Support technologies to cater for rockbursts and falls of ground in the immediate face area

Volume I

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Executive summary

Statistics of accidents in South African gold and platinum mines show that rockfalls and rockbursts account for a substantial proportion of fatalities. A large number of these (56%) occur within 2.5 m of the stope face, usually in front of the permanent support. This critical area, between the stope face and 4 m back, is known as the immediate face area and is where the main mining activities take place and where personnel are concentrated. To reduce the incidents of rockfalls and damage associated with rockbursts in the immediate stope face area and thus afford interim protection to workers while they work, appropriate temporary and face area support is required. The choice of face area support is dependent on several factors, amongst them being the stoping width, the nature and extent of the rock to be supported, the type of deformation to which the support system will be subjected, force-deformation characteristics of the support system, ease of installation, and cost effectiveness.

The aim of this project is to investigate temporary and face area support systems (with special reference to the use of tendon support). Improved face area support design methodologies are proposed, and a probability analysis is conducted to investigate excavation stability and the requirements of a temporary support system.

The project consists of the following six enabling outputs:

- **EO1**: Review of current face area support practice and systems.
- **EO2**: Identification of strata conditions which are most suitable for particular face area support systems.
- **EO3**: Identification of hangingwall deformation mechanisms and their impact on tendon performance requirements.
- **EO4**: Identification of operational constraints applicable to face area support systems.
- **EO5**: Identification of periods in the production cycle when face area support systems are least able to meet their performance requirements.
- **EO6**: Development of a methodology to determine the requirements of face area support systems for various situations.

With regard to the usage of tendon support in the immediate vicinity of the stope face, it is found that tendons are currently only used under quasi-static conditions. Typically tendons are used in shallow mines and to depths of 1600 m below surface in situations where the UCS of the hangingwall rock exceeds 170 MPa. Tendons have been successfully used in stoping widths as low as 0.9 m. The use of tendons is primarily based on the presence of at least one pronounced hangingwall parting at a reasonable distance (0.2 to 3 m) from the reef – hangingwall contact.

A detailed investigation into strata conditions, which are most suitable for particular face area support systems, was conducted. The use of tendons is generally recommended for strata conditions entailing a strong hangingwall, minimum hangingwall fracturing, but with problematic roof parallel discontinuities. In other strata conditions appropriate columnar support types with adequate areal coverage are recommended. In conditions of weak and fractured hangingwalls, high levels of areal coverage are strongly indicated. A major output of the investigation is in the form of tables giving recommended support types for various rock classes in shallow and intermediate/deep mining environments.
Underground investigations, as well as analytical and numerical models, resulted in an improved understanding of tendon interaction with a discontinuous hangingwall in quasi-static and dynamic conditions.

An engineering approach for the design of stope face support systems is proposed and facilitates the convenient evaluation of support resistance, energy absorption and spacing requirements of tendons, props and packs in the stope face area.

Consultations with production personnel led to insights into operational constraints of temporary and face area support systems. Specific constraints investigated include labour availability, time, availability of support units, transport and storage, stope width, dip of reef, effect of mine geometry, and position of marked shot holes. Various solutions to overcome the operational constraints are proposed.

The SDA II software (support design tool) was used to investigate periods in the production cycle when face area support systems are least able to meet their performance requirements. It was found that the shift, which normally enters the panel after the blast, is most vulnerable. To improve worker safety at the face, it is essential to reduce the unsupported hangingwall span before the workers enter the panel after the blast. In certain circumstances tendons are effective in meeting this requirement. Spray-on membrane support could also potentially provide this support in highly fractured conditions but the effectiveness and practicability of this type of support has yet to be evaluated in the aggressive face area environment. Practical constraints (appear to) militate against the use of coal mining type shield support in the face area of deep, narrow stoping width gold mine stopes mined by blasting.

A probabilistic study was conducted to quantify the risks of injury, depending on the type of support, condition of the rock, mechanisms of deformation of the rock and support, support installation constraints and personnel exposure. A methodology was formulated to determine the risks of injury associated with a selection of current support types and various support types recommended as optimal for representative classes of strata conditions. Detailed guidelines for applying the methodology and recommendations on the verification, calibration and expansion of the methodology are given in conclusion.
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# Table of contents

Executive Summary .................................................................................................. 2  
Acknowledgements ................................................................................................. 4  
Table of contents ..................................................................................................... 5  
List of figures ........................................................................................................... 11  
List of tables ............................................................................................................ 19  
Glossary of abbreviations, symbols and terms .................................................... 20

1 Introduction ........................................................................................................... 23  
   1.1 Problem statement ......................................................................................... 23  
   1.2 Scope of research ......................................................................................... 24

