Application of the Coal Mine Floor Rating to Assess the Floor Stability in a Central Appalachian Coal Mine

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ABSTRACT

Estimating the overall floor stability in a coal mine using deterministic methods that require complex engineering properties of floor strata is desirable, but generally it is impractical due to the difficulty of gathering essential input data. However, applying a quantitative methodology to describe floor quality with a single number provides a practical estimate for preliminary assessment of floor stability. The coal mine floor rating (CMFR) system, developed by the University of New South Wales, is a rock mass classification system that provides an indicator for the competence of floor strata. The most significant components of the CMFR are uniaxial compressive strength and discontinuity intensity of floor strata. In addition to the competence of the floor, depth of cover and stress notch angle are input parameters used to assess the preliminary floor stability. In this study, CMFR methodology was applied to a Central Appalachian coal mine that intermittently experienced floor heave. Exploratory drill core data, overburden maps, and mine plans were utilized for the study. Additionally, qualitative data (failure/nonfailure) on floor conditions of the mine entries near the core holes was collected and analyzed so that the floor quality and its relation to entry stability could be estimated by statistical methods. It was found that the current CMFR classification system is not directly applicable in assessing the floor stability of the Central Appalachian coal mine. In order to extend the applicability of the CMFR classification system, the methodology was modified. A calculation procedure of one of the CMFR classification system's components, the horizontal stress rating (HSR), was changed and new parameters were added to the HSR.

INTRODUCTION

Sears et al. (2018) stated an increasing problem in deep cover coal mines—that floor heave is usually observed when there is a presence of weak and moisture-sensitive immediate floor strata (typically clay), and the load-bearing capacity of floor strata is exceeded due to a high vertical or horizontal stress state.

The excessive amounts of floor heave causes narrowing of the mine entries and has the potential to lead to the closure of entries.

The unplanned closure of mine entries disrupts the production and ventilation of the mine and increases the difficulty for personnel traveling escapeways and causes trip hazards in certain cases of local instability (Klemetti et al., 2020). For a robust ground stability design, estimating the rock mass behavior is imperative. The coal mine floor rating (CMFR) classification system was developed to assess practically the potential behavior of floor strata in Australian coal mines (Mo, 2019). The CMFR system is composed of two components: CMFR and horizontal stress rating (HSR). CMFR is created to quantify the competence of floor, and HSR is created to include the effect of overburden stress and alignment of maximum principal horizontal with respect to the entries. In order to assess the stability of the floor in comparison with other failure and nonfailure cases in the database, Mo (2019) also created the floor heave index (FHI), which incorporates the CMFR and HSI into a graphical tool. FHI is employed to depict the correlation between failure and nonfailure cases from actual floor failure cases based on statistical methods. In this study, the CMFR system developed for Australian floor failure cases is applied to a Central Appalachian mine that intermittently experiences floor stability problems. It is observed that the estimation of floor stability of the case study mine using the FHI as defined by Mo (2019) is not as accurate as it is for the Australian mines. Due to these inaccuracies, a modification to the HSR calculations, including additional factors and different constants, are proposed in this study.

FLOOR HEAVE MECHANISM

There are different mechanisms of floor heave based upon the floor geology and operational conditions with different driving factors. Nemcik (2003) states that the mechanisms of floor heave at the longwall gate roads can be classified into three categories: bearing capacity failure (Figure 1a), swelling (Figure 1b), and buckling (Figure 1c). These three mechanisms of floor heave are also illustrated in Figure 2.

Bearing capacity failure of floor strata happens when the load transmitted from pillars to floor exceeds the load-bearing capacity of immediate floor strata. If the floor cannot provide a foundation

Figure 1. (a) Bearing capacity failure (Tyler and Sutherland, 2011), (b) swelling failure (Vasundhara, 1999), and (c) buckling failure (Van Dyke et al., 2018).
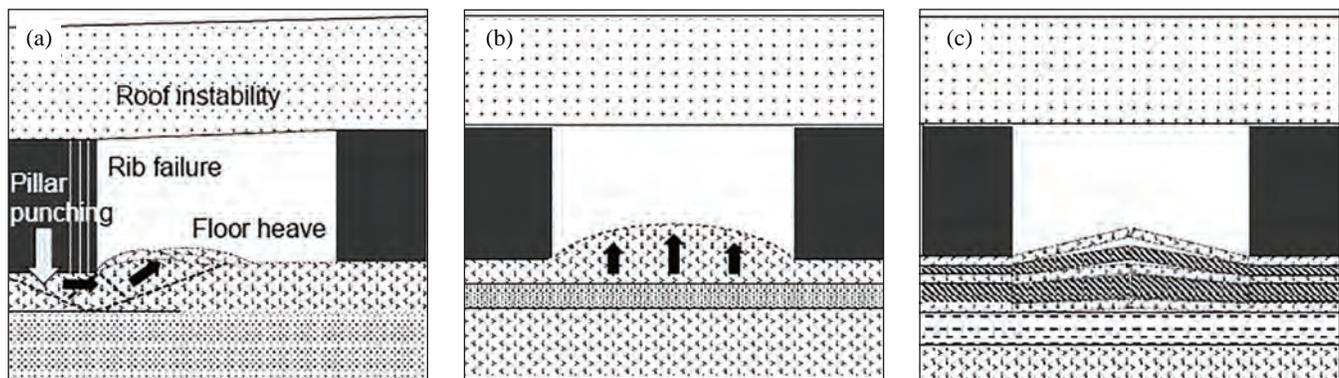

