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Analysing Slope Change at Globe Progress Open Pit, Reefton

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ABSTRACT

Airborne LiDAR and photogrammetry data collected across 2014 and 2015 was used to develop detailed digital terrain models and produce slope change models at the Globe Progress open pit mine in Reefton, New Zealand. Coupling of these slope change models with existing geotechnical data from the last eight years of mining allowed the north-east pit wall to be subdivided into four geotechnical domains, to understand the mechanism of failure and quantify the movement along the pit wall. The models were created in Leapfrog software developed by ARANZ Geo, allowing for data processing, measurements and models to be created in a single effective program. The range of maximum slope movement between the four domains is 1.6 m - 3.9 m with the volume of material loss from the pit wall in the order of 1800 m^3 - 4900 m^3. The failure across the domains is controlled by complex geology associated with the footwall of the major gold bearing shear zone. Asymmetric folds displaced by shears across the pit wall cause unfavourable bedding dip orientations, leading to the observed topple and planar failure within each domain.

Keywords: remote sensing, slope change, engineering geological model

1 INTRODUCTION

The use of remote sensing data has become common for assessing change in surface topography, for example the work undertaken by Turner et al. (2015) and Kromer et al. (2015). This work commonly uses freeware such as Cloudcompare developed by DanielGM to compare point clouds, providing the relative slope movement. A different software package known as Leapfrog developed by ARANZ Geo is used to investigate pit wall change at the Globe Progress open pit mine in Reefton, where the north-east (NE) pit wall is actively deforming.

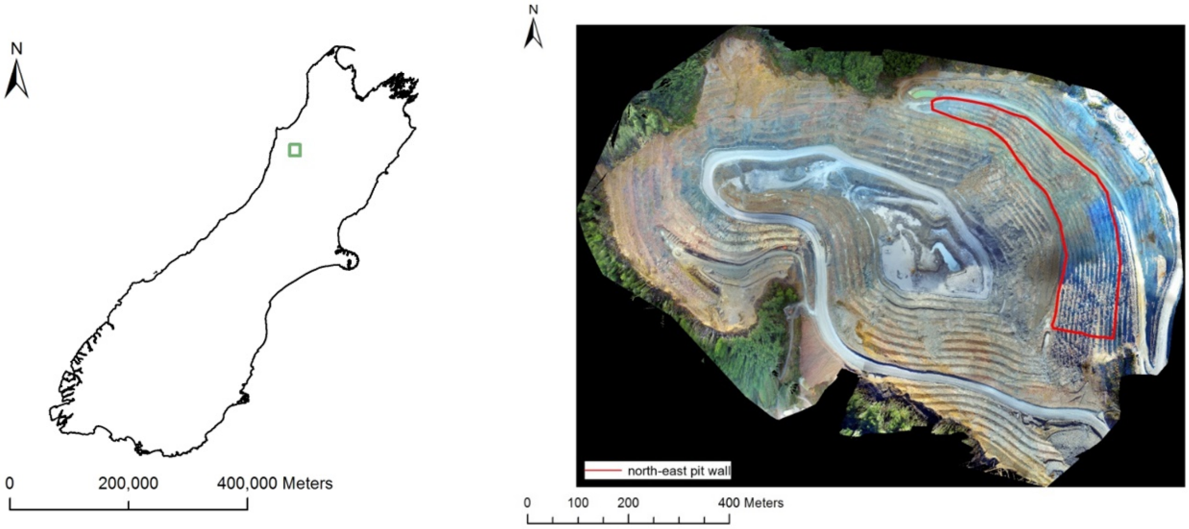
This software provides solutions to solve geological modelling problems through an implicit modelling technique (Alcaraz et al., 2015). Routinely used in the mining industry for exploration purposes, grade control (Stewart et al., 2014) and creating geological models (Rose and Ireland, 2014), the distance function is used to assess slope change between multiple point clouds.

This project aims to quantify slope change of the NE pit wall between successive 2014 and 2015 airborne Light Detection and Ranging (LiDAR) and photogrammetry surveys. A review of existing geological data coupled with the change models allows for the development of geotechnical domains.

