NZGS SYMPOSIUM 2021
Good grounds for the future
24-26 March 2021 · Dunedin · New Zealand

Innovation Under Pressure – Ohau Point Slope Stabilisation

M.B. Avery,
GeoStabilization NZ Ltd, Auckland

C. Barrett,
GeoStabilization International, Grand Junction, CO USA

ABSTRACT

Following the M7.8 Kaikoura Earthquake GeoStabilization NZ Ltd (formerly Hiway GeoStabilization Ltd) were awarded the North Face Ohau Point Scaling and High Tensile Mesh Installation contract. The original design to mitigate rockfall hazards included a pinned high tensile steel wire mesh. The ground conditions encountered were some of the worst in the region as the slope was highly affected by ground shaking and ridge amplification.

Subsequently the original programme was delayed by the condition of the slope. In order to accelerate access for road construction crews below Ohau Point a re-evaluation of the original efforts was required and a value engineered ring net drape solution was proposed by GSI to cover the highly unstable upper section of the bluff. The design, using WASHDOT and FHWA guidelines, incorporated innovative tools and techniques that were "outside-the-box" & different from traditional methods. GSI focused on an international best practice approach to the design and construction methodology which allowed us to complete the design and have it approved (by NCTIR) in less than a week.

The temporary works included coverage of approximately 5,500 m2 of 40˚ to 80˚ slopes. Key components of the design were the use of a 6on1 ring net to optimise coverage and minimise choking during helicopter installation, and the consideration of the frictional resistance (interface friction) provided by the ring net on the shallower upper slopes. The project exhausted the global supply of 6on1 ring net with materials airfreighted from suppliers in Western Europe and North America.

1. INTRODUCTION

Shortly after midnight on Monday 14th November, a large magnitude 7.8 quake struck the small South Island settlement of Waiau in North Canterbury, 100km north of Christchurch. The quake was the largest in New Zealand since the magnitude 7.8 Dusky Sound earthquake in 2009 (GNS 2016). While shaking was widespread with over 15,000 recorded 'felt reports', the worst shaking occurred about 50 seconds after the quake rupturing started. The energy of the tremor progressed north over several minutes with surface rupture recorded on a total of 21 faults. The length of all the fault ruptures combined is close to 100km (GNS 2016).

The degree of ground shaking was high, recorded as Modified Mercalli Intensity Scale (MMI) Level 8 – Severe. This level of shaking causes considerable damage in ordinary buildings with partial collapse including fall of chimneys, factory stacks, columns, monuments, walls, etc. At a human level, people experience difficulty standing; while furniture and appliances shift. Geologically the damage depends on the geological setting. In Kaikoura and the surrounding area, especially the coastal highway State Highway 1, north and south of the town, many of the slopes consist of over steepened weathered, fractured greywacke. During the quake, the shaking caused significant and widespread damage with a total of 26 major slips (and many smaller slips); closing both State Highway 1 and the Main North Rail Line between Picton and Christchurch.

The earthquake most severely impacted the coastal road and rail which hugs the coastline along a stretch of some 20 km north and south of the coastal tourist town of Kaikoura. These links serve as the South Island's primary rail and state highway routes. The transport corridor follows the coastal alignment and is situated on a very narrow bench at sea level. The coastal mountain range rises from sea level up to some 500 meters of elevation. The earthquake triggered a significant series of rockfall landslides with some 40 major slides reportedly dislodging some 750,000 m^3 of rockslide debris which buried many sections of the transport corridor. The town of Kaikoura was completely isolated for over a month until access south was re-established via an alternative inland route. During November and December, the initial recovery effort involved helicopter support to service Kaikoura and this effort was primarily supported by the coincidental presence of an international Navy operation which provided airlift and marine support from USA, Canada, Australia, and New Zealand.

The highway and rail north arteries were closed for 12 months and a reconstruction team, North Canterbury Transport Infrastructure Recovery (NCTIR), was quickly established as a government led alliance, tasked with the rebuild. A deadline of 12 months was established to have the full length of the alignment (southern and northern road and rail corridor) opened by Christmas 2017. The monumental task of the design-build recovery at an initial value of $1.5 billion and a workforce of up to 3000 personnel began in earnest in January 2017.

