

Safety in Mines Research Advisory Committee

Final Project Report

**Workshops around the Pillar System Design computer
program produced in SIMRAC project GAP334**

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Research agency: CSIR Mining Technology

Project number: GAP 641

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Executive Summary

After a mini-survey on the structure and content of the workshops, it was decided that a overhead/electronic presentation of the engineering rationale / principles established in SIMRAC project GAP334 should be presented in conjunction with the actual Pillar System Design program.

Four workshops were held, three in the Bushveld Complex, and one at the Conference Centre at CSIR Miningtek. The delegates comprised most of the industry rock mechanics practitioners who deal with pillar system design at shaft level.

The Pillar System Design program was perceived to be user friendly, with scope for a few minor improvements in this regard.

The new pillar system design principles and rationale embodied in the outputs of SIMRAC project GAP334 were well, even enthusiastically, accepted as an advance in pillar system design.

A successful technology transfer of the results of SIMRAC project GAP334, which was the main aim of this project, was therefore achieved.

Acknowledgements

This project has been funded by the Safety in Mines Research Advisory Committee.

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1 Mini-survey and discussions with appropriate personnel on shallow to intermediate level mines that make use of in-stope pillars, as to terms and scope of workshops

1.1 Introduction

SIMRAC project GAP334 produced an overall pillar system design methodology that was encoded in a simple Microsoft™ Excel™ spreadsheet. In the interests of technology transfer, it was felt that a series of workshops should be held to promote the correct use of the program in the rock mechanics fraternity.

Another potential benefit that was envisaged was that such workshops would create critical discussion and provide useful information with respect to needs of the industry in the pillar design topic that were not being addressed.

1.2 Discussions and decisions

Discussions were held with members of the AMPLATS rock mechanics staff, which included Mr K. Noble, Mr A. Akermann and Mr G. Priest. Internal discussions were also held with Mr Tony Jager and Dr Terry Hagan.

Arising from the discussions, it was decided that the length of the workshop should be no more than a morning, with the presentation to include the engineering aspects of the GAP334 pillar system design methodology. It was felt that this is important for two reasons:

- users should understand the meaning of each design parameter, and the overall design philosophy implicit in the program
- users should understand the assumptions and consequent limitations of some of the engineering work, and therefore the limitations of aspects of the design program

Copies of the presentation would be provided. The presentation would be on overheads or projection directly from the computer.

It was decided to present the material in conjunction with demonstrations of each aspect of the program. That is, when the engineering discussion regarding panel span design is completed, the relevant part of the program would be demonstrated, showing how the engineering design is captured in the program, and how to use that aspect of the program. This would then be repeated for each major component of the design methodology (panel span design, pillar design, foundation design).

2 Preparation of presentation and workshop material according to feedback provided in Chapter 1

The presentation is reproduced in Appendix A. The presentation was done in conjunction with the demonstration of the use of the program.

3 Presentations and workshops

Four workshops were held with:

- 1) the rock mechanics personnel of the AMPLATS group
- 2) the rock mechanics personnel of Impala Platinum Mine
- 3) the rock mechanics personnel of Impala Platinum Mine
- 4) various rock mechanics practitioners active in the gold mining sector.

Details of venues and delegates are given in Appendix B. Computers were set up at the workshops to allow delegates to use the program as the material was presented.

3.1 Feedback from workshops

Comments indicated that some aspects of the program were not entirely user – friendly. For example, where values are required to be entered in, say, Screen A, and information regarding selection of the values is found in Screen B, these values should be able to be selected in Screen B and automatically placed in the correct field in Screen A.

In general, delegates found the program easy to use, and were able to learn how to use it rapidly. In some cases, practical pillar design problems were done in the workshop, with results proving acceptable to the delegates.

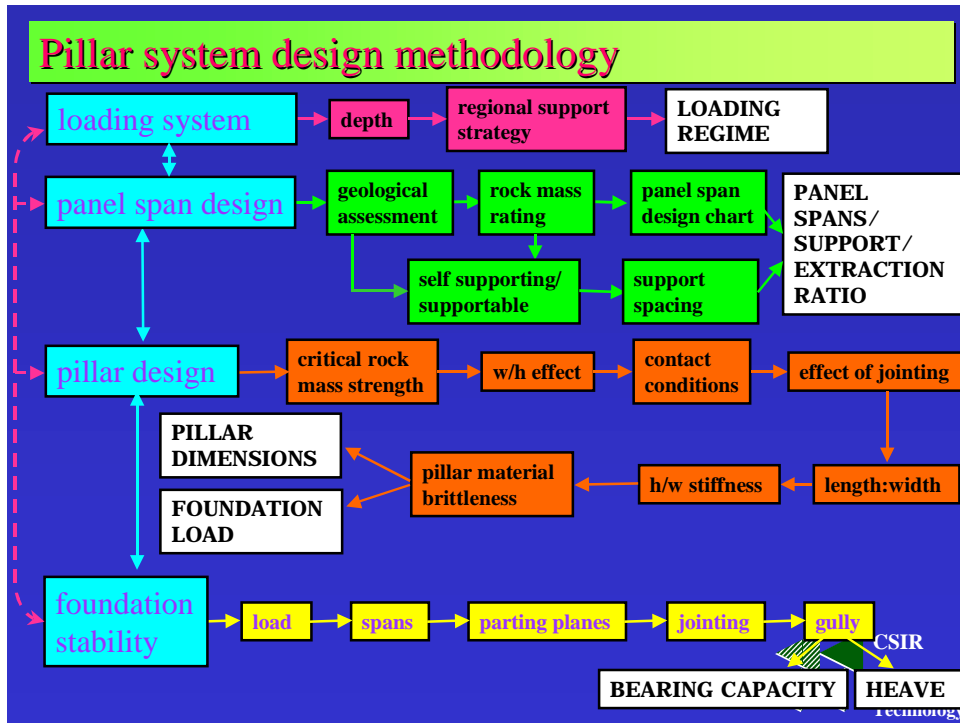
Delegates found that the new engineering methodology was a significant step forward in pillar system design. The notion of breaking the pillar system down into identifiable components, i.e. the hangingwall stability (panel span design), the pillar and the foundation design, was readily accepted. The main engineering factors influencing each of these components were discussed, and, where relevant, suitable engineering design rationales were introduced. In most cases, the new design rationales were enthusiastically accepted.

