**Safety in Mines Research Advisory Committee**

**Final Project Report**

# 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 b 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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# Glossary of abbreviations and symbols

## Abbreviations

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

## Symbols

| | |
|---|---|
| $J_r$ | Joint roughness number |
| $J_a$ | Joint alteration number |
| $s_n$ | Normal stress |
| $t$ | Shear strength of the joint |
| $JRC$ | Joint roughness coefficient |
| $f_r$ | Residual friction angle for weathered joints |
| $f_b$ | Basic friction angle for unweathered joints |
| $JCS$ | Unconfined compression strength of joint surface |
| $r$ | 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 |
| $j$ | Friction angle of bedding plane interface |
| $f$ | Friction angle of extension and shear fracture interface |

| | |
|---|---|
| $a$ | Angle of extension fracture (measured from h/wall skin) |
| $b$ | 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 |
| $s\ (x)$ | Zone of influence profile in two dimensions |
| $s\ (x,y)$ | 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 |
| $s_h^{crit}$ | Minimum stress |
| $\Omega$ | Scaling parameter |
| $d$ | Distance from the edge of the support to the fracture |
| $f$ | Fracture spacing |
| $z_x^-$ | 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 |
| $s_x$ | Magnitude of compressive horizontal stress in the hangingwall |
| $m$ | 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) |
| $DL$ | Closure acting on support unit |
| $e$ | support strain |
| $C_p$ | P-wave velocity |
| $C_s$ | S-wave velocity |
| $V_n$ | Input normal velocity |
| $V_n$ | Input shear velocity |

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