Figure 2. (a) Bearing capacity failure, (b) swelling failure, and (c) buckling failure (Mo, 2019) (Adapted from Whittles, Reddish, and Lowndes, 2007).

for the pillar any longer, the pillar starts moving downward into the floor and gradual pillar punching leads to failure of the floor. The punching of the pillar into the floor results in movement of floor material beneath the coal pillar outward and upward toward the ground surface (Speck, 1981). Speck (1981) stated that the load carried by a coal pillar before pillar punching is transferred upon floor failure to surrounding immediate roof/floor strata and adjacent pillars. The additional load exerted on the floor contributes to the bearing capacity failure and increases the severity of the failure. The successive occurrence of floor failure and continuous load transfer to the adjacent pillars causes propagation of floor bearing capacity failure throughout the mine.

Swelling is another mechanism of floor heave. Faria Santos and Bieniawski (1989) stated that swelling is observed as a result of exposure of clay-rich materials, such as fireclays, mudstone, claystone, and shale, to moisture. Exposure to water or moisture is one of the major components of all types of floor heave mechanisms; however, the role of water is crucial as a swelling mechanism. Swelling is defined as the expansion of floor material due to the interaction between moisture and floor material, such as the Smectite group of clay, which tends to shrink and swell. Clay mineral/water interaction causes a dramatic decrease in the mechanical properties of the material and ultimately results in floor failure, which endangers the functionality of mine entries.

The aforementioned floor heave mechanisms, bearing capacity, and swelling, are associated with the existence of weak immediate floor stratum. However, buckling, the third type of floor heave, occurs where the immediate floor layer is stronger than the layers

underneath. Buckling is typically observed where the strong immediate floor behaves as hardpan, hard and compacted layer. The presence of sufficiently high horizontal stress initiates buckling of the immediate floor layer and causes floor heave (Peng, Wang, and Tsang, 1995). An example of buckling failure is seen in the Beckley coalbed in West Virginia, where the competent and relatively strong floor has failed in a buckling manner due to the existence of a high horizontal stress field (Aggson 1978).

COAL MINE FLOOR RATING

Brady and Brown (2004) stated that understanding the complex nature of rock mass and making future predictions for rock mass response in advance is not simple. They support applying to the previous experiences of mining operations for the future decisions of similar conditions. Toward this endeavor, rock mass classification systems based on empirical approaches are developed in order to apply the gained experience to the similar conditions in other mines based on a standardized procedure.

There are numerous rock mass classification systems that incorporate sub-ratings of different parameters with varying weighting factors into an overall rock mass rating. These systems became a reliable methodology to follow in the predesign stage of many areas, such as tunneling, slopes, and foundations because of their ease of applicability. The pioneering studies on rock mass classification systems were performed by Deere et al. (1967), Bieniawski (1973), Barton, Lien, and Lunde (1974), and Hoek (1994). The most well-known and commonly practiced classification in U.S. coal mines is the coal mine roof rating (CMRR) system (Mark and Molinda, 2005). And recently, the CMFR system was proposed

for Australian coalfields (Mo, 2019). Application of the CMFR to assess the stability of floor strata follows calculating the CMFR, HSR, and plotting FHI.

Components of the CMFR

The CMFR is designed to represent the competency of floor strata based on geomechanical and lithological properties of immediate floor rocks. First, the CMFR divides the floor strata into different floor units based on the geological differences and calculates unit rating for each division. Uniaxial compressive strength of intact rock and discontinuity characteristics, more specifically the average discontinuity spacing of beddings and other discontinuities, are the main parameters used in the computation of unit ratings. Then, the thickness-weighted average of unit ratings is calculated. Since the configuration of the strong unit in floor strata also affects the overall behavior of the floor, the effect of the strong unit is integrated into the CMFR value using the strong unit adjustment (SUA) calculation.

