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Rawene Reserve landslips emergency response and stabilisation

Mesures de stabilisation d'urgence des glissements de terrain de Rawene Reserve

Simon Farquhar
Tonkin and Taylor Ltd, New Zealand, sfarquhar@tonkintaylor.co.nz

John Seward
Auckland Council, New Zealand

ABSTRACT: The Rawene Reserve landslips occurred in 2017 and resulted in the partial loss of a sealed carpark behind the Mokoia Road shops in Birkenhead, Auckland. The landslips are inferred to have occurred within uncontrolled fill materials placed in a gully during the 1960s and 1970s, and along softened and pre-sheared zones within residually weathered soils of the East Coast Bays Formation. The main landslip formed a debris flow of material which travelled up to 300 m downslope damaging local infrastructure, and inundating properties and local streams. Emergency action and stabilisation measures were undertaken by Auckland Council to prevent further movement, to make the surrounding area safe and allow for longer term repair works. Stabilisation measures included temporary sheet piles, cantilevered timber pole walls, an anchored concrete piled palisade wall, earthworks, and subsoil drainage. Engineered fill was placed to buttress the slope and form a new carpark. Construction was completed and the carpark reopened in October 2019, two years after the initial landslip event. Monitoring of strain in the piles using rebar strainmeters confirmed pile performance. The project was challenging given its urban location, multiple affected stakeholders and the emergency response required.

RÉSUMÉ : Les glissements de terrain de Rawene se sont produits en 2017 et ont entraîné la disparition partielle d'un parking à l'arrière du complexe commercial sur Mokoia Road, dans le quartier de Birkenhead à Auckland, Nouvelle-Zélande. Ces glissements sont présumés s'être produits au sein de matériaux de remblais placés sans contrôle dans une ravine dans les années 1960 et 1970, le long d'une zone affaiblie et pré-cisaillée de sols résiduels d'East Coast Bays Formation. Le principal glissement de terrain a créé une coulée de débris qui s'est étalée sur 300 m, endommageant les infrastructures locales et inondant les propriétés cours d'eaux adjacents. Des mesures de stabilisation d'urgence ont été entreprises par Auckland Council pour empêcher tout mouvements de sols supplémentaires et pour sécuriser la zone environnante et permettre des travaux de réparation à plus long terme. Les mesures de stabilisation d'urgence incluent des murs en palplanche temporaires, des murs de poteaux en bois en porte-à-faux, un mur de palissade en béton ancré, des travaux de terrassement et un drainage du sol. La construction d'un remblai pour renforcer la pente et créer un nouveau parking a été complétée et le parking a réouvert en Octobre 2019, soit deux ans après le glissement de terrain initial. La performance des pieux a été confirmée par le suivi de déformation des pieux à l'aide de tensiomètres. Ce projet était difficile de par son emplacement en milieu urbain, les multiples parties prenantes et les mesures d'urgence requises rapidement.

KEYWORDS: landslip, ground stabilisation, debris flow, anchored palisade wall, strainmeter

1 INTRODUCTION AND BACKGROUND

1.1 *Initial ground movement and emergency response*

Rawene Reserve is located behind the Mokoia Road shops in the suburb of Birkenhead on Auckland's North Shore (Figure 1). The reserve consisted of an asphalted carpark for the shopping area and a densely vegetated gully. Cracking was first identified in the carpark asphalt by Auckland Transport in 2015. A geotechnical investigation was undertaken identifying a slow-moving deep-seated landslip (GHD 2015). The cracks were sealed and the carpark visually monitored for further signs of instability. Creeping movement of the landslip was observed in August 2017. Auckland Transport closed a section of the carpark on 20 September 2017 for safety reasons. On 9 October 2017 significant movement of the landslip occurred over a period of approximately 5 hours. A 5 m high headscarp formed with a debris flow extending up to 300 m down the Rawene Gully, coming to rest in privately owned land (Figures 2 & 3). The debris flow dammed streams and destroyed a wastewater pipe bridge, causing sewage to overflow into the reserve.