2. INITIAL REMEDIATION ATTEMPTS

Immediately following the earthquake, it was imperative to get an understanding of the situation; what damage had occurred to what infrastructure. Representatives from the two main transport networks, New Zealand Transport Agency (NZTA) (road) and KiwiRail (rail), and their respective engineers inspected the main routes by helicopter. At the same time, geologists and earthquake specialists from the Institute of Geological and Nuclear Sciences (GNS) and around the world were undertaking more specific scientific inspections. It soon became very apparent that the severity of this quake was far worse than initially thought, and the damage to infrastructure was significant.

Geotech engineers identified over 85 slope failures affecting the road alone, while GNS scientists reported 21 faults (later expanded to nearly 30 separate fault surface ruptures). The slope failures affecting the road were categorized into primary, secondary and tertiary failures depending on the level of effect to the road. Primary failures, over 40 in total, were those directly affecting the highway, i.e., presenting an immediate hazard such as debris on the highway, or debris subject to imminent failure. Secondary and tertiary failures would likely affect the highway at some point (following future trigger events) but weren't immediately of concern.

Engineers quickly determined that treatment of the failed primary slopes was going to be non-conventional. The slopes were too steep and surrounded by inaccessible terrain to allow treatment using excavators and bulldozers, as would normally be used in such circumstances. The slopes were also too active, and the area was at high risk of further ground shaking events through the expected typical aftershock sequences.

Heli-sluicing was quickly identified as the most appropriate primary means of treating the slopes while the ground shaking activity subsided; this would also allow time to consider more direct, permanent treatment options. Heli-sluicing involves the use of helicopters fitted with firefighting 'monsoon' buckets dropping around 1000 liters of water at a time directly onto the slope. In the case of Kaikoura, the buckets were filled from the ocean and water washed onto the slopes in a targeted manner. Geotech engineers monitored the sluicing operations directing the helicopter pilots to target areas.

At the peak of operations, thirteen helicopters were in use, and in some cases up to seven machines focusing on single areas. This repeated washing of the slopes released significant volumes of material. While not as effective as manual scaling or blasting activities in the case of Kaikoura it was deemed the only suitable (safe) option in the short term. Adding to reduced effectiveness was the fact that the slopes were dry with very little rainfall in the weeks preceding the quake (heli-sluicing is most effective on already saturated slopes where even small volumes of additional water can mobilize, or keep mobilized, failed slopes). This being said the total volume of water exceeded 152M litres which had a profound effect on the slopes.

Sluice cannons were proposed initially but considered by NCTIR to be too ineffective and the decision was made to use helicopters. The benefit of using cannons is the delivery of high pressure and high volume. Heli-sluicing provides high volume, but only low pressure water delivery. To improve the effectiveness of the heli operations, some operators, especially those from the Central Otago region of the South Island where heli-sluicing is quite common, used modified buckets with a funnel at the outlet to concentrate the flow of water.

After some weeks of heli-sluicing, several of the sites were able to be treated through more traditional manual scaling operations using rope access techniques. The slopes were treated from the top down and typically work only focused on the head scarp area of the failures. This was to reduce the risk to the rope access technicians by limiting their exposure to rockfall further down the slopes, while still managing to create safer work areas at the base of the slopes for protected machinery to operate.

Figure 1: Kaikoura heli-sluicing operations

Extensive manual scaling and blasting began in earnest initially in the southern zone (the area of State Highway 1 south of Kaikoura) where NCTIR saw an opportunity to be able to reopen this section of the road before Christmas 2016. Rope access technicians were flown to the top of the slips and began clearing all large debris from the top down. Blasting was common on hard-to-move blocks, but airbags were more commonly used as a fast and highly effective way to dislodge blocks weighing more than 20 tonnes.

Shortly prior to Christmas 2016 the first heavy machinery was used to clear slip material from the

Figure 2: Before and after extensive heli-sluicing (and some earthworks) on Slip 3 North

road. The initial efforts used remote-controlled excavators, which were originally developed following the 2011 Christchurch earthquakes. This technique provided heavy machinery access into areas where ongoing rockfall presented too high a risk for human-operated machines, even with the most heavily armoured equipment. These efforts, clearing hundreds of thousands of cubic meters of slip material from the road, led to the southern zone reopening for the busy Christmas holiday traffic. Traffic resumption allowed a degree of normality to return to Kaikoura and boosted the local economy which is dependent upon on tourism and holidaymakers.

