Ohau Point Ring Net and TECCO Mesh Drape

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ABSTRACT

Following the M7.8 Kaikoura Earthquake in New Zealand, Hiway Geostabilization (HGS) was 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. During the project's design phase, the ground conditions encountered were some of the worst in the region as the slope was highly affected by ground shaking.

Subsequently the original programme was delayed significantly by the condition of the slope. In order to accelerate access for road construction crews below Ohau Point, a value-engineered ring net drape was proposed by HGS to cover the bluffs' highly unstable upper section. The design, using WASHDOT and FHWA guidelines, was completed and approved in less than a week and required coverage of approximately 5,500 m2 on 40˚ to 80˚ slopes. Key components of the design were the use of a 6-on-1 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 6-on-1 ring nets after materials were airfreighted from suppliers in Western Europe and North America.

Once installation was completed in early September 2017, manual scaling of the 12,000 m2 lower face was initiated using roped access rockfall technicians. The seawall construction team was subsequently provided staged access to the beach platform below Ohau Point; the first people to access this area in more than ten months.

1 INTRODUCTION

1.1 2016 Kaikoura Earthquake

Shortly after midnight on Monday 14th November, a large magnitude 7.8 (MMI8 - severe) quake struck the small settlement of Waiau in North Canterbury, north east of the South Island. 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 quake 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 and 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 range 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 on Kaikoura. These links serve as the South Island's main rail and state highway route. The transport corridor follows the coastal alignment and is constructed on a very narrow bench at sea level. The coastal mountain range rises from sea level up to some 500 metres of elevation. The earthquake triggered a significant series of rockfall landslides with some 40 major slides reportedly dislodging some 750,000 m3 of rockslide; which buried many sections of the transport corridor. The town of Kaikoura was completed isolated for some 2 months 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 hugely supported by the coincidental presence of an international Navy operation which provide airlift and marine support from USA, Canada, Australia and New Zealand.

1.2 Rockfall Mitigation

The highway and rail north were closed for 12 months and a reconstruction team, North Canterbury Infrastructure Repair (NCTIR), was quickly established as a government led alliance, tasked with the rebuild. A deadline of 12 months was established to have the 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 1500 personnel began in earnest in January 2017.

A tender was called for the Rockfall Mitigation works at Ohau Point, the largest and most strategically important of all the rockfall sites. In March 2017, the contract was awarded to Hiway Geostabilization, a joint venture between Geostabilization International from North American and Hiway Geotechnical, a specialist company based in New Zealand.

Figure 1: Ohau Point, December 2016 (photo courtesy Opus)

2 OHAU POINT

Ohau Point is the largest, northernmost, and most significant and challenging rockslide triggered by the Kaikoura event. Strategically this rockslide feature created a pinch point for the construction of a temporary haul route. This site quickly became the highest priority repair site and critical path to enabling the initial haul route to be established. The site is some 300 metres wide at the base and follows a triangular shape with the apex some 300 metre elevation above the roadway. As stated in the project specification (provided by NCTIR), the north face of Ohau Point "comprises closely jointed sandstone and mudstone of the Pahau Terrane deposits, consisting of bedded sandstone and mudstone. Initial helicopter sluicing and scaling of the face revealed surficial soils and boulders below the head scarp with a highly fractured and open jointed rock mass beneath".

Due to the significant damage caused by the November 2016 Kaikoura Earthquake, the slope had been extensively sluiced by helicopter; with additional scaling by roped access crews carried out to approximately the mid-point of the upper section.

3 REMEDIAL SOLUTIONS

3.1 Immediate Response

Following the earthquake, access beneath Ohau Point was not possible, for safety reasons but also due to the sheer volume of collapsed material covering the road and beach platform. The average annual daily traffic (AADT) volume pre earthquake of ± 7000 vehicles.

Having been significantly affected by landslide instability during the November 2016 Kaikoura Earthquake, Ohau Point had been extensively sluiced by helicopter in the weeks following the quake. Scaling by roped access crews along the crest and on the upper slopes of the face was also undertaken as safe access allowed. Even following this treatment, the slope continued to present a significant source of rockfall onto the lower slopes and highway bench below.

