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A mining approach to a civil engineering problem – Sumner Road Re-opening, Christchurch, New Zealand

D.P. Green, P.J. Horrey & M.F. Gibson
Beca Ltd, Christchurch.

M.L. Rogers
McConnell Dowell Constructors Ltd, Auckland.

ABSTRACT

In 2011, rockfalls made Sumner Road near Christchurch unsafe and the road was closed to all traffic. This 2.5 km-long Christchurch City Council operated road, an important alternative route to the Lyttelton Tunnel, sustained extensive damage due to rockfall and retaining wall failures during the 2011 Canterbury Earthquakes. Reconstruction of Sumner Road by head contractor McConnell Dowell Constructors Ltd began in November 2016 and included excavation of a 407-metre-long rock catch bench blasted from the rock slopes. The project was jointly funded by Christchurch City Council and Waka Kotahi New Zealand Transport Agency. After the rockfall risk had been sufficiently mitigated, repairs to damaged retaining walls, drainage structures and pavements followed. The rockfall catch bench design was informed and refined by 2 and 3-dimensional analysis of boulder path concentrations to ensure that the target level of rock retention would be achieved. This was calibrated with observation of actual rockfall trajectories and behaviour from the preceding scaling works. Catch bench drill-and-blast excavation progress was monitored by regular geological inspections and deformation monitoring equipment. Waste rock was deposited by end tipping from Evans Pass into nearby Gollans Bay Quarry, followed by re-contouring to a final landform. The design and construction of the catch bench and waste rock stockpile were more akin to a mining operation than a roading project, and experienced mining sub-contractors ensured that the works were undertaken safely and efficiently.

1 INTRODUCTION

The Sumner-Lyttelton road corridor in the Port Hills of Christchurch was affected by rockfall, cliff collapse and mass movement hazards as a result of the 2010-2011 Canterbury Earthquake Sequence (CES). The road between Lyttelton and Evans Pass was closed to all traffic in mid-2011, principally due to rockfall hazard.

The objective of this project was to provide stability improvement works that reduced the level of risk to this section of the road and its users. The construction works were undertaken on behalf of Christchurch City Council by McConnell Dowell Constructors Ltd, with Beca Ltd providing design and construction monitoring services to the contractor. Jacobs New Zealand Ltd and Golder Associates (NZ) Ltd were technical advisors to CCC.

Along with rockfall source treatment (scaling) and a mechanically stabilised earth (MSE) rockfall interception embankment, the rockfall risk mitigation works included:

- **Excavation of a catch bench.** A catch bench approximately 13 m wide and 400 m long was excavated into the slopes below the highest section of bluffs.
- **Development of a temporary stockpile in Gollans Bay Quarry.** A temporary stockpile of excavated soil and rock was formed in Gollans Bay Quarry by end tipping of material from Evans Pass.

The catch bench excavation and waste rock stockpiling were undertaken by McConnell Dowell's specialist subcontractors, Doug Hood Mining Ltd, Orica (NZ) Ltd and Inline Drilling Ltd.

The rockfall risk mitigation works were designed to achieve the project-wide Principal's Requirements of:

- ARL-2 risk level or better, based on the New South Wales RTA methodology (Stewart et al., 2002);
- Any rockfall related road closure to be no longer than 3 days after which the road must be able to be re-opened for normal public use at ARL-2.

2 CATCH BENCH DESIGN

The constructed catch bench is nominally 12.6 m wide and 407 m long, excavated into the moderately steep slopes below the most significant bluffs. 2D and 3D rockfall modelling was used to design a catch bench geometry that complied with the Principal's Requirement to retain at least 95 % of incident rock.

The catch bench commences from Sumner Road at approximately 750 m southwest of Evans Pass and rises to the west at a maximum longitudinal grade of 1V to 8H to allow construction access by 40-tonne six wheel drive Articulated Dump Trucks (ADT's). The catch bench has a transverse fall of 15H:1V back into the slope to improve the retention of fallen rocks and assist with drainage. The longitudinal slope of the bench is sufficiently shallow to mitigate the risk of boulders rolling along the bench.

The base of the catch bench comprises loose material to absorb impact energies and reduce the number of rocks which bounce or roll out of the catch bench. This involved 0.5 m depth of blasting and ripping below final grade to fracture and loosen the rock. The downslope edge of the catch bench is formed into a lip of in-situ rock nominally 2 m in height on the upslope face to form a natural barrier to retain rolling rocks and enable safe plant operations on the bench.

