CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 3.3 : MASSIVE UNDERGROUND MINING (HARD AND SOFT ROCK) **SUBJECT CODE:** COMRME **EXAMINATION DATE:** 11 MAY 2017 ~~MAY 2017~~ **TIME**: ~~3 HOURS~~14:30 – 17:30	**EXAMINER:** PJ LE ROUX **MODERATOR:** W JOUGHIN **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 11 (incl)

THIS IS NOT AN OPENBOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer **all questions**. Answer the questions **legibly** in English.
2. Write your **ID Number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.

NB: Your name **must not** appear on any answer book or loose sheets.

3. Show all calculations **and check calculations on which the answers are based.**
4. **NO** hand-held electronic calculators may be used for this exam.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. **Final answers** must be given to an accuracy which is typical of practical conditions, However be careful not to use too few decimal places during your calculations, as rounding errors may result in incorrect answers

   NB Ensure that the correct unit of measure (SI unit) are recorded as marks will be deducted from answers if the incorrect unit is used. (even if the calculated value is correct).
8. In answering the questions, full advantage should be taken of your practical experience as well as data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones are **NOT** allowed in the examination room.

QUESTION 1

You are designing the mining of the lower portion of a pipe shaped ore body. The upper part of the ore body was extracted by open cast mining.

a) Describe in detail how the mining span required to initiate caving in a pipe shaped ore body can be assessed using rock mass rating systems. **[7]**

b) Sketch the layout of the undercut, draw-points and gathering drives. **[6]**

c) Discuss the changes in stress that will occur in the gathering drives during mining using sketches. **[6]**

d) Thence recommend suitable support for the drives and drawpoints. **[6]**

[25 MARKS]

QUESTION 2

A massive tabular orebody is dipping at about 30° at a depth of 70 m to 200 m below surface. The mineralized zone is on average 25 m thick and 250 m on strike. The mineralization lies on and above the contact between massive dolomite and an overlying sandstone. The sandstone extends above the mineralized zone.

It is intended to mine the orebody using open stoping, drilling upward from drilling and loading drives on the contact and using remote controlled loading.

a) Draw the mining layout in plan and section. **[6]**

b) Describe the geotechnical investigations required to assess the stable spans which can be mined. **[6]**

c) Describe how you would assess the stable span of the hangingwall. **[8]**

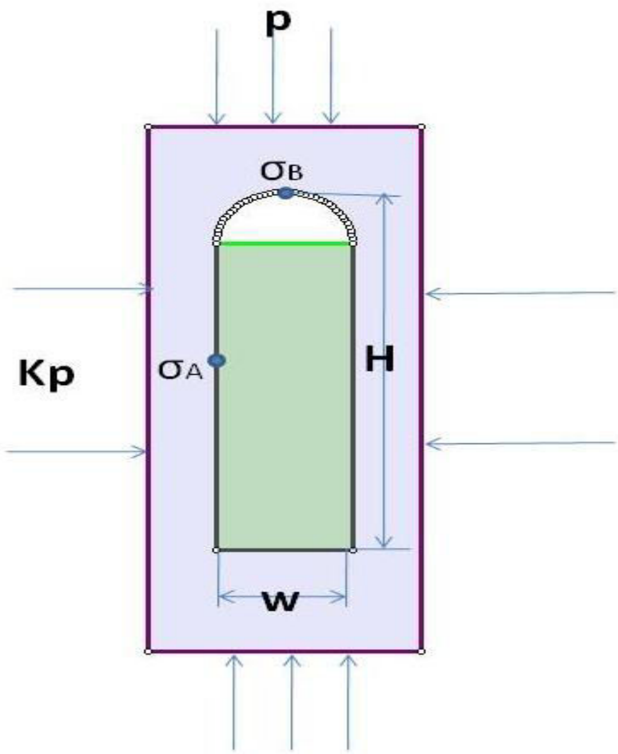
d) How would you control the hangingwall span considering the mining method. **[5]**

[25 MARKS]

QUESTION 3

The figure below is a schematic representation of a section through a cut and fill stope. The stress concentration factors at the crown and sidewall can be determined using the following equations.

