A Procedure for the Rapid Assessment of Coal Mine Roof Stability Against Large Roof Falls

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ABSTRACT

Advanced numerical models can be used to evaluate entry support systems in coal mines. However, these methods require specialized software and specialized skills to create the models and evaluate the results. Practicing support design engineers require a method to rapidly assess a proposed support system for a given geotechnical scenario. A prediction equation that can be used to assess roof support systems has been developed from the results of hundreds of FLAC3D analyses that were conducted during recent research. These models were validated against field cases and empirical design approaches and were found to adequately predict entry stability in coal mines. The understanding developed from the model outcomes was used to develop an equation to predict entry roof stability against large roof falls. Least-squares error analysis was conducted to find appropriate parameters for the nonlinear equation. The developed equation can be solved using spreadsheet software, allowing for rapid assessment of alternative support system performance in variable geological conditions. The performance of the prediction equation is evaluated against empirical design methods and against selected case histories of support practices at currently operating mines. Examples are presented that demonstrate the performance of the equation in variable geological settings. The stability factor (SF) prediction equation can be used as an assessment tool to assist in the design of coal mine roof support systems.

INTRODUCTION

Ground falls represent a significant proportion of injuries and fatalities in underground coal mines in the US. During 2013, ground falls were responsible for 4 of the 14 fatalities and 16.6 % of the 1,577 reportable lost-time injuries (MSHA, 2015). In addition, each year about 400 to 500 large roof falls are reported that can extend up to or above the bolted horizon. Large roof falls and associated ground fall hazards can be mitigated through improved support design.

The research presented here particularly addresses the problem of large roof falls that extend more than 90 cm (3 ft) above the roof line of an entry and may extend above the bolted horizon. Smaller roof falls that fall out between supports or extend less than 90 cm (3 ft) above the roof line are excluded. These smaller roof falls can be controlled by appropriate surface support such as roof screen or other skin control methods. Also excluded are roof falls that are associated with an individual geological structure such as a slip of fault. Structure-related instabilities can be controlled by strategically locating individual roof bolts or other supports appropriate for the local situation.

Numerical modeling procedures have been developed to assist support designers in assessing the stability of the roof of an entry against large roof falls (Esterhuizen, 2012; Esterhuizen et al., 2013a). The unit ratings of the roof rocks, determined by the Coal Mine Roof Rating (CMRR) system (Molinda and Mark, 1994), are used to develop model inputs (Esterhuizen et al., 2013b). The analyses are conducted with the FLAC3D software (Itasca, 2012) using a technique called the Strength Reduction Method (SRM) (Zienkiewicz et al., 1975) to determine a “stability factor” (SF) against large roof falls. The method makes use of numerical models to estimate the SF of the roof by successively reducing the rock strength until collapse is indicated in the model. Figure 1 illustrates the results of two numerical models showing a supported entry when the rock strength had been reduced to a critical point, just before collapse, and how further rock strength reduction results in collapse of the roof. The SF is determined as the ratio of the expected rock strength to the rock strength that would result in collapse.

Despite the usefulness of this approach for determining roof stability, creating the models and conducting the analyses can be time consuming, and requires specialized skill in the interpretation of modeling outputs. Support designers need a rapid assessment method that allows them to quickly compare support alternatives or to assess the impact of geological changes on likely support performance. A procedure has been developed that allows entry stability to be assessed using a statistically-determined equation that can easily be solved using a spreadsheet type program. The equation calculates an SF value that is similar to the value that would be predicted by a full FLAC3D model analysis.

The SF prediction equation is based on regression analysis of several hundred FLAC3D models of supported entries in a variety of geological and stress conditions and a variety of support types. Unsupported excavations were also analyzed. Part of the inputs required for the equation are similar to those required for a CMRR

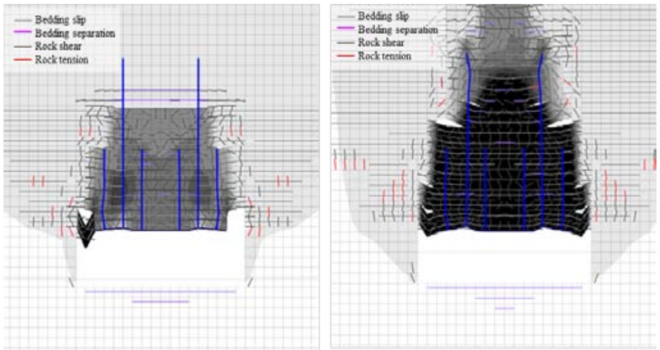


Figure 1. Model results showing a supported entry: a) when the rock strength has been reduced to a point of critical stability and b) when further reduction of the rock strength causes roof collapse.

assessment. Also, the equation requires knowledge of the stress conditions as well as details of strata layering and support types. Using the equation, it is possible to compare support systems using fully grouted and partially grouted solid bar bolts as well as partially grouted cable bolts. Because of the level of detail included in the assessment, it is possible to assess suspension effects, weak roof surcharge, and strength of the anchorage zone on overall entry roof stability. It is also possible to apply the equation at a reduced level of accuracy if only the CMRR is known without knowledge about the individual roof layering.

