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Inspection of open-pit mine drainage characteristics with a horizontal borehole camera

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Abstract. Horizontal bores and drains are crucial infrastructures for maintaining the stability of large open-pit mines. Induced deformations as the result of mining activities and the infiltration of water from large surface catchments during heavy rain events can cause the build-up of pore water pressures in brown coal batters. This can potentially lead to catastrophic slope failures. Horizontal boreholes and drains are commonly installed at shallow inclines and typically range in length from 150 to 400 metres. Due to complexities in surveying lengthy horizontal bores, the long-term internal properties of these structures are poorly understood. In this research, a specialised horizontal borehole camera was developed to observe a range of factors influencing borehole performance including the identification of fractured or jointed material, borehole geometry and features, and locationally dependent water outflow and drainage paths. Investigations were undertaken at an operational brown coal mine in the Latrobe Valley, located in Victoria, Australia. Features observed on the profile of horizontal bores are discussed, with an emphasis on providing in-situ material characterisation and for the purposes of maintaining stable mine batters.

1. Introduction

The implementation of horizontal drains is a common practice for maintaining slope stability in a range of different environments [1]. However, due to complexities in surveying lengthy horizontal bores, the long-term internal properties of these structures are poorly understood. In this research, visual inspection is proposed as a method to study features inside deep horizontal bores as their full length would be inaccessible by other means. A better understanding of horizontal borehole internal properties can lead to more efficient drainage systems in regards to mine batter stability [2].

The investigation was undertaken at an operational brown coal mine in the Latrobe Valley, located in Victoria, Australia. The age of boreholes varies with a range of 12-15 years for the middle-aged bores, whereas the oldest bores were drilled in the 1980s.

There seems to be limited information available for horizontal drainage methodology in regards to drain monitoring and maintenance [3]. Conventional bore monitoring involves the measurement of groundwater levels before and after installation [4]. For shallow horizontal boreholes, in most cases, a flush of a clean water jet is used to clear the drain from clogging material. In the case where dry materials are clogging the drain (e.g. plant roots, soil deposits), it is necessary to brush the drain during the flushing [5]. For deep boreholes, this type of maintenance can be impractical due to the length of the drains. Therefore, although there is no quantitative data available, it is reasonable to assume, that deep horizontal drains due to lack of maintenance can present a shorter effective life than expected.

This study describes a horizontal borehole camera development, its method configuration, laboratory trial and some of the internal boreholes' properties observed during the field inspection.

2. Methodology

2.1. Site

The Latrobe Valley located in Victoria, Australia has an estimated resource of close to 25% of the world's known brown coal reserves and approximately half of the valley's brown coal is 'potentially economic'. In this region, coal seams are typically located under only 10-20 meters of overburden. Therefore, brown coal lends itself to low-cost large-scale open-cut mining. The Loy Yang and Yallourn mines produce the majority of brown coal in the Latrobe Valley, for the purpose of power generation [6]. Figure 1 shows a typical Latrobe Valley Mine layout.

