3D terrain and geological modelling for the design of a cut slope in Wellington

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ABSTRACT

A 3D terrain and geological model has been used to assist in the design of a cut slope for a proposed house in Wadestown, Wellington. The natural slope of the site is ~30º and consists of colluvium overlying fractured greywacke. A 3D geological model was built from site investigation data, a topographical survey, and from point cloud data generated via photogrammetry (utilising photographs obtained by a UAV). The 3D model was analysed using TSLOPE; a 3D limit equilibrium slope stability package. This enabled calculation of the appropriate parameters for design of slope reinforcement.

Keywords: 3D, photogrammetry, slope stability, Wellington, geotechnical, modelling

1 INTRODUCTION

This paper outlines a methodology for deriving the design parameters for an appropriate slope retention system for a largely unmodified, north facing ridge in Upper Wadestown, Wellington. The site was originally covered by sparse bush/scrub that was cleared before investigations commenced. The site slopes much more steeply to the north-east than to the north. It is the north facing part of the site which will be excavated to accommodate a house over three levels. (Figure 1)

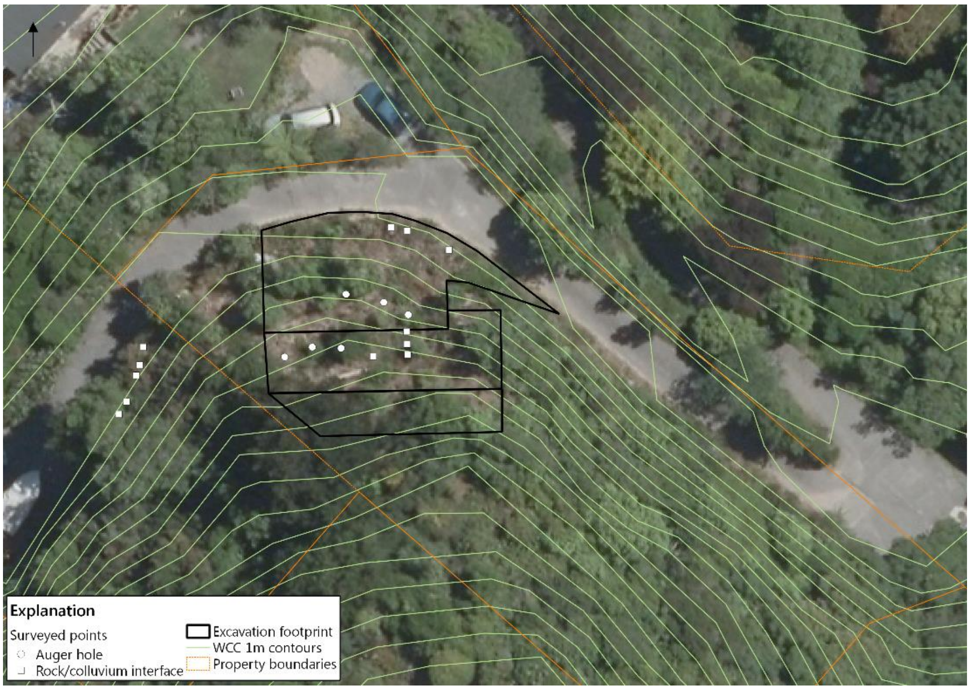

Figure 1. Topography, auger holes and surveyed rock/colluvium contacts

2 DATA ACQUISITION

A topographical survey of the pre-existing slope at the site was provided by the client. A site visit to examine the outcropping rock along the existing driveway cut revealed that as is typically found in the Wellington area varying amounts of colluvium were overlying weathered, fractured greywacke rock.

To investigate the depth and geometry of the colluvium/greywacke interface at the area of the proposed excavation, a bench was cut into the slope and rock was exposed in the southeast corner.

Following excavation, 6 holes were machine augured until at least 0.5m of rock was penetrated. The location of the auger holes and marked points along the outcropping and recently exposed rock/colluvium interface were then surveyed by a surveyor. Fracture orientation within the outcropping rock were measured with a Klaar compass.

