A Roof Quality Index for Stone Mines Using Borescope Logging

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) has collected pillar and span data at 34 stone mines in 10 states to develop pillar and roof span design guidelines for underground stone mines. Pillar, floor and roof conditions each contribute significantly to the overall mine stability. The roof may be stable for a century, or it may appear to be stable but fail with little warning. Clearly, an assessment of the mine roof is critical to the safety of these operations. However, up until now, the assessment of the mine roof came primarily from exposures in roof falls or portal areas. This provides only limited information, and a more proactive approach is needed to assess changing mine conditions.

A separate effort was undertaken to examine the roof structure with the use of a borescope. Numerous physical and geologic roof structures were observed with a stratascope/borehole video camera. The objective of this work was to develop a technique of assigning numerical values to features seen within the mine roof and apply those values to formulate a roof stability evaluation. Such features as changes in color, grain size, and general lithologies are readily observed. Minor structures in the rock, fossils and fractures are also readily identified. Each feature may have a variable and site-specific impact on roof quality.

A number of mines were visited and a series of holes were borescoped in each mine. The features identified in the roof were classified and potential for roof damage related to each feature was assessed. A process is presented that relates the structures and their locations to provide a numerical value, or roof quality index that can be used to assess roof stability.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has collected data at 34 underground stone mines to study factors that influence pillar and roof span stability. The data from the 34 mines has been studied with the objective of developing guidelines for designing stable pillars and roof spans (Esterhuizen 2007a).

Only surface features were observed during the initial phase of data collection at the 34 mines. Natural fractures such as joints, induced damage, such as blast damage in the pillars or the mine roof, and pillar load damage such as weak band loading or pillar spalling were all observed during data collection (Esterhuizen (2007b). Examination of mine roof using a borescope presented the opportunity to observe features that were not visible from the drift.

BACKGROUND

Underground stone mines pose numerous workplace safety problems. A major concern for all underground mines is the integrity of the mine roof and its potential to fall, whether it simply creates an obstacle, damages equipment, or causes harm to a worker. Engineers and geologists have developed rating systems for well over 100 years that attempt to use numerical values to improve workplace safety by predicting ground instability, stability. Ritter (1879) is generally acknowledged as the first to attempt a formal empirical approach to tunnel design to be used to establish support requirements. Further efforts to evaluate a rock mass have been developed since Ritter’s work because there is a pronounced need to tie the nature of the rock mass to engineering design. Currently, RQD as developed by Deere (1964, 1968) is commonly used during field logging of core to provide an assessment of potential rock quality. RQD is essentially a measure of the percentage of core that has a length component that is at least double its diameter, thus assessing the fractures within the rock structure. Other techniques of classifying rock masses, such as RMR, incorporate joint spacing, character of the joint surfaces, and orientation of joints relative to the load direction (Barton, 1974; Bieniawski, 1976, 1979; Hoek, 1995).

Efforts to use data collected with a borescope is now appearing in the literature. Malkowski et al., demonstrated the utility of an Endoscopic Rock Mass Factor (ERMF) in Polish underground coal mines (2008). Rock masses are rated across a range of six classes varying from intact rock (Class I) to a completely crushed rock mass (Class VI). Equipment is readily available to examine and record features in mine roof (Locotos, 2009). The equipment available today is relatively low in cost and easy to operate. Data collected from scoping of mine roof can also be an additional aid in supplementing a Roof Fall Risk Index (RFRI) (Iannacchione, 2007). After conditions have been mapped, they can be reviewed to assess changes.

EQUIPMENT AND PROCEDURES

The borescope and recording instrumentation fits neatly in a single carrying case, and a set of rods that attach to the camera are carried separately. The borescope is cylindrical and small enough to operate in a 1-in (25 mm) borehole (Figure 1). The camera attaches to a small distribution box and the video is seen on a screen and an audio narrative through a microphone can also be provided. The recording unit is an MP3 recorder and the files are saved on a digital card. The rods that are used to move the camera about in the borehole are indexed to provide the depth to the camera location. Files are readily transferred to a personal computer. Viewing the videos usually requires the installation of a CODEC[1]. Logs can then be generated from the video files. The video files are easily stored, and generally require less that 40 MB of storage space for an entire hole. In view of this file size, a 2 GB card will store the information from about 50 holes.

