A LIMIT EQUILIBRIUM ANALYSIS OF SURFACE CROWN PILLAR STABILITY

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ABSTRACT

One of the failure mechanisms involved in a study of the stability of surface crown pillars is that involving downward sliding of the pillar under gravitational loading. This sliding occurs when the total shear strength of surfaces which define the boundaries of the pillar is overcome by the weight of the pillar. The total shear strength is dependent not only upon the properties of the rock mass but also upon the horizontal in situ stresses acting upon the pillar and upon the groundwater pressures within the pillar. A limit equilibrium analysis of this type of failure is presented. The results of the analysis are displayed as a distribution of possible factors of safety and a probability of pillar failure, determined from the likely distribution of values for the input parameters. A BASIC listing of the program is given at the end of this paper.

RÉSUMÉ

Un des mécanismes de rupture à considérer lors de l'étude de stabilité des piliers est le glissement descendant du pilier sous les charges de gravité. Le glissement se produit lorsque le poids du pilier dépasse le total des forces de cisaillement des surfaces définies par les contours du pilier. La force de cisaillement totale dépend non seulement des propriétés de la masse rocheuse mais aussi des contraintes horizontales in situ agissant sur le pilier et sur la pression de l'eau souterraine du pilier. Une analyse à l'état limite de ce type de rupture est décrite dans cet article. Les résultats de l'analyse sont présentés sous la forme d'une distribution des facteurs de sécurité possibles et par une probabilité de rupture du pilier. Les valeurs sont déterminées à partir de la distribution probable des données des paramètres d'entrée. Un listage du programme en BASIC est fourni à la fin de cet article.

INTRODUCTION

An evaluation of the stability of surface crown pillars presents special problems for geotechnical engineers. The rock mass forming the pillar is usually weathered and it may also be covered with a layer of overburden soil. Consequently, the properties of this rock mass are difficult to quantify with any degree of certainty. Similarly, the in situ stresses acting on the pillar and the elevation of the groundwater table in the pillar may not be well defined.

A number of failure mechanisms have been postulated to explain surface crown pillar failures (Bétournay, 1987) and it is possible that there are other mechanisms which have not yet been investigated. It is also likely that more than one failure mechanism may operate in any given crown pillar and that the stability of that pillar is controlled by that mechanism or combination of mechanisms which give the lowest factor of safety for the unique set of dimensions and properties of that particular pillar.

In view of these uncertainties it is clear that any attempt to define a precise factor of safety for a surface crown pillar is unlikely to be successful. In order to provide a basis for practical decision making, an analysis should include some form of sensitivity study or Monte Carlo analysis which looks at the range of factors of safety associated with variations in material properties, in situ stresses and groundwater conditions (Priest and Brown, 1983). The limit equilibrium analysis presented in this paper deals with one mechanism of surface crown pillar failure and gives a mean factor of safety as well as a normal distribution of safety factors and a probability of failure.

LIMIT EQUILIBRIUM ANALYSIS

Consider a rectangular horizontal crown pillar with plan dimensions x and y as shown in figure 1. The thickness of the pillar is z and the water level is assumed to be at a level of z_w above the base of the pillar. The pillar is acted upon by the horizontal effective stresses σ'_x and σ'_y.

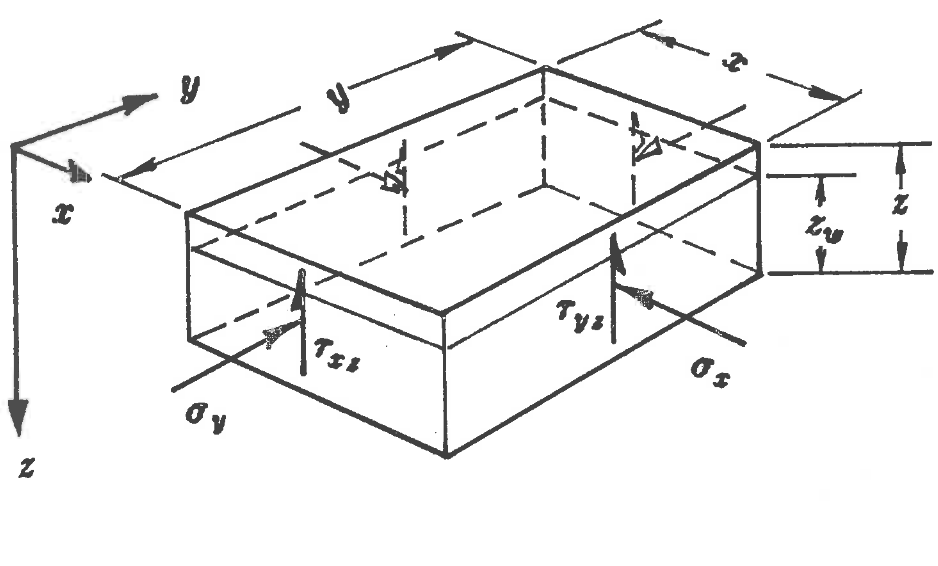

Figure 1 : Dimensions of pillar and directions of lateral stresses.