Emergency stabilisation measures designed by an independent consultant comprised 15 m deep, intermittent jet-grouted columns behind the headscarp. Column installation commenced in the carpark on 15 November 2017 to the east of the landslip and progressed in a westward direction. On 28 November 2017, a second failure (western failure) occurred immediately to the west of the initial failure (eastern failure). The western failure occurred during installation of the jet-grouted columns, resulting in the loss of the grouting rig in the landslip debris, as well as further loss of the carpark and the access road. In early January 2018, the western failure headscarp regressed causing loss of a footpath, which had previously been undermined. A sheet piled wall was installed 5 to 10 m behind the eastern and western headscarps to prevent further regression of the landslip towards the buildings at Mokoia Road. The sheet piles were driven 10 to 13 m below ground level, in 3 m wide groups in a 'hit and miss' pattern to prevent creating a groundwater dam. The landslip movement appeared to stabilise following the January 2018 regression with only minor surficial movement of the debris observed.

During the emergency works phase Auckland Council developed an emergency plan to monitor the landslip and implement contingency actions if required. Trigger levels included ground surface movement, building movement, inclinometer movement, groundwater level and predicted rainfall. Once the landslip stabilised, and private land and buildings were protected, longer term remedial options could be considered. Auckland Council (AC) engaged Tonkin + Taylor (T+T) in January 2018 to undertake detailed design of permanent remedial options.

Figure 1. Site location (map sourced from the LINZ Data Service and licensed for reuse under the CC BY 4.0 licence).

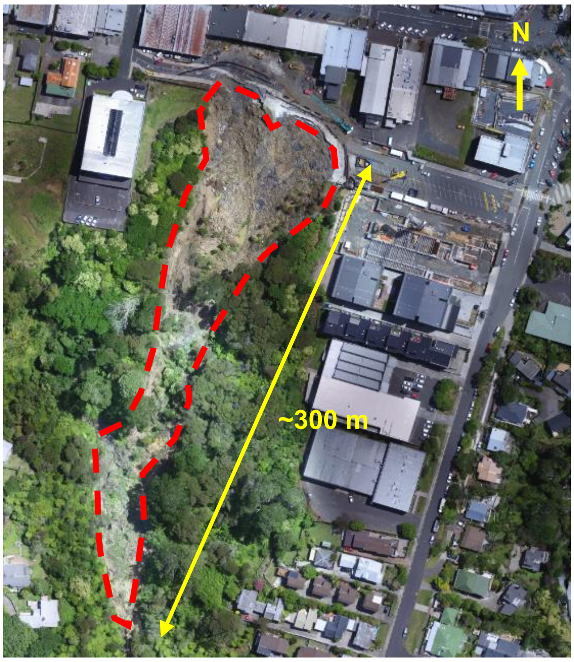

Figure 2. Landslip and debris flow extents (in red dashed line).

Figure 3. Aerial oblique photograph of landslip headscarp taken 7 January 2018.

1.2 *Remedial works objectives*

The project objectives were largely driven by the needs of, and effects on, the local community. Public interest in the project was high. Several public meetings were held to consult with the local community and understand their drivers. The project was challenging given its diverse range of stakeholders, including several AC departments and organisations fulfilling different roles on the project, such as Auckland Transport, Watercare Services Limited, AC parks, AC regulatory, AC closed landfill team and AC building control.

Building owners were concerned about damage to their properties and the safety of the occupants. A solution that provided assurance that the landslip was stabilised was required.

The landslip also resulted in the loss of approximately 90 parking spaces from the carpark. The construction of a new apartment building at the neighbouring 19 Rawene Road site utilised further carparks, and shoppers were resigned to parking down residential streets. The full reinstatement of the carpark was requested as quickly as possible to prevent further business disruption and nuisance. The construction method was required to limit effects on the surrounding businesses and residents. A robust, low maintenance solution was preferred by AC, as the whole of life costs for maintenance can easily outstrip construction costs. The potential for future development and use of the site was also to be considered.