The bench face was constructed at approximately 65°, based on the precedence that existing cut slopes on the site have performed favourably at similar angles. Aside for local shedding of small rocks, primarily triggered by rainfall, no instability of the cut face was observed during construction. Additional flattening of the cut slope above the upper bench was included at a gully feature near the western end of the catch bench, to reduce the effects of topographic concentration of rockfall at this location.

An additional upper safety bench was also included to retain the upper talus material that might otherwise fall into the catch bench during construction. The width of this upper bench was selected to provide the minimum safe access for the proposed excavators. The primary purpose of this upper bench was to reduce the risk to personnel constructing the catch bench, and it provides limited long-term benefit.

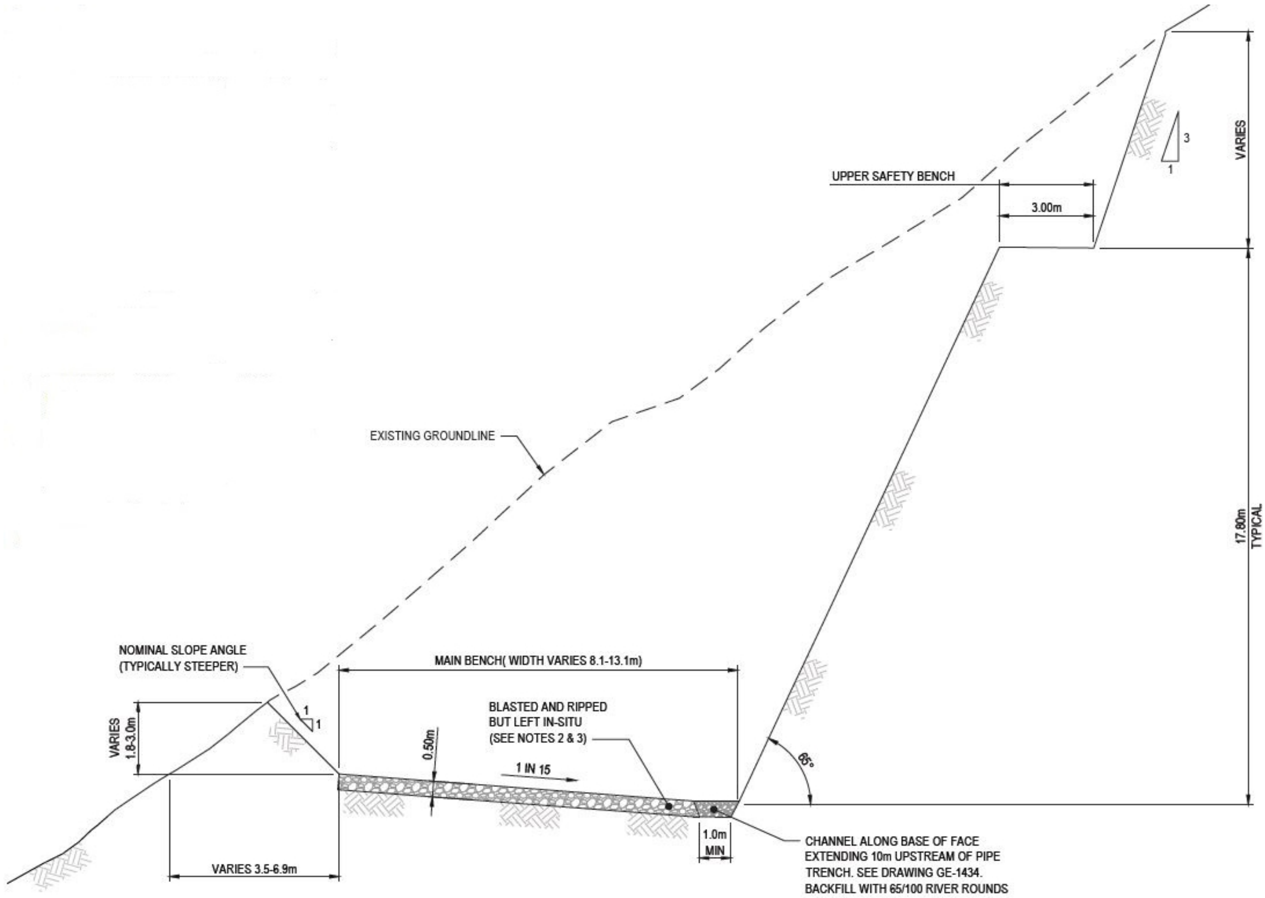

Figure 1: Catch bench typical cross-section

Due to the rockfall hazard no intrusive site investigations were possible prior to catch bench construction. Global stability of the catch bench excavation was assessed by limit equilibrium methods based upon the precedent stability of the slopes during the Canterbury Earthquakes; the only observed instability being discreet rockfalls from the face. Back-analysis of the existing slope using ground accelerations measured during the Canterbury Earthquakes allowed an adequate global factor of safety to be determined for the slopes with catch bench in place under the (lower) design acceleration. An array of remotely monitored tiltmeters operated continuously through catch bench construction to verify the catch bench excavation did not adversely affect global slope stability. This involved thirty tiltmeters located on potentially unstable sections of the bluffs above.

