



An effective face support system to minimize rockfalls

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Synopsis

An effective prototype face support system to minimize rockfalls in rockfall-prone mines was developed and patented during a project sponsored by the Mine Health and Safety Council (MHSC). An experimental development model (XDM) roof support unit was developed and evaluated. Mines with rockfall problems in the face areas can use the roof support system to reduce fatalities and injuries in the face area of stopes.

The roof support system consists of two similar support units connected to each other via two crank mechanisms. Each unit consists of a headboard supported by a 'wishbone' structure (top and bottom leg). In the first design a threaded bar with struts similar to a scissors jack keeps the legs apart. (In the final version that was field trialed, the threaded bar mechanism was replaced with a hydraulic cylinder). All the components are manufactured from steel. To move the system forward the first support unit is collapsed, the second remaining in the loaded position. The first unit then hangs from the second unit to which it is connected. The first collapsed unit is then manually cranked forward and prestressed. If the required position is still not achieved, the other unit is released and moved forward.

The specification for the system was determined and presented at a workshop with industry participants. Different concepts were developed and evaluated against the system specifications. A technology demonstrator was then developed and tested on surface. The technology demonstrator development process included detail design, building and testing of components and subsystems, design reviews and the building and commissioning of the technology demonstrator. The testing of the technology demonstrator was done in a 500-ton hydraulic press, in a mock-up stope and underground. A risk analysis, in which technical, logistical and economic aspects were assessed, was done to determine the critical areas of the system.

During the next phase of the project working prototypes were developed for underground tests and evaluation. This process indicated that it was necessary to adjust the system specifications and a redesign was called for. In an iterative process test units were built for purposes of evaluation, specification verification and field trialing. After the successful conclusion of the trials the equipping of a complete production stope started for purposes of integrating the system into the current mining process.

Introduction

Rockfalls continue to be the biggest cause of accidents that result in fatalities and injuries in underground mines in South Africa. The latest statistics according to Adams¹ have shown

that there has been a decrease in the number of rockfall occurrences resulting in lost man hours.

The number of rockfalls can be reduced further if affordable new technology for supporting the hangingwall can be developed. The statistics from the Department of Minerals and Energy reveal that the rockfall hazard has not been effectively addressed during the last ten years, as injury rates have remained almost constant. The cost of rockfall injuries must far outweigh the cost of an effective rockfall prevention measure. The most effective routes to rockfall control include:

- Good blasting practice
- Effective making safe procedures
- Vigilance and safety consciousness of employees
- Effective rockfall support systems
- Compliance with support standards and Code of Practice.

The current research addresses rockfall support systems although this is not the only means to reduce rockfalls. There is often a large space between the face and the first line of support, resulting in numerous fatalities and injuries in the area in front of the last line of support.

Specification

The design specifications for the new support system were compiled using previous work by Roberts *et al.*² and Burger *et al.*³ involving role players from industry and MHSC representatives. These specifications are expressed per

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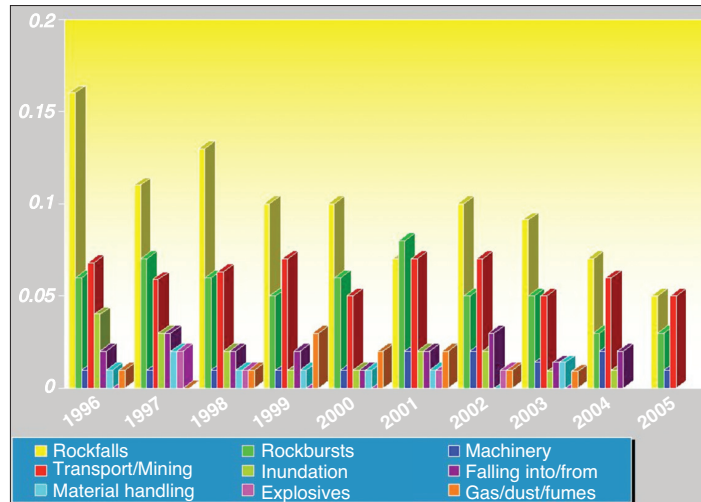


