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The paper was published in the proceedings of the 11th Australia New Zealand Conference on Geomechanics and was edited by Prof. Guillermo Narsilio, Prof. Arul Arulrajah and Prof. Jayantha Kodikara. The conference was held in Melbourne, Australia, 15-18 July 2012.

Use of 3D geological modelling for site characterisation on a challenging road project in Victoria

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ABSTRACT

The design and construction of the Western Highway Anthonys Cutting Realignment project in Victoria required over 1.3 million m³ of cut to fill earthworks. The excavations were up to 25m deep and penetrated through a mixture of soil and weathered basalt. To assist in the design of the earthworks and construction sequencing a 3D geological model was developed based on a site classification of the engineering geology. VulcanTM was chosen as the software to develop the 3D geological model.

The resulting 3D geological model was a valuable tool for characterising the site geology as well as a visual tool to communicate the site subsurface conditions to the wider project team. A number of challenges had to be overcome in developing the 3D model and a number of beneficial uses of a 3D geological model were identified during the project. The paper will explore how the challenges were overcome and the benefits of 3D geological models.

Keywords: Bacchus Marsh, engineering geology, VulcanTM, ground model

1 INTRODUCTION

The design and construction of a new 5km highway between Bacchus Marsh and Melton traverses over complex and challenging ground conditions. To facilitate the project an engineering geology classification system and a 3D model of the site were developed. A computer software package, VulcanTM, was used to generate a digital 3D model of site subsurface conditions with the road alignment and geometry being imported into the model. Using VulcanTM, a package familiar to the mining industry and rarely used in the civil engineering industry presented a number of challenges which were addressed. The resulting site 3D model assisted in understanding the site subsurface conditions, estimate excavation volumes, communicate ground conditions to wider project team and also assist in developing a digital drive through to show the community prior to construction.

2 OUTLINE OF PROJECT

2.1 Project site

The Western Highway Anthonys Cutting Realignment provides for the construction of approximately 5km of dual carriageway freeway on a new alignment between Harkness Road, Melton West and Bacchus Marsh Road, Bacchus Marsh, including an overpass at Bulmans Road and an interchange adjacent to Woolpack Road. The new highway is located a distance of 52km northwest from Melbourne.

2.2 New alignment

The new highway alignment traverses across topography varying in elevation by up to 50m. The vertical alignment was adjusted to balance the total cut volume with the total fill volume with consideration to minimal haulage distances. The proposed alignment would result in:

- 1.3 million m³ of cut material

- Excavations up to 25m deep and penetrating through mixed subsurface conditions consisting of soil and weathered rock
- Embankments up to 30m high.

2.3 Site Geology

The bedrock geology of the Port Phillip Sunkland and the plateau and ranges to the west of the Rowsley Fault is of Ordovician and Silurian age. They are marine sandstone, siltstone and shale beds and, in total, are kilometres thick. Although predominantly of thin beds and laminates (typically mm to only a few cm thick), occasionally decimetre to metre thick beds of sandstone occur. These rocks form the hills and ranges west of the Rowsley Fault, are exposed in the deeper valleys on the northwest margins of the Port Phillip Sunkland, and comprise the bedrock of the realignment site. They outcrop along the valley of Djerriwarrh Creek and in cuttings on the Western Highway.

The Ordovician sediments have undergone several episodes of deformation and now are tightly folded with the bedding planes inclined at a high to vertical angle. The strike of these inclined planes is approximately N-S although there is local variation. The formation of fractures and partings during deformation has provided conduits for fluids and allowed weathering to penetrate deeply into the rock mass. The NNE/SSW striking Djerriwarrh Fault forms a stratigraphic boundary between the Lower and Middle Ordovician rocks but has no obvious modern topographical expression.

Sediments of both marine and non-marine origin and younger in age than the Ordovician basement rock are widespread near the realignment site. They consist of a range of sediment size and types including seams of brown coal that are mined at Maddingley. Coarse, well-rounded bedrock clasts and vein quartz conglomerates with a sandy/silty matrix in places directly overlie Ordovician bedrock and also occur as lenses inside beds of fine sand and silt. There are also occasional seams of white clay several metres thick. The coarser-grained beds are commonly cross-bedded indicating high energy transport environments. They overlie the finer-grained beds with a marked disconformity.

The age of these beds is regarded as Miocene to Pliocene (between 20 million to five million years old). They are commonly iron-stained and in places are sufficiently cemented to form localised bands of ironstone. They also are locally cemented by silica.

