Empirical Design of Span Openings in Weak Rock based upon Support Type Employed

Ouchi, A. M.
Barrick Gold Corporation, Tulawaka Gold Mine, Tanzania, Africa
Norman B. Keevil Institute of Mining Engineering, University of British Columbia, Vancouver, BC, Canada
Pakalnis, R.
Norman B. Keevil Institute of Mining Engineering, University of British Columbia, Vancouver, BC, Canada
Brady, T.M.
Spokane Research Laboratory, National Institute for Occupational Safety and Health, Spokane, WA, USA

ABSTRACT: Existing empirical design tools have been developed from fair-to-good quality rock masses (RMR_{76} >50). This paper presents a focus of ground control research presently being conducted by the Rock Mechanics Group in the UBC Mining Department in incorporating weak rock masses (RMR_{76} <50) into existing empirical design relationships. An emphasis is being placed upon the updated span design curve/critical span graph originally developed at UBC. The original database has been augmented with over 450 weak rock data points from mines such as the Stillwater mine (Montana), the Eskay Creek Mine (BC) and several mines in the Carlin Trend and other parts of Nevada. The original database is comprised of spans supported with "traditional" mechanical bolting. In weak rock environments however, this type of support has been found for the most part, ineffective. This paper presents the span and weak rock RMR_{76} relationship for four different support categories. This work attempts to provide rock mechanic tools that will enable a mine operator to make economic decisions that will also ensure a safe working environment.

1. INTRODUCTION

The University of British Columbia Geomechanics group and the NIOSH Spokane Research Laboratory have been conducting research in the development of safe and cost effective underground design guidelines in weak rock environments with Rock Mass Ratings (RMR_{76}) [1] in the range of 20 to 50. A main area of the research is in the augmentation of the updated span design curve/critical span graph.

As "ideal" resources in competent ground conditions are depleted, there is an increase in the number of mines operating in weak ground conditions. This presents potentially difficult and hazardous mining conditions to workers in the industry resulting in a higher frequency of injuries and fatalities. This is evident in Nevada by the number of injuries resulting from uncontrolled rock falls during the time period of 1990 through 2007 (Figure 1) with a low of 2 in 2004 and a high of 28 in 1995 and 1997 [2,3]. In mid-1999 NIOSH started conducting visits and discussions with Nevada mines regarding weak rock and ground falls resulting in a statistical decline of ground fall related injuries over the next two years [4]. 2002 showed an increase in ground fall related injuries and in the middle of that year, NIOSH commenced technical mine visits. There was another spike in injuries in 2005. The last two years have had relatively low numbers of ground fall related injuries. However, last year there was one fatality from a fall of ground. Weak rock conditions are a concern and will continue to be in the years to come.

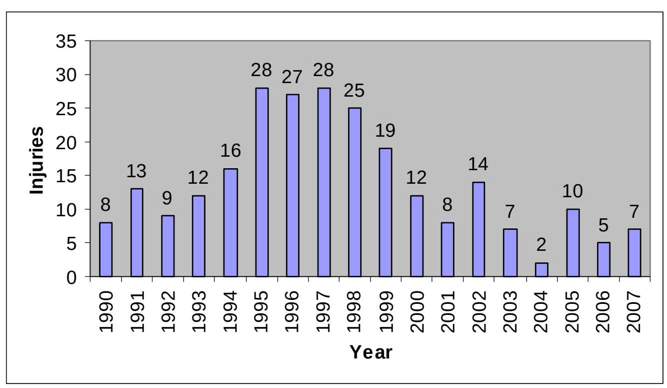

Figure 1: Ground Fall Related Injuries in Nevada, 1990-2007

The Critical Span Curve is a simple and useful tool that aids in the design of underground man-entry openings. With the increasing number of mines operating in weak ground conditions of RMR_{76} less than 50, there is the need to update the Critical Span Curve for the RMR_{76}

range of 20-50. The augmentation of this curve to include a larger database of points in the weak rock mass range will increase its accuracy and reliability in such conditions. For the purposes of this study, RMR_{76} values of 60 and less were used.

