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Use of rock classification to estimate roof caving span in oblong workings

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Summary

Indian coal measures have widely varying caving characteristics. The maximum roof span of a longwall or depillaring panel at the time of nether roof collapse is shown to have a direct relation with *RQD* from a study of 12 case histories. A similar relation between maximum unsupported span of openings and rock mass quality as defined by the *Q*-system was also demonstrated. A simple nomogram is presented to predict the face advance required to cause roof collapse when the *RQD* or rock mass quality is known.

Keywords: Rock classification; longwall mining; strata control; mine openings.

Introduction

Depillaring and longwalling in India has been carried out under widely varying roof strata, ranging from friable shales to massive sandstones. There are instances when roof areas up to 10 000 m^2 may stand only on pillar remnants during depillaring. In such conditions air blasts may occur depending on the number and size of entries, if the area of roof collapse is greater than about 5000 m^2. During caving of longwall panels supported by conventional friction and hydraulic props a major weight generally occurs simultaneously indicative of fall of the nether roof, increasing face convergence and prop load.

With the advent of rock classification methods (Deere, 1964; Wickham *et al.*, 1972; Bieniawski, 1973, 1976; Barton *et al.*, 1974; Barton, 1976), whose applicability has been considered for a number of mining problems (Sheorey and Singh, 1982), a better understanding of roof caving in extraction panels can perhaps be developed. The *roof caving span* is defined in this paper as the extent of face advance from the start line required to cause nether roof collapse. It is, in other words, the ultimate stable span of a continuously widening opening. If such a span is estimated beforehand, it can help in ascertaining the feasibility of depillaring or longwalling with caving, in predicting the occurrence of the first major weight and also in designing a panel. It is hoped that this study will throw some light on the stability of oblong rectangular openings in terms of a rock classification index.

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Influence of RQD on roof caving span

A total of 12 case histories were collected, nine of longwall panels (Sarkar, 1982) and three of depillaring panels, for the purpose of this study. The average *RQD* for the immediate roof, whose thickness is taken as five times the working height, is given in Table 1 along with other particulars. *RQD* was measured by scan line techniques on the face and roadway. The areas of fall had different rectangularities* in longwall panels, and in depillaring panels they were jagged trapezia as in Fig. 1a. Obviously it would be incorrect to expect a direct relationship between the area of roof fall and any rock classification index. Because of these differences in geometry it was necessary to estimate an 'equivalent' face advance or opening span as follows.

The maximum tensile stress in a rectangular plate simply supported and uniformly loaded is given by

$$\sigma_{max} = \beta\, qa^2 \qquad (1)$$

where β is a factor depending on the rectangularity b/a of the plate, q is the uniform load and a is the smaller plate dimension. When $b/a > 3$, β tends to a constant value β' (Timoshenko and Woinowsky-Kreiger, 1959). When $b/a < 3$ for a longwall roof, the equivalent face advance a_{eq} or

Table 1. Particulars of case histories for areas of roof caving.

Colliery	Method of work	Working height (m)	Depth (m)	Area at roof fall (m²)	*RQD* (%)	a_{eq} (m)	Remarks
1. Dhemo Main	LW	3.0	130	120 × 45	65	43	
2. Khottadih	LW	2.4	280	120 × 79	92	64	
3. Ningha 1	LW	2.4	245	87 × 43	60	39	
4. Ningha 2	LW	2.4	245	120 × 35	60	35	Wet roof
5. Moonidih	LW	1.8	220	110 × 38	46	37	
6. Banki 1	LW	2.2	130	120 × 14	17	14	
7. Banki 2	LW	2.2	130	120 × 18	17	18	
8. Bijuri	LW	1.8	65	85 × 60	71	47	No fall
9. East Katras	LW	1.4	50	90 × 36	71	34	Goaf existing 9 m above
10. Churcha	BP	4.5	170	6500	63	43	
11. Bankola (SE sector)	BP	7.8	100	8820	95	56	Contiguous workings with 3 m parting (no fall)
12. Bankola (Centenay Incline)	BP	4.0	50	3200	50	33	

N.B. Bord and pillar (BP) cases correspond to greater than 80% extraction.

* The term rectangularity is used for rectangularity in plan while in vertical section, the word oblongness is used throughout the paper.