Basalt lavas overlie the marine and non-marine sediments along most of the realignment site. The lavas extruded from numerous eruption locations across the Werribee Plains and around its margins. The lavas between Melton and Bacchus Marsh originated from Mount Bullengarook, Cabbage Tree Hill and Spring Hill. The lavas can comprise of various flow units of different eruptive style. Individual lava flows differ in thickness, geometry and intensity of fractures, spacing and abundance of vesicles, and weathering alteration.

Eruptions commenced on the Werribee Plains over four million years ago and occurred intermittently until about 1.5 million years ago. Outcrops shows pronounced vertical jointing and some with closely spaced horizontal or platy jointing where the lava has segregated into thin sheets. The more closely-spaced the fractures, generally the greater are the degree of weathering and alteration of the rock mass.

Gravels, sands, and clayey alluvial and colluvial sediments overlie the basalts in places and also occur between individual lava flows. The thickness of these varies from a veneer to several metres. They are generally quartz gravels and sands but in places include basalt and sandstone cobbles. In depressions on the basalt surface sediments are more clayey, in part derived from preservation of weathered in situ basalt. These sediments are also iron-stained and in places are weakly iron-cemented.

Anthropogenic (fill) deposits associated with past sand extraction and processing are present between Hopetoun Park Road and Pyrites Creek, consisting of overburden colluvium and washings from the processed sand. The washings range between low plasticity clays, silts, and fine sand.

3 SITE CHARACTERISATION

With a complex site geology and large cuts and volume of material to be excavated, it was considered necessary to develop a geological model to provide information for the design and construction phases of the project. The information had to be in a form easily and quickly communicable to the wider project team. Given the length and width (up to 50m) of excavations, the model was to be developed in 3D and be able to handle data from various sources. Thus the solution for the site characterisation was to develop a 3D engineering geology model in a computer software package called Vulcan3D. Whilst Vulcan3D had limited use in the civil engineering industry in Australia, it has been widely used in the mining industry for over 20 years.

3.1 Data sources

The Bacchus Marsh region is noted for its complex and challenging geology and thus it was important to understand the project geology. This was assisted by a site fly-over, geological mapping, drilling, probing, and test pitting. The data gathered from the various investigation techniques came in borehole logs, test pits logs, maps, and cone penetrometers tests. To complicate this further the format of the logs was different for the four different companies who had undertaken eight separate investigations in the project corridor since 1968.

3.2 Engineering Geology Classification

A project classification system was developed and the engineering geology classes were selected based on the engineering properties rather than their origin. The four primary classes selected are:

- Class A - Materials located essentially above the basalt
- Class B - The basalt
- Class C - Tertiary Age materials below the basalt
- Class D - Ordovician rocks

There are locally transported materials, colluvium and alluvium that have not been included in the project classification. as they are a minor unit and thinly spread out.

Secondary classes have also been developed and are summarised in Table 1.

Table 1 Project Classification of Engineering Geology

Secondary Class	Description
Class A1	Basaltic clay overlying the basalt cap. This material is silty clay that has been formed by decomposition of the basalt. It is usually red-brown, very stiff to hard and reactive.
Class A2	Sandy clay sand and gravel deposited above the basalt, sometimes directly on the rock and commonly above Class A1.
Class B1	Basalt, very high substance strength, widely spaced (average is about 1,000mm) near vertical joints and incipient near horizontal defects at about 300mm spacing. The rock mass frequently contains vesicles which are mostly aligned horizontally. These small holes do not appear to significantly affect the rock substance or rock mass strength. The high angle defects are often open at the surface. B1 basalt forms the capping of the Hopetoun plateau and occasional thin layers at a lower elevation.
Class B2	Basalt, very high strength, vertical joint spacing similar to B1 but the rock mass contains closely spaced near horizontal defects (average 40mm). Vesicles may be present but are not common. The difference between B1 and B2 is the presence of more fracturing with no significant loss in substance strength. B2 commonly underlies B1 but can form the cap.
Class B3	Basalt, medium to high strength. The fracture pattern is similar to B1 and B2 with high angle defects more widely spaced than the low angle fractures. The difference between B3 and B2 is the significantly lower substance strength which may be an original feature of the rock or more likely as a result of alteration after deposition. B3 basalt can underlie

