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Testing of temporary face support systems under rockfall conditions

J.L. HUMAN* and N. FERNANDES†
**SRK Consulting, Johannesburg*
†Impala Platinun Limited

The rockfall hazard is the major contributing agency to fatal accidents in South African platinum mining operations. The majority of these accidents occur in close proximity to the working stope face. The collapse of fractured or blocky ground between individual temporary support units or the closest permanent support line to the stope face has not yet been adequately addressed.

A large-scale stope support system testing facility funded by the Safety in Mines Research Advisory Committee (SIMRAC), has been designed and constructed to test support systems and stimulate innovative thinking by mining personnel, support manufacturers and suppliers by providing a facility where the interaction of stope support systems, a rigid stope face and a discontinuous hangingwall beam can be observed during quasi-static and dynamic conditions.

Tests have been carried out on various types of stope support systems, focusing on the temporary support systems used in the immediate stope face area. The interlinking of the temporary support units with mesh or safety netting has been explored in the prevention of falls of ground between support units during gravity driven falls of ground.

These tests illustrate the facility's ability to be used to stimulate innovative thinking and provide a testing ground for the development of temporary support systems in order to reduce the risk of fall of ground injury to mining personnel at the stope face.

Introduction

A stope support system testing facility was initiated and constructed in 1999 through a SIMRAC funded project, GAP 611, at Savuka satellite training centre in the Northwest province of South Africa. This project consisted of four phases, design, construction, a proof test and a brief programme of testing support systems.

The initial drive behind the project was the perception that existing support testing equipment could provide only a quality control function. To stimulate development of innovative types of support and support accessories that would overcome some of the limitations of existing systems required the development and construction of a completely different type of facility. The two most important differences compared with conventional testing procedures would be the provision of a discontinuous roof surface, which would be subjected to dynamic loading (Ortlepp, 2000).

SIMRAC has committed itself to continued funding of the test facility for a period of three years, under the project name SIM 020305.

Project objectives

The initial project objective was to stimulate innovative thinking with regards to rockburst stope support systems. With the interest shown by Impala Platinum Mine, with regards to support performance under gravity driven loading conditions, a test procedure was formulated to meet the mine's needs. This new type of testing supports the main objectives set for the facility. The increased range of testing now available to the industry makes the facility applicable to all underground stoping operations which are exposed to fall of ground hazards and is no longer exclusive to rockburst prone mines.

The main objectives are as follows:

- Increase the knowledge of performance characteristics of stope support systems under realistic dynamic and fall of ground conditions
- Provide a facility that will stimulate innovative design and allow physical testing of new support systems, in collaboration with leading manufacturers and suppliers
- Research and develop test types and testing procedures
- Transfer technology to the industry
- Develop a business plan for the continuation of the test facility as a commercial venture.

Test facility description

The GAP 611 project was driven by the perception that traditional testing of stope support was seriously deficient for two main reasons. It was limited to testing one support unit at a time and could not recognize the possibility of a collapse of rock between support units, which is a frequent occurrence in reality. The side view of the testing facility is sketched in Figures 1, while Figure 2 illustrates the general plan view of the test facility. Figure 2 illustrates the locations of the tie-down cables and installed positions of the stope support units. The tie-down cables are installed in strategic positions to stabilize the discontinuous beams and decks. With most of the testing conducted at the facility requiring prestressing of the support units, the tie-down cables prevent the lifting of the concrete beams and load distribution pyramid while prestressing the support units during installation.