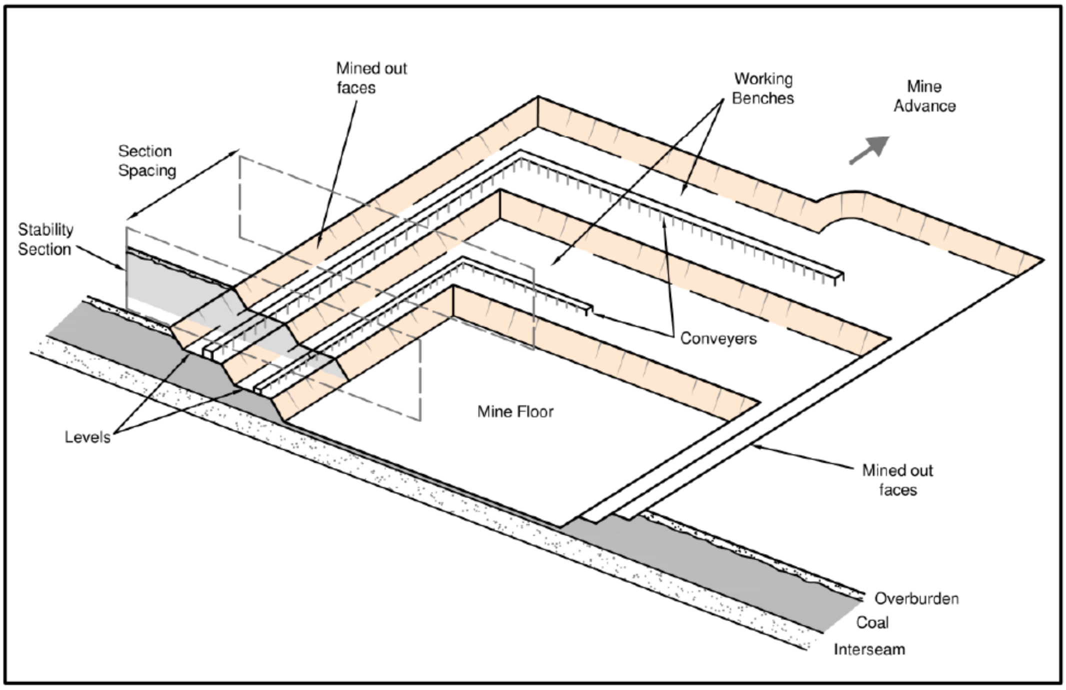

Figure 1. Typical Latrobe Valley mine layout and terminology [7]

As control measures of ground and surface water, horizontal bores have played a long term and essential role in maintaining the stability of mine batters in the Latrobe Valley. At Yallourn mine, for operational safety and stability, horizontal drainage bores are drilled ahead from where the mine faces are. This is done to lower the level of free water and reduce the unconfined water (coal-water) to an acceptable level, and therefore, to ensure the stability before further excavation. Past experiences have shown that maintaining a low groundwater level in the coal seams while ensuring low groundwater pressures in the aquifers and interseam clays below the mine floor are critical parameters for mine batter stability. The impact of high groundwater and interseam pore pressures can cause large scale ground movements leading to slope failure [8].

At the mine site, horizontal borehole lengths vary from about 150 meters to 400 metres. The frequency of boreholes is defined based on stability analysis according to joint pattern or orientation. The horizontal drains are drilled in such a way to ensure intersection within all possible vertical joints to facilitate natural drainage of rainfall runoff that has entered the joints in the coal. In the Victoria brown coal open-cut mines, joints or geological discontinuities in coal seams can control the groundwater flows. The water pressure, caused by the flow and hydrostatic pressures, inside the joints can contribute to batter failure due to a greater active force than the shear strength of the slip surface [9] as happened in 2007 when the northeast batter of Yallourn East Field Mine failed [10].

2.2. Horizontal borehole camera development

Latrobe Valley mine drains often exceed 400 metres in length. For this reason, the use of conventional instrumentation for exploration of drainage systems (such as fibre optic cables and borehole televiewers) is often considered either impractical or ineffective. Due to the considerable length of the drainage infrastructure, coupled with the high-moisture environment of Victorian brown coal, a robust, waterproof camera was designed to inspect the internal characteristics of horizontal boreholes.

The camera assembly was fitted to a PQ drill rod attachment, allowing a horizontal drill rig to insert the camera into the bore. The device was equipped with a protective cage in front of the camera (Figure 2) to prevent the build-up of soil and slurry near the lens, as the camera penetrates the bore. With the addition of the protective cage to the camera setup, the total size of the camera attachment totalled 1.2 metres in length, with a diameter of 90 millimetres. To further prevent a layering of material on the lens, the system was also fitted with a pressurised water jet for the purposes of in-situ cleaning of the camera. To capture video footage, the camera was equipped with a long, durable coaxial cable running along the exterior of the drill rods, terminating at a logging encoder (as shown in Figure 3).