The paper briefly explains the development of the SF prediction equation and demonstrates the success of the method in predicting FLAC3D model outcomes. The method is compared to the empirical Analysis of Roof Bolt Systems (ARBS) (Mark, Molinda and Dolinar, 2001), and stability assessments are made of 36 case histories at currently operating mines. Also, examples are presented showing the capabilities for predicting roof support performance in complex geological settings.

DEVELOPMENT OF THE SF PREDICTION EQUATION

The equation attempts to predict the SF that would be determined by conducting an advanced FLAC3D model analysis of a coal mine entry. The results of 670 FLAC3D numerical models of coal mine entries were analyzed to develop the SF prediction equation. The models represent entries with a variety of depths of cover, field stress conditions, geological settings, and support systems that are encountered in US coal mines. The ranges of parameter values assessed are as follows:

- Depth of cover: 100 m (330 ft) to 600 m (1960 ft)
- CMRR-based unit rating of roof units: 35 to 60
- Horizontal tectonic strain: 0.0002 to 0.0006
- Fully grouted bolt lengths: 1.8 m and 2.4 m (6 ft and 8 ft)
- Cable bolts lengths: 3.6 and 4.9 m (12 ft and 16 ft) with 260 kN (30 t) and 380 kN (40 t) capacity
- Entry widths: 4.8 (15 ft) to 10.2 m (33 ft)

Initially, 450 combinations of the variable parameters were modelled and SF values were obtained for each model. Additional models were created to clarify specific questions that arose during the analysis of the results. For example, 120 models were created to better understand the effect of strong beds within and above the bolted horizon. Specific models were also created to investigate the effect of weak overlying strata on support performance. Each geological scenario was evaluated up to sixty times, by modelling it in different horizontal stress fields, depths of cover, and support systems.

Using the numerical model results, it was possible to clearly identify the contribution of each support type to the overall stability of the excavation. It was also possible to obtain a better understanding of how stress is redistributed in the roof of an entry and how failure initiates and progresses until a collapse of the roof is initiated.

The SF Prediction Equation

The prediction equation considers all the parameters that were identified as having a significant impact on entry stability. The final form of the equation considers the stability of the roof in three zones, illustrated in Figure 2. The first zone is the immediate roof within the first 90 cm (3 ft) above the roof line. The stability of this zone is evaluated when determining the self-supporting capacity of the unsupported entry. The second zone is the bolted horizon, which is reinforced by the primary bolts. The third zone is the anchorage zone of the cable bolts, if present. This zone is evaluated when estimating the contribution of the cable bolts to overall stability. The entry stability factor is determined by combining the contribution of the three zones to stability.

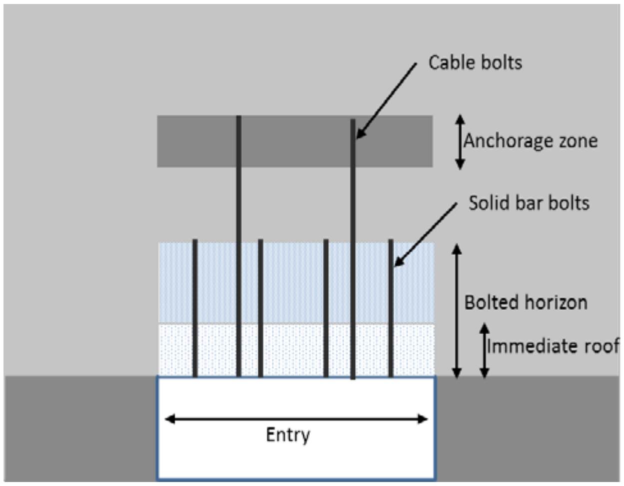


Figure 2. Diagram showing typical supported entry with roof stability zones indicated.

The SF prediction equation for coal mine entries is as follows:

$$SF = SSC + PSE + SSE \qquad (1)$$

where:

SSC = Self-supporting capacity of immediate roof

PSE = Primary support efficiency

SSE = Secondary support efficiency

The calculation of the SSC, PSE and SSE parameters is presented below, together with the reasoning behind the development of each component.