4 Conclusions

The technology transfer exercise was successful. A large section of the industry rock mechanics practitioners currently dealing with pillar systems in the scope of their professional duties, attended the workshops.

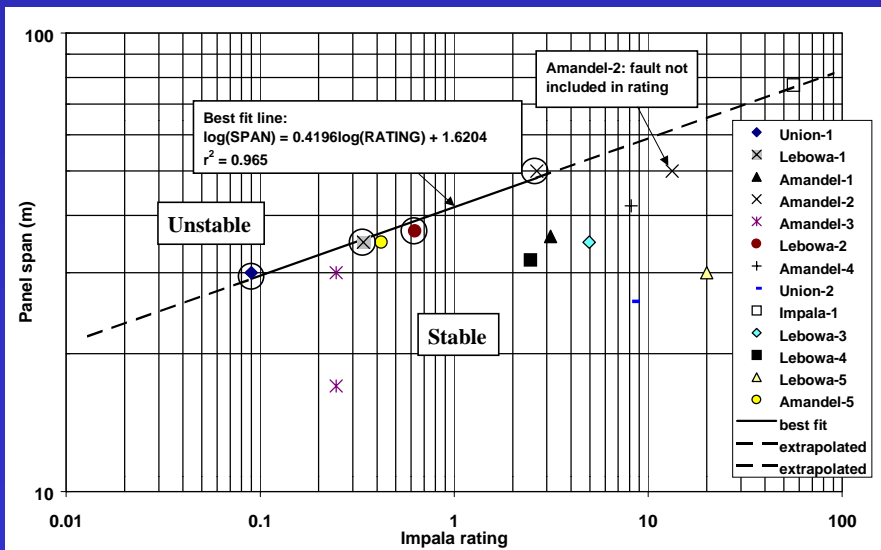
Delegates found the program easy to use and useful. More importantly, the engineering results and rationale were generally understood, and in this sense, the significant outputs of SIMRAC project GAP334 were successfully transferred to the industry.

APPENDIX A Workshop presentation



Slide 1

Panel span design: empirical approach



Technology

Slide 2

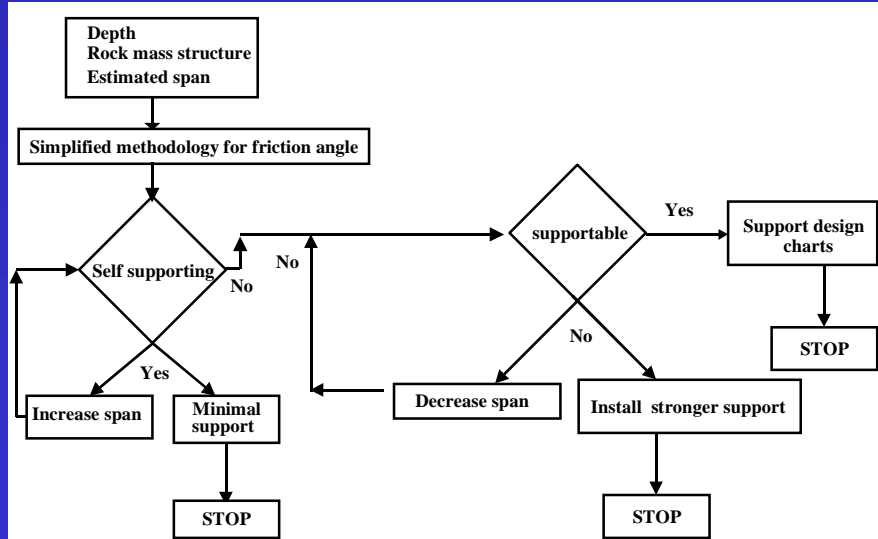
Considerations for improving the “Critical Panel Span Design Chart”

- Horizontal stress determination
- Orientation of joints included
- Persistence
- Major features analysed separately