2.1 Rockfall modelling

2.1.1 2-dimensional modelling

2D rockfall modelling was carried out to assess the effectiveness of the catch bench at intercepting rocks falling from the slopes above. This was performed using Rocscience RocFall software. The analysis, undertaken along cross-sections perpendicular to the bluffs above the bench, adopted a design boulder volume of 6 m^3, based on the 95th percentile volume of fallen boulders observed on or near Sumner Road.

Modelling was initially performed using both the GNS recommended parameters (Massey et al, 2012) and the Golder/Jacobs modified GNS parameters adopted for preliminary design (Golder/Jacobs, 2015). We found that the GNS parameters did not provide modelling outputs consistent with field observations for this site, in that more rocks are observed resting on the upper slopes than modelling with the GNS parameters would predict. For the design analysis we adopted a set of parameters combining individual parameters from both these previous sets to provide a model consistent with field observations.

The calibrated 2D rockfall modelling indicated that the design catch bench profile results in less than 5 % of incident rocks passing the downslope edge of the catch bench at any of the modelled sections, demonstrating compliance with the Principal's Requirements for the project.

2.1.2 3-dimensional modelling

An assessment of rockfall behaviour was also made using the RAMMS: Rockfall 3D modelling software, as a cross check of the 2D modelling. This software applies the rockfall trajectory modelling method developed by Leine et al (2013). This 3D modelling was undertaken to provide further insight into the topographic effects that might focus or spread rockfall trajectories in certain sections of the catch bench.