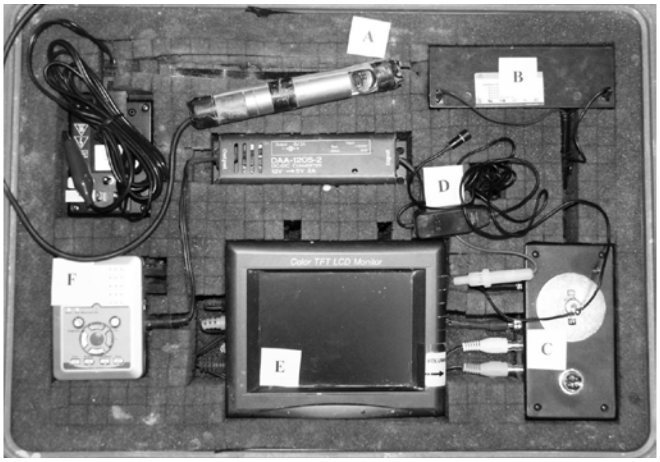


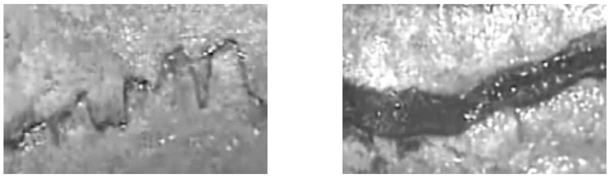
Figure 1. Borescope in carrying case. A) Camera, B) Battery, C) On/Off power distribution, D) Microphone, E) Video Monitor, and F) MP3 Recorder.

In some cases, the borehole wall will be covered with debris from the drilling process, and it is necessary to clean the hole. A garden sprayer equipped with a brush or roller can be used to clean the wall of the borehole.

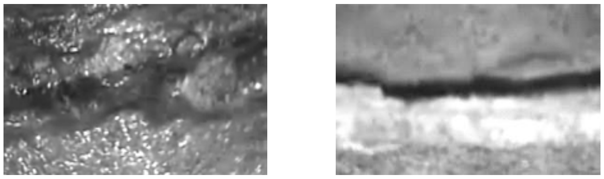
FEATURES OBSERVED

NIOSH scoped roof holes at 13 stone mines in six states. A total of 71 holes were logged, consisting of over 700 feet of hole. Considering the overall amount of hole length examined, the features observed on a regular basis were relatively few. Stylolites, partings, contacts and cracks (later split into closed or open cracks) constituted nearly all of the features observed.

The most common feature or discontinuity observed was a stylolite. Stylolites seen in the borescope are visible as a dark gray to black jagged discontinuity. The filling is often clay, iron oxide, or carbon. Stylolites develop after the deposition of the limestone and result from compaction and pressure solution during the life of the rock (Figure 2a).



2a) Stylolite 2b) Parting



2c) Lithologic Change 2d) Crack

Figure 2. Photographs of features encountered while borescoping. 2a) Stylolite, 2b) Carbon parting, 2c) Lithologic change, and 2d Open Crack.

The second most common feature observed is a carbon-filled parting. Carbon partings are observed as a black trace or bedding plane in the borescope (Figure 2b). The filling in the parting may actually be carbonaceous or dark colored clay and is representative of a bedding plane. Partings, by their nature, tend to have lower cohesion with the rock above and below them than a continuous bed of rock, and by their nature would represent a weaker plane than stylolites.

The third type of feature observed was a lithologic change. The exposed roof in all the mines visited was limestone. In some cases, the rock observed along the entire hole was limestone, and no change of lithology was exposed. In other cases, the limestone was found to be overlain by shale or sandstone. An example of a lithologic contact is shown in Figure 2c.