Slide 3

Panel span design: numerical approach

Design flowchart

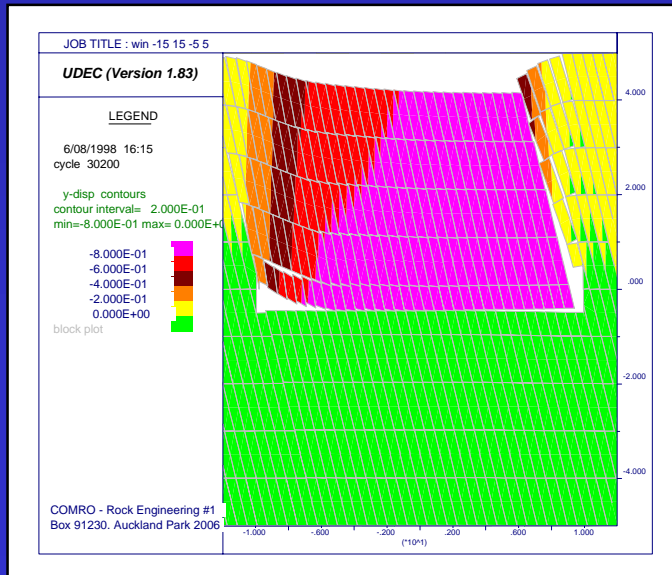


Technology

Slide 4

Effect of friction angle

$$\phi = 15^\circ$$

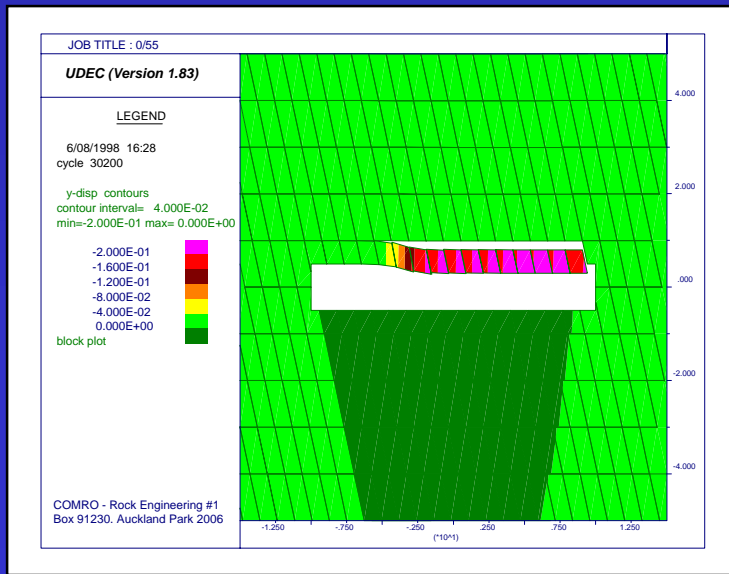


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Effect of friction angle

$$\phi = 35^\circ$$

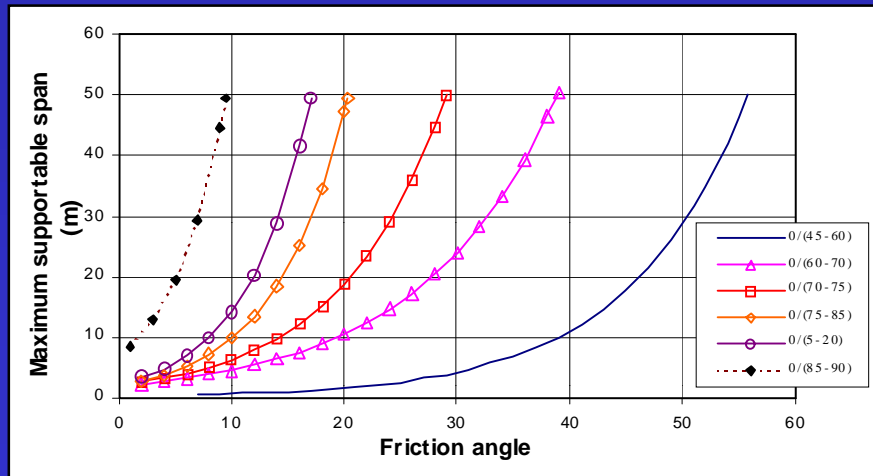


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Slide 6

Panel span design: numerical approach

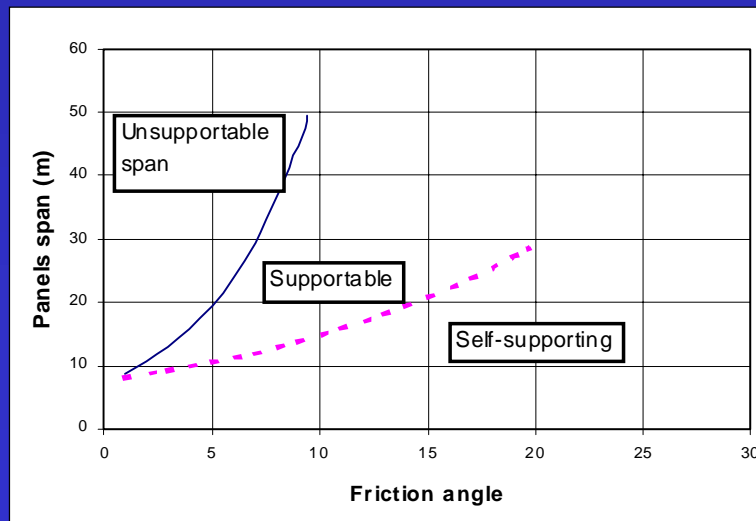
Supportable panel spans



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slide 7

Panel span design: numerical approach 0°/(85°-90°) joint sets



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Panel span design: numerical approach Features of methodology to determine friction angle

- joint roughness (base friction angle) **and** joint waviness into account (dilation)
- account for scale effect
- in-filling OR no in-filling
- non-weathered OR weathered joint compressive strengths

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Conclusions

Current research in panel span design

- reasonable to good rock mass rating:
large panel spans can be achieved in absence of
 - adverse geological features
 - abnormal stress conditions
- poor rock mass rating:
unraveling expected - function of panel span
- rational design of panel spans:
 - safety
 - economics



Slide 10

Current status of pillar design

Pillar design formula

$$S = Kh^{\alpha}w^{\beta} \quad S = \Theta[(1-a)w/h + a]$$

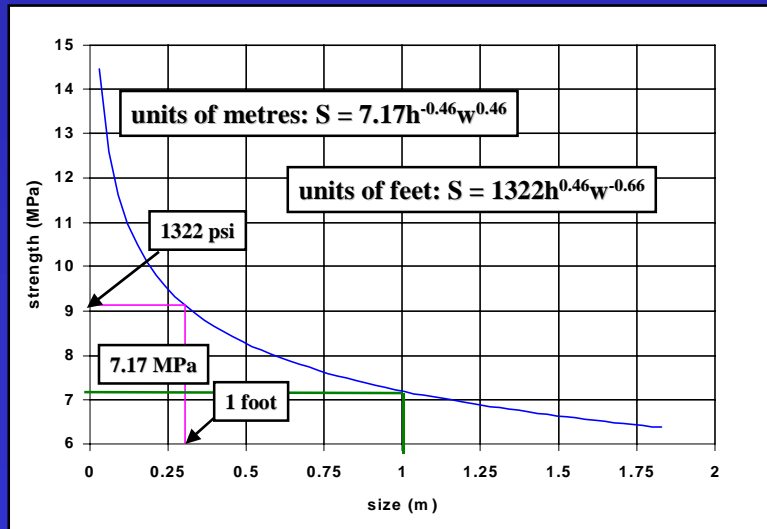
Hard rock mining

- *in situ* K or Θ - factor of UCS, downgrading - H+B, NGI
- value of "a" adopted from laboratory testing
- α and β values adopted from coal or Hedley and Grant



Slide 11

K as a material property ?



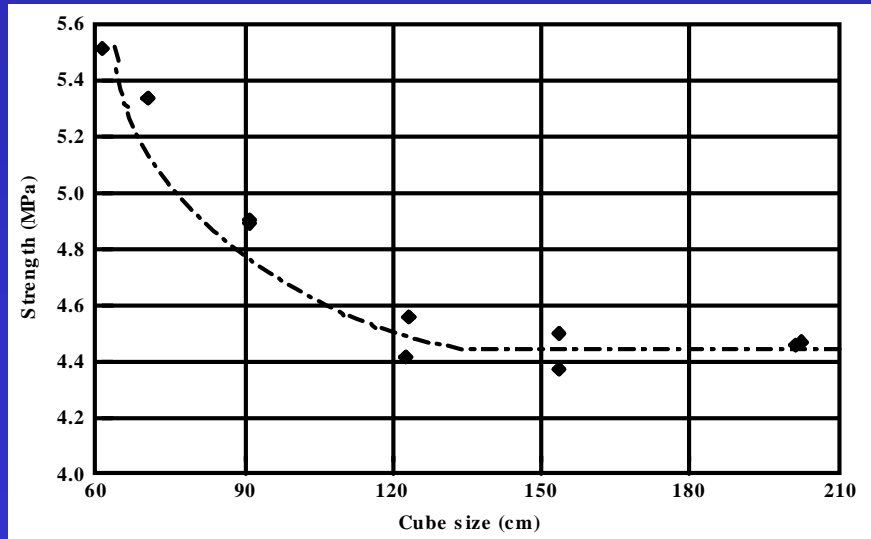
Slide 12

Salamon and Munro POWER FORMULA

- empirical
 - normal restrictions - size, w/h ratio, s/w
 - some combination of factors - UNKNOWN
- CONCLUSION :
 - GIVEN that variables w and h ONLY are captured
==> parameters K, alpha and beta:
best fit statistical parameters
for the particular combination of factors
 - K is not a material strength
 - alpha and beta are not material constants that
define the volume effect