Self-Supporting Capacity

The self-supporting capacity (SSC) considers the stability of the first 90 cm (3 ft) of rocks above the entry roof line. The SSC is calculated as follows:

$$SSC = 15.20\left(\frac{SFIM \times SURIM^{0.290}}{W^{1.04} \times D^{0.287}}\right)^{0.832} \tag{2}$$

where:

SFIM= Thickness-weighted average stability factor of the immediate roof units

SURIM = Surcharge factor to account for presence of weak beds above the immediate roof

W = Width of entry (m)

D = Depth of cover (m)

The immediate roof is defined here as the roof units 90 cm (3 ft) above the entry roof line. The stability factor of each individual unit in this interval is calculated as the ratio of the rock mass uniaxial compressive strength (UCSM) to the pre-mining horizontal stress. The UCSM of each unit is estimated from the CMRR unit ratings, as described in Esterhuizen et al. (2013). The pre-mining horizontal stress component in the direction perpendicular to the direction of entry advance is used. The pre-mining stress in each geologic unit is estimated after Mark and Gadde (2008) and Dolinar (2003).

The immediate roof surcharge factor *SURIM* accounts for the negative effect of having weaker strata overlying the immediate roof, similar to the surcharge factor included in the CMRR method. It is simply the ratio of the average strength of the upper roof rocks to the average strength of the immediate roof rocks. The upper roof is defined as 2.4 m (8 ft) above the immediate roof—that is, the roof rocks extending from 0.9 m (3 ft) to 2.7 m (11 ft) above the entry roof line. The surcharge factor has a maximum value of 1.0, which occurs when the immediate roof and upper roof are of equal strength.

Primary Support Efficiency

The primary support efficiency (PSE) represents the contribution of the primary supports, typically fully grouted solid bar bolts, on entry stability. The primary support efficiency (PSE) is calculated as follows:

$$PSE = 0.020(PSI \times SFRR^{0.895} \times SBF^{0.096})^{1.440} \tag{3}$$

where:

PSI = Primary support intensity, which represents the amount of primary supports per unit area

SFRR = Thickness-weighted average stability factor of reinforced rock units within the bolted horizon

SBF = Strong bed factor, to account for the presence of strong units in the upper half of the bolted horizon

The primary support intensity (PSI) is calculated as follows:

$$PSI = \frac{NB \times LB^{2.59}}{BS \times W} \tag{4}$$

where:

NB = Number of installed bolts in a row

LB = Length of the bolts (m)

BS = Bolt row spacing (m)

W = Entry width (m)

The stability factor of the reinforced rock units *SFRR* is again calculated as the ratio of the rock mass uniaxial compressive strength to pre-mining horizontal stress in each rock unit, similar to *SFIM*.

The strong bed factor (*SBF)* follows the example of the CMRR approach by accounting for the added benefit of strong units within the supported horizon. The *SBF* is calculated as follows:

$$SBF = 1 + \left(\frac{UCSMA}{UCSMB} - 1\right) \times \frac{SBT}{2.4} \tag{5}$$

where:

UCSMA = Rock mass UCS in the suspension zone (MPa)

UCSMB = Thickness-weighted average rock mass UCS in the bolted horizon (MPa)

SBT = Strong bed thickness (m), with a maximum of 2.4 m (8 ft).

For the purpose of calculating the SBF the suspension zone is defined as the rock within the upper 60 cm (2 ft) of the bolted horizon. The 60-cm suspension zone is required to be fully located within a single strong-rock unit for the strong bed effect to be applicable. The *SBT* is set to zero if the suspension zone is intersected by more than one rock unit. This requirement may be conservative, but is justified by the fact that variable roof sag between two relatively strong units could degrade the quality of the grout bond in the strong bed.

Secondary Support Efficiency

Secondary support analyzed in the models was always in the form of cable bolts that are partially grouted. The grout length was typically 1.2 m (4 ft) with the remainder of the bolt being free and was fixed by a bearing plate to the entry roof. The cable bolts were assumed to have about 5 tons of pretension. The cable bolts were supplementary to the primary supports, and were never evaluated as the only support system. The secondary support efficiency *SSE* parameter is therefore only applicable for cable bolts used in the manner described here. The equation for the *SSE* is as follows:

$$SSE = 0.283\ (SSI \times SFCA^{1.472})^{0.770} \tag{6}$$

where:

SSI = Secondary support intensity

SFCA = Thickness-weighted average stability factor of the rock in the cable bolt anchorage zone.

