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Responses to three 2017 landslide events affecting road networks in the lower North Island of New Zealand

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ABSTRACT

Case histories are provided for the response to three landslide events that significantly disrupted main road networks during 2017 in the lower North Island. A large rock fall event on 11 July 2017 blocked traffic into Wellington on State Highway 1 (SH1) in Ngauranga Gorge, followed two weeks later by a larger rockslide event on Ngaio Gorge Road, a main arterial road into Wellington CBD. In the Manawatu Gorge, displacement of the slope above the road (SH3) including a retaining wall (Kerry's Wall) was of particular concern to the Waka Kotahi NZ Transport Agency from early 2017. In April 2017 two landslides in the gorge closed the road, and SH3 has remained closed due to repeat landslide events and risk of a large-scale slope failure at the Kerry's Wall site. The paper describes the three slope failures and the various stages of the responses to the three landslides. The use of drones and other innovative survey techniques assisted the risk assessments and enabled a better understanding of the slope conditions and performance to help manage safety for workers and road users. Lessons learnt will be discussed, which it is hoped may assist response to future such events.

1 INTRODUCTION

A period of frequent landslide events in 2017 highlighted the vulnerability of key road networks in the lower North Island. In the Wellington area, two rock fall events in July 2017 blocked main road routes to the Central Business District (CBD). Further north, deformation of a retaining wall (Kerry's Wall) and adjacent slope in the Manawatu Gorge had been a concern to Waka Kotahi NZ Transport Agency (NZTA) from early 2017. At the time this was being assessed, two landslide slips in the Manawatu Gorge closed the road in April 2017. Due to its history of slope failures, the ongoing slope failures issues and risk of a large-scale catastrophic slope failure at the Kerry's Wall site, SH3 has remained closed. The gorge route is to be abandoned, with a replacement route, bypassing the gorge, currently being designed.

This paper describes responses to the two significant landslide events in Wellington and assessment of the ongoing slope deformation at the Manawatu Gorge site. Observations from the three events and lessons learnt are provided, which it is hoped will assist management of risks for future such events. These include the value of recent survey technologies such as laser surveying, sensors and drones and greater availability of data to assist in risk assessment of vulnerable slopes. The locations of the sites are shown in Figure 1.

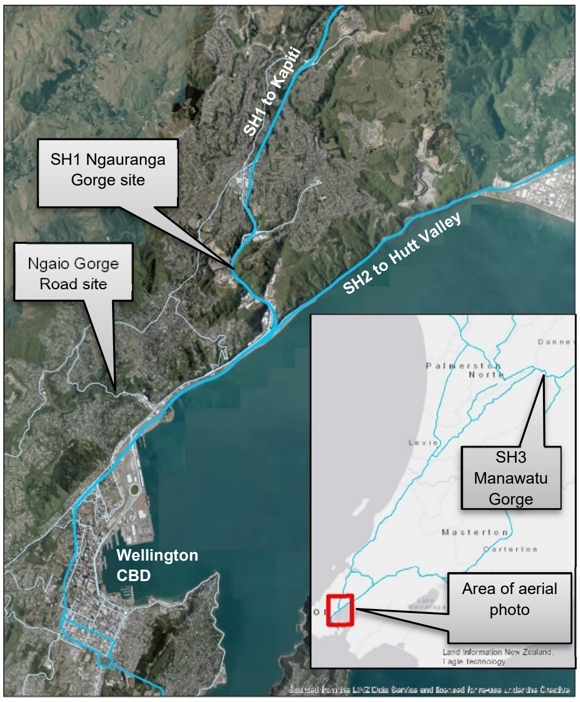

Figure 1: Main road networks showing location of landslide sites

2 SH1 NGAURANGA GORGE ROCKFALL

The route for State Highway 1 (SH1) out of Wellington passes through Ngauranga Gorge (Figure 1). This highway is on a steep grade, with three lanes of traffic each way below steep rock cuttings up to 50 m high. Rockfalls and slips are relatively infrequent, however they can be very disruptive when they do occur, due to the high traffic volumes affected (80,000 vehicles per day). On 11 July 2017, a rockfall event occurred just after 12 noon affecting the downhill lanes of Wellington bound traffic (Figure 2). The event occurred in relatively fine weather. The debris landing on the road fortunately did not cause a serious accident, presumably as smaller precursor events gave warning for cars to slow and then stop before the bulk of the debris fell.

