Figure 3(b). This means there is the potential for more boulders to fall and the cliff to retreat in future seismic event. However, it is possible that “fretting

and crack width could increase under normal climatic conditions and be exacerbated by prolonged precipitation” (Kupec 2016).



Figure 4. Talus at the base of approx. 100 m high sea cliff and sediment in the sea below Searidge Lane, Scarborough (14/02/16 Aurecon).

Observations made by Engineering Geologists during a site walkover four days after the event revealed a tilted concrete pile on Property A, refer to Figure 5(a), although this may have already been tilted in an event prior to the VDE as it was in an area recently exposed by the Contractor. However, this pile does indicate movement on the site. It appears there has been vertical displacement and horizontal movement towards the cliff edge. This hypothesis is supported by evidence from the aerial photo showing a series of cracks in structures on Property A that run sub-parallel to the cliff, see Figure 5(b).



Figure 5(a). Tilted $>10^\circ$ concrete pile (P) on Property A (18/02/2016 Aurecon).

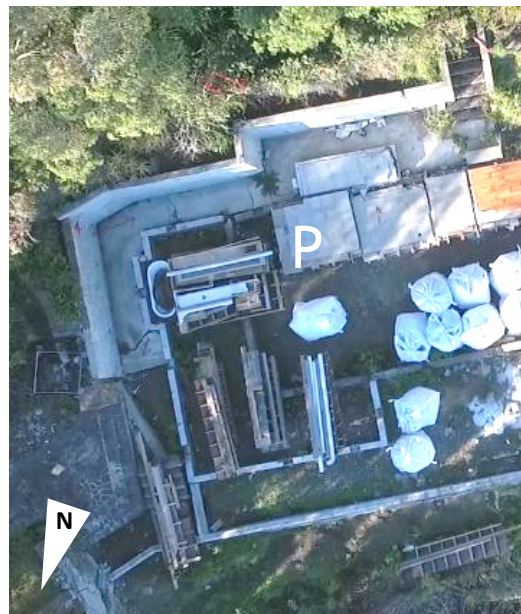


Figure 5(b). Cracked and displaced reinforced concrete ring foundations and retaining walls on Property A (18/02/2016 Aurecon).

2.3 Possible failure modes and implications for further land damage

It has become apparent in each M5+ earthquake centred near the Port Hills of Christchurch that some land damage is expected to occur along the already damaged sea cliffs at Whitewash Head. In the

February 2011 earthquake approximately 42,000m³ of material fell from the slope and over 150,000m³ in June 2011 (Massey et al. 2012). The level of shaking from the VDE caused new cracks to appear in the cliff face, released large volumes of rock and soil and has created new rock blocks that are susceptible to failure in future earthquakes.

It appears that each event is causing either further cracking and weakening of the rock with some retreat of the cliff as seen in February 2011, or a significant retreat of the cliff edge as seen in June 2011. Following this trend, a large volume of material could fall from the slope in the next M5+ earthquake.

2.4 Options for management of future land clearance sites affected by geotechnical hazards

The risk management of the long term effects of these events has already lead to the 'red-zoning' of properties in these geotechnically high risk areas. The cliff-collapse that occurred on Whitewash Head on February 2011, June 2011 and February 2016 demonstrated the necessity for these mitigation measures.

Further destabilization of the cliff caused by the VDE has led to the necessity for the demolition methodology for these two structures to be changed. Based on the deformation observed by members of Aurecon and GNS, amendments include an already restricted access area near the cliff edge, see Figure 2, to be brought further back and the requirement for a larger specialized remote controlled excavator with greater reach that can bring down the structures from a greater distance than required before the VDE. Current monitoring techniques have proven to be effective at documenting movement on Whitewash Head and can continue to be utilised in the new methodology.

3 CONCLUSION

On 14 February 2016 a M5.7 earthquake struck 2km off the coast of Christchurch city approximately 8km deep, causing further land damage in the Port Hills. The damaged areas included already 'red-zoned' properties causing cracking and collapse of sea cliffs. This has resulted in a further destabilized slope where failures can occur under normal climatic conditions. Luckily, there were no fatalities from this event. Engineering geologists from Aurecon and GNS observed movement on Whitewash Head demolition sites using monitoring techniques installed prior to the aftershock. A Digital Laser Rangefinder provided measurements of tell-tales placed over known cracks that recorded movement towards the cliff edge with mm accuracy. This is also evident in the concrete piles that have been tilted, indicating vertical displacement and horizontal movement in the same direction. A UAV proved to be an effective tool for aerial reconnaissance of the sites that showed cracks sub-parallel to the cliff and in the cliff face, and retreat of the cliff edge shown with the loss of landmark structures. These techniques when used together were effective tools for displaying seismically induced land damage on Whitewash Head.

4 ACKNOWLEDGEMENTS

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