Crown: $\sigma B/p = K - 1 + 2K(H/W)^{1/2}$
Sidewall: $\sigma A/p = 1 - K + 2(W/H)$



a) Plot graphs of the stress concentration factor versus the H/W ratio. Use H/W values of 1,2,5,10, and 20 and K=1 **[12]**

b) The stress concentrations in the crown and sidewall change as H increases. How will this influence stability? Briefly suggest methods of managing stability. **[5]**

c) Describe, with the aid of sketches, how you would carry out pre-reinforcing of the crown using long cables. **[8]**

[25 MARKS]

QUESTION 4

The following stress field data has been determined through elastic modelling in an area of a mine:

σ_{zz} = 30 kPa.m^{-1} (vertical stress gradient)

h = depth below surface

k_{xx} = 1.5 (000^0 - 180^0) (k-ratio in the x-direction - horizontal)

k_{yy} = 2.5 (90^0 - 270^0) (k-ratio in the y-direction - horizontal)

The principal stresses are aligned with the co-ordinate axes. The rock mass has a high joint density with a uniaxial compressive strength of 180 MPa. The horizontal excavations are greater than 6m x 6m.

4.1 Calculate the RCF at 500 m depth below surface for:

4.1.1. a vertical ore pass

4.1.2. a horizontal tunnel orientated East-West and

4.1.3. a horizontal tunnel orientated North-South

In each case, describe the stress distribution (elastic), expected fracturing, ground conditions and support requirements for anticipated mining-induced stress changes (no seismicity). Use annotated sketches as required. **[18]**

4.2 The depth of fracturing (R_f) around an excavation can be estimated using the following relation:

$$R_f = \left\{a * (0.5 + 1.25 * \left(\frac{3\sigma_1 - \sigma_3}{\sigma_c}\right)\right\} - a$$

Where a is the (effective) radius of the excavation.

Calculate the depth of failure for the vertical ore pass in question 2.1, which has a 5 m diameter. **[3]**

4.3 The main access ramp follows a continuous downward spiral inclined at 9^0 to access the underground workings. Which orientations of the tunnel will experience greater stress-driven fracturing? What strategies could you suggest to the mine manager to minimise the effects of high stress concentrations? How will this benefit the operation in terms of cost, safety and productivity? **[4]**

[25 MARKS]
TOTAL MARKS: [100]

REFERENCE SHEET

$$n = FoS\,\frac{\rho g t}{P_f}$$

Where:			
	FoS	=	Factor of Safety
	ρ	=	*Hangingwall Rock Density (Tonnes.m-3)*
	g	=	*Gravitational Acceleration (9.81m.s-2)*
	P_f	=	*Yield Strength of Rock Bolt (kN)*
	t	=	Design Beam Thickness (m)
	n	=	Number of Rock Bolts required per m^2

$$RCF = \frac{3\sigma_1 - \sigma_3}{F\sigma_c}$$

***Table** 7.3.14 Support recommendation for good ground conditions (RCF < 0.7)*

Case	**Primary support (Typical requirements)**	**Secondary support (Typical requirements**
Static stress conditions	'Spot' support where necessary (Split Sets, rock studs, etc.)	'Spot' support where necessary (rock studs, etc.)
Stress changes anticipated	'Spot' support where necessary (Split Sets, rock studs, etc.)	Fully grouted tendons > 1.5 m in length, installed on basic 2 m pattern. Support resistance: 30 - 50 kN/m². Rope lacing (sidewalls only)
Seismic activity anticipated	Split Sets or tendons > 1.2 m in length, installed as close to face as possible, on basic 2 m or 1.5 m pattern. Support resistance: 30 - 50 kN/m².	Fully grouted (pref. yield) tendons > 1.5 m in length, installed on basic 2 m pattern. Support resistance: 50 kN/m². Mesh and lace (hangingwall and sidewalls)

