

8 Review of principal findings and recommendations for further work

Rockfalls and rockbursts continue to account for the single largest cause contributing towards the toll of injuries and fatalities suffered by the workforce during deep-level mining operations. Of the 1800 rock-related fatalities recorded since 1990, approximately 56 % occurred in the stope face area and the majority of these occurred in the immediate face area (between the face and first line of permanent support). Face area and temporary stope support is installed to reduce the hazards associated with cleaning and drilling in the immediate face area. In many instances, however, the face area and temporary support is inadequate to carry the imposed loads, yield progressively during dynamic (rockburst) loading conditions, and/or provide sufficient areal coverage.

The objective of this project is to gain further insights into the performance requirements of support systems in the immediate face area. A support design methodology is developed, resulting in improved and optimised temporary support, which will ultimately lead to a reduction in rock related accidents.

Six enabling outputs were defined to reach this objective:

- 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.

The six enabling outputs, as well as their associated principal findings, conclusions and recommendations for further work, are reviewed in Sections 8.1 to 8.6.

8.1 Review of current face area support practice and systems

8.1.1 Summary

A literature review is conducted to determine current face area support practices and systems. The review covers immediate face area support requirements, specifically in terms of support resistance and energy absorption criteria for rockfall and rockburst conditions, respectively. Face area support is classified according to external support systems (timber, mechanical, and hydraulic props) and internal support systems (continuous mechanically coupled, continuous friction coupled, and discrete mechanically and friction couple tendons). An overview of temporary and face area support systems considers (i) design criteria, (ii) factors influencing choice of support system, (iii) types of support, (iv) support spacing and areal coverage, and (v) installation and removal.

Numerous mine visits were conducted to investigate the current application of support systems (with specific reference to rockbolting) in the immediate face area. The mines investigated were Evander, Western Platinum, Vaal Reefs, Randfontein Estates, Beatrix, East Driefontein, West Driefontein, Kloof, Elandsrand, Libanon, Western Deeps South (now Mponeng), Rustenburg Platinum, H.J. Joel, and Bambanani Mine. The mine visits give valuable insights into current support practices and operational aspects thereof.

The performance of current face area support systems in high stoping widths is reviewed. Specific attention is given to the performance of hydraulic props, mechanical props, and elongates. Correction factors to downgrade the performance characteristics of support units (taking into account the increased potential for buckling failure) are reviewed and further developed, based on established column buckling theories.

Finally, the yieldability of current face area support systems is investigated. The force versus deformation behaviour of the most commonly used elongates (see Appendix 2), mechanical props, and tendons are reviewed. These performance curves are used in subsequent chapters to assess the suitability of specific support types for rockfall and rockburst conditions, and estimate suitable spacing thereof.

8.1.2 Principal findings and conclusions

The principal findings reviewed here pertain to tendon practices and issues. These findings are based on the various mine visits and discussions with rock engineers, who had first-hand experience with tendon usage in the stope face vicinity.

Loading conditions

Tendons are currently used under quasi-static conditions. There is no application of tendons in a stope, where loading conditions are predominantly dynamic (i.e. high levels of seismicity). The main reasons given for this are:

- i) difficulty in drilling in highly fractured rock,
- ii) poor anchorage or loss of grout in fractured rock,
- iii) insufficient areal coverage,
- iv) poor yieldability and resistance to shear deformation.

Depth of mining

Apart from Kloof Gold Mine, where a special tendon was successfully applied at a depth of about 2700 m, tendons are currently used at a depth range down to about 1600 m below surface. At these depths, the influence of stress fracturing is comparatively low.

Strength of hangingwall

Tendons are currently used in situations where the UCS of the hangingwall rock is in excess of 170 MPa. This is probably due to the type of tendon mostly used (expansion shell rockbolt). At $UCS < 170$ MPa the rock can be crushed by the anchoring device and slippage can compromise the effectiveness of the tendon.

Stoping width

Apart from Western Platinum mines, where tendons are successfully used in a stoping width of 0,9 m, most mines are only able to use tendons when the stoping width is generally greater than 1 m. A modification to the drill machine used and a change to cable-bolts could permit the use of rockbolts in narrow stoping widths. For instance, at the No. 10 shaft of Vaal Reefs, rockbolts are not be used at stoping widths less than 1,8 m although strata conditions are suitable for rockbolting. This is due to the design of the drill rigs employed for the installation of rockbolts.