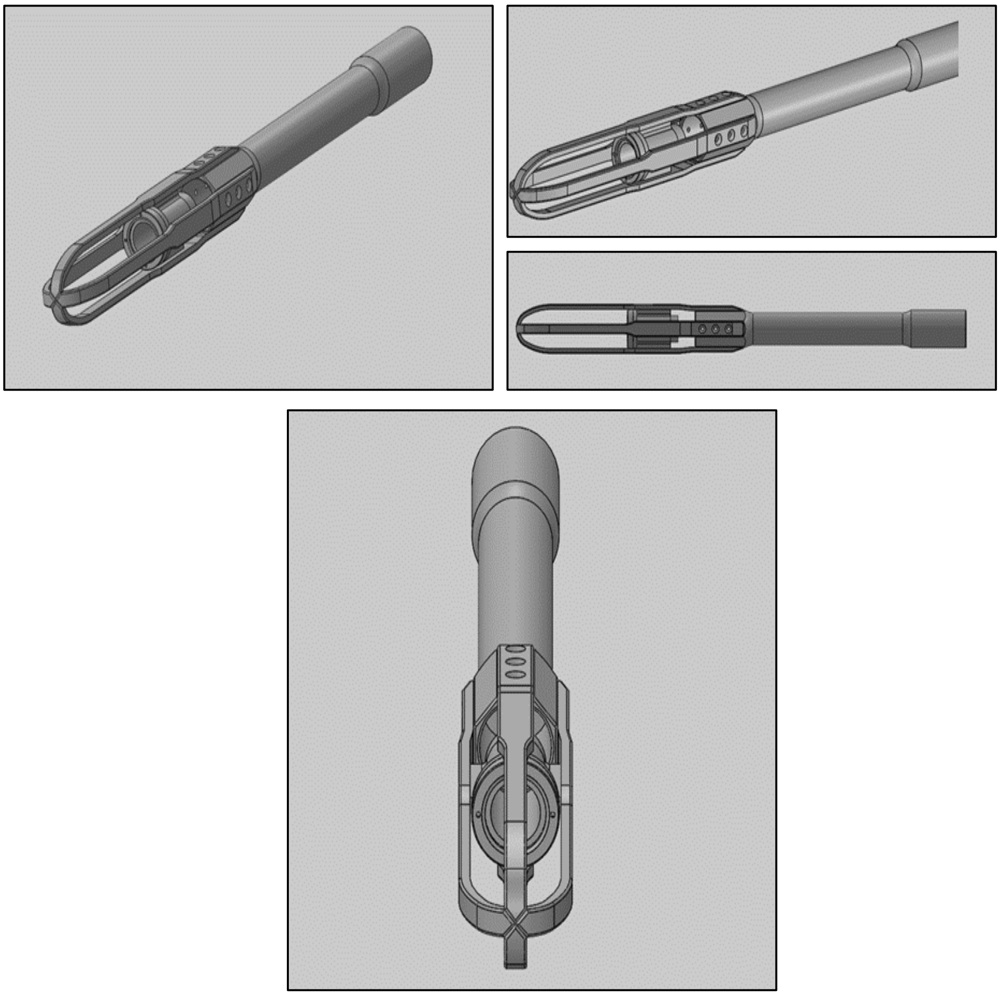

Figure 2. Horizontal borehole camera design

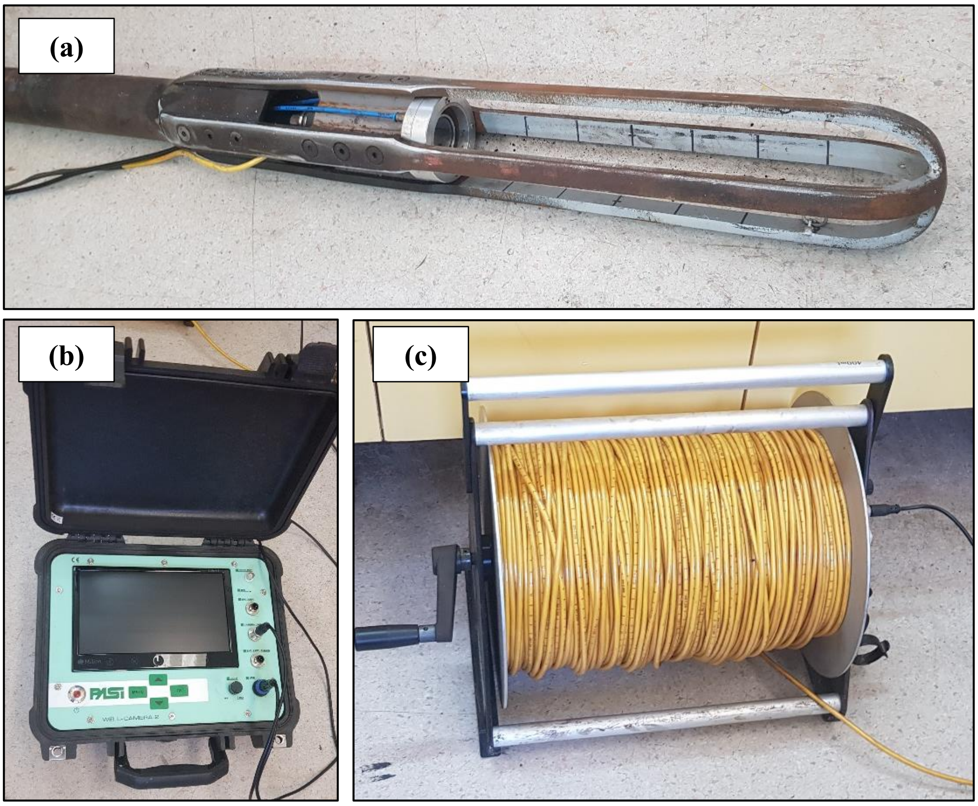

Figure 3. Borehole logging apparatus. (a) Borehole camera (b) Logging encoder (c) cable spindle wheel.