2 Review of temporary support practice and systems ........................................... 27  
   2.1 Literature review .......................................................................................... 27  
      2.1.1 Immediate face area support requirements ............................................. 27  
      2.1.2 Support resistance required to control rockfalls in the stope face .......... 27  
      2.1.3 Determination of the rockburst energy absorption criteria for the stope face area ................................................................................................................ 28  
      2.1.4 Current estimate of support resistance and energy absorption requirements .. 28  
   2.2 Classification of immediate face area support systems ................................ 29  
      2.2.1 Classification of external support systems used in the immediate face area .... 29  
         2.2.1.1 Timber props ...................................................................................... 29  
         2.2.1.2 Mechanical props .............................................................................. 30  
         2.2.1.3 Hydraulic props ................................................................................. 31  
      2.2.2 Classification of rock tendons .................................................................. 31  
         2.2.2.1 Introduction ...................................................................................... 31  
         2.2.2.2 Continuous mechanically coupled (CMC) tendons ......................... 32  
         2.2.2.3 Continuous friction coupled (CFC) tendons ..................................... 33  
         2.2.2.4 Descrete mechanically and friction coupled (CMFC) tendons .......... 33  
   2.3 Overview of currently available temporary support systems ....................... 34  
      2.3.1 Introduction ............................................................................................ 34  
         2.3.1.1 Design criteria .................................................................................. 35  
         2.3.1.2 Factors influencing choice ................................................................. 35  
         2.3.1.3 Temporary support types ................................................................. 35  
         2.3.1.4 Support density and areal coverage ................................................... 36  
         2.3.1.5 Installation and removal ................................................................. 37  
   2.3.2 Current application of rockbolting in the immediate face area ............... 38  
      2.3.2.1 Evander Mine (Kinross) ..................................................................... 38  
      2.3.2.2 Western Platinum mine ..................................................................... 41  
      2.3.2.3 Vaal Reefs ........................................................................................ 44  
      2.3.2.4 Randfontein Estates .......................................................................... 45  
      2.3.2.5 Amandebult mine ............................................................................. 45  
      2.3.2.6 Other in-stope applications of rockbolt ............................................. 45  
      2.3.2.7 Conclusion ...................................................................................... 46
2.4 Temporary support in high stoping width ............................................................... 47
2.4.1 Introduction .................................................................................................. 47
2.4.2 Hydraulic props ......................................................................................... 48
2.4.3 Mechanical props ..................................................................................... 49
2.4.4 Elongates ..................................................................................................... 51
2.4.5 Corrections for high stoping widths ......................................................... 52

2.5 Load-deformation behaviour of commonly used temporary support types .. 55
2.5.1 Introduction ................................................................................................. 55
2.5.2 Behaviour of elongates ............................................................................. 55
2.5.3 Behaviour of mechanical props ................................................................. 57
2.5.4 Tendon behaviour ..................................................................................... 58

3 Identification and classification of strata conditions and quantification of their temporary support requirements .......... 61
3.1 Introduction ..................................................................................................... 61
3.1.1 Definition of the face area ......................................................................... 61
3.1.2 Methodology .............................................................................................. 62
3.2 Mining environments/conditions .................................................................. 63
3.2.1 Introduction ................................................................................................ 63
3.2.2 Shallow mining environments .................................................................. 65
3.2.3 Intermediate and deep mining environments ........................................... 65

3.3 Parameters influencing strata conditions in shallow mining environments. 65
3.3.1 Introduction ................................................................................................ 65
3.3.2 Rock types and UCS .................................................................................. 66
3.3.3 Reef parallel structures ............................................................................. 69
  3.3.3.1 Introduction ............................................................................................ 69
  3.3.3.2 Bedding and lithological contacts ............................................................. 69
  3.3.3.3 Bedding parallel faults and joints ............................................................. 71
  3.3.3.4 Parting potential ..................................................................................... 71
3.3.3 Reef perpendicular structures .................................................................... 72
  3.3.3.1 Introduction ............................................................................................ 72
  3.3.3.2 Joints ..................................................................................................... 72
  3.3.3.3 Strike slip faults ..................................................................................... 74
  3.3.3.4 Summary of reef parallel and perpendicular structures ....................... 74

3.4 Strata conditions and support requirements for shallow mining environments ......................................................................................................................... 75
3.4.1 Support types ............................................................................................. 75
3.4.2 Recommended support types for various classes of strata conditions ......... 76