Hangingwall parting

The current use of rockbolts is based primarily on the presence of at least one pronounced hangingwall parting at a reasonable distance (0,2 to 3 m) from the reef-hangingwall contact.

Tendons are applied to clamp these partings and suspend the lower strata from the competent rock above the parting.

Type of tendon

Expansion shell rockbolts are the most widely used rockbolt type in the stope face area. This is due to fact that they can be tensioned on installation to generate initial forces (10 – 20 kN).

Installation distance from the face

The distance at which tendons are installed from the face varied from one mine to the other and ranges from 0 m to 3,5 m before the blast. The reasons for the variability in distances include the type(s) of face area support(s) used and installation cycle, sensitivity of installation to blast and whether or not grouting is used. In those mines where the practice is to install tendons as close as possible to the face, other temporary support systems (e.g. mechanical props) are employed to complement the tendons. The additional temporary support units offer protection to the machine operators while they drill and install the tendons.

Tensioning

Loosening of rockbolt anchors from the walls of the borehole after the blast appears to be a major problem in most of the mines. This is due to the current tensioning method, which is done manually with a simple tool such as a spanner. Comparatively low forces of 10 - 20 kN are generated with this method and therefore after the blast, they have to be re-tensioned. It should be noted that, if multiple bolts lose their grip after the blast, the potential for a beam failure is high, especially if there are no other in-stope support units. Also pose a safety hazard in the stope, as workers may unintentionally strike themselves against them. It is highly recommended that a torque wrench be used for tensioning rockbolts and to ensure optimum pre-tension forces, thereby minimising the potential for rockbolt dislodging during blasting.

Another reason for the loss of rockbolt grip against the walls of the borehole after a blast is incorrect borehole diameter or incorrect installation angle. Also, the proper installation of tendons is compromised under steep-dipping stope conditions due to the practical difficulty of drilling holes upwards in stopes.

Other problems associated with the use of tendons in stopes

The correct angle of possible installation, quality control and sensitivity of installation practice, and susceptibility of tendons to blasting has been mentioned above to affect the performance of tendons. The following are other perceived problems associated with tendons in the stope face area:

- Length of possible installation (undulating parting planes make an accurate estimate of required tendon length difficult).
- Worker perception (cannot see action of tendons externally as compared to units like poles, props, etc.).
- Localisation of failure (tendon action creates fracturing of thin rock slabs around base plate).
- Poor areal coverage.
- Questionable reliability under dynamic loading conditions.

In spite of the above problems, rockbolts, as they are being used currently, can be more successful under rockfall conditions if attention can be given to their installation, tensioning and spacing. The benefits of rockbolting are numerous. These include ease of integration with other support types, low mass, minimal congestion at the immediate stope face area, ease of cleaning of the face and reduced risk of rockfalls in the face area during cleaning.

8.1.3 Recommendations for further work

For further assessment of the suitability of tendon support in the face area it is recommended that field trials be conducted, using different tendon types, in various geotechnical areas.

Currently comparatively little information is available on the tendon performance during dynamic loading, i.e. under seismic conditions.

8.2 Identification of strata conditions which are most suitable for particular face area support systems.

8.2.1 Summary

The objective of enabling output 2 is the identification and classification of strata conditions and the determination of the most suitable temporary support systems for particular strata conditions. The term “strata” condition is defined as the hangingwall rock mass condition (manifested by the degree and orientation of discontinuity) and its integrity when considering the impact on choice of temporary support.

Mining environments and conditions are classed as (i) shallow and (ii) intermediate/deep using various criteria. Strata conditions for each of the environments are divided into various classes based on various combinations of parameters which contribute to hanging wall instability. The parameters used in the classification are: rock type, UCS, reef parallel structures, reef perpendicular structures and mining induced fracturing. A classification scheme into categories of hanging wall conditions is used rather than an index based scheme as the former is designed specifically with the objective of grouping conditions into categories suitable for certain types of support. An index scheme necessitates high and low values implying good and poor conditions which is not the purpose of this work. Support types are assigned to the various classes of strata conditions after consideration of stoping width and mode of rockfall or rockburst failure.

