Monitoring technologies to manage landslide risk to transportation routes in the Lower North Island

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ABSTRACT

There is significant uncertainty in predicting the behaviour of slopes due to natural processes and events. The inherent variability in rock and soil make the use of precedent behaviour a much more attractive tool. However, precedent only goes so far. When precedent is not an option what tools do we have left?

This paper considers observed slope behaviour around the lower North Island since the 2016 Kaikoura Earthquake, including some large disruptive landslides. Comments on the relative contributions of the November 2016 earthquake as well as storm events, and other site characteristics are presented. Monitoring technologies offers the potential to better understand the behaviour of slopes and manage risks. This paper discusses the use of drones and other monitoring techniques to improve site 'visibility' and manage the risks from uncertainty regarding slope behaviour, using examples of large landslides affecting key lower North Island roads such as Ngaio Gorge Road and Cape Palliser Road and slips affecting the railway line north of Wellington. The use of drone and LiDAR models and movement sensors will be discussed, including the advantages and limitations of such technologies to alert and help manage risk.

1 INTRODUCTION

Climate change, aging infrastructure and in New Zealand an active seismic environment, present challenges for those seeking to manage risks to transport routes. In New Zealand's geologically young and active terrain, technologies that can assist risk assessment and management are becoming increasingly available and viable.

Since 2016 several larger landslide events have been observed in the lower North Island - examples being the 2016/17 events affecting State Highway 3 (SH3) in the Manawatu Gorge, and the July 2017 events in Wellington affecting Ngaio Gorge Road, a key arterial road to the CBD, and Ngauranga Gorge section of the

SH1 motorway (described in more detail in Stewart 2018 and 2021). Similarly to Manawatu Gorge, Cape Palliser Road along the southeast coast of the North Island was observed to have had renewed movement (possibly coinciding with the 2016 Kaikoura earthquake) at Johnsons Hill, the site of a large ‘dormant’ landslide. Movement of this landslide provides a direct threat to the only road access route to coastal communities at the south eastern tip of the North Island.

The effects of climate change and sea level rise will present added challenges for transport network operators who manage coastal roads, rail routes and walking tracks.

1.1 Risk Environment and Risk Management Tools

Slope risk rating / assessment tools and schemes provide a good start to identify sites that are likely to present slope movement risks in order to focus monitoring efforts. However, such schemes have limitations, and in heavy rain events, highly disruptive events can occur on slopes perceived as moderate or lower risk, from e.g. soil slippage and debris flows - Stewart and Brabhaharan (2013) and Stewart and McConchie (2019).

Following landslide events which affect transport routes, remedial and risk mitigation works are typically required, which required money and time (for design and procurement). Often neither of these is available, hence this is where the monitoring becomes a critical risk management tool.

The use of drones (also called UAVs or unmanned aerial vehicles) enables safer inspections and easy capture of data to facilitate site assessment and change detection (Stewart et al 2019 and Follas and Stewart 2016).

Technologies are increasingly becoming available to provide smarter monitoring and better connectivity to make a real difference for managing slope risks on our transport routes.

The use of ‘trigger action response plans’ (TARPs) has become more common in recent years, to allow informed responses to triggers such as heavy rainfall and other types of data changes.

More informed use of monitoring will help us to better understand the behaviour, causes and triggers of slope movements, in order to facilitate more effective slope risk management.

The current paper provides examples from monitoring at three road and rail sites in the lower North Island, and then provides a discussion and lessons learnt section, covering monitoring systems, data and alerts.

2 NGAIO GORGE ROAD 2017 ROCKSLIDE MONITORING

A large (~1500m3) rockslide occurred on a 1970s rock cutting in late July 2017 after a period of heavy rain (Figure 1). A 1974 precedent for this type of failure was discovered retrospectively at the site however not of this magnitude. Due to the unprecedented scale of this failure, the 2016 earthquake may well have weakened the slope providing the conditions for a larger than normal failure to occur.

In order to manage rockfall risks to workers removing the debris (in order to reopen the road), a network of reflective targets was strategically placed around the perimeter of the slip by abseilers. These targets were monitored by a manned real-time EDM instrument (Figure 1). Accelerating movement was detected on one target during earthworks, enabling sufficient warning to the excavator operator working under the scarp to move out of way prior to a large secondary failure.