2.3. Camera configuration and laboratory trial

Prior to the field investigation, the horizontal borehole camera was initially tested in the laboratory to determine the capability of the device to detect a range of joint aperture dimensions and orientations. Incisions of various shapes and sizes were made in a polyvinyl pipe, to be used as a sleeve over the top of the camera (Figure 4). Incisions made at angles of 15, 30 and 45 degrees, with widths of 5, 10 and 20 millimetres were considered, simulating a set of potential joint characteristics for fractured coal joints. Given uniformly spaced markers placed on the interior of the protective steel barrier, directly in front of the camera, the angle and size of each of the joints were successfully calculated using simple trigonometry, confirming the ability of the camera to detect joint orientations and aperture diameters. Given the validation of joint characteristics in the laboratory, the camera was considered appropriate for site investigation.

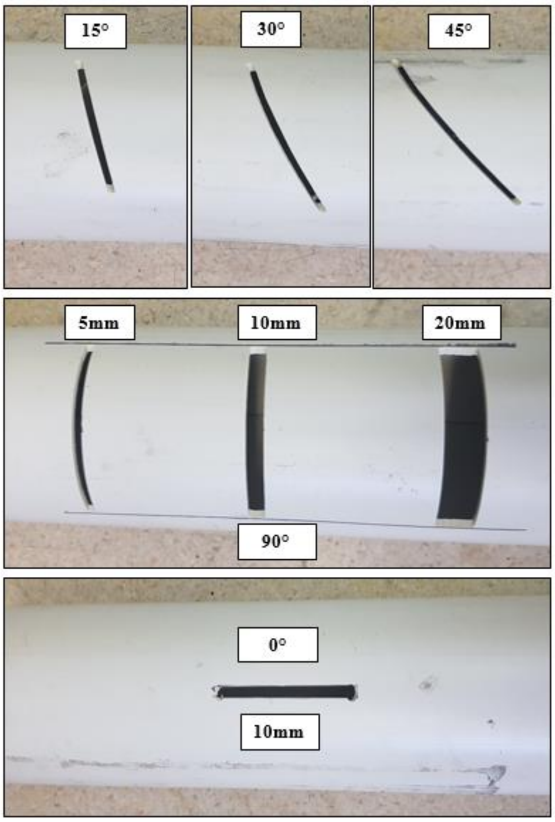

Figure 4. Simulation of joint apertures for camera validation.

3. Results and discussion

The submergible camera inserted into the drain bores collected visual information from inside the boreholes including the presence of joints, infill material, water flow condition, evidence of shear and blockage among other features. These features are discussed as follows.

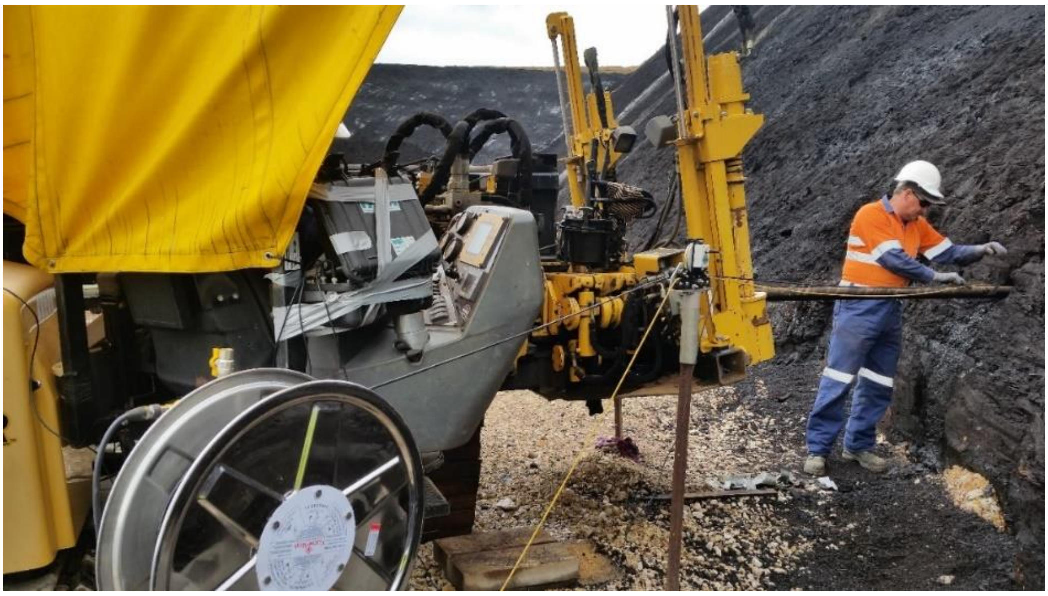

Figure 5. Camera being inserted through the drain using a drilling rig.