In addition, a review of possible alternative support technologies is given. The advantages and disadvantages of 11 alternative support system types are discussed, namely:

- 1) twin beam support system,
- 2) powered support for hard rock mining,
- 3) membrane support (Evermine),
- 4) mesh support for stopes,
- 5) strapping between tendon support,
- 6) large headboards and base plates,
- 7) safety nets,
- 8) Fortrac Geogrids,
- 9) modified stope support system using hydraulic props,
- 10) rock tendon support, and
- 11) inflatable supports.

8.2.2 Principal findings and conclusions

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 considered appropriate taking into account available and proven technology. In particular, the application of complete areal coverage in conditions of weak and complexly fractured hangingwall is strongly suggested. Further details of specific support systems suitable for various rock classes are given in Table 8.2.1 and Table 8.2.2 for shallow and intermediate/deep mining environments, respectively.

The hangingwall rock mass typically has a complex, variable nature resulting in varying degrees of discontinuity and hence changes in strata conditions. The experience and knowledge of rock

mechanics practitioners is an important and essential input in determining the nature of the parameters influencing local strata conditions and in the definition of ground control districts.

The investigation into alternative support technologies has shown that systems such as the twin beam support system, the safety net, large headboards and possibly membrane support types are potentially suitable and practical to reduce the rock related hazard at the stope face. However further development and evaluation involving field trials are required before they can be recommended for certain classes of hanging wall conditions. Other technologies (e.g. powered support, shields) theoretically have the potential to significantly increase worker safety, however at this stage the practicality of their application in a narrow, tabular hard rock stoping environment is questionable and would require further research endeavours. The foresight shown by SIMRAC in further pursuing this avenue of research is commendable.

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

CLASS	1	2	3	4
ROCK MASS	WEAK	WEAK	WEAK	WEAK
REEF PARALLEL STRUCTURE	PROBLEMATIC	PROBLEMATIC	NON-PROBLEMATIC	NON-PROBLEMATIC
REEF PERPENDICULAR STRUCTURE	PROBLEMATIC	NON-PROBLEMATIC	PROBLEMATIC	NON-PROBLEMATIC
S.W.: < 1,8 m	2 + 8 (7)	2 + 6 + 10	2 + 7 (6)	1 (2)
> 1,8 m	2 + 8 (7)	2 + 10	2 + 11 (6)	1 (13) (11)

CLASS	5	6	7	8
ROCK MASS	STRONG	STRONG	STRONG	STRONG
REEF PARALLEL STRUCTURE	PROBLEMATIC	PROBLEMATIC	NON-PROBLEMATIC	NON-PROBLEMATIC
REEF PERPENDICULAR STRUCTURE	PROBLEMATIC	NON-PROBLEMATIC	PROBLEMATIC	NON-PROBLEMATIC
S.W.: > 1,8 m	1 + 7 (10)	2 + 9	2 + 6	1
< 1,8 m	2 + 7 (11)	1 + 12	1 + 11	1 (12)

SUPPORT TYPES			
STIFF (eg Mechanical props, Timber sprags)	1	AERIAL SUPPORT (eg Net, Evermine)	8
STIFF - P/S (eg Yieldable camlock prop)	2	CABLE - NON-GROUTED (eg Cablebolt, Conebolt)	9
PS Elongate (eg Ebenhaesser)	3	CABLE - GROUTED (eg Cement grouted cablebolt, Conebolt)	10
Rapid Yield Hydraulic Prop	4	BAR - GROUTED (eg Cement grouted expansion shell, Cablebolt)	11
HEADBOARDS - NON DIRECTIONAL (eg Pots)	5	BAR - NON- GROUTED (eg Expansion shell)	12
HEADBOARDS - DIRECTIONAL	6	CONTINUOUSLY FRICTION COUPLED TENDONS (eg Split sets)	13
HEADBOARDS - (WIDE)	7	RESIN GROUTED CYLINDRICAL TUBES	14

