THE AUTOMATION OF THE 'MAKING SAFE' PROCESS IN SOUTH AFRICAN HARD-ROCK UNDERGROUND MINES

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ABSTRACT

In South African hard-rock mines, best practice dictates that the hanging-walls be inspected after blasting. This process is known as 'making safe' and although intended to save lives, it is laborious and subjective. Pressure is placed on the barrer (inspector) to conduct the test quickly and efficiently as daily operations can only continue after the area has been declared safe. The process involves the barrer tapping the potentially loose rock mass with a sounding bar, listening to and assessing the generated acoustics, and deciding whether it is intact or loose. For a loose rock mass, the barrer would either bar it down or support it. For the purposes of this report, only the 'making safe' process is considered. It is highly dangerous and limits the critical decision making to the experienced barrer. Fatality rates due to falls of ground (FOG) can be reduced by implementing a simple tool that will give consistent results in the 'making safe' exercise.

Keywords: Mining, Hard-rock, sounding, making safe, pre-entry, fall of ground (FOG), narrow tabular ore-body (stope), rock mass stability

1 INTRODUCTION

Underground mining is the art of extracting minerals from deep within the earth's crust [1]. South Africa is a major mining country which boasts reserves in gold and platinum, these minerals require mining at very deep levels. This is known as hard rock mining and it is carried out in narrow tabular ore-bodies with mining heights less than 1.5 m. The challenge with deep level, hard rock mining is the high stresses in rock masses which lead to rock bursts and falls of ground (FOG).

In an attempt to mitigate the prevalence of rock burst and FOG accidents, an assessment of the rock mass condition prior to entering a narrow tabular ore-body is carried out. This is usually carried out after blasting.

Determining whether a narrow tabular ore-body is safe to mine in, is thus both dangerous and highly subjective. This is due to the fact that the process is currently influenced by, inter alia, human factors such as fatigue, inexperience, hearing ability and pressure to quickly execute the task [2].

Errors arising from these human factors can be made while trying to accurately characterize the rock mass under assessment. The accurate assessment of the stability or possible instability of a hanging wall and proper alerts to the worker/miner are critical to the safety of miners working in a narrow tabular ore-body.

1.1. Mine fatality rates and causes

An assessment of fatality rates in South African Mines over the past five years (May 2005 to March 2010) reveals that the majority of underground hard rock mining accidents are caused by FOG accidents. This paper examines the possibility of using automation to improve the making safe process, hence mine safety.

FOG refers to incidents that involve the collapse of a hanging wall. During the period under assessment, 837 accidents occurred in the South African mining sector. Hard rock mines (platinum and gold) contributed over 77% (633) of the total as shown in Figure 1.

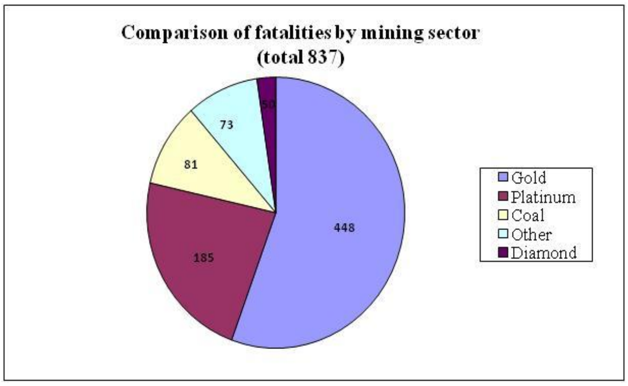

Figure 1. Comparison of fatalities by mining sector as classified by Dickens [3].

FOG accidents contributed over 35% of the total hard rock mining sector accidents as shown in Figure 2.

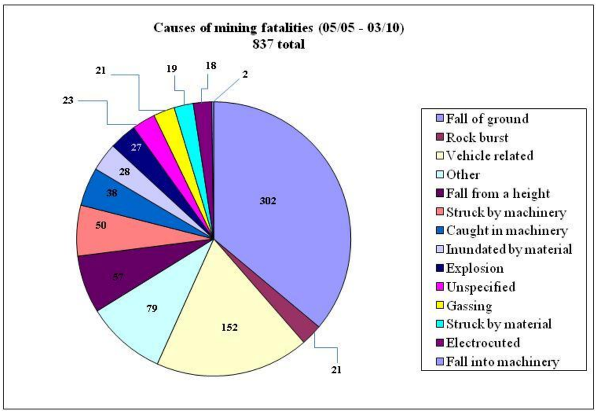

Figure 2. Causes of mining fatalities as classified by Dickens [3].

