Secondary breaking strategy for block 4 at De Beers—Finsch Mine

by R.D. Hull* **Paper written on project work carried out in partial fulfilment of B.Sc. (Eng.) (Mining) degree**

Synopsis

As a partial fulfilment for the degree of B.Sc. (Eng) (mining) at the University of the Witwatersrand, a dissertation was to be completed in the mining industry. This was done at Finsch mine, with the purpose of determining the best solution to the required secondary breaking problem. In order to complete the study of the secondary blasting method available for use in the new block 4, cave mining method at Finsch mine the following problem statement was identified and solved

'The methods currently in use, for the secondary breaking of oversize rocks at their source in the current production levels, are to be investigated, and their applicability to the new block 4 mining project determined'.

To effectively achieve this problem statement above; time was spent researching and investigating, in depth, the methods that are currently in use at both Finsch and Koffiefontein mines; so as to gain practical knowledge of these. The methods were identified and independently evaluated, taking into consideration factors such as costs of the equipment, time to break oversize rocks, advantages, disadvantages, safety and labour requirements, etc. This in turn then allowed for a direct comparison between the methods and the decision as to the best to apply to the new block 4 production level.

The methods that were investigated included:

➤ Concussion blasting, where concussion bombs and lay-on charges are used to break hang-ups and boulders.

➤ Drill and blast methods, where holes are drilled in large rocks and charged manually with explosives.

➤ Emulsion secondary blasting, which is a new project in use at Koffiefontein mine from African Explosives Limited.

➤ The Ro-Bust™ breaking system, a hydro-fracturing breaking system.

Once all the methods had been evaluated and compared it was found that the Ro-Bust™ Breaking system was the most applicable for the breaking of boulders, with, the Emulsion Blasting System being used for hang-ups.

Further information and the more in-depth version of this report, is stored in the resource centre at De Beers—Finsch Mine and the School of Mining Engineering WITS University.

Introduction

Finsch Diamond Mine, an operating division of De Beers Consolidated Mines Limited, Central Mines, extracts diamondiferous ore from a kimberlite pipe located in the asbestos hills near Lime Acres. Lime Acres is situated approximately 145 km west of the town of Kimberley. The mine is on the farm Carter in the magisterial district of Postmansburg, in the province of the Northern Cape, South Africa.

In 1960 a prospector, Mr A. Finscham, who was prospecting for asbestos found indicator minerals that are associated with kimberlite and also an area of increased vegetation growth due to the water retention properties of kimberlite. Sampling of the area led to the discovery of a diamond bearing kimberlite pipe, the largest and richest at its time, to have ever been found. The pipe is a near vertical intrusion into the Ghaap plateau dolomite formation and the Kuruman member of the asbestos hills ironstone formation. The pipe is estimated to have originated 118 million years ago and has been classified as a group II kimberlite intrusion, the only one currently known in South Africa. The pipe was weathered to a depth of 80 m below surface where, during mining, relatively unaltered kimberlite was intersected, and had a surface area of approximately 17 ha.

Finsch Diamonds (Pty) Ltd started mining on a small scale. In October 1964 De Beers began to mine the pipe as an open cast operation until September 1990 when this was terminated and the underground operations took over the entire production. At this time the pit had a surface area of 55 ha and a depth of 423 m below surface.

Finsch mine currently employs a blast hole open stoping method of mining on three production levels with the intention that production on levels below 630 m will be by a mechanized block cave mining method. The ground will cave under gravity and be recovered through established draw points. The reason for the change in the mining method is that it is expected that over the next

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15 years approximately 10 million tons of dolomite will fall from the open pit walls, due to sidewall failure, ending up at the pit bottom. This causes the dilution of the ore and makes the mining of block 4 by blast hole open stoping not economically viable. The solution was to use this new method so as to reduce waste by operating with the use of draw control

Production in block 4 is expected to commence in 2002. The block will consist of a total of 282 draw points, and is expected to produce approximately 36 million tons over a 14-year period. Ground handling will be by means of LHDs tipping directly into dump trucks near the orebody. The dump trucks will tram the ore to a gyratory crusher situated at the shaft where thereafter the ore will be conveyed to the current storage passes on the 650 m below collar level.

The block 4 block cave will have a smaller than usual vertical thickness and therefore larger rock fragments are expected to occur in the draw points. This is due to the lower stresses and shorter time of commutation between rock fragments. The loading of these large rocks will have a detrimental effect on the downstream processes causing excess wear on equipment, such as the dump trucks, the gyratory crushes, and also on the in-drive installations. It is therefore required that these large fragments are to be broken within the draw points by secondary breaking mechanisms. The need therefore arises to evaluate and finalize the methods of secondary breaking to be utilized and hence the necessity of this project.