The factor of safety of the pillar against vertical downward sliding is given by the ratio of the sum of the shear forces acting on the four sides of the pillar to the weight of the pillar. Hence

$$F = \frac{2(\tau_{xz}.xz + \tau_{yz}.yz)}{\gamma_r.xyz} \tag{1}$$

giving

$$F = \frac{2}{\gamma_r}\left(\frac{\tau_{xz}}{y} + \frac{\tau_{yz}}{x}\right) \tag{2}$$

where γ_r is the unit weight of rock and τ_{xz} and τ_{yz} are the shear strengths of the xz and yz faces respectively.

These shear strengths can be defined by the angle of friction ϕ' and the cohesion c' of the Mohr-Coulomb failure criterion or they can be determined directly from the non-linear failure criteria proposed by Barton (1976) or by Hoek and Brown (1980, 1988). For the purposes of this discussion, the Hoek-Brown failure criterion will be used since this includes a means of estimating the shear strength directly from the rock mass quality determined in the field.

The shear strength τ_{xz} is given by :

$$\tau_{xz} = \left(\cot\phi'_{ixz} - \cos\phi'_{ixz}\right)\frac{m\sigma_c}{8} \tag{3}$$

$$\phi'_{ixz} = \arctan\frac{1}{\sqrt{4h_{xz}\cos^2\theta_{xz} - 1}} \tag{4}$$

$$\theta_{xz} = \frac{1}{3}\left(90 + \arctan\frac{1}{\sqrt{h_{xz}^3 - 1}}\right) \tag{5}$$

$$h_{xz} = 1 + \frac{16(m\sigma'_y + s\sigma_c)}{3m^2\sigma_c} \tag{6}$$

where m and s are the material constants of the Hoek- Brown failure criterion and σ_c is the uniaxial compressive strength of the intact rock material. Note that the shear strength τ_{xz} depends upon the magnitude of the lateral stress σ'_y while τ_{yz} depends upon σ'_x as shown in figure 1.

The shear strength τ_{yz} is given by substitution of yz values in place of the xz subscripted parameters in equations 3, 4 and 5 and σ'_x in place of σ'_y in equation 6.

Assuming that the material forming the surface crown pillar has been disturbed by blasting, percolation of groundwater and movement of the rock mass surrounding the stope, the Hoek-Brown material constants m and s can be estimated from Bieniawski's rock mass rating (RMR) value by the following equations (Hoek and Brown, 1988) :

$$m = m_i.\exp\left[\frac{RMR - 100}{14}\right] \tag{7}$$

Table 1 : Approximate values of constant m_i for different rock types.

Carbonate rocks with well developed crystal cleavage *dolomite, limestone and marble*	$m_i = 7$
Lithified argillaceous rocks *mudstone, siltstone, shale and slate (normal to cleavage)*	$m_i = 10$
Arenaceous rocks with strong crystals and poorly developed crystal cleavage *sandstone and quartzite*	$m_i = 15$
Fine grained polymineralic igneous crystalline rocks *andesite, dolerite, diabase and rhyolite*	$m_i = 17$
Coarse grained polymineralic igneous & metamorphic crystalline rocks *amphibolite, gabbro, gneiss, granite, norite, quartz- diorite*	$m_i = 25$

$$s = \exp\left[\frac{RMR - 100}{6}\right] \tag{8}$$

where m_i is the value of the constant m for the intact rock material given in table 1.

The lateral effective stresses σ'_x and σ'_y can be determined from the dimensions of the crown pillar and the water level in the pillar as defined in figure 1.

$$\sigma'_x = \frac{\gamma_r.z.K_x}{2} - \frac{\gamma_w.z_w^2}{2z} \tag{9}$$

$$\sigma'_y = \frac{\gamma_r.z.K_y}{2} - \frac{\gamma_w.z_w^2}{2z} \tag{10}$$

where K_x and K_y are the ratios of horizontal to vertical stress in the x and y directions respectively and γ_w is the unit weight of water.

In order to determine the factor of safety of a surface crown pillar subjected to failure by shear of the four faces as defined in figure 1, the calculation follows the equations listed in reverse order. This calculation is included in the simple BASIC program listing given at the end of this paper.

FAILURE PROBABILITY ANALYSIS

In view of the high level of uncertainty associated with many of the input parameters for the limit equilibrium analysis, as discussed in the introduction, a study of the likely distribution of factors of safety and of the probability of pillar failure is presented next.

