BORESCOPE TECHNIQUES FOR ASSISTING COLLIERY ROOF CONTROL

By
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\textbf{ABSTRACT}

Evidence will be presented to show that borescope inspection of mine roofs is one of the most useful techniques available for stability assessments. ACIRL currently has four borescopes, comprising two fibre-optic units of 2.7 m and 4.5 m length and two optical rod units (introsopes) 6 m and 8 m in length. The 6 m unit is not yet fully operational because of modifications needed to meet safety regulations. Using the fibre-optic units, photographs of hole walls or ends can be taken to record features.

Roof lithology and crack patterns can be observed in roof holes from 25 – 60 mm in diameter. Several crack parameters are useful: type, location in the roof with respect to height and lithological boundaries, presence of individuals or zones containing crack clusters and the estimated amount of dilution. These data are readily computer-plotted to form “borescope logs”. Provided that the holes remain open, a hole or group of holes can be re-surveyed at intervals to monitor crack development across or along a roadway, for example with respect to an advancing blind-ended roadway face.

Information collected is important for determining roof failure mechanisms(s), support pattern (particularly roof bolt length) and time-dependent fracturing. It is particularly valuable when used in conjunction with extensometer installations. Some examples of fractured mine roofs will be discussed in relation to failure mechanism and failure prediction. There is generally a much greater need for regular inspections of roofs (especially at four-way intersections) for the purpose of detecting conditions likely to lead to roof falls.

\textbf{INTRODUCTION}

It is now 20 years since the first short boreholes were examined underground using a purpose-built type of periscope called an introscope (Thomas, 1966) for use in British collieries. ACIRL also quickly began using the same type of instruments (Nove, 1967), but it is only relatively recently that ACIRL staff have made a concerted effort to re-apply such instruments for stability evaluation purposes. The US Bureau of Mines (Fitzsimmons et al., 1979) introduced a fibre-optical unit, and some work has been carried out by the

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Chamber of Mines using a petroscope fabricated in-house to study South African gold mine fracturing (Adams and Jager, 1980).

A variety of instruments are now available which serve a similar purpose and are known by a variety of names: introscopes, stratascopes, borescopes, endoscopes, fibrescopes and petrockes. We shall adopt the general term borescope. All of these instruments have been designed for examining fractures and rock types in the walls of small diameter boreholes.

In general the use of fibre-optical borescopes is easier because they can be operated using a standard colliery cap lamp and battery as a power supply. They are also flexible. The optical-rod borescopes require a separate battery pack, are fairly rigid and operate using variable length extension rods. Consequently, they are much heavier to use and tend to be used for special purposes.

**Borescopes Used by ACIRL**

Table I summarises the borescopes currently in use by ACIRL. The fibre-optical units are generally easier to use because a more constant light output is available from a cap lamp. The rod units are also subject to bending stresses, so require careful handling to avoid damage and they are also unsuitable for use in wet holes.

<table>
<thead>
<tr>
<th>Type</th>
<th>Length (m)</th>
<th>Diameter (mm)</th>
<th>Power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrescopes</td>
<td>2.7</td>
<td>19</td>
<td>1 cap lamp (halogen globe)</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Rod-optical</td>
<td>6.5</td>
<td>25</td>
<td>6 volt battery pack to be devised</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

A combined fracture and lithological logging system enables the use of an encoding form at the roof survey site. The technique can be used for vertical, inclined or horizontal holes in the roof, floor, solid coal or pillars. This paper deals only with borescope surveys of mine roofs.

A number of parameters are entered on the coding form, such as lithology, crack type, estimated crack width and if the cracks are individuals or in zones. Generally, cracks are classified according to whether they are bed-parallel shear, low angle shear, tensile bed delaminations, high angle joints or extension cracks. Crack width can be estimated quite accurately using the diameter of the field of view of the ocular lens and a borescope gives an observer the opportunity to rotate the instrument to examine features around the hole wall. The most useful head viewing lens views the hole at 90° to the hole axis (Fig. 1). The attitude of a fracture plane can be accurately surveyed in a hole using a Bureau of Mines technique devised by Mahtab et al (1973). To date we have not needed to adopt this method.

Borescope observations and the results from extensometer installations are complementary. The borescope information is particularly useful for interpreting the results from extensometer installations. The
Fig. 1 - Photograph of an open crack in coal in the sidewall of a 38 mm-diameter hole.