***Table** 7.3.15 Support recommendation for average ground conditions (0.7 < RCF < 1.4)*

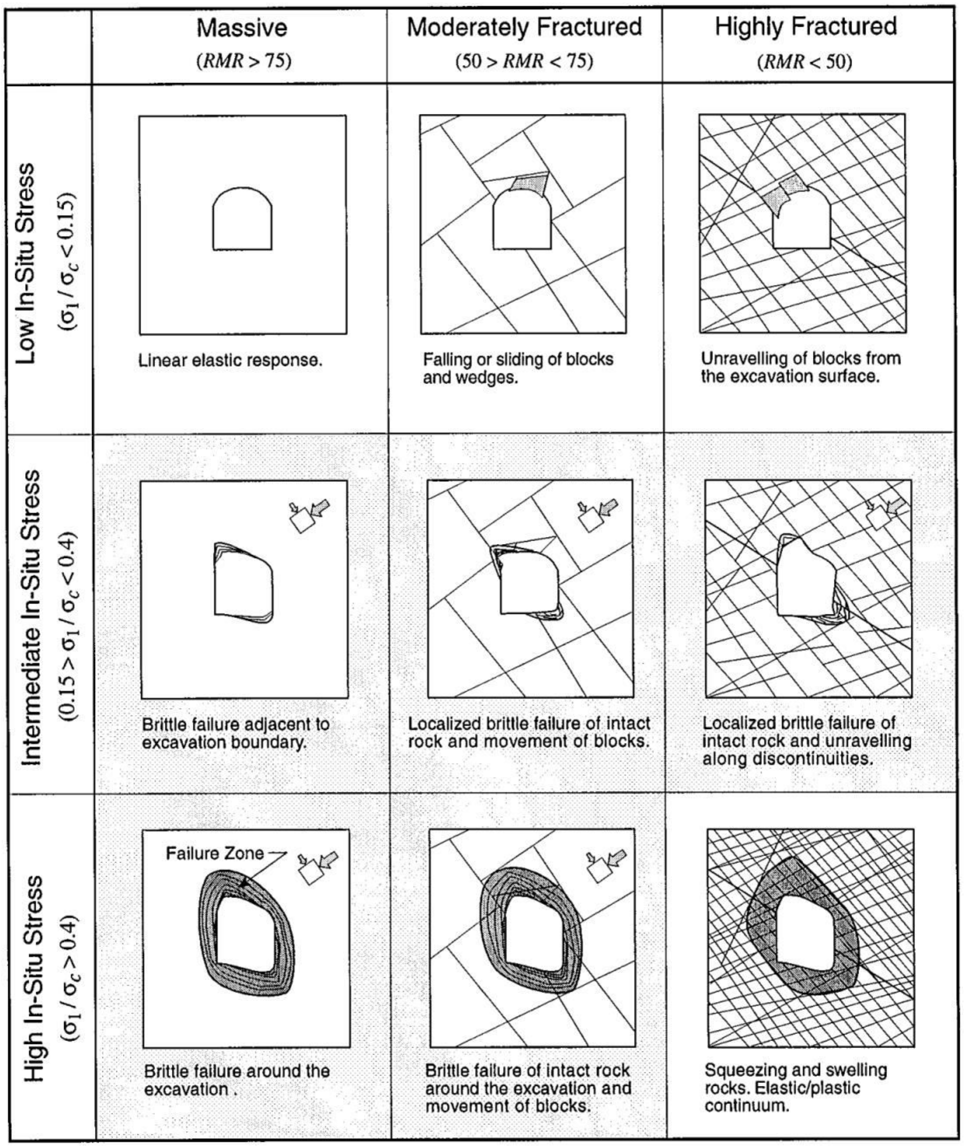
Case	**Primary support (Typical requirements)**	**Secondary support (Typical requirements**
Static stress conditions	Rock studs or tendons > 1.5 m in length, installed as close to face as possible on basic 2 m pattern. Support resistance: 30 - 50 kN/m².	Steel strapping or rope lacing integrated with primary support tendons; or gunite.
Stress changes anticipated	Fully grouted tendons or steel ropes > 1.8 m in length, installed as close to face as possible, on basic 2 m or 1.5 m pattern. Support resistance: 40 - 60 kN/m².	Rope lacing and wire mesh integrated with primary support tendons.
Seismic activity anticipated	Fully grouted (pref. yield) tendons or steel ropes > 1.8 m in length, installed as close to face as possible, on 1.5 m or double 2 m pattern. Support resistance: 80 - 110 kN/m².	Rope lacing and wire mesh integrated with primary support tendons, plus optional gunite.