For the purposes of this analysis it will be assumed that the pillar dimensions, defined by x, y and z, and the unit weights of rock (γ_r) and water (γ_w), are known with a high enough degree of precision that they can be assigned unique values. The other six parameters are the water depth in the pillar (z_w), the rock mass rating (RMR), the uniaxial compressive strength of the intact rock material (σ_c), the value of the Hoek-Brown constant m for the intact rock material (m_i), the horizontal to vertical stress ratio (K_x) in the x direction and the horizontal to vertical stress ratio (K_y) in the y direction. These six parameters are each defined by a mean value and a standard deviation and it is assumed that the values are normally distributed around the mean.

The mean $\overline{V}$ of a set of observations of a variable V is given by

$$\overline{V} = \frac{\sum\limits_{i=1}^{n} V_i}{n} \tag{11}$$

where V_i is the ith observation and
n is the number of observation

The sample variance S^2 is the square of the standard deviation S and is given by

$$S^2 = \frac{\sum\limits_{i=1}^{n} (\overline{V} - V_i)^2}{n-1} \tag{12}$$

The coordinates (Y, V_i) of the curve defining the normal distribution of the variable V are calculated from

$$Y = \frac{1}{S\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{V_i - \overline{V}}{S}\right)^2} \tag{13}$$

One method which can be used to investigate the distribution of factors of safety is the Monte Carlo technique. In applying this method to the surface crown pillar problem, a random number generator would be used to determine a value V_i for each of the six normally distributed variables and these values would then be used to compute a factor of safety. If this process is repeated say 1000 times, a histogram of the factor of safety distribution can be plotted.

The Monte Carlo technique is computationally intensive and, in some applications it can be replaced by Rosenbleuth's point estimate method (Rosenbleuth, 1972). This technique is based upon the fact that a quantity, calculated from an equation containing a number of normally distributed variables, will itself be normally distributed. Hence, for each variable, two point estimates are made at fixed values of one standard deviation on either side of the mean ($\overline{V} \pm S$) and the equation is solved for every possible combination of point estimates. This produces 2^m solutions, where m is the number of normally distributed variables involved.

In the case of the surface crown pillar, the factor of safety equation contains six normally distributed variables and hence 64 values of the factor of safety are obtained from this process. The mean and standard deviation for the factor of safety are calculated by means of equations 11 and 12 and the normal distribution is plotted from equation 13. Figure 2 illustrates the screen display given by the program, listed at the end of this paper, in which the normal distribution of the factor of safety is calculated using Rosenbleuth's method. This distribution is plotted for a range of $\pm$ 3 standard deviations on either side of the mean factor of safety.

The probability of failure is given by the ratio of the area under the normal distribution curve for factor of safety values from $-\infty$ to 1 (shown shaded in figure 2) to the area under the curve from $-\infty$ to $+\infty$.

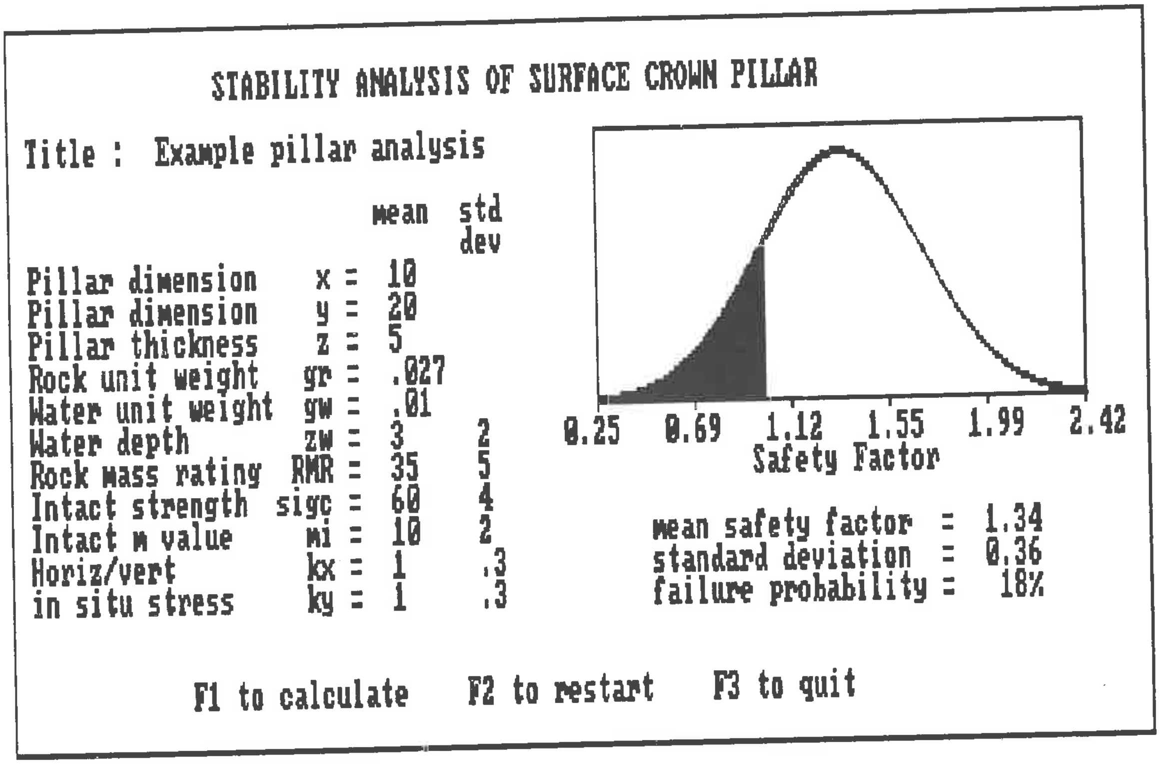

Figure 2 : Screen display of input data and calculated factor of safety distribution and probability of failure.