After investigations were completed a DJI Phantom 3 advanced unmanned aerial vehicle (UAV) was deployed over the site using Pix4D capture (Pix4D, 2016) to photograph the modified topography. The UAV was flown in autonomous mode to generate an overview of the site, and in free-flight mode to better photograph the face of the cut.

3 MODELLING

The data from the original topographical survey was gridded and triangulated using TECHBASE (MINEsoft, 2016) software to populate a cell table and give an 'original' ground surface.

Using surveyed points from the greywacke/colluvium contact as seen in outcrop, the excavated cut and the augured holes, Leapfrog® (ARANZ Geo, 2016) geological modelling software was used to interpolate the top of greywacke surface.

The photos taken by the UAV were processed using Pix4D (Pix4D, 2016). This program uses geolocation data and photo stitching algorithms to generate a highly accurate 3D point cloud (Figure 2) and an orthomosaic image of the site.

Figure 2. The resultant 22,609,500 point, 3D point cloud showing the excavated bench.

The model is highly accurate internally, however, there can be errors of up to 5m when matching the model to real-world coordinates and elevations. It is therefore often necessary to reposition the model using control points (points with known geometries and elevations).

Using the locations and elevations of the surveyed auger holes as control points, it was possible to align the two point clouds generated from the free and autonomous flight paths with each other, and also with the actual ground surface by picking common points in CloudCompare (CloudCompare, 2016), an open source point cloud manipulation software program.

The topography, as modified by our investigations, was modelled from the UAV derived point cloud giving a 'current' surface. It was necessary to clean the point cloud in CloudCompare by manually removing trees and other 'noise' not representing the ground surface from the model and interpolating a surface from the lowest points contained within 0.5m cells. This gave an accurate topographical surface.

After comparing the 'original' topographic model to the 'current' topographical model generated from the UAV data it was seen that there were inaccuracies to the east in the original model due to lack of survey information in that area. A number of points with x, y and z were picked from the 'current' surface and were added to the original topographic model thus forcing it to reflect the actual topography. It was also noticed that the site had been terraced at some time in the past. Lack of detail in the traditional survey meant that this was not obvious from the 'original' topographic model.

The owners supplied their proposed excavation plans. These were used to set bench levels and dimensions into the 'original' topography by selecting the points of the original topographical model that were within the proposed bench areas and setting their elevations to those of the proposed benches. Batters were calculated by triangulation between these benches. This gave us a 'proposed' final excavation surface.

The area of exposed rock was segmented out of the point cloud using CloudCompare for fracture analysis. CloudCompare generated a stereonet from the point cloud giving us mean joint direction and mean joint angle (Figure 3)