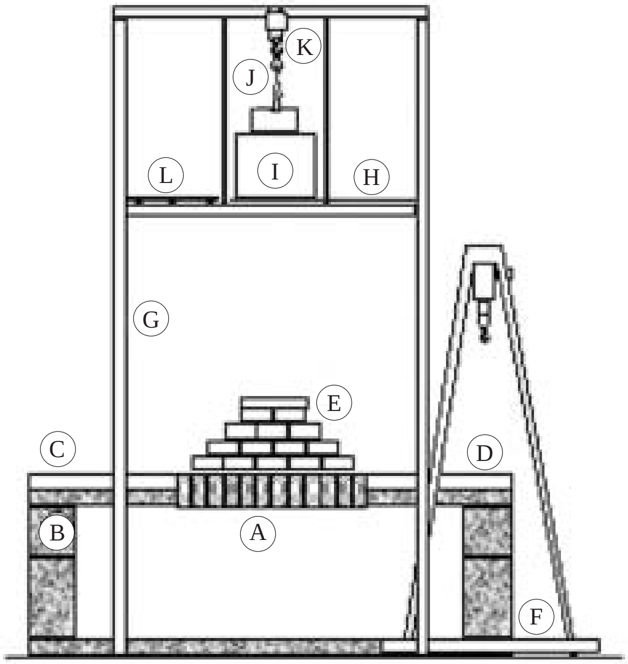

Figure 1. General section of the test facility

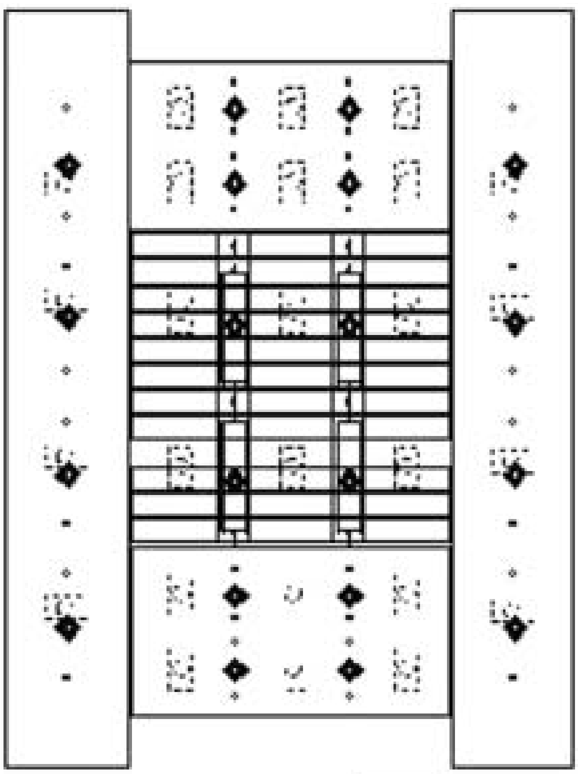

Figure 2. Plan view of the testing facility

The facility consists of two essential components, the collapsible roof that represents the fractured hangingwall of the stope and a 10-ton drop weight to provide the dynamic energy pulse, which is transferred through a load distribution pyramid on to the collapsible beams and stope support system (Figure 1).

For dynamic testing the maximum drop height of 3 metres can be accommodated by the facility, which translates to a kinetic energy impulse of 294 kJ with an impact velocity of 7.67 ms^{-1}. The load distribution pyramid transfers this kinetic energy impulse to the 3 m x 3 m artificial stope area, where the installed stope support system for testing will arrest the three discontinuous, collapsible beams, which consist of 12 blocks each.

The concrete blocks making up the three discontinuous beams in the centre of the facility are allowed to move freely into the stope area under dynamic conditions during a drop test. These blocks are only restrained by the installed stope support system and the friction between the individual concrete blocks enhanced by a 230 kN transverse clamping force imparted on the beam by a pretensioned central bolt and tightening nuts. This transverse load is maintained for safety purposes during lifting and installation of the Voussoir beams for the fall of ground tests and later released to allow the hangingwall blocks to slide under gravity.

The fall of ground test configuration does not make use of the 10-ton weight and the load distribution pyramid, as the concrete blocks in the central discontinuous hangingwall beam are released under gravity by releasing the transverse clamping force applied to the beam. Once the transverse clamping force is sufficiently low, the concrete blocks are able to slide differentially into the stope area, only being retained by the installed stope support units and any interlinking support system, be it weld mesh, netting or lacing.

