CHAMBER OF MINES
of South Africa

DRILLING AND BLASTING IN HARD ROCK NARROW TABULAR MINES

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INTRODUCTION

Falls of ground has been responsible for great loss of life, permanent disability, serious injuries, lost time injuries and dressing cases ever since the inception of formal large scale underground mining in South Africa nearly 120 years ago. It is true to say, statistically, that falls of ground are the single largest cause of harm, from a safety point of view, in South African mines. In the early days of large scale mining in South Africa, this may have been as high as 50% of all safety related incidents. Recently this number has reduced to approximately 30% of the total number of safety related incidents.

FATALITY RATES IN ALL SOUTH AFRICA MINES (2003 TO 2015)

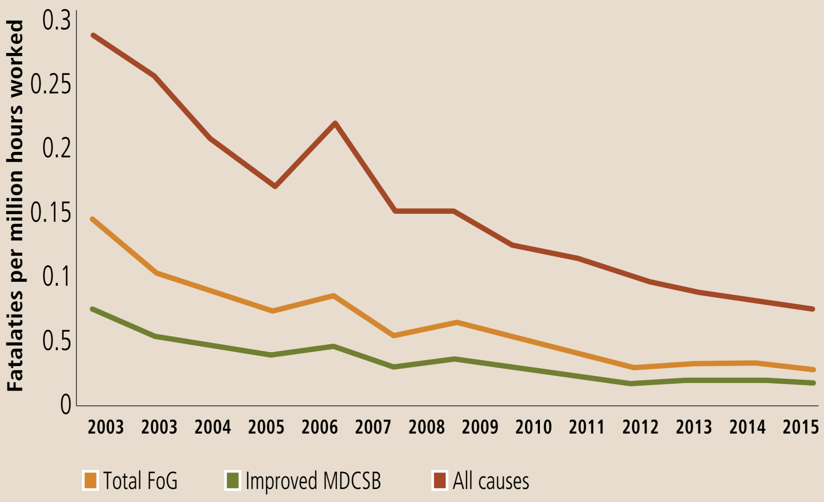

Figure 1: The safety performance of the South African mining industry from 2003 to 2015. The contribution of fall of ground (FoG) to the total is clear. The lowest line is the estimate that improved marking, drilling, charging, stemming and blasting (MDCSB) could have on improving safety.

"Falls of ground made up approximately 33% of all fatal incidents in 2015."

Falls of ground made up approximately 33% of all fatal incidents in 2015 (25 out of 77). The lowest curve in Figure 1 shows the expected contribution that good drilling and blasting practice could make in improving rock related safety.

It may be tempting to blame the geology of the rock surrounding the mine opening as the cause of all the fall of ground problems, and it must be acknowledged that many of the problems of poor strata control are found under this category, but often poor geological conditions and many other non-problematic geological conditions are made worse and unstable by the act of mining, particularly the activities involved in marking, drilling, charging and blasting.

Holmberg and Persson state, in Underground Excavations in Rock (E Hoek and ET Brown): "The innocent rock mass is often blamed for insufficient stability that is actually the result of rough and careless blasting. Where no precautions have been taken to avoid blasting damage, no knowledge of the real stability of the undisturbed rock can be gained from looking at the remaining wall rock. What one sees are the sad remains of what could have been – a perfectly safe and stable rock face".

It is reasonable to suppose that, if the quality of drilling and blasting improved, there may be a reduced number of unsafe incidents related to falls of ground. The lowest curve of Figure 1 presents a speculative view of the state of rock related safety if the improvement had been 47%. This 47% is based on an examination of all rock related accidents during 2013/2014 where each accident was assessed as to the role that poor drilling and blasting practice played in contributing to the rock fall that resulted in a fatal accident.

IMAGE

Accurate, clear marking of the face to indicate where the shot holes should be drilled is critical to executing a good blast.