The event was recorded on a number of car dashcams with video shown on news feeds; refer hyperlink in the References at the end of this paper (Stuff 2017a). A Principal Geotechnical Engineer from Opus (now WSP) was mobilised to site to assist the highway network contractor (Capital Journeys) and NZTA to manage the remedial actions to get the highway open again. The initial concern was whether further loose rock blocks were about to fall from overhanging sections of greywacke bedrock in the source area, delaying the clear-up operations.

In order to address the residual risks of further falling blocks, a number of approaches were considered and attempted with varying success. The first approach involved mobilising a fire engine and sluicing the upper face with a high-pressure hose (Figure 3). However, the water pressure was insufficient to reach the source area due to its height and high winds. A platform of debris was then constructed to attempt to reach the source area with a very long reach excavator. The reach of the excavator also proved to be inadequate. The approach that provided greatest success was using a helicopter with monsoon bucket to sluice loose material from the upper face. Following clearing of large amounts of debris off the face in this way, the slope was inspected by experienced abseil based staff, removing remaining loose rocks by hand (scaling).

Figure 2: Debris from the 11 July 2017 Ngauranga Gorge rockfall crossed all three southbound lanes with some blocks hopping the central barrier. Full road closure in place at time of photo (taken at 1.20pm).

Figure 3: Sluicing of loose debris from the face was initially attempted using a fire hose, followed by helicopter with monsoon bucket. A check of the face was then carried out using abseil staff. Photo taken at 3.45pm on 11 July 2017

In order to open two south bound lanes, a bed of gravel was placed on the outer lane to cushion the energy of any falling rocks, with a concrete barrier placed between this and the traffic lanes. To open all south bound lanes, removal of some loose rock overhangs were undertaken by the abseil crew by hand scaling (and the use of low energy explosives), and a layer of steel mesh was draped across the slope to control any residual blocks that may become loosened and fall. The mesh was hung from steel cables attached to steel anchors drilled and grouted into a bench immediately above the site (Figure 4). The equipment was mobilised to the upper bench site using a helicopter.

The aftermath of the event was also independently observed by GNS Science natural hazards staff, who carried out a 3D laser scan of the slope. They subsequently compared this with previous Council LiDAR (Light Detecting and Ranging) topographic data which showed about 130m^3 of material had evacuated the slope in a 'rock avalanche' style event. Opus was able to utilise the laser scan data to quickly establish the height to the source area (30m above road level), which accelerated the preliminary remedial design process. In addition, a drone was used by Opus to inspect the slope and assist with remedial works observations (Figures 4 and 5) and develop a 3D model of the slope geometry following debris clearance.

Figure 4: The solution to enable full reopening of the highway involved drilling of ground anchors at the upper bench with draped mesh placed over the exposed slip face and slope below.

Figure 5: Abseilers completing draped mesh installation at SH1 Ngauranga Gorge rockfall site. 20 July 2017 Opus Drone image

3 NGAIO GORGE ROAD ROCK SLIDE

On 29 July 2017 a number of small to moderate sized slips occurred following a moderately heavy rain event, at a location midway up Ngaio Gorge Road in Wellington (Figures 1 and 7). This road is a key arterial road carrying more than 10,000 vehicles per day from the northern suburbs to the CBD. Wellington City Council immediately responded to manage the risk to the users of Ngaio Gorge Road by closing the road, due to the risk of further debris falling. Council also made an immediate decision to engage the expertise of an Opus senior engineering geologist and geotechnical engineers to assess the slope stability and mitigation options.

GNS geologists also attended the site on the 29th (and 30th) July and carried out a ground inspection of the slope, drone inspections and laser scanning of the slip area. These suggested the possibility of a larger failure developing (Figure 6). Opus geotechnical staff arrived early on the morning of 30th July, to discover that a much larger failure had indeed occurred. Comparison by GNS of a laser scan with Council LiDAR data indicated a landslide volume of about 1,300 m^3. A bedrock failure of this size is a relatively rare event in the Wellington region, being controlled by moderately steep persistent rock defects (joints/shears). The failure had occurred in a greywacke slope cut in the 1970's for a corner easing realignment (Figure 7). In addition to risk to the road, a Transpower pylon is located at the top of the slope immediately above the landslide (Figure 7).