SENSITIVITY STUDY OF FACTOR OF SAFETY

The program given at the end of the paper can be used to determine the safety factor distribution and probability of failure, as shown in figure 2, or it can be used to calculate a unique factor of safety by entering zero values for all the standard deviations. This method can be useful when it is desired to explore the sensitivity of the factor of safety to changes of each of the variables in turn.

Figure 3 illustrates the results of one such study for a case in which the following values were chosen to give a starting value of 1.00 for the factor of safety :

x = 7 m, y = 20 m, z = 5 m, gr = 0.027 MN/m^3, gw = 0.01 MN/m^3, zw = 5 m,
RMR = 40, sigc = 60 MPa, mi = 10, kx = 0.5, ky = 0.5

Figure 3 shows that the factor of safety is very sensitive to the value of the rock mass rating (RMR), particularly for values in excess of about 50. This trend is in agreement with practical observations which would suggest that this type of failure is unlikely in very high quality rock masses.

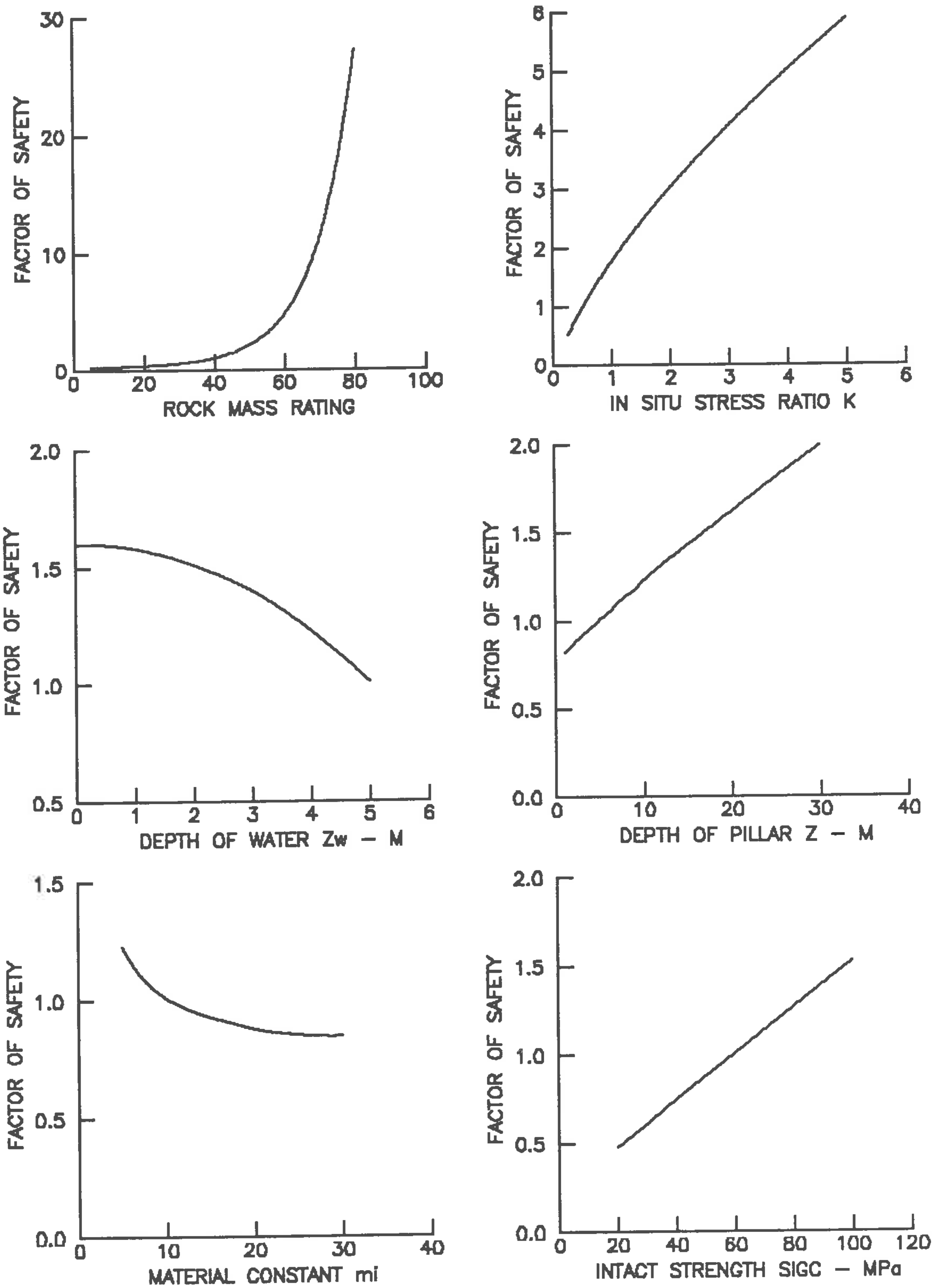

Figure 3 : Sensitivity of factor of safety to input parameter variations

The factor of safety is also very sensitive to changes in the value of the ratio of horizontal to vertical in situ stresses. Again, this trend is consistent with intuitive reasoning based upon practical experience. It also suggests that decreases in lateral stresses acting on the pillar, resulting from progressive failures of pillars or support in underlying stopes, may be responsible for some of the time-dependent surface pillar failures which occur in abandoned mines.

Variations in the other parameters involved in this analysis do not result in large changes in factor of safety. This suggests that failure induced by slow deterioration in rock strength or by fluctuations in groundwater level would only occur in pillars which have a factor of safety very close to 1.

CONCLUSIONS

The analysis discussed in this paper deals with one type of surface crown pillar failure. No claim is made that this is the only or even the most important failure mechanism and the reader should be aware that many other types of failure are also possible. Consequently, in using this analysis to study actual mining problems, care should be taken that other possible failure mechanisms are also considered and that analyses of the type described by Bétournay are run in parallel with this analysis.

The BASIC program listing given at the end of the paper can be keyed in and used without restriction by any interested reader. The program will run under BASICA or GWBASIC or it can be compiled by one of the newer BASIC compilers. A very efficient executable file has been produced using Microsoft's Quickbasic 4.0 and a copy of this file can be obtained on disk by writing directly to the author.