Figure 1—Fatality rate in all South African mines¹

support subsystem, so that the proper objectives are set for the design process. Some of the qualitative data, such as 'safe to operate', 'ease of assembly', etc. are omitted from the specifications, but not ignored. The quantitative specifications are based on industry-accepted standards, and consensus on issues such as stope roll rate and maximum operating dip. Table I summarizes the design specifications.

Concept

Different concepts were generated and evaluated against the system specifications and performance criteria. During the concept evaluation the concept based on the scissors jack was selected but during trials this proved to be impractical in use and manufacture. The system was changed to use a hydraulic cylinder to provide the required vertical force. The hydraulic cylinder is activated using hydropower or intensifier pumps used for prestressing devices. The structure of the selected concept initially (Figure 2) consists of a headboard (A), two main beams (top and bottom leg) (B) connected by a hinge (C) and two loading arms (D). The members of the structure are connected via a threaded rod (E) as used in a scissors jack. The headboard connected to the top leg is to provide areal coverage to protect the workforce. The system is pre-loaded by turning the threaded rod. It is envisaged that the loading will be done with a handheld pneumatic torque wrench or any other mechanical means capable of generating the required torque.

In the revised design (See Figure 4) the structure still consists of the headboard (A), top and bottom legs (B and C) connected by the hinge (D) but now incorporates a hydraulic cylinder (E). In this system preloading is achieved by using the prestressing or hydropower pump to activate the cylinder.

Two support units are connected via a crank mechanism (F, Figure 2) to form the support system. The two units are connected at the hinge between the top and bottom leg at C and the hinge between the headboard and the top leg, forming a parallelogram. The cranks have an eccentricity of 150 mm, which results in an incremental movement of maximum 300 mm per step. Figure 2 shows the support system with two units connected. In Figure 3 the movement

of one unit during a single forward step is shown in a sequence of sketches. The forward movement of the system remained unchanged during the development process and is as follows:

- To move the support forward, unscrewing the threaded rod retracts the legs of one unit. In the current format the pressure in the cylinder is released and a set of springs retracts the leg. Figure 3A
- The unloaded unit then hangs via the cranks from the adjacent preloaded unit which remains preloaded in position. See Figure 3B
- The unit is then manually cranked forward before being preloaded, achieving an advance of 300 mm. See Figure 3C.

The process is repeated a number of times depending on the advance required as a single step results in an advance of 300 mm.

Detail design

The system configuration and layout was designed making use of solid modelling as well as dynamic modelling. The solid modelling package Solid Works® was used to determine the relative sizes of the different linkages and the movement of the system. The relative movement of the different components was modelled using the dynamic modelling package Visual Nastran Desktop 4D.

The detail design of the structural elements of the system was carried out using finite element analysis. The finite element models were constructed in MSC Patran and analysed using MSC Marc. The support was designed for a worst vertical load case of 10 ton with a safety factor of 3 for determining the size of the various components. To analyse the stability of the system the two loadings arms (D in Figure 2) was verified for buckling. The simulations were done for the minimum stopping height of 900 mm and the maximum stopping height of 1 200 mm. As expected the highest stresses occur at the minimum stopping height. The free body diagram of the loads and reaction forces acting on the system is shown in Figure 5. Figure 5 shows the Von



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Table 1

Design specifications for rockfall support unit* (as revised after trials at Lonmin)