In order to manage risks to traffic from further slope failures and allow 2-way traffic flow, a shipping container barrier was installed at the slope base (Figure 2), which has remained in operation to present (>4 years). The containers are double stacked, welded together and tied back with anchors, and the bottom row weighted with concrete blocks. The performance of the slope was able to be monitored by a 12 month trial network of GPS sensors, which showed clear movement trends in at least 2 sensors over winter 2018 (Figure 2). The movement at these sensors was able to be verified by EDM surveys of nearby reflective targets. On notification of the elevated risk of failure of the slope, Wellington City Council installed concrete barriers below the slope and Transpower initiated routine survey monitoring of their pylon above the site. The slope movement rates dissipated with no catastrophic movement resulting.

Figure 1: Ngaio Gorge Road, July 2017 rockslide and EDM target monitoring setup during earthworks

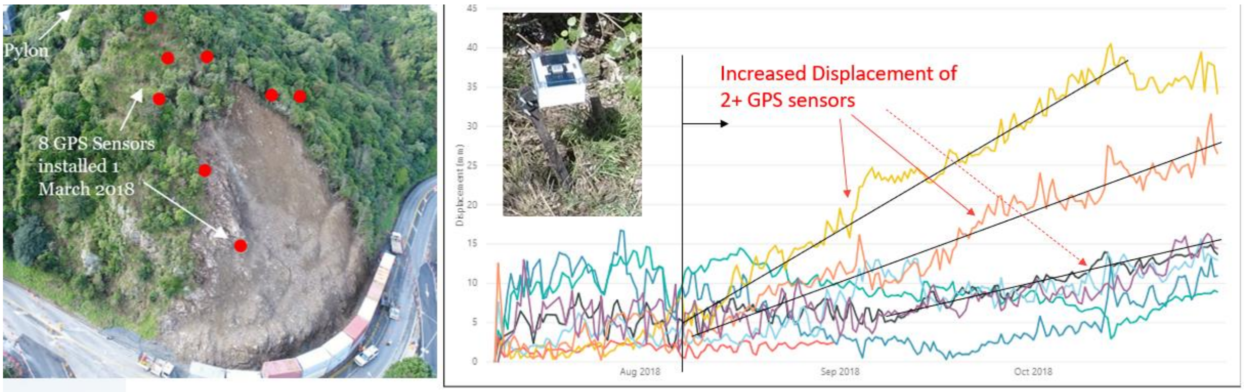

Figure 2: GPS sensor trial and displacement data following remedial works, Ngaio Gorge Road rockslide

3 KAPITI NIMT RAIL SLOPES

3.1 Paekakariki Escarpment

The steep slopes along this coastal section north of Wellington present ongoing risks to road, rail and the popular Paekakariki Escarpment walking track (Figure 3). While seismic risks have precipitated the construction of the Transmission Gully highway to manage the risk to road access to Wellington, the risks to the North Island Main Trunk (NIMT) line and walking track remain. Storm events in 2020 and 2021 have resulted in slips that pose heightened risks. Monitoring has played a key role in assisting risk management of the NIMT.

Figure 3: Paekakariki Escarpment – with multiple slope hazards affecting road, rail and the Te Araroa (TA) trail. Works to mitigate NIMT 33.44 slip site visible at upper right

Following a slip in late 2020 upslope of the line at NIMT33.44, two catch fences were constructed beneath the main slip area below the TA track (Figure 3). These were instrumented with tilt sensors, draw wire extensometers and cameras, and a digital rain gauge and camera were installed at rail level. During a heavy rainfall event in August 2021, significant tilting of the upper fence was identified (Figures 4 and 5) resulting in an increased likelihood of an event that could affect the rail below. Without tilt sensors this movement would have gone undetected, until inspections many days later. Cameras taking photos along the fence every 30 minutes allowed retrospective viewing of the failure in (slow) motion and allowed the full width of moving slope to be identified. While the slope did not fail catastrophically the movement indicated the slope at that location and time had a factor of safety below 1.0. During heavy rain in early December 2021 tension cracks developed on the slope above the walking track. A tilt sensor was relocated to this marginally stable slope to help manage risk to contractors stabilising the slope below. A heavy rain event in mid December 2021 resulted in further movement of this slope and sensor (Figure 4) which was directly correlated with the rainfall.

