Presented at 2004 AGM-CIM Edmonton

Update of Span Design Curve for Weak Rock Masses

Andrea M. Ouchi and Dr. Rimas Pakalnis

Department of Mining Engineering, University of British Columbia, Vancouver, BC, Canada

Tom M. Brady

Spokane Research Laboratory, National Institute for Occupational Safety and Health, Spokane, WA, USA

Abstract

A major focus of ground control research presently being conducted by the Geomechanics Group in the University of British Columbia Mining Engineering Department is to incorporate weak rock masses (RMR_{76} less than 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 by mapping of one mine in Montana and of several mines within the Carlin and Getchell Trends in Nevada. In addition, a neural network analysis has been performed and modifications of the span design curves at the lower RMR_{76} range have been made. The common factor in all the above mentioned mines is a weak back and/or walls. In most cases, the ore zone is the weakest rock unit and must be dealt with to safely extract the mineral bearing rock. 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.

Introduction

The University of British Columbia Geomechanics group and the NIOSH Spokane Research Laboratory have started research in the development of safe and cost effective underground design guidelines in weak rock environments with Rock Mass Ratings (Bieniawski 1976) (RMR_{76}) 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.

Many of the underground gold mines in Nevada experience very weak ground conditions resulting in potentially difficult and hazardous mining conditions. Evidence of this can be shown by the number of fatalities and injuries resulting from uncontrolled rock falls during the time period of 1985 through 2000 (Table 1). A comparative analysis by the Mine Safety and Health Administration (MSHA) for the years 1990 through 1999 indicates that the number of roof/back fall injuries in Nevada has varied from a low of 8 in 1990 to a high of 28 in 1995 and 1997 (Figure 1). As of late 1999, the number of injuries was still significantly high at 19 (Brady et al. 2003).

TABLE 1: Ground control injuries and fatalities in underground gold mines in Nevada, 1985-2000

Fatalities	7
Permanent disabilities	4
Lost-time injuries	49
Restricted-activity injuries	46
Other injuries	110
Total	216
Reported rock falls with no injuries[1]	69

[1]Includes MSHA data for noninjury incidents where a reportable fall of ground occurred but did not cause injuries because the mining area was unoccupied.

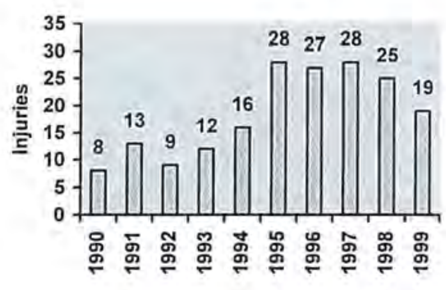

Figure 1: Injuries in Nevada, 1990-1999 (Hoch 2000)

The "critical span curve" is a simple and useful tool that aids in the design of underground man-entry openings. As "ideal" resources in competent ground conditions are being depleted, an increasing number of mines are operating in weak ground conditions of RMR_{76} less than 50, thus indicating a need to update the "critical span curve" for the RMR 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. In this preliminary study, six mines in Nevada and one mine in Montana have added an additional 135 points to the database.

Evolution of the Span Design Curve

The "critical span curve" has undergone modifications since its development in 1994 by Brennan Lang at the University of British Columbia. The initial curve was developed to evaluate back stability in cut and fill mines and consists of two straight lines that divide the graph into three zones (stable, potentially unstable and unstable) (Figure 2). The database for this graph consisted of 172 points from the Detour Lake mine owned by Placer Dome Inc. with most of the points having RMR_{76} values of 60 to 80 (Lang 1994). The database was expanded to 292 observations in 2000 with case histories from an additional six mines (Table 2). The new database included RMR_{76} values from 24 to 87 with 63% of the cases in the range of 60 to 80 (Wang et al. 2002). Less than 10% of RMR_{76} values in the updated database fall below an RMR_{76} value of 40 and less than 20% fall below a value of 55 (Figure 3) (Brady et al. 2003). The updated curve (Figure 4) has uncertainties below RMR_{76} values of 50 and above RMR 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.