Secondary breaking methods

In order to evaluate secondary breaking and to find the best method to use, the report has been broken up into the relevant methods, and each is discussed independently and then directly compared in order to reach a conclusion on the best applicable method.

There are four types of problems that cause a need for secondary breaking, discussed below and may be seen in Figure 1:

- *High hang-ups* are where a large fragment lies across the entrance to the draw bell up to 19 m above the footwall. This type of hang up is very rare though, and it is more common that this will only occur up to a distance of 5 m above the draw point floor.
- *Rock jumble* is where several ore fragments of rock smaller than two cubic metres form an arch in a drawbell. This is found to occur especially in the throat of a draw point.
- *A low hang up* is a large fragment of over two cubic metres is hanging in the throat or on the floor of a draw point blocking the flow of ore.
- *Draw point oversize* is any large fragment over two cubic metres on the floor of a draw point and effectively prevents loading by LHDs.

For the sake of simplifying the problems mentioned above, in this report high hang ups, rock jumble and low hang-ups will be given the general term hang-up. Similarly to this draw point oversize will be referred to as a big rock or a boulder.

There are many products on the market today that promise the effective secondary breaking of both hang-ups and boulders, including Cone packs, The Quick draw system, The Boulder buster and the Penetrating Cone Fracture (PCF) Rockstik™. Unfortunately these products were either not available to be investigated within the De Beers group of mines, or their use were not permitted by South African Law and therefore not investigated. This project concentrates on the four methods that are in use. That is concussion blasting, drill and blast, emulsion secondary blasting and the Ro-Bust™ hydro fracturing breaking system.

Concussion blasting secondary breaking method

Concussion blasting refers to the conventional means of breaking up boulders and the bringing down of hang-ups, in draw-points, by the use of what is termed concussion bombs or lay-on charges. These charges are strategically placed on, or near, the boulders and exploded resulting in the breaking of the boulder or the bringing down, to the footwall, of a hang-up. The placing of a concussion bomb may be seen in Figure 2. Concussion blasting is a traditional method used for secondary breaking and has been employed on all the underground levels throughout the history of the mine. Currently this method is still used. It is one of the easiest, but unfortunately, most dangerous of all the secondary breaking methods.

Time study

The following average times were calculated from

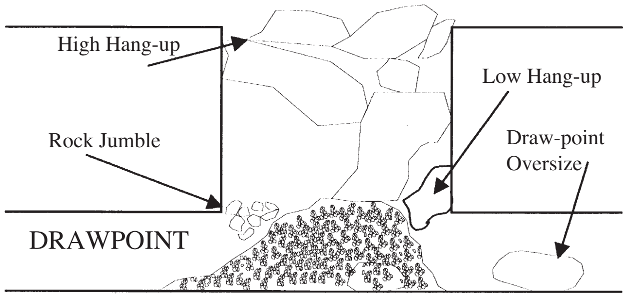

Figure 1—Draw point showing problems requiring secondary breaking

Figure 2—Placing of a lay on charge (mud-pack)

observation whilst working with the concussion blasting crews:

- Anfex Bomb: 68 minutes
- Lay on charge: 64 minutes.

These times are found considering a set of steps required to perform the required outcome, and are found taking the average time for each step then summing this.

Explosive quantities

The following are average quantities of explosives required per blast and are calculated from observation whilst working with concussion blasting, it is to be noted that these are averages calculated to the nearest explosive unit:

- Averages per hang up 1 (25kg) Bag of Anfex
  1 Detonation device
- Averages per blast 22 Sticks of Powergel
  1 Detonation device.

Labour and equipment requirements

This method requires three personnel and one Light Delivery Vehicle. The miner, who must be the holder of a valid blasting certificate and his two charging assistants. These assistants are used as guards during the initiation of the charges by the miner.

Costs

The following are the average costs associated with this method of secondary breaking. To obtain these the values, average values from the above sections were taken and multiplied by average costs obtained from the mining industry for the year 2000.

- Capital cost = R185 000
- Operational costs (servicing, fuel etc.) = R38 260/annum
- Personnel costs = R142 700/annum
- Explosive Costs - Anfex Bomb = R 66/hang-up
  - Lay on Charge = R 56/boulder.

Advantages

The following are the positive aspects associated with this method of concussion blasting secondary breaking.

- The method can be used to blast down both stable and unstable hang-ups.
- The explosives can be very effective in their purpose, if placed correctly.
- The method is not limited to where it can be used, conditional on safety.
- This method is simplistic.

Disadvantages

The following are the negative aspects associated with this method of concussion blasting secondary breaking:

- Damage to the draw-point brow, tunnel support and other installations occur with every blast, with the severity depending on the explosive placement position and quantity
- The method is very time consuming
- The holder of a valid blasting certificate is required
- Placing of explosive charges may be a hazardous process
- Over-use of explosives as the miners do not like to have to repeatedly charge and blast a certain draw point so they over-charge
- Interruption of production occurs as people in the vicinity of the blast must be evacuated, for a minimum ten-minute re-entry time, due to the generation of explosive gasses and dust
- Majority of the energy created by the explosives is lost to the environment and is not focused into the rock.