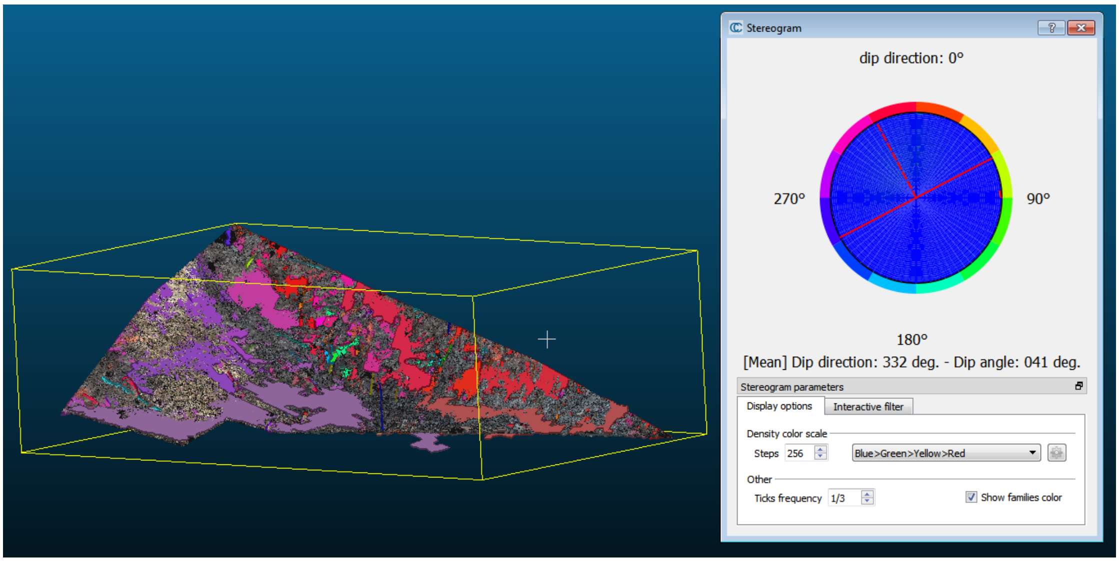

Figure 3. CloudCompare fracture orientation and stereonet

The stereonet results compared well with those compiled from field measurements ([Mean] Dip direction: 316 deg. – Dip angle: 041.5 deg.) Although these measurements correlated well, due to the highly fractured nature of the rock it was decided that there were no clear trends to the fracturing and this will not be used in the stability analysis.

The slope is considered to be 'dry'. There was no indication of groundwater seepage at the various cut slopes nearby, and groundwater was not encountered in our investigation holes, no further analysis was conducted to account for seasonal water flows.

Mohr Coulomb shear strength parameters for the two lithologies were summarised from a literature review of relevant references in the Wellington Region (Table 1).

Table 1. Material strengths

Author	**Material**	**Cohesion (kPa)**	**Angle of friction (degrees)**
Davidge 2007	Colluvium	6	31
	Weathered GW	40	35
Christie *et al.* 2015	CW Greywacke	10-15	35-36
Glue *et al.* 2015	CW Greywacke	9-13	31.6-35.1
Kong *et al.* 2005	Greywacke	30	26
Pender 1980	HW Greywacke	39	33
Pender 1985	HW Greywacke	50.4	33.08

On the completion of investigations and modelling we had; an accurate ‘original’ topographical surface, an accurate ‘modified’ topographical surface, an accurate ‘proposed’ excavation surface and an inferred greywacke/colluvium interface (Figures 4, 5). We also had highly detailed aerial imagery, a segmented point cloud representing freshly cut greywacke and some guidelines for material strengths. We now had the information required to model the slope.