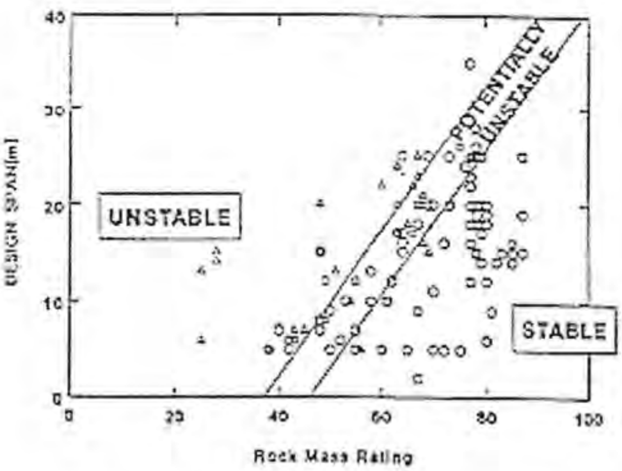

Figure 2: Critical Span Curve (Lang 1994)

TABLE 2: Case history data sources (Wang et al. 2002)

Mine	Number of data cases			
	Total	Stable	Potentially unstable	Unstable
Detour Lake mine, 1994	172	94	37	41
Detour Lake mine, 1999	22	10	0	12
Photo Lake mine	6	0	6	0
Olympias mine	13	4	1	8
Brunswick Mining	17	5	3	9
Musselwhite mine	46	35	10	1
Snip Operations	16	12	2	2
Summary	292	160	59	73

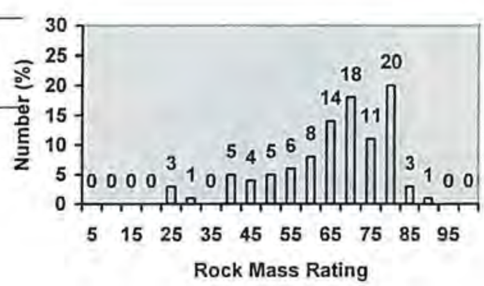

Figure 3: RMR Distribution

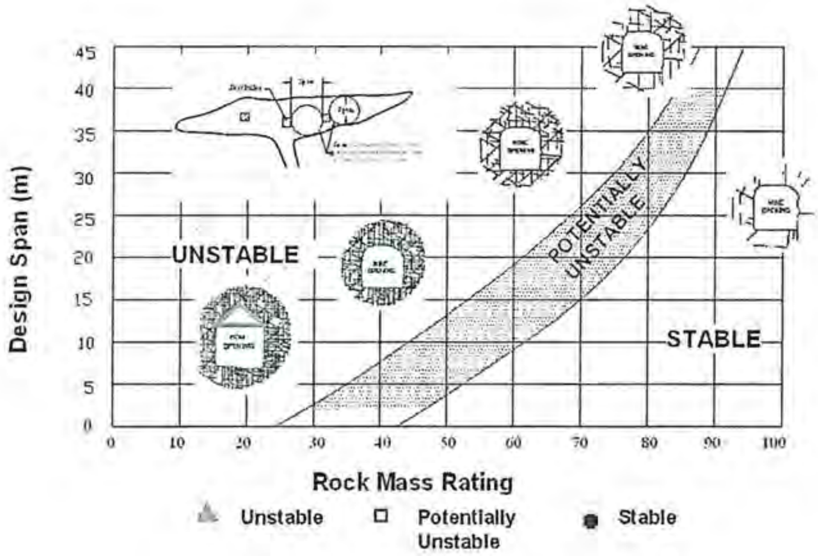

Figure 4: Updated Critical Span Curve

The term "critical span" used by these graphs refers to the largest circle that can be drawn within the boundaries of the excavation when viewed in plan (Figure 5). The term "design span" refers to spans that have no support and or spans that have used limited local support consisting of pattern bolting (1.8m long mechanical bolts on a 1.2m x 1.2m pattern). Local support is deemed as support that is used to confine potential blocks/loose that may open/fall due to subsequent mining activities in surrounding areas (Pakalnis and Vongpaisal 1993).