The secondary support intensity is calculated similarly to the PSI value using this equation:

$$SSI = \frac{NC \times LC^{1.16}}{CS \times W} \qquad (7)$$

where:

NC = Number of installed cable bolts in a row

LC = Length of the cable bolts (m)

CS = Cable bolt row spacing (m)

W = Entry width (m)

SFCA is the thickness-weighted average SF of the rocks in the cable grout anchorage zone. This zone is typically 1.2 m (4 ft) or greater in length. The *SFCA* is calculated using the same procedure as described above for *SFIM* of the immediate roof. There are no strong bed or surcharge adjustments for the cable bolts. Further research and modeling analysis is needed to establish whether these parameters are significant.

PERFORMANCE OF THE SF PREDICTION EQUATION

The validity of the results calculated by the SF prediction equation was first compared to the SF values calculated by the FLAC3D models. The next step was to compare the equation predictions to the empirically based ARBS design method. Finally, a large number of case histories were evaluated representing individual case histories in which detailed rock strength and support performance information was available.

Comparison to FLAC3D calculated SF Values

The correlation between SF values calculated by the prediction equation and the FLAC3D numerical models of 549 entries that have SF values of less than 3.0 is shown in Figure 3. The standard error was calculated to be 0.26, which represents a coefficient of variation of 17.7%. The coefficient of determination is 0.87 as shown in Figure 3.

The quality of the match between the equation predicted and FLAC3D calculated SF values is affected by the seemingly erratic rock mass response to small changes in input parameters. This can be ascribed to the strain softening rock mass that was modelled, in which the response can change dramatically based on a small change in input values.

The results presented in Figure 4 demonstrate how well the SF prediction equation can track changes in the SF as the depth, rock mass strength, and support type change. It can be seen that the equation follows the same trends as the FLAC model results; however, the variable SF response of the individual FLAC3D model outputs can clearly be seen.

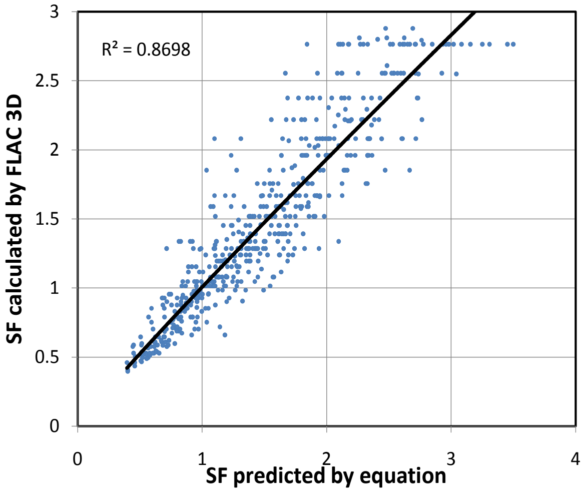


Figure 3. Comparison of SF values calculated by FLAC3D and the prediction equation for the 549 cases in which the FLAC3D calculated SF was less than 3.0.

Comparison to ARBS-calculated SF Values

The predictive capability of the SF prediction equation was further evaluated by comparing its performance against the ARBS empirical method developed by Mark et al. (2001). The 98 case histories in the ARBS database were used to determine whether the SF prediction equation could improve the separation between "successful" and "unsuccessful" cases compared to ARBS. Since the ARBS database does not contain the full geotechnical data of each rock unit in the roof of the entries studied, it was necessary to derive some of the required inputs.

The Rock Mass Strength

It was not possible to directly calculate the rock mass UCS, required for the prediction equation, from the ARBS database.

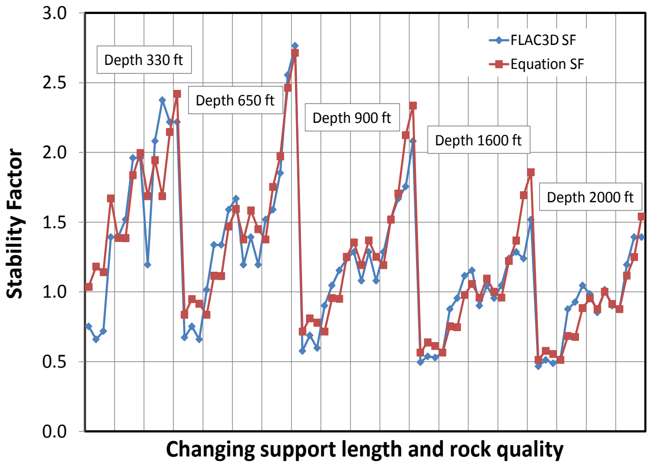


Figure 4. Comparison of equation-predicted SF values to FLAC3D-calculated SF values for supported entries in variable ground conditions and increasing depth of cover.

