# Implementation
# of
# In-stope Roof Bolting
# at
# Elandsrand Gold Mine

**B B NEL (Pr. Eng cand)**

**B Sc Mining Engineering (UP)**

**Mining Manager, Harmony - Elandsrand Gold Mine**

**ABSTRACT**

As part of Elandsrand Gold Mine's (EGM) Safety Campaign "At WAR with Falls of Ground" the implementation of In-stope Roof Bolting as a mine standard at EGM attempt to reduce the unsupported spans created by the effect of a normal support design and potential FOGs after the blast within the unsupported face are.

The paper deals with the advantages of In Stope Roof bolting that include:

Reduced risk of potential personal injury due to FOG by promoting safety by protecting workers in the face to permanent support area both during drilling and cleaning operations.

Produce blast resistant safe hanging wall support after the blast

Reduced cleaning delays thus more effective cleaning operations.

Stoping width could potentially be reduced.

Since implementation of in-stope roof bolting at EGM a marked reduction in the number of injuries as a result of FOG accidents/incidents was noted.

## 1. Introduction

As part of Elandsrand Gold Mine's (EGM) Safety Campaign "At WAR with Falls of Ground" and in an attempt to improve immediate hanging wall conditions, in-stope roof bolting was investigated with the purpose of finding a suitable system for bolting stopes at Elandsrand Gold Mine.

The Mining Department in association with the Rock Engineering Department evaluated different alternatives which included conventional hand held machines combined with different types of air legs, mechanised drill rigs, different types of roof bolts and associated technical aspects.

This paper deals with the technical analysis of in-stope roof bolting as a viable option in a deep level narrow tabular operation as well as the practicality of the installation thereof, with recommendations on implementation.

## 2. EGM – Geology and Underground Mining Environment

EGM is situated on the West Wits line as part of the Witwatersrand basin. EGM is located +- 80km South West of Johannesburg, geographically between Carletonville and Fochville. EGM produces gold exclusively from the Ventersdorp Contact Reef (VCR), a quartz pebble conglomerate.

EGM is classified as a deep level narrow tabular operation. Depth is associated with increased and high stress levels around and in close proximity of all underground excavations. The host rock has the following Uni-axial Compressive Strength values that are used for stability analysis and support design purposes:

| | |
|---|---|
| Hanging (lava) | 220 MPa |
| Reef (VCR) | 210 MPa |
| Footwall (quartz) | 180 MPa |

Numerical modelling attempts to give some estimation of the stress levels for various types and sizes of excavations. At depth it is accepted practice to assume that the stress is high enough to induce fracturing around excavations.

The fracturing as mentioned above has a number of consequences:

a. The immediate skin of rock around an excavation is weakened.
b. The depth of fracturing (penetration) into the solid depends on a number of factors, and in general can be up to 5m for some stoping operations.
c. Horizontal clamping forces are induced in the rock mass that tends to knit the rock together in a more coherent beam.
d. Key blocks are always present and dislodging of one or more of these could lead to an uncontrolled fall of ground.
e. Fracturing might in some cases terminate on dominant geological structures such as bedding planes or joints etc, since the latter are associated with a different mode of rock mass behaviour and characteristics.
f. It is important to know that the face is not recognized as support. The reason for this is that the face and hanging wall are fractured and due to the position of the stress fractures created by the advancing face in relation to the stope face.

These aspects are best illustrated in fig.1 below. Take note that it is a simplified model of the actual fracture profile around u/g excavations.

*Fig.1: Section view of a typical underground stope environment*

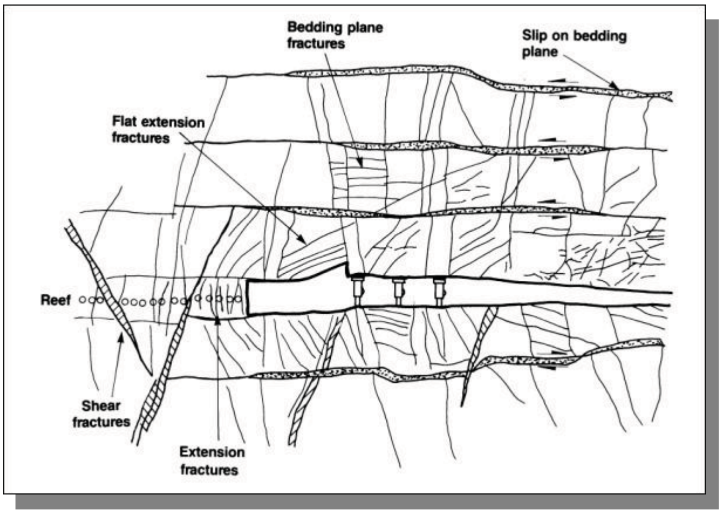
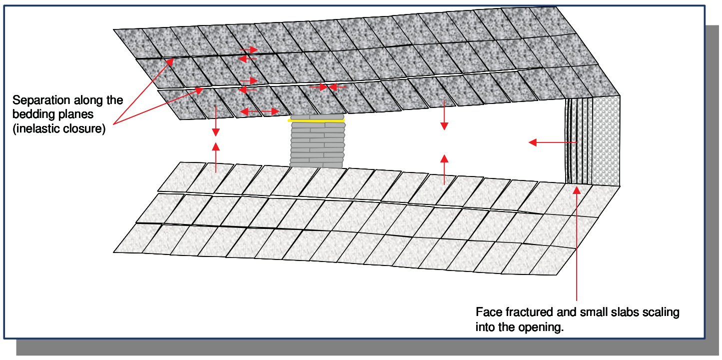