The aim of this paper is to challenge the reader to think about one particular failure mechanism and to consider the consequences of wide variations in some of the input parameters. The presentation of results of the factor of safety calculation in the form of a distribution curve and a probability of failure is considered to be a realistic solution to this particular problem. The ease with which this calculation can be carried out will enable the reader to explore some of the practical implications of changes in pillar dimensions, in situ stress conditions and rock mass properties. The calculation can also be used to compare the benefits of investing in site investigations to improving the level of confidence in each of the normally distributed input parameters.

REFERENCES

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```
10 ' Limit equilibrium analysis of surface crown pillar stability
20 ' Evert Hoek, University of Toronto, July 1989.
30 '
40 ' Dimension variables and screen display
50 '
60 DIM V(20, 60), SF(70): KEY OFF
70 FOR I = 1 TO 3: KEY I, "": NEXT I: KEY 1, "c": KEY 2, "r": KEY 3, "q"
80 SCREEN 2: CLS : COL = 27: FLAG = 0: LINE (5, 5)-(635, 185), , B
90 LOCATE 3, 15: PRINT " STABILITY ANALYSIS OF SURFACE CROWN PILLAR"
100 LOCATE 5, 3: PRINT "Title : ": LOCATE 5, 11: LINE INPUT " ", T$
110 LOCATE 7, 27: PRINT "mean"
120 LOCATE 7, 33: PRINT "std": LOCATE 8, 33: PRINT "dev"
130  LOCATE 9, 3: PRINT "Pillar dimension    x = "
140 LOCATE 10, 3: PRINT "Pillar dimension    y = "
150 LOCATE 11, 3: PRINT "Pillar thickness    z = "
160 LOCATE 12, 3: PRINT "Rock unit weight   gr = "
170 LOCATE 13, 3: PRINT "Water unit weight  gw = "
180 LOCATE 14, 3: PRINT "Water depth        zw = "
190 LOCATE 15, 3: PRINT "Rock mass rating  RMR = "
200 LOCATE 16, 3: PRINT "Intact strength  sigc = "
210 LOCATE 17, 3: PRINT "Intact m value     mi = "
220 LOCATE 18, 3: PRINT "Horiz/vert         kx = "
230 LOCATE 19, 3: PRINT "in situ stress     ky = "
240 LOCATE 22, 14: PRINT "F1 to calculate"
250 LOCATE 22, 33: PRINT "F2 to restart"
260 LOCATE 22, 50: PRINT "F3 to quit"
270 '
280 ' Program for data input and cursor control
290 '
300 NO = 1: SUMSF = 0: SUMDIF = 0: A = 9: GOSUB 540
310 Q$ = INKEY$: IF LEN(Q$) = 0 THEN 310  'scan keyboard
320 IF ASC(Q$) = 13 THEN GOSUB 570: GOTO 310
330 IF LEN(Q$) = 2 THEN Q$ = RIGHT$(Q$, 1)
340 IF Q$ = "H" THEN GOSUB 520: GOTO 620             'up
350 IF Q$ = "P" THEN GOSUB 520: GOTO 670             'down
360 IF Q$ = "M" THEN GOSUB 520: GOTO 720             'right
370 IF Q$ = "K" THEN GOSUB 520: GOTO 740             'left
380 IF Q$ = "c" OR Q$ = "C" THEN 790                 'calculate
390 IF Q$ = "r" OR Q$ = "R" THEN 80                  'restart
400 IF Q$ = "q" OR Q$ = "Q" THEN CLS : END           'quit
410 IF Q$ = "0" THEN GOSUB 540: GOTO 530             'enter zero
420 IF Q$ = "-" THEN GOSUB 540: GOTO 530             'enter minus
430 IF Q$ = "." THEN GOSUB 540: GOTO 530             'enter period
440 IF VAL(Q$) < 1 OR VAL(Q$) > 9 THEN 310           'enter number
450 GOSUB 540: LOCATE A, COL: PRINT VAL(Q$)
460 LOCATE A, COL + 2: INPUT "", IN$: V(A, COL) = VAL(Q$ + IN$)
470 LOCATE A, COL: PRINT "      "
480 LOCATE A, COL: GOSUB 600: GOSUB 580
490 IF COL = 33 AND A = 20 THEN 500 ELSE 510
500 COL = 27: A = 9: GOSUB 570: GOTO 310
510 GOSUB 540: GOTO 310
520 GOSUB 550: LOCATE A, COL: GOSUB 600: RETURN
530 LOCATE A, COL: PRINT Q$: GOTO 460
540 GOSUB 560: LINE (P, Q - 8)-(P + 25, Q - 2), 1, BF: RETURN
```