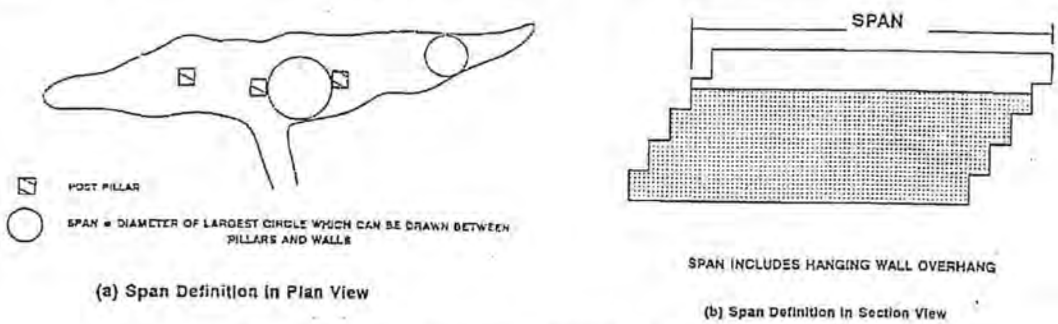

Figure 5: Span Definition (Pakalnis and Vongpaisal 1993)

The stability of an excavation is classified into three categories:

1) Stable Excavations
    a. No uncontrolled falls of ground
    b. No observed movement in the back
    c. No extraordinary support measures implemented
2) 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 (Pakalnis 2002)
    c. Increase in the frequency of popping and cracking indicating ground movement
3) Unstable Excavations
    a. Area has collapsed
    b. Support was not effective in maintaining stability

When evaluating areas with shallow dipping or flat joints, a correction factor of 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.

Weak Rock Augmented Span Design Curve

The span curve database has been augmented with an additional 135 points from seven mines in the United States (six in Nevada and one in Montana) (Table 3). The augmented database includes RMR_{76} values from 15 to 62 with 79% of the cases in the range of 30 to 50. More than 85% of RMR_{76} values in the augmented database fall below an RMR_{76} value of 50 and 35% fall below a value of 40 (Figure 6). The spans ranged from 1.5m to 12.8m with 93% of the cases being less than 7.6m. The weak rock mass augmented curve is shown below (Figure 7).

TABLE 3: Weak rock mass case history data sources

Mine	Number of data cases			
	Total	Stable	Potentially unstable	Unstable
1	3	3	0	0
2	3	2	0	1
3	6	6	0	0
4	4	2	0	2
5	1	1	0	0
6	13	12	0	1
7	105	58	39	8
Summary	135	84	39	12