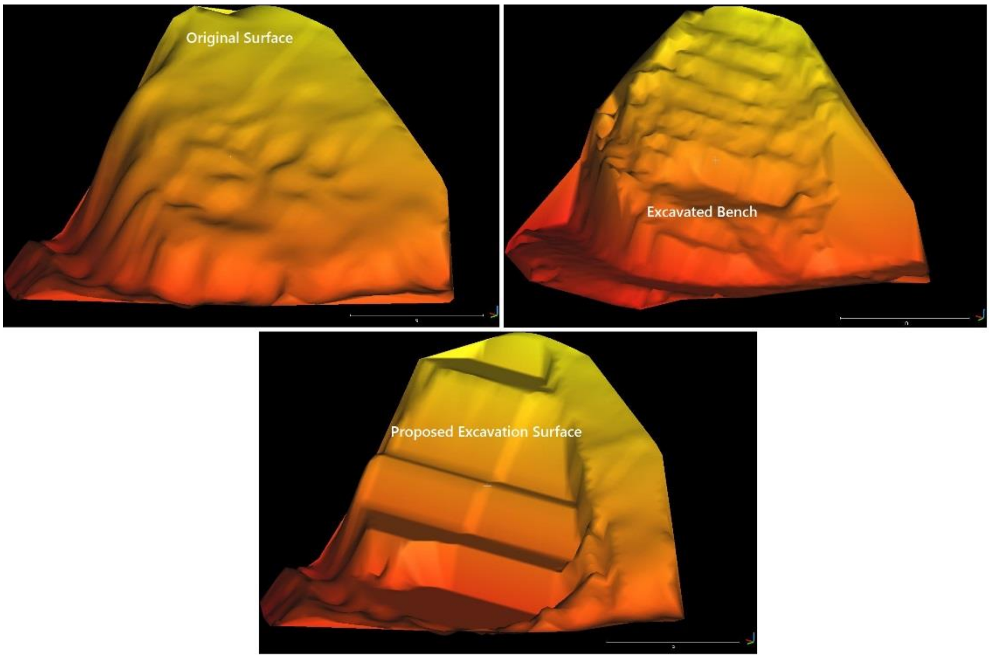

Figure 4. ‘Original’, ‘current’ (showing the bench excavated for investigation) and ‘proposed’ ground surfaces

4 SLOPE ANALYSIS

TSLOPE (TAGAsoft, 2016) a 2D and 3D limit equilibrium slope stability package was used to analyse slope stability. Initially a back calculation was performed to verify the strengths provided by the literature review. The natural slope has been stable for a long period. Following the excavation undertaken as part of the site investigations, the current and unsupported slope has remained stable over a 9 month period.

A stability analysis was performed using the colluvium strengths recommended by Davidge (2007). Figure 5 shows the current slope and the colluvium/greywacke interface located beneath the current surface. Figure 6 shows the slope in cross-section.

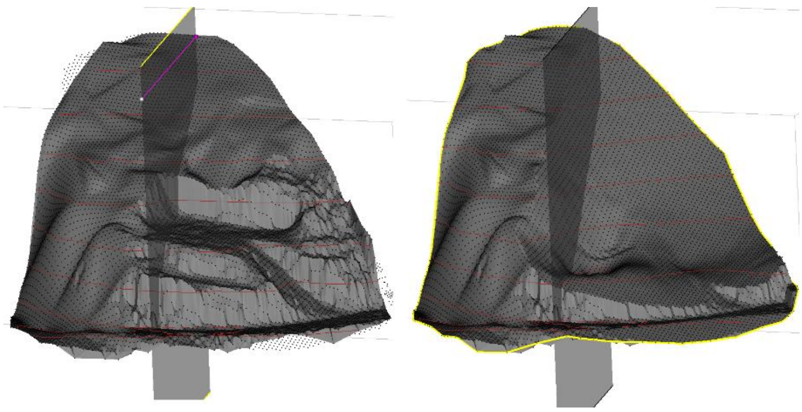

Figure 5. Current slope (left) and GW/CV interface (right), showing cross-section line

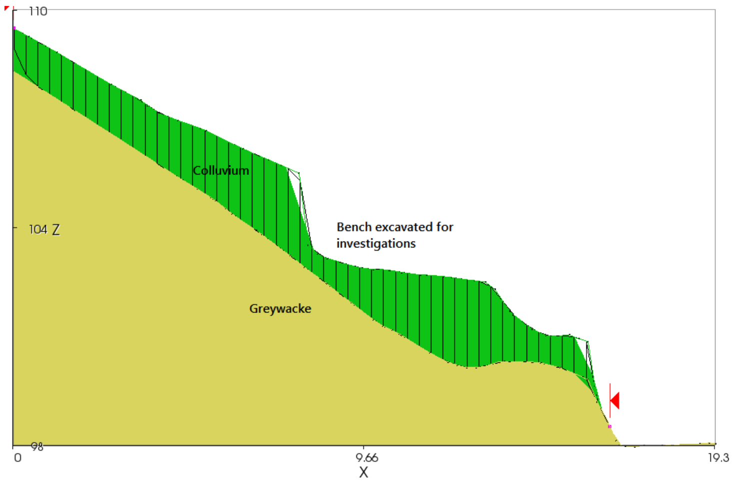

Figure 6. Cross-section showing slope failure controlled by greywacke/colluvium contact

A back calculation was performed using the 'current' slope geometry. The strengths from the back calculation (Figure 7) show that Davidge's (2007) parameters may be non-conservative and therefore inappropriate to use for a forward analysis of the excavated slope. A more appropriate strength to use in forward analyses may be picked from the red line on Figure 7 indicating a factor of safety of 1.0.