Following the emergency works, the project was separated into three phases of work (of which Phases 1 and 2 are described in this paper):

- Phase 1: Temporary stabilisation works and construction access (upper landslip),
- Phase 2: Slope repair and carpark remediation works (upper landslip),
- Phase 3: Downslope clean-up of debris from public and private land (lower landslip).

2 SITE DESCRIPTION

2.1 *Site history*

Rawene Reserve is a narrow natural gully with a stream that discharges into the Chelsea Estate Heritage Park stormwater ponds, which in turn discharge into the Waitemata Harbour. Development in the vicinity of the gully was already underway in 1940, with predominantly residential development backing onto the gully.

Filling of the gully commenced in the early 1960's. Filling occurred from Rawene Road, in the area currently occupied by the carpark where the landslip occurred. The site was developed by end-tipping of fill material into the head of the gully. Based on historical aerial photographs, the majority of the filling occurred between the early 1960's and the late 1970's. A final phase of filling and formalisation of the carpark and access ways in the western part of the area occurred between 2010 and 2015. The fill material typically comprised sand/clay/silt materials from the surrounding area, with some construction and demolition waste. Buried topsoil (paleosol) encountered in some boreholes indicates that site preparation for earthworks (such as topsoil stripping, benching and drainage) may not have been undertaken.

2.2 *Subsoil model*

A series of investigations have been completed at the site and were used to determine the site subsoil model. The site is underlain by East Coast Bays Formation (ECBF) Rock, a very weak sedimentary rock that consists of interbedded layers of siltstone and sandstone. The gully is formed on residually weathered soils of the East Coast Bays Formation) which are present at the ground surface or are underlying the fill layer.. The residual ECBF soil is underlain by weathered to unweathered ECBF rock. Polished shear surfaces were identified in some boreholes at the contact between the landslip debris and residual soils. Holocene age alluvial soils (Tauranga Group) are present in the lower gully area. As a result of the landslip, soft, saturated, remoulded landslip debris materials up to 5 m thick were deposited over the alluvial and residual soils in the base of the gully. The soft debris presented challenges for construction. The subsoil model is presented in Figure 4.

Groundwater monitoring indicated that the groundwater level after the landslip was typically located near the fill and natural soil interface in the upper portion of the slope, and 'daylighted' in the now inundated stream at the base of the gully. It is believed that perched groundwater may have been present within the fill materials prior to the landslip given the high saturation of the materials and 'flow' type failure that occurred.

2.3 *Failure mechanisms and causes*

The landslips are considered to have occurred due to one of, or a combination of, the following failure mechanisms: uncontrolled fill placement resulting in poorly compacted fill over soft soil layers (paleosols); oversteepened slopes; saturation of the fill (due to surface infiltration and inadequate drainage in the fill); failure through saturated and softened zones in the fill and ECBF soil; failure on the organic layer / buried topsoil at the base of the fill; failure on pre-sheared defects in the residual ECBF soil (Figure 4).

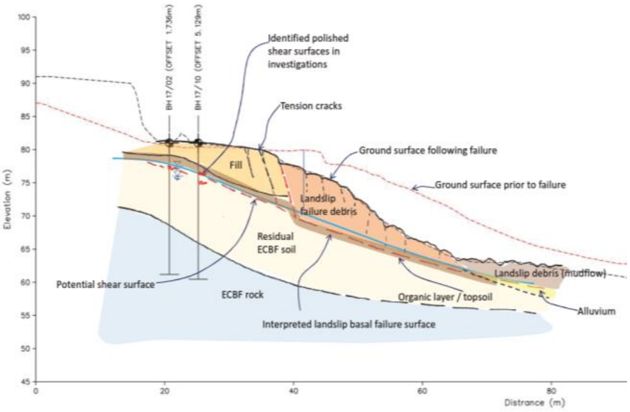

Figure 4. Geological model of site following the landslip with inferred translation failure mechanism.