The final feature observed while borescoping was a crack. A crack can be either a failure within a bed, or a separation where contrasting units meet, and may be of geologic origin or mining induced. Most of the cracks observed in this study were encountered in locations that one would consider to be natural planes of weakness such as limestone to shale contacts or bedding planes that would be contributed to mining. For purposes of this work, cracks are further distinguished as “closed” if the aperture is less than 1/32 in (1 mm) or “open” if the aperture exceeds 1/32 in (1mm) (see Figure 2d). The immediate concern is the extent of the crack. That is, does it occur over a large area, such that the drift span can be compromised or is the damage confined to a few square feet, thereby reducing the probability of contributing to roof failure. This is addressed by assigning a more significant weight to open cracks than closed cracks. Figure 3 shows the frequency distribution of features encountered in the 71 holes logged during this study.

RATING AND ASSIGNMENT

This work is directed toward the development of a rating system that is mine specific, i.e., the numerical rating of a given hole at one mine is not intended to be related to a different mine, but should

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[1] Mention of company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

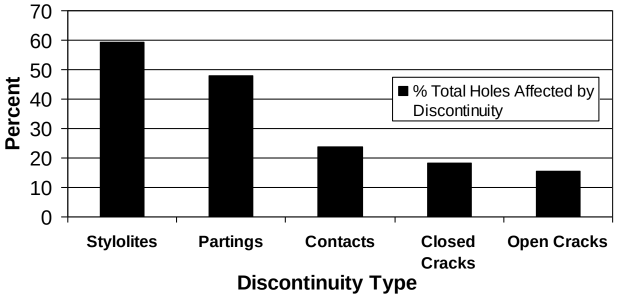

Figure 3. Relative frequency of discontinuities observed in 71 holes.

relate to other holes at the same mine. Characteristic features of the mine roof for a given mine are identified and assigned to zones and weighted to give the resultant numerical value. Each borehole is reviewed individually. The example presented in Figure 4 shows several typical holes. Each feature is assigned a frequency value and a zone weight value. The values are multiplied together, and added to give zone weights and the zones are added together to yield total hole values. These factors will be discussed in more detail below.

General discussions with mine personnel have resulted in the assumption that the features encountered in the roof tend to have less impact on roof control when they are encountered more than 4 ft from the roof horizon (Esterhuizen 2007b). The roof zone rating is included to take into account the position of the feature in the roof. A higher weighting value is generally assigned to zones that are closest to the exposed roof. The thickness of each zone can be adjusted to fit the specific site, as well as the number of zones. Three or four zones are recommended with a higher weighting value assigned to the immediate roof. There may be exceptions to the normal weighting profile such as a situation where mechanical bolts are being installed in which case, the zone including the anchorage horizon may be weighted more heavily.

The first step in developing a mine specific rating system is to examine several holes that can be assumed to be representative of the mine roof. The holes should be spread across the mine and located to include the variety of conditions that may be expected throughout the mine. Frequency values are established by identifying the features that are seen in a given zone of the roof and assigning a numerical value to the feature for that zone.

The feature weight allows for characteristics to be given more detailed consideration with regard to the zone of the roof where they are encountered. For example, a lithologic change in the roof that is encountered in the first foot or two of the roof may cause greater concern than if it is encountered at a depth of 7 ft. By separating and adjusting the characteristic weight in each zone, the changes in anticipated impact are easily recognized (see Figure 5).

When features that pose concerns are identified in a hole, the weighting of severity and location will produce a number that is notably different from holes with no such feature. The higher value should immediately alert the operator to do further examination to establish the extent of the concerns and conduct appropriate actions to compensate for the condition.

Although the rating presented is intended as a template that should be altered to provide emphasis on features of concern at a specific mine, it was applied to the holes from all the mines in the study to establish variability. The rating values were found to range from a low of zero to a high of 326. Figure 6 shows the distribution of rating values. Cracks and open cracks that were encountered in the first two to four ft (0.7-1.3m) were weighted more heavily when cracks were encountered close to the immediate roof resulting in high rating values. Although roof rating index values of less than 100 would appear to carry reduced concern of failure, any abrupt relative change on an area may indicate the need for further scrutiny. In a situation where borescoping is being done routinely, it would be desirable to drill additional holes to establish the extent of an open crack or other feature that results in an increase from the surrounding ratings. Support or travel patterns may then be altered if warranted.