Heli-sluicing continued at various locations around Kaikoura through until May 2017 dropping over 152,000,000 liters of water with an estimated cost of USD 1.2M per week. Manual scaling activity reduced during September and October 2017 with no further large-scale work undertaken by Christmas of that year. Earthworks were all but complete by Christmas 2017.

3. REEVALUATING THE ORIGINAL EFFORTS

Following the Christmas of 2016, the focus moved onto designing and constructing more permanent stabilization solutions, as well as focusing on reopening the road in the northern zone (SH1 north of Kaikoura). The first durable design, for Slip 6 North Ohau Point, was released to invited tenderers in February 2017. This site was identified as the largest, most hazardous site on the network, and a potential choke point for rebuilding the road north of Kaikoura; due to its sheer size, the significant area requiring treatment, and the high degree of exposure from out-sized rockfall.

Hiway GeoStabilization (HGS), a joint venture between GeoStabilization International and the Hiway Group from New Zealand, (now operating as GSI) were the successful tender winners with work starting mid-March. The solution for this slope was typical for almost all the remainder of slope treatments throughout the Kaikoura region and included pattern bolting and meshing of affected areas. Due to durability requirements, most of the slopes, including Ohau Point, were treated with high tensile steel wire TECCO mesh from Geobrugg which has a superior protective coating.

Completion of the installation at Ohau Point would allow safe access to the lower reaches of the slope that required additional remedial work, as well as significant debris clearance on the highway platform below. Before the meshes' and anchors' installation, significant manual scaling was needed to prepare the slopes and make them safe for access. Again this was typical of all sites in the rebuild. The total area of treatment

Figure 3: Ohau Point, December 2016 (photo courtesy Opus)

on the upper slope at Ohau Point was in the order of 5,600 m2. The lower face, requiring manual scaling and localized rock bolting, had an area of around 12,500 m2. The total area of slopes treated with this same or similar solution exceeded 50,000 m2.

Figure 4: Rockfall barrier adjacent Raramai Tunnels

For Ohau Point, GSI proposed the use of a low carbon, low phosphorous steel hollow bar product as an alternative to the proposed standard galvanized steel hollow bar. The reduced carbon content bar improves both the durability and ductility of the steel, which is critical in a coastal, high seismic environment.

Other sites throughout the rebuild involved very similar designs with local variations in dowel/nail depth and spacing. High angle, high risk, unstable slopes were predominantly treated with dowels/nails and high tensile steel wire mesh while low angle, lower risk sites used dowels/nails and mild steel wire double twist mesh. No sites were treated with dowels alone although several sites were treated with various drape solutions.

In addition to the slope treatments extensive rockfall and debris flow barrier installations were completed in the south with several long, moderate capacity (2000 to 3000 kJ) systems planned for construction in the north zone during 2018. The majority of the systems have been installed at or slightly above road level which reduced installation time and costs. In areas where space was available, rockfall and debris flow bunds were constructed. All these systems have already been proven effective with several requiring emptying and repair following recent (early 2018) rainfall-triggered slope failures. At these specific sites, no material reached the highway.

4. THINKING OUTSIDE THE BOX

Several sites were remediated with unique solutions considered outside-the-box in terms of traditional slope remediation techniques. One of these is Site 14 South where treatment of the source area was deemed not to be cost-effective. A bespoke rockfall attenuator was designed for the site in combination with the early massive scaling and heli-sluicing operations. A sluice cannon was also used at this site, with great effect, to remove more unstable surficial material.

The installed rockfall attenuator is a modification of a Geobrugg rockfall barrier. The structure of the barrier is the same in regards to posts, base plates, and upslope anchors, but varies with a reduced number of lateral wire ropes (no bottom rope is used). The mesh and ring net of the main system is not attached at the bottom and is left to hang down the slope beyond the base of the normal rockfall barrier structure. This provides similar energy absorbing capacity of the original barrier, but allows the captured material to continue downslope to an area where it can be easily removed. These systems are ideal for sites where a high volume of material is expected to impact the system, or where access for future cleaning and maintenance is difficult.

This is the second installation of these high energy attenuators in New Zealand with two Geobrugg 3000 kJ and one 5000 kJ system installed on SH6 at Diana Falls (Haast Pass) following a significant landslide event in 2013. While these systems have required ongoing maintenance due to a very high energy environment, the road has not yet been affected by rockfall since the installation was completed.