THE STATE OF OUR CURRENT KNOWLEDGE OF MARKING, DRILLING, CHARGING AND BLASTING

- The quality of marking, drilling, charging and blasting affects the mining cycle from the face to the mill.
- There is a need for comprehensive, experiential training to equip people for these jobs.
- Thrust adaptions (air-legs) aligned with drilling are sub-optimal and should be improved for greater penetration speeds and efficiencies.
- Fragmentation impacts the mine call factor but also helps or hinders cleaning and transport.
- Poor marking, drilling, charging and blasting can compromise the face shape.
- 9% to 27% of the energy from the explosives is useful energy for breaking the rock – use it wisely by adhering to a design.
- Different rock types require different explosives types with different delays between shot holes.
- The shot holes are the most important part of the process and, once they are drilled, the end result can almost be predicted:
    - correct position (marking), spacing and burden (particularly at the toe of hole), correct direction (horizontal and vertical) and length of the holes are all critical success factors.
- Relief holes or free breaking surfaces are critical.
- Rock is damaged by drilling, overburdened holes, vibrations from the explosive detonation and incorrect sequence of timing.
- The break angle of any hole must be maximised.
- Sequencing of shot holes in the blast is critical to minimising misfires and therefore straight faces.
- Square patterns of holes rather than staggered patterns should be used.
- Bottom holes should be fired first.
- Higher velocity of detonation (VOD) explosives should be used.
- Drilling of holes using button bits will increase penetration but water pressure should be sufficient for hole flushing with these bits.
- Holes in stope panels should be drilled at right angles to the face, which together with the correct explosives type and the appropriate timing will ensure that the broken rock is thrown into the gully when the explosives detonate.
- Gullies should be deep enough and be carried with the face to facilitate blasted rock storage.
- The gully should be ahead of the stope panel to provide a breaking surface for the panel blast.
- Percussion action is detrimental to people and machines and should be phased out.
- Supervision is critical to success and it is generally lacking.
- Explosives are expensive and not used optimally but often wasted.
- Emulsion explosives are safer to handle and only become "unstable" in the hole.
- Shock tube does not always fire sequentially and may result in misfires and poor face shapes.

"Poor marking, drilling, charging and blasting can compromise the face shape."

IMAGE
Drilling at right angles to a well-marked face, with top and bottom contact lines and drilling direction lines indicated, ensures that the angle of the drill is close to parallel to the top contact.

“Drill rigs need refining to be used optimally and operated remotely.”

OPPORTUNITIES FOR THE INDUSTRY

The industry does not use the following optimally:

- Availability of better explosives:
  - variety of tailored explosives types (such as VOD and emulsion explosives)
  - initiation systems – electronic blasting – for accurate sequencing of detonation
- Drilling of shot holes:
  - direction of holes is not consistent
  - lengths of holes are not always similar
  - marking and spacing of holes is not carried out with enough precision
  - insufficient holes are used to break the rock (burdens are too large)
  - free breaking points are not always sufficient
  - ineffective application of relief holes where there is no free face to provide a breaking surface
- Appropriate quantities of explosives:
  - hole size to the quantity of explosives is not carefully considered
  - holes are often overfilled but sometimes under-filled
  - use of capsuled explosives or accurately dispensed emulsion explosives
- Stemming of holes is not carried out
- Supervision is either lacking or incompetent for appropriate input
- Drill rigs need refining to be used optimally and operated remotely

Suggestions to maximise a positive return on drilling and blasting

- Introduce more experiential learning in the training centres.
- Mark the face clearly every time. Use visible paint (red may not be the best colour) and ensure paint is always available.
- Be aware of the direction of drilling – 90 degrees to face, sub-horizontal, together with the correct explosive type and timing sequence.
- Design the drill pattern – correct burdens and free breaking surfaces.
- Thrust on drills should be along the drill – drill rigs may help to achieve this.
- Ensure enough flushing water when using button bits.
- Supervision should improve – shift bosses and miners should be trained.
- Electronic detonation should be timed.
- Design the blast.
- Match the explosive to the rock (encourage the use of emulsion explosives).
- Use stemming.
- Smoothwall blasting should be practised in rock and excavations as necessary.
- The use of rigs and remote operation of drilling machines should be investigated.

IMAGE
Marking and securing areas prior to drilling.