3.2 Permanent Remediation

The permanent rockfall source treatment on Ohau Point included high tensile steel wire TECCO mesh from Geobrugg; secured with rock anchors in an offset diamond pattern. This allowed for safe access to the lower reaches of the slope for further remedial work, and debris clearance on the highway bench below. Prior to the mesh and anchor installation, further manual scaling was required to prepare the slopes and make them safe for access. The total area of treatment on the upper slope was in the order of 5,600 m2. The lower face, requiring manual scaling and localised rock bolting, had an area of around 12,500 m2.

The rockfall mitigation design required pattern bolting and TECCO mesh installation over the (assumed, approximate) 3,400m2 upper slope. As part of the contract negotiation, the contractor proposed an alternative anchor bar using T 40 low carbon & low phosphorous steel hollow bar product. This alternative was accepted due to characteristics of lower corrosion and improved ductility of the steel, which in a high level seismic environment is critical.

The original programme allowed for approximately three months of construction time including manual scaling, pattern bolting, and TECCO mesh installation. Understandably, the client was requiring access to the road and beach platform below in the shortest timeframe possible to enable construction of a new seawall and highway.

3.3 Fast Track Stabilisation

With weather delays, unfavourable winter conditions, and difficult & dangerous ground conditions causing delays in completing the original design work, the client requested an alternative methodology/solution to fast track access below the site. In June 2017, the contractor, after considering a number of stabilization options, selected a mesh drape system concept. This option provided the fastest means of stabilising the slope to make the slope safe for the installation team and the road reconstruction team working below. Additionally, after evaluating ways to improve productivity, the site was deemed too unstable to add further drilling equipment as the site would become too crowded. A number of options, involving alternative solutions, were proposed to accelerate the programme. These included,

1. Drape Mesh (Geobrugg S4-130 SPIDER)
2. Drape Mesh (Geobrugg G65/3 TECCO)
3. Drape Ring Net (6-on-1 with 10" rings)
4. Sacrificial Mesh with Gunite (Geofabrics DT mesh)
5. Gunite (polypropelene fibres)

After careful consideration including material supply and overall programme, the ring net drape option was accepted by the client as an addition to the existing TECCO mesh drape design. The ring net was required to contain potential large volume instabilities. A 6-on-1 ring net was chosen as it maintains its width when lifted and placed by helicopter. An important consideration was planning and logistics of the ring net placement in order to minimise helicopter time and cost. The TECCO mesh was installed on top of the ring net to stop small diameter material releasing and creating a hazard to workers on the slope.

This design came with considerable challenges. Including allowance for overlap and wastage, the global supply of 6-on-1 ring net was exhausted, with suppliers in North America and Western Europe providing their entire stock (approx. 5600 m2). The contractors design and review (by NCTIR) was completed within one week and perimeter anchor installation began immediately following. Due to time constraints, materials were air freighted from both Europe and North America. The ring nets' installation began three weeks after the start of the perimeter anchor installation.

4 DESIGN OF RING NET AND MESH DRAPE

It was necessary to make a number of assumptions during the design of the drape. Some of these included,

1. Slope will be partially scaled prior to drape installation:
   - Loose unstable material scaled by hand
   - Some of the large semi-detached blocks will be blast removed prior to drape installation. Some may be blast removed post drape installation.
   - Full slope will be considered rough terrain for purpose
2. Drape system is intended to:
   - Control potential block failures and have these failures retained behind the ring net drape for maintenance and clean-up
   - Control spall of rock down to a size of 30-50mm diameter
   - Provide maximum volume block failure (single failure/per panel) estimated at 2m^3
3. Drape system is <u>not</u> intended to:
   a. Achieve 100% rock fragment containment
   b. Contain soil ravelling
   c. Support the slope during or following significant ground shaking
4. Drape system is of the secured type as system is anchored across the base by wire rope with brake elements