Uniaxial Compressive Strength

Uniaxial compressive strength (UCS) is widely used by a large percentage of rock mechanic engineers to represent the strength of rock for surface and underground designs. UCS can be obtained through indirect tests, such as the point load test, Schmidt hammer test, sonic logging, and so on. Sliwa et al. (2006) states that sonic logging has become an increasingly widespread method for rock strength estimation in Australia. Analogously, the UCS scale for the CMFR system was developed for the UCS values obtained by sonic logging (Table 1). It is believed that the competence of floor stratum with less than 10 MPa is governed only by UCS, that is, not influenced by the average discontinuity spacing any longer.

Table 1. CMFR unit ratings for UCS tests.

UCS (MPa)	Ratings
<10	10
12–20	$2 \times UCS - 10$
20–30	$UCS + 10$
30–80	$0.3 \times UCS + 31$
80–160	$0.125 \times UCS + 45$
>160	65

Discontinuity Spacing

In rock engineering, two main classification terms exist to define rocks: intact rock and rock mass (Priest, 1993). *Intact rock* refers to the rock material in an ideal state where there is not any discontinuity or fracture (massive) in the rock matrix, whereas *rock mass* refers to in situ rock material with a possible discontinuity/fracture network. For the sake of ease, rock masses are sometimes assumed to be intact rock. However, in real-world application, discontinuities always exist within the rock matrix.

Discontinuities in rock mechanics serves as an inclusive term of all fractures, such as faults, joints, shears, weak bedding planes, and contacts (Brady and Brown, 2004). The intensity of weakness planes within the rock governs the mechanical behavior of rock mass in the sense that densely packed planes of discontinuities adversely affect the strength of rock mass (Hoek and Brown, 2018).

Therefore, discontinuity properties, more specifically discontinuity spacing, are commonly used as a measure of rock mass quality and employed in many rock mass classification systems.

In the CMFR, discontinuity spacing is applied to implicate frequency of weakness planes, including bedding, lamination, joints, fractures, and any other kind of planes that result in weakness in a rock mass. Discontinuity spacing, the average distance between each discontinuity plane per unit length along a drill core, can be calculated by dividing unit thickness of layer with the number of discontinuities +1. The CMFR system scale for discontinuity spacing is shown in Table 2.

Table 2. CMFR unit rating for discontinuity spacing.

Discontinuity Spacing (mm)	Discontinuity Spacing Rating
<20 (lamination)	0
20–60	5
60–200	15
200–600	25
> 600	35

Strong Unit Adjustment

In the stratified depositional nature of coal roof and floor geology, it is likely to find several different units with varying geomechanical properties. Mark and Molinda (2007) state that the strongest layer within the bolted area in the roof heavily influences the roof performance. Similarly, the presence of a strong unit in the floor strata is considered by the CMFR system while predicting the competence of floor strata. Since the application of bolts in floor strata is very rare, the existence of a bolted area concept that is used in CMRR for floor strata is not applicable. Instead, the first 3-m interval of floor strata is taken into consideration in order to investigate the effect of a strong unit on the floor performance. Including the adjustment for a strong unit depends on the stratigraphic sequence of strong units within 1 m of floor strata. In order to apply the SUA calculation, the strongest layer within the 1 m of floor interval must have a minimum thickness of 0.7 m.

CMRR considers how much stronger the strong unit is than the others in the strata (Mark and Molinda, 2007). Analogously, the CMFR distinguishes the strongest layer with the highest unit rating. Then, the strong unit difference (SUD) calculation is established to understand the relative strength of layers. The SUD is calculated by subtracting the unit rating of the strong layer from the thickness-weighted average unit rating within 3 m of floor strata. If the SUD is greater than 20, 5 is added to the thickness-weighted average unit rating as SUA.