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

CLASS	1	2	3	4	5	6	7	8
ROCK MASS	WEAK	WEAK	WEAK	WEAK	WEAK	WEAK	WEAK	WEAK
M.I. FRACTURE (DIP)	>50°	>50°	>50°	>50°	<50°	<50°	<50°	<50°
REEF PERPENDICULAR STRUCT.	PROB.	PROB.	NON-PROB.	NON-PROB.	PROB.	PROB.	NON-PROB.	NON-PROB.
REEF PARALLEL STRUCT.	PROB.	NON-PROB.	NON-PROB.	PROB.	PROB.	NON-PROB.	NON-PROB.	PROB.
ROCKBURST: < 1,8 m	3(4) + 8	3 + 7(6)	3 + 7	3(4) + 7	4 + 6(7) + 8	4 + 6(7)(8)	3(4) + 7	4(3) + 7(6)
> 1,8 m	2(1) + 14(8)	2(1) + 7	1(2) + 7	1(3) + 7	2(1) + 14(8)	1(2) + 6(7)(8)	1(2) + 7	1(2) + 7(6)
ROCKFALLS: < 1,8 m	3(4) + 8	2(1) + 7	3(2) + 7(6)	3 + 7	3(4) + 6 + 8	3(2) + 6(7)(8)	3 + 7	2(3) + 6(7)
> 1,8 m	2(1) + 14(8)	1 + 7(6)	1(2) + 7	1 + 7	1(2) + 14(8)	1(2) + 6(7)(8)	1(2) + 7	1(2) + 7

CLASS	9	10	11	12	13	14	15	16
ROCK MASS	STRONG	STRONG	STRONG	STRONG	STRONG	STRONG	STRONG	STRONG
M.I. FRACTURE (DIP)	>50°	>50°	>50°	>50°	<50°	<50°	<50°	<50°
REEF PERPENDICULAR STRUCT.	PROB.	PROB.	NON-PROB.	NON-PROB.	PROB.	PROB.	NON-PROB.	NON-PROB.
REEF PARALLEL STRUCT.	PROB.	NON-PROB.	NON-PROB.	PROB.	PROB.	NON-PROB.	NON-PROB.	PROB.
ROCKBURST: < 1,8 m	3(4)+8	4 + 6	3(4)	4(3) + 5(6)	4 + 8 + 6	4 + 6 + 8	3(4) + 6	3 + 6
> 1,8 m	1(2)+8(10)	1(2) + 6	2(1)	2(1) + 9	3(2) + 6	2(3) + 6 + 9(6)	2(3) + 10	3 + 9
ROCKFALLS: < 1,8 m	2(3)+8	1 + 6	1	2 + 5	1 + 8 + 6	3(4) + 6	2 + 6	2 + 6
> 1,8 m	1(2)+8(10)	1 + 6	1	2 + 12 + 9	1 + 8 + 10	2 + 6 + 12	2 + 12	3 + 12

SUPPORT TYPES			
STIFF (eg Mechanical props, Timber sprags)	1	AERIAL SUPPORT (eg Net, Evermine)	8
STIFF - P/S (eg Yieldable camlock prop)	2	CABLE - NON-GROUTED (eg Cablebolt, Conebolt)	9
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HEADBOARDS - (WIDE)	7	RESIN GROUTED CYLINDRICAL TUBES	14

8.2.3 Recommendations for further work

It is emphasised that the tables indicating classes of strata conditions and corresponding suitable support types (i.e. Table 8.2.1 and Table 8.2.2) are 'working documents', i.e. they should continuously be modified, updated and optimised. It is recommended that the tables be widely distributed throughout the gold and platinum mining industry and used as a reference tool to optimise face area support.

8.3 Identification of hangingwall deformation mechanisms and their impact on tendon performance requirements

8.3.1 Summary

This section focuses on hangingwall deformation mechanisms and their influence thereof on tendon support in the immediate stope face area. Hangingwall deformation mechanisms are investigated on a macro scale (i.e. considering the interaction between adjacent tendons and the stability of the complete hangingwall), as well as on a reduced scale (focussing on the interaction of tendons with individual blocks of rock).

The tributary area theory is applied and practical results are gained regarding the spacing requirements of various tendon types in rockfall and rockburst conditions. The tendon spacing implications on rock mass stability are further investigated by making use of previous SIMRAC work dealing with zones of support influence.

Numerical models are used to investigate the influence of various rock mass, support and stress wave parameters on the stability of the rock mass under dynamic loading conditions.

Finally, an engineering approach to the design of stope face support systems in tabular stopes is given. This approach is applicable to tendon, prop and pack type support systems, and is based on a set of seven graphs, which facilitate the design of support systems under various loading and geotechnical conditions.