Mode of roof dilation and specific intervals and lithologies where fracturing occurs can be determined. Conversely the extensometer results can be used to calibrate the roof dilation estimates obtained from the borescope.

**ROOF BORESCOPE SURVEY RESULTS**

**TYPICAL BORESCOPE ROOF LOG**

The results of a typical hole survey are shown in the computer output of Fig. 2. The height surveyed into the roof at a Western Coalfield colliery was 6.2 m above the Lithgow Seam. Fracture and lithological data are combined into a useful presentation and cumulative graphs are also given of the number of fractures up the hole and the dilation.

At this site the laminitic roof was badly damaged, especially at around the 2.1-2.3 m position and above the yellow claystone horizon. Most of these cracks were low angle shear planes at an angle of 0-30° to the bedding. A further zone of some shears was also present at about 4.3 m in grey mudstone. All the other cracks were tensile bed delaminations. The total crack dilation in the roof at this point was 323 mm, a figure in close agreement with the measured roof sag at the centre of the heading of 310 mm.

**ROOF STABILITY MONITORING OVER TIME**

Roof stability can be monitored over time at various locations using the borescope to log specially drilled roof bolt holes. Fig. 3 shows a series of five spaced bolt holes drilled at the face of an advancing heading. The roof rock was laminitic and bolting was carried out immediately after cutting. Two cracks were present in one bolt hole directly after cutting. After 18 hours the cracking had extended to all 5 holes and was beginning to form an arch, with some cracks near the skin and close to the corners of the opening and others forming higher up, particularly in the centre holes. Seven days after the site was driven extensive cracking had occurred in all five holes within the bolted horizon. A pronounced lower arch of sheared rock was present beneath an upper horizon of more horizontal partings.

The dilation of each crack was also logged and plots of total dilation within each hole and fracture frequency can be constructed to show the rates of roof deterioration (Fig. 4). In this case crack formation and dilation occurred at the greatest rates in the first week, after which the rates reduced and in some instances reversed close to the roof. Cracks closure can be caused by roof loads being transferred to passive support such as props.

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Fig. 2 - A typical borescope log from data observed using a rod instrument.
Fig. 3 - Development of progressive roof fracturing; note spare bolt hole length is 2.35 m.

**Spatial Variation of Roof Fracturing**

The borescope may also be used to identify lateral changes in roof conditions, with increasing distance from areas of interest. Using this technique it is possible to identify the location of longwall abutment loads, or the distance that cracking commences behind developing faces.

Fig. 5 shows a series of four 6 m holes, drilled in mudstone roof along a cut-through at right-angles to an extracted goaf area. Borescope examination of these holes revealed that the most deterioration of the roof had occurred in the centre of the panel between B and C cut-throughs, at a distance of 130 m from the goaf edge. The amount of cracking and the amount of crack dilation decreased laterally from this point, away from the goaf. This was reflected in a concurrent improvement in roof conditions.

On the basis of this information it was possible to partially attribute stability problems in the panel to the proximity of the goaf and to suggest that such effects were negligible beyond a distance of 170 m. Such information has implications both for support and for choice of belt roads.

It is interesting to note that cracking also showed some decrease towards the goaf edge, although insufficient holes were examined to identify if this trend
Identification of roof failure mechanisms

One important advantage of borescope observations over other forms of geomechanical monitoring is that the operator can actually see what is going on in the mine roof. This is of paramount importance when trying to establish the exact failure mechanism responsible for roof deterioration. A trained operator can distinguish between the five different types of fractures commonly seen in mine roofs.

Various combinations of these fracture types are indicative of the underlying causes and mechanisms of failure (Table 2).

Further observations on the amount of displacement on the different types of fractures and more importantly, critical evaluation of any roof falls that may be present, result in the correct identification of failure mechanism. The nature of extremely sheared roof rock and its effect on support can be seen in Fig. 6.

Fig. 5 - Schematic east-west cross-section showing borescope logs along a cut-through at right-angles to the goaf. (Dashed line indicates point below which significant crack dilation occurs).

Fig. 6 - Extremely sheared laminate roof exposed in a fall showing large lateral movements and deformed roof bolts. (Bolt diameter is 25 mm).