*Fig.2: Section view of a typical stope closure*




3. Mining Method deployed at EGM

Sequential grid mining has been applied at Elandsrand Gold Mine in the sub-vertical shaft area since 1988. This system of regularly spaced dip stabilizing pillars was introduced to provide regional stability by reducing stope spans and, subsequently, the potential of seismic activity. A macro sequence is adhered to with panels mining in Sequential Grid adhering to strict lead and lag controls. At present backfill is used to compliment the Sequential Grid stability pillars for regional support as well as providing local stability to the hanging wall. EGM mines 20 000$m^2$/month at an average dept of 2800 metres below surface at an average stoping width of 1,3 metres.

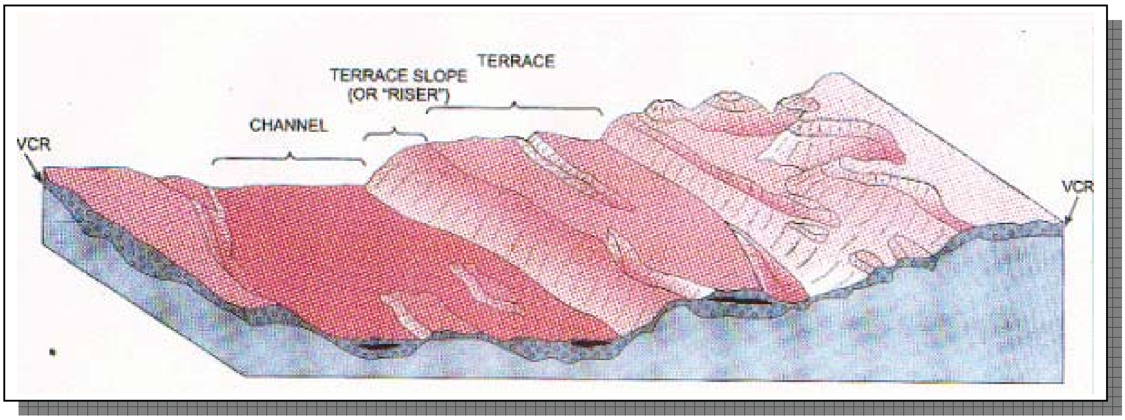
4. Ventersdorp Contact Reef (VCR) at EGM

The Ventersdorp Contact Reef (VCR) rests unconformably on the quartzite of the Witwatersrand Supergroup. This quartzite belongs to the Mondeor Formation in the Western part of the lease area and the Elsburg Quartzite Formation in the eastern part of the lease area. The unconformity angle becomes more perceptible towards the east. The average dip of the VCR is 24 degrees to the SE and the VCR has an average strike of N72 degrees east.

Geological discontinuities observed on Elandsrand Gold Mine include faults, dykes, jointing and sills. Silling may occur in the footwall in many areas adjacent to certain dykes. Flat bedding plane faulting also occurs and results in reef duplication, elimination and brecciation. Faults and dykes are classified according to their relative geologic ages. The most prominent structural direction is NNE/SSW. Structural features conforming to this trend are steeply dipping, normal faults of post VCR age.

The facies model at Elandsrand Gold Mine is based on the Palaeotopographic or Slope and Terrace model. Nine facies types have been recognised at Elandsrand, eight sedimentological and one structural. Four of the facies are thick, high-grade, geologically distinct, reef terraces separated from one another by thin low-grade slope reef. The sand filled channel is a thick low-grade facies. Sandy TC2 is found on the same elevation as TC2 but is essentially a pebbly quartzite with no grade. The Mondeor conglomerates have been identified subcropping against the VCR in stopes on the 36, 37, 38 and 39 lines and have been delineated as a separate facies in these areas.