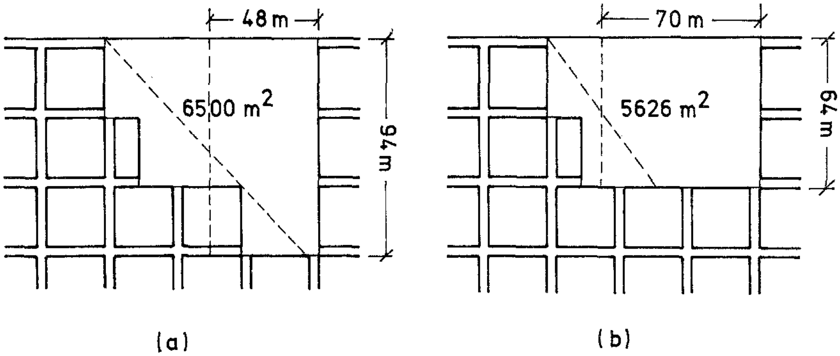

Fig. 1. Areas of roof collapse in depillaring panels.

roof caving span can be found for an infinitely long face (i.e. when $b/a > 3$), when a fall would occur. Thus

$$a_{eq} = (\beta/\beta')^{\frac{1}{4}}\ a = \alpha\ a \tag{2}$$

The multiplier α can be calculated from tabulated values of β and β' from books on the theory of plates and has a plot as in Fig. 2. The equivalent face advance or opening span causing nether roof fall was thus calculated for each longwall case.

In the case of bord and pillar extraction panels, a simple trapezium was obtained, leaving out 'notches', which was converted into a rectangle of the same area and a_{eq} was then calculated as before in Fig. 1a. These values of a_{eq} are given in Table 1.

The variation of the equivalent face advance or ultimate stable span a_{eq} with *RQD* is found to give a reasonably good linear regression (Fig. 3) having the equation

$$a_{eq} = 0.59\ RQD + 5.2\ \text{m} \tag{3}$$

This equation has a correlation coefficient (square root of the coefficient of determination r^2 in the case of linear regressions) $r = 0.975$ at a significance level of 0.001 considering seven degrees of freedom, as obtained from the table of r. The regression is thus very significant. The existence of this correlation indicates that the simply supported plate theory used for estimating the equivalent face advance appears to be adequate. Any other more realistic supports like elastic foundations could be considered but this would complicate the procedure unnecessarily.

Equation 3 is applicable to longwall panels employing conventional supports and to those depillaring panels where the coal left as remnants is not more than 20%. With powered supports, the rate of advance is high and time effects may tend to increase the span. It may not be applicable to wet roofs and to those strata which have slickensided or clay-filled joints and distinct joint sets (not random joints) besides bedding planes.

The two cases where no fall had taken place have not been included in the regression analysis, but have been shown in Fig. 3. Case No. 9 is also not considered because of the presence of a goaf 9 m above the longwall panel.

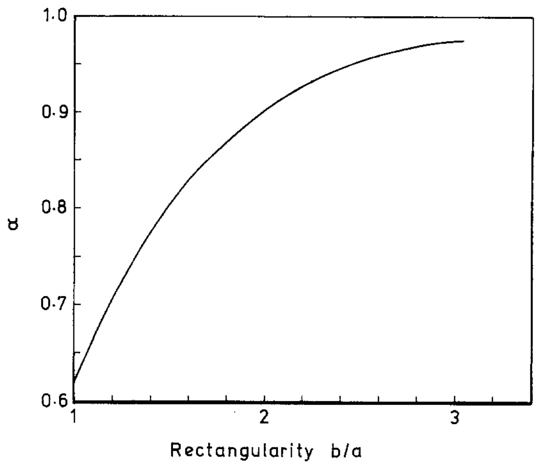

Fig. 2. Relation between multiplier α and rectangularity (after Timoshenko and Woinowsky-Krieger, 1959).

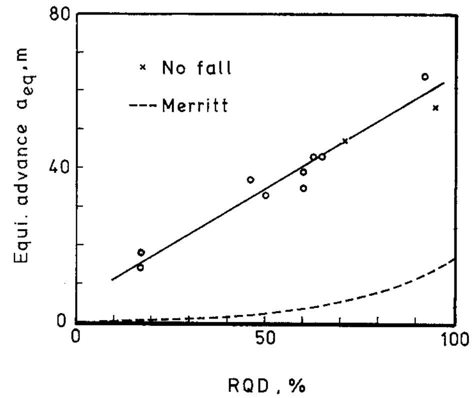

Fig. 3. Relation between point of roof collapse for an infinitely long face (a_{eq}) and *RQD* of roof rocks.

Equation 2, which is linear, does not agree with the work of Merritt (1972) who proposed a rising nonlinear relation between *RQD* and unsupported tunnel width as shown by the dashed line in Fig. 3. This may be because of the oblongness of the openings being considered here. Also these oblong openings are of the continuously widening type. Barton's Equation 3, discussed later, also does not seem to agree with Merritt's curve.

Q-system application

The above analysis can be made more general by considering the Q-system of Barton *et al.* (1974) which considers several other joint parameters besides *RQD*. It can thus be applied to Coal Measures with different joint sets and characteristics as well as to noncoal mines, e.g. a wide stope opening.