Remedial works initially involved removal of the over-steepened, loose scarps at the top of the landslide using large excavators (Figure 8), operated by highly experienced operators with extensive quarry experience. The risk to the excavators was further managed by installation of survey targets by abseillers around the perimeter of the landslide headscarp which were then monitored by surveyors in real-time to check for adverse movements. Locations for targets were chosen by an engineering geologist who was highly experienced in rock slope assessments. Accelerating movement was detected on one target during earthworks, which provided warning to allow an excavator high on the slope to safely move away prior to an approximately 150 m^3 rockfall event (Figure 8). Helicopter sluicing was using to remove loose debris that was out of reach of the excavator.

Once all debris was removed, a shipping container wall was installed on the downhill lane to contain any future rockfalls at the site (Figure 9). Two weeks after reopening the road to two lanes, a 200m^3 rockfall event from the head of the landslide was halted by the shipping containers (Figures 10 and 11), with no effect on traffic. To allow construction and public traffic to bypass the site, the fortuitous position of the old road alignment (Figures 6 and 7) was reinstated as a single lane road.

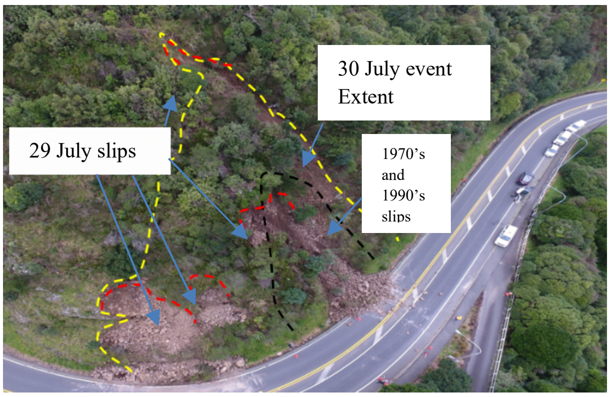

Figure 6: Drone image from 29 July 2017 after the initial slips on Ngaio Gorge Road, with the extent of the 30 July landslide indicated. Photographic evidence of previous bedrock landslides of smaller size at this site in the 1970's and 1990's indicates a

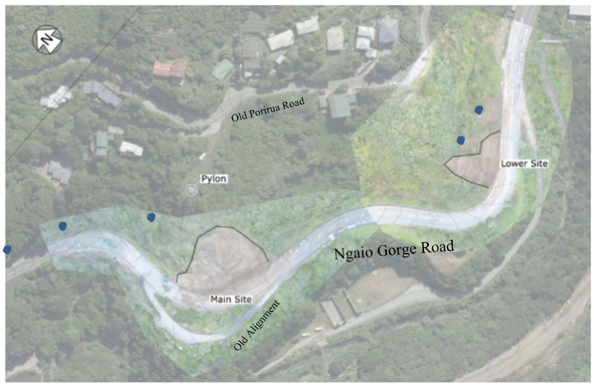

Figure 7: Location plan of the slips occurring in July 2017 along Ngaio Gorge Road, including the two main rockfall sites and a number of smaller slips (blue dots). The map is built up from drone derived imagery taken in late 2017 after site clean-up, superimposed over older Council aerials.

precedent for reasonable size bedrock failures here (albeit not of the size that occurred in 2017). GNS image.

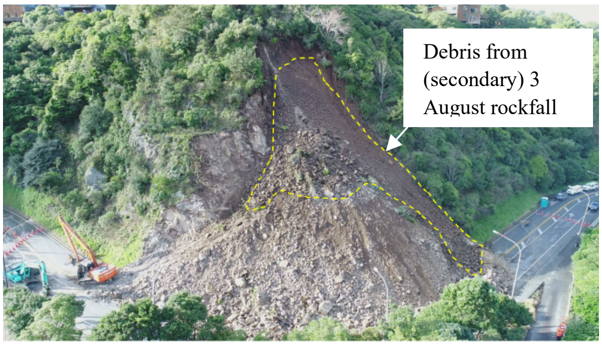

Figure 8: Ngaio Gorge rock slide site nearing end of earthworks to trim the over-steepened upper scarps remaining after the main failure. Drone photo taken on 3 August immediately following a 150 m3 rockslide event, which was mitigated by real-time survey monitoring.