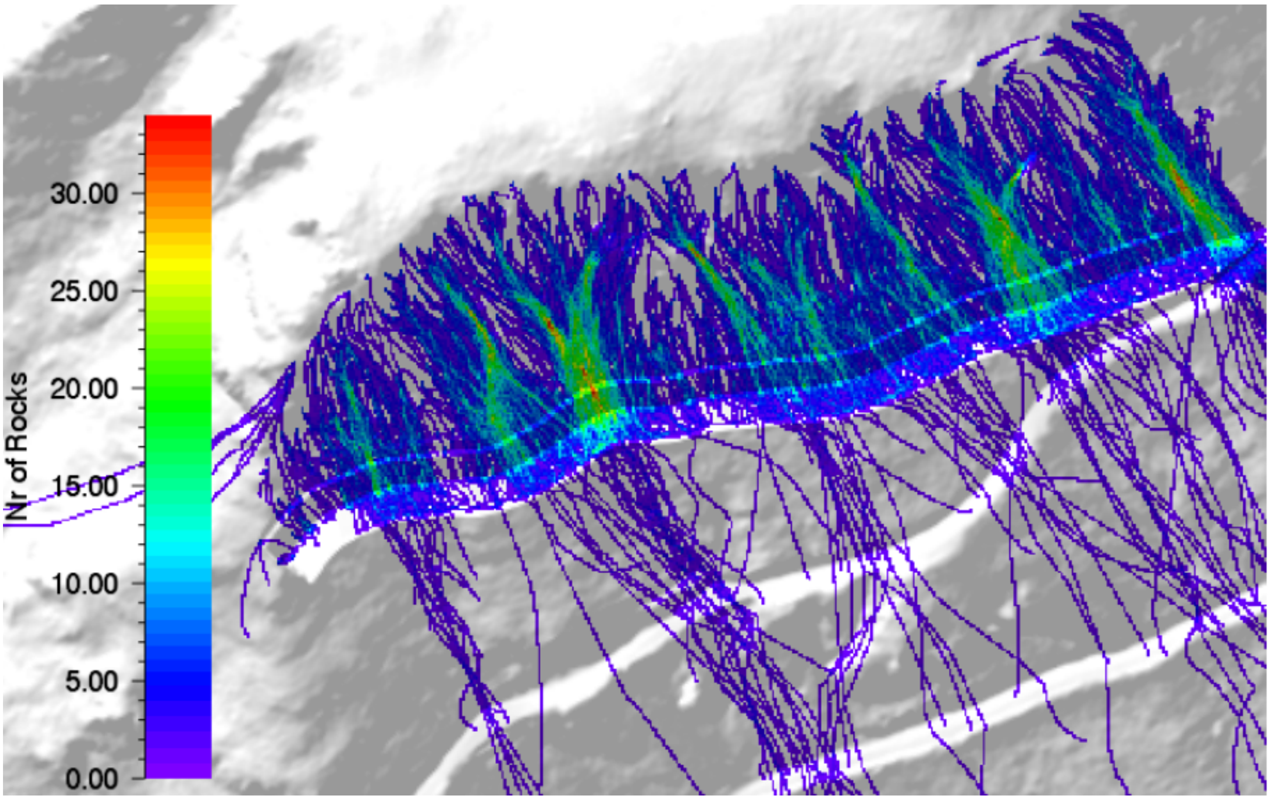

Figure 2: Output from 3D rockfall modelling of the catch bench

Prior to 3D modelling of the catch bench, a sensitivity analysis was carried out using input parameters from published sources, and Beca's previous experience. Based on this analysis, input parameters for the catch bench modelling were chosen.

The 3D modelling indicated concentration of rockfall trajectories in gullies, and fewer trajectories over ridges; local topographic effects consistent with site observations. Although the catch bench is designed to allow only 5 % of incident rocks to pass its downslope edge, the topographic effects mean that the actual number of rocks represented by 5 % of fallen material varies somewhat along the bench.

An area of rockfall trajectory concentration was observed near the western end of the catch bench. This concentration coincides with a gully upslope of the catch bench and resulted in an area where a higher proportion of rocks pass the catch bench in the model. When modelled using the RAMMS software it appears that many of the rocks bounce off the back edge of the excavation and over the catch bench. To remediate this effect, the design included locally cutting the back face of the upper safety bench into the slope. This reduces the ability of falling rocks to bounce directly upslope of the catch bench and over the catch bench, by widening the effective width of catch bench presented to rocks falling at steep angles, akin to 'opening up the baseball mitt'.