No.	Parameter	Quantity or quality of support unit
1.	Maximum weight per component	25 kg
2.	Colour	Bright
3.	Corrosion resistance	Yes
4.	Rockfall protection for operator	Constant
5.	Blast-on capability	Yes
6.	Assembly	Simple (as few parts as possible)
7.	Maintenance	Simple (as few parts as possible)
8.	Stoping width range first design extended design	800–1450 mm To be limited by practical design considerations
9.	Maximum loading eccentricity	15 degrees
10.	Maximum uncovered hangingwall between units Breast mining dip strike Up-dip/down-dip mining dip strike	1.2 m 0.7 m 0.7 m 1.2 m
11.	Minimum areal coverage of hangingwall by system when installed	10%
12.	Step time	Maximum 1 minute per step
13.	Steer ability	Support units must be steerable to prevent down-dip drift when advancing on strike
14.	Prevention of simultaneous release	Incorporate device to prevent accidental simultaneous release of units
15.	Maximum dip change rate	10 degrees/metre
16.	Maximum operating dip	45 degrees
17.	Minimum pre-load force (to accommodate blast out) (Strata control handbook)	50 kN/leg
17.1	Yielding cylinder preload: Range: 800–1200 mm (short prop) 1000–1450 mm (long prop)	95 kN ± 5 kN 75 kN ± 5 kN
18.	Resistive force (max. load carried by both legs) (to support a dead weight of 1.5 by 1.5 by 1.1 m block with density 3300 kg/m ³ (Strata control handbook)	80 kN over a 1.5 by 1.5 metre area, which translates to: 36 kN/m ²
19.	Release range	100 mm
20.	Maximum safe stope closure on system without becoming dangerously loaded or damaged	30 mm
21.	Maximum hangingwall contact stress	30 MPa
22.	Maximum footwall contact stress	30 MPa
23.	Minimum advance rate per day	1 m
24.	Bulking factor	1.5 (see Figure 2)
25.	Maximum support distance from face	700 mm (see Figure 1)
26.	Rockfall after headboard release	Must fall away from operator
27.	Blasting barricade	Provision must be made for blast barricade
28.	Total cost per ton mined to buy, operate, and maintain support system	Equal to or less than currently available systems
29.	Integrate ability	Support system must be able to integrate with current support systems and with the mining cycle
30.	Risk of use and integration into existing mining systems	Support system must result in a material reduction of risk in all mining activities when integrated into the stoping cycle
31.	Flexibility	System must be able to provide safe, cost-effective support in a wide variety of geotechnical conditions

*The specifications in the table are given per support unit, which consists of two identical support subsystems coupled together by a bell crank

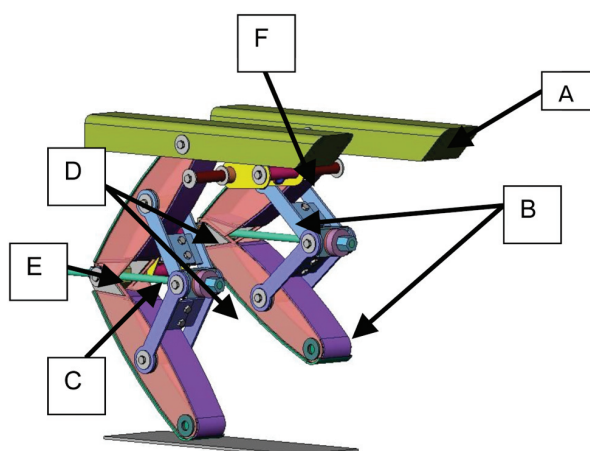
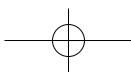


Figure 2—Support system showing two units connected



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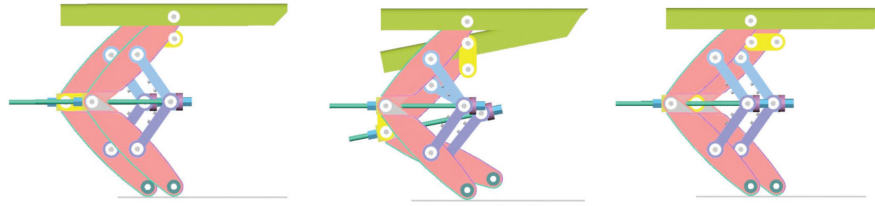