Figure 9: Site after slope trimming, debris removal, and container wall installation. Opus drone image 15 August 2017 just prior to reopening of two lanes of traffic

In addition to the main landslide, a number of other smaller nearby slip events occurred through late 2017 (Figure 7) which underlined the continuing safety and resilience risks of the cut slopes at the wider site area. On 18 August 2017 two rock blocks fell from steep slopes at the lower site, 150 m down the road from the main site (Figures 7 and 13). This resulted in a ‘near miss’, captured on dashcams from two cars, with videos supplied to news websites. For the hyperlink for the Ngaio dashcam videos refer Stuff (2017b) in the References.

While the main landslide site is protected by containers, the other sites were not well protected, hence a detailed assessment of other slip sites was carried out by experienced abseil contractors and geotechnical staff. Abseil based inspections and loose rock removal occurred at these sites during planned three day road closures in late September 2017 and again in February 2018.

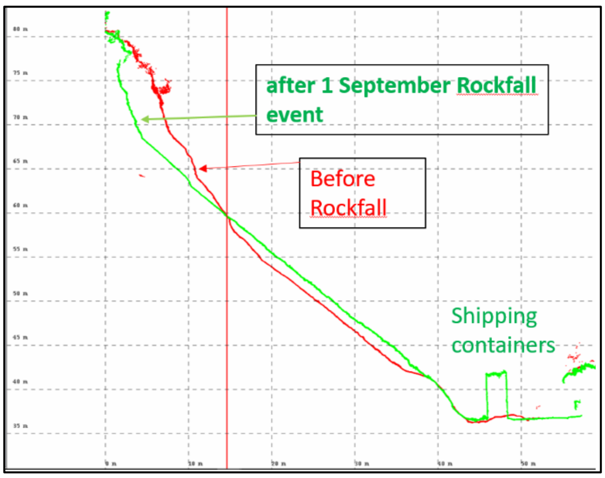

Figure 11: Comparison of slope profiles from 3D

Figure 10: Anchored shipping containers installed in mid August 2017 allowed re-opening of two lanes of traffic; these stopped debris from the 1 Sept 2017 (200 m3) rockfall

models developed from drone imagery before and after the 200m3 rockfall event on 1 September 2017

Figure 12: Abseillers installed GPS sensors (left) around the two main slip sites in a trial to allow future movement trends to be picked up much more quickly than from conventional surveying

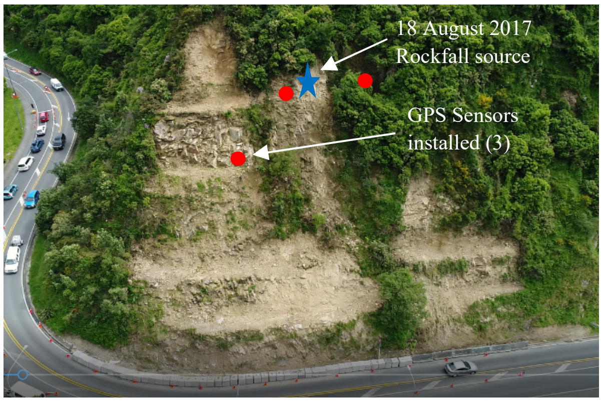

Figure 13: Lower Ngaio Gorge Slip site following late August 2017 slope remedial works.

Drones were used on a regular basis to document the site conditions and provide imagery for Council to post on their website or to news media (Figure 8). In addition to images, 3D terrain models were generated to assist engineering and risk assessments (Figure 11).
The long-term risks were deemed as significant for this key route, and Wellington City Council secured funding for the long-term remedial works, involving one or more of - slope cutbacks, mesh and rock anchoring, or large rockfall catch structures. For the period of WSP involvement until early 2019, short term risks were being managed by further abseil inspections / loose rock removal and slope deformation monitoring, and periodic drone inspections. The survey monitoring of the two main sites, comprised electronic distance measurement (EDM) survey of reflective targets and a 12-month trial of a network of 11 GPS slope monitoring sensors (Figures 9, 12 and 13). The GPS trial carried out in conjunction with Viclink (Victoria University), tested GPS data coverage from both solar and battery powered sensors and at a number of different site 'types', and provided frequent (daily) data on the position of the sensors. Whilst some variation in data quantity and quality was obtained indicating limitations of the technology as installed, it did enable identification of some slope movement trends, in particular increased movement rates in sensors in one area during the winter of 2018 (which were confirmed by EDM check surveys).

