

PROCEEDINGS  
2019 AUSTRALIAN GEOMECHANICS SOCIETY  
VICTORIAN SYMPOSIUM

**Geotechnical characterisation –  
managing design and construction risk**

Wednesday, 30 October 2019, 8:00am – 7:00pm  
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY  
**VICTORIA CHAPTER**



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# PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2019 Australian Geomechanics Society Victorian Symposium held on 30 October 2019.

In recent years Victoria has seen significant growth in the construction industry. Investment in both public infrastructure and commercial real estate is growing, and as our cities and infrastructure grow, so too does the need to develop parcels of land with challenging ground conditions. Economical and safe geotechnical design requires efficient and well thought through ground investigation and characterisation to identify and manage ground risks and opportunities.

The 2019 Australian Geomechanics Society Victorian Symposium presents an overview of current state-of-the-art practices, innovation, new research results and case studies relating to geotechnical characterisation with an emphasis on its implications for addressing and managing design and construction risk. The 2019 Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of ground characterisation.

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# Site characterisation along the Shipwreck Coast – two case studies using multiple geotechnical investigation techniques

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## ABSTRACT

Arup carried out geotechnical investigations at two sites along the cliffs of the 'Shipwreck Coast' in 2018. Proposed project works include a cantilevered steel box truss lookout at the existing 12 Apostles Castle Rock lookout (The Saddle Lookout), and a viewing platform spanning the cavern to the north-east of the Blowhole at Loch Ard Gorge (The Blowhole Lookout).

The geotechnical site investigations comprised borehole drilling and imaging, geophysics, and RPAS LiDAR and photogrammetry scans.

The sites are located in the Port Campbell Limestone region, with sub-vertical limestone cliffs up to 60m high. The cliffs are actively receding due to physical and chemical weathering. Erosion of the limestone cliffs has created the Blowhole at Loch Ard Gorge, and the steep cliffs and rock stacks at the Castle Rock Lookout and 12 Apostles area.

Careful characterisation of the structure and lithological units was required to input to a probabilistic assessment of future rockfall events impacting the proposed structures. This paper will present the methodology for characterisation, including site investigation and three dimensional modelling techniques. The paper will focus on how site investigation data was manipulated to inform the risk assessment and foundation design. A summary of the geological characterisation of the two sites is also presented.

*Keywords:* RPAS, LiDAR, photogrammetry, site investigation

## 1 INTRODUCTION

Upgrades to the viewing structures are proposed along the Shipwreck Coast as part of the 'Shipwreck Coast Masterplan'. In January 2018, Denton Corker Marshall and Arup were engaged by Parks Victoria to complete investigations and prepare designs for Stage 1 of the Masterplan.

Arup undertook geotechnical investigations at the sites to inform the design. These investigations complimented a previous preliminary investigation completed at the site by Others.

A multi-pronged approach with a variety of investigation techniques was adopted. The outputs were combined into a three dimensional geological model. The three dimensional model was interrogated for foundation design and cliff stability risk assessments and a geological characterisation of the sites was developed. Risk assessments were ultimately carried out in accordance with the AGS (2007) Guidelines for Landslide Risk Management.

## 2 PROPOSED STRUCTURES

The two proposed structures discussed in this paper include the following:

- The Blowhole lookout: A lookout structure is proposed spanning the rock bridge over the cavern to the north-east of 'The Blowhole' at Loch Ard Gorge.
- The Saddle Lookout: The design comprises a cantilever box structure viewing platform that is proposed to replace the existing viewing platform at the Castle Rock lookout in the 12 Apostles area.

The structure locations are shown in Figure 1.

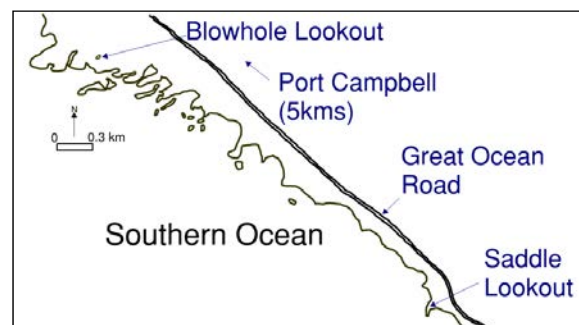


Figure 1: Lookout Locality Plan

## 3 GEOLOGICAL SETTING

The coastal cliffs are Miocene-aged Port Campbell Limestone. These deposits are carbonate materials with soil properties (clay, silt and sand), typically transitioning with depth into carbonaceous claystone (calclutite) and carbonaceous sandstone (calcarene) rock, with occasional zones/nodules of harder, well-cemented material (calcrete). The presence of several subsurface solution/doline/karst erosion features has also been identified. The cliffs in the 12 Apostles area are up to 60 m high.