3.5 Parameters influencing strata conditions in immediate and deep mining environments ................................................................................................................................. 77
3.5.1 Introduction ................................................................................................ 77
3.5.2 Rock types and UCS .................................................................................. 77
3.5.3 Mining induced fracturing .......................................................................... 77
3.5.4 Reef parallel structures ............................................................................................. 78
3.5.5 Reef perpendicular structures .................................................................................. 79
3.6 Strata conditions and support requirements for immediate/deep mining environments ......................................................................................................................... 79
3.7 Possible alternative support technologies in concept that may assist in alleviating rockfall and rockburst problems .................................................................................. 81
   3.7.1 Introduction ................................................................................................................. 81
   3.7.2 Twin beam support system ....................................................................................... 81
      3.7.2.1 Introduction ............................................................................................................ 81
      3.7.2.2 Discussion ............................................................................................................. 81
   3.7.3 Powered support for hard rock mining ..................................................................... 84
      3.7.3.1 Introduction ............................................................................................................ 84
      3.7.3.2 Discussion ............................................................................................................. 85
      3.7.3.3 Performance of powered supports ........................................................................ 88
   3.7.4 Evermine ..................................................................................................................... 90
      3.7.4.1 Discussion ............................................................................................................. 90
   3.7.5 Wire mesh and lace for stope support ...................................................................... 92
   3.7.6 Strapping between tendon support .......................................................................... 93
   3.7.7 Large headboards and base plates ......................................................................... 94
      3.7.7.1 Introduction ............................................................................................................ 94
      3.7.7.2 Discussion ............................................................................................................. 94
   3.7.8 Safety net ..................................................................................................................... 96
      3.7.8.1 Introduction ............................................................................................................ 96
      3.7.8.2 Discussion ............................................................................................................. 96
   3.7.9 Fortrac Geogrids ........................................................................................................ 100
      3.7.9.1 Introduction ............................................................................................................ 100
      3.7.9.1 Discussion ........................................................................................................... 101
   3.7.10 Modified stope support system using hydraulic props ......................................... 103
      3.7.10.1 Introduction ........................................................................................................ 103
      3.7.10.2 Discussion ......................................................................................................... 103
   3.7.11 Rock tendons support system .............................................................................. 104
      3.7.11.1 Introduction ....................................................................................................... 104
   3.7.12 Inflatables ................................................................................................................ 105
      3.7.12.1 Introduction ....................................................................................................... 105
      3.7.12.2 Discussion ......................................................................................................... 105
3.8 Discussion and recommendations .............................................................................. 108
4 Identifying hangingwall deformation mechanisms and their impact on rockbolt performance requirements ................................................................. 109
   4.1 Introduction .................................................................................................................... 109
   4.2 Rockbolting at the stope face ..................................................................................... 109
      4.2.1 Introduction ............................................................................................................ 109
      4.2.2 Rock mass instability and mechanisms of rock bolt interaction ............................... 110
      4.2.3 Envisaged evaluation and design process ............................................................... 111
      4.2.4 Numerical modelling evaluation ............................................................................. 112
         4.2.4.1 Rockbolt reinforcement parameters ................................................................. 113
7
with face-parallel fractures (FPFs) .......................................................... 185
4.8.2.5 Support requirements for rockfall conditions and blocky hangingwalls .... 186
4.8.2.6 Support requirements for rockburst conditions and blocky hangingwalls ..... 189
4.8.2.7 Support spacing calculation procedure .............................................. 190

4.8.3 Support Design Procedures ................................................................. 191
4.8.4 Conclusions ....................................................................................... 203

5 Operational constraints .............................................................................. 204

5.1 Introduction ............................................................................................ 204

5.2 Operational constraints applicable to temporary support ...................... 204

5.2.1 Drilling and charging ........................................................................... 204
  5.2.1.1 Labour availability ........................................................................ 204
  5.2.1.2 Time constraints ........................................................................... 205
  5.2.1.3 Availability of support units .......................................................... 206
  5.2.1.4 Transport mechanism and in-stope storage facilities for support units .... 206
  5.2.1.5 Stope width ................................................................................... 206
  5.2.1.6 Dip of reef .................................................................................... 206
  5.2.1.7 Effect of mine geometry .............................................................. 207
  5.2.1.8 Position of marked shot holes ....................................................... 207

5.2.2 Blasting ............................................................................................... 207

5.2.3 Cleaning operation ................................................................................ 208

5.2.4 Other constraints .................................................................................. 208

5.3 Solution to overcome operational constraints applicable to temporary support .......................................................... 209

5.3.1 Drilling and charging ........................................................................... 209
  5.3.1.1 Labour availability ........................................................................ 209
  5.3.1.2 Time ............................................................................................ 209
  5.3.1.3 Availability of support units .......................................................... 210
  5.3.1.4 Stope width ................................................................................... 210
  5.3.1.5 Dip of reef .................................................................................... 211
  5.3.1.6 Marking and drilling of shot holes ................................................ 211

5.3.2 Blasting ............................................................................................... 211

5.3.3 Cleaning operation ................................................................................ 211

5.3.4 Other recommendations ....................................................................... 212

6 Stability of unsupported span in the production cycle ............................ 213

6.1 Introduction ............................................................................................ 213

6.2 Production cycle ..................................................................................... 213

6.2.1 Entry examination ................................................................................ 214

6.2.2 Temporary support installation .......................................................... 214

6.2.3 Drilling ............................................................................................... 214

6.2.4 Permanent support installation .......................................................... 214

6.2.5 Charging up and blasting operation ................................................. 214

6.2.6 Cleaning period .................................................................................. 215

6.3 Analysis of the effect of increasing unsupported span stability .......... 215
  6.3.1 Rockfall conditions-discontinuum ...................................................... 215
6.3.2 Rockfall conditions-continuum analysis ...............................................................218
6.3.3 Rockburst conditions-continuum analysis............................................................221
6.4 Conclusions .................................................................................................................224

7 Development of a design methodology to determine the requirements of temporary and face area support systems........225

7.1 Introduction ..................................................................................................................225
7.2 Summary .......................................................................................................................225
7.3 Principal findings.........................................................................................................226

8 Review of principal findings and recommendations.........................227

8.1 Review of current face area support practice and systems.................227
  8.1.1 Summary ....................................................................................................................227
  8.1.2 Principal findings and conclusions ........................................................................228
  8.1.3 Recommendations ................................................................................................229

8.2 Identification of strata conditions which are most suitable for particular face area support systems...........................................230
  8.2.1 Summary ....................................................................................................................230
  8.2.2 Principal findings and conclusions ........................................................................230
  8.2.3 Recommendations for further work .......................................................................232