	either B1 or B2.
Class B4	Basalt, low strength composed of interlocking rock fragments or angular fragments in a clay matrix. This material is essentially similar to A1 and represents the decomposition product of basalt. B4 commonly underlies B3 and appears to infill pre-deposition depressions in the previous erosion surface.
Class C1	Clayey sand and sandy clay, light brown and yellow, stiff and dense. Poorly cemented. Underlies the basalt and is exposed in the quarry floor.
Class C2	Silty sand and sandy silt, white, stiff and dense. Poorly cemented. C2 underlies C1 and is exposed in the face of the disused quarry west of the alignment.
Class D	Metasandstone and metasiltstone, low strength within the project exploration, foliated and folded. D is located under the eastern section of the road alignment and outcrops in the lower slopes of Djerriwarrh Creek.

3.3 Site Model Development

Prior to populating the modelling software with the data, the data was re-interpreted in accordance with the project engineering geology classification as discussed above. The re-interpreted data was populated into the modelling software and the software triangulated engineering geology surfaces. Some modification and rationalisation of the dataset was required to 'smooth out' some anomalies in the data. Subsequent to rationalisation and triangulation, the resulting 3D engineering geology was used to provide information to the project team. In addition, the CAD road geometry was imported into the modelling software and cut batter modelled based on the 3D engineering geology class model. The interactive 3D model was also exported into other CAD software packages to calculate earthwork volumes to verify the results from the modelling software. An example of the Class profile from the 3D model is shown in Figure 1.

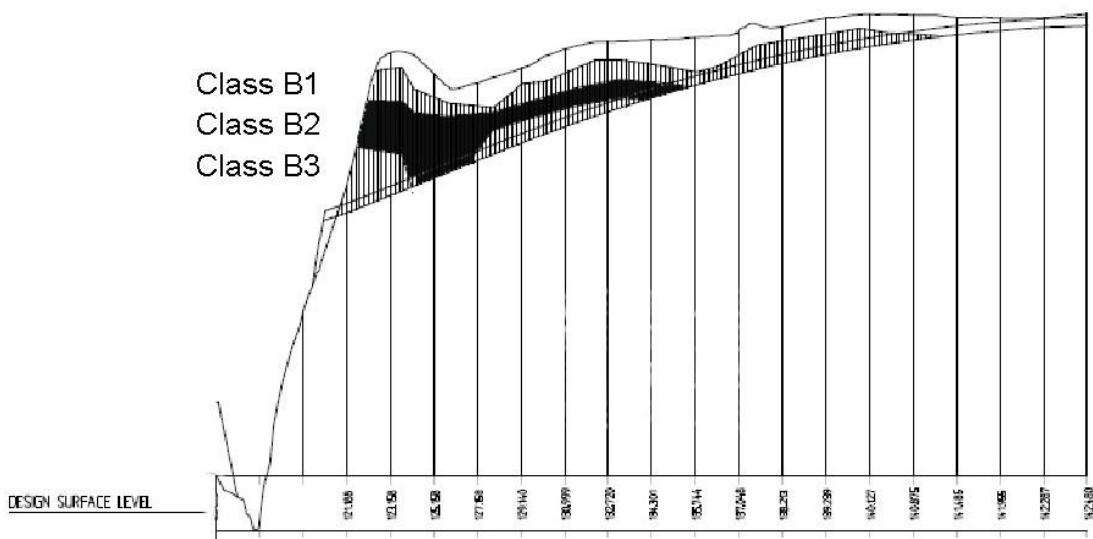


Figure 1 Basalt Class Profile from 3D model

Developing the interactive model with road geometry and project engineering geology classes presented a number of challenges which are outlined below, but also greatly assisted the project to achieve its objective.

3.4 Challenges in developing model

The most predominant challenge in developing the model with Vulcan™ was derived from the transition from mining software into a civil space. The modelling software was developed for the mining industry 20 years to model resource estimates and has had limited use in the civil industry.

However the fundamentals of the software should allow for cross over to the civil space. It is understood that one of the inherent problems with the modelling software is its limitations of modelling structural features. Given the Tertiary age of the main geological units in the corridor which have not been subjected to significant tectonic activity, the limitations to model structural features is not a significant issue for our project. It is understood that add-on packages can be used to address this limitation. This issue should be considered for other projects with significant structural features.