```
550 GOSUB 560: LINE (P, Q - 8)-(P + 25, Q - 2), 0, BF: RETURN
560 P = 8 * (COL - 1): Q = 8 * A: RETURN
570 LOCATE A, COL: GOSUB 540: RETURN
580 IF COL = 27 AND A = 19 THEN COL = 33: A = 13
590 A = A + 1: RETURN
600 IF V(A, COL) < .000001 THEN 610 ELSE PRINT V(A, COL): RETURN
610 PRINT " 0": RETURN
620 IF A = 9 THEN A = 9: GOTO 660                      'move cursor up
630 IF COL = 27 THEN GOTO 650
640 IF COL = 33 AND A < 15 THEN A = 15
650 A = A - 1
660 GOSUB 570: GOTO 310
670 IF A = 19 THEN A = 19: GOTO 710                    'move cursor down
680 IF COL = 27 THEN GOTO 700
690 IF A < 14 AND COL = 33 THEN COL = 27
700 A = A + 1
710 GOSUB 570: GOTO 310
720 IF A > 13 AND COL = 27 THEN COL = 33 ELSE COL = 27
730 GOSUB 570: GOTO 310                               'move cursor right
740 IF COL = 33 THEN COL = 27                         'move cursor left
750 GOSUB 570: GOTO 310
760 '
770 ' Factor of safety calculation
780 '
790 LINE (295, 32)-(632, 152), 0, BF: GOSUB 520: COL = 27: GOSUB 520
800 FOR J = 14 TO 19: IF V(J, 33) = 0 THEN V(J, 33) = 1E-09
810 NEXT J: X = V(9, 27): Y = V(10, 27): Z = V(11, 27)
820 GR = V(12, 27): GW = V(13, 27): ZW(1) = V(14, 27) - V(14, 33):
830 ZW(2) = V(14, 27) + V(14, 33): RMR(1) = V(15, 27) - V(15, 33)
840 RMR(2) = V(15, 27) + V(15, 33): SIGC(1) = V(16, 27) - V(16, 33)
850 SIGC(2) = V(16, 27) + V(16, 33): MI(1) = V(17, 27) - V(17, 33)
860 MI(2) = V(17, 27) + V(17, 33): KX(1) = V(18, 27) - V(18, 33)
870 KX(2) = V(18, 27) + V(18, 33): KY(1) = V(19, 27) - V(19, 33)
880 KY(2) = V(19, 27) + V(19, 33)
890 FOR A = 1 TO 2: FOR B = 1 TO 2: FOR C = 1 TO 2
900 FOR D = 1 TO 2: FOR E = 1 TO 2: FOR F = 1 TO 2
910 GOSUB 1040: SF(NO) = FOS: NO = NO + 1
920 NEXT F: NEXT E: NEXT D: NEXT C: NEXT B: NEXT A
930 FOR NO = 1 TO 64: SUMSF = SUMSF + SF(NO): NEXT NO
940 MEANSF = SUMSF / 64
950 FOR NO = 1 TO 64: SUMDIF = SUMDIF + (SF(NO) - MEANSF) ^ 2: NEXT NO
960 IF FLAG = 1 THEN FLAG = 0: GOTO 1580
970 SDFS = SQR(SUMDIF / 64)
980 IF SDFS > 0.0001 THEN GOSUB 1220: GOSUB 1320: GOTO 300
990 LOCATE 13, 45: PRINT "Safety Factor = ": LOCATE 13, 60
1000 PRINT USING "###.##"; MEANSF: GOTO 300
1010 '
1020 ' Subroutine for factor of safety calculation
1030 '
1040 M = MI(D) * EXP((RMR(B) - 100) / 14)
1050 S = EXP((RMR(B) - 100) / 6)
1060 SIGX = GR * KX(E) * Z / 2 - (GW * ZW(A) ^ 2) / (2 * Z)
1070 SIGY = GR * KY(F) * Z / 2 - (GW * ZW(A) ^ 2) / (2 * Z)
1080 HXZ = 1 + 16 * (M * SIGY + S * SIGC(C)) / (3 * M ^ 2 * SIGC(C))
```