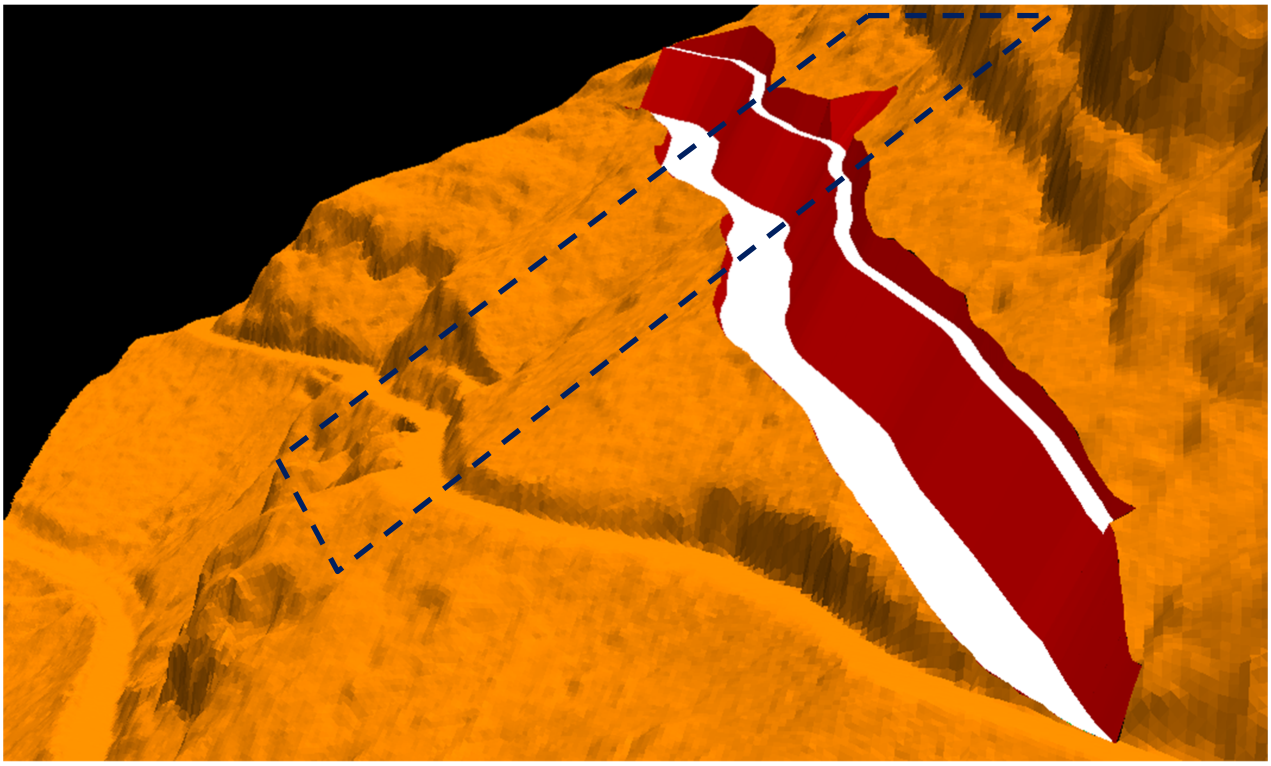

Figure 3: Oblique view of the catch bench as designed. Local flattening of the slopes above the gully feature indicated by dashed area

2.2 Observations of rockfall behaviour from scaling

Video and direct observation of rockfall behaviour based on 'light' and 'moderate' scaling (dislodging large blocks or boulders using bars or airbags) was undertaken to verify the parameters used in the design rockfall modelling. Some general observations were made, as summarised below.

- Video evidence consistently showed that boulders approaching the design boulder size typically break up before reaching the base of the source zone. In fact, very few boulders larger than approximately 2 m^3 were observed to reach Sumner Road without breaking up to some degree.
- In general, rolling, rather than bouncing was observed to be the most common mechanism of downslope travel for boulders, with bounce heights observed to rarely exceed approximately 2 m. This is significantly lower than the modelling for design of the catch bench suggested, where some modelled boulders were shown bouncing clear over the entire bench or directly impacting the downslope lip.
- Run-out distances have been observed to be significantly greater than those suggested by the rockfall modelling undertaken to date, with > 50 % of observed falling boulders from 'moderate' scaling (using airbags to prise large blocks from the rock face) reaching Old Sumner Road (below Sumner Road), and many reaching the harbour. This observation is somewhat incidental though, as the design performance of the catch bench in protecting Sumner Road is not affected by consideration of total run-out distance below Sumner Road.

These observations suggested that the catch bench will perform as well as, or better than, assumed by the design.

3 CATCH BENCH CONSTRUCTION AND PROGRESS MONITORING

Excavation was staged both vertically and longitudinally. A "pioneering" bench was excavated near the top of the proposed cut using a tracked excavator to allow access for drilling equipment. The excavation was then lowered in a series of "flitches" by drill and blast techniques. Initially spoil was passed to a lower ramp level by 30 tonne excavators for removal by the ADT's. Once the excavation reached suitable width and level, temporary ramps were developed to provide haul truck access to the working area for direct loading.