1.1 Geological Setting

The Globe Progress open pit mine is located 7 kilometres south-east of Reefton and was commissioned by OceanaGold in 2007 (Figure 1). The goldfield is located within a highly active geological zone. Hydrothermal fluids emplaced ~65,000 kg of gold in typical quartz vein hosted deposits, associated with an east - west shortening event during the late Ordovician early Silurian approximately > 390 Ma (Clark, 1996; Kennedy, 2009).

The mine consists of several open pits developed along a regional shear structure, in intensely folded and sheared greywacke and argillite turbidite sequences (Clark, 1996; Kennedy, 2009). The region receives significant annual rainfall of around 2000 mm (Kennedy, 2009). The area of interest at the NE pit wall is approximately 7 ha, from relative level (RL) 410 to 530 within the OceanaGold co-ordinate system.



(a) *(b)*

Figure 1. (a) South Island, New Zealand; and (b) approximate 7 ha area of interest outlined, from RL 410 – 530 within the NE pit wall at the open pit mine

2 METHODS

2.1 Analysing Slope Change

Georeferenced airborne LiDAR and photogrammetry data supplied by OceanaGold consisted of dense point clouds which were reduced in size using a least squares system approach. This allowed for more user friendly datasets to be compared. The processed point clouds were implicitly modelled into detailed digitals terrain models (DTM) across 2014 and 2015.

The nearest neighbour distance between the two DTMs quantifies the surface movement between successive years and identifies areas which were prone to movement across that time period. This method was adapted for each of the two surfaces in order to measure the 'gain' and 'loss' with reference to the 2014 surface (Figure 2). The 2014 surface was treated as the lower surface, therefore anything which was above this surface was considered 'material gain' while anything below this original surface was considered 'material loss'. All changes are assumed natural in this project.

A Leica TM30 total station was installed at the open pit mine, with 22 prisms located within the area of interest. The vector distances at discrete locations along the pit wall were measured to compare with the point cloud derived model. Radar data was also available for the pit wall; however this is useful for 'real time' measurement and prediction of rockfall across hour to day time periods. A comparison cannot be made between the radar and annually acquired point cloud data due to the difference in temporal resolution.

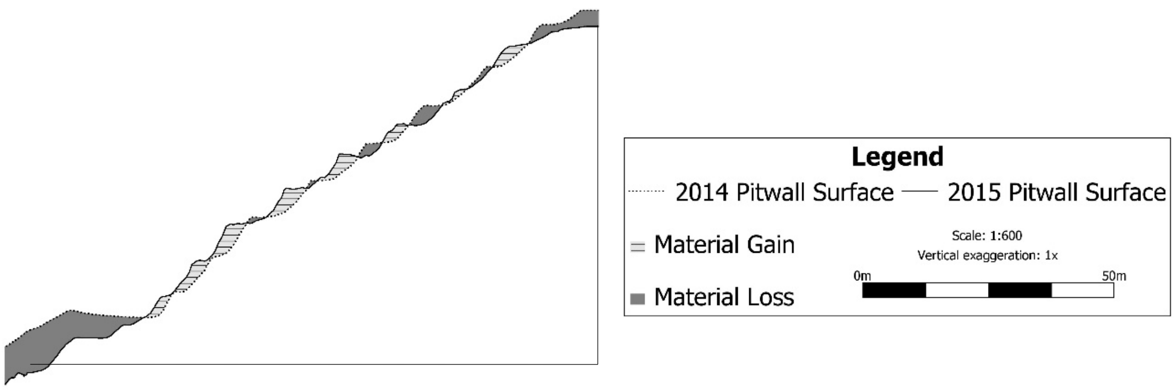


Figure 2. Nearest neighbour measurement of material loss and material gain from the 2014 pitwall topographic surface. Both the volume and distance between successive surfaces was calculated.