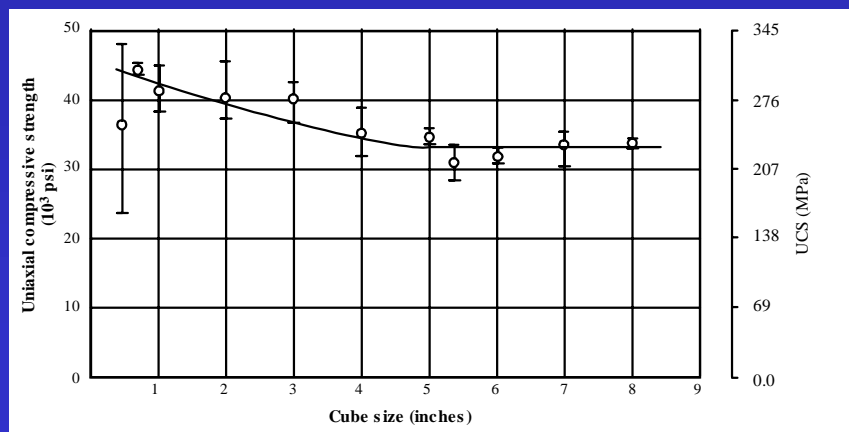
Slide 13

Pillar design
Scale effect - coal - Bieniawski



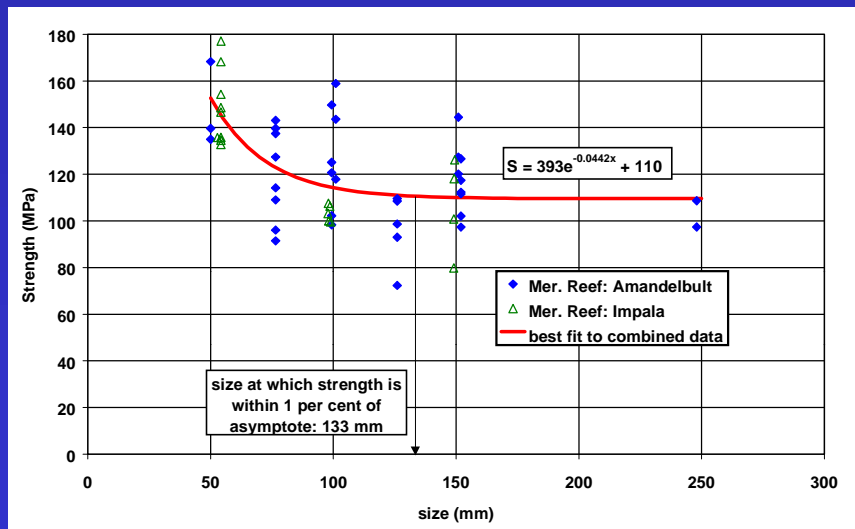
Slide 16

Pillar design
Scale effect - norite - Bieniawski



Side 17

Pillar design Critical rock mass strength



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Approximate method to determine the critical rock mass strength (Θ_c)

1st prize: strength - size relation

2nd prize: infer the critical rock mass strength from the UCS

HOW?

– UCS to $w/h=1$: $\Theta_{50} = \text{UCS} \times 1.20$ (at size=50 mm)

– Θ to critical rock mass strength: $\Theta_c = \Theta_{50} \times 0.70$

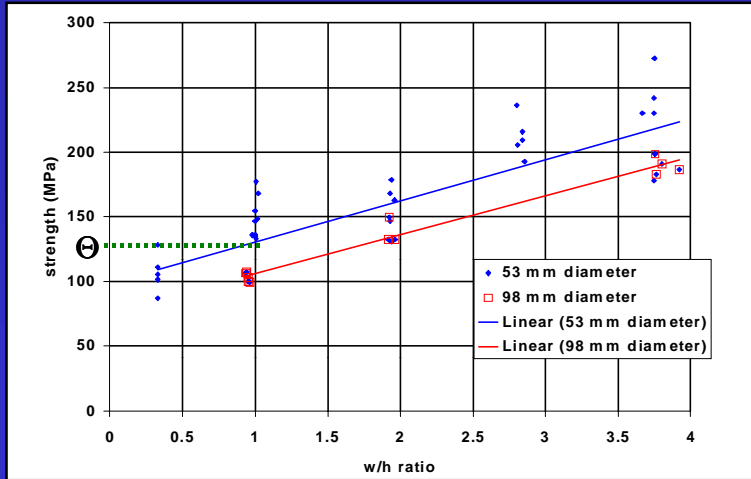
– total factor = $1.2 \times 0.7 = 0.84$

$\Rightarrow \Theta_c = \text{UCS} \times 0.84$

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Linear function



$\sigma = m(w/h) + c$; let $\Theta = \text{strength at } w/h = 1 \Rightarrow \sigma = \Theta[(1-a)*(w/h) + a]$
 $\sigma = 34.99(w/h) + 103.51 \Rightarrow \Theta = 138.5 \text{ MPa}$
 $\sigma = 138.5[0.25(w/h) + 0.75]$

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Effect of w/h ratio

Size (mm)	No. of samples	r^2	Linear function parameters		Normalised linear function parameters	
			m	c	Θ	1-a
50	9	0.80	51.47	88.15	145	0.31
77	17	0.59	49.07	62.84	120	0.27
101	14	0.90	30.55	97.43	121	0.36
152	13	0.95	14.46	101.80	117	0.23
248	8	0.91	27.15	75.88	105	0.24