Calculation of the CMFR

The CMFR calculation starts with the evaluation of unit ratings, which consists of a UCS rating (Table 1) and a discontinuity spacing rating (Table 2). A minimum unit rating of 25 is applied to all floor units. Upon the calculation of unit ratings for each floor stratum, a SUA can be added to the corresponding strong unit. Then, the thickness-weighted average of unit ratings is calculated within 3 m of floor strata in order to achieve an overall CMFR number based on a 0–100 scale, which represents the competence
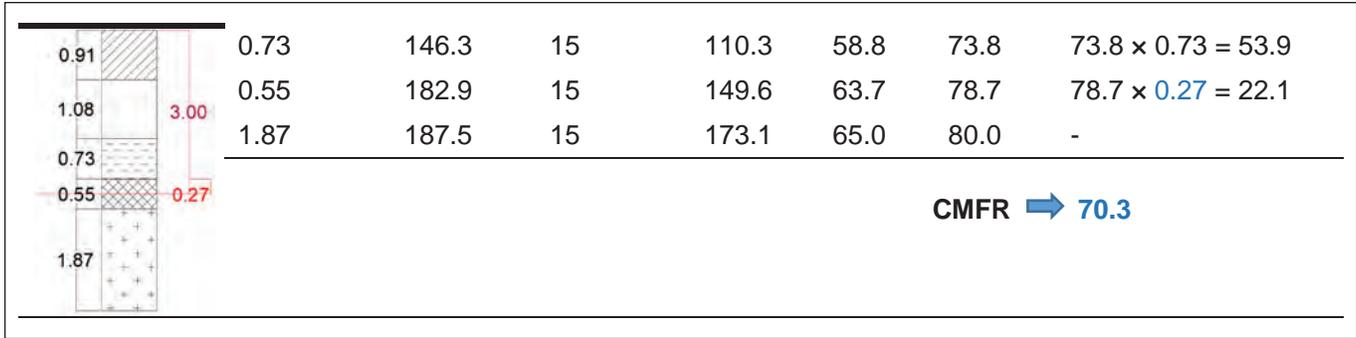
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	0.73	146.3	15	110.3	58.8	73.8	73.8 × 0.73 = 53.9
	0.55	182.9	15	149.6	63.7	78.7	78.7 × 0.27 = 22.1
	1.87	187.5	15	173.1	65.0	80.0	-

CMFR ➡ 70.3

Figure 3. Calculation procedure of unit rating and CMFR.

of the floor strata within 3 m. Figure 3 represents the calculation of the unit rating of each stratum and thickness-weighted averaged CMFR value for an available drill core from the case study mine. It should be noted that the last 0.27 m of the bottom unit with a thickness of 0.55 m is excluded from the CMFR calculation as it is not within the 3 m of floor strata.

Horizontal Stress Rating
Stress state of the floor strata is as important as the floor material quality to assess the floor stability in a coal mine. In order to include the stress state of floor into the FHI system, the HSR is established. The HSR is composed of depth rating and angle rating.

Depth rating is simply the division of depth of cover in meters by 10. Angle refers to the angle between the entry and major horizontal stress. The angle rating scale for the HSR is shown in Table 3.

Floor Heave Index
FHI is an empirical method developed from statistical methods. FHI is employed in order to combine the CMFR value and HSR into one output. Incorporating CMFR and HSR of failure and nonfailure cases into FHI provides visual comparison of binary outcomes of failure and nonfailure cases using the logistic line.

FHI was developed for the case study mines in Australia, shown in Figure 4 (Mo, 2019). The addition of new case studies using FHI by calculating CMFR and HSR can assist in the estimation of floor stability conditions of other mines for future geotechnical investigations.

CASE STUDY MINE

General and Geological Information on Case Study Mine
In the case study mine, metallurgical coal is extracted by utilizing the longwall mining method. The longwall mine is located in the Central Appalachia. The mine extracts from the Pocahontas No. 3 coal seam, which belongs to the western part of the valley and ridge physiographic province; this province is characterized by folded and faulted thrust belts that cause steep-sided mountain ridges and valleys that follow a northeast trend.

The operating depth of the mine exceeds 600 m. The overburden thicknesses range from 426.7 to 670.5 m. The width and length of the entry are 6.1 and 24.4 m, respectively. The coal seam thickness ranges from 1.5 to 1.8 m. The longwall panels are approximately 220-m wide by 3,660-m long. In the studied part of the mine, the

Table 3. CMFR horizontal stress rating.

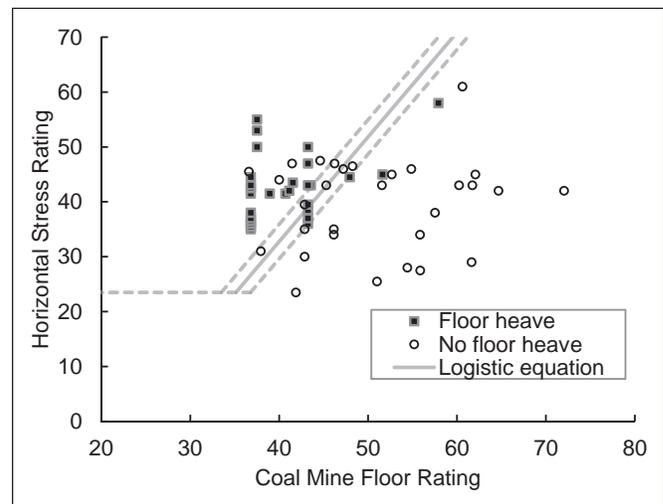| Stress Notch Angle (°)	Angle Rating
> 30	5
20–30	3
10–20	1
< 10	0

Figure 4. Floor heave index for Australian mines (Adapted from Mo, 2019).

depth of cover ranges from 457 and 731 m, and the coal seam thickness varies between 1.7 and 3.2 m.