4 KERRY'S WALL, SH3 MANAWATU GORGE

Kerry's Wall is a 10m high gabion faced wall (Figure 14), constructed in 1998 to buttress part of the slope immediately above SH3 after a number of moderate to large sized landslide events at this location in the 1990s. Following a period of relative stability, deformation of the wall was noted in 2012. Subsequent deformation monitoring of the wall and slope above by Beca (part of the NOC team with contractor Higgins) in February 2017 identified a significant displacement over a period which included the November 2016 Kaikoura Earthquake. NZTA's Structures Consultant for the area, Opus (now WSP), then carried out an assessment of the wall deformation in order to assess remedial options for the wall. A key part of the puzzle involved locating 1990's reports and wall construction information, which fortunately was able to be sourced through NZTA and long-time Higgins and consultant staff involved in the construction. This enabled corroboration, between 1990's documents, construction photos and staff involved, to determine the "as-built" state of the wall and slope. The second part of the puzzle involved trying to determine the extent and mechanism of movement at the wall and surrounding slope. NZTA had procured LiDAR through the gorge after the very large 2011 Manawatu Gorge landslide event (described by Hancox and Robson, 2015), which was assessed by GNS to determine landslide features in the gorge, including the slope above Kerry's Wall.

On 24 April 2017 two almost simultaneous moderate to large landslide events about 2km apart occurred in the gorge, during a relatively dry period. One of the events occurred immediately adjacent to Kerry's Wall with debris falling onto the shelf on top of the wall. The characteristics of this failure in colluvium soils appeared to be unrelated to the movement of Kerry's Wall which was believed to be related to movement in the greywacke bedrock (Figures 14 and 15). Ongoing monitoring by Beca through to May 2017 indicated sporadic movement trends of the wall and rock face above, followed by accelerating movement to early July. During this period, enlargement of the colluvium slip also occurred with two further moderate to large slips occurring in May and June 2017, engulfing a rebuilt rockfall attenuator fence and the road itself adjacent to Kerry's Wall (Figure 15).
Attempts were made to assess the movement trends and extent of movement in the wall and surrounding slopes by comparison of survey models from multiple drone flights and the 2011 LiDAR and LiDAR procured by Higgins/NZTA in February 2017. These proved inconclusive (in large part due to the highly vegetated nature of the slope above but also challenges when comparing data utilising different survey datums) and the best data continued to be from periodic laser scans of the wall and the upper rock face and EDM surveying of targets on the wall face and rock slope to the east of the wall (Figures 14 and 15).

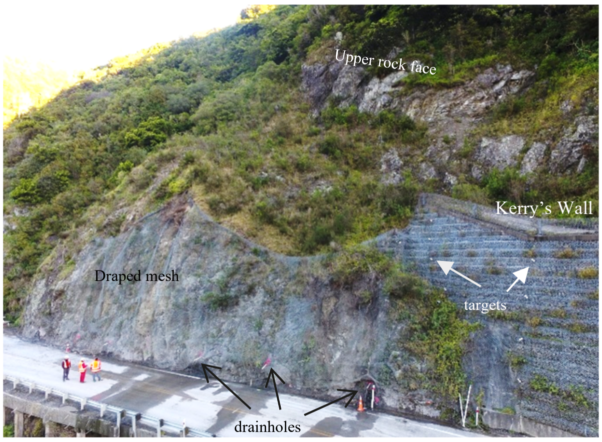

Figure 14: Kerry's Wall at right with survey targets visible on the wall. A laser scanner set up at road level surveyed the wall and upper rock face. Wet patches on the road are from deep drainholes drilled into the lower rock slope in June 2017. Drone photo 29 June 2017.