- $S = c + m(w/h) \Rightarrow S/\Theta = [a + (1-a)(w/h)]$
- average r^2 for linear fit = 0.83
- r^2 for power fit = 0.80
- average "a" of [GAP334 + GAP024] = 0.27

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Laboratory tests: cylindrical samples

Conclusions

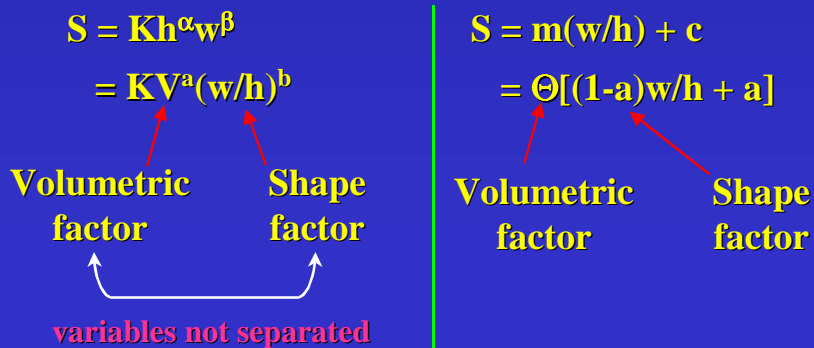
- Total loss of cohesion in core of $w/h = 4$
- exponential increase in strength after about $w/h = 6$
- stable “yield” pillar at about $w/h = 6$
- w/h ratio = 10 samples fail!!



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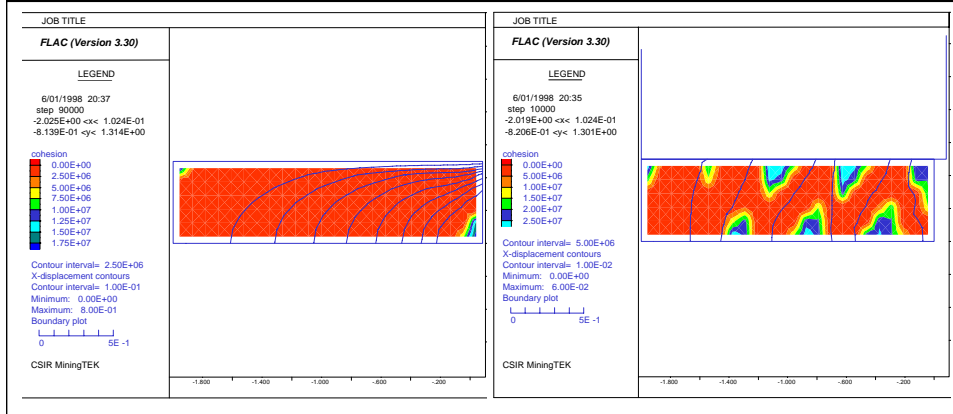
Power vs. linear pillar formula

Pillar design formula



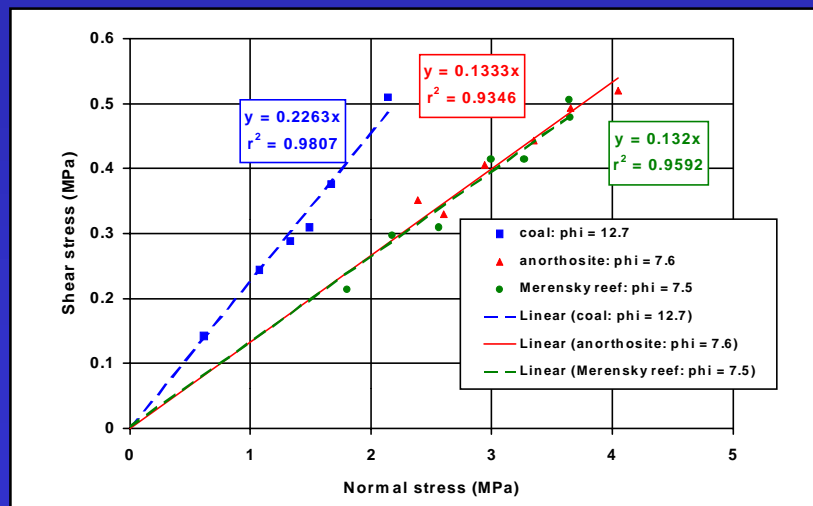
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Effect of interface friction on sample strength: FLAC model of laboratory model pillar, w/h=4