8.3 Identification of hangingwall deformation mechanisms and their impact on tendon performance requirements ................232
  8.3.1 Summary ....................................................................................................................232
  8.3.2 Principal findings and conclusions ........................................................................232
  8.3.3 Recommendations for further work .......................................................................234

8.4 Identification of operational constraints applicable to face area support systems ......................................................................234
  8.4.1 Summary ....................................................................................................................234
  8.4.2 Principal findings and conclusions ........................................................................235
  8.4.3 Recommendations for further work .......................................................................237

8.5 Identification of periods in the production cycle when face area support systems are least able to meet their performance requirements........................237
  8.5.1 Summary ....................................................................................................................237
  8.5.2 Principal findings and conclusions ........................................................................237
  8.5.3 Recommendations for further work .......................................................................237

8.6 Development of a methodology determine the requirements of face area support systems for various situations .....................................................238
  8.6.1 Summary ....................................................................................................................238
  8.6.2 Principal findings and conclusions ........................................................................238
  8.6.3 Recommendations for further work .......................................................................239

9 References ..................................................................................................................240
List of figures

Figure 1.2.1 Distance of fatalities from the stope face for Carbon Leader, VCR, Vaal Reef and Basal Reef rockbursts .......................................................... 26
Figure 1.2.2 Distance of fatalities from the stope face for Carbon Leader, VCR, Vaal Reef and Basal Reef rockfalls .......................................................... 26
Figure 2.2.1 Force-compression curve for yielding timber props as determined in laboratory tests and underground .................................................. 30
Figure 2.2.2 Typical force-deformation curve for an SS7 mechanical prop ........................................ 31
Figure 2.2.3 Resin grouted rebar - tensile loading across a joint .................................................. 32
Figure 2.2.4 Split set type SS 39 – tensile loading across a joint .................................................. 33
Figure 2.2.5 Expansion shell anchored rockbolt – tensile loading across a joint ............................... 34
Figure 2.3.1 Temporary support spaced as per mine standards but without areal coverage under blocky ground conditions on a mine ........................................ 37
Figure 2.3.2 Inclination of rockbolts with respect to orientation of parting planes and extension fractures, Kinross mine ................................................. 38
Figure 2.3.3 Variability in hanging wall thickness (Kinross Mine) .................................................. 39
Figure 2.3.4 Rockbolt used successfully in undercutting ............................................................... 40
Figure 2.3.5 Lose of grip of rockbolt after blasting ........................................................................ 40
Figure 2.3.6 Hangingwall layering ideal for rock bolting ............................................................... 41
Figure 2.3.7 Layers of roof being bolted together ........................................................................... 42
Figure 2.3.8 Drill rig ideal for bolting in narrow stoping width stopes ............................................. 42
Figure 2.3.9 (a) Application of rockbolt as an immediate face support.  
(b) An expansion shell rockbolt used in the stope ............................................................... 43
Figure 2.3.10 Improper tensioning of rockbolt at stope face ........................................................... 43
Figure 2.3.11 Rockbolting of the undulating fault, VCR Klerksdorp and a geological section through UG2 Western Platinum Mine indicating application of rockbolt ........................................ 44
Figure 2.4.1 Frontline props blast out versus stoping width, 80 kN props ........................................ 48
Figure 2.4.2 Frontline props blast out rate versus distance to stope face (80 kN props) ................... 49
Figure 2.4.3 The force-length relationship for two types of mechanical props ................................. 50
Figure 2.4.4 Roc props used as a face area support in a 4.5 m high stope at Beatrix Mine ................ 50
Figure 2.4.5 Buckling potential of yielding timber elongate (200 mm diameter profile prop) as a function of increasing length and stope closure ................................................. 51
Figure 2.4.6 Buckling adjustments versus stoping width ...............................................................53
Figure 2.4.7 Normalised $\sigma_{\text{crit}}$ versus slenderness ratio based on the Johnson and Euler column buckling theories.................................................................54
Figure 2.5.1 Comparison of laboratory slow test results with underground performance of Ebenhaeser props......................................................................................................56
Figure 2.5.2 Comparison of laboratory slow test results with underground performance of Loadmaster props......................................................................................................56
Figure 2.5.3 The force-deformation curve of a 1.5 m long medium duty mechanical prop...........57
Figure 2.5.4 Force deformation curve for a yieldable Camlock prop.............................................58
Figure 2.5.5 Shear characteristic of typical rockbolt installations under static laboratory shear loading.........................................................................................................................59
Figure 2.5.6 Direct tensile tests of support units............................................................................59
Figure 3.1.1 Diagram illustrating the face area...............................................................................62
Figure 3.2.1 Flowchart determining mining environments and conditions.....................................64
Figure 3.3.1 Punching of the support unit into the weak argillaceous hangingwall (face to the right)............................................................................................................................67
Figure 3.3.2 Weak hangingwall - Westonaria Formation lava (face to the right)...........................68
Figure 3.3.3 Strong hangingwall – silicious quartzite (face to the right) ........................................69
Figure 3.3.4 Ripple-marked bedding plane defining fallout............................................................70
Figure 3.3.5 Fallout along a shaly bedding plane...........................................................................71
Figure 3.3.6 Influence of joint characteristics on the degree of discontinuity ................................73
Figure 3.3.7 The effect of reef parallel and reef perpendicular structures on hangingwall condition.................................................................................................................................75
Figure 3.7.1 Twin beam support system ........................................................................................82
Figure 3.7.2 Mobile Stope Support System (MSSS)......................................................................83
Figure 3.7.3 Layout of Frame support (Mining Progress, Inc.)......................................................85
Figure 3.7.4 Chock support ............................................................................................................86
Figure 3.7.5 (a) $2F_{h}/420_{0.75}$ shield and (b) $4V/500_{0.8}$ shield............................................................87
Figure 3.7.6 $4V/600_{0.85}$ chock shield...............................................................................................87
Figure 3.7.7 Setting load versus roof convergence........................................................................88
Figure 3.7.8 Typical form of variations in support resistance (Peng et al., 1982)..........................89
Figure 3.7.9 Photo showing cured Evermine on brick after dynamic load test..............................90
Figure 3.7.10  Evermine mixer equipment: its gearbox and pneumatic motor, stem pump, hoses and nozzle ................................................................. 91
Figure 3.7.11  Note ease of application and zero rebound ................................................................. 91
Figure 3.7.12  Strapping between tendons ...................................................................................... 93
Figure 3.7.13  Gully wing headboard in general operation and just before blasting (after Spearing, 1992) ........................................................................ 95
Figure 3.7.14  Net installed with straps ............................................................................................. 96
Figure 3.7.15  Net installed with chains ............................................................................................. 97
Figure 3.7.16  Straps around elongate did not slip down elongate ................................................... 97
Figure 3.7.17  Net pulled tight by hand only .................................................................................... 98
Figure 3.7.18  Net showing signs of wear after seven blasts ......................................................... 98
Figure 3.7.19  Damage to net from blast ......................................................................................... 98
Figure 3.7.20  Note perimeter webbing broken due to been caught by scraper .............................. 98
Figure 3.7.21  The Geogrid easily holds the goaf behind the longwall ......................................... 100
Figure 3.7.22  Rolling up the mesh on surface at Springvale colliery ........................................... 101
Figure 3.7.23  View along longwall showing the boat winches every second support positioning the mesh roll tightly against the canopies ........................................ 102
Figure 3.7.24  Lightweight 80kN blast-on face support system (after Glisson and Roberts, 1991) 104
Figure 3.7.25  (a) Performance characteristic of the air-filled support unit. (b) Performance characteristic of the water filled support unit ........................................ 106
Figure 4.2.1  Rock bolt reinforcement and support schemes for stope face area stability ........ 110
Figure 4.2.2  Conceptual design process for stope face rock bolting ........................................... 111
Figure 4.2.3  Example of UDEC modeling of reinforced stope face hangingwall structure .... 113
Figure 4.2.4  Relative influence of rock bolt length (at 0.5 metre spacing) on reinforced beam capacity ........................................................................... 114
Figure 4.2.5  Relative influence of rock bolt spacing (at 1.0 metre rock bolt length) on reinforced beam capacity ................................................................. 115
Figure 4.2.6  Relative influence of rock bolt inclination (at 1.0 metre rock bolt length) and fracture inclination on reinforced beam capacity ........................................ 116
Figure 4.2.7  Relative influence of stope face area hangingwall span on reinforced beam capacity (1.0 metre bolts, 70° at 0.5 metre spacing) ........................................ 117
Figure 4.2.8  Influence of fracture angle relative to the stope hangingwall and reinforcement inclination on reinforced rock mass structure capacity ........................................ 118
Figure 4.2.9 Influence of sub-horizontal bedding spacing on reinforced rock mass structure (70° fracture dip) capacity