Surface support is almost always used in weak rock environments. The type of support used can vary widely. The development of the weak rock augmented Span Design Curve has also been separated into four different support categories; Pattern Friction Sets (A), Pattern Friction Sets with Spot Bolting of Rebar (B), Pattern Friction Sets with Pattern Rebar Bolts (C) and Cablebolting/"Heroics" (D). Category D includes cablebolts and other engineering designed support systems such as cemented rock fill (underhand cut and fill mining), significant application of shotcrete (typically 76mm), spiling or timber sets.

2. SPAN DESIGN, MAN ENTRY

The "critical span curve" has undergone modifications since its development in 1994 by Lang and the University of British Columbia [5]. The database was expanded to 292 observations in 2000 with case histories from an additional six mines [6]. The span curve and its updates (Figure 2) has been widely accepted in the North American mining community and provides a quick and simple tool to estimate a maximum span that may be designed based upon the observed RMR_{76} value.

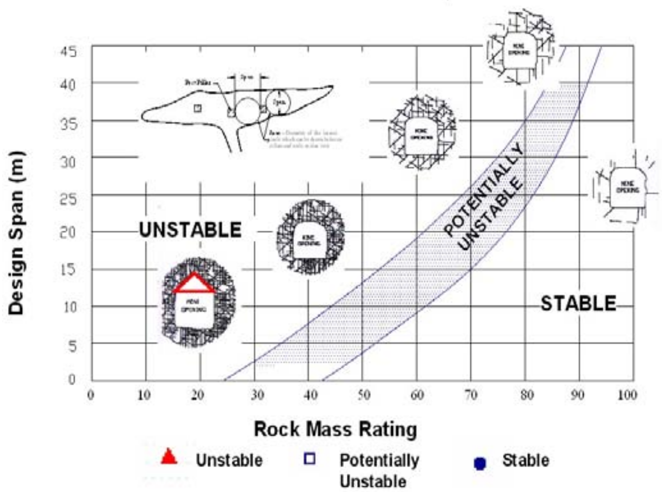

Figure 2: Updated Critical Span Curve

The updated database included RMR_{76} values from 24 to 87 with 63% of the cases in the range of 60 to 80 [6]. Less than 10% of RMR_{76} values in the updated database fall below a value of 40 and less than 20% fall below a value of 55 [7]. The updated curve has uncertainties below RMR_{76} values of 50 and above RMR_{76} values of 80. At the lower RMR_{76} range (and in the unstable zone), it has been shown in mining operations that openings can remain stable with only local support [8]. The augmentation of this curve to include a larger database of points and to split it into separate support categories in the weak rock mass range will increase its accuracy, reliability and usability.

The stability of and excavation is separated into three categories described below. A brief description is presented below and the reader is referred to the detailed reference as outlined by Pakalnis [9].

i. Stable Excavations
   a. No uncontrolled falls of ground
   b. No observed movement in the back
   c. No extraordinary support measures implemented
ii. Potentially Unstable Excavations
   a. Extra ground support has been installed to prevent potential falls of ground
   b. Movement in the back of 1mm or more in 24 hours has been observed
   c. Increase in the frequency of popping and cracking indicating ground movement
iii. Unstable Excavations
   a. Area has collapsed
   b. The depth of failure of the back is 0.5 times the span (in absence of structure related failure)
   c. Support was not effective in maintaining stability

When evaluating areas with shallow dipping or flat joints, a correction factor minus 10 is applied to the final calculation of RMR_{76}. This correction factor is usually applied in high stress environments where these flat lying joints typically develop. In the weak rock environment, typically heavily jointed, it is expected that the addition of a flat lying joint set will play a minor role in the overall stability of the opening. Therefore, the application of this correction factor for flat lying joints is questionable. Where structures of discrete wedges have been identified, these must be supported prior to employing the use of the critical span curve.