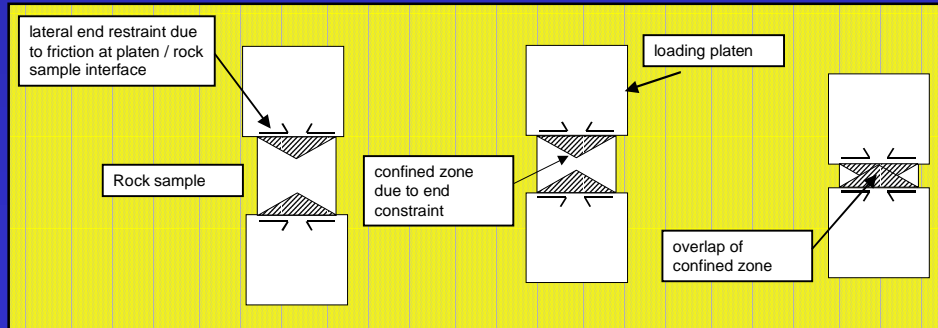
Slide 24

Contact conditions: rock / steel platen interface friction angle



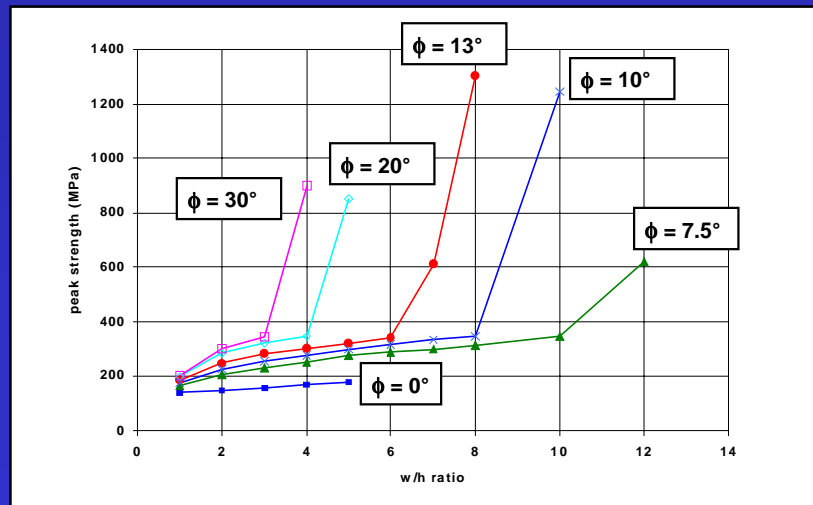
Slide 25

Frictional end restraint



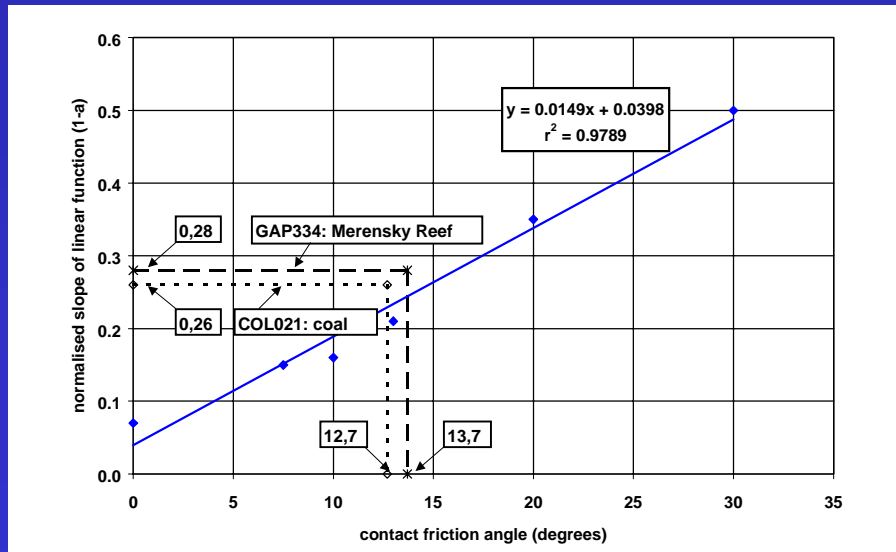
Slide 26

Effect of interface friction on slope of ($\sigma - w/h$) function FLAC model of laboratory tests



Slide 27

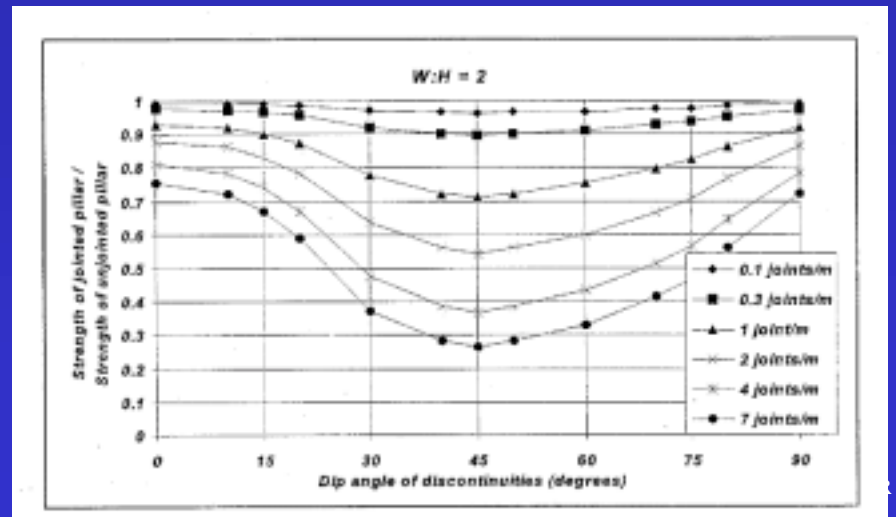
Pillar design: w/h strengthening factor as a function of contact friction angle



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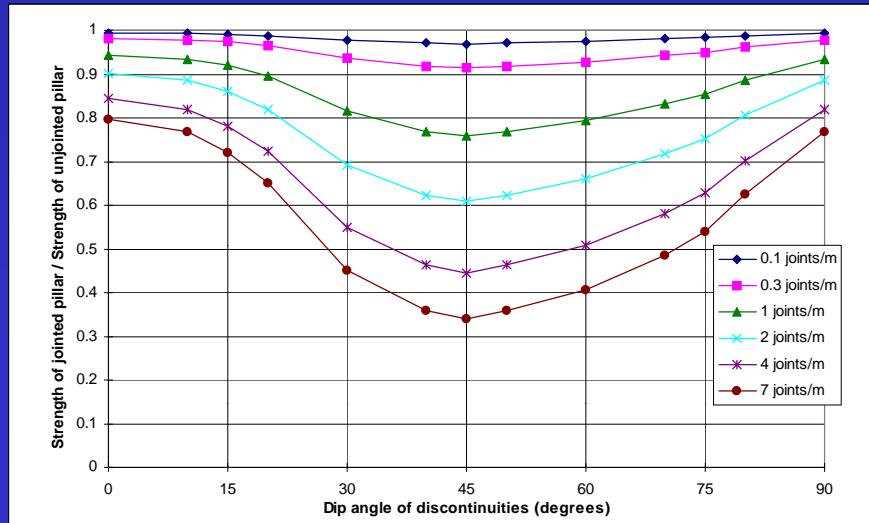
Pillar Design: Effect of jointing w/h = 2



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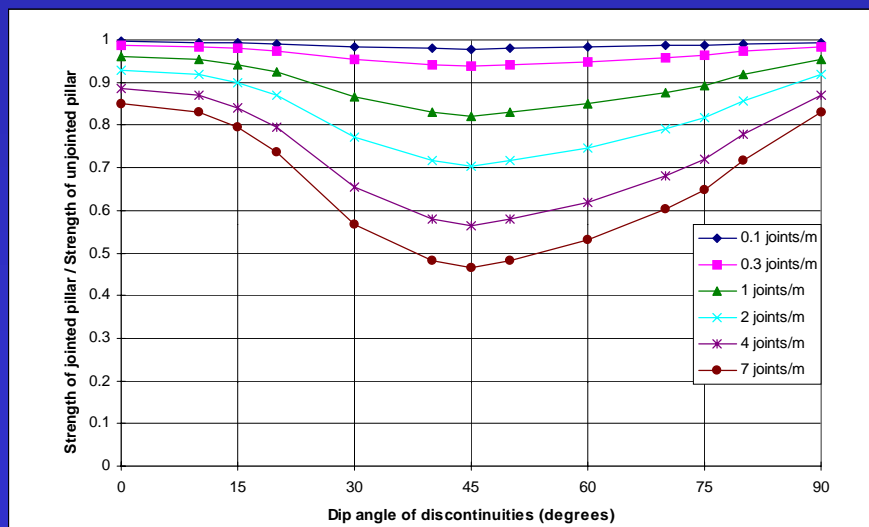
Slide 29