Figure 3 shows the causes of fall of ground accidents ranging from seismic events to improper identification of unsafe areas after the entry examination.

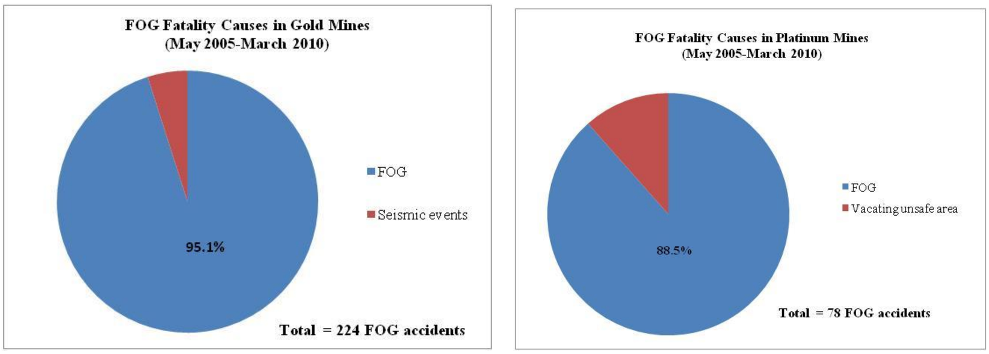

Figure 3. An assessment of the causes of FOG accidents in gold and platinum mines.

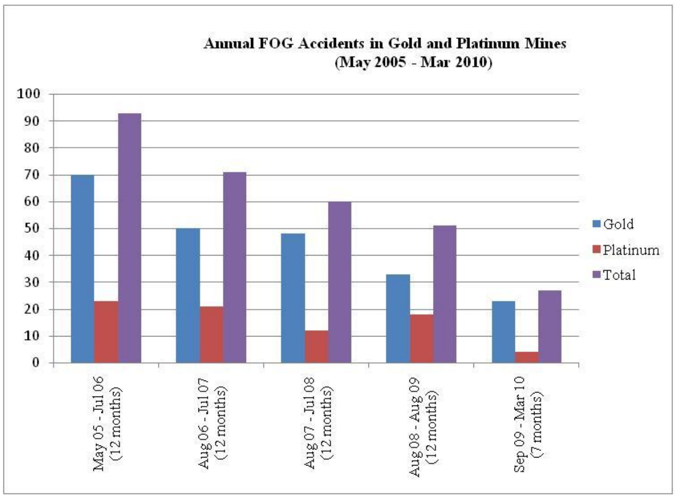

Figure 4. Annual fall of ground fatalities in gold and platinum mines.

Figure 4 shows the number of FOG accidents from May 2005 to September 2010, averaging 5.3 accidents per month. For the last seven months under assessment, an accident rate of 3.85 per month was recorded.

Although there is an overall decline in the FOG accident fatality rates over the time period discussed, the unpredictability of rock mass collapse implies that further mitigating actions are necessary.

1.2. Causes of FOG accidents

From the data collected over the past five years (May 2005 to March 2010), three main causes of fall of ground accidents were identified and a discussion of each follows [3], [4]:

a. Poor identification of 'unsafe' areas

This can be linked to many factors including improper identification of unsafe areas. The remedial action is usually barring down, support and visual assessment. In many cases, assessment of rock mass stability is only carried out on masses that appear to be dangerous when visually inspected. This is due to time and production issues linked to the making safe process.

To avoid fall of ground fatalities due to workers not being aware that the area they are entering in unsafe, a way to identify/mark unsafe areas is needed. The automated device being discussed will include this as a specification.

b. Seismic activity

Causes of seismic events that lead to fall of ground may include the shift of the rock mass, blasting, change in rock mass/crust geology and many more.