Figure 15: Location of Kerry's Wall and monitored rock outcrop, with excavation in progress to clear debris from 24 June colluvium slip event immediately to the west of the wall (Drone photo 29 June 2017)

At the time of the NZTA's decision to close the gorge to all staff, when significant accelerating movement trends were identified, a programme of drainhole drilling was underway in an attempt to lower water pressures in the slopes at Kerry's wall (Figure 14). At that stage proposals had been developed to carry out comprehensive slope monitoring and subsurface investigations at the site, to better define the rate and spatial extent of movement. These proposals included remote monitoring techniques such as slope movement scanners and real-time instrumentation. The aim was to gather near real-time data in an attempt to establish patterns of movement, in order to see whether changes in slope movement behaviour could be assessed ahead of potential or actual failures. If confidence in the cause and effect relationship could be achieved then the risk for access to the site could be managed. This would be in staged way: firstly for contractors carrying out investigations, secondly for carrying out remedial works and ultimately for reopening to the public if sufficient confidence in the slope performance could be established. While our data relates to the period up to July 2017, NZTA indicated ongoing issues at Kerry's Wall since then, as well as significant slope

movements reported elsewhere in the gorge. A more detailed account of mechanisms of the failure for the Kerry's Wall area is presented by Punt et al (2019), based on ongoing survey monitoring.
The combined risk from slope failures at the Kerry's Wall site and other slopes in the gorge was deemed sufficiently high that NZTA are not planning to the re-open the gorge to traffic. A preferred alternative Manawatu Gorge route was identified in March 2018 to the north of the gorge, and is currently under investigation and design.

5 OBSERVATIONS AND IMPLICATIONS FOR THE FUTURE

Some observations and common patterns from the three landslide cases are provided below, as well as thoughts on the implication of these for other locations. It is hoped that these may be of assistance for those responding to similar events in the future.

5.1 Contributing Factors / Triggers

While large landslides have occurred periodically in the Manawatu Gorge, the size of the two Wellington failure events in July 2017 is rare in the Wellington region. The influence of the Kaikoura Earthquake in November 2016 followed by a wet period through 2017 are considered contributing factors to these events.
Common factors in the cases are :

- All three failures occurred in aging cut slopes in greywacke bedrock.
- The two Wellington landslides failed on moderately steep outward dipping persistent rock defects.
- All sites had a precedent for similar slope events decades in the past; however only at the Kerrys Wall site was this common knowledge.

5.2 Future Risk Management

- Despite a period of relative quiet since 2018 in central New Zealand, the influence of the current more active seismic environment (since the Christchurch earthquake of 2010) in central New Zealand and more extreme climate events from climate change, is considered likely to increase the scale and frequency of landslide events in the future, resulting in increased challenges for risk managers.
- Increased preparedness will be required to respond in a timely and appropriate manner to events in order to manage the increased impact of landslide events. This requires greater collaboration for key resource availability in terms of staff and plant.
- Proactive identification of sites with higher risk should include assessing sites with deteriorating cut slopes or those with a previous history of failure.
- Focussing on network resiliency will ensure that disruption is minimised. Interventions which enhance resilience are, according to Mason and Brabhaharan (2017), those that minimise the loss of access (availability state) and/or enable quick recovery (outage state) after an event. Response planning is one such intervention.

5.3 Access to Relevant Data

- The importance of prompt access to key data on the condition and history of slopes_and associated structures is highlighted for managing risks in our fragile natural environment. This allows more accurate and timely assessment of the residual risks at the site following a failure event. Access to such data can also facilitate proactive (rather than reactive) screening of slopes to identify high risk sites before events occur.
- Obtaining key data on sites immediately after an event can be a lottery. Hence ideally, access to such information on site history would be available on an online portal/database accessible to relevant geotechnical personnel. This would include as-builts for earthworks and structures, past inspection and failure reports, along with relevant historical photography, and access to aerial photography and survey data e.g. LiDAR data.
- Precedents and/or databases of relevance include the NZ Geotechnical Database (which holds site investigation data), the GNS Landslide Database and the LINZ database (for survey information) and the

Retrolens database (for historical aerial photographs). Possibly one of these databases could be expanded or a portal developed to allow access to various databases.