Further analyses will be able to inform design of the slope stabilisation system by incorporating the loads that need to be applied. These have yet to be completed.

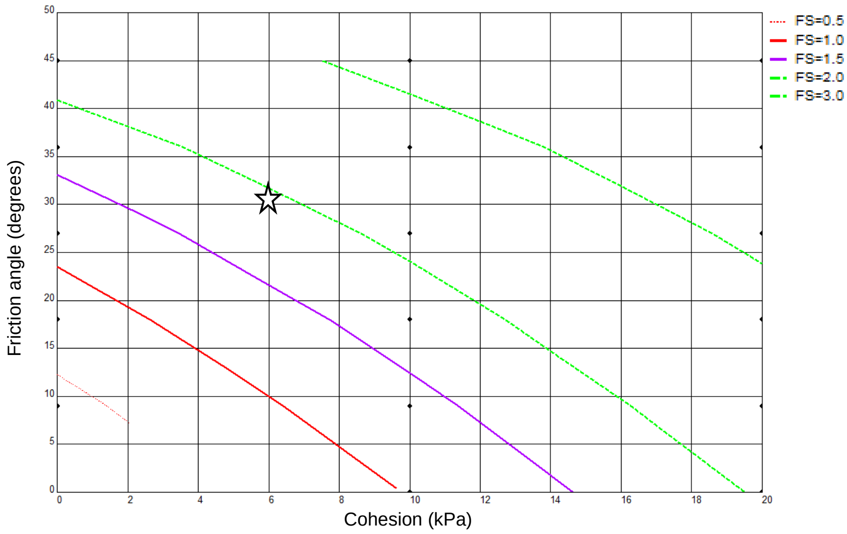

Figure 7. Cross plot of friction angle versus cohesion for a range of factors of safety. The star indicates Davidge (2007) parameters.

5 CONCLUSIONS

Using a UAV to survey a site can provide detailed and valuable information which can supplement or even replace more traditional methods. This method of surveying is fast, highly detailed and relatively inexpensive. Having a highly detailed point cloud/3D model and a high resolution orthomosaic is very helpful for site visualisation.

For the site described, using a model gained from a UAV flight during the process of site investigations allowed us to better predict the material strengths of the lithologies as this reflected a cut slope scenario with batters of a steeper angle than the original slope. This enabled more informed design parameters for slope retention.

When it is unsafe or impractical to access rock faces geological features may be mapped directly from the point cloud, allowing mapping where it may otherwise have been prohibitively dangerous or expensive. In this example, analysis of dip direction and orientation of fractures performed in

CloudCompare gave us some indication of rock jointing patterns and the interface between greywacke and colluvium could be traced.

Being able to work in 3D in TSLOPE, and having a highly detailed topographical surface, made our modelling more accurate. This was particularly relevant in this situation as the greywacke/colluvium interface had a concave dish shape that was dipping out of the slope.

Although the models provided through photogrammetry are very accurate internally, depending on the accuracy called for, or the need to work in a known coordinate system, they may need to be aligned with the use of ground control points.

There are many benefits to UAV surveying and photogrammetry however the best results are obtained given favourable conditions. These include stable weather, few shadows and clear ground. Vegetation can be filtered out of the point cloud to allow for ground surface modelling but this will not be possible for an area under a dense canopy.

The work flow we have developed within this paper will become an important part of future projects. UAV's and photogrammetry have increased the ease with which site investigations may be carried out but the information gained from these methods must still be interpreted and supplemented using sound geological practice.

6 ACKNOWLEDGMENTS

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