According to Barton's system, the rock mass quality Q is expressed as

$$Q = \frac{RQD}{J_n} \frac{J_r}{J_a} \frac{J_w}{SRF} \tag{4}$$

where J_n is the joint set number, J_r is the joint roughness number, J_a is the joint alteration number, J_w is the water reduction number, and SRF is the stress reduction factor. All these parameters have been tabulated by Barton *et al.* (1974). Also, according to this system the 'safe' unsupported span a_{eq} is related to Q by

$$a_{eq} = 2\ ESR\ Q^{0.4}\ \text{m} \tag{5}$$

where ESR is the excavation support ratio having values of 3–5 for temporary mine openings.

The above parameters are given very approximately in Table 2 for the 12 case studies of Table 1. Some points with reference to Table 2 should be noted. The joint set number J_n has been assigned the value of 1.0 corresponding to sparse jointing where the *RQD* is high, say greater than 90%. Since the depth of cover is moderate to shallow, SRF is 1.0, which defines 'medium stress' condition. In case nos. 6, 7 and 9, however, SRF is 2.0 (high stress condition), the former two because of notoriously weak Barakar measures in the roof and the last one because of a goaf 9 m above the longwall panel. Case no. 9 can thus be included now because the *Q*-system accounts for the influence of stresses in the form of *SRF*. All panels were dry except case no. 4 which had a wet roof. It should be noted, however, that because of lack of detailed supporting data, values of *Q* are strongly dependent on estimates of *RQD*, and this may affect the validity of any conclusions.

Fig. 4 shows the values of *Q* plotted against a_{eq} and the best-fitting regression line together with Barton's original Equation 3 in logarithmic form. The best fit has a correlation coefficient of 0.976 at the significance level of 0.001 corresponding to eight degrees of freedom. The two relations are found to be close. The value of the excavation support ratio *ESR*, which is an important time factor in the *Q*-system, is obtained as 4.56–4.83 from the two relations.

Prediction of fall

When it is required to predict the face advance *a* for nether roof fall in any given panel whose face length *b* is known, a_{eq} can be replaced in Equation 2 and 5 to give

$$a = \frac{2\ ESR\ Q^{0.4}}{\alpha(b/a)} \tag{6}$$

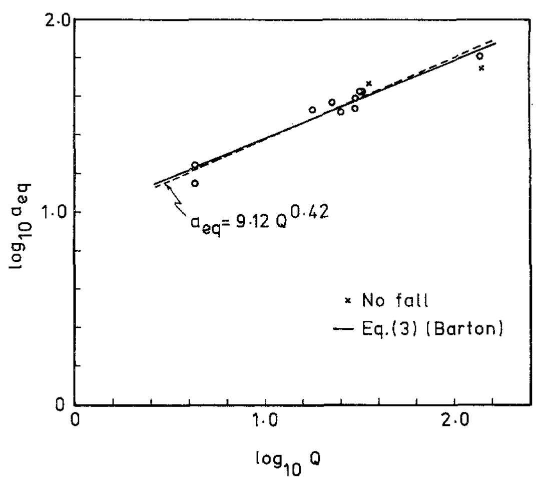

Fig. 4. Relation between a_{eq} and estimates of *Q* for roof rocks.

Table 2. Q-system parameter estimates for roof rock in the case studies of Table 1.

Colliery	RQD	J_n	J_r	J_a	J_w	SRF	Q
1. Dhemo Main	65	3	1.5	1	1	1	32.5
2. Khottadih	92	1	1.5	1	1	1	138.0
3. Ningha 1	60	3	1.5	1	1	1	30.0
4. Ningha 2	60	3	1.5	1	0.66	1	20.0
5. Moonidih	46	3	1.5	1	1	1	23.0
6. Banki 1	17	3	1.5	1	1	2	4.25
7. Banki 2	17	3	1.5	1	1	2	4.25
8. Bijuri	71	3	1.5	1	1	1	35.5
9. East Katras	71	3	1.5	1	1	2	17.75
10. Churcha	63	3	1.5	1	1	1	31.5
11. Bankola (SE sector)	95	1	1.5	1	1	1	142.5
12. Bankola (Centenary Incline)	50	3	1.5	1	1	1	25.0

J_n: 1, sparsely jointed; 3, one-jointed set + random.
J_r: 1.5, rough planar joints.
J_a: 1, little alteration.
J_w: 1, dry excavation; 0.66, moderately wet.
SRF: 1, medium stress condition; 2, high stress condition.

in which α is shown as a function of b/a. Since α (Fig. 2) cannot be expressed exactly by a known mathematical function, this equation has to be solved numerically. The simple nomogram of Fig. 5 was constructed by numerical solution for predicting the face advance a for nether roof collapse when the face length b and rock mass quality Q are known. The procedure consists of obtaining a_{eq} from Equation 5 (using $ESR = 4.7$), measuring b/a_{eq} on the ordinate and forming a rectangle touching the curve in Fig. 5 as shown. When a/a_{eq} is measured, both the face advance a and the area of fall ba are known. This nomogram thus gives the maximum stable plan area of a rectangular opening.