*Fig.3: Diagrammatic section depicting the terraced landscape used in the slope and terrace model on EGM.*

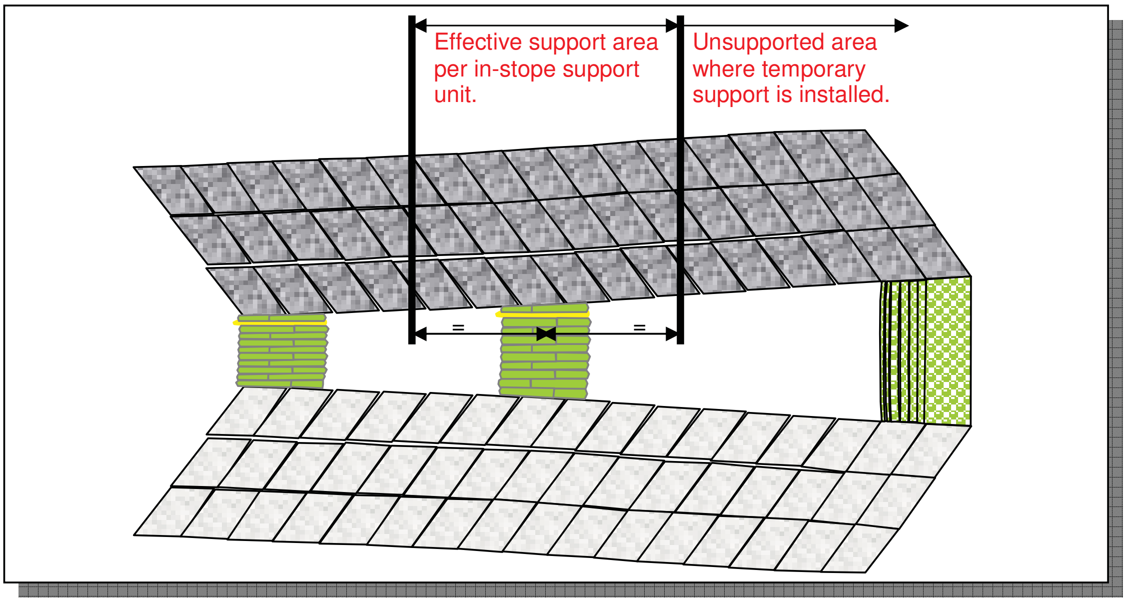



The only economical reef horizon currently exploited at Elandsrand is the VCR. The VCR has the Klipriviersburg lava as a hangingwall and the Elsburg quartzites as a footwall.

5. Effect of Normal Support Mechanism

The implementation of the In-stope Roof Bolting as a mine standard at EGM attempt to reduce the unsupported spans created by the effect of a normal support design and potential FOGs after the blast within the unsupported face area.

*Fig.4: Diagrammatic section depicting the effect of a normal stope support design.*




At EGM and especially, as part of a cleaning operation that comprises of water jet assisted cleaning, supporting the unsupported area between the last line of permanent support and the face is invaluable. Night shift works within the face area, especially in the proposed cycles where support is 2.5-3m from the face after the blast.

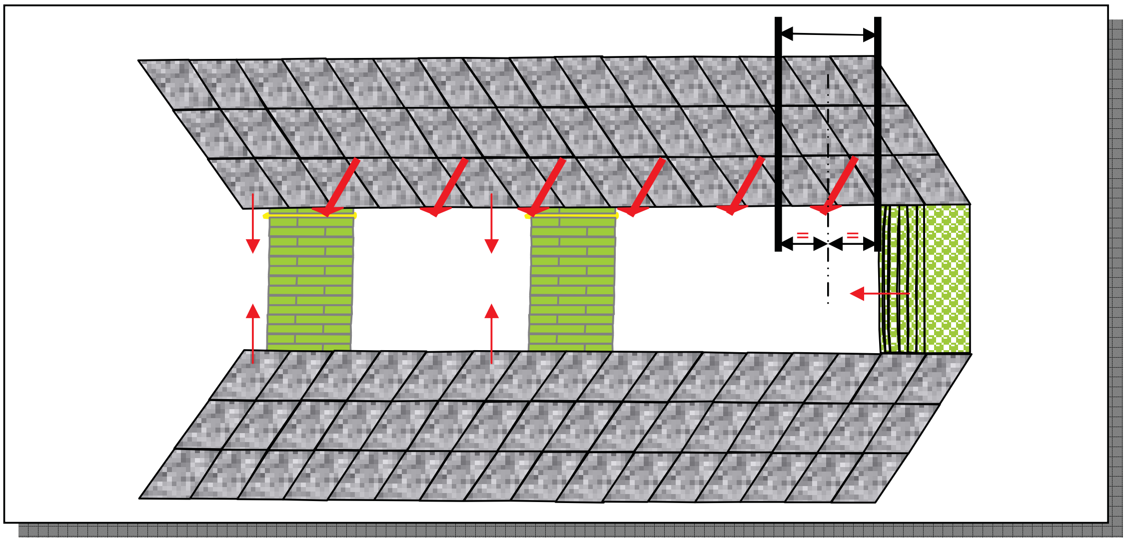
Any FOG results in cleaning delays (panels not being cleaned to satisfaction), loss in production and potential personal injury. Therefore the application of In-stope Roof Bolting reduces the risk of the entire mining operation.