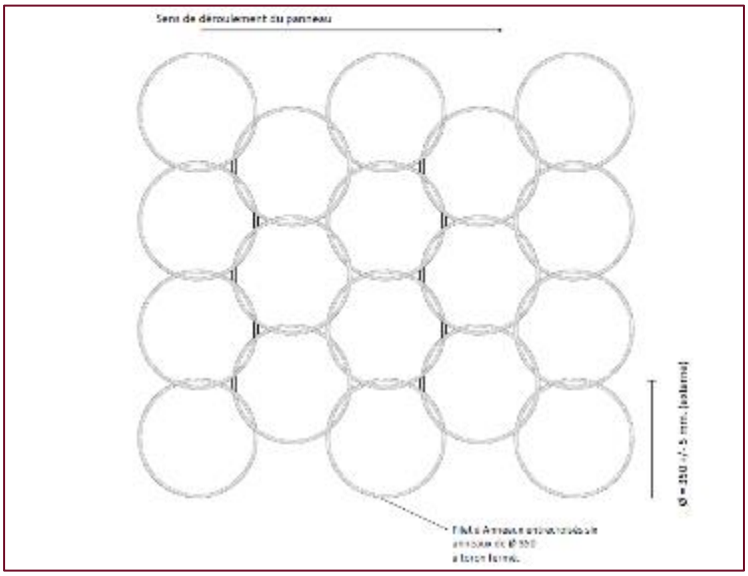

Figure 2: Typical 6 on 1 ring arrangement

Based on these assumptions, and international availability of ring net, the IGOR 6-on-1 ring net was chosen combined with Geobrugg G65/3 TECCO mesh. The ring net was placed on the slope first as this has the higher strength and is more capable of retaining larger blocks should they fail during construction. Additionally, the ring net conforms to the slope better than the high tensile chain link mesh. The TECCO was placed over the ring net to form a permanent solution.

The IGOR D300 ring net is a 300/6 (300mm diameter, 6 strands per ring) with 6-on-1 ring assembly (any one ring has six connected rings). Various panel sizes were used based on what was available from the suppliers (30, 40 and 50 m2 panels). Maximum load bearing capacity of the IGOR net is 340 kN or 30 kN / ring.

The TECCO mesh is made of high-tensile steel wire with an ultimate tensile strength of 1770 N/mm2. The diamond shaped, three-dimensional mesh exhibits homogeneous characteristics with a load-bearing capacity of 150 kN/m in the primary bearing direction (lengthwise). This product also uses Geobrugg's Ultracoating corrosion protection system providing significantly higher corrosion resistance than standard galvanizing. Mesh panel sizes are 105 m2.

Consideration was given to installing the TECCO mesh under the ring net however for two reasons it was decided that the TECCO installed on the outside is most suited:

1. The ring net will conform to the highly irregular slope better than the TECCO
2. The TECCO does not have sufficient strength to retain any potential large volume failures that may occur during the installation process (prior to installing ring net).

4.1 Design

Many factors were considered during the design of the drape. Critical were the components of the system; ring net, mesh, anchor bar etc, but also the slope geology and geometry. The upper slope of Ohau Point is characterised by two different slope angles - the top 35 m of the slope is at a substantially lower angle than the bottom of the slope with a slope angle of ± 35˚ for the top 40 m (surficial soils and boulders) and ± 65 ˚ for the lower 40 m (predominantly competent rock). The frictional resistance (interface friction) of this top section would have a significant impact on the anchor design loads. However, time constraints meant the calculation of this inexact science was not possible. But based on calculations from previous projects with similar slope profiles and ring net types, the frictional resistance on the upper slope could realistically mean there would be no load transfer onto the anchors from almost half of the drape system.

As the consequences of a system failure on the slope were very high, it was decided to include the full height of the drape system in the perimeter anchor calculations. The weight of the combined ring net and mesh was calculated, as was the weight of likely debris loads (from failures) and impact loads (minimal). The total load on the mesh was calculated as,

$$P_{TOTAL} = W_{(DRAPE)} + W_{(DEBRIS)} + W_{(IMPACT)}$$

$$= 274 \text{ kN} + 3{,}100 \text{ kN} + 25 \text{ kN}$$

$$= \underline{3{,}399 \text{ kN}}$$ With an apply factor of safety (FoS) = 1.3 = 4,418 kN

The capacity of the perimeter anchors was calculated at 430 kN based on destructive pull out tests undertaken on site. With a factor of safety of FoS = 2 applied, the load requirements on the 36 anchors was less than half the capacity of any individual anchor. Increasing the redundancy of the system was a second row of anchors (taking the total number to approximately 72each) installed to lift the edge of the drape above ground level and creating an 'open throat' system to catch any rolling boulders from above the system.