INTERACTIONS AND LESSONS FROM MINES

VISITS TO MINE TRAINING CENTRES

Visits were conducted to two large mining companies (one gold and one platinum) to assess the quality and comprehensiveness of training in marking, drilling, charging and blasting. In both cases, it was clear that the syllabus was good and covered all theoretical aspects of the wider issues around drilling and blasting. It seems that the content is available to all who attend the courses. However, poor performance underground indicates lack of comprehension or skill of workers regarding the knowledge passed on to them. This may be due to low education levels, inappropriate material and methods to convey the message, insufficient experiential and practical teaching and, more importantly, behaviour of workers and supervisors that encourages non-compliance and shortcuts.

A large platinum mine uses its team mobilisation programme to teach more than theory in terms of MDCSB. Candidates are shown, among others, the impact of drilling short holes. A grid is marked on the ground and two teams go through the process of mining for a month. The team that drills the correct hole lengths consistently moves far ahead of other teams. It is possible to illustrate the square metres gained or lost.

UNDERGROUND VISITS

A number of underground visits have been made to different hard rock operations, sometimes with the express purpose of assessing drilling and blasting, and sometimes for other reasons. These visits provided insight into handheld drilling on hard rock mines.

"These visits provided insight into handheld drilling on hard rock mines."

An obvious shortcoming, in many instances, was in marking the faces to be drilled and blasted. Marking of the face, which includes positions to drill the shot holes, top and bottom reef contacts, hole direction lines and elevation lines, were not clear and sometime missing. Gully lines were not clear or missing. In one instance, the reason was that they had run out of paint and the budget did not allow for the purchase of more paint. The number of spray cans in the budget did not last a month.

The use of red spray paint was not best for marking. Even when the face was marked, it was difficult to decide where the collaring points were located. If colour blindness is an issue, this may compound the problem.

As a result of poor marking, the burdens were variable.

The direction of drilling was not at 90 degrees to the face. It is often fanned as a result of drilling a number of holes from the same position. Holes are often excessively inclined or decline away from the horizontal with the result that the ends of holes come too close to the reef/country rock contacts and even penetrate these boundaries. The result is blast damage of the surrounding rock of the excavation. This is particularly problematic if the rock in the hangingwall is weak and damaged as strata control problems may follow. However, during updip drilling, the problem of drilling into the surrounding rock is a real possibility, especially if the reef dips steeply. This rock, although damaged, does not pose a rockfall risk but results in a stepped footwall, which is difficult to build support on. This in turn means that the support may not be as adequate as anticipated so the hangingwall may not be as stable and falls of ground may easily occur.

Alternatively, during down dip drilling, for example during ledging, drilling into the hangingwall is common and may result in unstable hangingwall conditions.

If additional support is needed close to the face, if possible, elongate support should be installed with headboards rather than packs. The support resistance may be correct but drilling of the face may be seriously compromised by using packs close to the face as non-parallel, non-perpendicular holes to the face will be drilled and burdens will inevitably be irregular. Consequently, the face will be crooked.

OTHER ANECDOTAL EVIDENCE

Lack of accurate marking

Underground measurements of shot hole spacing are inconsistently placed from one another and the contacts. This has the obvious effect of producing irregular footwall and hangingwall contacts as well as damage to hangingwall and footwall where burdens are too large.

Figures 2, 3 and 4 indicate the variation in spacing between the shot holes (Figure 2) and the variation in distance from the shot hole to the hangingwall (Figure 3) and footwall contacts (Figure 4).