Minimization of air-blast violence

Since the violence of an air blast is directly proportional to the area of collapse, Fig. 5 shows that, for the same Q value, the area of collapse will increase with rectangularity. The ideal is to induce a square (or nearly square) area of fall of the side 1.55 a_{eq} to minimize air-blast violence. Thus, if the face length is chosen as 1.55 a_{eq}, a fall will take place after an advance of 1.55 a_{eq}, minimizing the fall area. This is more applicable to depillaring than to longwall panels in which the face length may be governed by other factors besides roof control.

Fig. 6 indicates the manner in which the fall area increases with face length or rectangularity. As an example, if the value of a_{eq} is 45 m (correspondingly to $Q = 43$) the immediate roof can fall over a square area of 4865 m^2 when the face length is $1.55 \times 45 = 70$ m, or over a rectangular area of 6075 or 8100 m^2 when the face length is 135 or 180 m, respectively. In this particular example,

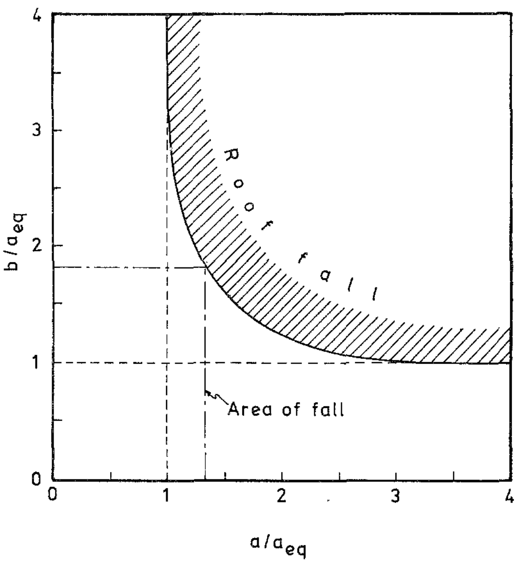

Fig. 5. Nomogram for estimation of roof collapse.

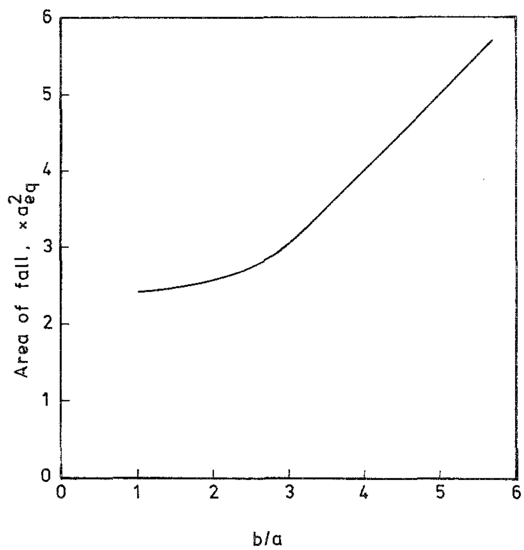

Fig. 6. Relation between fall area and rectangularity.

the panel will then give rise to an air blast when the face is long, which will not happen if the face length is 1.55 a_{eq}, taking the cut off value as 5000 m^2 for air blasts.

Case no. 10, the Churcha Colliery depillaring panel (Table 1), can be considered here as another example. The original fall area of 6500 m^2 in Fig. 1a can be reduced effectively if a panel consisting of two pillar rows is extracted, as in Fig. 1b, instead of three pillar rows. In the latter case the equivalent area of fall (*ba*) is 94 × 48 m, a_{eq} is 43 m and the actual fall area is 6500 m^2. If two rows are extracted, the equivalent area of fall will be 64 × 70 m from Fig. 5 and the actual expected fall area will be 5626 m^2, something like that in Fig. 1b.

Conclusion

In longwall and depillaring panels the maximum equivalent face advance a_{eq} at which the nether roof collapses has a direct relationship with *RQD*. A more general relation exists with estimates of rock mass quality *Q*. The excavation support ratio *ESR* used in the *Q*-system appears to have a value of about 4.7 for temporary mine openings like longwall and depillaring panels.

The area of roof fall, which increases with rectangularity of the panel, can be effectively reduced by adopting a face length of 1.55 a_{eq}, where a_{eq} is given by Equation 5.

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