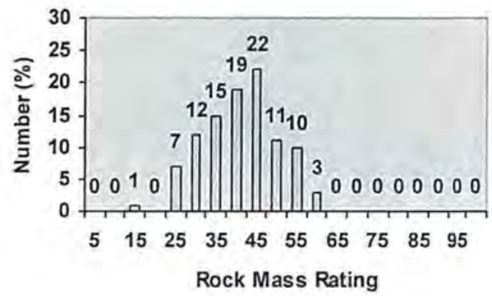

Figure 6: Augmented Database RMR Distribution

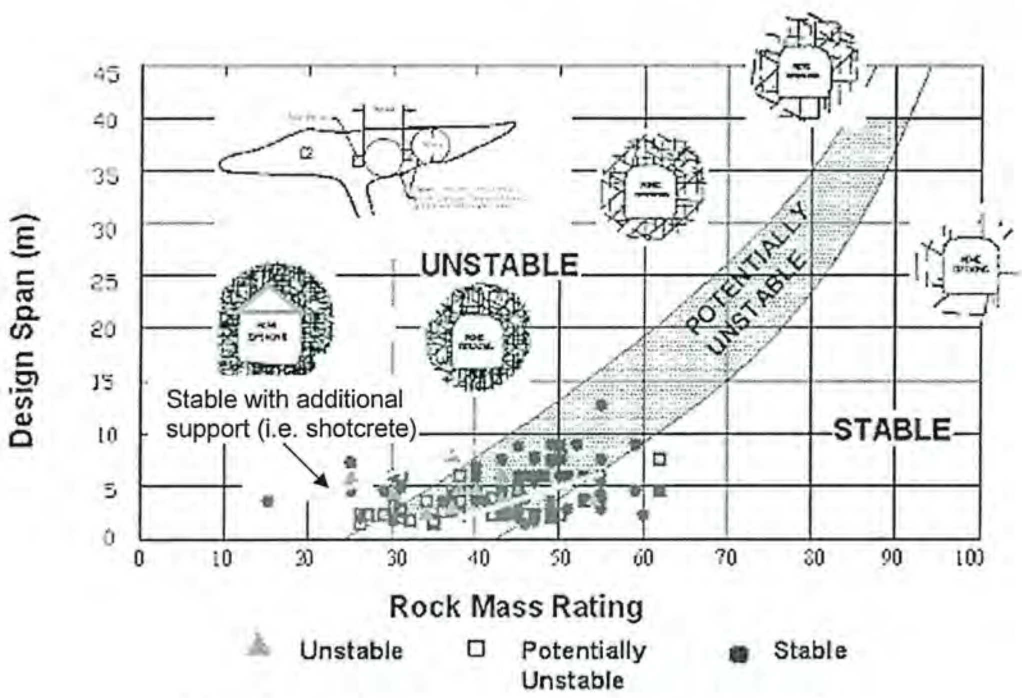

Figure 7: Weak Rock Mass Augmented Span Design Curve

A preliminary neural network analysis using a software program called Neuroshell Predictor (Ward Systems Group 2003) was performed with the weak rock mass database of 135 points. The network was trained once with RMR_{76} and span values to predict stability. A genetic analysis (interpolation only) was used on 120 points of data and set to minimize the average error. Fifteen (15) points were used to verify the trained network. Once the network was trained, the network was used to make predictions on a grid that covered the RMR_{76} range from 20 to 60 and span range from 2m to 10m. The results were mapped on to an RMR versus span chart and contoured at the unstable/potentially unstable transition and the stable/potentially unstable transition. These lines are shown on the augmented span design curve (Figure 7). These lines indicate that the slope of the curves should decrease as the RMR and span values decrease. A note must be made in that the upper curve indicating the transition from the unstable zone to the potentially unstable zone is for openings with additional support such as shotcrete. The individual points will be analyzed in terms of their support potential as the support used in the weak rock mass database varied from the use of splitsets, swellex, mechanical bolts, shotcrete and any combination of the above. A comparison of stability with respect to the conditions present will also be done.

Conclusions

Due to the increasing number of mines that are being developed in weak rock mass environments, the University of British Columbia Geomechanics group and the NIOSH Spokane Research Laboratory have initiated the incorporation of weak rock mass data into existing design relationships such as the "critical span curve" relationship. With data from seven mines, an additional 135 points in the weak rock mass range have been added to the span curve database allowing for increased accuracy and reliability of the curves at the lower RMR_{76} values. A neural network analysis indicates that the lower portions of the span design curves could decrease in slope and extend more towards the lower RMR_{76} and span values. This change in the lower end of the span design curves conforms to what one actually sees in mining operations as there are openings stable at these lower values. The span design curve shown in this paper will be augmented in terms of support strengths. The hangingwall and footwall of the individual longhole stopes have also been recorded and will be analyzed in a similar manner.

Acknowledgement

The authors' thanks go to NSERC, NIOSH and AMEC whose sponsorship has made this research possible and to the mines that offered the information and data used in this study.

References

BRADY, T., MARTIN, L. and PAKALNIS, R., 2003. Empirical Approaches for Weak Rock Masses. 98th annual AGM-CIM conference, Montreal, QC.

BIENIAWSKI, Z.T., 1976. Rock Mass Classifications in Rock Engineering. Proceedings: Symposium on Exploration for Rock Engineering, Johannesburg, S. Africa, pp. 97-106.

HOCH, T., 2000. Ground Control Seminar for Underground Gold Mines, Elko, NV, Sept. 20. Sponsored by MSHA Ground Control Division, Pittsburgh, PA.

LANG, B., 1994. Span Design for Entry Type Excavations. M.A.Sc. Thesis, University of British Columbia, Vancouver, BC.

PAKALNIS, R., 2002. Empirical Design Methods – UBC Geomechanics Update. NARMS-TAC 2002.

PAKALNIS, R. and VONGPAISAL, S., 1993. Mine Design – an empirical approach, International congress on mine design, Kingston, ON, (Rotterdam: Balkema), pp. 455-467.

WANG, J., MILNE, D. and PAKALNIS, R., 2002. Application of a Neural Network in the Empirical Design of Underground Excavation Spans, Transactions of the Institution of Mining and Metallurgy, London, Vol. 111, January – April, pp. A73-A81.

WARD SYSTEMS GROUP (Frederick, MD), 2003. Neuroshell Predictor Version 2.01. http:www.wardsystem.com.

Biographies

Andrea Ouchi is at the University of British Columbia working towards an M.A.Sc. in rock mechanics in the Department of Mining Engineering. She obtained a B.A.Sc. in mining engineering from the University of British Columbia in 2002.