## 6. <u>Support Mechanism of Roof Bolting</u>

It is important to know that by installing a rock bolt, it assists in reinforcing the hanging wall beam being created by the effective length of the rock bolt. By reinforcing the beam, it deflects and reacts almost elastically controlling the inelastic closure that to some extent is expected to reduce the closure. Separation along the stress-induced fractures is minimized as the bolting results in the clamping of these fractures.

Due to the face-to-permanent-support-distance, inelastic closure is allowed to occur (bed separation on pillow lava contacts). Falls of ground can occur within the face area as a result of poor blasting practice in conjunction with the bed separation.

*Fig 5: Section view of a typical in-stope roof bolting installation*



Why In-stope roof bolting in a massive hanging wall formation (Klipriviersburg lava)?

Very topical and perhaps unconventional is the implementation of In-stope roof bolting in a massive hanging wall formation. The question remains, is the Klipriviersburg lava a massive hanging wall formation?

EGM is classified as a deep level narrow tabular operation with the (Klipriviersburg lava) at a Uni-axial Compressive Strength value of 220 MPa. As mentioned, depth is associated with increased stress levels around and in close proximity of underground excavations that result in fracturing. Fracturing often terminate on dominant geological structures such as faults, dykes, contacts of pillow lava and specifically joints at EGM causing potential FOG. Calcite/quarts veins in the lava at EGM are typically flat dipping (30°) and cause wedge type fallouts in the face to permanent support area.

In-stope bolting knits the stress/blasting induced fractures, jointing (typically steep and striking parallel to faces at EGM) and other geological discontinuities mentioned above together thus limiting wedge type fall outs/separation along stress/blast induced fractures.

## 7. Equipment

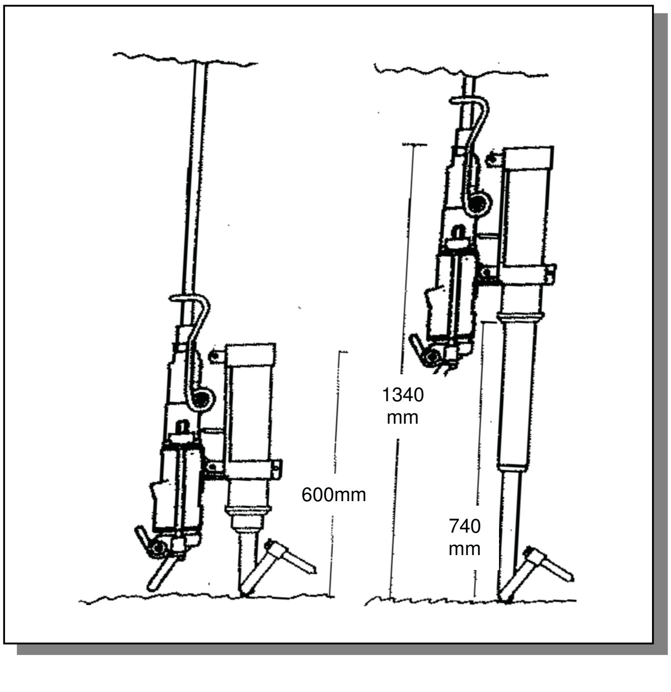
The challenge of installing roof bolts in a narrow tabular ore body in a “sub 1 meter stoping width” environment initially seems to be a near impossible task. On investigation, there are however technology available that has been amongst others well researched and developed in specifically the platinum mining industry. The challenge was to find suitable equipment for the application at EGM.

Mechanisation (Drill rigs) vs Conventional (Handheld machines with air legs)

Mechanised mining requires an entire different approach and methodology in application. As old methodology, in terms of efficiency, is fast becoming absolute the need for mechanisation is immense. EGM could however not find a suitable mechanised drill rig solution that met the criteria of a cost effective and simple to operate application.

EGM opted for a specifically designed Roof bolt Telescopic Air leg supplied by Rock Tool Services used with a standard SECO 215 pneumatic rock drill. The product is designed for drilling holes vertically, or at a steep inclination, in a confined space into the stope hanging wall. This facilitates the installation of support roofbolts in the critical face area where most falls of ground accidents/incidents occur.