2.2 Geotechnical Domain Development

Georeferencing and overlaying the data in Leapfrog enabled the areas of slope change to be compared against the engineering geological review. Leapfrog Mining software was used to fit surfaces to the measured geotechnical data from 8 years of mining, including bedding and joints, to create representative 3D surfaces. This enabled the NE pit wall to be refined into domains in order to accurately represent the movement within these areas. The change, volume loss and failure mechanism could then be understood for each section of the pit wall and better describe the situation occurring.

3 CHANGE MODEL

The change model indicated the absolute loss of material from the pit wall was between 0 m - 3.6 m (Figure 3) across the NE pit wall. The volume lost across the wall is 12,850 m^3. The maximum gain of material was 3.9 m measured as the nearest neighbour distance which could also be influenced by rockfall from above. The total station prisms indicated movement of 0.3 m – 4.9 m in a direction of 150° – 270 °.

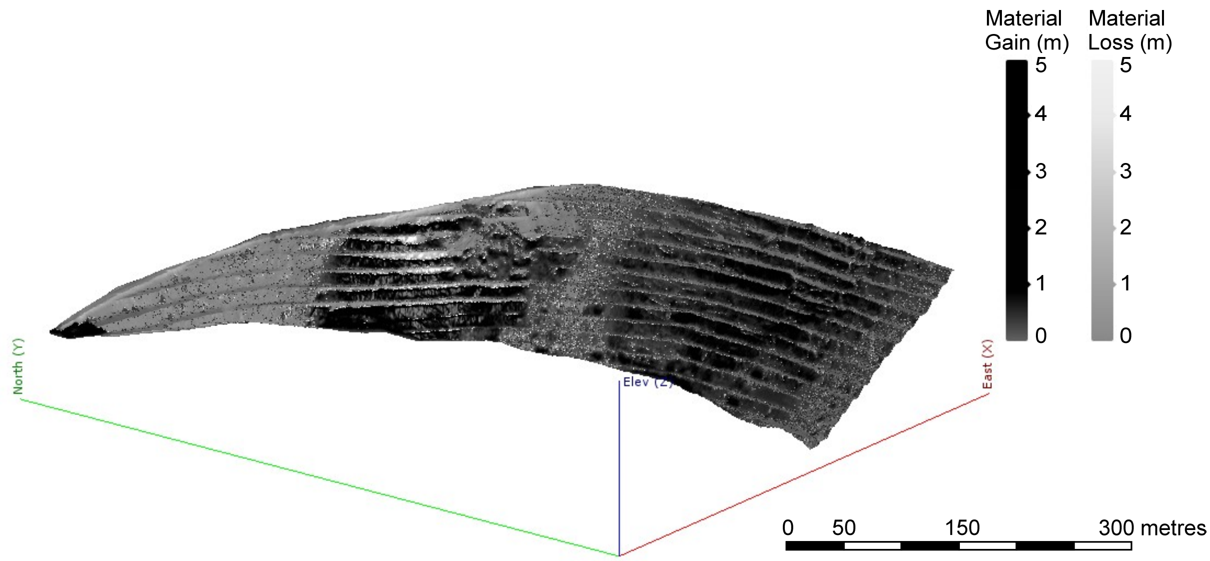


Figure 3. DTM change model developed from LiDAR and photogrammetry point clouds

A comparison of the change measured through each technique shows that similar values are observed across similar areas of the wall, validating each method of measuring the slope change. Advantages of continuous point cloud data include data across the entire pit wall and the ability to estimate volume changes. Disadvantages include shadow areas or occlusion zones through data acquisition and the computer power required for data processing. The lack of spatial coverage across the slope limits prism monitoring, as this does not assist with the interpretation of local complexities within the failure mass

The two point clouds were assumed to be georeferenced correctly with relation to one another and therefore it was deemed unnecessary to validate them as with other similar studies such as Turner et al. (2015). In the future, validation of the two point clouds could be undertaken to ensure any errors in the data are accounted for.