Van Dyke et al. (2018) stated that geology in the studied area of the mine significantly alters from mains adjacent to pillar 25 through pillar 28, and they constructed generalized vertical geological columns (Figure 5) in the interest area based on nearby drill cores. From the analysis of drill cores, it is observed that the floor strata composed of 0.15 m of shale and 0.7 to 1.8 m of fireclay, which is overlaid by bedded sandstones. The roof in the studied area is qualified as competent. The immediate roof consists of 2.74 m of massive sandstone with an underlying 0–3 m of silty shale.

This study focuses on the southeastern mains of the mine along both entries and crosscuts, which experiences floor heave problems.
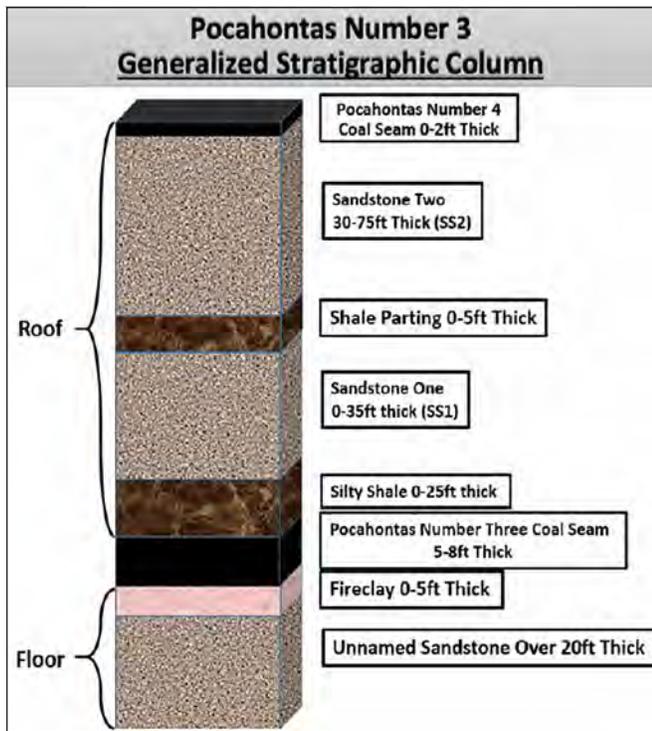
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Figure 5. Generalized stratigraphic column of the Pocahontas No. 3 seam for floor heave in the case study mine (Adapted from Van Dyke et al., 2018).

Figure 6. Mine layout and drill core locations for failure and nonfailure cases in the U.S. case study mine.

The mine layout part of the case study mine where floor heave is observed is shown in Figure 6, along with yield-abutment-yield gate road design. The longwall panels are extracted from bottom to top, and extraction advances from left to right through the mine. Due to the split in the top of the seam, which led to a very weak clay roof, the direction of mine advance was changed and oriented 45° toward the south starting from Panel 25.

According to the published paper about the floor heave in the area of interest in the case study mine (Van Dyke et al., 2018), an initial unexpected occurrence of floor heave, an inch or less, was observed in the recovery area of Panel 25, which is overlaid by thick over-burden strata with the thickness ranging from 610 to 730 m. It was noted that floor heave in the vicinity of Panel 25 remained the same during the extraction of Panel 26. After the extraction of Panel 26, a significant increase in the amount of floor heave (up to 1.2 m) was observed. As the mining resumed down to Panel 29, it was recorded that the floor heave progressed through Panel 29. Figure 6 shows the area that intermittently experienced floor heave.

Available drill cores close to the floor heave areas and discussions with the geologist of the mine were utilized in order to character-ize the floor geology in failure cases. Figure 6 shows the location of the drill cores that are used to characterize three failure and eight nonfailure cases used in the analysis.