However, the CMRR of the bolted horizon was known for each case. In order to proceed, the UCSM value was estimated by assuming that the CMRR is also a predictor of the UCSM, as in most other rock mass classification systems. The relationship between CMRR and UCSM was determined using the procedures for estimating rock mass strength described in Esterhuizen et al. (2013b) as implemented in the 670 geotechnical scenarios that were modelled. The relationship was determined to be as follows:

$$UCSM = 5.0 \times 10^{-5} \times CMRR^{3.31}\ (MPa) \qquad (8)$$

The calculated UCSM value was assumed to be uniform in the roof of the excavation. The surcharge and strong bed factors in the nonlinear equation were set to 1.0 in all cases, since this information is already included in the CMRR.

Horizontal Stress

The SF prediction equation explicitly considers the horizontal stress by incorporating the horizontal tectonic strain. The horizontal stress was calculated using a tectonic strain parameter of 0.0005 for all the cases located in the eastern US coal regions, indicating unfavorable stress conditions. A tectonic strain of 0.004 was used for cases located in the western US, capturing the lower horizontal stress in those regions.

Intersection Dimensions

The ARBS considers the increased excavation width at intersections in the calculation of the SF, which is not included in the SF prediction equation. To account for intersection dimensions in the equation, an adjustment is made to the entry width. The equivalent entry width (W_e) representing the increased width of an intersection is calculated as follows:

$$W_e = W + 0.3 \times \left(W_i - \sqrt{2} \times W\right) \qquad (9)$$

where:

W = true entry width

W_i = average intersection diagonal dimension

If an intersection is perfectly cut with no rounding of the corners, the equivalent width will be equal to the normal entry width. As the corners are rounded or cut out, W_e increases by 30% of the increase in diagonal length.

Table 1. Prediction of support system success using ARBS and the nonlinear equation.

ARBS Prediction				Nonlinear Equation Prediction				Overall	
Successful cases		Unsuccessful cases		Successful cases		Unsuccessful cases		Correct prediction	
Correct	Wrong	Correct	Wrong	Correct	Wrong	Correct	Wrong	ARBS	Equation
38	13	24	9	36	15	29	4	62	65
75%	25%	73%	27%	73%	27%	88%	12%	73.8%	77.4%

Discriminant and Results

The performance of the SF prediction equation in discriminating between successful and unsuccessful cases in the ARBS database was determined by optimizing the discriminant SF value to produce the greatest number of successful predictions. It was found that an SF value of 1.7 provided the best performance. Table 1 shows how the equation and ARBS perform in predicting successful and unsuccessful support systems. The equation performs better than ARBS in the overall prediction of support performance. In the important case of predicting unsuccessful cases, ARBS achieves 73% correct predictions while the equation achieves 88%.

The SF of 1.7, used as a discriminant for the prediction equation, applies to intersection stability using the equivalent entry width. This value of SF might be considered to be appropriate for the design of intersection support. The SF of the entries in the database is approximately 0.3 greater than for the intersections, indicating that an SF of about 2.0 might be appropriate for designing entry support systems. However, support and mining practices have changed considerably since the ARBS data was collected in the 1990s. Particularly, the ARBS research indicated the importance of limiting intersection spans, and consequently much better control of intersections is practiced today. Also, support capacity and length of supports have increased since the 1990s. The topic of an appropriate SF is discussed further at the end of the paper.

Calculated SF Values of Documented Case Histories

A further validation exercise was conducted in which the SF values of supported entries at currently operating mines were calculated. The objective was mainly to determine the range of SF values that can be associated with current support practice and compare these to the results of the ARBS database analysis. The prediction equation was used to determine SF values at 34 different locations at 12 mines located in both the eastern and western US coal regions. Data on support systems, geological conditions, and rib stability were collected at these mines during 2012 and 2013. All the support systems could be considered to be 'acceptable' since the mines were operating within acceptable safety norms.

The detailed geotechnical data of the roof layers were not available at these case history mines. The rock mass UCS was therefore estimated using equation 8 to allow the SF prediction equation to be used. The entry dimension was used in the calculation; the results therefore represent the SF of entries, and not intersections. The horizontal stress field was again defined according to the geologic region in which the mines were located. The support systems consisted mainly of fully or partially grouted rock bolts, and in six of the cases supplementary cable bolts were used. The cable bolts were 3.7 m (12 ft) and 5 m (16 ft) in length.