3. WEAK ROCK AUGMENTED SPAN DESIGN CURVES

The span curve database has been augmented with a total of 463 points in the RMR_{76} range of 15-60. The weak rock data has been collected from 12 mines across Canada and the US. As shown in Figure 3, 58% (267 points) of the data has RMR_{76} values below 50, 32% (147 points) of the data falls below 45 and 13% (60 points) of the data falls below 40. This weak rock database has been split into four support type categories. These categories were created to be able to compare similar support types/capacities.

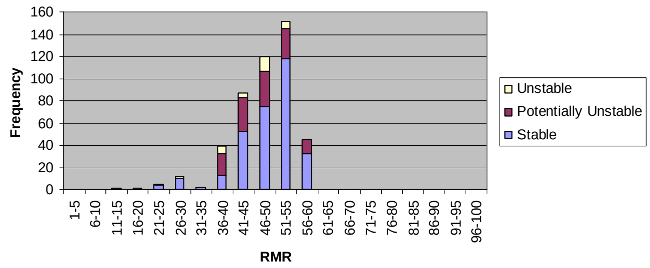

Figure 3: Weak Rock Database RMR_{76} Distribution

For each category, a neural network analysis was performed. The Neuroshell Predictor program from Ward Systems was used [10]. The networks were trained on approximately 60% of the data and verified with the remaining 40%. Genetic analyses were preformed to obtain interpolation results. Stable points were given values of 1, Potentially Unstable points were given values of 2 and Unstable points were given values of 3. For the categories that achieved an acceptable correlation and error, the networks were used to make stability predictions on a grid that covered an RMR_{76} range from 20 to 60 and a span range from 1.5m to 13m. From this data, the transitions from 1 to 2 mapped the Stable/Potentially Unstable transition line and the transitions from 2 to 3 mapped the Potentially Unstable/Unstable transition line.

3.1. Category A: Pattern Friction Sets

This category is comprised of spans that were pattern bolted (typically 1.2m x 1.2m or 0.9m x 0.9m) solely with frictions sets (Split Sets and/or Swellex). The Category A database includes 47 points from 7 mines across North America. RMR_{76} values range from 20 to 60 with spans from 1.8m to 12.2m. The neural network analysis obtained a correlation of 0.90, R-squared of 0.80 and average error of 0.18. Figure 4 shows the updated weak rock curves overlaid with the updated curve.

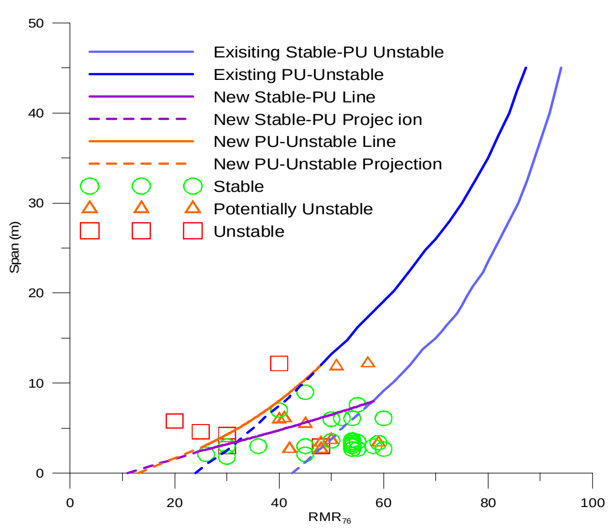

Figure 4: Category A New S/PU and PU/U lines

The resultant curves mimic what is seen in the field. It is known that stable excavations are possible at lower RMR_{76} values with smaller spans. However, once a certain span is exceeded, the span typically fails. This is shown with the new transition curves. As the RMR_{76} values decrease, the transition between Stable, Potentially Unstable and Unstable really becomes a drastic transition between Stable and Unstable with a very small to non-existent Potentially Unstable zone where spans typically have warning signs prior to failure. On the graph, the maximum stable span at 25% RMR_{76} is 3m. Due to the small database, it is recommended that mines use caution around this lower end of the weak rock database and establish site specific data.