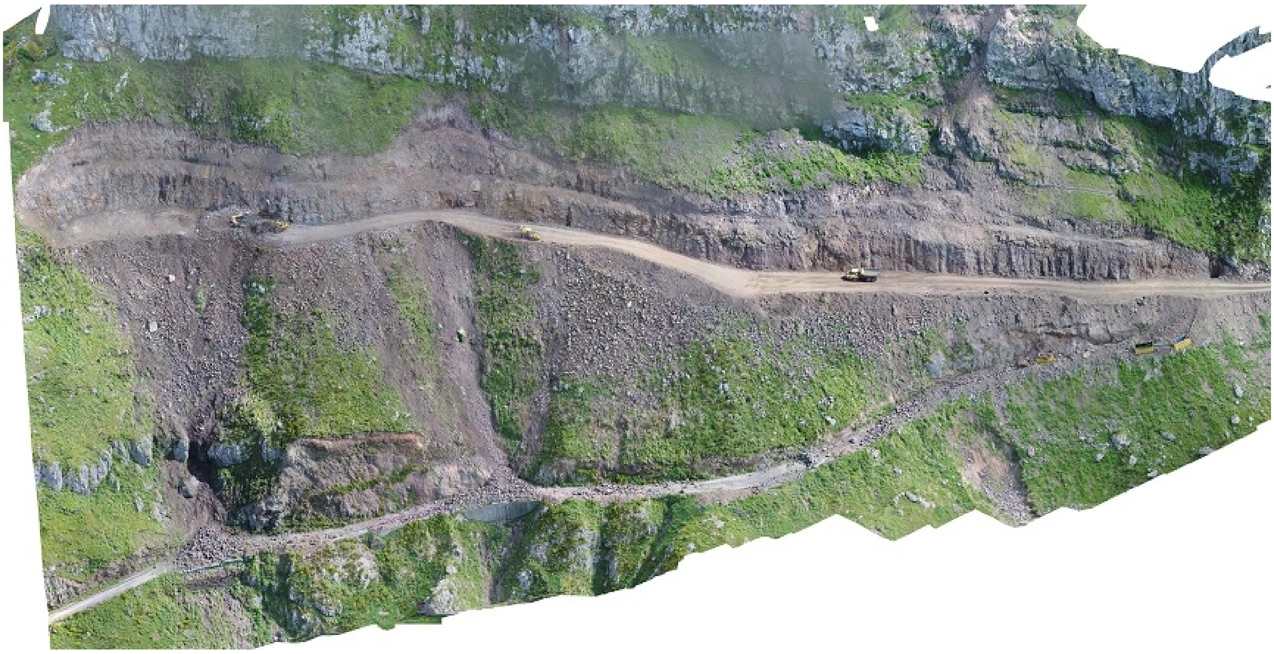

Figure 4: Oblique UAV image of the catch bench during construction

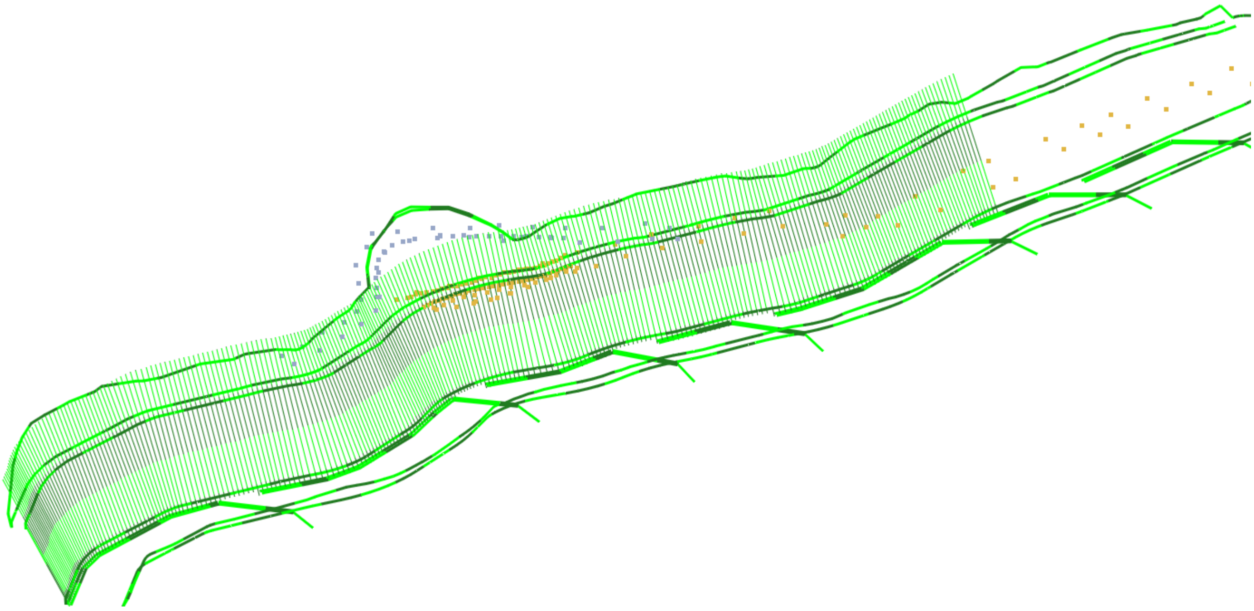

Figure 5: Extract of 3D modelling undertaken using Leapfrog to verify pre-split drillhole conformance with design catch bench geometry. Green subvertical lines are actual drillhole alignments; dashed green/black lines represent the design geometry.