4 ENGINEERING GEOLOGICAL REVIEW OF THE NORTH-EAST PIT WALL

4.1 Rock Mass

The north-eastern and eastern (E) pit walls make up the footwall of the Oriental shear which is associated with greater deformation than the hanging wall with a Geological Strength Index (GSI) of 35 – 50 (OceanaGold, 2015; Golder Associates, 2014). Complex geological structures generally comprising of several tight asymmetric folds trending N – S, with a number of NE – SW striking shears and faults that offset the folds are characteristic of this area (Golder Associates, 2014). Closely spaced bedding surfaces form the dominant structural fabric while less persistent jointing is also prevalent (Golder Associates, 2014).

4.2 Observed Failures

The majority of the NE pit wall is cut along the western limb of an anticline which results in bedding dipping out of the face at approximately 30 – 40°. The upper eastern pit wall is cut through the eastern limb of an anticline resulting in bedding dipping at 60 - 80° into the face (Golder Associates, 2014). Two zones of planar sliding and a large zone of flexural toppling have been observed in the NE and E pit walls (OceanaGold, 2015; Golder Associates, 2014). Planar sliding is associated with bedding surfaces which daylight and dip out of the batter slopes, while toppling is experienced along steeply dipping limbs (~62°) of the anticline structure into the pit wall (OceanaGold, 2015; Golder Associates, 2014).

4.3 Batter Design

The batters at the NE pitwall are designed according to the local structures and failure type. A management style approach, whereby smaller bench scale failures and prevention of deep seated failure is designed for. The areas which are considered susceptible to planar sliding have been designed with an angle of 34 – 38°, while the areas prone to topple have been designed at ~45° and cable bolted allowing a safe and easier clean-up of debris and prevention of a deeper seated failure (OceanaGold, 2015).

5 GEOTECHNICAL DOMAINS

The engineering geological review encompassing data from the last eight years of mining, site observations and associated change models enabled the NE pit wall to be further divided into four geotechnical domains (Figure 4). The domain locations are ultimately controlled by the fold hinges and shears which offset bedding. As mentioned above, the major controls on failure are closely spaced bedding surfaces forming the dominant structural fabric while less persistent jointing of the pit wall provides release mechanisms for kinematic failure. Schematic cross sections illustrating the failure mechanisms are shown on Figure 5. A summary of the change information measured in each domain along with the mechanism of failure provided within Table 1.