3.2. Category B: Pattern Friction Sets with Spot Bolting of Rebar

This category is comprised of spans that were pattern bolted (typically 1.2m x 1.2m or 0.9m x 0.9m) with frictions sets (Split Sets and/or Swellex) along with spot bolting using resin grouted rebar. The Category B database includes 176 points from 7 mines across North America. RMR_{76} values range from 30 to 60 with spans from 1.5m to 9.1m. The neural network analysis obtained a correlation of 0.89, R-squared of 0.79 and average error of 0.12. Figure 5 shows the updated weak rock curves overlaid with the updated curve.

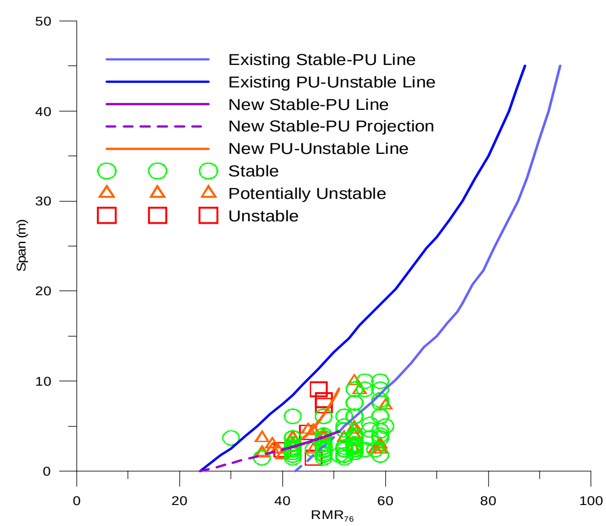

Figure 5: Category B New S/PU and PU/U lines

The results from this category are similar to those from Category C and will be discussed in concurrence with those from Category C below.

3.3. Category C: Pattern Friction Sets with Pattern Rebar Bolts

This category is comprised of spans that were pattern bolted (typically 1.2m x 1.2m or 0.9m x 0.9m) with frictions sets (Split Sets and/or Swellex) and pattern bolted (typically 1.2m x 1.2m or 0.9m x 0.9m) with resin grouted rebar. The Category C database includes 152 points from 2 mines across North America. RMR_{76} values range from 26 to 60 with spans from 1.8m to 10.7m. The neural network analysis obtained a correlation of 0.92, R-squared of 0.85 and average error of 0.15. Figure 6 shows the updated weak rock curves overlaid with the updated curve.

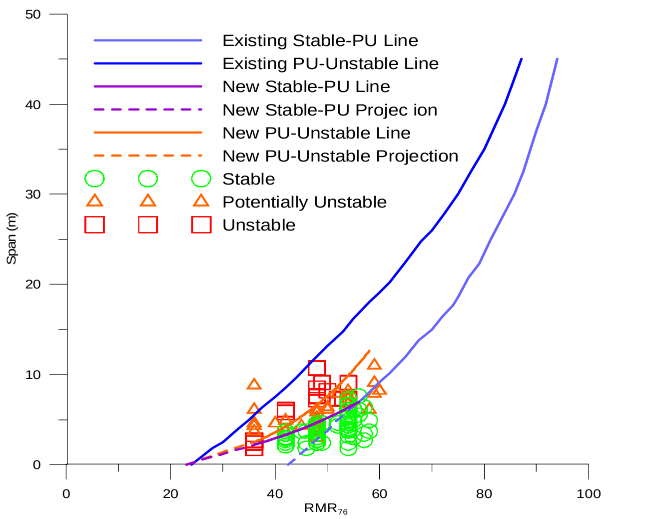

Figure 6: Category C New S/PU and PU/U lines

The resultant curves for Categories B and C are a little surprising. The stable lines do move up indicating that stable excavations are possible down to RMR_{76} values of 35. However, they have not moved up as much as the same line for Category A. Also, one would figure that the Potentially Unstable/Unstable lines would fit closer or to the left of the existing line due to the increased yield and bond strengths of rebar as compared to friction sets. The RMR_{76} range of the databases for Categories B and C have a lower range of about 35 as compared to 20 for Category A. The trends exhibited in Categories B and C indicate that data in the RMR_{76} 20-25 range for both graphs would be unstable.