Effect of jointing: dip and friction angle pillar $w/h = 3$



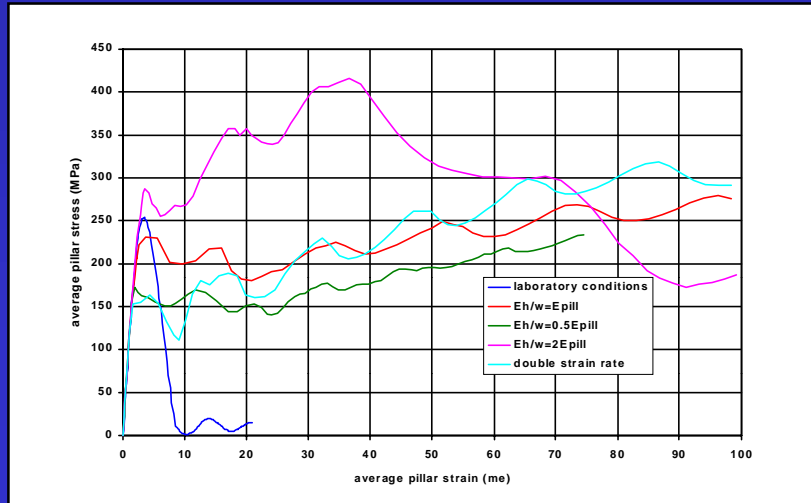
Slide 30

Effect of jointing: dip and friction angle pillar $w/h = 6$



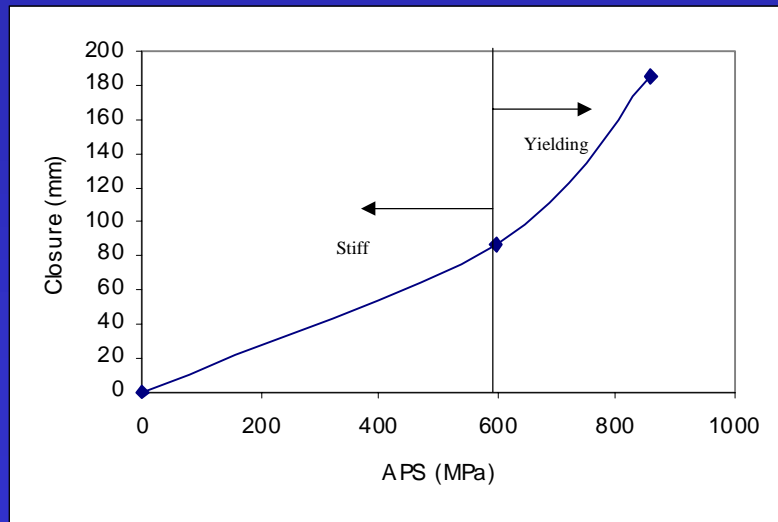
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Effect of hangingwall stiffness pillar width = 3m, w/h=3, span = 21m



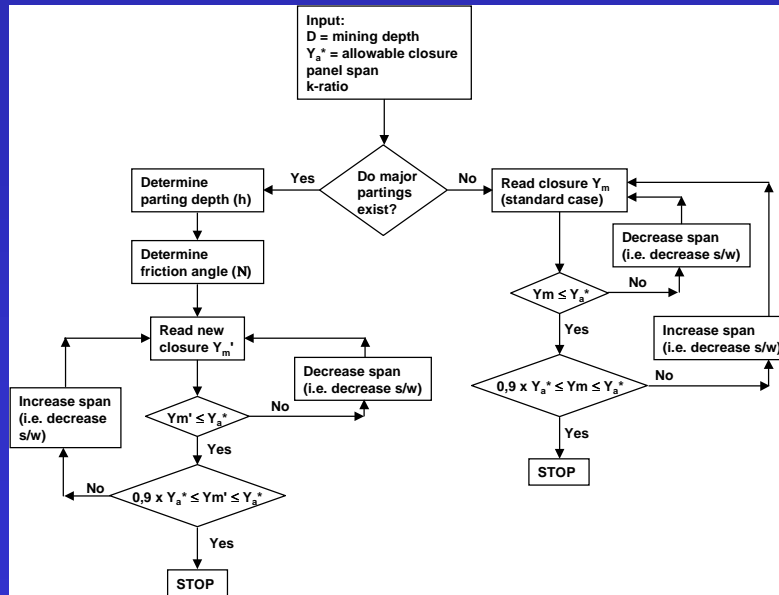
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Pillar foundation design methodology



Slide 33

Foundation / yielding elongate design optimisation flow chart



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Worked Example: Foundation design / support consideration

PROBLEM:

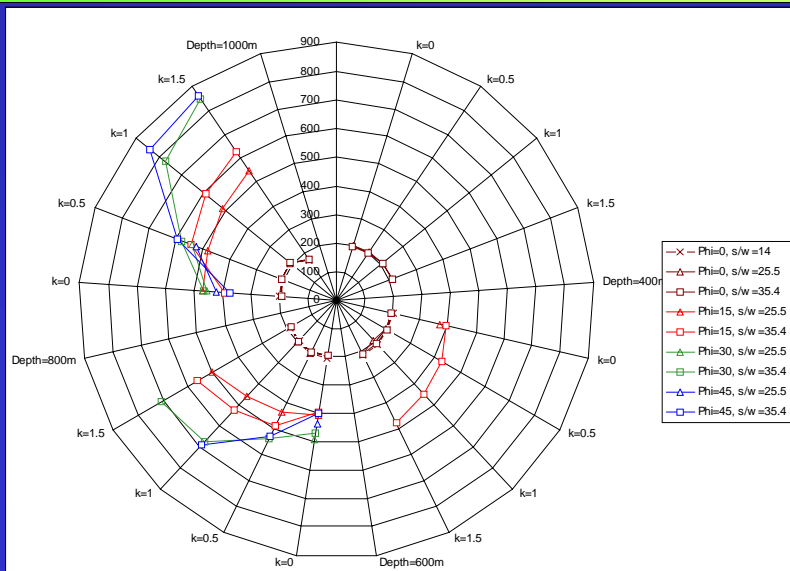
- Depth = 1000 m
- k-ratio = 0.5
- ratio of span : pillar width (s/w) = 14
- parting depth = 1 m
- friction on parting = 0°