SPACING OF DRIILL HOLES – DISTANCE TO NEIGHBOUR

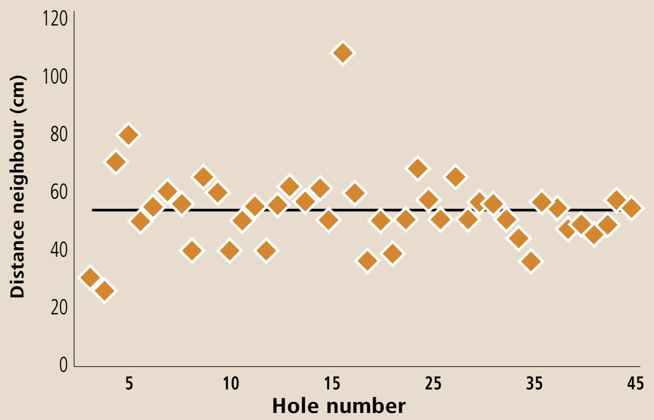

Figure 2: Distance between nearest neighbour shot holes

DISTANCE OF HOLE COLLAR TO TOP CONTACT

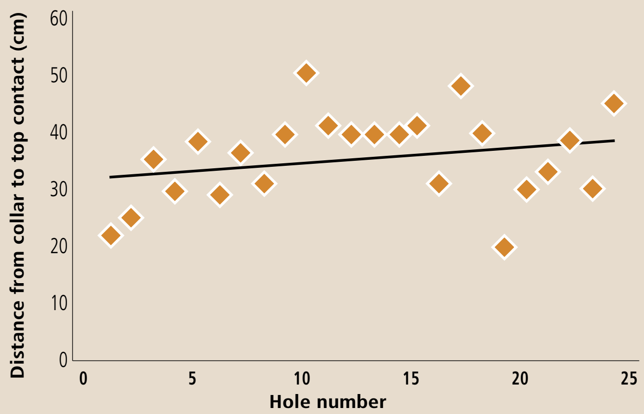

Figure 3: Distance from shot holes to top reef contact

DISTANCE OF HOLE COLLAR TO BOTTOM CONTACT

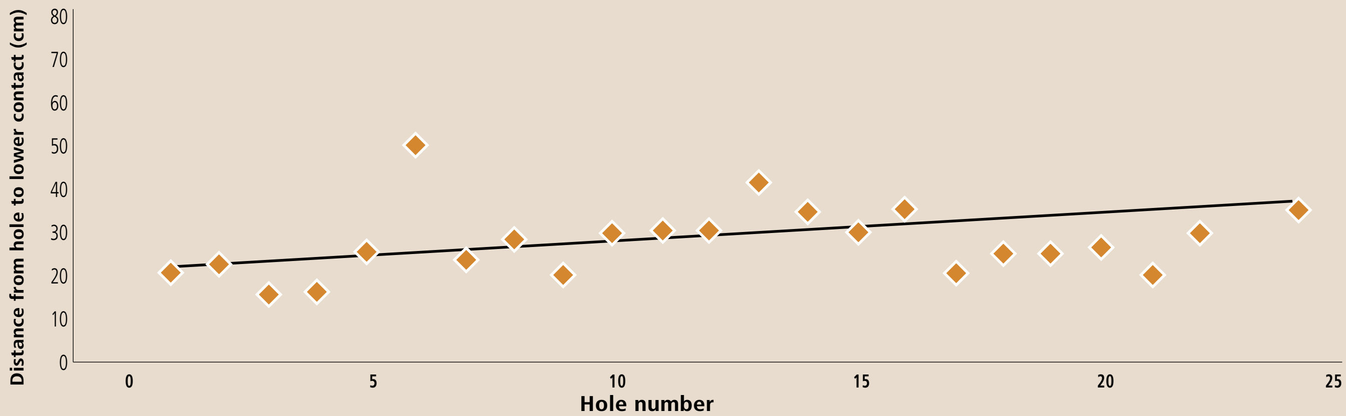

Figure 4: Distance from shot holes to lower reef contact

Poor control of shot-hole length

Figure 5 shows the effect of drilling different lengths of shot hole at various angles to the face and at various angles to the horizontal. The result is an irregularly shaped face as the ends of the shot holes terminate at a multitude of different distances from the face into which they were drilled.