Research has identified changes in rock mass condition as one of the contributors to fall of ground accidents [4]. This is due to the fact that rock formations in hard rock mines have been exposed to enormous forces since their creation. The changes may lead to seismic events.

c. Ineffective Assessment

This was found to be the primary cause of fall of ground accidents [5]. Human factors are closely linked to this. The human factors involved in the making safe process include fatigue, hearing ability and experience.

Fatigue affects most people involved in laborious exercises; such as working in confined, warm and humid environments. The layout of the stope area is usually only 1 m high with a 30 m long panel and dips that range from 8° for platinum to 20° for gold mines.

The sounding bar used to test the wall stability and subsequently bar down unsafe rocks is typically a 25 mm hexagonal mild steel bar that weighs 4.3 kg at 1.2 m and 6.96 kg at a length of 2 m. The mine conditions together with the weight and size of the tool used in the making safe process make it difficult for miners to continue working for prolonged periods.

Another factor that affects workers involved in the making safe process is hearing ability which may be linked to mine operations such as blasting, drilling and other duties that induce noise levels above 8 db which is deemed safe.
In addition to the human factors mentioned above, procedural, environmental, work practice and competence issues contribute to ineffective examination [4].

2 CURRENT PRE-ENTRY EXAMINATION (MAKING SAFE) PRACTICES

A technique which has been in use for many years to assess the integrity of a rock mass in a mine working environment involves a person tapping a rock mass with a steel sounding bar, listening to the sound generated and making an assessment of the integrity of the mass according to the sound which is heard.

The sound which is heard is caused primarily by the acoustic wave generated through the vibration of the rock mass and other sources, for example the sounding bar, in the surrounding environment. The sound has a unique frequency distribution which must be interpreted in order for a determination of the integrity of the rock mass to be made [6].

This process is known as “making safe”, and comprises two linked, but separate steps, namely, the detection of the hanging wall hazard and the remediation thereof. For the purposes of this report, only the hazard identification step of the making safe process will be explored.

Making safe or pre-entry examination is conducted after blasting; this is a process where explosives are used to mine the ore.

A significant amount of fall of ground accidents occur during re-entry into a workplace as the inspection and making safe procedures are carried out to stabilize the rock mass before work in that particular area begins [7].

The pre-entry examination is one of the most critical exercises undertaken in underground hard rock mines. This is due to the fact that mines rely on it to ensure that the work area is safe. Most mines specify that no one should enter the area before the area under consideration is declared safe [8]. This puts pressure on inspectors as operations rely on how fast and efficiently they can carry out the examination. Production in a mine is linked to financial reward and recognition.

While this exercise is critical to the miners’ safety, it is often rushed and improper assessment may be made.

Making safe is also laborious as the object used to perform the assessment is often heavy and the environment hot and humid. Miners who carry out this exercise together with the remediation measure of barring down can often only work for eight minutes before rest is necessary [9].

A way to mitigate errors and human factors involved in the making safe process is required in the attempt to reduce fatal rock fall incidents. Green shows in his paper that automation in the form of robotics has the potential to improve mine safety [10].

The making safe process can be automated in two stages. Stage 1 involves the automation of the tool in order to remove subjectivity and variation in the assessment of the impact produced and the decision making process. Stage 2 of the automation will make it possible to execute the making safe process without human involvement using an autonomous platform. The former will ensure that the process is highly repeatable and the latter will address the delay caused by the presence of noxious fumes, dust and gases which are harmful to humans [10].

This will allow for mine operations to resume sooner than is currently possible. Also, the isolation of direct human involvement in the process will help remove subjectivity from the process.

This implies that future examination techniques will include remote assessment. Miners will still be required to bar or support potentially unsafe areas. The automation of the entry examination will enable them to do so with a clear idea of unsafe areas.

3 PROPOSED AUTOMATION OF PRE-ENTRY EXAMINATION

a. The design stages

The full automation of the device will be undertaken in three stages; full automation implies a system which is somewhat completely closed in nature. The three stages are classified as follows:

Stage 1: Build a hand-held device that can be used by miner to accurately characterize the rock mass under test. The device should enable testing from a safe distance and remove subjectivity from the making safe process.
Stage 2: Make the device in stage 1 smarter by automating the wall-approach and representation of unsafe areas on a map using the underground localization system (beacons) [11].
Stage 3: Mount onto a safety platform and incorporate the capability to link into other sub-systems of the platform, such as AziSA [12], [13], [14].