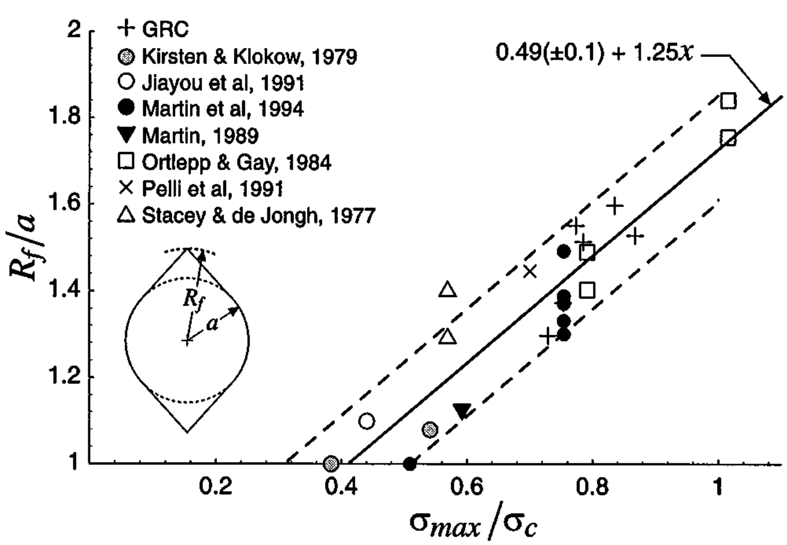
Table 7.3.16 Support recommendation for poor ground conditions (RCF > 1.4)

Case	**Primary support (Typical requirements)**	**Secondary support (Typical requirements)**
Static stress conditions	(If necessary) gunite to face, then fully grouted tendons or steel ropes, length > 1.8 m on basic 1.5 m pattern, as close to face as possible. Support resistance: 80 - 110 kN/m^2.	Steel wire mesh integrated with primary support; optional gunite/shotcrete.
Stress changes anticipated	(If necessary) gunite to face, then fully grouted steel ropes or yielding tendons, length > 1.8 m on basic 1 m or double 2 m pattern, as close to face as possible. Support resistance: 120 - 230 kN/m^2.	Rope lacing and wire mesh integrated with primary support. Add integral gunite in long life tunnels. If necessary, additional hangingwall support comprising grouted steel ropes.
Seismic activity anticipated	(If necessary) gunite to face, then fully grouted steel ropes or yielding tendons, length > 2.3 m on basic 1 m pattern, as close to face as possible. Support resistance: 220 - 290 kN/m^2.	Rope lacing and wire mesh integrated with primary support. Add integral gunite in long life tunnels. If necessary, additional hangingwall support comprising grouted steel ropes.

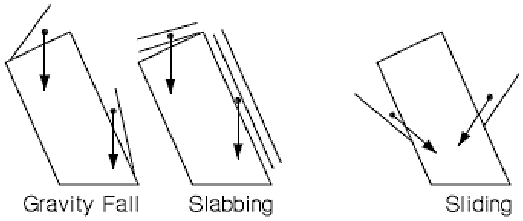
Induced radial stress in the x-direction at a distance r from the centre of a circular excavation with radius R:

$$\frac{\sigma_{\theta\theta}}{\sigma_{xx}} = \frac{1}{2}\left[2 + \ (1+k_x)\left(\frac{R}{r}\right)^2 + 3(1-k_x)\left(\frac{R}{r}\right)^4\right]$$