PLAN VIEW OF END POINTS OF DRILLED HOLES

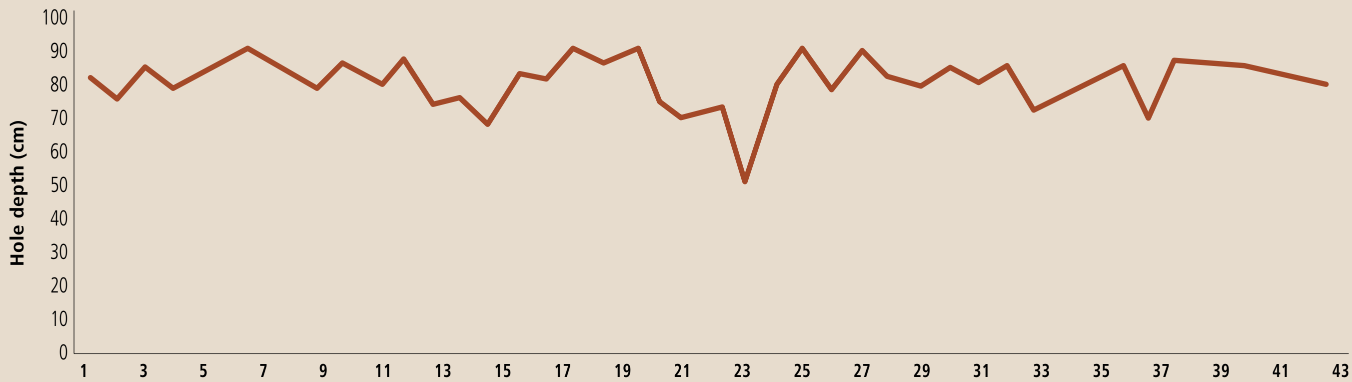

Figure 5: A trace of the ends of shot holes in an average panel demonstrates the irregular nature of the face that may be expected after the blast.

INTERVIEWS

A number of interviews were conducted with underground production personnel. The result was that there seemed to be sufficient knowledge of the required practices needed to achieve optimal drilling and blasting.

Some of the prominent issues included:

- Miners/team leaders acknowledge that drilling into the hangingwall and footwall results in unfavourable conditions. From in situ observation, it is clear that the machine operators do not appreciate this fact fully.
- Holes should be drilled at a consistent distance from the top and bottom contacts respectively. The bottom holes on up dip drilling often are too flat and intersect the bottom contact as the drilling machine is too bulky.
- Holes are mostly not parallel and usually more than one hole drilled from one position. A stopped face with packs close to the face poses a problem.
- Supervisors could provide more coaching, be available to help as needed and motivate workers. They should not criticise the miner in front of the team but correct and advise when necessary. They should not shout but rather instruct, and they should not change plans without consultation.
- Supervisors need to help order equipment.
- When changing anything related to explosives, more information and training is needed. The changes should be communicated by a senior official, such as a shaft manager, in terms easily understood by everyone.
- Using cartridge explosives ensures that the same amount of explosive is used in each hole.
- Stemming is always necessary but not always at the same length.

BEHAVIOUR ISSUES

Some leadership behaviour issues that need to be addressed include:

- Follow-up by the training centre is necessary to establish whether or not the training is relevant and followed underground. Communication with the workers and supervisors is important.
- Production pressure and face time – supervisors should acknowledge and help to understand and solve problems with their subordinates.
- Provision of materials such as paint – a relatively insignificant cost with significant implications.
- Regular quality assessments/measurements during the drilling shift – to ensure uniformity in
  - marking the face
  - direction and length of holes
  - free breaking face or relief holes with the cut
- Interest in each crew and their leaders (team leader and miner) and coaching underground.
- Developing respect and care for individuals.

CONCLUSION

It is possible, in theory, to list items that would improve drilling and blasting practice. However, anecdotal evidence suggests that, although many mines know what to do, buy-in is inconsistent among stakeholders. It is difficult to encourage personnel in our large labour intensive mining operations to adopt good drilling and blasting practice. The MOSH approach, where emphasis is placed on understanding and directing people's behaviour, is well suited to improving adoption.

QUICK WINS

- Introduce more experiential learning in the training centres.
- Mark the face clearly every time. Use visible paint (red may not be the best colour) and ensure it is available.
- Design the drill pattern – correct burdens and free breaking surfaces.
- Direction of drilling – 90 degrees to the face, sub-horizontal, together with the correct explosive type and timing sequence.
- Supervision should improve:
  - inspection and quality control of drilling
  - training for shift bosses and miners to advise and coach
- Use stemming.
- Use the correct amount of explosives for the hole.
- Supervision should report daily on quality of drilling. The current practice of merely recording if the panel is blasted or not is meaningless.

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