Application of CMFR Methodology to the U.S. Case Study Mine

The CMFR methodology, described in the preceding sections, was applied to the Central Appalachian coal mine. The CMFR and
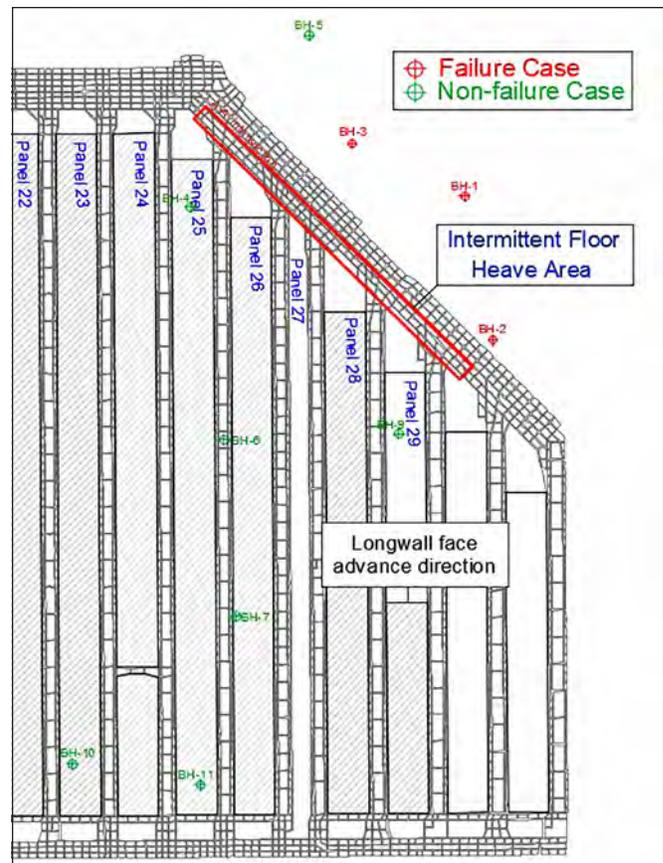
HSR is calculated for 11 drill core samples in the case study and summarized in Table 4.

The CMFR and HSR values shown in Table 4 are used to plot FHI for the U.S. case study mine shown in Figure 7.

MODIFICATIONS ON FHI

Figure 7 shows that FHI could not accurately separate failure and nonfailure cases from each other for the Central Appalachian case study mine. It is hypothesized that the inaccurate classification of failure and nonfailure cases for the Central Appalachian mine results from the angle rating calculations used in the HSR. In the Central Appalachian case, the angle between mine entry and maximum horizontal stress is 90° and 45° for failure and nonfailure cases, respectively. The angle rating developed for the Australian mines assigns a rating of 5 for any angles larger than 30°. Therefore, the same angle rating of 5 is assigned to all cases in the Central Appalachian mine regardless of different maximum horizontal stress alignments. In order to examine the hypothesis, a modified HSR with the more detailed scale of angle is derived for the Central Appalachian mine.

In the case study mine, maximum and minimum principal stresses (σ_1 and σ_3) are the horizontal stresses, while intermediate principal stress (σ_2) is the vertical stress. For more realistic in situ vertical stress calculations, including the effect of topographic relief in stress conditions, a large-scale model is constructed through a

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Table 4. Calculation of the horizontal stress rating for the Central Appalachian.

| Borehole Name	Failure/ Nonfailure (F/NF)	Depth of Cover (m)	Depth Rating	Stress Notch Angle (°)	Angle Rating	Horizontal Stress Rating	CMFR
BH 1	F	672.02	67.2	90	5	72.2	67.58
BH 2	F	595.40	59.5	90	5	64.5	67.49
BH 3	F	731.63	73.2	90	5	78.2	74.75
BH 4	NF	669.90	67.0	45	5	72.0	70.87
BH 5	NF	562.80	56.3	45	5	61.3	73.88
BH 6	NF	451.44	45.1	45	5	50.1	85.38
BH 7	NF	650.07	65.0	45	5	70.0	70.32
BH 8	NF	614.53	61.5	45	5	66.5	68.30
BH 9	NF	578.42	57.8	45	5	62.8	72.38
BH 10	NF	678.51	67.9	45	5	72.9	72.59
BH 11	NF	683.90	68.4	45	5	73.4	61.16
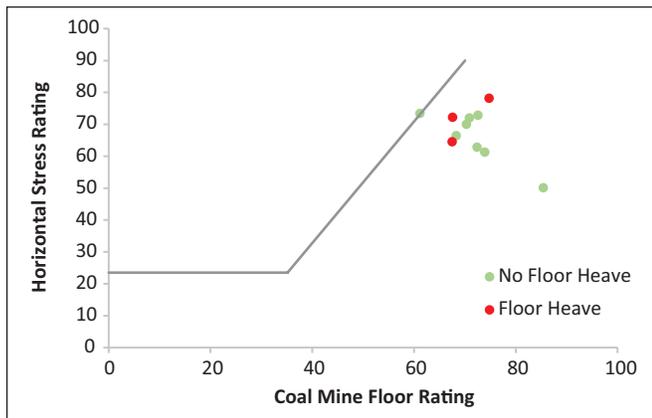
Figure 7. Floor heave index for the U.S. case study mine.

collaborative use of boundary element software, LaModel, and stability mapping (Heasley,1998). In situ vertical stress distribution, a result of the effect of topographic stress on the mine floor, for the case study mine is shown in Figure 8. The area shown in Figure 8 is meshed with 1,400 × 1,400 3-m elements in the LaModel software.