3.1. Joints

Joints could be observed inside the bores as expected (Figure 6) as the geological structure and, in particular, the natural jointing and faults of the brown coal govern the macro-permeability in the Latrobe Valley coal seam [11]. Joints are the most numerous and obvious structural features in the brown coals in this specific region and are of particular significance to the stress of the region [7].

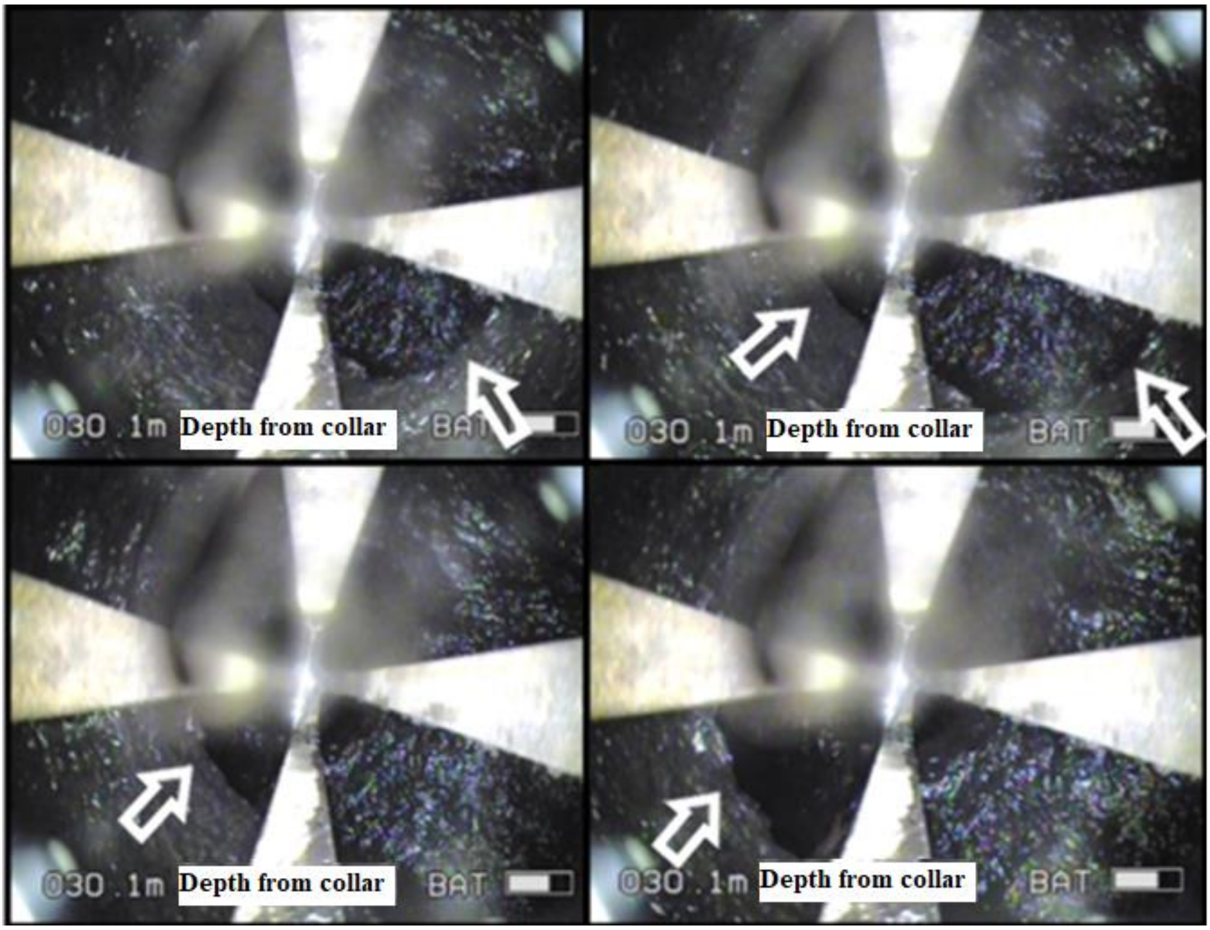

Figure 6. Joint observed from inside a horizontal bore through the camera inspection pointed by white arrows.

A visual inspection was also carried out in a bore located next to the one cited previously and another joint could be observed as shown in Figure 7. The flow of water through a joint into the borehole can be observed in the top left photo.