A key output of the 3D ground model was volumes of the various Classes as described in Table 1. Initially, the modelling software was used to calculate excavation volumes for each Class. To validate our calculations the digital model was imported into other project CAD software. These project CAD software resources were then used to create long-sections and cross-sections in the areas of interest and to compute resource estimations on various classes of interest to verify earlier calculations. In our experience, the modelling software was not suitable as a stand-alone software package to calculate excavation volumes. It must be noted that this statement can be qualified by stating that this may have resulted more from inexperience in using the software rather than the software itself.

The model is only as good as the data, the quality of the data, and number of data points. For example, the dataset had over 160 data points for top of basalt, whereas only 50 data points for the base of the basalt. The resulting surface contours for the top and bottom of the basalt looked quite different with the top surface more refined than the base. The reason for a greater number of data points for the basalt top was that data points were sourced from test pits and shallow auger holes that refused on rock. Based on a lack of rock floaters observed in test pits or on surface, it was assumed that refusal of a test pit or an auger hole was on top of rock and not on a floater. The coarseness of the basalt base was sufficient for the project as the excavation only penetrated through the basalt at two locations.

All the geotechnical investigation data collected was only available in hard copy except for the Alliance data. Thus the data had to be re-entered into the software manually. The geotechnical data generated by the Alliance was generated in geotechnical database and easily bulk loaded into the modelling software.

Typically road projects are seen as linear infrastructure and the site investigation should be evenly spread along the alignment. As a result of the deep excavations and dual carriageway, the variation in geology laterally along the alignment was also important to understand and thus it was important to undertake investigations in a grid like spacing (as opposed to linear spacing). This meant a greater number of investigation points although this was constrained by time and budget.

Very late in the design phase of the project a major change occurred in the road alignment at the eastern end of the project resulting in the new alignment sitting outside of the dataset. The project program didn't allow for additional geotechnical investigations and the earthworks in this area proceeded based on an extrapolation from the dataset. The excavations in this area did encounter unexpected ground conditions which were poorer than expected. This resulted in some rock slope treatment work. The treatment work could not be blamed on the ground model.

3.5 Benefits from model

Whilst a number of challenges were presented by developing a 3D engineering geology model, most of these were resolved and the model provided a number of benefits to the project team. Some of the benefits include:

- The model allowed for a quick identification of data gaps, and assisted in developing the scope of work for the additional geotechnical investigations. The data gaps could be identified via space between data points or from the roughness of boundaries developed with the model.
- The model was adjusted for additional geotechnical data or changes in road geometry or alignment. This was important as the project had over 50 road options.
- Data collected by the Alliance was imported into modelling software via a simple bulk load spreadsheet or imported directly from the logging software.
- The model calculated excavation volumes for the various Classes, and the model was exported to other CAD software to verify volume calculations.

- The design cut batter slope was dependent on the engineering geology Class and the model generated cut slopes profiles based on the Classes.
- The model was used to assist staging of earthworks. The cut batters were linked to the classification system. The Class B1 was determined to require blasting for excavation. The model indicated that the Class B1 typically was an upper unit in the basalt and immediately beneath the residual soils. To suppress blasting and control fly rock, the residual soils were left in place and the Class B1 was blasted in place. The depth of the drill holes for blasting was based on the 3D model.
- The model provide a snapshot of the expected pavement subgrade conditions ranging from expansive soils to component rock thus allowing an estimate of the area for each pavement design option.
- The 3D interactive model provided a great visual tool to communicate to the wider team the variation in ground conditions as well as how the project would look. In fact, at tender stage a drive through was generated depicting how the project would look on completion and the cut batters slopes shown in the drive through were generated from the ground model at the time. This drive through was used as a visual tool to show the community how the project may look on completion as well.
- The visual and interactive nature of the model allowed for the geotechnical engineers to work closely with the Earthwork Manager to program the construction earthworks and optimise the earthwork staging to minimise double handling of materials. Although difficult to quantify, using modelling software on this project provided significant time and costs saving for the project.
- The dataset within the model provides a comprehensive collection of data collected from within the project corridor and collected for the project and is easily retrievable for future work if required.

4 CONCLUSION

A 3D engineering geology model was adopted to establish a better understanding of the subsurface conditions. Whilst many challenges are presented in using software packages like Vulcan™, it has been shown that with careful management, the benefits from a visual 3D interaction tool outweigh the challenges and can assist in the successful delivery of earthworks.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance from the Alliance partners AECOM, John Holland Group and VicRoads. In particular Simon Keane, Mark Rynhoud, and Cris Gibcus deserved significant acknowledgement for their assistance and input into the 3D model solution. Support was also provided by Patrick McGregor and Neville Rosengren.