The total horizontal stress applied to the floor strata is the summation of the tectonic stress and the stress resulting from the Poisson effect and can be calculated using Equations 1 and 2.

$$\sigma_{h, Poisson's\ Effect} = \sigma_{2,total} \times \frac{\vartheta}{(1+\vartheta)(1-2\vartheta)} \quad \text{(Equation 1)}$$

$$\sigma_{h, Tectonic\ Stress} = \varepsilon_{tectonic\ strain} \times E \quad \text{(Equation 2)}$$

where

ϑ = Poisson's ratio of rock mass
ε = tectonic strain
E = elastic modulus of rock mass

Sears et al. (2018) states the elastic modulus of shale in the case study area as 14.01 GPa. For the case study mine, the tectonic strain is calculated as 1,070 microstrain and verified with the high tectonic

strain of 1,040 microstrain, which is specified for the Central Appalachian mines (Dolinar, 2003). The input parameters for the total horizontal stress calculation are elastic modulus of 14.01 GPa for shale, the tectonic strain of $1.07 * 10^{-3}$, and Poisson's ratio of 0.2. The calculated total horizontal stress is considered as the maximum total horizontal stress (σ_1, σ_{h1}). The maximum horizontal stress to the minimum horizontal stress ratio is stated as 1.5 by Sears et al. (2018). The same ratio is used for the stress calculations in the case study mine, and the maximum principal stress (σ_1, σ_{h1}) is set to be 1.5 of the minimum principal stress (σ_3, σ_{h3}).

The HSR is modified by changing the calculation procedure of angle rating. The counterclockwise two-dimensional (2-D) stress transformation formula from continuum mechanics is implemented to the angle rating calculation procedure, which makes it possible to calculate the rating for every single angle value from 0 to 90° (Equations 3 and 4).

$$\sigma'_{xx} = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}(\sigma_{xx} - \sigma_{yy})\cos(2\theta) + \sigma_{xy}\sin(2\theta) \quad \text{(Equation 3)}$$

$$\sigma'_{yy} = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}(\sigma_{xx} - \sigma_{yy})\cos(2\theta) - \sigma_{xy}\sin(2\theta) \quad \text{(Equation 4)}$$

Through Equations 3 and 4, maximum principal stress (σ_1, σ_{h1}) and minimum principal stress (σ_3, σ_{h3}) is rotated for angles of 45° and 90°. In addition to rotating the principle stresses, the horizontal stresses are normalized by dividing the minimum principal stress (σ_3, σ_{h3}) by the maximum principal stress (σ_1, σ_{h1}). The coefficient calculated upon normalization provides a value between 0 and 1, which enables an easy comparison between minimum and maximum principal stresses. By rotating and normalizing the principal stresses, the effect of horizontal stress orientation is calculated. The ratio of average maximum horizontal stress (σ_1, σ_{h1}) to average in situ vertical stress (σ_2, σ_v) is calculated as 1.23, which includes the effect of horizontal stress magnitude to the modified HSR. It should be noted that this ratio is specific to the case study mine and has to be calculated individually for other mine sites. To integrate the effects of orientation and magnitude of horizontal stress into the modified HSR, previously calculated normalized coefficients corresponding to horizontal stress orientation are multiplied by the ratio of average maximum horizontal stress and average in situ vertical
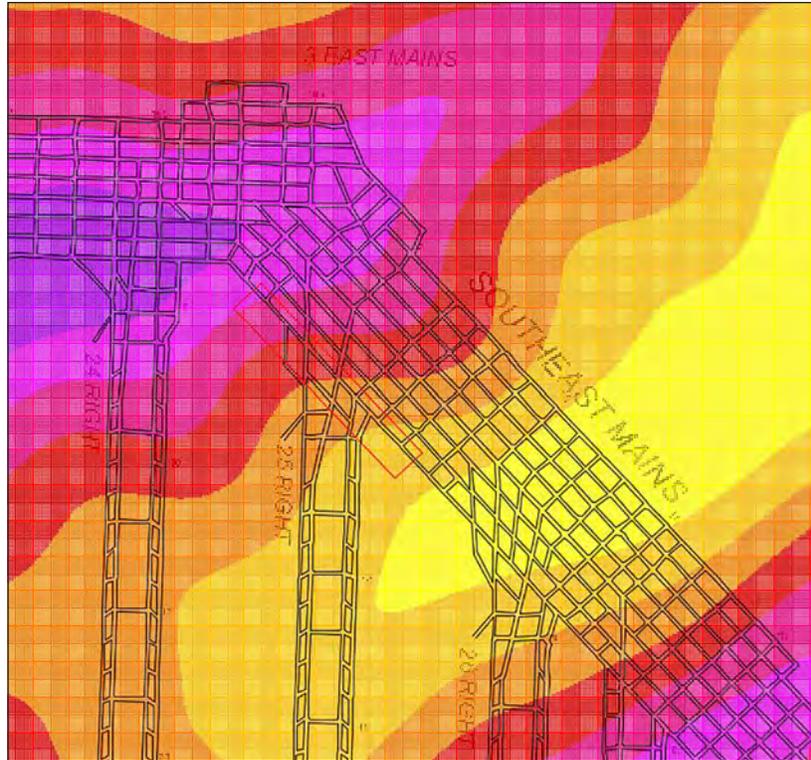
Figure 8. LaModel mesh for overburden stress.