8.3.2 Principal findings and conclusions

In general, three types of rockbolt interaction mechanisms can be identified, namely:

- *suspension* of unstable rock mass volume,
- *beam building* within unstable rock mass volume, and
- *cantilever* within unstable rock mass volume.

These mechanisms need to be considered in the tendon design process, which comprises the following main components:

1. Estimate the depth of rock mass instability and loading conditions (quasi static / dynamic).
2. Determine the mechanism of rock mass stabilisation by the appropriate reinforcement and support scheme (suspension, beam building, or cantilever).

3. Estimate the potential for rock mass instability between the tendon reinforcement.

Numerical models indicate that the critical issue for the stability of the reinforced hangingwall is the angle of rockbolt installation in relation to the structure of the rock mass (as reflected by the angle of fracturing relative to the horizontal). The fracture angle could thus represent a potential geotechnical control on the applicability of rockbolting for the stope area stability. The inclination of the rockbolt reinforcement influences both the depth of rock mass reinforcement and the mechanism of interaction between the rockbolt and the rock mass. A further important parameter is the depth of rock mass reinforcement.

Design charts are given to estimate the maximum tributary area of various tendon types as a function of different bedding thickness. The design charts are based on the force versus deformation characteristics of various tendon types (under axial loading) and are given in Figures 8.3.1 and 8.3.2 for rockfall and rockburst conditions, respectively. Note that for this analysis it is assumed that the tendons are anchored beyond the potentially unstable zone into the more competent overlying rock mass. Furthermore, if yielding tendons are used (e.g. cone bolt), the required yield length must lie above the potentially unstable zone. From Figure 8.3.2 it is evident that for rockburst conditions the tributary area is significantly reduced, and for practical purposes tendon usage at this stage is limited to the Conebolt or, in the case of thin bedding, the Flexirope.

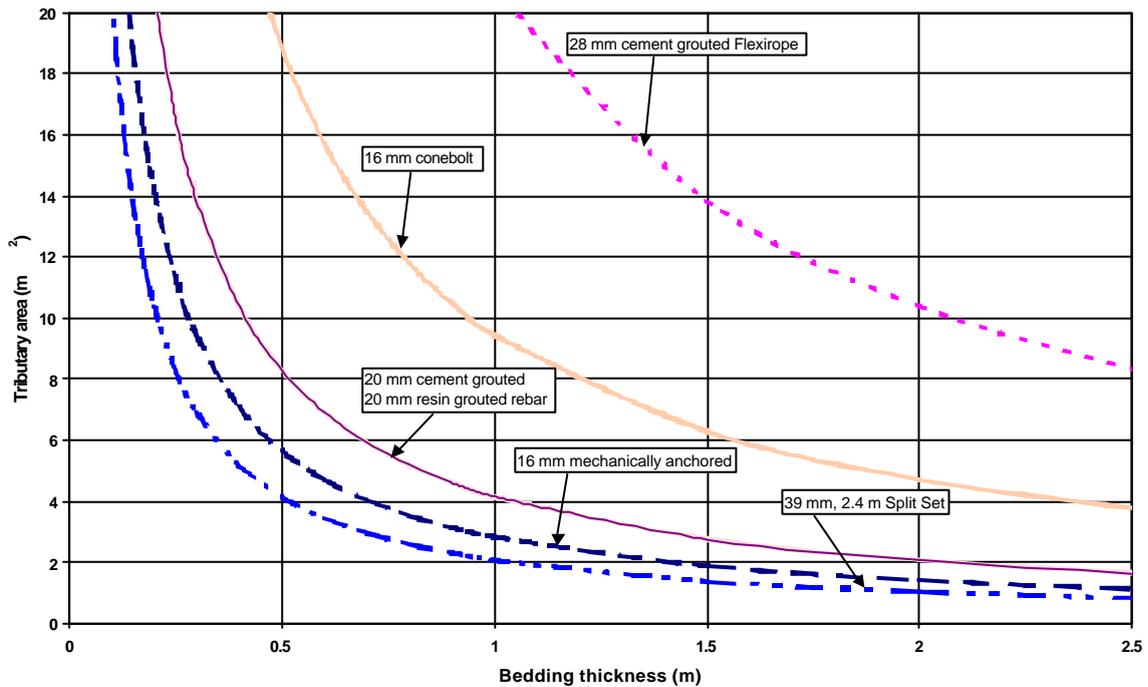


Figure 8.3.1 Maximum allowable tributary area as a function of different bedding thickness and peak load of tendons (rockfall conditions).