Figure 3—Single step forward movement of system

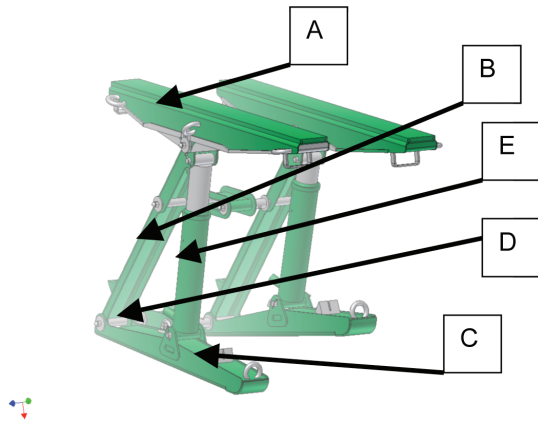


Figure 4—Updated design with hydraulic cylinders

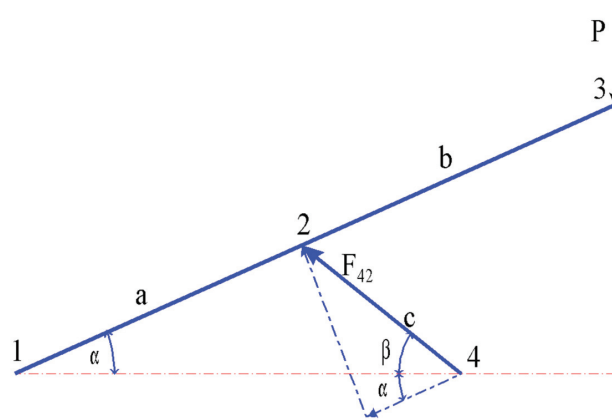


Figure 5—Force diagram of top leg (schematic)

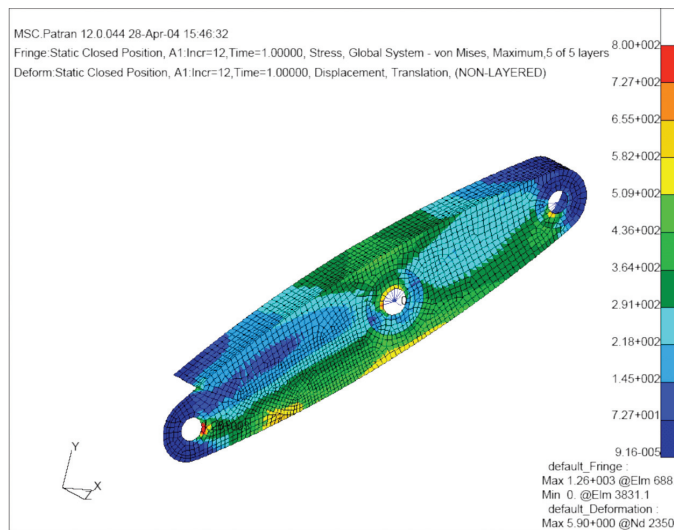


Figure 6—Von Mises stress in beam for minimum stoping height (MPa)

Mises stresses in the beam in the minimum stoping position and Table II summarizes the Finite element results.

An analysis of the forces in the top beam of the support gives the following

$$\begin{aligned} \sum M_1 = 0 & \quad F_{42} = F(a+b)\cos(\alpha)/a*\sin(\alpha+\beta) \\ \sum F_v = 0 & \quad F_{1v} = P - F_{42}\sin(\beta) \\ \sum F_h = 0 & \quad F_{1h} = F_{42}\cos(\beta) \\ & \quad \sin(\alpha) = (h/2)/(a+b) \\ & \quad \sin(\beta) = [a\sin(\alpha)]/c \end{aligned}$$