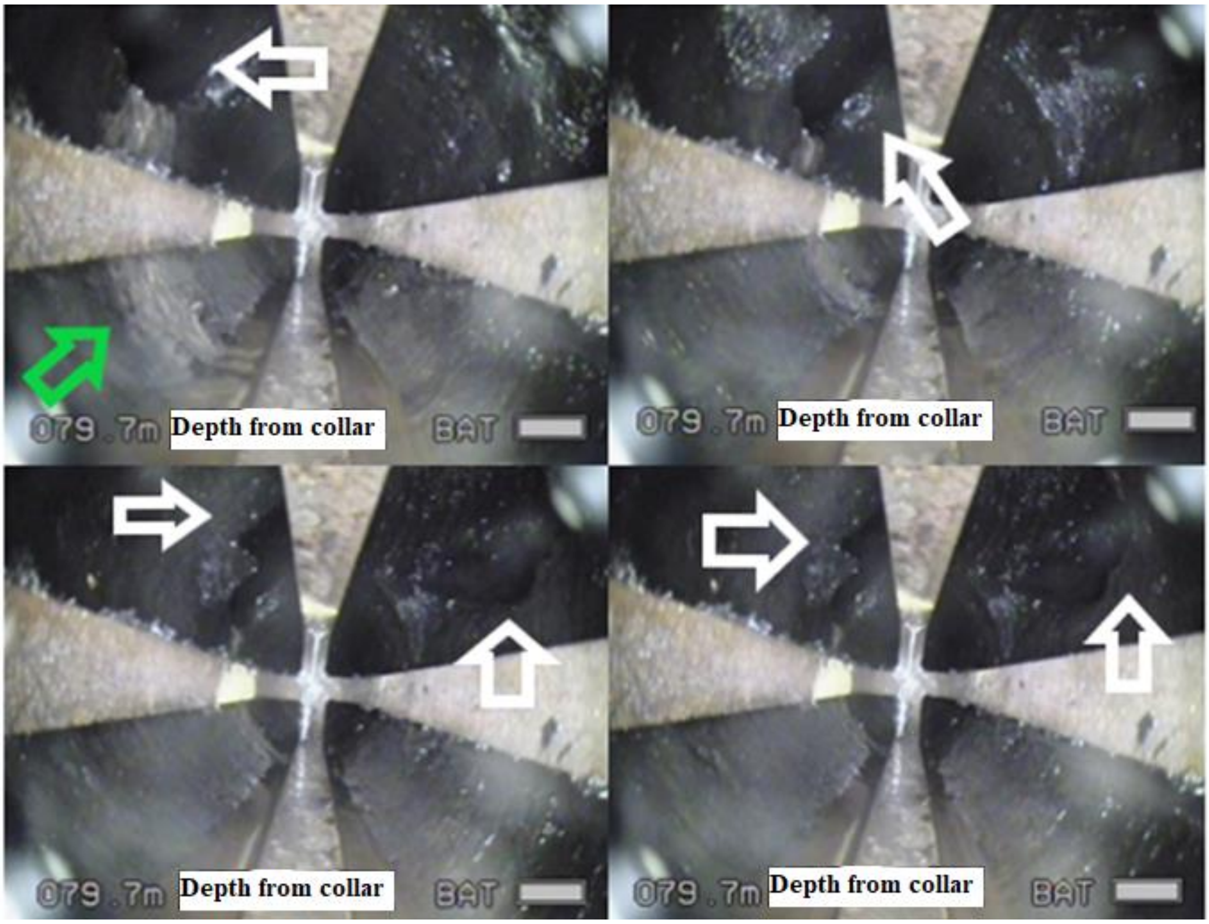

Figure 7. Joint observed through the camera inspection inside the bore located next to the previously investigated bore pointed by white arrows. Flow of water through a joint into the borehole can be observed in the top left pointed by the green arrow.

As it is known that joints in the brown coal batters are typically sub-vertical and comprise two sub-orthogonal sets and penetrate the full depth of the coal seam [9], it is reasonable to assume that these two identified joints inside the two bores are the two joints observed from surface mapping as highlighted in Figure 8. Therefore, it might be possible to link boreholes internal properties to those observed on the surface.

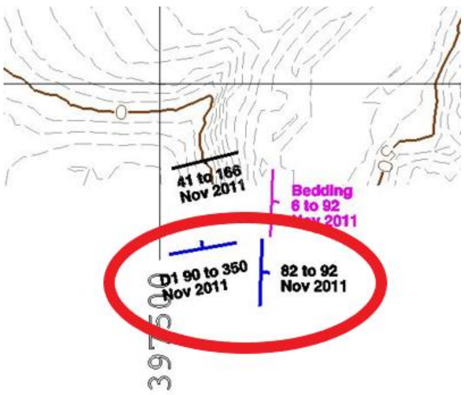

Figure 8. Yallourn mine defect mapping.