A typical fall of ground test set-up is illustrated in Figure 4, where 8 blocks of the central Voussoir beam are allowed to fall freely once the horizontal clamping force has been released. The safety net is pinned against the hangingwall by the mechanical props and attached to the prestressed timber elongates by means of clips or hooks.

Measurements are made using a dumpy level survey instrument to determine the vertical displacement of the individual blocks making up the central Voussoir beam. Reference targets consist of short lengths of graduated tape suspended from each concrete block in the central beam.

The displacement of each individual block making up the central hangingwall beam is measured after each significant vertical movement observed during the releasing of the horizontal clamping force of the central beam. The vertical displacements and horizontal clamping force are recorded and plotted. Tests have shown that block displacements usually occur with the horizontal clamping force between 20 kN and 50 kN, while complete beam collapse occurs between 8 kN and 10 kN.

Test results

Fourteen gravity-driven fall of ground tests have been conducted at the test facility. The test results are summarized in Table 1. The test series involved the testing of three manufactured products, initially starting at a 1-ton load, which was provided by allowing only four central concrete blocks to fall onto the safety net secured by mechanical props. This was later increased to 2 tons in the test series, which was provided by allowing eight central blocks to fall onto the safety net. To allow eight central

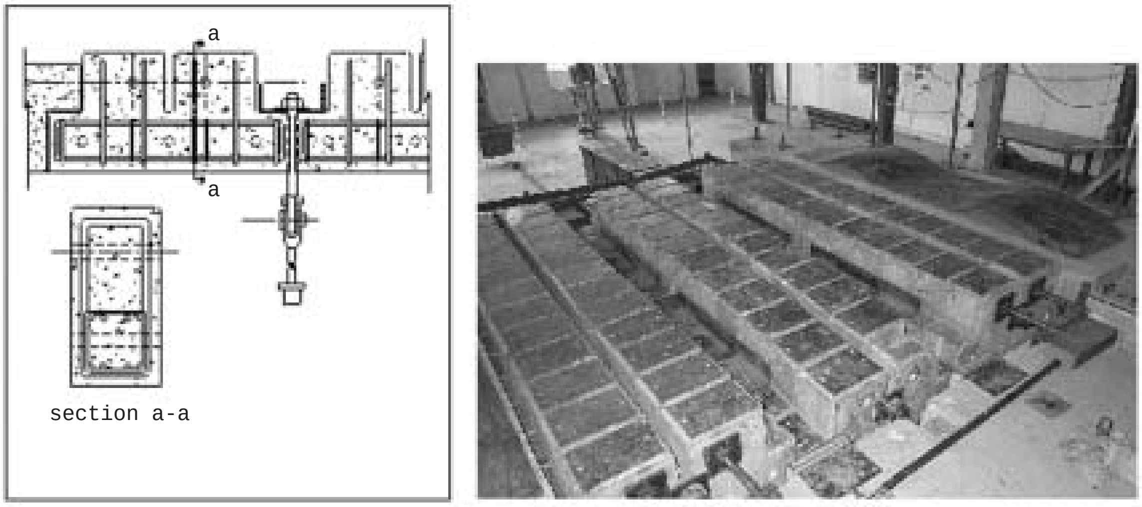

Figure 3. Detail of concrete blocks and tie-down cables with accompanying photograph of the three Voussoir beams