The beams, links and the headboard are manufactured from Wieldox 700 steel plate, 8 mm thick, with yield strength of 700 MPa and an ultimate strength of 780 MPa. All the pins are manufactured from EN9 with a yield strength of 310 MPa

Load case	Results	Maxima
Maximum stoping height	Von Mises Stress	430 MPa
Minimum stoping height	Von Mises Stress	650 MPa
	Displacement	5.9 mm



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and an ultimate strength of 600MPa. The system was tested in a 500 ton press at Duraset, a Business Unit of AVENG Africa LTD. During the testing of the system (two units, totalling the applied load to 200 kN) strain gauges were bonded to the components and the measurements were used to verify and calibrate the Finite element model.

With lessons learnt during the field trial phase and the subsequent change in specification, the hydraulic version of the product was redesigned according to SANS 10162 with 20% overload factor per component.

The geometry provided for a stoping width from 800 mm to 1200 mm and for 1000 mm to 1450 mm when the cylinder length is adjusted accordingly.

In addition, the first value engineering exercise indicated that a material change to Domex Wear instead of Weldex 700 is advisable.

Technology demonstrator

Two roof support units, forming a single system, with connecting cranks were built and assembled. The walking of the system was commissioned and tested at the test stope of the University of Pretoria. Figure 7 shows the assembled system in the test stope.



Figure 7—Photo of technology demonstrator roof support system in mock-up stope



Figure 8—Photo of technology demonstrator in dedicated jig

Surface testing

Laboratory tests

The technology demonstrator was tested in a purpose-made jig to verify design parameters via telemetry.

Tests in mock-up stope

The 6 m by 6 m mock-up stope of the University of Pretoria with an adjustable stoping height from 0.8 m to 1.8 m was used to test the walking and handling of the roof support system. The stope has undulating foot and hangingwalls as well as fallouts.

The operation and handling of the system was successfully tested and demonstrated in the mock-up stope. The system was advanced and retreated in a number of directions and places in the stope. See Figure 9. Results from the tests show that two workers can move one line of 20 support units forward 1 m in a 30 m panel in approximately 40 minutes.

Underground evaluation

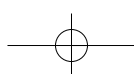
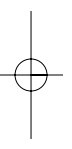
The rockfall support system was successfully evaluated and demonstrated at Newman incline shaft of Eastern Platinum Limited. The system was moved forward a number of times as the face advanced took a number of blasts. Although the system withstood the blasts, a better blasting barricade will improve the durability of the system and make scraping easier. Figures 10 and 11 show the roof support system installed underground after a blast as well as the support of loose rock after a blast. During the demonstrations the moving of the system as well as its steering ability was demonstrated.

Conclusion and recommendations

The technology demonstrator roof support system for rockfall-prone mines was successfully developed and tested on surface as well as underground. The tests and risk assessment of the roof support system as well as a workshop held with industry identified certain areas that need to be addressed in order to implement the new support system safely underground. The further development of the support system focused on the following areas:



Figure 9—A preproduction unit undergoing trials in the stope. Note the prestress device pump in the background



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Figure 10—The original version installed underground after blast. Note the threaded rod sticking out the back



Figure 11—Photo of roof support system supporting loose rock after a blast

- The specification of the system was revised to include the latest findings of face support requirements
- The 10-ton preload requirement is too high and was reduced to 5 ton (maximum fallout height of 1.1 m)
- Improved design taking the results of the tests into account
- Quality control during manufacture
- Correct and safe installation procedures
- Safe operating procedures
- Reduced contact stresses on the footwall
- The threaded rod sticking out at the back was a problem but the hydraulic cylinder removed the problem
- The possibility to do remote loading and release of the system as well as the automation of the system should be investigated at a latter stage.

During the next phase of the project a full working stope will be equipped to prove the integration into the existing mining system. The system will be further developed to integrate with other equipment such as blasting barricades, drill rigs and hydropower.

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