This report addresses stage 1 of the project with the design and manufacturing of the initial prototype.

Our automated device is known as the wall stability assessor (WSA). This will be incorporated into the existing technological devices. The device will have the design objectives as indicated below.

b. Design objectives

The main objective of this work at stage 1 is to help reduce the prevalence and therefore the impact of fall of ground (FOG) accidents in South African gold and platinum mines.

To achieve this main objective a number of interrelated elements were identified and itemized in order to simplify the design process.

1. To remove the subjectivity involved in the process by implementing a device that will offer accurate assessment of the rock mass integrity.
2. To remove ‘specialty’ from the making safe process by introducing a device that will be light and easy to operate by all miners.
3. To incorporate proper and consistent classification of the rock mass under assessment.
4. To introduce the demarcation of potentially dangerous areas both for immediate and long-term data use (stage 2).

From the design objectives, five functions were identified as follows:

1. **Function 1: Extend from the safe area**

   Safe area is classified as the area that has a clear escape route if rapid evacuation is required, this could be a side panel or a supported stope area [8]. The maximum length of the current tool is typically 2 m. A 1 m length telescopic aluminium pipe is used to allow the device to extend to 2 m. Aluminium was chosen for its price, stiffness ratio and weight. At this stage, the decision of whether to extend or not will be made by the operator depending on where he/she is standing in relation to the test area.

2. **Function 2: Approach the test structure**

   A 10 mm proximity sensor is used for this application. This implies that the proxy sensor will go on every time the device is 10 mm away from the rock mass. This is such that testing is conducted from a known and consistent position every time.

3. **Function 3: Excite rock mass under evaluation**

   Apply sufficient impact force to the structure or rock mass under assessment to ensure that enough signal (amplitude) is generated for the ESD to make an assessment. A solenoid is used to apply such impact. This will be refined through the involvement of pulse-width modulation and other relevant electronic control in stage 2 of the project.

4. **Function 4: Feedback system**

   Capture the sound produced by the wall excitation tool. The ESD uses neuro-sensors together with an on-board Linux single board computer to capture and assess the sound generated by the normal sounding bar [2]. The frequency response of the rock mass to the impact is analyzed and classified as safe or unsafe based on the expert training of the neural network classifier. Based on the response that he/she gets, the operator has the option of whether to re-test, demarcate as unsafe or proclaim the area safe.

5. **Function 5: Demarcation of unsafe rock**

   A mechanical lever connected to a solenoid is used to depress the spray can in order to demarcate potentially unsafe rock mass.

c. Controllers

One switch for the excitation mechanism and the other switch for the spray mechanism are included in the design. Two LED lights to indicate the position of the individual switches will be used. These switches are connected to the power supply as appropriate.

d. Power supply

A sufficient power supply that lasts for the required period of one shift, which is typically 4 hrs, is incorporated into the design. Ten 1.2 V cells are connected in series to make up the 12 V required by the two solenoids.

e. Enclosure

An appropriate enclosure of sufficient thickness and International or Ingress Protection (IP 65) rating is used in the design. The IP Code reflects the degree of protection as "IP" followed by two numbers; the first digit shows the extent to which enclosures are protected against particles, and protection to others from enclosed hazards. The second digit indicates the extent of protection against water [15]. IP 65 means that the contents of the enclosure are protected against dust and water jetting [16].