Borescope analysis for support selection and performance monitoring

Once the failure mechanism has been established the borescope can be used to inspect the roof at critical points for signs of instability, or to determine support parameters such as bolt length or the need for secondary support.

Two illustrations of the use of borescope information for support selection are shown in...
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Table 2
Analysis of fracture types related to roof failure mechanism

<table>
<thead>
<tr>
<th>Fracture types present</th>
<th>Failure mechanism</th>
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<tbody>
<tr>
<td>low angle shears, bed parallel shears, extension cracks</td>
<td>shearing by excessive lateral stress</td>
</tr>
<tr>
<td>(high angle) tensile bed delaminations</td>
<td></td>
</tr>
<tr>
<td>bed parallel shears, tensile bed delaminations</td>
<td>beam failure by vertical load and moderate lateral stress (semi-ductile beam)</td>
</tr>
<tr>
<td>bed parallel shears, extension cracks (high angle)</td>
<td>beam failure by vertical load with minimal lateral stress (semi-brittle beam)</td>
</tr>
<tr>
<td>tensile bed delaminations</td>
<td></td>
</tr>
<tr>
<td>high angle joints</td>
<td>blocky failure on joints under minimal lateral stress</td>
</tr>
<tr>
<td>extension cracks (high angle)</td>
<td></td>
</tr>
<tr>
<td>tensile bed delaminations</td>
<td></td>
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</tbody>
</table>

Figs. 7 and 8. The rocks adjacent to the yellow claystone in Fig. 7 are prone to shearing. Two different working heights and bolt lengths are shown, in conjunction with the borescope information on where the yellow claystone and failed horizons are. 1.8 m point anchored bolts would be unsatisfactory at 13 cut-through but may be sufficient at 24 - 25 cut-through, where the roof has been cut up closer to the yellow claystone.

In Fig. 8 the bulk of the cracking within the roof is restricted to the lower 0.75 m, around a prominent surface shear zone. If 1.8 m bolts were installed at this site their anchorage horizon should still be intact.

The borescope method can assist with the diagnosis of specific support problems such as inadequate bolt performance. For example the bolts may be anchored in a horizon that is prone to shearing as was shown in Fig. 7.

Fig. 7 - Schematic cross-section of borescope results showing the influence of a soft, yellow claystone and adjacent sheared mudstone on bolt length determination.

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The borescope technique is very useful for assisting stability evaluations both ahead of and at advancing development heading faces. It is also just as useful for backby stability assessments and in longwall gateroads.

In the past the borescope technique has most probably been under-utilised. There are numerous sites throughout most collieries, especially in main entries designed for a long life, where checking roof stability may be desirable periodically for safety purposes. The borescope method is a rapid and relatively cheap means of achieving this. Roadway intersections can be easily checked for signs of deterioration.

Although this paper has concentrated on the application of borescopes to roof stability problems, they are also very useful in regard to floor and rib/rib/rib pillar stability.

Specific problems that can be tackled using borescopes are as follows:

1. Mapping lithological variation in a mine roof.
2. Identifying fracture distribution and type in relation to lithologies and making inferences about roof failure mechanisms.
3. Assistance with determining support requirements, especially bolt length and checking on the efficacy of bolting together with other techniques such as bolt load tests.
4. Checking and monitoring of roof stability used in conjunction with roof extensometer and convergence measurements.
5. Analysis of the spatial and temporal distributions of roof fractures, especially for examining the effects of higher loading adjacent to goaf edges and in longwall gateroads. A borescope is

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**Fig. 8** - Borescope logs of roof fractures across a heading showing a concentration of shears above a narrow roof shear zone (gutter).

Borescope observations may be able to pinpoint the weak horizon and determine if significant resin loss or shearing has occurred. Appropriate action can then be taken, such as a change in bolt or encapsulation length.

Another important use of the borescope method is for investigations of the condition of the roof in longwall gateroads, prior to the commencement of a retreating face. It is often quite difficult to assess the severity of fracturing in a roof that is obviously damaged without a borescope. The height and extent of fracturing is quite easily determined using a borescope and appropriate secondary support requirements can be evaluated. These may range from installing longer bolts and mesh to the need for Monitor Big Bags where space permits.
useful ahead of an advancing heading face, because information on fracturing can be obtained before conventional geomechanical techniques can be used.

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REFERENCES