The cumulative distribution of the resulting SF values are presented in Figure 5. The SF against large roof falls in these operating mines varies between 1.49 and 8.41. The majority of the results are clustered between SF values of 1.5 and 3.6, and the median value is 2.75.

Figure 6 allows comparison to be made of the SF associated with current support practices with the SF of the case histories in the ARBS database. The results show that in general the entries in the ARBS database had lower values of SF when compared to current practice. This is not unexpected, since many of the supports were only 1.2 m (4 ft) long and only a single case of 2.4 m (8 ft) bolts was included in the ARBS database.

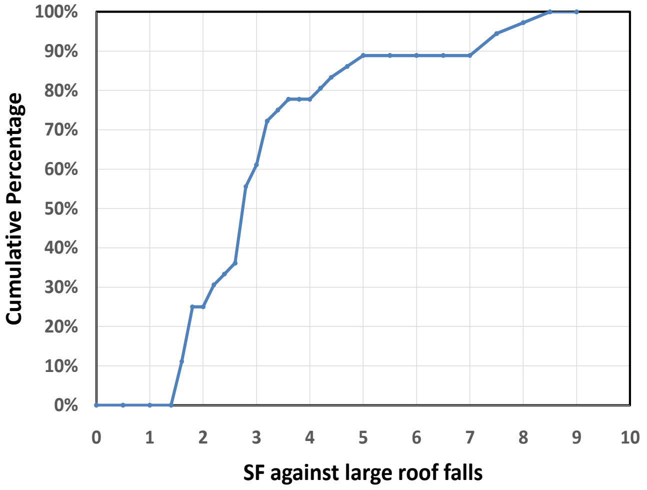


Figure 5. Cumulative distribution of SF values of supported entries at currently operating mines using the prediction equation.

EXAMPLE OF APPLICATION OF THE SF PREDICTION EQUATION

The effect of weak and strong beds located at various distances above the roof line of an entry is used to demonstrate the type of results that can be obtained by the SF prediction equation. The first scenario simulates a 5.7-m-wide (19-ft-wide) entry at a depth of cover of 200 m (650 ft) located in shale that has a CMRR-based unit rating of 43. The effect of weak overlying shale with a unit rating of 29 is evaluated. The weak bed is 1.2 m (4 ft) thick and has a UCS of 24 MPa (3500 psi). The geotechnical parameters of the roof rocks are summarized in Table 2. The entry is simulated in a stress field typical of the Central Appalachian coal region and is assumed to be unfavorably oriented relative to the major horizontal stress. The calculated SF result for the base case entry in uniform shale, supported by four 1.8-m solid bar fully grouted bolts, is shown in figure 7a. The SF value of 1.97 is likely to be sufficient for the base case geology and loading conditions. Figure 7b shows how the addition of two cable bolts 3.7 m (12 ft) long increases the SF to 2.84. It is assumed that a separate calculation has been made to ensure that the bolts and cables have sufficient capacity to support the dead weight of the rock within the bolted horizon. The effect on the SF of introducing a 1.2-m-thick (4-ft-thick) strong bed at various locations above the roof is shown in figure 7c through 7h. Examination of the results shows that the strong bed has no impact until it is intersected by either the bolts or cable bolts. However, once the supports are sufficiently anchored in the strong bed, the SF values are significantly increased by the suspension effect. Also interesting is the result that shows how the strong bed effect is reduced when the strong bed is located below the anchorage of the cable bolts, shown in figure 7f.

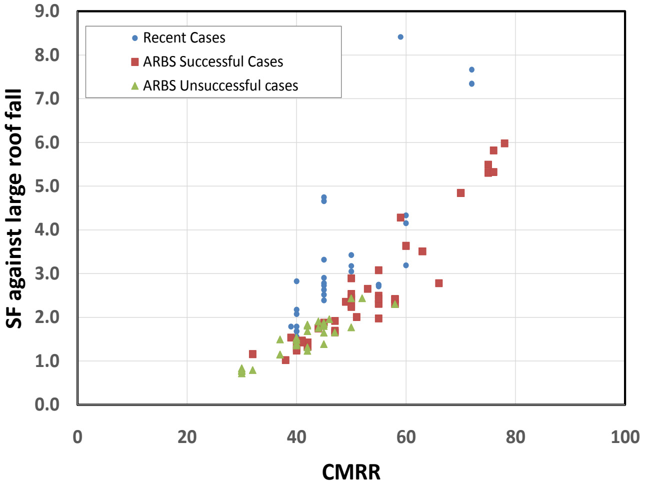


Figure 6. Calculated SF values using the SF prediction equation versus CMRR for current mining operations and case histories in the ARBS database.