Figure 5: Rockfall/debris flow bund at Mangamaunu

Ohau Point was another site where non-traditional solutions were employed. During the early stages of the rebuilding process, the New Zealand Government pledged that up to NZ $2B would be spent to open this vital road and rail link. In addition to this funding pledge, the government pledge that the road would be open by December 15, 2017. The original programme for Ohau Point allowed for approximately three months of construction time including manual scaling, pattern bolting, and mesh installation. Understandably, the client required access to the road and beach platform below in the shortest timeframe possible to enable construction of a new seawall and highway.

Along with this increased pressure from the government and now the people of New Zealand, significant weather delays, unfavourable winter conditions, and challenging & dangerous ground conditions were causing delays in completing the original design work. To accelerate access below Ohau Point, NCTIR requested GSI provide an alternative methodology/solution.

Some options to accelerate the programme for the original solution were proposed; however, after lengthy consideration, all were deemed to be unsuitable for various (mainly safety) reasons. GSI then started to think outside-the-box and suggested some alternative solutions including polypropylene reinforced Gunite treatment of the entire slope.

After careful consideration including material availability and overall programme, the client accepted a ring net drape option to be installed as an addition to the existing permanent pinned mesh solution. Sequencing involved installing the drape system immediately and in its entirety, with tensioned wire ropes across the bottom of the drape creating a closed system allowing access to the beach platform below Then the pinned mesh solution would be constructed. The drape's design included perimeter anchors connected with wire rope, a primary ring net drape over the full 5,600 m2, followed by a secondary high tensile mesh drape over the top of the ring net. Lastly, wire ropes were installed across the base of the system and tensioned.

While in many situations the original high tensile mesh could be installed to act as a drape and no further work would be required, the size of potential rock failures behind the mesh would risk compromising the system. The ring net was chosen to protect against more significant potential failures, and the high tensile secondary mesh installed to contain the smaller material. A 6-on-1 ring net was chosen as it maintains its width when lifted (doesn't choke in the middle) – which is critical when installation is via helicopter. The ring net was installed first as it conforms to the slope better than the high tensile mesh. At the completion of the drape, the pattern bolts of the original design were installed directly through the drape with all components (ring net and high tensile mesh) now forming part of the permanent system.

Figure 6: Installing the drape on Ohau Point

5. LOGISTICS & PLANNING

Undertaking construction work of this nature is challenging at the best of times, even when resources, services, and transport options are abundant. Add to the mix the remoteness of the Kaikoura area, combined with severely restricted services following a major earthquake (including limited transport routes and essential emergency services), and it is easy to imagine the significant logistical exercise these projects became.

Planning for replenishment of materials and consumables required careful consideration of numerous factors, none the least the weather. With construction continuing through the winter, an average week saw the loss of 2-3 work days. The steepness of the terrain in the region means that the majority of the slip sites have only helicopter access to and from the work site. This predestined air delivery of all staff, materials, tools, plant & equipment, and regular replenishing of consumables (such as water and fuel for grouting operations) - a very laborious effort.

While helicopters are great tools in this industry, they have considerable downsides. They are highly dependent on weather for example, and the Kaikoura region is subject to regular low sea fog which inundates the coastal cliffs; as well as strong coastal winds. For safety reasons, work is cancelled for the day if either of these conditions set in since the only emergency rescue option available is via helicopter and being left stranded on the top of the site overnight is not very appealing, nor safe.

With such irregular and uncontrollable delays inflicted on the construction programme, daily and weekly planning takes considerable time and effort. Coordination with local and national providers is essential. Even with the significant improvements to the slip sites, the road south of Kaikoura was regularly closed due to fresh activation of slips. This led to considerable delivery delays and local providers had only limited stock that needed to be continuously replenished.