Figure 4.2.10 Influence of fracture spacing (70°) on reinforced rock mass structure capacity

Figure 4.2.11 Shear deformation of smooth bar rock bolt

Figure 4.2.12 Relative sensitivity of reinforced rock mass structure to design variables

Figure 4.3.1 Cantilever failure of hangingwall beam

Figure 4.3.2 Gravity induced failure of block in hangingwall

Figure 4.3.3 Shear failure at the abutment

Figure 4.3.4 Buckling failure of hangingwall due to horizontal stress

Figure 4.3.5 Deadweight causing a tensile stress in the roofbolt

Figure 4.3.6 Shear stress exerted perpendicular to roofbolt along the parting plane

Figure 4.3.7 Effect of bending moment on the stability of rockbolt

Figure 4.3.8 Maximum allowable support spacing for different bedding thickness and preload of tendons

Figure 4.3.9 Load-deformation curves for cone bolts, rockbolts and grouted ropes

Figure 4.3.10 Maximum allowable support spacing for different bedding thickness and preload of tendons

Figure 4.3.11 Maximum allowable support spacing as a function of different bedding thickness and peak load of tendons

Figure 4.3.12 Maximum allowable support spacing for a block experiencing a velocity of 3 m/s. The support spacing is a function of bedding thickness and energy absorption capabilities of the tendons

Figure 4.3.13 Maximum allowable support spacing for a block experiencing a velocity of 2 m/s. The support spacing is a function of bedding thickness and energy absorption capabilities of the tendons

Figure 4.3.14 Maximum allowable support spacing for a block experiencing a velocity of 1 m/s. The support spacing is a function of bedding thickness and energy absorption capabilities of the tendons