A review of rainfall data collected from a monitoring station 1 km from the site indicated that the rainfall in the month prior to the October and November 2017 landslips was not significantly higher than in earlier months (Figure 5). Daily (24 hour) rainfall data was first assessed. Glade (1997), notes that there are limitations when looking at daily rainfall data only. A prolonged rainfall event may occur over a number of days. Pore-water pressure may take days to infiltrate and dissipate from a slope. As such, 5, 20 and 30 day cumulative rainfall values were also compared.

The first ground movement was observed in 2015 and following this, softened zones and sheared surfaces may have begun to develop. As such, the main landslip was not thought to be caused by extreme short term weather conditions. However, long term rainfall may have contributed to increased saturation of the fill. Short term rainfall may have triggered subsequent smaller failures (i.e. the January 2018 regression).

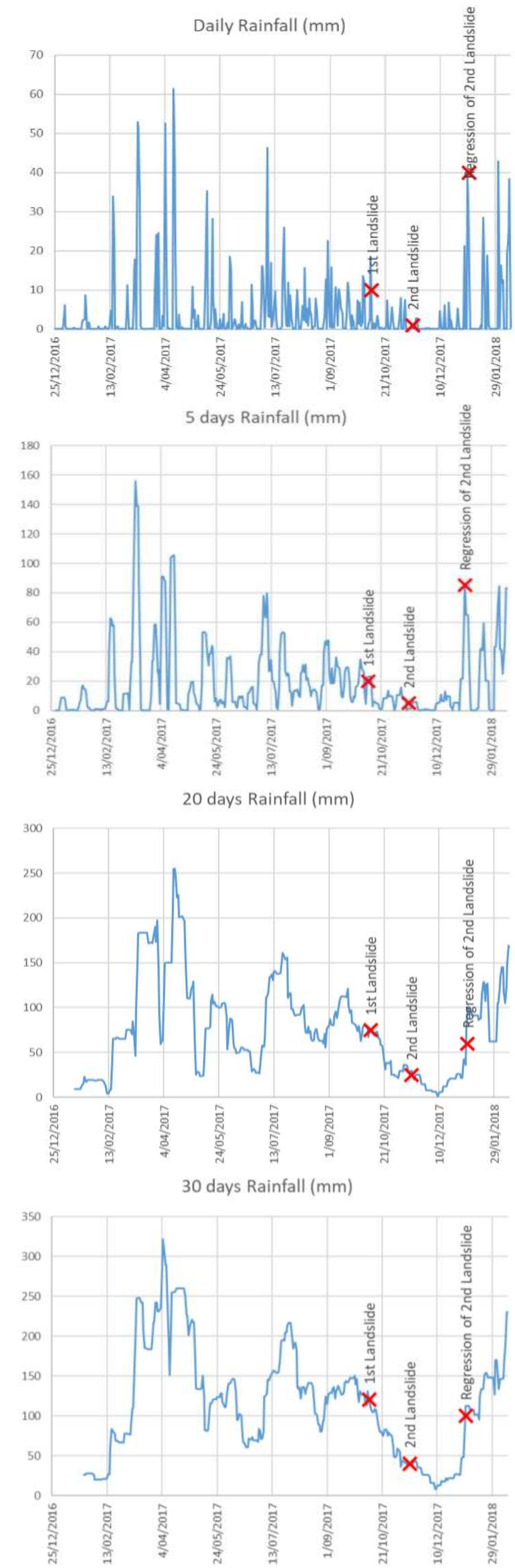

Figure 5. Cumulative rainfall data from 26 Miraka Place, located approximately 1km away from Rawene Reserve (red crosses note landslip events). From top to bottom: a) 1 day, b) 5 days, c) 20 days, d) 30 days.

3 DESIGN AND CONSTRUCTION SUMMARY

3.1 *Phase 1 – Temporary stabilisation works*

Phase 1 temporary stabilisation works focused on making the site safe, and providing suitable access for Phase 2 works.