Choose span to optimise yielding support design

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Pillar foundation / support design Example 1



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Worked Example: Foundation design / support consideration

SOLUTION:

$$APS = q/(1-e) = 450 \text{ MPa}$$

from Bearing Capacity design chart: $q = 200 \text{ MPa}$

$q < APS \Rightarrow$ footwall yielding

\Rightarrow elongate support is required

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Worked Example: Foundation design / support consideration

Chosen elongate has yield capacity $Y_a^* = 180 \text{ mm}$

From maximum closure design chart, $Y_m = 60 \text{ mm}$

$Y_m < 0.90 \times Y_a^* \Rightarrow$ increase span: try $s/w = 25.5$

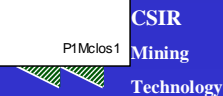
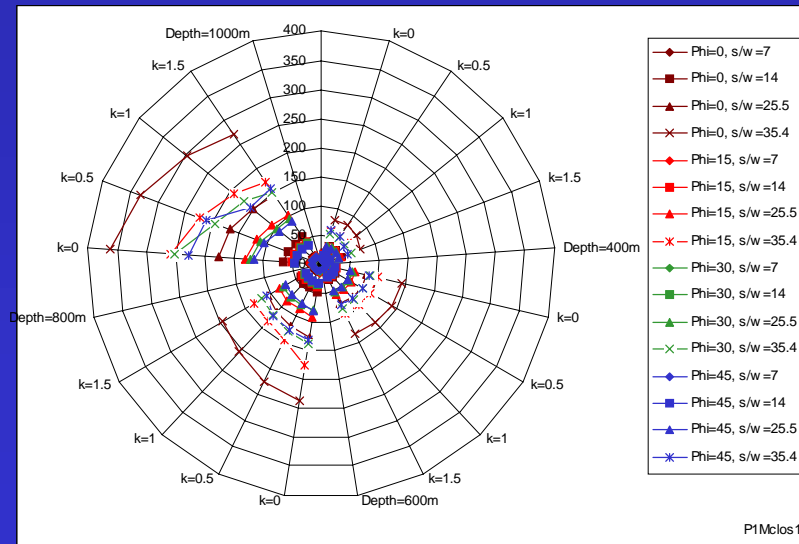
$\Rightarrow Y_m = 170 \text{ mm}$

$0.9 Y_a^* < Y_m < Y_a^* \text{ -----} > \text{OK}$



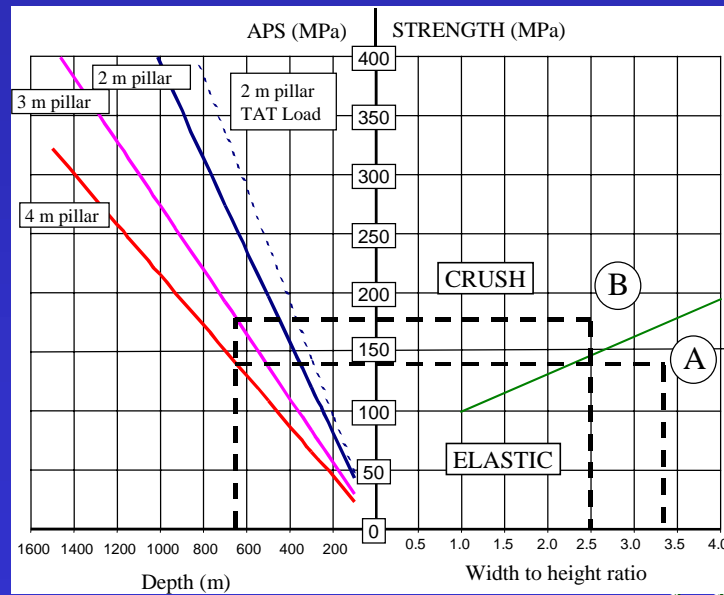
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Pillar foundation / support design Example 1



Slide 39

Crush pillar design flowchart



Slide 40

Limitations in current design methodology

Panel span design

- empirical
- UDEC approach

Pillar design

- joints
- local loading
- k ratio (stress regime)
- contact conditions

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Limitations in current design methodology

Footwall stability

- non-horizontal jointing
- variability of footwall material
- local stiffness

APPENDIX B Details of workshops

Workshop 1

Venue: AMPLATS Development Centre, Rustenburg

Delegates: The rock mechanics staff of the AMPLATS group

- K. Noble (Group Rock Mechanics Engineer)
- K. Akermann (Amandelbult)
- L. van Aswegen (Amandelbult)
- G. Priest (Rustenburg Section)
- G. Holder (Rustenburg Section)
- P. Miovsky (Rustenburg Section)
- J. Lombard (Rustenburg Section)
- H. Esterhuizen (Rustenburg Section)
- G. Pretorius (Union Section)
- R. Lamos (Union Section)

Workshop 2

Venue: Impala Rock Mechanics Department

Delegates: The rock mechanics staff of Impala Platinum Mine

- N. Fernandes
- W. Hartman
- L. Gardner
- F. Flanagan
- J. Rademan

Workshop 3

Venue: Lonrho Platinum Mine

Delegates: The rock mechanics staff of Lonrho Platinum Mine

- A. Day
- G. More O' Farrel

Workshop 4

Venue: CSIR Miningtek Conference Centre

Delegates: Various invited delegates from the gold mining rock mechanics practitioners industry.

A number of industry personell declined the invitation, or failed to arrive.

Name	Affiliation
F.R.P. Basson	Avgold
J.W.L. Hanekom	SRK
E.O. Mäkinen	SRK
J.J. Laas	Anglogold
A.H. Swart	SRK
M.J. Dunn	Anglogold
J. M. Oelofse	Anglogold
E. Scoltz	Driefontein
P. Lehong	Driefontein
L. Jiyana	South Deep
M.K.C. Roberts	CSIR Miningtek
M. Pretorius	SRK
D. Louw	Beatrix
W. Joughin	SRK