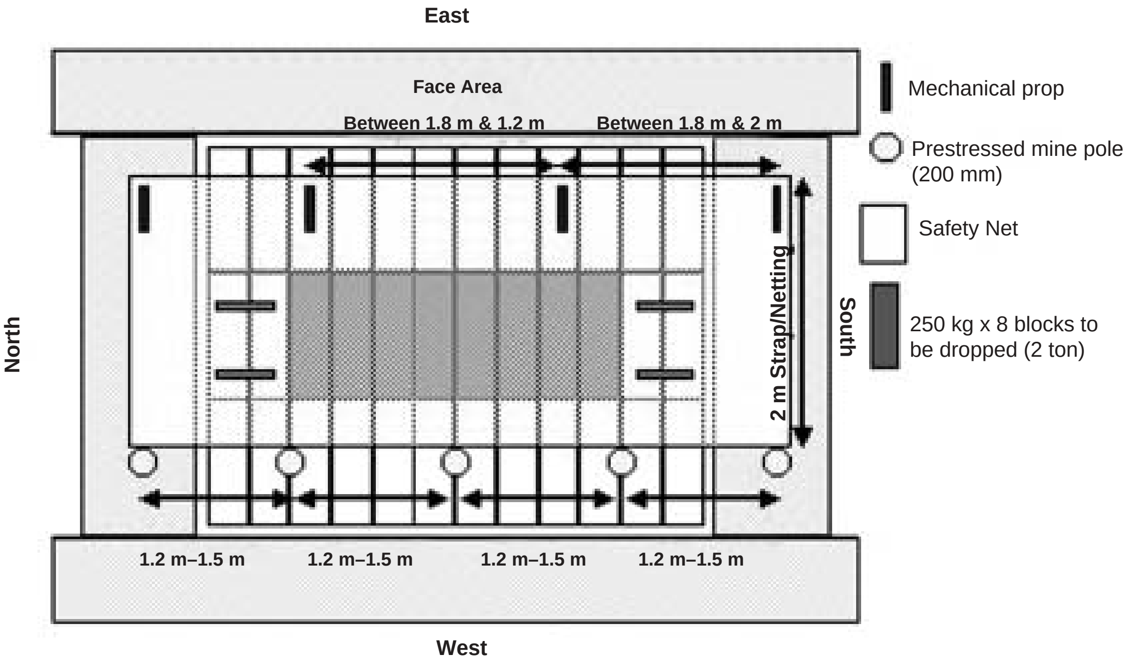

Figure 4. Plan view of a typical fall of ground test configuration with eight blocks weighting 2 tons total free to fall onto the safety net

hangingwall blocks to fall, the mechanical prop spacing was increased from 1 m by 1.25 m to 2.0 m by 2.0 m, making the simulated tests more realistic when compared to mechanical props spacings used by mines in their underground operations.

The progression of the testing and development of the manufactures products are described in Table I.

Learning points

The research and development process followed by the various suppliers was to develop a safety net system, which was capable of arresting and retaining gravitational falls of ground with a mass of 2 tons. Several vital aspects, which can cause a safety net system to fail, were identified. These learning points can be summarized as follows:

- Safety net systems must be installed as close to the hangingwall as practicably possible, as testing has shown that if the hangingwall blocks are first allowed to gain momentum before the safety net comes in contact, the net tends to fail.
- The preload placed on the support units securing the safety nets needs to be sufficient in order to withstand the lateral loading, which is placed on support units when the safety net is loaded by a fall of ground. The most frequent mode of failure observed during testing was the slipping of the support unit's headboard on the hangingwall, allowing the support unit to be pulled out during the loading of the safety net. The smooth hangingwall at the test facility does provide the worst case scenario with regards to this problem. Although the facility does have a set of rough hangingwall blocks, it was agreed that the worst case scenario would be appropriate, as smooth hangingwall conditions do exist underground, especially on the UG2 reef horizon