Table 5. Calculation of modified HSR.

Borehole Codes	Failure/Nonfailure (F/N)	New Horizontal Stress Coefficient	In Situ Vertical Stress (MPa)	Modified Horizontal Stress Rating	CMFR
BH 1	F	1.23	17.94	22.02	67.58
BH 2	F	1.23	15.69	19.26	67.49
BH 3	F	1.23	17.94	22.02	74.75
BH 4	N	1.02	16.64	17.02	70.87
BH 5	N	1.02	14.92	15.27	73.88
BH 6	N	1.02	11.77	12.04	85.38
BH 7	N	1.02	16.01	16.38	70.32
BH 8	N	1.02	14.97	15.32	68.30
BH 9	N	1.02	13.96	14.29	72.38
BH 10	N	1.02	16.52	16.90	72.59
BH 11	N	1.02	16.84	17.23	61.16

stress, and new horizontal stress coefficients are obtained for corresponding angles.

Lastly, the new horizontal stress coefficient that corresponds to the angle between maximum horizontal stress and the gate road is multiplied by the in situ vertical stress, provided by LaModel, for each drill core, which gives the modified HSR. Table 5 summarizes the modified HSR calculation steps for each drill core sample.

FHI for the U.S. mine study case is plotted using the modified HSR in Figure 9. The dashed line is established to separate failure and nonfailure cases from each other. However, it should be noted that the line is not established for design purposes and can be modified in the future if new case studies are included to the database.

CONCLUSION

The CMFR classification methodology was developed for preliminary assessment of the floor stability. Application of the CMFR to assess the stability of floor strata follows calculating the CMFR, HSR, and plotting FHI. The CMFR value represents the competence of floor strata based on UCS and intensity of discontinuities in the floor strata. The HSR brings the effect of
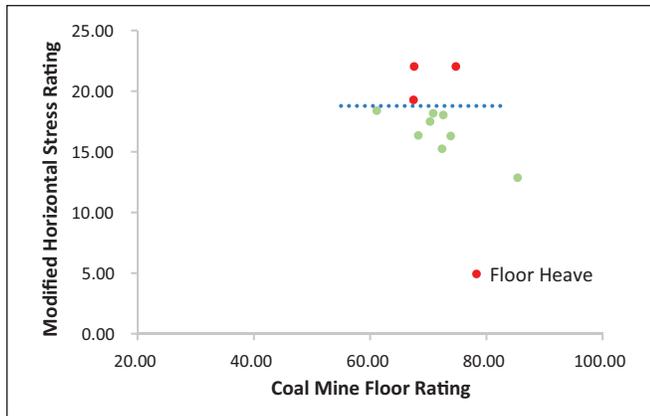
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Figure 9. Floor heave index using the modified horizontal stress rating.

mining depth and horizontal stress alignment with respect to the entries into the analysis. The FHI incorporates the CMFR number and HSR into a plot, which depicts the correlation to each other. Also, the logistic regression line in FHI is derived with statistical methods to sufficiently separate the failure and nonfailure cases from each other.

In this study, the CMFR system is applied to a Central Appalachian coal mine to examine the applicability of CMFR, purely developed based on Australian case studies for a U.S. mine. It was found that the logistic regression line in FHI developed for the Australian database is not adequate to separate failure and nonfailure cases from each other for the U.S. case. It is believed that the insufficient separation results from the angle rating in the HSR. For this reason, HSR is modified and an elaborative way of calculation for angle rating is implemented into the HSR where angle rating is calculated for each angle separately. A better separation of failure and nonfailure cases from each other is observed with FHI using the modified HSR. Future studies will aim at expanding the database with case studies from the U.S. mines in order to suggest a design line for future floor stability assessments. Further, the effect of moisture to the competency of the floor unit will be investigated in order to integrate moisture sensitivity to the CMFR system.

ACKNOWLEDGMENT
The authors thank Sungsoon Mo and Serkan Saydam from the University of New South Wales for their kind support and guidance during the preparation of this manuscript.

DISCLAIMER
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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