```
1090 IF HXZ < 1 THEN 1120
1100 THETAXZ = .5235988# + 1 / 3 * ATN(1 / SQR(HXZ ^ 3 - 1))
1110 PHIXZ = ATN(1 / SQR(4 * HXZ * COS(THETAXZ) * COS(THETAXZ) - 1))
1120 HYZ = 1 + 16 * (M * SIGX + S * SIGC(C)) / (3 * M ^ 2 * SIGC(C))
1130 IF HYZ < 1 THEN FLAG = 1: RETURN
1140 THETAYZ = .5235988# + 1 / 3 * ATN(1 / SQR(HYZ ^ 3 - 1))
1150 PHIYZ = ATN(1 / SQR(4 * HYZ * COS(THETAYZ) * COS(THETAYZ) - 1))
1160 TAUXZ = (1 / TAN(PHIXZ) - COS(PHIXZ)) * M * SIGC(C) / 8
1170 TAUYZ = (1 / TAN(PHIYZ) - COS(PHIYZ)) * M * SIGC(C) / 8
1180 FOS = 2 * (TAUXZ / Y + TAUYZ / X) / GR: RETURN
1190 '
1200 ' Subroutine for printout of results
1210 '
1220 LOCATE 15, 53: PRINT "Safety Factor ": LOCATE 17, 46
1230 PRINT "mean safety factor  = ": LOCATE 17, 67:
1240 PRINT USING "###.##"; MEANSF: LOCATE 18, 46:
1250 PRINT "standard deviation  = ": LOCATE 18, 67
1260 PRINT USING "###.##"; SDFS: LOCATE 19, 46:
1270 PRINT "failure probability = ": GOSUB 1540
1280 LOCATE 19, 69: PRINT USING "###_%"; PROB * 100: RETURN
1290 '
1300 ' Subroutine to plot normal distribution
1310 '
1320 LINE (330, 32)-(600, 100), , B:
1330 XL = MEANSF - 3 * SDFS: XR = MEANSF + 3 * SDFS: XD = XR - XL
1340 XA = (600 - 330) / XD: YMAX = 0
1350 FOR XG = 330 TO 600: X = XL + (XG - 330) / 270 * XD
1360 GOSUB 1520: IF Y > YMAX THEN YMAX = Y
1370 NEXT XG: YB = 0: YT = 1.1 * YMAX: YD = YT - YB: YA = (100 - 32) / YD
1380 FOR XG = 330 TO 600: X = XL + (XG - 330) / 270 * XD
1390 GOSUB 1520: YG = 100 - (Y - YB) * YA
1400 IF X < 1 THEN 1410 ELSE 1420
1410 LINE (XG, YG)-(XG, 100): GOTO 1430