Table I
Summary of fall of ground tests

Test Series No.	Test Description	Load applied (kN)	Comments
59-01	6 mechanical props on a 1.25 m by 1.0 m spacing, with a plastic safety net installed to retain the four central hangingwall blocks.	10	The safety net failed to retain the hangingwall blocks, allowing the central beam to collapse, except for blocks 4 and 9 that were directly above the mechanical props.
61-02	6 mechanical props on a 1.25 m by 1.0 m spacing, with a plastic net and additional 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern.	10	The four central blocks were retained by the plastic safety net and interweaving of material strapping.
64-03	6 mechanical props on a 1.25 m by 1.0 m spacing, with a material strap safety net, 100 mm apertures.	10	Safety net failed, with all blocks falling to the ground except for blocks 4 and 9 that were directly above the mechanical props.
65-04	6 mechanical props on a 1.25 m by 1.0 m spacing, with a plastic net and additional 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern.	20	This test was a repeat of 61-02 but with an increased load of 20 kN acting on the safety net. All hangingwall blocks fell through, the failure of the plastic netting and material strapping was caused by momentum allowed to the system while pulling straight the material strapping which was woven /wrapped through the plastic netting,
66-05	6 mechanical props on a 1.25 m by 1.0 m spacing, with a plastic net and additional 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern.	20	This test was a repeat of 65-04 but the material strapping was not wrapped through the netting apertures but kept flat, increasing the stiffness of the safety netting. The safety netting retained the four central hangingwall blocks.
68-06	3 mechanical props on a 1.5 m by 1.0 m spacing, 200 mm diameter timber elongates, with a plastic net and additional 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern.	12.5	The spans between mechanical props were increased to 1.5 m by 1.0 m. 12.5 kN was held by the net suspended between the line of mechanical props and the permanent timber elongate support units.
69-07	6 mechanical props on a 1.25 m by 1.0 m spacing, with a material strap safety net, 100 mm apertures.	10	The four central blocks (10 kN) were retained by the strengthened safety netting tested in 64-03
71-08	6 mechanical props on a 1.25 m by 1.0 m spacing, with weld mesh installed as a safety net with 100 mm square apertures.	10	The weld mesh retained the four central blocks.
72-09	3 mechanical props on a 2.0 m by 0.75 m spacing, 3 x 180/200 mm timber elongates 2.0m from mechanical props with a plastic net and additional 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern.	22.5	The four central blocks fell through. The lateral load caused by the loading of the safety net dislodged a mechanical prop.
73-10	3 mechanical props on a 2.0 m by 0.75 m spacing, 3 x 180/200 mm timber elongates 2.0m from mechanical props with a plastic net and 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern. Plastic rivets were used to secure the strapping intersections.	22.5	All hangingwall blocks fell through, except those supported by the mechanical props and timber elongates. The plastic rivets sheared through under loading.
74-11	3 mechanical props on a 2.0 m by 1.5 m, 3 x 180/200 mm timber elongates with a plastic with 6 mm steel cabling reinforced netting.	20	The safety netting retained all eight hangingwall blocks.
75-12	3 mechanical props on a 2.0 m by 1.5 m, 3 x 180/200 mm timber elongates with a plastic net and 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern. Plastic rivets were used to secure the strapping intersections	20	All hangingwall blocks fell through, except those supported by the mechanical props and timber elongates. The plastic rivets sheared through under loading.
76-13	3 mechanical props on a 2.0 m by 1.5 m, 3 x 180/200 mm timber elongates with a plastic net and 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern. Plastic rivets were replaced by stitching to secure the strapping intersections.	20	Plastic netting and reinforcement strapping retained all hangingwall blocks. The replacement of the plastic rivets by stitching removed the weak point observed in the test 75-12.
77-14	3 mechanical props on a 2.0 m by 1.5 m, 3 x 180/200 mm timber elongates with a plastic net and 32 mm wide material strapping weaved in the netting on a 0.5 m by 0.5 m square pattern. Plastic rivets were replaced by stitching to secure the strapping intersections.	20	Plastic netting and reinforcement strapping retained all hangingwall blocks. This test was a repeat of test 76-13 and proved successful.