Figure 4.4.1 Example of numerical modelling of rock mass stability between rockbolt reinforcement

Figure 4.4.2 Chart of relative stability of rock mass structure between rockbolts reinforcement based on numerical modelling

Figure 4.4.3 Chart of the influence of rockbolt spacing, based on rock mass classification as derived from figure 4.4.2, on depth of instability between the rockbolts
Figure 4.4.4 Proposed chart to determine tendon spacing and depth of unstable rock between tendons (a) rockfall and (b) rockburst conditions........................................................................138

Figure 4.4.5 Proposed flow chart to determine tendon spacing and depth of unstable rock between tendons based on GAP 335.................................................................140

Figure 4.4.6 Maximum extent of the zone of support influence governed by bedding plane friction angle and bedding plane height.................................................................141

Figure 4.4.7 Numerical versus analytical support resistance profile .................................................................142

Figure 4.4.8 Principal stress trajectories through a hangingwall beam decritised by 90, 75, 60, 45 and 30 degrees extention fractures ........................................................................143

Figure 4.4.9 Stress trajectories through a hangingwall beam discretised by obliquely dipping extension fractures.............................................................................................145

Figure 4.4.10 Zone of influence profiles for $\alpha = 90^\circ$, $60^\circ$ and $30^\circ$ .................................................................146

Figure 4.4.11 Simplified model used to quantify the zone of support influence in a clamped, discontinuous hangingwall beam........................................................................147

Figure 4.4.12 Zone of influence within a homogeneous beam in the shape of a circular paraboloid......................................................................................................................148

Figure 4.4.13 Principal stress trajectories through a homogeneous hangingwall beam loaded by a single support unit. ($b = 1.0 \text{ m}, \varphi = 40^\circ, F = 100 \text{ kN}, w = 0.2 \text{ m}$)........................................................................149

Figure 4.4.14 Principal stress trajectories through a hangingwall beam discretised by 90, 60, 45 and 30 degree extension fractures (UDEC modelling results)................................151

Figure 4.5.1 Voussoir beam geometry for hangingwall beam analysis ..........................................................152

Figure 4.5.2 Span versus minimum beam thickness at 10 % beam deflection for various values of in situ rock mass modulus ($E'$) .................................................................153

Figure 4.5.3 Buckling stability envelopes of a discontinuous hangingwall beam ........................................154

Figure 4.5.4 Potential keyblock instability due to shear failure at the abutments ........................................155

Figure 4.5.5 Schematic diagrams showing possible failure modes due to shear at discontinuity interfaces ..................................................................................................................156

Figure 4.5.6 Geometry parameters governing the rotational stability of hangingwall blocks.................157

Figure 4.5.7 Maximum stable span versus discontinuity angles for $\sigma_x = 1.0 \text{ MPa}, b = 1.0 \text{ m}$ and $\mu = \tan 40^\circ$. Both carpet (top) and contour (bottom) plots are given to facilitate convenient data interpretation .................................................................158

Figure 4.5.8 Stability definitions in the various parts of the $\alpha$, $\beta$ plane .................................................................159

Figure 4.6.1 Flow chart for the design of rockbolt support taking into account deadweight, shear movement and cantilever failure of hangingwall beam........................................160

Figure 4.7.1 Graphical presentation of model ........................................................................................................163

Figure 4.7.2 Sine wave applied as a normal stress to boundary of model.........................................................164
Table of Figures:

- Figure 4.8.9 Rockburst stability envelopes for hangingwalls with FPFs as a function of instability height, unsupported span, support load and discontinuity orientation ($\gamma = 90^\circ - \phi$, where $\phi$ is the friction angle associated with the fracture surfaces)...
- Figure 4.8.10 Example of a blocky hangingwall...
- Figure 4.8.11 Length requirements of yielding tendons...
- Figure 4.8.12 Classification of a rock mass on the basis of the aspect ratio parallel to the hangingwall skin and the volume of the blocks...
- Figure 4.8.13 Maximum unsupported span for blocky rock mass structures as a function of rock mass class and depth of instability (rockfall conditions)...
- Figure 4.8.14 Maximum unsupported span for blocky rock mass structures as a function of rock mass class and depth of instability (rockburst conditions)...
- Figure 4.8.15 Design flowchart for shallow mines...
- Figure 4.8.16 Design flowchart for intermediate- and deep-level mines...
- Figure 4.8.17 Force versus deformation characteristics of the Loadmaster prop...
- Figure 4.8.18 Corrected Loadmaster reference curve (90 % probability)...
- Figure 4.8.19 Dynamic force versus deformation characteristics of the Loadmaster prop...
- Figure 4.8.20 Energy absorption capacity of the Loadmaster prop...
- Figure 5.2.1 The effect of prop mass on the physical effort to install a prop...
- Figure 5.3.1 A proposed production cycle for a crew to improve on support installation practices...
- Figure 6.1.1 Typical production cycle...
- Figure 6.3.1 Investigation of stability in the immediate face area for varying spans – shallow-dipping face parallel fractures...
- Figure 6.3.2 Investigation of stability in the immediate face area for varying spans – moderate dipping face parallel fractures (up to 55,50 degrees)...
- Figure 6.3.3 Investigation of stability in the immediate face area for varying spans – moderate dipping face parallel fractures (up to 55,50 degrees)...
- Figure 6.3.4 Investigation into instability in the immediate face area for varying spans – moderate dipping face parallel fractures (up to 55,50)...
- Figure 6.3.5 Investigation into instability in the immediate face area for varying spans – continuum analysis for shallow to intermediate conditions...
- Figure 6.3.6 Investigation into instability in the immediate face area for varying spans – continuum analysis for shallow to intermediate conditions – Effect of prestressing the immediate face area support units...
- Figure 6.3.7 Investigation into instability in the immediate face area for varying spans – continuum analysis for shallow to intermediate conditions – Effect of using stiffer,
non-removal, blast resistant immediate face area support units