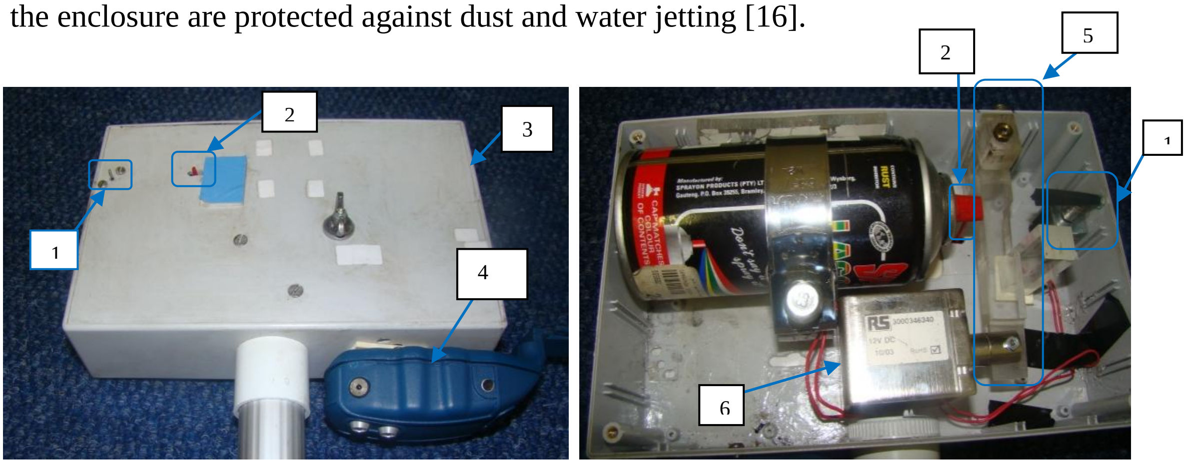

Figure 5. Prototype WSA Head – 1. Wall exciter (solenoid) 2. Spray nozzle extender 3. Enclosure 4. ESD 5. Mechanical lever 6. Solenoid for the spray mechanism.

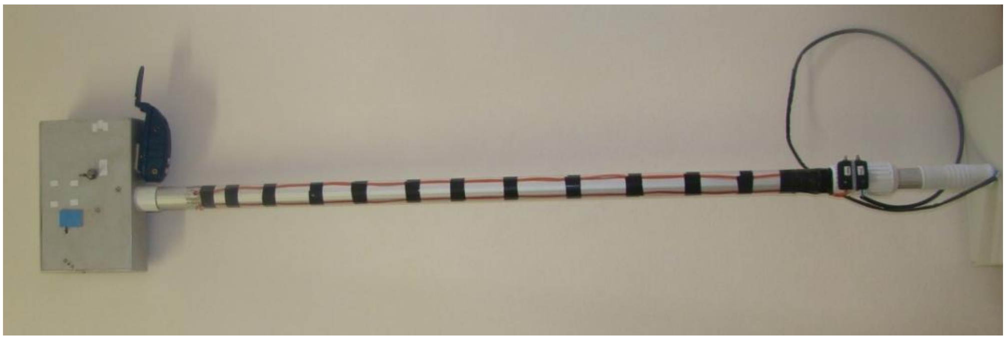

Figure 6. Prototype WSA.

4 VALIDATION

The two phases of validation are designated as Training and Testing. The ESD units were trained and tested to function in four different reefs.

4.1. Training

To train the ESD, a specific variant on the ESD design was created to record the audio samples and allow the operator to indicate whether the recorded sample should be labelled as an example of a ‘safe’, ‘unsafe’ or an ‘unknown’ indicating sound. These Training ESDs were used by mine personnel over a few months to accumulate samples from various reefs.

The recordings from each reef were added together and all ‘unknown’ readings removed to optimize neural network training.

This process yielded a total of 699 useable recordings for each of the reefs as follows:

- Ventersdorp Contact Reef (VCR) – Westonaria: 376 recordings
- VCR – Alberton: 162 recordings
- Middelvlei Reef – Quartzite: 119 recordings
- Carbon Leader – Quartzite: 42 recordings

4.2. Testing

The tests were conducted on different reefs and at different ground conditions as shown in Table 1 below.

Table 1: ESD testing conditions.

Reef	Testing area	Conditions		Samples	Barring incidents	Noise level during test
		Ground	Ground water			
VCR – Westonaria	Panel	Intact	Dry	94	17	little background noise
VCR – Alberton	Stope	crushed and fractured	dry	100	1	a lot of background noise
Middelvlei Reef – Quartzite		solid, intact hanging wall	moist	97	44	relatively quiet period
Carbon Leader – Quartzite	Panel 1	crushed, fractured	dry	95	10	little background noise
	Panel 2	crushed	moist	50	16	relatively quiet

Note: All tests were conducted during the entry examination.

4.3. Results

The testing process resulted in comprehensive performance results of the ESD in various ground conditions, different ground water conditions, and on four different reefs.