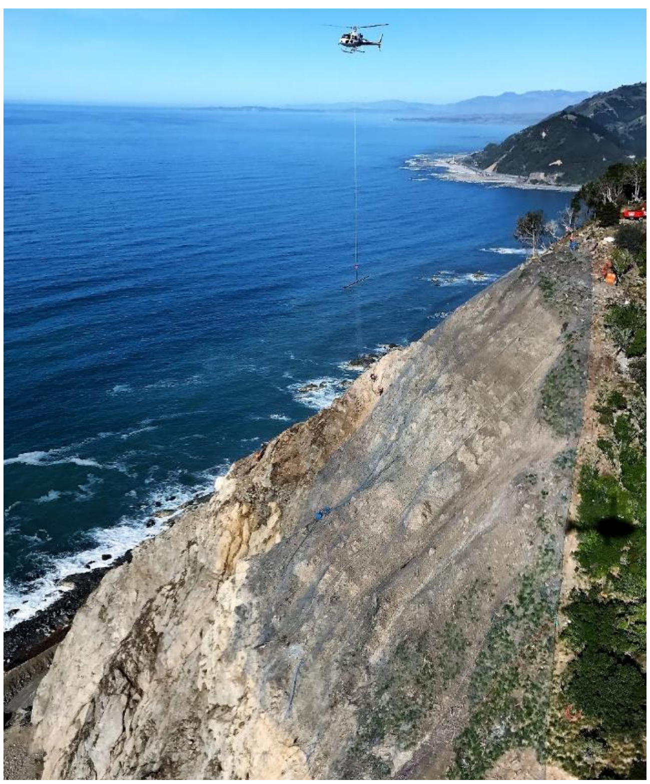

Figure 7: Installing the drape on Ohau Point

For the redesign of Ohau Point, considerable challenges needed to be overcome. The design (by GSI) and review process were completed within one week, and perimeter anchor installation began immediately following. Sourcing of the 6-on-1 ring net resulted in a worldwide search, and eventually, the global supply was exhausted. Suppliers were found in North America and Western Europe, and due to the significant pressure from Government, the ring net was flown into New Zealand on specially chartered aircraft. The ring net installation began three weeks after the start of the perimeter anchor installation.

Further logistical issues arose with New Zealand's supply of shackles, required to connect the ring nets, being exhausted before even the first order was completed. The remainder of the product came from as far away as Europe as Australian suppliers scrambled to maintain stock. This replenishment in itself became a daily struggle, balancing daily quantities of ring net installation with urgent courier deliveries of bags of shackles.

While Ohau Point had significant challenges, these were combined with logistical problems from 40 other rockfall construction projects, over 60 km of road reconstruction, over 1 million cubic meters of earthworks, and rebuilding of 100 km of rail including collapsed bridges and damaged tunnels.

6. SUMMARY

The rebuild of the road and rail networks damaged after the Kaikoura earthquakes has been the largest such undertaking ever in the history of New Zealand. With four of the largest contracting firms in the country combining their resources to form the NCTIR alliance, and a plethora of sub-contractors ranging from bridge experts to rockfall specialists, at times up to 3000 workers have been involved in the rebuild.

Remedial measures have at times been somewhat rudimentary and at others entirely left field from more traditional solutions. During the initial response many decisions were made on the fly in order to simply make the area safe for restricted access, and while longer term, permanent solutions were being designed. Add to this political pressures requiring significant design changes only further complicated the already incredibly challenging task of working in this environment.

While work will be ongoing through 2018 and beyond, the target to get the road open on December 15th 2018 was achieved to the relief of the nation.

Major project milestones:

- 19th November 2016 - Inland Road into Kaikoura open, 5 days after quake
- 12th December 2016 - SH1 south into Kaikoura open (restricted)
- 9th June 2017 - First rail into Kaikoura (from south)
- 8th September 2017 - SH1 north into Kaikoura, safe route under Ohau Point established
- 15th September 2017 - Rail open north and south of Kaikoura
- 15th December 2017 - SH1 Road Open. One year, one month, one day on from the earthquake

7. ACKNOWLEDGEMENTS

Matt Hayes Photography - www.matthayes.co.nz, for the use of photos.

NCTIR for access to work sites throughout the rebuild zones.

South Pacific Helicopters for ongoing helicopter support.

8. REFERENCES

GNS Science, 2016. M7.8 Kaikoura quake the biggest since the Dusky Sound jolt in 2009 - 15/11/2016, GNS media release, 14/11/2016 7:49am

FHWA, 2009. Use of Ring Nets for Slope Protection for Rockfall: End-of-Construction Report. Experimental Feature Study, Geotechnical Report C-7540, SR 28, Rock Island – Rock Slope Nettings.

NCTIR, 2017. SH1- Ohau Point, the last slip in the red zone. September-November 2017 - milestones achieved. NCTIR Newsletter, online release.