At gully sites 2km to the north, debris flows present a hazard to the railway in heavy rain events. At one site monitoring of tilt sensors on a debris catch fence and rain gauge provides KiwiRail with a warning system to alert train control of higher risk conditions. Cameras provide supplementary data sources to check the condition of the fence.

Figure 4: Monitored catch fences (arrowed) at NIMT 33.44; tilted sensor at right after movement

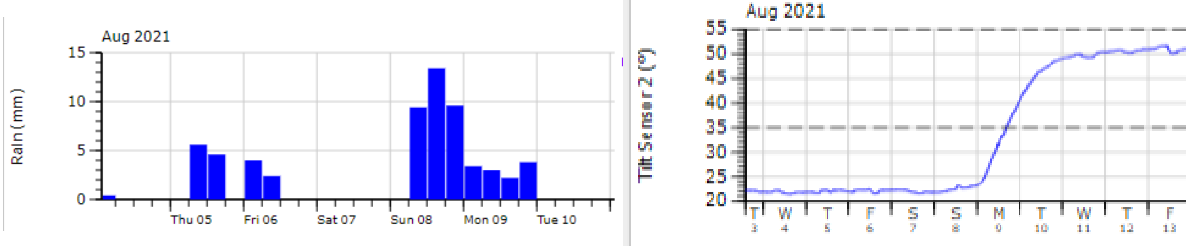

Figure 5: Site rainfall and upper fence tilt sensor 2 data, showing tilting on 9 August 2021 during rain event

3.2 Paraparaumu Slope Change detection

Spatial monitoring based on comparison of 3D models is useful to identify locations of changed elevation that may be indicative of slope movement. An example is a change model for the slopes south of Paraparaumu station; where 3D models derived from drone photo surveys 6 months apart show areas of elevation change at two known slip areas (Figure 6). An obvious slippage event at NIMT 47.40 occurred between the February and September 2017 drone flights. This (photo based) method has the disadvantage of also picking up vegetation elevation changes.