The example presented in Figure 8 demonstrates how the presence of a low strength shale bed with a unit rating of 29 can impact roof stability. In this case the shale bed is assumed to be overlain by a stronger sandstone unit. The calculated SF results for this case are presented in figure 8a through 8h. An interesting result is shown in figure 8d where the cable bolt effectiveness is largely negated by the fact that the bolts are anchored in the weak shale unit.

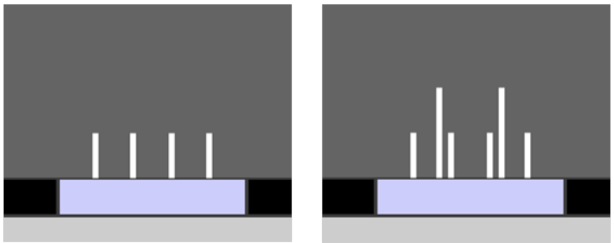
Table 2. Geotechnical parameters of roof beds evaluated in the example applications.

Rock type	UCS	Bedding cohesion	Bedding spacing	Unit rating
Shale	48 MPa (7,000 psi)	Weak planar Rating 16	50 mm (2 in) Rating 12	43
Weak shale	24 MPa (3,500 psi)	Very weak Rating 9	< 50 mm (<2 in) Rating 10	29
Sandstone	80 MPa (12,000 psi)	Moderate Rating 20	30 cm (12 in) Rating 20	61

SELECTION OF AN APPROPRIATE STABILITY FACTOR

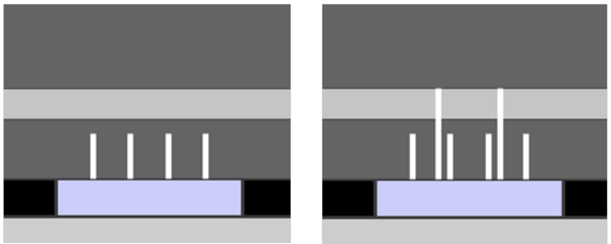
Entry support systems are required to be highly reliable because the consequences of failure are unacceptable. However, achieving the desired degree of reliability is difficult when the rock strength, field stress, and support installation quality can be highly variable and may be poorly understood. The required stability factors are necessarily high to account for the uncertainty and variability of the conditions.

The stability factors calculated by the SF prediction equation for currently operating mines are greater than 1.5. For roof rocks with CMRR unit ratings below 50, the SF values have an average of about 2.4. At present it is not possible to give better guidance for selecting an appropriate SF for design. Nevertheless, at this time, it would be prudent to use the SF prediction equation as a tool for comparison, so that the relative impact of changes in geology or support systems are evaluated, rather than targeting a specific SF value.



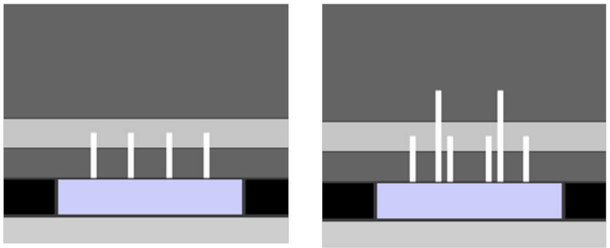
a) SF = 1.97. Base case uniform shale supported by 1.8-m solid rebar bolts

b) SF = 2.84 Base case uniform shale geology with 3.7-m cable bolts added



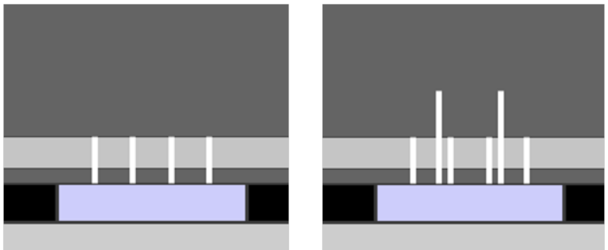
c) SF = 1.97 Strong sandstone bed has no impact on roof stability

d) SF = 4.08 Cable bolts anchor in strong sandstone providing suspension



e) SF = 2.29 Increased stability as bolts provide suspension in sandstone

f) SF = 3.15 Cable bolts anchored above strong bed have reduced effectiveness



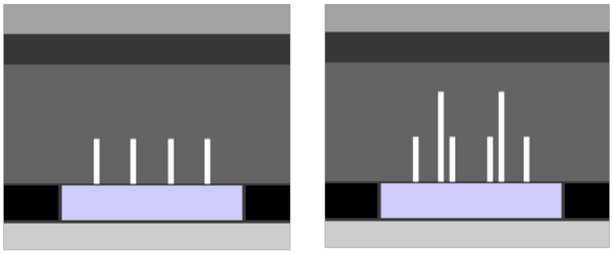
g) SF = 2.77 Bolts are highly effective as strong bed is reinforced

h) SF = 3.61 Cable bolts are relatively ineffective above the strong bed.