Figure 6.3.8 Investigation into instability in the immediate face area for varying unsupported spans-continuum. Elbroc RB 80 Hydraulic prop used as temporary support.

Figure 6.2.9 Investigation into instability in the immediate face area for varying unsupported spans-continuum. Elbroc RB 80 Hydraulic prop used as temporary support.

Figure 6.3.10 Investigation into instability in the immediate face area for varying unsupported spans-continuum. Elbroc RB 80 Hydraulic prop used as temporary support.

Figure 6.2.11 Investigation into instability in the immediate face area for varying unsupported spans-continuum. Mechanical prop, Ebenhaeser MK1 1.0m Rockburst and Pack.

Figure 6.2.12 Investigation into instability in the immediate face area for varying unsupported spans-continuum. Mechanical prop, and an integration of Ebenhaeser MK1 1.0m Rockburst and a Pack.

Figure 8.3.1 Maximum allowable tributary area as a function of different bedding thickness and peak load of tendons (rockfall conditions).

Figure 8.3.2 Maximum allowable tributary area for a block ejected at a velocity of 3 m/s. The support spacing is a function of the bedding thickness and energy absorption capabilities of the tendons (rockburst conditions).
List of tables

Table 2.1.1  Fallout thickness for the various reefs at 95 per cent frequency level as the support resistance criterion.................................................................28

Table 2.1.2  Ejection thicknesses for the various reefs at 95 per cent frequency level and the associated energy absorption criteria.................................................................29

Table 2.5.1  Summary of shear test results.................................................................60

Table 3.2.1  Mining environments and associated conditions...........................................63

Table 3.3.1  Classification of UCS of intact rock (after Guler et al., 1998)..........................66

Table 3.3.2  Classification of UCS of intact rock (after Guler et al., 1998).........................70

Table 3.3.3  Classification of discontinuities based on discontinuity sets (after Guler et al., 1998)........................................................................................................73

Table 3.3.4  Classification of discontinuity spacing (after Brady and Brown, 1985)...........74

Table 3.4.1  Classes of strata conditions and recommended support types for each class......76

Table 3.5.1  Characteristics of mining induced fractures in deep gold mine stopes (amended after Daehnke et al., 1998). Types 1 to 4 represent extension fractures while type 5 represents shear fractures......................................................................................78

Table 3.6.1  Classes of strata conditions and the recommended support types for each class for intermediate/deep mines .................................................................80

Table 8.2.1  Classes of strata conditions and recommended support types for each class (shallow mining environment).................................................................231

Table 8.2.2  Classes of strata conditions and recommended support types for each class (intermediate/deep mining environment).................................................................231
Glossary of abbreviations and symbols

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM</td>
<td>Big Pebble Marker</td>
</tr>
<tr>
<td>UCS</td>
<td>Uni-axial Compressive strength</td>
</tr>
<tr>
<td>VCR</td>
<td>Ventersdorp Contact Reef</td>
</tr>
<tr>
<td>CMC</td>
<td>Continuous mechanically coupled tendons</td>
</tr>
<tr>
<td>CFC</td>
<td>Continuous frictionally coupled</td>
</tr>
<tr>
<td>DMFC</td>
<td>Discrete mechanically and frictionally coupled</td>
</tr>
<tr>
<td>AAC</td>
<td>Anglo American Corporation</td>
</tr>
<tr>
<td>RYHP</td>
<td>Rapid Yielding Hydraulic Props</td>
</tr>
<tr>
<td>UDEC</td>
<td>Universal Distinct Element Code</td>
</tr>
<tr>
<td>RQD</td>
<td>Rock Quality Designation</td>
</tr>
<tr>
<td>SDA</td>
<td>Support Design Analysis</td>
</tr>
<tr>
<td>PPV</td>
<td>Peak Particle Velocity</td>
</tr>
<tr>
<td>SB</td>
<td>Smooth bar (16mm);</td>
</tr>
<tr>
<td>RB</td>
<td>Rebar (16 mm);</td>
</tr>
<tr>
<td>VB</td>
<td>Twist bar (12 mm sq.)</td>
</tr>
<tr>
<td>CB</td>
<td>Cone bolt (16 mm)</td>
</tr>
<tr>
<td>R1</td>
<td>Rope # 1 (12 mm)</td>
</tr>
<tr>
<td>R2</td>
<td>Rope # 2 (12 mm)</td>
</tr>
<tr>
<td>R3</td>
<td>Rope # 3 (14 mm)</td>
</tr>
<tr>
<td>R4</td>
<td>Rope # 4 (16 mm)</td>
</tr>
<tr>
<td>SS</td>
<td>Split Set (SS 39)</td>
</tr>
</tbody>
</table>