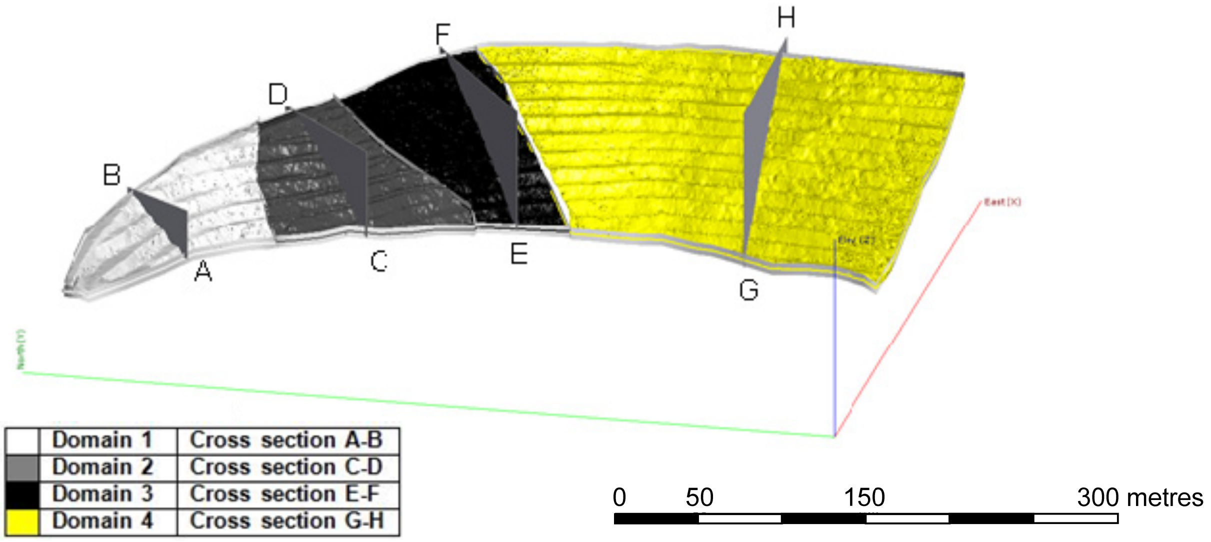
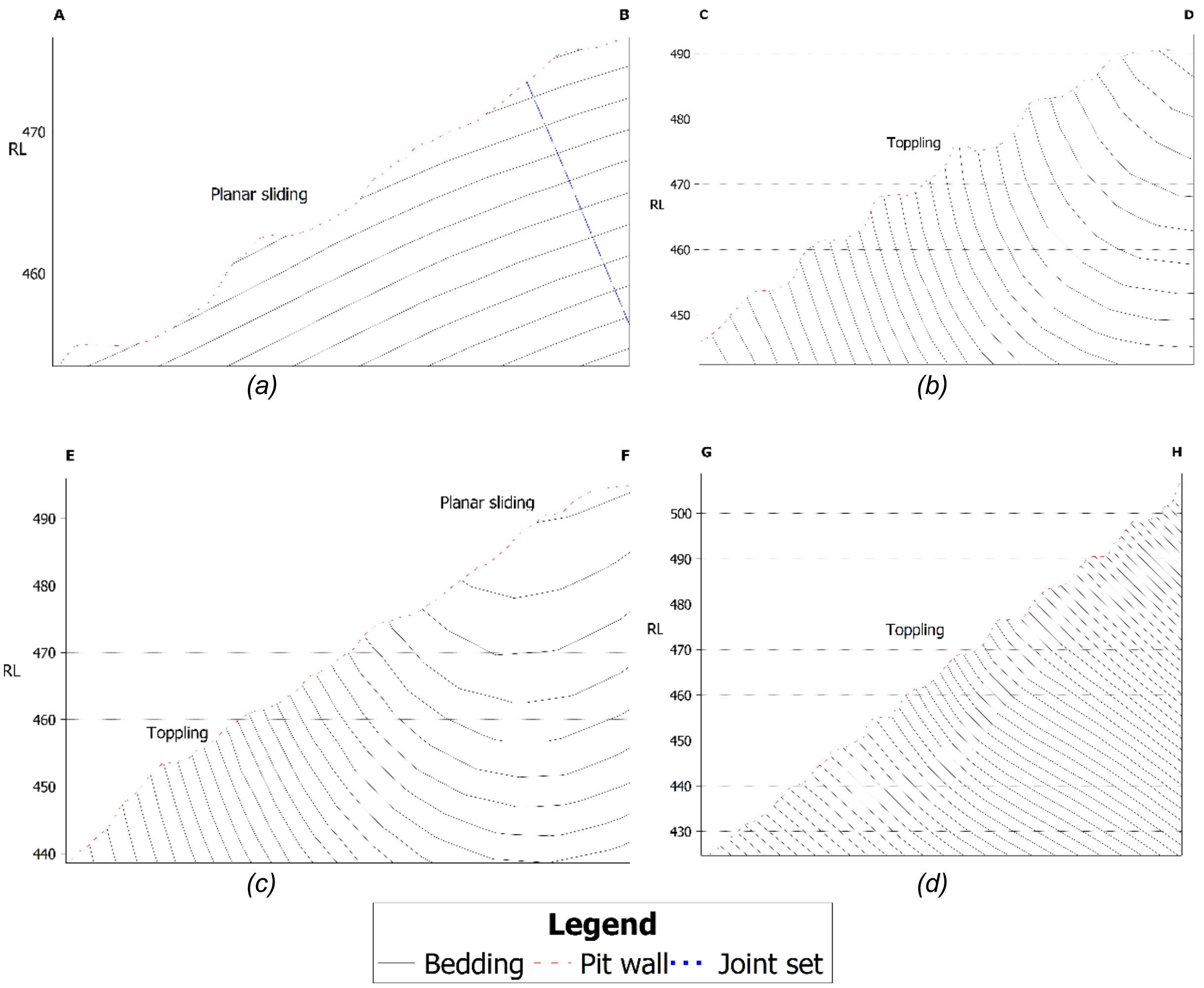


Figure 4. Geotechnical domains based upon geotechnical information and measurements of slope change. Planes show locations of cross sections through each domain.