Figure 3: 6on1 net (left) and other net (right). Note contraction (necking of other net during lifting. (photo courtesy FHWA, 2009)

5 INSTALLATION METHODOLOGY

The basic construction sequence allowed for the installation of the perimeter anchors and wire rope prior to the installation of the ring net and mesh. The total programme for the installation was delayed due to unfavourable drilling conditions on the site. Two light-weight wagon rigs were in operation working outwards to either side of the crest. To accelerate the overall programme, the second row of anchors was eliminated from the lower portions of the perimeter, these were redundant from a design perspective so this had no detrimental effect on the system's performance. Also to accelerate the programme, the ring net installation began before the completion of the perimeter anchor installation. This increased the resource requirements on the project as two drill rigs were in operation as well as a full grouting crew plus the drape installation crew.

Figure 4: Acceptance testing of the perimeter anchors.

A critical part of the drape's installation was the ground crew. The logical and organised preparation of the ring net and mesh panels was essential to a seamless installation process. Different size panels were required at different times based on the slope's profile of the slope. With a turn-around time of approximately 8 minutes between hoists, clear communications between the helicopter pilot, installation crew on the slope, and the ground crew was critical. All panels were pre-shackled on the ground to accelerate their installation on the slope. As a measure of the scale of the operation, as well as the global supply of ring net being utilized, the shackles consumed on the project exhausted the Australasian supply three times over. The project required weekly supplies of air freighted product delivered from Australia.

5.1 Perimeter rock bolt and wire rope installation

The perimeter anchors were installed up to 6.0m deep with a socket length of 2.0 m required into competent rock. Grout take on the holes was highly variable, with between theoretical volume up to in excess of 3000 litres per hole. Light-weight wagon mounted drill masts were used, running on a combination of pneumatic and hydraulic drives. All power plants for the rigs were located at the top of the bluff in a secure working area with two 375 cfm compressors providing air flush. With access to the site restricted, all materials, consumables, and fuels were delivered daily or as required by helicopter.

Figure 5: Helicopter installation of the ring net

A single 20 mm diameter steel wire perimeter rope was connected to each anchor head around the perimeter of the system. This was used to connect the ring net and mesh to the top support anchors. Once all anchors were installed and the grout sufficiently cured, the wire rope was tensioned. The maximum length between end terminations was 30 m in order to allow sufficient tension to be applied to the rope without introducing excessive friction into the system. A secondary 16 mm diameter wire rope to provide load share was installed in short lengths tying the front row of anchors to the back row.

5.2 Ring net and mesh installation

The various ring net panels were 10m long by 3m, 4m and 5m wide. Panels were pre-stitched on the ground with two panels connected together length ways (to create one 20m long super panel). Originally three panels were combined into one super panel. However with the variable wind conditions on site, it was deemed more efficient (and safer) to reduce each load to two panels. The 1.5 ton connecting shackles were installed along one side and the bottom edge of the super panels to accelerate the installation process on the slope. A specially developed spreader bar was fabricated which allowed the pilot to release the panel remotely once placed on the slope to allow for safer panel installation for the rope access crew working on the slope. The panels and spreader bar were attached to the helicopter via a 30 m long line. Using highly qualified and experienced pilots, the panels were flown onto the slope at every available weather window. A total of 23 days were required to fully install the drape system.

Once the drape was installed, three bottom ropes were connected across the base of the drape with rated braking elements installed at the northern end. The bottom ropes were then tensioned to ensure no material could escape the base of the drape should another failure occur.

6 PROJECT MILESTONE

At the completion of the drape's installation, the road crew below Ohau Point pushed a haul road across the raised beach platform. Then for the first time since the earthquake, road crews working to re-open State Highway 1 had access all along the coastal route north of Kaikoura.

"By August 2017, a construction access platform was cut around the hillside, enabling machinery to make quicker progress to clear the slip material. For the first time since the earthquake, work crews from both sides of the landmark could work together."

Figure 6: Completed drape showing perimeter anchor connection detail

6.1 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.*