1420 LINE (XG, YG)-(XG + 1, YG + 1)
1430 NEXT XG
1440 FOR X = 330 TO 600 STEP 54
1450 LINE (X, 102)-(X, 100): NEXT X
1460 C = 38: FOR K = 0 TO 5: LOCATE 14, C
1470 S = XL + XD * K / 5: PRINT USING "###.##"; S;
1480 C = C + 7: NEXT K: COL = 27:
1490 Q$ = INKEY$: IF LEN(Q$) = 0 THEN 1490          'scan keyboard
1500 IF Q$ = "r" OR Q$ = "R" THEN 80                'restart
1510 RETURN
1520 Y = (1 / (2.506628 * SDFS)) * EXP(-.5 * ((X - MEANSF) / SDFS) ^ 2)
1530 RETURN
1540 PZ = (1 - MEANSF) / SDFS
1550 R = EXP(-PZ * PZ / 2) / 2.506628: T = 1 / (1 + .33267 * ABS(PZ))
1560 T = 1 - R * (.4361836 * T - .1201676 * T ^ 2 + .937298 * T ^ 3)
1570 IF PZ >= 0 THEN PROB = CSNG(T): RETURN ELSE PROB = 1 - T: RETURN
1580 LOCATE 7, 55: PRINT "WARNING": LOCATE 9, 48
1590 PRINT "Input data unacceptable,": LOCATE 10, 48
1600 PRINT "try reducing magnitudes ": LOCATE 11, 48
1610 PRINT "of standard deviations. ":  COL = 27: GOTO 300
```

SURFACE CROWN PILLAR EVALUATION FOR ACTIVE AND ABANDONED METAL MINES

INTERNATIONAL CONFERENCE PROCEEDINGS

COMPTE RENDU DE LA CONFÉRENCE INTERNATIONALE

ÉVALUATION DE PILIERS DE SURFACE POUR LES MINES DE MÉTAUX ACTIVES ET ABANDONNÉES

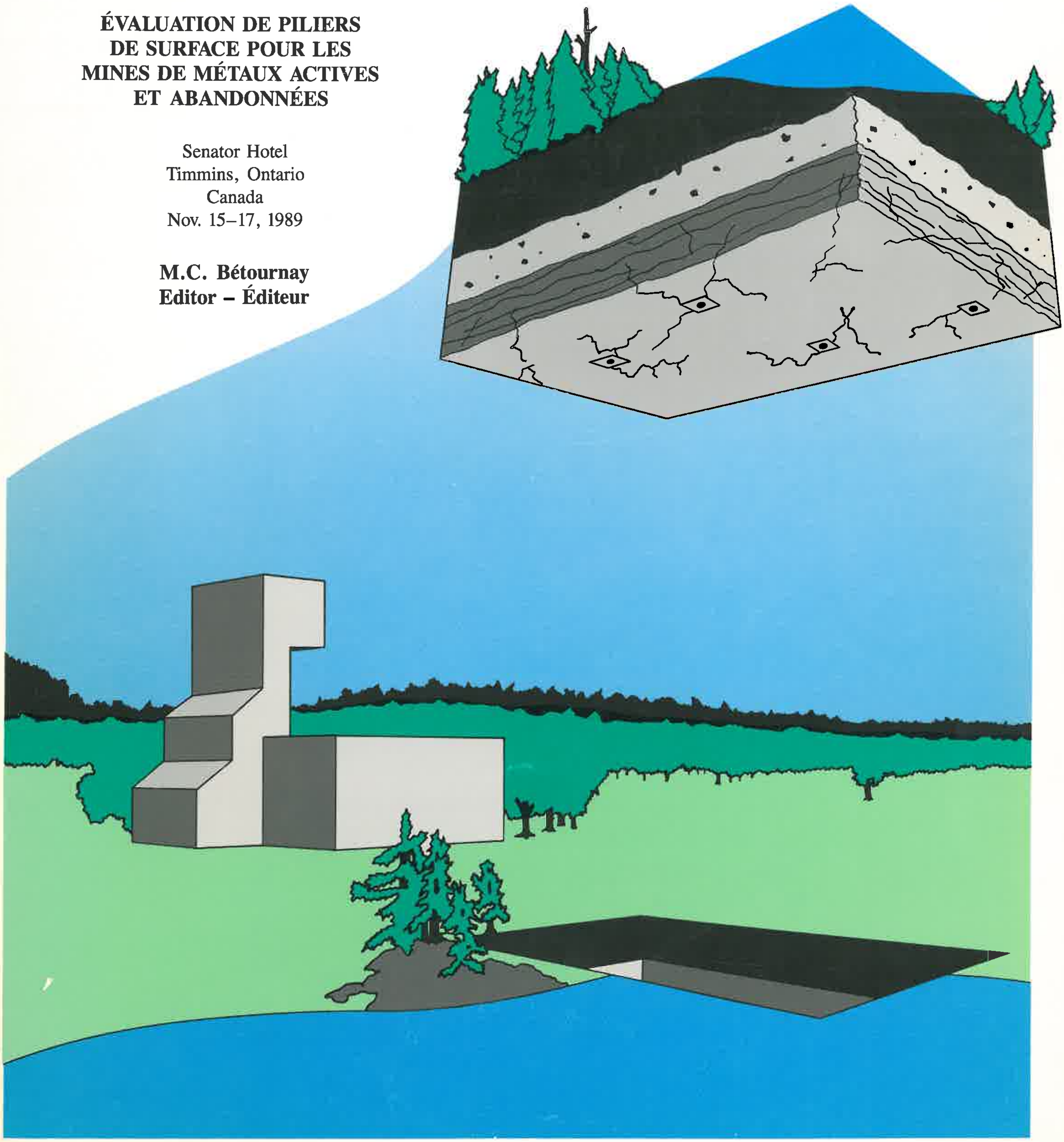
Senator Hotel
Timmins, Ontario
Canada
Nov. 15–17, 1989

M.C. Bétournay
Editor – Éditeur

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada
CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Ministry of Northern Development and Mines
Ontario
Ministère du Développement du Nord et des Mines

CIM ICM



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