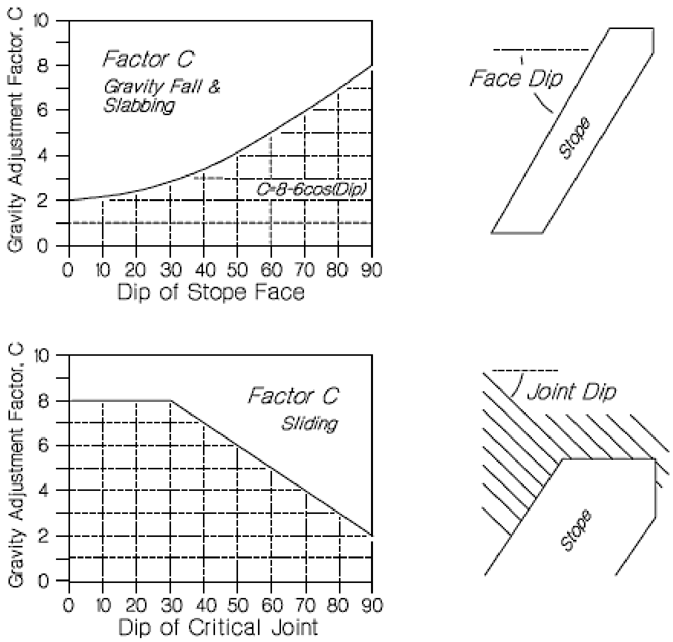

Massive
(RMR > 75)
Moderately Fractured
(50 > RMR < 75)
Highly Fractured
(RMR < 50)
Low In-Situ Stress
($\sigma_1 / \sigma_c < 0.15$)
Linear elastic response.
Falling or sliding of blocks and wedges.
Unravelling of blocks from the excavation surface.
Intermediate In-Situ Stress
($0.15 > \sigma_1 / \sigma_c < 0.4$)
Brittle failure adjacent to excavation boundary.
Localized brittle failure of intact rock and movement of blocks.
Localized brittle failure of intact rock and unravelling along discontinuities.
High In-Situ Stress
($\sigma_1 / \sigma_c > 0.4$)
Failure Zone
Brittle failure around the excavation .
Brittle failure of intact rock around the excavation and movement of blocks.
Squeezing and swelling rocks. Elastic/plastic continuum.


GRC
Kirsten & Klokow, 1979
Jiayou et al, 1991
Martin et al, 1994
Martin, 1989
Ortlepp & Gay, 1984
Pelli et al, 1991
Stacey & de Jongh, 1977
0.49(±0.1) + 1.25x
R_f/a
R_f
a
2
1.8
1.6
1.4
1.2
1
0.2
0.4
0.6
0.8
1
σ_{max}/σ_c

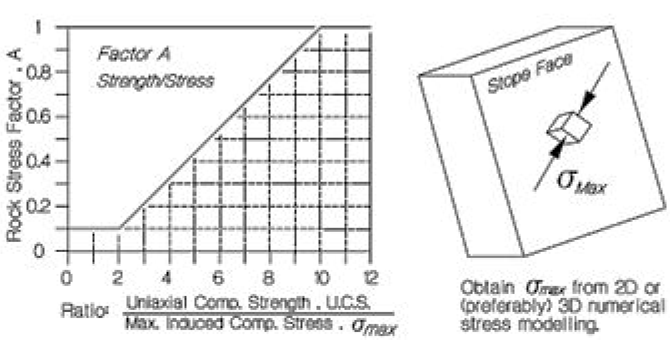
1) Determine the most likely mode of structural failure in case study using the figures below:



2) Next determine the gravity adjustment factor, *C* , based on the failure mode using the appropriate chart below.



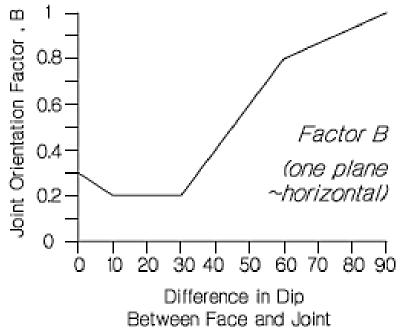
Determine maximum induced tangential stress (compressive) acting at the centre centre of the stope face being considered. Obtain uniaxial compressive strength strength for the intact rock. Evaluate Stress Factor, *A* , using the graph below:



Obtain σ_{max} from 2D or (preferably) 3D numerical stress modelling.

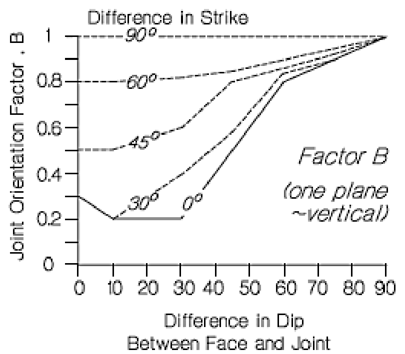
Horizontal Joint or Horizontal Stope Face (Back):