5.4 Risk Assessment tools

- Ongoing advances in survey related technology has provided a number of useful tools to provide greater certainty on site conditions and assisting risk assessments. Examples used in the case histories include drones (for inspections and 3D model generation), greater coverage of LiDAR data, enhanced and more available survey techniques such as laser scanners including real-time monitoring capability of instruments, as well as moderately priced remote sensors for detecting real-time or near real-time movement of the ground and structures. Other technologies of relevance for monitoring slope movements include satellite radar (inSAR) and ground based radar.
- GNS Science (being based in Wellington) carried out laser scanning of the two Wellington rockfall sites immediately following the events, as part of their landslide database and science research role. Their scan data was requested and provided to Opus, and this assisted in assessing emergency remedial options in a timely manner.
- The use of drones is much more commonly used by engineering consultants, contractors and some Councils. The use of drones for geotechnical assessment is described in more detail by Stewart and Follas et al (2019). Aerial imagery and 3D model outputs are very effective for communicating site issues to stakeholders, including the public. News media are increasingly using drones and posting imagery of landslides online which can assist assessments.
- The ubiquitous presence of dashcams in vehicles now means there is a good chance that landslide events will be videoed especially in high volume road areas. Such videos provide extremely valuable records of slope failure mechanisms, as well as the impact and resultant behaviour of the public. Video links seem to readily appear in newsfeeds, hence a mechanism to capture these in appropriate databases such as GNS's landslide database would be helpful.
- Technology is becoming increasingly available to be able to monitor hazardous sites remotely_and in some cases in real-time. This opens up the option of improving site availability/access at times of lower assessed risk, based on the knowledge of the relationship between causes / triggers and observed slope behaviour. The trial of GPS sensors at Ngaio Gorge showed the value of this type of technology for monitoring movement trends.
- A good engineering geological model of the site and landslide mechanism is a fundamental input into both the risk assessment and monitoring phases for responses to significant landslides. While the model with be crude initially, development of the model is typically an iterative process as more information is obtained about the geology and behaviour of the slope.

5.5 Access to adequate resources

- Having access to proficient personnel is fundamental for assessing high risk sites following failure. This involves a collaboration between geotechnical and operational staff, the latter who understand the day to day performance of the slopes on the network, including the history of the slope in question.
- Early availability of proficient geotechnical and cut slope earthworks personnel was crucial after the two Wellington rockfall events, in order to develop an appropriate risk management plan in a timely manner. This allowed assessment of the likely failure mechanism, provisional residual risk and mitigation options for the immediate and subsequent stages of the response.
- If the residual risk is deemed unacceptable, options for addressing slope features of possible imminent risk of failure depend on a number of variables such as the access to (and height of) the source area and availability of appropriate plant. At the two Wellington sites, options used (with varying success) included: helicopter monsoon bucket sluicing, long reach excavator, and abseil scaling, with fire hose sluicing also attempted at the Ngauranga site.
- Response planning including knowledge of the availability and capability of specialist resources such as those listed above, will contribute to more effective responses to landslide events, in particular where rapid response is needed.

6 CONCLUSIONS

- The number and scale of the landslides that occurred in 2017 in the lower North Island, was unusual and appears to be related to the 2016 Kaikoura Earthquake as well as a period of higher rainfall.
- Landslide events in New Zealand appear to be happening at a more frequent rate and at a larger scale, due to climate change as well as the influence of recent seismic events in central New Zealand, resulting in increased challenges for authorities responsible for maintaining services such as road availability.
- The three events all caused significant disruption to road networks. However, it is noted that smaller events can also cause significant disruption, in particular where the residual risk is deemed unacceptably high to reopen the road.
- All three of the landslides occurred in aging greywacke cut slopes, which were all found to have previous significant landslide events decades ago. Identification of similar steep aging cut slopes and those with a past history of landslides will assist in planning resilience interventions and managing risks elsewhere.
- Increased preparedness will be required in order to manage the increased impact of landslide events in the future, requiring greater collaboration, in terms of key resource availability for personnel (including geotechnical and specialist earthworks staff and abseillers) and plant (e.g. long reach excavators, water sluicing options etc).
- The geotechnical role involves iteratively developing a sound engineering geological model of the site and landslide, including assessment of the likely failure mechanism(s), to allow a robust assessment of residual risk and the mitigation options for the immediate and subsequent stages of the response.
- Recent advances in survey monitoring techniques and data management provide the opportunity to greatly enhance our understanding of the behaviour of slopes and hence improve risk management. Examples include enhanced and greater use of drones (for inspection and 3D model generation), LiDAR data, laser scanners, sensors with real-time and near real-time monitoring capability and satellite monitoring.
- Key data related to sites is often very hard to source in a timely manner, hence a coordinated national database/portal would greatly assist in carrying out robust risk assessments, especially in times of heightened risk. Such data could include as-built data for earthworks and related structures, past landslide records and photographs, aerial photographs, and survey data (including LiDAR).

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