Dr. Rimas Pakalnis is presently associate professor in the Department of Mining Engineering at the University of British Columbia. He is a graduate mining engineer from McGill University (1978) and the University of British Columbia, where he received his M.A.Sc. and Ph.D. (1986). Dr. Rimas Pakalnis has over twenty years of experience and has worked in over fifty mining operations/projects throughout North America in the gathering, analysis and implementation of design for underground and surface operations. Research areas include applied mine design, composite bolts, instrumentation of mine support and bulkhead design. He is a registered Professional Engineering in British Columbia and Ontario.

Tom Brady

Appendix 1: Case Histories 1-20

Case no.	RMR (%)	Span (m)	Stability
1	26	1.5	P
2	43	3	S
3	51	3	S
4	47	5.5	S
5	55	7.6	S
6	55	12.8	S
7	30	1.8	S
8	37	3.7	S
9	45	4.6	S
10	50	7.9	P
11	26	2.4	P
12	27	2.4	P
13	30	3	S
14	30	4.3	U
15	45	4.3	U
16	51	6.1	S
17	50	9.1	S
18	35	1.5	P
19	55	3	S
20	43	3.7	U

S = Stable, P = Potentially Unstable, U = Unstable

Appendix 1: Case Histories 21-40

Case no.	RMR (%)	Span (m)	Stability
21	25	4.6	S
22	40	4.6	U
23	47	7.9	S
24	49	9.1	S
25	46	1.5	S
26	30	3.7	S
27	37	3.7	P
28	45	4.6	P
29	62	4.6	P
30	40	7	S
31	47	7.6	S
32	32	1.8	P
33	44	2.4	S
34	36	2.7	P
35	37	2.7	P
36	43	4.6	S
37	43	4.6	P
38	48	6.1	P
39	43	7.6	S
40	37	7.9	U

S = Stable, P = Potentially Unstable, U = Unstable

Appendix 1: Case Histories 41-90

Case no.	RMR (%)	Span (m)	Stability
41	47	7.9	S
42	46	2.4	P
43	36	3.7	S
44	31	6.1	P
45	38	3.7	P
46	45	6.1	S
47	31	2.7	P
48	47	6.1	S
49	49	2.1	S
50	30	6.1	S
51	43	4.6	P
52	49	7.6	S
53	50	6.1	S
54	53	6.1	S
55	25	7.3	S
56	60	2.4	S
57	43	2.7	S
58	55	3	S
59	40	3.7	S
60	43	4.3	S
61	45	9	S
62	40	4.6	P
63	30	6.1	S
64	31	2.1	P
65	37	3	U
66	31	4.9	S
67	55	7.6	S
68	37	3.7	S
69	37	4.6	P
70	46	6.1	S
71	55	6.1	S
72	59	9.1	S
73	43	3.7	S
74	25	4.6	S
75	15	3.7	S
76	54	3.7	U
77	49	7.3	S
78	43	3.4	S
79	52	9.1	S
80	30	3	U
81	43	3	P
82	49	3.2	S
83	46	4	S
84	55	4.3	S
85	40	7	S
86	41	3.7	S
87	45	4.3	S
88	45	2.1	S
89	43	6.1	U
90	34	3.7	P

S = Stable, P = Potentially Unstable, U = Unstable

Appendix 1: Case Histories 91-135

Case no.	RMR (%)	Span (m)	Stability
91	55	4	S
92	59	4.6	S
93	31	3	P
94	37	3	S
95	40	6	S
96	49	2.1	P
97	42	4	P
98	37	2.7	P
99	45	5.5	S
100	53	3.7	S
101	53	3.7	P
102	62	7.6	P
103	55	7.6	S
104	35	1.8	P
105	42	2.4	P
106	38	2.4	P
107	55	5.5	S
108	53	3.7	S
109	29	4.6	S
110	49	3.7	S
111	47	1.8	S
112	38	6.1	P
113	29	2.4	P
114	37	3.7	P
115	47	2.4	P
116	55	3.7	S
117	44	2.7	S
118	45	3	S
119	38	4.6	U
120	38	4.6	P
121	53	4	S
122	26	2.1	S
123	34	2.4	U
124	43	2.4	P
125	47	2.4	S
126	50	2.4	P
127	37	4.3	S
128	40	4.6	S
129	62	4.6	S
130	55	5.5	S
131	25	5.8	U
132	30	6.1	S
133	48	6.1	S
134	50	6.1	S
135	50	7.6	S

S = Stable, P = Potentially Unstable, U = Unstable