The authors have observed that resin grouted rebar is difficult to install in weak rock. Full resin coverage of the bolt is difficult to achieve due to the jointed nature of the rock mass. The resin tends to either get caught in open fissures of the rock mass, the tubes break part way into the hole or the resin spins out into the surrounding rock mass thus resulting in incomplete coverage of resin along the length of the bolt. This incomplete coverage would result in a decrease the in the bond strength of the rebar bolts. This could be a reason why there are so many spans in the previous Potentially Unstable zone that have failed. The use of resin grouted rebar in weak rock environments could give an operator a false sense of security if the bolts are not installed properly.

3.4. Category D: Cablebolting/"Heroics"

This category is comprised of spans that were bolted with cablebolts or that were supported using another engineering designed support system such as cemented rock fill (underhand cut and fill mining), significant application of shotcrete (typically 76mm), spiling or timber sets. The Category D database includes 88 points from 10 mines across North America. RMR_{76} values range from 15 to 55 with spans from 2.1m to 13.1m. This category did not achieve acceptable correlation and error results with the neural network analysis. This is most likely due to the varied engineered support systems which act differently on the rock mass resulting in distinct support mechanisms with different factors of safety. The data is displayed in Figure 7 to show that spans in the Unstable zone may be supported with detailed engineering support design.

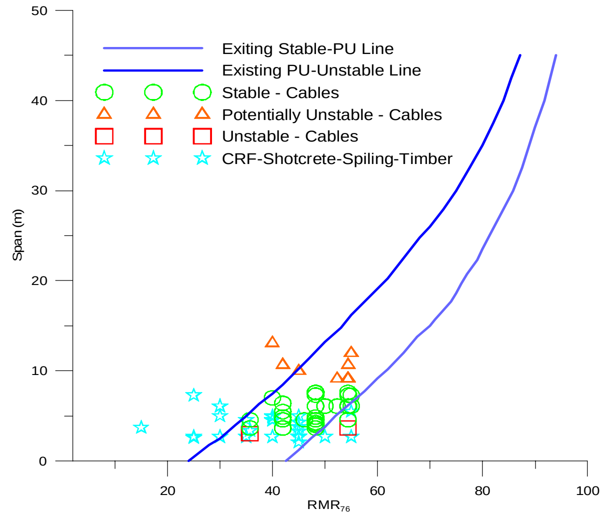

Figure 7: Category D points on Span Design Curve

4. CONLUSIONS

The University of British Columbia Geomechanics group and the NIOSH Spokane Research Laboratory have been conducting research in the development of safe and cost effective underground design guidelines in weak rock environments with RMR_{76} in the range of 20 to 50. An update of the Span Design Curve was conducted for this weak rock mass range. A total of 463 points were added to graph.

Surface support is almost always used in weak rock environments. The type of support used can vary widely. The development of the weak rock augmented Span Design Curve has been separated into to four different support categories.

Category A (pattern friction sets) yields good results and follow what is seen in the field, though caution should be used as the dataset is small with 47 points. Categories B and C yielded similar results with the Stable/Potenially Unstable line moving up. However the Potentially Unstable/Unstable line moved in to the right. This is unexpected, but may be explained by the difficulty experienced in the installation of resin grouted rebar. Category D, the "heroic" category did not obtain positive results from the neural networks analysis, but still demonstrates that spans can be stable at lower RMR_{76} values with detailed engineering support design.

As with any empirical design, it is important to understand the data behind the design. The empirical design graphs presented in this paper are intended to aid the experienced operator in making safe and economical design decisions.

This work would not have been possible without the partnership between the University of British Columbia, NIOSH and the mine sites involved. The mine sites involved include Cameco, Carlin East, Deep Post, Eskay Creek, Getchell, Jerritt Canyon, Midas, Myra Falls, Red Lake, Rodeo, Stillwater and Turquoise Ridge.

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