The Port Campbell Limestone is overlain by approximately three to five metres of surficial clay and sand deposits of the Tertiary aged Hanson Plain Formation.

A detailed geological characterisation of the region is provided in Bird (1993).

## 4 GEOMORPHOLOGICAL SETTING

### 4.1 Saddle Lookout site

The site of the Saddle Lookout comprises a significant north-south trending promontory (Castle Rock) leading from mainland (Figure 2).

Progressive erosion of the cliffs is ongoing and over a timescale of decades to hundreds of years it is expected the Castle Rock headland will completely detach from the mainland and form a new sea-stack; or collapse completely into the ocean. Some undercutting has already occurred at the wave zone on both the western and southern cliffs.

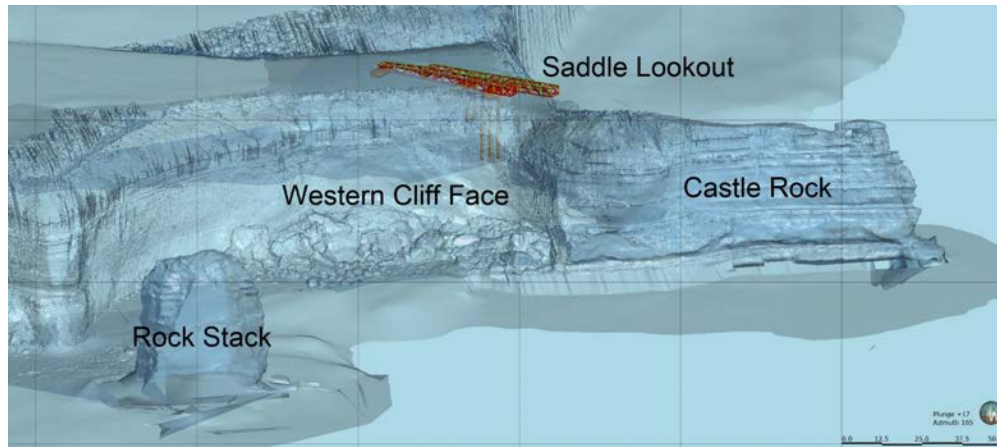


Figure 2. Saddle Lookout (Perspective View)

### 4.2 Blowhole Lookout Site

The site of the Blowhole Lookout is a north-east to south-west trending karst feature comprising a longitudinal tunnel (doline) leading from the ocean to an oval shape opening to the ground surface (the Blowhole) (Figure 3). The cavern continues north-east from the Blowhole where it likely terminates some distance inland.

The cavern was formed due to progressive erosion of the limestone, due to chemical dissolution and wave action. The blowhole itself was likely formed due to weakening of the cavern roof leading to a large scale collapse.

The north-east to south-west trend of the cavern is indicative of the orientation of the regional structural discontinuities in the rock and the development of karst features in this orientation.

## 5 GEOTECHNICAL INVESTIGATIONS

### 5.1 Objectives

The objectives of the geotechnical investigation were as follows:

- Stratigraphic characterisation
- Geologic structure characterisation
- Spatial survey (cliff and cavern geometry)

### 5.2 Completed investigations

To achieve the objectives the following site investigation techniques were adopted:

- Inclined borehole drilling
- Downhole acoustic borehole imaging
- Multichannel Analysis of Surface Waves (MASW) geophysics survey
- LiDAR and Photogrammetric survey by Remote Piloted Aircraft System (RPAS)