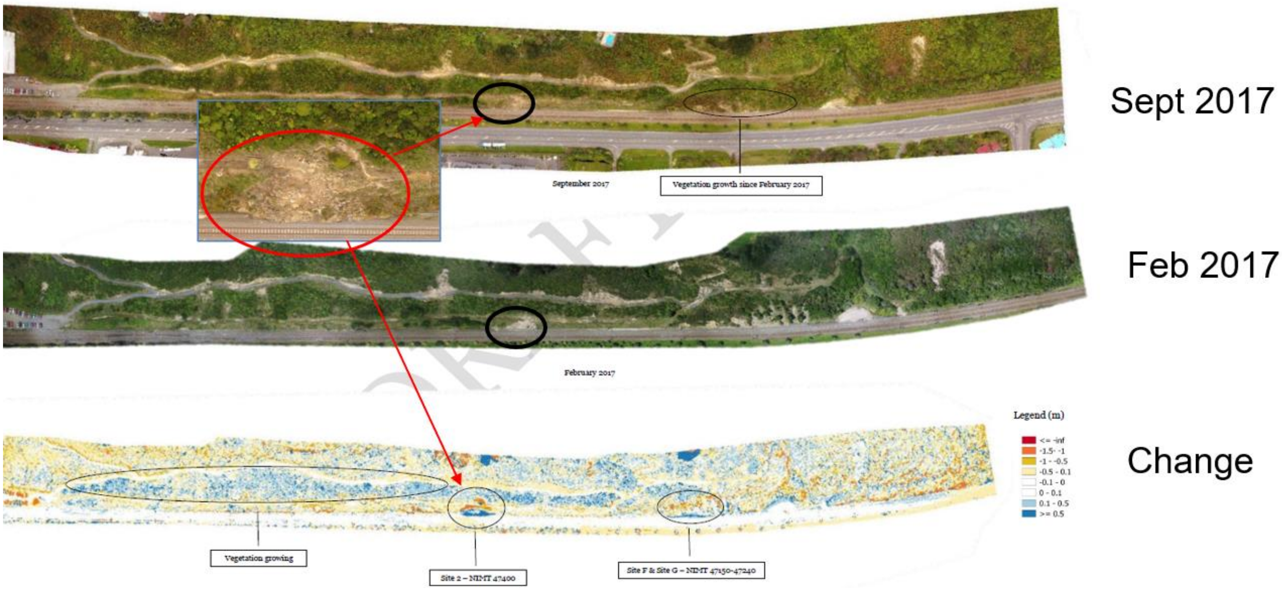

Figure 6: Orthophotos from 3D survey models from drone surveys taken 6 months apart, with elevation changes between the two models shown below.

4 CAPE PALLISER ROAD

4.1 Landslides

Coastal roads in hilly terrain face multiple threats from climatic, coastal and seismic events. The Johnsons Hill landslide (Figure 7) affects a ~200m long section of Cape Palliser Road and periodically moves, with reactivation noted following the 2016 Kaikoura Earthquake. Given the increasing risk to the landslide from sea level rise, South Wairarapa District Council are undertaking investigation of the landslide and monitoring including slope change detection from repeat UAV models as well as set up of a monitoring system. This will enable movement trends to be identified to allow targeted risk mitigation measures to be implemented to maximise the security of the road. Using UAV 3D models and existing regional LiDAR data (Figure 8), the geomorphic expression of the landside features was able to be mapped, despite being obscured by vegetation. The use of these 3D models allows rapid inspection and visualisation of the landslide features that would not otherwise be able to be easily identified, and assists optimising of locations for monitoring points, on the surface or in boreholes.

Figure 7: Lower section of Johnsons Hill landslide on Cape Palliser Road, UAV 3D model snip, with coastal erosion acting as a key contributor to slope instability. Model allows viewing of difficult-to-reach features.

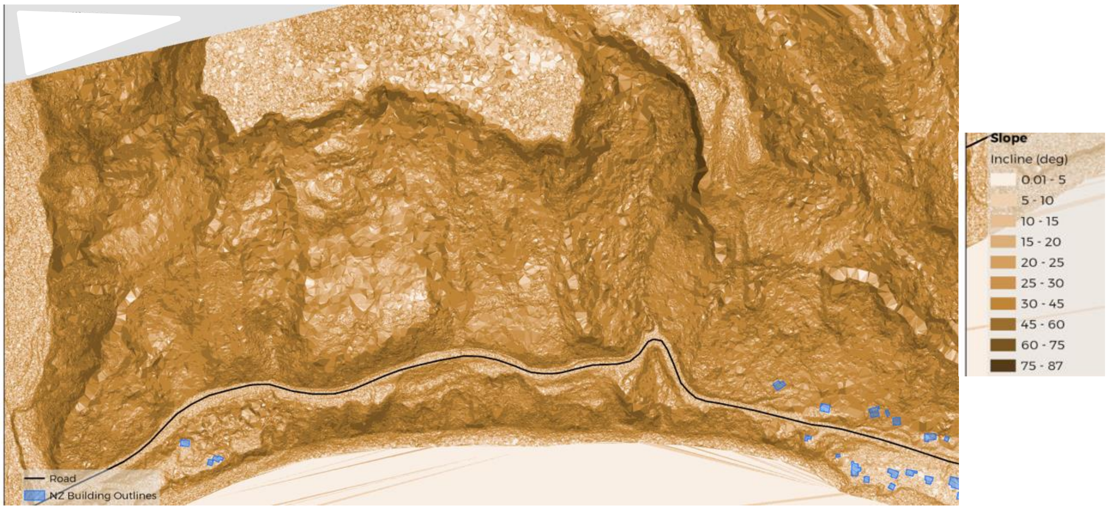

Figure 8: Slope angle map on ground surface layer of 2013 LiDAR survey facilitated landslide mapping in the Johnsons Hill area, despite slopes above the road being covered by vegetation

5 DISCUSSION

The various examples presented show applications of monitoring to assist slope risk management.

Spatial change detection methods, such as from repeat drone surveys, provide a good means of screening large areas for slope movements. Whereas contact instruments allow monitoring of the behaviour at discrete points.