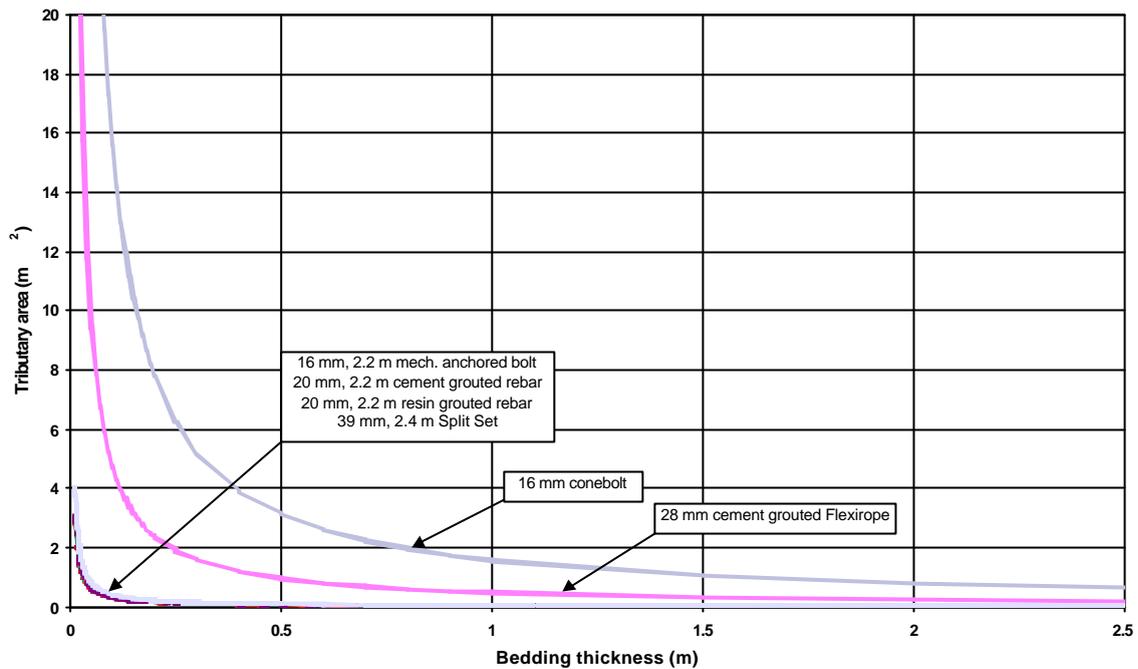


Figure 8.3.2 Maximum allowable tributary area for a block ejected at a velocity of 3 m/s. The support spacing is a function of the bedding thickness and energy absorption capabilities of the tendons (rockburst conditions).

The zones of support influence of tendons are found to closely correspond to those of props and packs. Hence, the work conducted in SIMRAC project GAP627 is applicable and the results and mathematical formulation of zones of support influence can be used for tendons, props and packs.

The proposed engineering approach for the design of stope face support systems is a convenient method to estimate support resistance, energy absorption and spacing requirements of support units. The method caters for both hangingwalls discretised by face-parallel mining induced fractures and blocky hangingwalls. A support design example is given to illustrate the application of the design methodology.

8.3.3 Recommendations for further work

It is recommended that the support design methods developed here be incorporated in a program such as SDA II for use in the gold and platinum mining industry.

8.4 Identification of operational constraints applicable to face area support systems

8.4.1 Summary

Consultations with production personnel, rock engineers, and personnel in safety departments were held and underground visits were made to gold and platinum mines to identify the operational constraints with respect to temporary support practices. The effect of these on three operational activities, (i) drilling and charging, (ii) blasting, and (iii) cleaning, are considered.

Solutions to overcome the operational constraints applicable to temporary and face area support systems are proposed.