The design comprised three main elements:

- Reducing water pressures behind the headscarp, to improve stability, through column aggregate drains and submersible pumps on trigger switches.
- Strengthening the existing sheet pile wall by connecting the individual sheet pile groups with a reinforced concrete capping beam,
- Earthworks and subsoil drainage including:
    - Construction of a ramped access trench to provide safe access for plant onto the landslip face. The trench was supported with timber pole walls (constructed top down). The walls formed part of the permanent works in Phase 2.
    - Reshaping of the slope to a stable angle of approximately 20°. The mass of landslip debris was moved from the upper part of the scarp down towards the toe of the failure to provide a buttress.
    - Construction of aggregate filled underfill and gully subsoil drains.
    - Importing 4,500 m3 of soft pit run (SPR) rockfill to form access tracks and a piling platform for Phase 2 works.

Several other contingency options were developed in case the proposed works did not stabilise the landslip sufficiently or difficulties were encountered during construction. An observational approach was used with a 'toolbox' of measures that could be applied if required. These included:

- Installing Glass Reinforced Plastic (GRP) bar ground anchors through the capping beam if movement was observed (PVC ducts were cast into the capping beam to allow for this);
- Soil nailing with flexible mesh facing for oversteepened areas; or
- Additional column and horizontally bored drains or trench (counterfort) drains in locations where high water levels or flow are observed.

During construction between May and October 2018, the author was present on site most days to monitor the works and confirm the appropriate remedial measures and earthworks. Survey monitoring of the landslip indicated that the site was stable during construction and as such, no additional contingency measures were required. However, additional undercutting and SPR fill was required as access across the soft landslip debris proved difficult, especially during wet weather months.

3.2 *Phase 2 – Permanent stabilisation and carpark remediation*

Phase 2 works focussed on re-establishing the carpark and ensuring the site, and supported buildings met adequate long term stability requirements. The design (Figure 6) primarily consisted of:

- An anchored in-ground reinforced concrete pile palisade wall.
- Placement of up to 27,000 m3 of imported SPR fill above and below the palisade wall to reform the carpark and slope.
- Rows of driven timber poles to stabilise landslip debris down-slope of the palisade wall.
- Construction of a timber pole retaining wall to support a new service lane behind the Mokoia Road shops on the uphill side of the carpark.
- Civil works and services including pavements, stormwater drains and treatment devices.

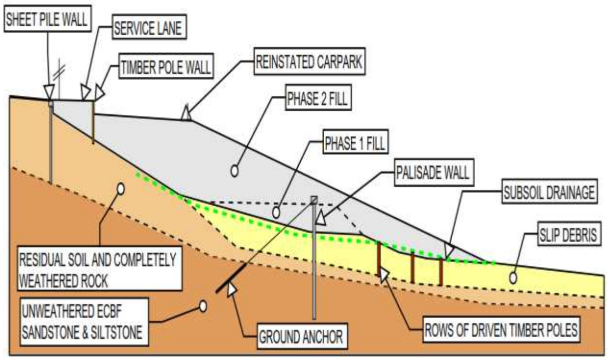

Figure 6. Typical section down slope showing Phase 2 design elements (approximate only)

Placement of the fill, up to 15 m thick, took place quickly during winter months with the aim of opening the carpark as soon as possible. The fill was placed over top of the 5 m thick layer of saturated landslip debris and alluvial materials, with characteristic undrained shear strength of 30 kPa (measured from in-situ and core barrel hand-held shear vanes). Photos of the works at different design stages are shown in Figure 9.

3.3 *Phase 2 Design Methodology*

Geotechnical design parameters were determined from site investigation data and a back analysis of the October landslip event.

The design of the palisade wall was undertaken following the method described in Poulos (1995). The approach involves three main steps: (1) determining the shear force needed to increase the factor of safety of the slope to the target value; (2) evaluating the shear force that each pile can provide to resist sliding (3) selecting the number and type of piles and the most suitable location in the slope.