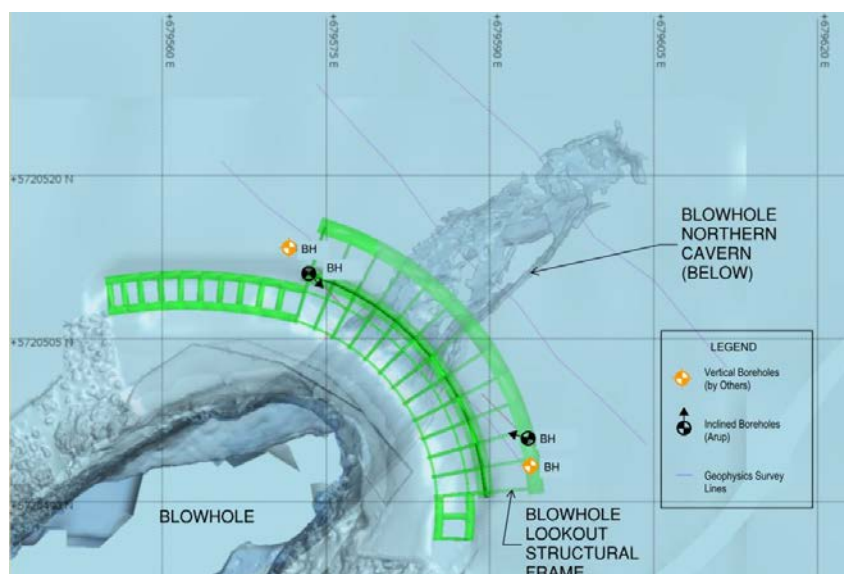


Figure 3. Loch Ard Gorge Blowhole (Plan View)

### 5.2.1 Borehole drilling and downhole acoustic imaging

Seven boreholes were completed (four at the Blowhole site and three at the Saddle site) utilising HQ3 wireline drilling techniques. The boreholes were drilled to a maximum depth of 60 m. (Figure 4)



Figure 4. Inclined borehole drilling at the Saddle Lookout site

The boreholes were oriented 30 degrees from vertical and were angled perpendicular to the cliff faces and cavern crown. The objective of the angled holes was as following:

- Target sub-vertical structures striking parallel to the cliffs and cavern roof
- Penetrate as close as feasible to the face of the cliff and cavern roof to enable structural characterisation at the active eroding face.
- To allow a downhole orientation survey to be completed.

Full core recovery was obtained from all drill holes. It was not possible to orient the core due to the general low strength of the rock mass.

Downhole acoustic imaging was completed to compliment the core logging. The downhole imagery was undertaken using a portable system with a 50 mm probe. The imaging was completed with the holes filled with clean water. The holes were flushed prior to deploying the imaging tool, however some mud smear remained on the borehole walls and the images were obscured in some sections. The objectives of the acoustic imaging was to identify the presence of karst features and to provide accurate oriented information for the characterisation of the structural features.

### 5.2.2 Multichannel Analysis of Surface Waves geophysics surface survey

A MASW geophysics survey was completed at each of the sites. Linear arrays were laid on a grid pattern over the proposed foundation positions. MASW was adopted in preference to seismic refraction survey due to the ability to identify zones of lower density material underlying higher density material; such as is typical in karstic terrain.

The objectives of the MASW survey were to assess the presence of karst features (such as dolines and cavities) beneath the footprints of the structures and to identify pervasive structural features (such as joints and faults) to

compliment the structural geology characterisation from the boreholes.

### 5.2.3 LiDAR and Photogrammetric Survey

The investigation required a detailed and accurate survey of the Castle Rock cliff faces, Blowhole and caverns in order to establish offset distances between the proposed structures.

The primary objective of this information was to inform cliff slope stability risk assessments, however the survey information would also prove useful for architectural design and visualisation.

Geology mapping of the cliffs and blowhole were also required to identify structural features in the rock mass to compliment the structural geological model.

Various methods were considered for acquiring this data including the following:

- Rope access visual survey and mapping
- Land based LiDAR / Photogrammetry data acquisition
- RPAS LiDAR and Photogrammetry data acquisition

A key requirement of the survey was to acquire data from within the cavern beneath the proposed Blowhole Lookout structure. The cavern leading to the blowhole is accessible from the coast, however the swell conditions render boat access unsafe. Rope access into the blowhole would likely be possible, however visibility into the cavern would be limited by the position of the operator and swell conditions would also render rope access difficult.

RPAS LiDAR and Photogrammetry data acquisition was ultimately chosen as the preferred data acquisition method.

To acquire data within the blowhole cavern, the operator was able to manoeuvre the Remotely Piloted Aircraft (RPA) at the blowhole cavern entrance and acquire LiDAR data approximately 12 m past the lip of the blowhole cavern (Figure 5). Photogrammetric survey was not possible within the Blowhole cavern due to low light conditions, but was undertaken on all the light-exposed cliff faces of the Blowhole Lookout and Saddle Lookout sites.



Figure 5. RPAS survey of Blowhole cavern

The photogrammetry survey was performed with a multirotor 'Inspire 2' Remotely Piloted Aircraft (RPA) equipped with a 35Mb digital camera fitted with a Post Processed Kinematic workflow and supported by a base station.