8.4.2 Principal findings and conclusions

The principal findings of the operational constraints are reviewed according to the type of operational activity:

Drilling and charging

- Labour availability: Due to the current bonus system adopted by most mines, emphasis is placed on high face advance rates. This could be at the expense of quality support installation (particularly with respect to spacing, footwall preparation and correct angle of installation).
- Time constraints: In some cases insufficient time is available for a panel to be cleaned, supported, drilled and charged within the specified mining cycle. Therefore, temporary support is often installed concurrently with drilling to ensure that the drilling and charging operations are completed before the end of the shift. The consequence of this is that some operations, such as marking of the face and charging-up, are done under an unsupported roof and, if used, the few mobile units are prone to failure in case of rockfall or rockburst situations.
- Availability of support units: The availability of sufficient numbers of support units is vital for the proper spacing of support units in the immediate face area. It was revealed during the underground visits that shortage of support units is not uncommon and in such instances insufficient support is installed as a result.
- Transport and storage: Inadequate material transport routes and frequent mono-winch breakdowns (or absence thereof) affect the delivery of support units to the stope face and subsequently, the quality of support installed in the immediate stope face area. Storage facilities for temporary support units, especially in backfilled stopes, has been found to be inadequate.
- Stope width: Handling of heavy support units is difficult in narrow stoping width conditions (< 1 m). Worker movement is restricted and the ease and accuracy with which support units are installed is reduced. The use of tendons in the immediate face area in most mines has been limited by stoping widths less than 1,2 m (example Vaal Reefs, Beatrix Mine, etc.). In very high stoping width situations, the practical use of hydraulic props is limited by their weight, as handling is difficult and individual props become a safety hazard by toppling before installation. The blast out rate and buckling potential is also high.
- Dip of reef: As the dip of reef increases, so does the difficulty in handling and installing support. In flat dipping stopes, the transportation of support units to the stope face becomes difficult and this is exacerbated if the stoping width is narrow as well. As a consequence of transportation difficulties, more time is spent moving support units and consequently less time is available to install sufficient number of support units.
- Effect of mine geometry: The shape of mining excavations can have an adverse effect on rock conditions. Out of shape stope faces produce additional unfavourably oriented stress fractures, which further add to the burden of the support.
- Position of marked shot holes: A reduction in support spacing in the immediate face area creates interference with other activities, particularly drilling. In practice, occasions do arise when either the support will have to be moved to a position where it does not interfere with the drilling process, or, alternatively, the drilling process will be compromised either by changing the drill angle or shifting the collaring position. This problem is reduced by offsetting rows of support such that the support units are aligned parallel to the drilling direction.

Blasting

- Blast damage: Face area support systems are prone to be blasted-out as well as damaged by the blast. It is hence essential that the direction of shot holes and the charging process are according to standard.
- Blast-induced fracturing: Incorrectly drilled shot holes and over-charging could alter the stoping width and induce intense blast induced fracturing in the hangingwall, which would negatively affect the placement of temporary support in the subsequent shift.

Cleaning

- Scraper damage: Depending on the straightness of the face, the scraper scoop or rope can damage and/or dislodge face area support units.
- Inadequate cleaning: Broken rock left lying on the footwall also interferes with support installation, as it creates a cushion between the rock surface and the support.
- The practice of scraping sweepings and fly rock behind the face area often has a detrimental effect on support design in as much as the strike spacing, which usually should be smaller than the dip, has to be increased to accommodate the width of the scraper.

Solutions proposed to overcome the operational constraints include:

- Modified bonus systems.
- Improved panel and stope layout planning, bearing in mind the workload and number of people allocated to each panel. Consider a small “floating gang” to assist where necessary.
- Modified production cycle.
- Emphasis on optimising mono-winch routes.
- Improved storage facilities in stopes.
- Sufficient supply of support units in the working area.
- Tight control over stoping width.
- Use of pre-stressable units such as hydraulic, mechanical or elongate units (particularly in steeply dipping reefs) to provide active support and reduce blast out.
- Offset rows of support to align with drilling direction.
- Application of optimum blasting techniques and accessories.
- Increased use of tendons particularly to improve support during cleaning, making safe and charging up operations.
- Selection of scraper size to match the optimum strike spacing of support units or blast barricades with water jet cleaning.
- Improved and more frequent training of supervisors and miners (hazard identification, basic strata control, support practices, blasting practices).
- Good ventilation to provide a working environment conducive to high standards of work performance and productivity.