3.2. Bore Geometry
Changes in the bore diameter were observed through the visual inspection (Figure 9). The reason behind it is unknown. One assumption is that internal stress releases within the coal may cause some coal block movements along horizontal drains. A second assumption is sediment accumulation. The geometry in this particular instance may also have been altered due to the drilling method as sometimes it can be challenging to control the drilling angle as well as the bore shape.

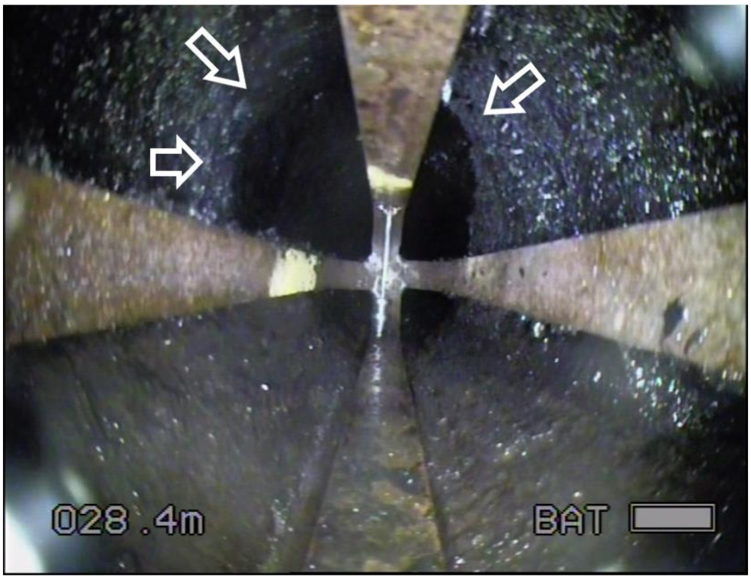

Figure 9. A change in the borehole diameter is observed

3.3. Water flow properties
At the mine different sets of boreholes behave differently in terms of flow and response to rain events and groundwater recharge. The response is governed by mine activity and local geology, particularly, coal joint networks.

The camera inspection showed a variation in water flow along the bore length, which can be observed in Figure 10. In some instances, after an evident joint, the flow of water is significantly reduced as the open coal joint intersected in the drain hole works as a preferential path for water. As boreholes that are a short distance apart can intersect different numbers of joints, further investigation can be carried out for a better understanding of the water flow dynamic in between bores sharing the same joint network.

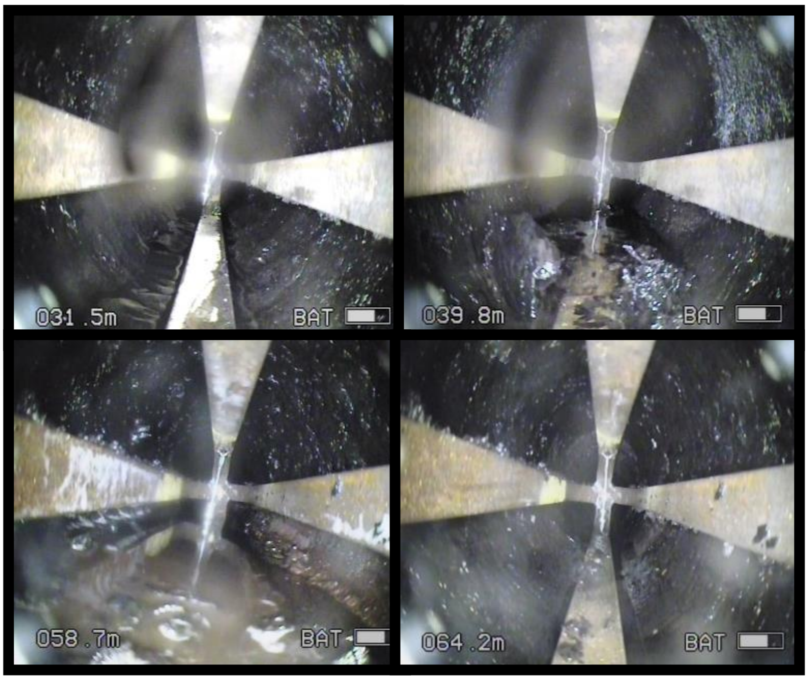

Figure 10. Variation of water flow along the bore

3.4. Material properties

The camera also allowed the observation of different materials along the bore with different surface roughness seeming to be coal and clay (Figure 11).