The images were captured as raw data inputs to create an orthophoto and digital three dimensional surface mesh. The geolocated images and ground survey was imported into photogrammetry software to produce the above-mentioned data outputs.

The LiDAR survey was performed with a multirotor 'Inspire 2' RPA equipped with a LiDAR system. A Post Processed Kinematic workflow corrected the RPA's trajectory and referenced the data to the adopted ground control.

LiDAR was captured and processed to create a point cloud. The point cloud was later classified and further processed to create a Digital Terrain Model and elevation contours. The LiDAR data was also used to create a digital three dimensional surface mesh inside the Blowhole cavern.

## 6 DATA ANALYSIS

### 6.1 Photogrammetry images

The high-resolution photogrammetry images were manipulated to generate a highly accurate digital three dimensional surface mesh of the terrain at both sites.

The photographs were also interrogated qualitatively identify the location and orientation of persistent joints or faults, and loose blocks. These structural features were not integrated into the three dimensional model, however they were considered qualitatively in risk assessments and foundation designs.

### 6.2 Three dimensional modelling

The investigation data (borehole data, downhole imaging data, RPAS survey and geophysics data) was imported into three dimensional geological modelling software to enable the development of a geological model of the Saddle Lookout and Blowhole areas.

Structural defects such as joints were visualised as discs and discrete stratigraphic boundaries were modelled. The geometry of the cliff was interrogated in cross section to enable an assessment of the interaction between joints in adjacent boreholes and to assess the cliff geometry relative to the structural defects and lookout foundations.

## 7 GEOLOGICAL CHARACTERISATION

### 7.1 Karst

The geophysics interpretation identifies the top of bedrock at approximately three to five metres depth at both sites, with the bedrock surface generally following the profile of the land surface. There are occasional depressions (dolines) to eight metres depth from surface. There are no abrupt or deep features in the bedrock surface.

While the study areas contain a complex group of solution features, none are more than metre-scale and appear to be filled with less consolidated material than the surrounding rock.

## 7.2 Geologic Structure

### 7.2.1 Bedding

The bedding is observed to be near-horizontal throughout the study area. This is consistent with the regional bedding observations of the Port Campbell Limestone.

### 7.2.2 Faulting

Faulting in the Port Campbell limestone is localised and restricted to small thrust faults with displacements of less than a metre.

Field mapping and geotechnical investigations have not identified any faulting that would impact the structure foundations.

### 7.2.3 Saddle Lookout

Tectonic joint fractures are common and are a major factor in the behaviour of the Port Campbell Limestone and development of landforms. Jointing appears to define the broad-scale configuration of the headlands and embayments and the profile of cliffs and caves and may be the critical factor in determining the modes and frequency of rock mass displacement on the coastal slopes.

Joints in the Port Campbell Limestone are produced by several mechanisms, the most widespread resulting from stresses during tectonic uplift. These fractures may be initiated or amplified by stress release when confining pressures are reduced by denudation of the overlying and laterally confining rock mass.

Joints become obvious as the fracture planes are widened by weathering and deepened by removal of weathered and fractured rock particles: in limestone this in part is due to dissolution of carbonate.

On a local scale, sheeting joint fractures were observed to develop parallel with the cliff face regardless of orientation in response to stress release as part of ongoing coastal cliff recession.

Joint spacing is consistent resulting in even-sized orthogonal fracture blocks apparent in the cliff faces. Many cliffs show smooth or slightly convex outward profiles with thin ( $\pm 1$  m) sheets of rock that develop from stress release as rock confining pressure is reduced as the cliffs erode and recede.

The core samples had a break spacing ranging from approximately 100 to 300 mm and the core appeared considerably more fractured than indicated by the downhole imaging. The majority of core fractures were perpendicular to the core and not observed in the acoustic images. These features were therefore interpreted to be drilling induced breaks. The natural defect frequency spacing was typically greater than 1000 mm. Some minor fractured zones, and a number of short zones of core loss were identified in the boreholes, however no significant fracturing or voiding was identified at the same elevations in the downhole images.