The design was controlled by the short term (undrained) loading case. Placement of the fill prior to the construction of the palisade wall was also limited. Settlement of the landslip debris and alluvium was considered, however, the majority of the settlement was expected to occur during construction, and prior to final surfacing (asphalt) being constructed on the carpark. The design was undertaken using a limit equilibrium analysis (Geostudio Slope/W) to determine the stabilisation load required to reach the desired factor of safety for stability of 1.5. The stabilisation load, at a factor of safety of 1.5 was then modelled as a uniformly distributed load (UDL – refer to Figure 7) over the length of pile in the area of predicted movement to design the pile and anchors. The retaining wall design was undertaken using WALLAP.

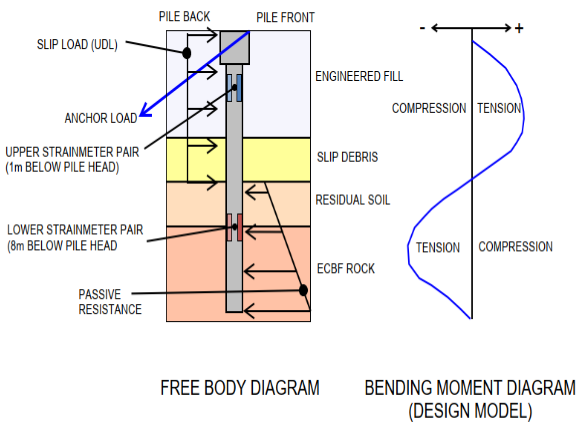

Figure 7. Free body diagram and bending moment diagram showing idealised loading and design actions.

3.3.1 *Instrumentation and Monitoring*

A common problem for geotechnical engineers is confirming the ongoing performance of underground structures and drainage after construction. For this project five vibrating wire (VW) piezometers were installed near the base of the fill and two pairs of VW rebar strainmeters were installed in five of the palisade wall piles. The strainmeters and piezometers were read during construction by a logger outside of the earthworks zone. The strainmeters and piezometers allow AC to come back at regular intervals following completion of the project to assess the performance of the palisade wall and drainage. Figure 8 shows the strain in the VW strainmeter pairs. Strain can be seen developing during anchor stressing as well as during earthworks. Strains can then be seen to stabilise following completion of earthworks. The strain in the piles can be monitored in the future to confirm ongoing performance of the structure. As of August 2019, VW piezometers indicate that there is negligible porewater pressure build up within the hardfill. Pile inclinometers were considered as they would provide information about pile movement with depth, however they were not used as it was considered too difficult to protect the inclinometers during construction (i.e. placement of fill above the wall).

The strainmeters typically show for the upper pairs (located 1 m below the top of the pile) a positive bending moment of approximately 175 kNm is measured (25% of the calculated design action). For the lower pair of strainmeters (located 8 m below the top of the pile) a negative bending moment of 415 kNm is measured (30% of the calculated design action). The ULS design load for the wall was determined using limit equilibrium analysis targeting a factor of safety of 1.5. For large failure surface areas this can result in very high stabilisation forces being required. The monitoring indicated that the actual (working) loads in the piles are significantly smaller than the design loads. Additional strainmeter pairs would have helped to confirm the full bending moment profile along the length of the piles. However, this would have added significant cost to the project.