Symbols

- $J_r$: Joint roughness number
- $J_a$: Joint alteration number
- $\sigma_n$: Normal stress
- $\tau$: Shear strength of the joint
- $JRC$: Joint roughness coefficient
- $\phi_r$: Residual friction angle for weathered joints
- $\phi_b$: Basic friction angle for unweathered joints
- $JCS$: Unconfined compression strength of joint surface
- $\rho$: Dry density of rock (kg/m$^3$),
- $g$: Acceleration due to gravity (9.8 m/s$^2$ ) and
- $r$: Rebound on weathered joint surface (Schmidt Hammer Test)
- $R$: Rebound on unweathered rock surface (Schmidt Hammer Test)
- $JRC_0$, $JCS_0$: Appropriate values for the length of joint actually rated
- $L_0$: Length of joint actually rated
- $L_n$: Total length of the joint
- $b$: Height of bedding plane above hangingwall skin
- $\phi$: Friction angle of bedding plane interface
- $\phi$: Friction angle of extension and shear fracture interface
\(\alpha\)  
Angle of extension fracture (measured from h/wall skin)

\(\beta\)  
Angle of shear fracture (measured from h/wall skin)

\(f\)  
Spacing of discontinuities such as shear fractures & joints

\(F\)  
Support load

\(r\)  
Radius of cylindrical support unit

\(w\)  
Width of rectangular support unit

\(\sigma (x)\)  
Zone of influence profile in two dimensions

\(\sigma (x,y)\)  
Zone of influence profile in three dimensions

\(x\)  
Co-ordinate perpendicular to stope face

\(y\)  
Co-ordinate parallel to stope face

\(z\)  
Extent of zone of influence from support unit edge

\(z_x\)  
Zone of influence extent extending in the \(x\)-direction from the support unit edge

\(z_y\)  
Zone of influence extent extending in the \(y\)-direction from the support unit edge

\(F_v\)  
Maximum vertical force

\(\sigma^{\text{min}}\)  
Minimum stress

\(\Omega\)  
Scaling parameter

\(d\)  
Distance from the edge of the support to the fracture

\(f\)  
Fracture spacing

\(z^-\)  
Extent of the zone of influence on the left-hand side of the support

\(H\)  
Depth of mining

\(z_b\)  
Effective zone of influence

\(c\)  
Average of the measurements from backfill face to backfill - hangingwall contact

\(a\) & \(b\)-values  
Values associated with a backfill stress - strain graph

\(W\)  
Weight of a block

\(s\)  
Span between adjacent support units

\(\sigma_x\)  
Magnitude of compressive horizontal stress in the hangingwall

\(\mu\)  
Coefficient of friction

\(F\)  
Adjusted force

\(F_o\)  
Original force determined by means of laboratory tests on 1 m elongates

\(h\)  
Underground stoping width

\(d\)  
Displacement

\(P_{cr}\)  
Critical load

\(A\)  
Area of column

\(k\)  
Radius of gyration

\(l\)  
Column length (stoping width)

\(E\)  
Young’s Modulus

\(S_y\)  
Yield strength of the column material

\(L\)  
Installed support length (stoping width)

\(\Delta L\)  
Closure acting on support unit

\(\varepsilon\)  
support strain

\(C_p\)  
P-wave velocity

\(C_s\)  
S-wave velocity

\(V_n\)  
Input normal velocity

\(V_s\)  
Input shear velocity
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_t$, $V_{II}$</td>
<td>Frictional resistance at abutments</td>
</tr>
<tr>
<td>$E$</td>
<td>Total energy to be absorbed by the support system</td>
</tr>
<tr>
<td>$m$</td>
<td>Mass of the hangingwall (dependent on fall-out height)</td>
</tr>
<tr>
<td>$v$</td>
<td>Initial hangingwall velocity</td>
</tr>
<tr>
<td>$h$</td>
<td>Downward hangingwall displacement</td>
</tr>
<tr>
<td>$L$</td>
<td>Actual unsupported span of the hangingwall beam</td>
</tr>
<tr>
<td>$L_s$</td>
<td>Maximum stable span</td>
</tr>
<tr>
<td>$L_{max}$</td>
<td>Maximum support spacing (centre to centre)</td>
</tr>
<tr>
<td>$M_x$</td>
<td>Mid-point of the support unit</td>
</tr>
<tr>
<td>$A_p$</td>
<td>Area of the panel</td>
</tr>
<tr>
<td>$A_b$</td>
<td>Area of a block</td>
</tr>
<tr>
<td>$N$</td>
<td>Number of blocks in the panel</td>
</tr>
<tr>
<td>$f_x$</td>
<td>Joint spacing in the x-direction</td>
</tr>
<tr>
<td>$f_y$</td>
<td>Joint spacing in the y-direction</td>
</tr>
<tr>
<td>$S_x$</td>
<td>Support spacing in the x-direction</td>
</tr>
<tr>
<td>$S_y$</td>
<td>Support spacing in the y-direction</td>
</tr>
<tr>
<td>$P$</td>
<td>Probability that a block is supported</td>
</tr>
</tbody>
</table>