In the summation of the results, it is important to keep what is being measured and what it is being measured against. No truly objective measure was made of whether the rock mass that was being sounded was truly safe or unsafe, but rather the readings rely on the subjective measurement of an experienced operator. Therefore the performance of the ESD is measured against the judgment of the operator, and the correlation between the two judgments is the measure of success.

Table 2: ESD test results.

Reef	Judgement correlation success	Cautious errors (%)	Unsafe errors (%)	Ground conditions
VCR – Westonaria	76.47	11.77	11.76	Intact
VCR – Alberton	78.38	16.21	5.41	Crushed, fractured
Middelvlei Reef – Quartzite	78.40	7.80	13.80	Intact
Carbon Leader – Quartzite	89.19	6.76	4.05	Crushed
	78.48	16.46	5.06	Crushed, fractured

The correlation mismatches between the ESD and an experienced operator can be divided into cases where the ESD was overly cautious, i.e. the ESD predicted an unsafe rock mass where the operator judged it safe, and where the ESD made a potentially dangerous error, i.e. the ESD predicted a rock mass safe where the operator judged the rock mass to be unsafe. Table 2 above shows that the increase in unsafe errors correlates to the ground conditions of the testing area. Higher unsafe errors are observed for areas where the ground conditions are described as 'intact' and 'stable'. Possible solutions to minimize unsafe errors include sampling more recordings during the training process in these areas, and then evaluating whether increased exposure increases the efficacy of the neural network model. It is suspected that the make-up of the rocks in an area with intact ground conditions may deliver a different frequency response from those in a crushed and fractured ground condition.

5 FOG ACCIDENT MITIGATION

5.1. Other techniques

For the past hundred years, little change has been experienced in the South African deep level platinum and gold mining methods [17]. Mining in South Africa is still perceived to be a very dangerous and hazardous job. The CSIR together with the industry recognizes that efforts need to be taken to make mining safe and attractive to a new generation of miners. In order to achieve this, research into better mining methods through the use of technology is required. A shift in focus is therefore imperative in improving the hard rock mining conditions.

Extensive research has been and is currently being undertaken to develop novel mining methods to assist in improving the safety of our mines. Methods such as using thermal imagery [18], [19] and electronic sounding [2] to determine the condition of the rock mass have been explored. Thermal imagery involves the identification of temperature difference between loose and intact rock masses. The idea revolves around the premise that a loose rock mass will be cooler than an intact one due to the fact that the heat flow from the host rock to the loose rock is interrupted by the crack. The cooler ventilation air therefore preferentially cools the loose rock mass [20]. Although effective, the thermal imager only carries out an assessment in a narrow field of view.

The CSIR has patented a method and apparatus for testing installation quality in a grouted anchor system (U.S. Pat. 7,043,989 B2). This apparatus is known as In-Situ Bolt Integrity

Testing (ISBIT). This is a process by which the rock mass integrity is established through the testing of the support anchor bolt/tendon [21]. This method is not appropriate for our application as it can only be implemented after the loose rock mass has been supported.

6 CONCLUSION

Automation will speed up the process of making safe in a sense that seismic threats after blasting and the presence of gases does not affect machines. Seismic threats and the presence of gases typically delay the making safe process by approximately 4 hrs, which is the time required for seismic events to settle as well as ventilation to take effect.

If the pressure and haste is removed from the making safe process, it is my position that the prevalence and impact FOG accidents will be minimized.
Removing subjectivity from the process will lead to consistent and accurate assessment of the rock mass integrity.

The WSA will ensure that specialty involved in the making safe is removed due to its being light and easy to operate.

Demarcating potentially unsafe areas to all who enter the work area will empower workers to take responsibility of their wellbeing by vacating these areas and/or taking proper action to minimize the risk.

Automation will not only enhance the process but also save time, in turn removing the pressures involved in the making safe process. This will allow for mine operations to resume sooner than is currently possible.

7 FURTHER WORK (RECOMMENDATIONS)

The project will proceed with stage 2 and 3. Stage 2 involves the acquisition of geopositioned data through the use of underground localization system (beacons).

Once the position is captured, a capability to interface with the AziSA system will be built into the device. Stage 3 also includes the ability to be mounted onto the safety platform for full automation. It is imperative that the WSA have the capability to interface with all the systems involved in the final automation of the ‘making safe’ process.

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