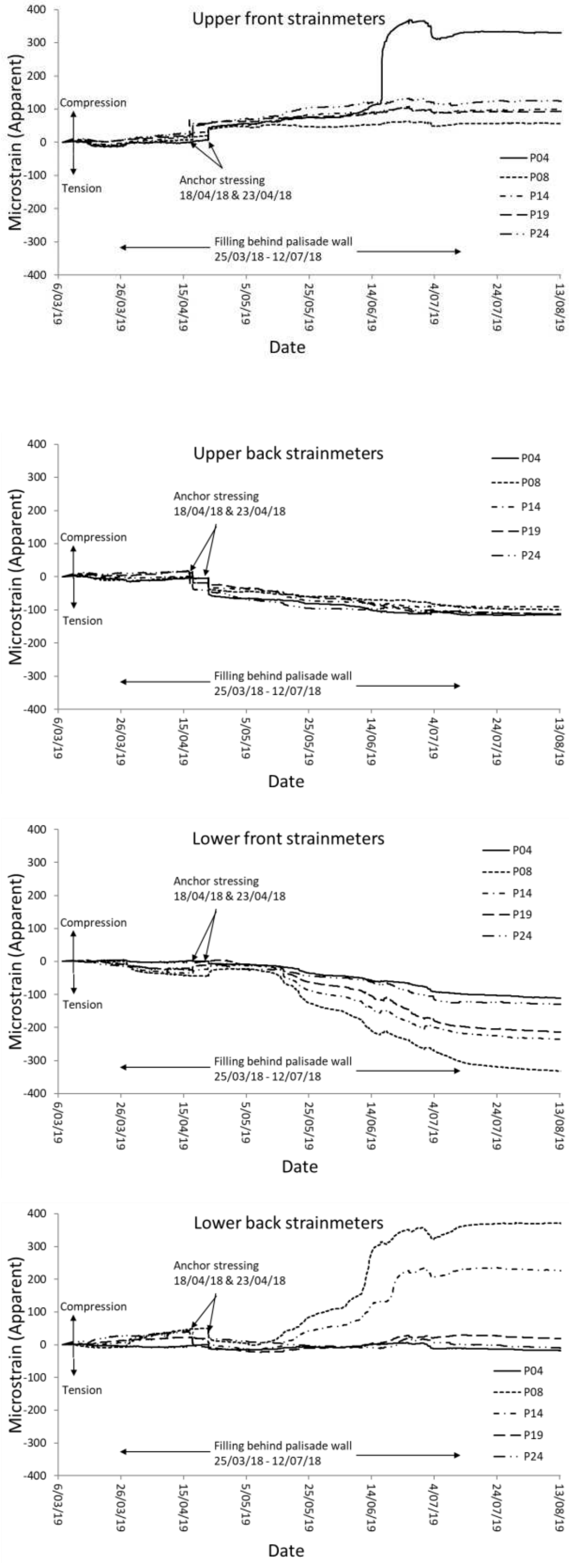

Figure 8. Palisade wall pile rebar strainmeter comparison. Note spike in strain during anchor stressing. Strain increased during filling, negligible change in strain following earthworks indicates that movement of the palisade wall is not occurring. From top to bottom: a) upper front, b) upper back, c) lower front, d) lower back.

Figure 9. Photos of site from time-lapse camera: a) 28 June 2018 – Phase 1, prior to earthworks, b) 3 March 2019 – Phase 2, palisade wall completion, c) 5 July 2019 – Phase 2, fill 90% complete, timber pole wall construction, d) 22 November 2019 – carpark completion.

4 CONCLUSIONS

The Rawene Reserve landslip was a series of landslip failures in an urban area. A large area of a popular carpark which serviced the local Birkenhead community was lost. The landslip occurred within and along the interface between saturated uncontrolled fill materials and natural soils. The landslip debris inundated reserve and private land, and infilled a stream.

A quick, reliable solution that reinstated as much carpark area as possible was desired by Auckland Council. Stabilisation measures included an anchored reinforced concrete palisade wall and earthworks to form a new carparking area.

Further work is proposed by Auckland Council to plant the fill slope and tidy the landslip debris in the lower Rawene Gully. The project has provided stability to the site, reinstated the carparking that the community requested and will eventually provide a natural space in a suburban area.

Lessons learnt from the project include:

- The importance of stakeholder consideration during design and construction.
- The benefit of a staged design, consenting and construction approach in reducing the overall project programme and allowing observations from early construction stages to inform the design of later stages.
- Vibrating wire strainmeters are a useful inclusion in buried structures to confirm design performance which cannot be visually inspected.

5 ACKNOWLEDGEMENTS

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