*Fig.6:* Roof bolt Telescopic Air leg supplied by Rock Tool services



The double telescopic air leg is designed to have a retracted length of 600mm, a stroke of 740mm and therefore a total extended length up to 1340mm. The SECO 215 pneumatic rock drill is side mounted onto the air leg therefore ensuring an air leg and machine assembly that stand +- 600mm tall. To be able to drill holes in a "sub 1 meter stoping width" environment, specifically manufactured lengths of drill steel supplied by Atlas Copco is used. The drill steel is manufactured to lengths of 300mm, 600mm and 900mm. Each hole is firstly drilled 300mm deep, thereafter deepened to 600mm and finally drilled to the required depth using the respective lengths of drill steel.

The solution of the Roof bolt Telescopic Air leg used with a standard pneumatic rock drill has an added advantage in that the capacity and skills already employed to perform maintenance and repairs on standard stoping and development rock drill machines and air legs are extended to include the maintenance and repairs of this equipment. No additional skills are required to repair and maintain drill rigs for example.

## 8. <u>Different types of Roof Bolts</u>

Different types of roof bolts have distinct different characteristics, both in terms of performance and installation. To find an optimum solution four types of bolts were initially considered. The mechanism and details thereof are outlined in Fig.7 and table 1 respectively.

*Fig.7: Types of bolts initially considered*

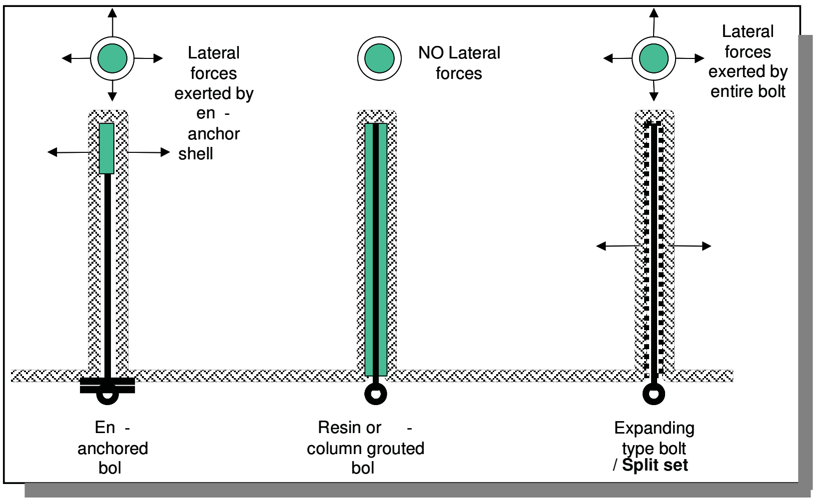


*Table 1*: Summary of types of bolts initially considered

| **Characteristics** | **End-anchor / rock stud** | **Resin / full column grouted** | **0.9m Inflatable type** | **39mm x 0.9m Split set** |
|---|---|---|---|---|
| Equipment requirements | T-spanner/pneumatic torque wrench | Pusher steel, capsule gun (Hammer) | 25 MPa pump, hoses and couplers | Pusher dolly |
| Installation time | 60 seconds | 60 seconds | 40 seconds | 40 seconds |
| Re-tensioning | Often needed | Not needed | Not needed | Not needed |
| Full column support | No | 100% | Appr. 87% | Appr.87% |
| Active support | Yes | Semi-active | Yes | Yes |
| Typical peak load | 10.5 tons | 15.5 tons | 10.7 tons | % of uts only; typically 5 tons on installation |
| Installed reliability | > 70% | > 90% | > 90% | > 90% |
| Sensitivity to undersize borehole diameter (e.g. bit wear) | Not generally sensitive | Not sensitive | Decreases performance due to partial inflation | Increases performance |
| Underground resilience | Damaged plate, thread, bar if not tensioned | Excellent | Very good; valve damage unlikely | Excellent |
| Shear Yieldability | Good 18mm | Low, approx. 7mm, unsafe | Good 18mm | Good 18mm |
| Appr. Cost per bolt | R 23-50, +2.5 (10% bolt wastage loss of shells) = R 26 | R 9-50, R 8-50 grout capsules; no bolt wastage = R 18 | R 29+3.5 (Pump), no bolt wastage = R 32-50 | R 15+plate R 2-50, no bolt wastage =R 17-50 |
| End anchoring & critical bond length | No, cbl of approx. 650mm | No, poor, 132 cm | No, cbl of 380mm + 60mm = 440mm or longer (partial) | No, cbl of approx. 2000mm;poor |
| Comments | Expensive | Low cost, low SF | Expensive | Mechanism? |

3 types of bolts were tested on a trial basis:

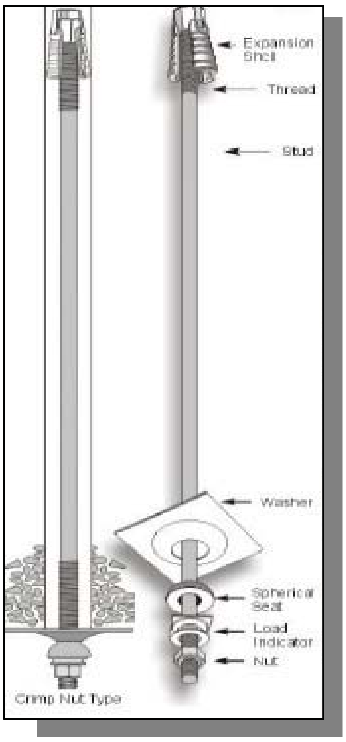
*1.) End-anchor type units* supplied by Videx Mining Supplies offer improved installation quality, but relies solely on the end-anchor unit and re-tensioning with time to be effective. Its effectiveness becomes null and void in case of large ground movement.

2.) The commonly used resin or full column grouted type bolt (*shepherd crook)* has been in use on EGM for a significant period of time in gullies and development. It offers a fairly high load with limited yield. It also requires the use of resin / capsule / full column grouting as a support mechanism. It is generally labour intensive and the quality of installation is difficult to guarantee. No lateral forces are produced after installation and it remains a passive support type during its life cycle.

3.) The *friction type bolt* was used previously on EGM for a significant period of time, mainly in the form of Split sets supplied by RSC affiliate of M&R for gully support. A variation thereof is the Expanding type units, (Expandabolt supplied by New Concept Mining) that operate like an inflated bladder, where water is used to install the unit. Its main advantage is that it induces lateral clamping forces along its length into the immediate rock mass by means of radial deformation. The friction type bolts are however perhaps not optimally suited for application in some lava hanging wall formations i.e. lava, as only once movement occurs bolts are rendered effective.

An end-anchored tendon supplied by Videx Mining Supplies at a bolt length of 0,9m was identified as optimal for conditions on EGM. In-stope bolting would therefore theoretically reinforce a beam thickness of 0.78 - 0.82m, depending on the angle of installation relative to the hanging wall.

*Fig.8:* An end-anchored tendon supplied by Videx Mining Supplies




9.) <u>Tensioning devices.</u>

Adequate tensioning and re-tensioning of end-anchored tendons is critical to its success and support resistance design criteria. Traditional T-spanners as well as ¾” impact wrenches supplied by ATS 2000 (PTY) LTD were trialled.

Tightening roof bolts with traditional T-spanners are strenuous and tightening to the required preload can not be guaranteed. Re-tensioning is problematic if done with T-spanners.

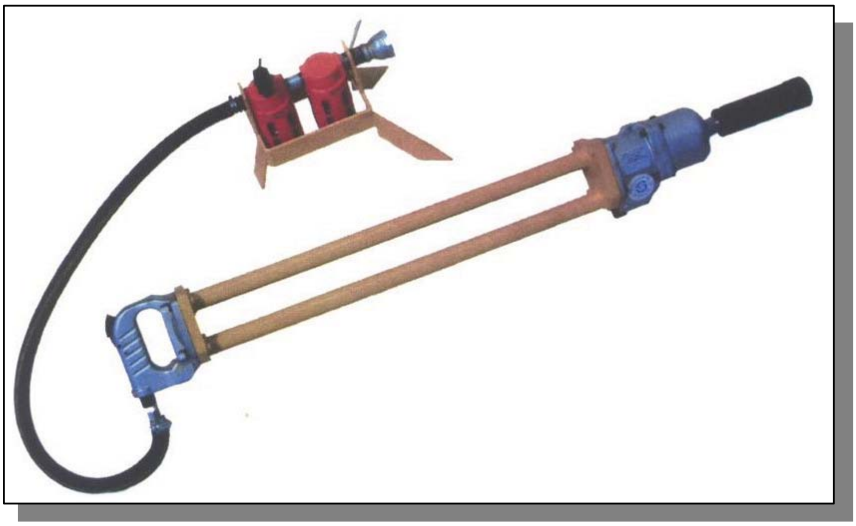
The ¾" impact wrenches ATS-WS 19-31X and XM is a unique design that extends the motor housing closer to the tightening point, eliminating large power losses in long extended sockets for applications further from the tightening point i.e. high SW. Tightening to the required preload is ensured. The light weight design allows for one operator to work with ease and simplicity.