8.4.3 Recommendations for further work

It is recommended that the findings of this section be widely communicated to the mining industry and, if necessary, the codes of practice should be modified to include some of the improved supporting practices. The authors are of the opinion that significant scope exists to improve worker safety by adhering to some of the fundamental issues investigated here.

8.5 Identification of periods in the production cycle when face area support systems are least able to meet their performance requirements

8.5.1 Summary

Large unsupported spans are typical of certain cycle activities associated with stoping operations in the immediate face area. The production cycle is defined together with the associated activities. Based on underground visits and discussions with relevant personnel, an attempt is made to quantify the unsupported spans during various periods of the production cycle. A two-dimensional support design tool (SDA II, CSIR, 1999) is used to determine the effect on stability of these increased unsupported spans during the identified periods for varying strata conditions.

8.5.2 Principal findings and conclusions

The principal findings are as follows:

- Increasing support distance from the face results in an increase in the likelihood of hangingwall failure under both rockfall and rockburst conditions.
- The extent of the face area likely to fail is a direct function of the type of installed support, the distance of the last line of support from the face and the spacing thereof.
- The shift which enters the panel after the blast is most vulnerable. The situation is exacerbated when removable temporary support units are used. The removable face support system protects personnel during drilling and charging-up activities; this support system is, however, not present during barring and cleaning of the stope face and on occasion during charging up. These comments apply equally to the mine pole face support systems, as many of these support units are dislodged by the blast.
- The choice of support (both temporary and permanent) with the appropriate load deformation behaviour will greatly impact on the extent of failure in the stope face area.
- The use of stiffer, non-removable blast-on face area support units with adequate support resistance capabilities is recommended, although it may not be able to completely eliminate the likelihood of failure in the stope face during all shifts. Under rockburst conditions, the ability for the support units to yield in a controlled manner without failing is important.

8.5.3 Recommendations for further work

To improve worker safety, the unsupported spans (particularly immediately after the blast) between the first line of support and the face need to be significantly reduced. It is

recommended to conduct further work into alternative support systems offering high levels of areal coverage, particularly for the crew entering the stope after the blast. These support systems should be able to be rapidly and conveniently installed, preferably remotely and before the production crew enters the stope.

8.6 Development of a methodology to determine the requirements of face area support systems for various situations

8.6.1 Summary

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.

8.6.2 Principal findings and conclusions

The principal findings of the probabilistic analyses to quantify support requirements in the immediate vicinity of the stope face are as follows:

- For rock burst conditions the probabilities of hanging and footwall failure are somewhat higher than for the support.
- The probability of support failure due to loading from the hangingwall is slightly higher than for loading from the footwall.
- The probability of diagonal tensile failure of the hanging and footwall predominates the overall probability of failure.
- The probability of diagonal tensile failure of the hanging and footwall is sensitive to a critical dip angle for discontinuities dipping into the face.
- The probability of diagonal tensile failure of the hanging and footwall is also sensitive to a critical spacing for the diagonal tensile reinforcement.
- The probability of diagonal tensile failure of the hanging and footwall is not sensitive to the capacity of the diagonal tensile reinforcement, but more to the presence of such reinforcement or not.
- The probability of compression failure of the support exceeds that of rotational failure.
- The probability of failure of yielding support is governed by deformation and not load.
- The probability of failure of non-yielding support is governed by load and not deformation.
- At between 10 and 20 per cent, the absolute magnitudes of the probabilities of failure are comparatively high.

8.6.3 Recommendations for further work

Further work is recommended with regard to geotechnical parameters, seismic parameters, mining parameters, support installation statistics, support properties, operational statistics, refinement of the methodology and application of the methodology. The parameters that are required in applications of the methodology cannot be obtained in every instance by measurement or testing, but should rather be available from standard data bases for particular classes of application or should be obtained from standard classifications. Standard qualitative descriptions of the ranges of parameter values that may be obtained in this way are accordingly given.

The methodology may be refined with regard to a number of aspects including confirmation of the probabilities of ejection freedom, determination of its sensitivity to the various mechanisms of deformation, non-symmetrical adjoining spans, inequalities in adjoining supports and stability of the face as support. Application of the methodology may be promoted by providing systematic training throughout the industry.