(a) *(b)* *(c)* *(d)*

Figure 5. Schematic cross sections highlighting failure mechanisms for each geotechnical domain at the NE pit wall – (a) Domain 1; (b) Domain 2; (c) Domain 3; and (d) Domain 4.

5.1 Domain 1

The failure mechanism in domain 1 is planar sliding, giving rise to slope changes of 0.1 m – 3.6 m. Bedding dipping between 35° - 43° out of the slope, with joints dipping steeply into the slope at 56° – 88° provide release planes for planar sliding to occur. The slope change model of this area shows that the majority of the slope surface within this domain has experienced material loss.

5.2 Domain 2

Toppling is the dominant mechanism of failure in domain 2, with slope changes of 0 m – 3.9 m. Bedding dips between 37° – 90° into the pit wall. A failure at lower RL below the area of interest in April 2015 has led to the greatest movement in this zone. Slumping below has created 0.5 m – 0.8 m steps above the zone, with the aperture of toppling between 0.5 m – 1.0 m. The major control on failure is the release of this lower key block which has allowed the bedding to topple in a west direction.

5.3 Domain 3

A complex zone with both planar sliding and topple failure mechanisms present, related to the synclinal hinge intersecting the surface at 480 RL. Lower in the domain below the hinge, the major failure mechanism is toppling which can be seen in the change model with the tops of benches portraying a higher volume loss. The geotechnical model shows bedding dipping steeply into the face between 70° – 80° also corresponding with topple mechanisms. The bedding tends to dip out of the face at a shallower angle approximately 25° – 40° above 480 RL giving rise to planar sliding. We notice on the change model that the entire surface tends to portray loss as we would expect from planar sliding with larger volumes of material moving.

5.4 Domain 4

Domain 4 is characterised by a topple failure mechanism, with movement of 0 m – 1.6 m. Bedding dips steeply into the slope between 33° – 80°. The change models show that movement generally occurs higher on the slope above 470 RL. Again the material loss occurs at the top of benches; while the most gain is found at the toe of the benches.

5.5 Geotechnical Domain Summary

Table 1. Geotechnical domain summary

Domain	Approx. RL top of zone	Approx. RL base of zone	Max. loss slope material (m)	Total volume lost (m^3)	Failure mechanism	Failure control
1	465 – 485	455 – 440	3.2	4960	Planar	Bedding / joint
2	485 – 500	440 – 432	3.9	3160	Topple	Bedding
3	500 – 510	432 – 425	2.8	1890	Planar / topple	Bedding / joint
4	510 – 530	425 – 410	1.6	2840	Topple	Bedding

6 CONCLUSION

Leapfrog software can be used to develop geological models, assess slope movement from both point cloud and discrete prism data which can be useful for volumetric calculations, mine planning and hazard assessment. Change models could be useful during mine works in order to update and develop geotechnical models, as well as contributing to rockfall and hazard assessment. Volumetric calculations could be undertaken at the same time in order understand pit wall movement.

At the north-east pit wall of the Globe Progress open pit mine in Reefton, slope change models and geotechnical information collected over the last eight years allowed for the development of geotechnical domains. Each domain has a different failure mechanism which is ultimately controlled by the complex folding within the area. The orientation of asymmetric fold structures with limbs dipping between 30° – 60° provide a mechanism for movement. Several shears and faults offset the hinges of such structures which results in the variation of failure mechanisms across each of the domains.

Future work could include comparing point cloud data with mine plans, providing feedback to mine designers as the pit is progressing. Comparison with a mine design mesh could provide valuable feedback to slope designers during mining to understand where the pit wall is different to the design.

7 ACKNOWLEDGEMENTS

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