*Table 2*: Specification o f¾" impact wrenches:

| | |
|---|---|
| **Square Drive** | ¾" (19.05mm) |
| **Bolt Capacity** | 16-32mm |
| **Weight** | 5.5 Kg |
| **Length** | 310 – 3000mm |
| **Air Pressure** | 620Kpa |
| **Air Inlet Size** | ⅜" |
| **Hose Size** | ½" |
| **Max Torque** | 1360Nm |

*Fig.9:* ¾" ATS-WS 19-31X

*Fig.10:* ¾" ATS-WS 19-31XM including inline filter and lubricator c/w hose.



For conditions on EGM the ¾" impact wrenches ATS-WS 19-31X and XM supplied by ATS 2000 (PTY) LTD were found to be the optimum tensioning device.

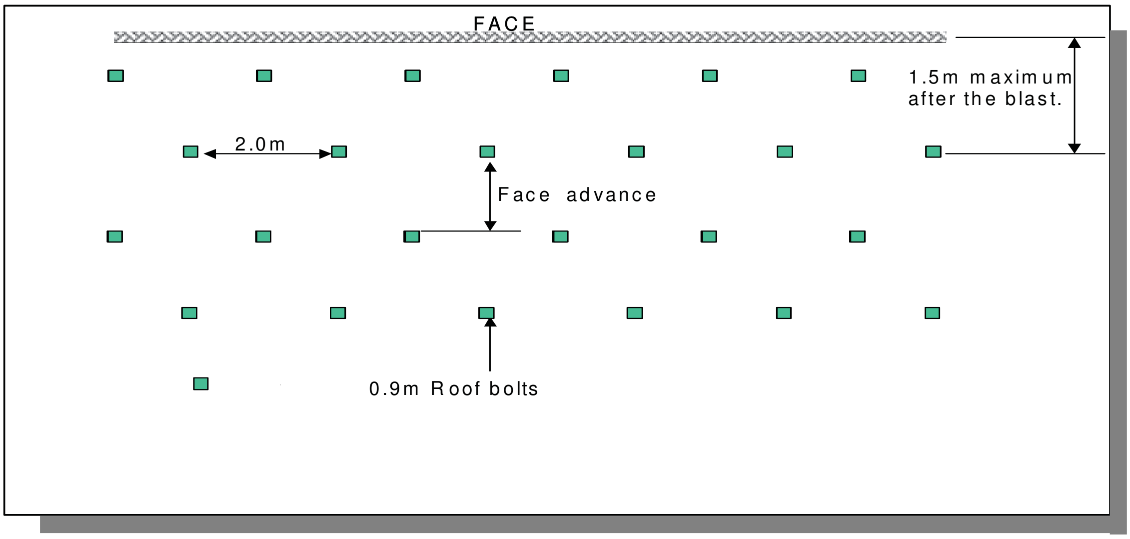
10.) Support design

The newly proposed support standard for In-stope roof bolting was based on the support design as per EGM Code of Practice. In-stope roof bolting was included as additional support with no alteration or relief with regards to the original support layout. (Spacing of support units for example.)

Support standard for In-stope Roof Bolting:

In-stope Roof Bolting is done on an off set pattern, on a 2m dip x Function (face advance) on strike spacing. In-stope Roof bolting is done after every blast, installed maximum 0.5m from the advancing face before the blast. In-Stope Roof bolting does not replace the installation of temporary or permanent support installed to address the fallout thickness design, it compliments it.

*Fig.11:* EGM In-stope Roof Bolting Mine Standard




11.) <u>Notes on Implementation</u>

Key to the implementation of any intervention is communication and commitment in execution. The initial commitment had been established at management level of the operation. Once the accountability and responsibility had been established at shaft management team level the intervention was communicated down the organisation to create support and buy-in.

In creating support and involvement a number of steps were followed:

a Introduction and presentation through Joint Health and Safety Committee structure

b Technical visit - Joint Health and Safety Committee members as well as key Production Supervisors

c Negotiation for commitment with Unions and Associations
  - 1 additional RDO per panel on CONOPS
  - Installs roof bolts prior to face drilling
  - Bonus undertaking

d Introductory Study - 1 Month then roll out.

e Training and underground instructors.

f A comprehensive implementation schedule was formulated.

It is essential that the production crew experience the advantages of In-stope Roof bolting to address initial resistance.

In creating this involvement the awareness levels increased and it ensured overall support for the introduction of in-stope roof bolting at EGM. The principle of "no bolts no blast" now became institutionalised at the mine.

12.) Quality Control - Follow up.

In order to align behaviour (what physically happens at the rock face) to the initial value proposition one cannot over emphasise the importance of follow up. Key to the process was the introduction of independent observers in addition to line supervision. The observers were selected from the HRD committee. They are responsible to do daily observations and record compliance to standards as well as gathering information with regards to practical problems experienced in implementation. These observations and compliance reports are directly reported to the Mining Managers office.