MAPPING

Data collected from borescoping can readily be stored on a computer and designated on a map to provide a stability assessment. An example of a mine map showing borescope weighted values is shown in Figure 7. Note that one of the values is unusually high. Since the values on the map relate to a rating and assignment like the one described earlier, the high value should immediately draw attention. A further assessment with additional holes would then conducted to establish the extent of the area influenced by the feature that produced the high rating. As the amount of data on the map increases, it becomes possible to contour values and analyze trends.

COST AND BENEFIT

The cost of borescoping by a mine operator can be highly variable and is largely a function of the cost of the borescope, the frequency of use, and the level of record maintenance. Several quality borescopes are available, and a high quality instrument with recording capabilities can be acquired for under $5,000. After the purchase of equipment, the cost to an operation will be driven by the amount of data desired, and whether records of examinations are accumulated. While one operator may elect to scope a single hole at each intersection to confirm roof horizon control, and not maintain written records as long as results confirm expected conditions, a different operator may elect to examine a hole from each round and record the data in a CAD program for future reference.

The borescopes are relatively easy to use and may be operated with little training. The unit used in this study simply requires that the camera, microphone and MP3 player be switched on, and the MP3[1] player set to “record.” An engineer or geologist should be able to recognize features in the roof. Since there are relatively few features encountered in the boreholes, virtually any interested party can be trained to operate the borescope. If borescoping is not performed as part of the mining cycle, more time will probably be spent in moving from hole to hole than is involved in the scoping effort. The examination time for a single hole is likely to take about 10 to 15 minutes.

Date		Date		Date		Date		Date	
No.:	1	No.:	2	No.:	3	No.:	4	No.:	5
Level:		Level:		Level:		Level:		Level:	
Loc:		Loc:		Loc:		Loc:		Loc:	
Rating	**61**		**54**		**12**		**138**		**81**
Oper.	JLE	Oper.	JLE	Oper.	JLE	Oper.	JLE	Oper.	JLE
									X
	X		**X**						Sandy SH
8'	Sandy SH	8'	**SHALE**	8'		8'		8'	Sandy SH
	Sandy SH		**SHALE**						Sandy SH
	Sandy SH		**SHALE**		X				Sandy SH
	Sandy SH		Sandy SH		**SHALE**				Sandy SH
7'	Sandy SH	7'	Sandstone	7'	**SHALE**	7'		7'	Sandy SH
	SHALE		**SHALE**		**SHALE**				Sandy SH
	SHALE		**SHALE**		**SHALE**				Sandy SH
	SHALE		**SHALE**		**SHALE**				Sandy SH
6'	Sandstone	6'	Sandy SH	6'	**SHALE**	6'		6'	**SHALE**
	SHALE		Sandy SH		**SHALE**				**SHALE**
	SHALE		Sandstone		**SHALE**				**SHALE**
	SHALE		**SHALE**		**SHALE**				**SHALE**
5'	**SHALE**	5'	**SHALE**	5'	**SHALE**	5'		5'	**SHALE**
	SHALE		**SHALE**		**SHALE**				**SHALE**
	SHALE		**SHALE**		**SHALE**				**SHALE**
	SHALE		**SHALE**		**SHALE**				**SHALE**
4'	**SHALE**	4'	**SHALE**	4'	**SHALE**	4'		4'	**SHALE**
			SHALE		**SHALE**				**SHALE**
	Sty		**SHALE**		**SHALE**				**SHALE**
					SHALE				**SHALE**
3'	Sty	3'		3'		3'		3'	**SHALE**
			Sty						**Open Crack**
	Sty		Sty				X		
	Sty						**Open Crack**		
2'		2'		2'		2'		2'	
			Sty				Sty		Sty
							Closed Crack		
	Sty						Sty		
1'		1'		1'		1'	Sty	1'	Sty
			Sty						
	Sty								

Figure 4. Logs of hole showing significant features and locations.