Continued advances in the technology are anticipated, with developments such as UAVs that can fly in all weather, advanced obstacle avoidance capability and more use of other sensors on UAVs such as infrared and LiDAR (Light Detection and Ranging).

Comparison of repeat 3D models allows identification of changes between capture dates. The cheapest and most available method is from UAV photo(grammetry) surveys; however, this method doesn't screen out vegetation height changes. Good quality LiDAR (Light Detection and Ranging) is best for vegetated slopes, as the LiDAR pulses can penetrate the vegetation. Satellite inSAR, such as was used at Kaikoura after the 2016 Earthquake, provides the greatest spatial coverage to detect ground elevation changes.

Assessment of 3D digital terrain models (DTM) facilitate remote geomorphic mapping of terrain features e.g. to optimise the locations for instrumentation.

Rainfall gauges provide a very useful data set for slope monitoring, as typically rainfall is a key causative factor if not trigger for many slope movements. Modern digital rain gauges provide real-time data. While rainfall amount (e.g. mm per day) is a key indicator, rainfall intensity and antecedent rainfall (degree of saturation) provide more nuanced tools to help understand the types, and likely locations, of landslide events (Stewart and McConchie, 2019). For example, high intensity rainfall in gullies can result in debris flows if sufficient soil/debris is present.

All monitoring methods have limitations and hence it is advisable to have more than one method / tool in place, to provide checks and validation of data indicating possible slope movement.

Data indicating movement, or acceleration of slope movement, suggests that the slope is or has recently been unstable. This movement means a state of elevated risk which needs to be translated to the transport network operator in a form that is useful. The worst case is that the outcome is completely uncertain (i.e. catastrophic failure is possible) in which case a conservative risk management response is likely. In a number of cases, such as the large-scale Kerry's Wall failure in the Manawatu Gorge (discussed in Stewart, 2021) and the Ngaio Gorge winter 2018 acceleration (Figure 2), catastrophic failure did not result. In the former case risk levels in the gorge were deemed too high resulting in abandonment of the gorge.

Where alerts are set on incoming data, a clear plan of action is needed once the alert threshold has been reached. Alerts can be set at somewhat conservative (or lower) values, e.g. for technical staff to keep a closer eye on the site (commonly referred to as orange alert). Providing orange alerts to network operation control centres can result in un-necessarily conservative risk mitigation actions, which can make such systems counterproductive.

An increased amount of data can overwhelm operators unless this is adequately filtered. Pragmatic sanity checks are recommended to be put in place. The value of 'old school' experienced inspectors should not be understated; they often have a rich knowledge of how certain slopes behave and hence this precedent behaviour provides a very good starting point as a sanity tool. Notwithstanding this, climate change and periods of increased seismic activity, mean that future behaviour may extend beyond the normal precedent behaviour in a given area.

Current monitoring technologies are at the point of being able to provide a viable alternative to expensive physical risk mitigation works; at the very least to 'buy time' in order to be able to determine viable alternatives.

6 CONCLUSIONS

Monitoring technologies provide valuable risk management tools for transport network operators to help mitigate the increasing risk from natural hazards to transport networks.

Given the inherent uncertainty in slope behaviour, monitoring should be regarded as a tool which, in conjunction with other risk mitigation measures, can help transport network operators manage slope risks.

A variety of tools is available, from spatial methods for screening large areas to identify slope changes through to 'in place' real time sensors on vulnerable slopes or structures.

Due to the inherent limitations of individual methods, typically multiple methods should be employed to provide independent checks of data changes to be made in a timely manner.

In order to prevent confusion, well thought out 'trigger action response plans' (TARPS) should be developed to ensure a procedure is in place so that appropriate responses occur when data thresholds are exceeded.

The value of drones to rapidly capture imagery to allow inspection of difficult sites and then prepare 3D digital terrain models from photos should not be understated.

3D digital terrain models from drone photogrammetry, or other forms of scanning such as LiDAR, allow terrain evaluation to identify landslide features, which assists location of landslide monitoring points. Comparison of repeat 3D models allows slope change detection.

Given the increased risks posed by climate change and the active seismic environment, further research into monitoring systems to help understand slopes movements and manage risks would be very timely.

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