The downhole imaging completed in the three boreholes identified five individual joints. Jointing was tight with no

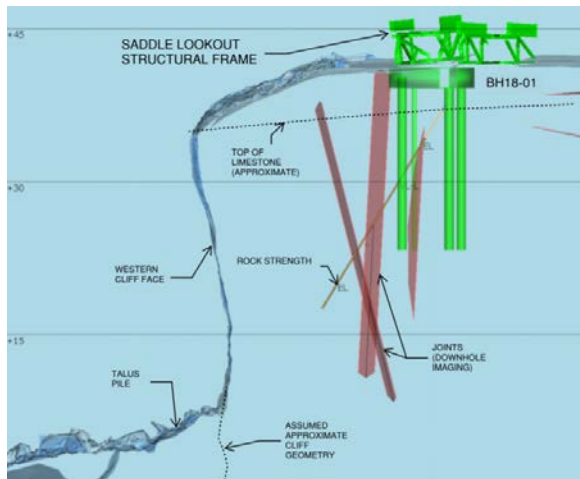


Figure 6. Saddle Lookout Cross Section

observed aperture. Joint sets of a consistent spacing were not encountered in the Geotechnical Investigation.

These joints were plotted in a three dimensional model and are represented as discs at the encountered depth in the three dimensional geological model. The joints are plotted relative to the boreholes, foundation pile group for the lookout structure and western cliff in Figure 6.

#### 7.2.4 Blowhole Lookout

The RPAS LiDAR survey provided an accurate survey of the cavern immediately under the proposed lookout structure and the drilling data enabled identification of structural features

The minimum thickness of the rock bridge directly above the tunnel at the proposed location of the Blowhole Lookout structure is estimated to be approximately 7 m.

Erosion of the tunnel roof will likely occur via a slab failure mechanism where blocks of limestone fail along intersecting joint surfaces. The persistent joint surfaces appear to be a sub-horizontal bedding surface and two orthogonal joint sets dipping at approximately 45 degrees, and striking approximately along the alignment of the tunnel system.

The intersection of the joints defines a lineament parallel to the axis of the tunnel. A sketch indicating the persistent joint sets at the brow adjacent to the proposed lookout structure is shown in Figure 7.

## 8 CONCLUSION

The paper demonstrates a multi-pronged approach utilising a variety of geotechnical investigation techniques enabled a comprehensive characterisation of the two sites along the shipwreck coast.

The paper demonstrates that targeted inclined borehole drilling complimented with downhole imaging is appropriate particularly where the orientation of structural features is required and where orientation information can be obscured in weak rock core.

RPAS LiDAR and photogrammetry is clearly the methodology of choice for acquiring mapping and survey data over a wide area, particularly at sites that involve steep cliff faces and caverns.

Modern three dimensional geological modelling software tools have the ability to import and manipulate a large variety of geotechnical investigation information. The development of a three dimensional model is generally straightforward once the inputs are defined in the correct formats. three dimensional geological models are particularly useful at sites such as those discussed in this paper as accurate visualisation of the complex geometry and structural geology is enabled.

## 9 ACKNOWLEDGEMENTS

Arup wishes to thank Parks Victoria for their permission to publish information relating to this project.

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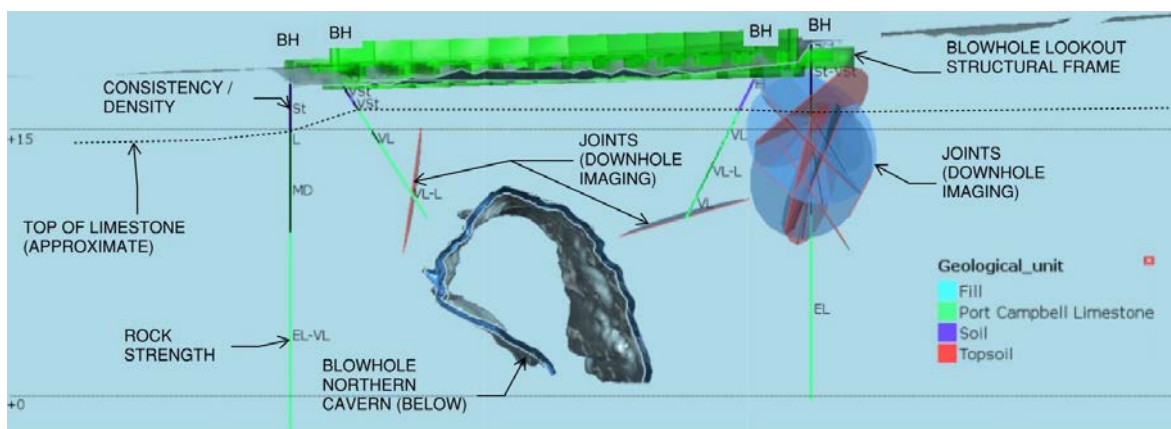


Figure 7. Blowhole Lookout – Cross Section

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