The safety function was mobilised to do compliance audits as well as ad hoc external independent audit teams were used to observe compliance but also understand problems experienced.

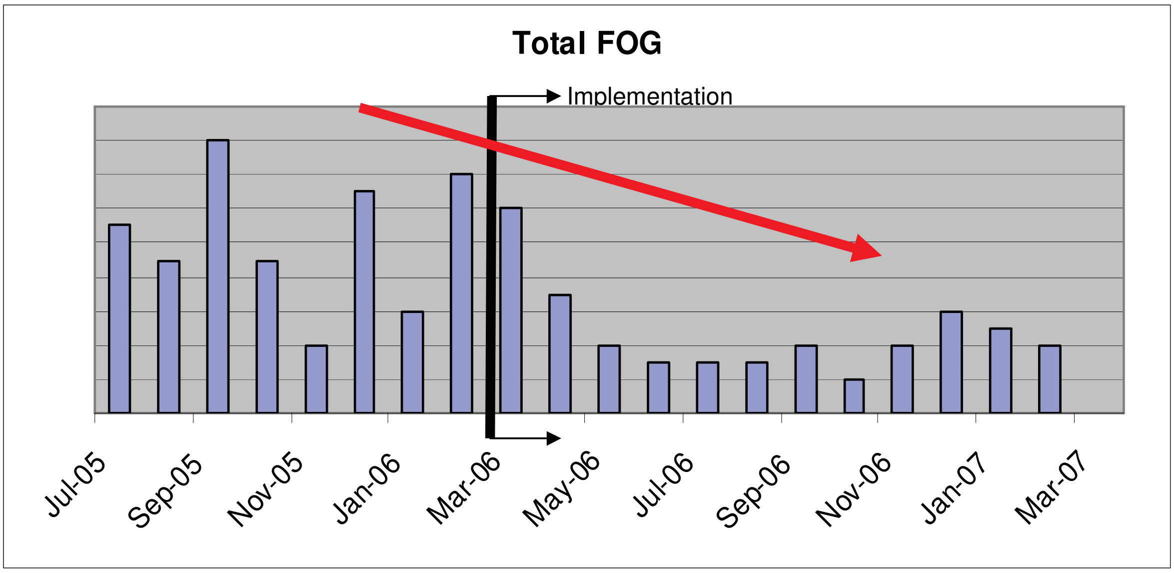
13.) Quantifying the effectiveness of In-stope Roof bolting

Amongst others the controls established by management to reduce the likelihood of FOG include:

- Design and Mining method: Sequential grid.
- Dip stabilizing pillars.
- Lead and lag controls.
- Approaching Geology at largest possible angles.
- Bracket pillars on geological features.
- Reduced mining spans.
- Headings with follow behind gullies.
- Support design – Pre-stressed elongates, packs with backfill placement.
- Centralised blasting.
- Stope pre-conditioning.

As in-stope roof bolting is aimed at reducing the occurrence and effect of FOG accidents/incidents and to improve immediate hanging wall conditions the effectiveness of in-stope roof bolting is quantified by the reduction in the total number of rock-related (seismic and dynamic) injuries pre and post implementation of in-stope roof bolting .

*Graph.11:* Total FOG accidents pre- and post implementation of In-stope roof bolting




Since implementation of in-stope roof bolting a marked reduction in the number of injuries as a result of FOG accidents/incidents was noted.

The major benefits are:

**Reduced risk** of potential personal injury due to FOG by promoting safety by protecting workers in the face to permanent support area both during drilling and cleaning operations.

Produce blast resistant safe hanging wall **support** after the blast

Immediate **hanging wall conditions** could improve as a direct result.

**Reduced cleaning delays** thus more effective cleaning operations.

**Stoping width** could potentially be reduced.

The implementation of in-stope roof bolting had no negative impact on productivity; in fact there has been a noticeable improvement in the mining cycle. The increase in face advance can not necessarily be attributed to the implementation of in-stope roof bolting per say, but rather a combination of improvement initiatives addressing both conditions and behaviour.

14.) Conclusions

Striving to achieve continuous improvement is the challenge faced by leaders of industry today. The Mine Health and Safety Summit held in 2003 for example, where employers, labour and government agreed to work towards achieving national health and safety milestones, necessitate steady improvement in occupational health and safety over the next decade (ending December 2013).

Having said that, Elandsrand Mine is committed to a methodology of continuous improvement with regards to Heath and Safety and the implementation of in-stope roof bolting is our commitment to derive a practical solution that will result in conceptual change with regards to fall of ground accidents.

Since the implementation of in-stope roof bolting as a part of an overall support strategy to support the "At WAR with Falls of Ground" campaign, there has been a marked decrease in the occurrence of fall of ground related incidents that lead to personal injury.

Acknowledgements

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