Figure 7. Effect of changing location of a strong sandstone unit on the SF of the roof of an entry as determined by the SF prediction equation.

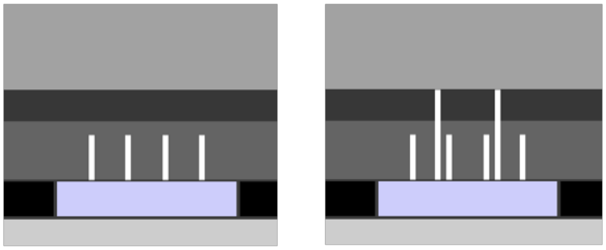
SUMMARY AND CONCLUSIONS

An equation has been developed that allows the stability factor of supported and unsupported coal mine entries to be estimated without the need to conduct advanced numerical model analysis. The SF prediction equation was developed by evaluating the results of 670 numerical models of supported and unsupported entries.



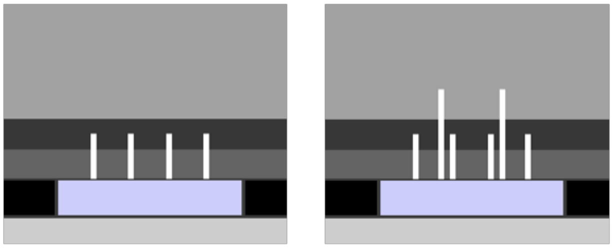
a) SF = 1.97 Base case with 1.8-m bolts and weak bed well above roof line.

b) SF = 2.84 Base case with 3.7-m cable bolts added



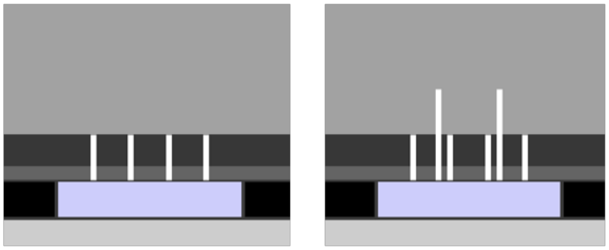
c) SF = 1.84 Weak bed surcharge reduces SF slightly from base case

d) SF = 1.98 Cables anchored in weak bed are not very effective



e) SF =1.92 Slight improvement, surcharge is reduced by strong sandstone

f) SF = 4.03 Cables anchored in strong sandstone



g) SF = 1.45 Bolts anchored in weak bed have reduced effectiveness.

h) SF = 3.61 Cable bolts anchored in strong sandstone have significant effect.

Figure 8. Effect of changing location of a weak unit on the SF of the roof of an entry as determined by the SF prediction equation.

The numerical models were validated against empirical design approaches and actual excavation performance in coal mines. Parameters for the equation were identified through least-squares error analysis.

The SF prediction equation is simple to calculate and is easily incorporated into a spreadsheet type analysis. The stability factors predicted by the equation are suitable for the rapid assessment of support alternatives during the initial stages of entry layout and support design.

The equation is shown to provide improved predictions of the successful and unsuccessful case histories in the ARBS database when compared to the predictions of the empirically developed ARBS equation. When applied to support systems in currently operating mines, 80% of the stability factors fell in the 1.5 to 3.6 range.

Since the SF prediction equation is based on the analysis of a given set of geological conditions and support types, it should only be used to evaluate support systems that fall within the bounds of the parameters used in the original analyses.

The SF prediction equation is valid for entries in bedded rocks supported by fully grouted primary supports and partially grouted cable bolts as secondary support. The numerical models forming the basis for developing the equation did not consider entries supported by cable bolts alone and should not be used to evaluate cable bolts without primary supports.

It is assumed that the support units have sufficient capacity to carry the dead weight of the rock within the supported horizon. Support capacity should therefore be checked beforehand.

Stability factors for design can be selected through back analysis of known support systems. Alternatively, the calculated SF values can be used to compare alternatives to one another.

The results of an assessment using these procedures should be used as a tool to supplement the detailed analysis and engineering evaluation of proposed entry layouts and support systems.

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DISCLAIMER

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