Zone	Characteristic (Char)	Frequency	Char Weight	Zone weight	Item Value
A (0-2')	Stylolite		1	10	0
A	Lith change		3	10	0
A	Parting		2	10	0
A	Crack <1/32		6	10	0
A	Crack >1/32		10	10	0
A	Other			10	0
B (2-4')	Stylolite		1	6	0
B	Lith change		2	6	0
B	Parting		1	6	0
B	Crack <1/32		5	6	0
	Crack >1/32		8	6	0
B	Other			6	0
C (4-6')	Stylolite		1	3	0
C	Lith change		1	3	0
C	Parting		1	3	0
C	Crack <1/32		4	3	0
	Crack >1/32		7	3	0
C	Other			3	0
D (6-td)	Stylolite		1	1	0
D	Lith change		1	1	0
D	Parting		1	1	0
D	Crack <1/32		2	1	0
	Crack >1/32		5	1	0
D	Other			1	0
Composite hole rating					**0**

Figure 5. Sample rating and assignment table. The total rating value will appear when frequency values identified in the hole are entered.

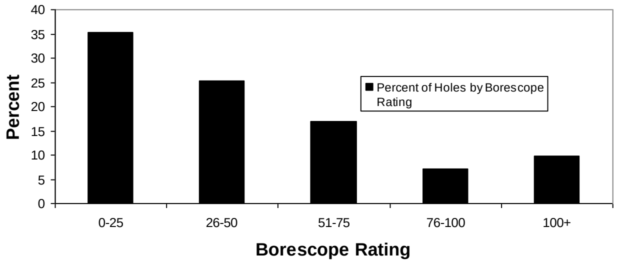

Figure 6. Distribution of borescope ratings for 71 boreholes.

CONCLUSIONS

A number of features were observed in this study during borescoping. However, not all features contribute significantly to roof weakening. For example, although stylolites were encountered frequently, they rarely created a plane of weakness that threatened ground stability. Contacts, or lithologic changes, can be significant, but generally have less effect as their distance into the roof increases. Partings represent inherent planes of weakness. Cracks in the roof are a cause for concern and as a result should be given increased weight in the evaluation. Closed cracks tend to be local while open cracks are more likely to involve a more extensive area.

The following conclusions are supported by this study of stone mine roof:

1. borescoping results in improved recognition of general roof conditions,
2. the level of security by 'knowing the conditions' is improved compared to the uncertainty of assuming what is there,
3. borescoping can aid in roof horizon control,
4. changes in mine roof can be mapped and reviewed, and
5. the thickness of the main roof beam can be confirmed.

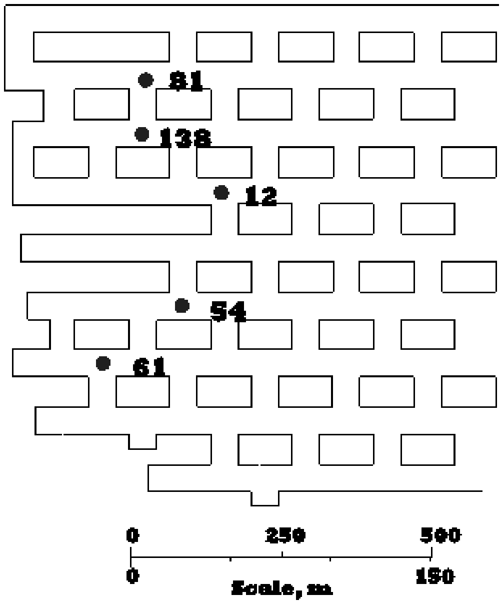

Figure 7. Mine map showing borescoped hole locations and roof index ratings.

When there is a question about the integrity of a stone mine roof, borescoping is an excellent tool to establish the nature of the roof and its stability. The equipment is easy to use, and can be used as much or as little as needed. Each mine will tend to have its own characteristic roof features, so that recognition training can be undertaken with a short learning curve. It is recommended that site specific ratings be used to provide emphasis on roof features that are problematic at any given mine.

Ultimately, NIOSH plans to incorporate the borescoping assessment into a Roof Fall Risk Assessment procedure that will be used to assist in span design for underground stone mines.

DISCLAIMER

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent agency determination or policy.

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