- The interface between the support units and safety netting is an important aspect, as failures do occur when the support unit 'guillotines' the safety netting during loading. The safety net should be adequately reinforced at its interface with the support units or constructed in such a manner so that this problem does not occur
- Safety nets, which consist of an integrated weaker netting material and a stronger ridge reinforcing member-like cable lacing or woven cargo strapping, must be constructed in a manner that does not cause the ridge member to deform and shear the weaker netting material during loading, which can result in failure of both members
- Safety nets should be designed for ease of installation and removal. It was observed that although safety nets, which are secured directly to the hangingwall by the support units, perform well due to their close proximity to the hangingwall, but are not easy to install. Conversely, safety nets that are user friendly to install, like those which hook onto the support units, tend to be further from the hangingwall. This increases the risk of failure of the safety net caused by increased momentum, as discussed earlier. The various safety net suppliers are still addressing this quandary.

Success story

On 28 November 2003, the life of a rock drill operator was possibly saved due to the installation of strapping which was initially tested at the Savuka test facility. The fall of ground incident occurred at Impala Platinum Mine's No. 14 Shaft, in the 16-101 4 south panel. The rock drill operator was busy drilling the stope face, when a fall of ground with an estimated mass of 350 kg occurred. The accident investigation done by the mine concluded that, although the safety strap had caused one of the temporary support units to dislodge, the strap had sufficiently reduced the momentum of the fall of ground, resulting in no serious injuries to the drill operator. Figure 5 shows the scene of the fall of ground incident and the position of the drill operator.

The 300 mm wide strap used when the fall of ground incident occurred has subsequently been replaced by larger safety netting, providing greater areal cover as shown in Figure 6. Two types of these larger safety nets are currently being used on the mine; both have reinforcing members, one woven cargo strapping and the other 6 mm cable.

Both of the safety net systems were installed and tested to hold 2 tons at the Savuka test facility under gravity-driven fall of ground conditions. The evaluation of these safety nets is still ongoing at Impala Platinum mine and further

Figure 5. Scene of the fall of ground accident where the narrow safety strapping minimized the extent of the injuries to a stope worker

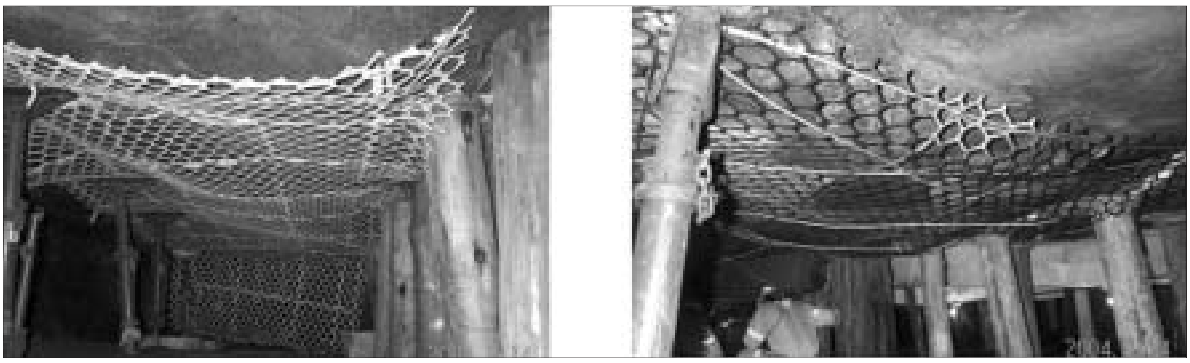

Figure 6. Photographs of the current types of safety net installations at Impala Platinum Mine

improvements will be first evaluated at the test facility before being implemented underground.

Conclusions

With the lessons learnt from the testing of various safety nets under gravity-driving loading conditions at the facility, improvements have been made to the safety nets in order to retain gravity-driven falls of ground up to 2 tons. This was achieved through the understanding of the various modes of failure in a controlled testing environment. By understanding the causes of these failures, which would not have been as obvious in underground trials, improvements can be made to the safety nets in order to better control the ground between support units during a fall of ground, thus reducing, if not eliminating injuries and possibly saving the lives of mining personnel.

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