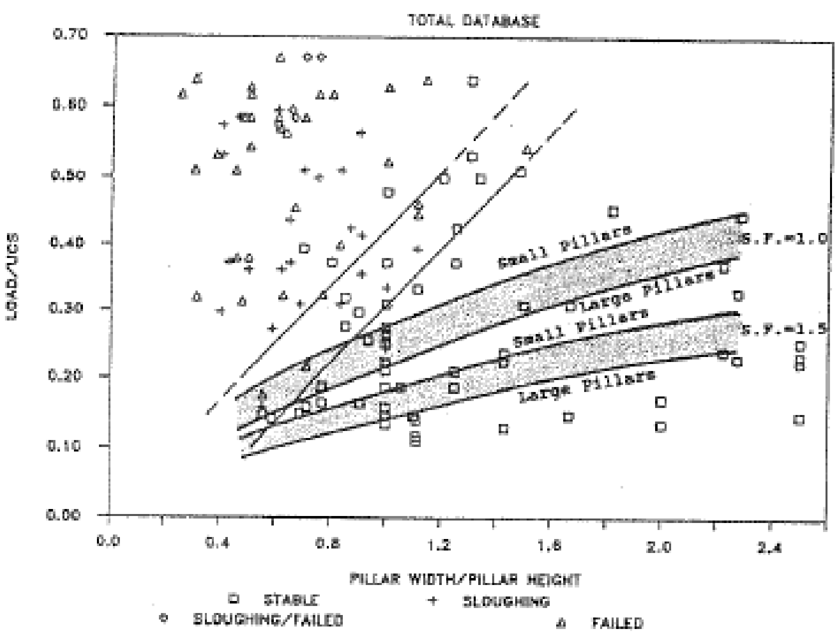
Consider only the difference in Dip between the stope face and the joint plane using the graph at right to determine *B*. When one plane is approximately horizontal, then the difference in Dip approximates the true interplane angle.

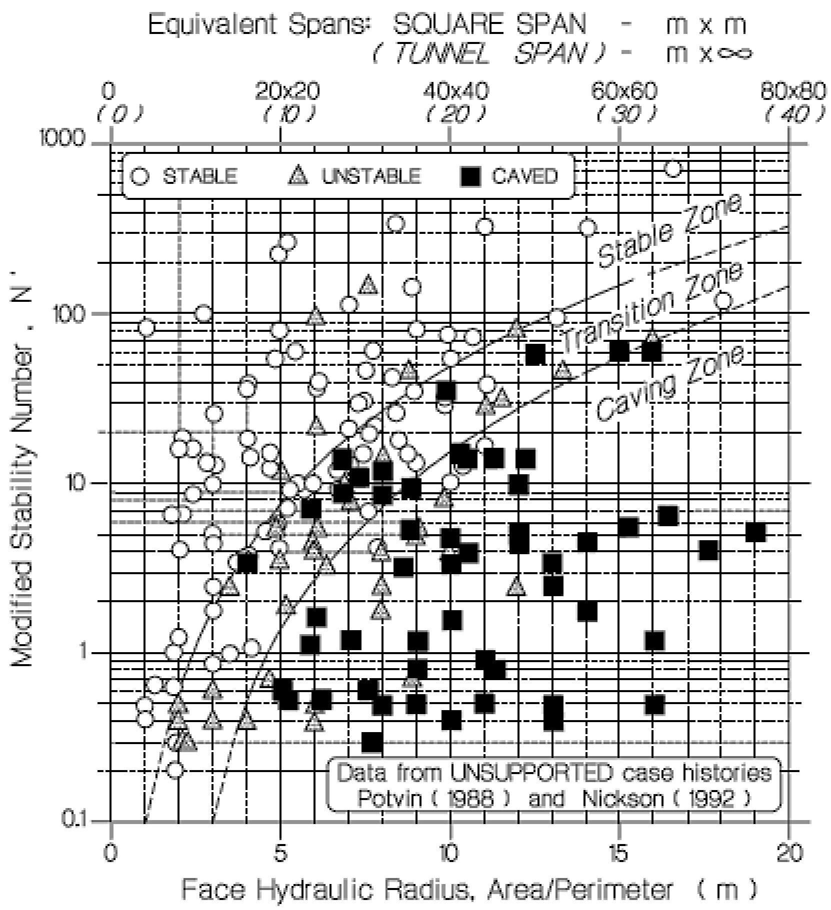


Near Vertical Joint or Near Vertical Stope Face:

The difference in Strike (or in Dip Direction) must also be considered in the case of vertical features. Note that this relationship as presented by Potvin (1988) should only be used when one of the planes is near vertical.







$N' = Q' \times A \times B \times C$