Initially a series of 'pre-split' holes were drilled down the back face of the catch bench, extending deep enough to place charges to 0.5 m below design floor level. Drillhole position, length and inclination data from the field was input to a 3D model using Leapfrog software to compare it to the design geometry. This meant that excavation of the blasted rock could simply follow the line of pre-split holes to achieve the design geometry. In general, excavation works achieved a catch bench geometry within 0.5 m of design.

4 WASTE ROCK STOCKPILE

Catch bench construction resulted in excavation of approximately 83,300 m^3 of in-situ rock and soil. Spoil was hauled back up Sumer Road and tipped into Gollans Bay quarry from tipheads at Evans Pass and along the adjacent quarry bench. This method was used to a limited extent at the site following the 2011 earthquakes to dispose of spoil arising from emergency remedial works. Based on a bulking factor of around 1.35 and a further contingency factor of 10 % a required stockpile capacity of approximately 123,000 m^3 was assumed. Retaining walls had to first be repaired or rebuilt at three locations along the haul route to allow 40t ADT's safe access to the Evans Pass tiphead.

The tipped spoil material initially filled the upper benches immediately below the tipping points, before beginning to accumulate on the quarry floor where it gradually established a natural angle of repose. An overall angle of repose of 33° was adopted in defining the design stockpile envelope.

Enabling works prior to commencing tipping operations included establishment of a permanent rock roll bund along the toe of the stockpile. This was intended to intercept and retain individual rocks which roll beyond the toe of the stockpile. Surface water diversion drains were constructed upslope of the stockpile footprint, with a contact water collection system and sediment treatment pond constructed in the quarry floor to meet consent water runoff quality requirements. Once enabling works were complete, tipping commenced from selected points near Evans Pass.

The tipping process naturally sorted the material, with larger blocks tending to roll further and come to rest against the rock roll bund. Once an apron of larger rocks developed against the bund this acted to retard the runout for further blocks due to increased surface roughness. While a small number of rocks overtopped the bund and came to rest on the adjacent access road (which was closed during the tipping phase), these were readily removed upon completion. No end tipped material passed beyond the lower access road.

The natural sorting resulted in a ready source of coarse durable material, and some of this was subsequently removed and utilised as erosion protection on other CCC projects around Christchurch.

By using an end tipped methodology similar to a mine waste rock stockpile it was possible to avoid the construction of a dedicated haulage route from Sumner Road to the Gollans Bay quarry floor. Such a route would have required large and expensive retaining walls to achieve a workable gradient, with additional costs to either remove it on completion or provide ongoing maintenance following the approximately 11-month period of tipping and stockpile formation.

On completion of tipping, the spoil material was re-shaped from the top down using a 30-tonne excavator and 40 tonne dozer to provide a flat-topped landform approximately coincident with the pre-tipping RL 154 m quarry bench. Material in the central portion of the stockpile was left higher than RL 154 m as this would still be easily removable by accessing along the bench from the west. This bench provides the initial access for removing the stockpile via the existing lower quarry access road. Re-shaping involved dozing down of material above RL 154 m, and progressive clearance and recontouring of spoil material remaining on higher quarry benches.

The stockpile is a temporary facility with the intention that the material may be readily removed and used in future Lyttleton Harbour reclamation works or similar as required. The stockpile was assumed to remain in the quarry for a period of 35 years, as specified by CCC, and was designed to be stable for this period.

Figure 6: Waste rock stockpile during re-profiling works. A temporary haul route to directly transport waste rock to the quarry would have traversed the steep slopes visible in the foreground.

5 CONCLUSION

Experience from the Sumner Road project has shown that a design approach tailored to the site environment and appropriate construction methods can result in safe and efficient construction phase. The constraints, risks and challenges associated with earthworks in steep rocky terrain can have more in common with open-cast mining techniques than conventional roading works, and the methodologies are directly transferrable. The approach led to clear benefits in terms of construction safety in a rockfall hazard zone; In May 2019, McConnell Dowell won the health and safety initiative award at the New Zealand Minerals Forum for the *rockfall decision matrix*, a trigger action response plan (TARP) incorporating responses to rockfall triggers and occurrences calibrated to actual rockfall observations on the site.

ACKNOWLEDGEMENTS

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