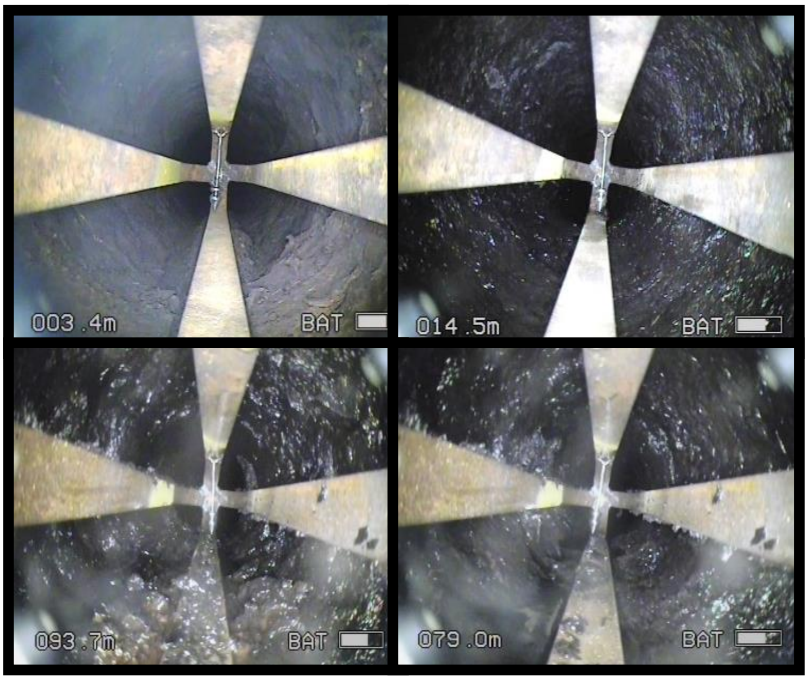

Figure 11. Different roughness along the bore.

4. Conclusion

Various features inside deep horizontal bores such as joints as well as variations in water flow, material properties and geometry were observed during a visual inspection using a camera specifically designed for this purpose. Results to date showed that the camera is an effective tool to inspect the boreholes and allow the interpretation of the visual observations. It is anticipated that future work and inspections will lead to further revelations such as realizing the cause of the reduction in the efficiency of horizontal boreholes, the connectivity of joints within the joint network and to the surface. Of further interest is the linkage between rates of water inflow from the surface and the response time within the joints.

References

[1] Rahardjo, H., Hritzuk, K., Leong, E., & Rezaur, R. (2003). Effectiveness of horizontal drains for slope stability. *Engineering Geology 69*, 295-308.
[2] Hawkes, C. (2007, August 4). *Assessing the mechanical stability of horizontal boreholes in coal.* Retrieved from NRC Ressearch Press: cgj.nrc.ca
[3] Pohll, G., Carrol, R., Reeves, D., Parashar, R., Muhunthan, B., Thiyagarjah, S., Willoughby, K. (2013). *Design Guidelines for Horizontal Drains used for Slope Stanilization.* Washington State Department of Transportation.
[4] Martin, R., & Siu, K. L. (1996). *Use of Horizontal Drains for Slope Stabilization in Hong Kong.* The Hong Kong Institution of Engineers.
[5] Works branch. (1991). Monitoring and Maintenace of Horizontal Drains. *Works Branch Techincal Circular No. 10/91*. Hong Kong Government.
[6] Earth Resources Regulation. (2019, 12 10). *Earth Resources & Jobs, Precints and Regions Department. Geology & exploration.* Retrieved from Coal: https://earthresources.vic.gov.au/geology-exploration/coal
[7] Barton, C. (1981). Regional stress and structure in relation to brown coal open cuts of the Latrobe Valley, Victoria. *Journal of the Geological Society of Australia, 28*, 333-339.
[8] Department of Economic Development, Jobs, Transport and Resources. (2015). *Guideline for Managing Ground Control Risks in Victorian Brown Coal Mines.*
[9] Shaghaghi, T., Tolooiyan, A., & Mackay, R. (2018, April 10 to 13th). Numerical investigation of potential pore water pressure changes in jointed brown coal due to waste material placement against a brown coal open-cut batter. Sevilla, Spain: XIV Congreso Internacional de energia y Recursos Minerales.
[10] State Government of Victoria. (2008). *Mining Warden Yallourn Mine Batter Failure Inquiry. No 156 Session 2006-08.*
[11] Woskoboenko, F., Stacy, W., & Raisbeck, D. (1991). Physical Structure and Properties of Brown Coal. In *The Science of Victorian brown Coal: structure,Properties and Consequences for Utilization* (pp. 151- 246). North Ryde: CSIRO, Division of Coal and energy Technology.

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