Safety

This method of secondary breakage is not very safe as it is often requires that the miners climb into the draw points so as to get an effective placing for the explosives. This has not yet resulted in a fatality on this mine but in my opinion there is a high risk of this in the future.

Fragmentation

The fragmentation resulting from this method of secondary breaking is dependent on the type and amount of explosives that are used. The use of an Anfex bomb may result in no fragmentation but if it brings down a high hang-up to a place where it is able to be dealt with then it has succeeded in its purpose. In another light, the use of mudpacks may result in fragmenting a rock into manageable sizes, or if over-charged mostly fines. Unfortunately most draw points end up being over-charged in the incorrect areas and result in lots of fines together with many boulders that require additional blasting.

Possible improvements to the method

Improvements to this method are to educate the miners, in that accurate placing of explosives for a maximum result to occur. This education would have to also include the effects of safety and how their acts could influence the mine as a whole. Also the encouragement of the workers in to using the saplings that are supplied underground. This would enable charging to occur more safely as they would not have to enter draw points.

Conclusions

This method of secondary breaking is the most used method at Finsch mine. It is a very simplistic method with many applications, but it is unfortunately the most dangerous of all the methods and it should be phased out as far possible. There is no price for a human life and if this method is not avoided it will, one day soon, in my opinion result in a fatality.

Conventional drill and blast secondary breaking

This method of secondary breakage comprises of drilling holes, in the most beneficial positions, into boulders, using a secondary breaking drill rig (Figure 3); charging these with explosives and then blasting. This method uses the same principles as concussion blasting, but the explosives are now confined to a hole, and therefore result in less damage. However, the requirement of a person with a valid blasting certificate, and the re-entry period of concussion blasting still exists. This method is only applicable to the breaking of boulders.

Time study

The following average times were calculated from

Figure 3—The Commando 100 secondary breaking drill rig

observation whilst working with the drill and blast secondary blasting crew:

- Drill and blast boulder = 48 minutes.

These times are found considering a set of steps required to perform the required outcome, and are found taking the average time for each step then summing this.

Explosive quantities

The following average quantities of explosives required per blast are calculated from observation whilst working with the drill and blast crew. It is to be noted that these are averages calculated to the nearest explosive unit:

- 7 Magnum cartridges/Charged hole
- 1 Fuse/charged hole.

Labour requirements

This method requires three personnel, a drill rig and a Light Delivery Vehicle. One person to operate the drill rig and act as a guard during the initiation of the charges, the other persons involved are the miner and his charging assistant.

Costs

The following are the average costs associated with this method of secondary breaking. To obtain these the values, average values from the above sections were taken and multiplied by average costs obtained from the mining industry for the year 2000.

➤ Capital cost = R741 200
➤ Operational costs (servicing, fuel etc.) = R330 000/annum
➤ Personnel costs = R152 500/annum
➤ Explosive Costs - Drill and blast = R 37/boulder.

Advantages

The following are the positive aspects associated with this method of secondary breaking.

➤ More effective use of the explosives as they are confined to a drill hole and are therefore able to convert more of their energy into energy that breaks the boulders. As opposed to the majority of the energy dissipating into the atmosphere as is what happens with concussion blasting.
➤ The usage of explosives is less as opposed to concussion blasting.
➤ Good fragmentation results are achievable, conditional on the correct position of the drilled holes.
➤ The method is fast and simplistic.
➤ There are no delays required after drilling, as with emulsion blasting, and charges may be fired immediately.

Disadvantages

The following are the negative aspects associated with this method of secondary breaking.

➤ There is limited use for this method in unstable draw-points and those with rocks that are hung-up. These may only be blasted if there is a certainty that they will not collapse onto the drill rig during the drilling operation.
➤ High capital costs are involved in the purchase of the equipment (drill rig) required.
➤ Production interruptions occur due to the requirements that no personnel are permitted in the vicinity of the area to be blasted during ignition and blasting. There is also a re-entry period of a minimum of ten minutes due to the dust and explosive gasses that are generated.
➤ The holder of a valid blasting certificate is required for the charging and blasting operations.

Safety

This method of secondary breakage is safer than that of concussion blasting but still lacks the required safety levels, in that during charging the miner may be required to proceed into the draw point. Using the remote control allows for heightened safety in the drilling process.

Fragmentation

This method, if correctly utilized, results in good fragmentation with a few small rocks being created. On the other hand if not correctly used, this method can result in a very high fragmentation with a lot of fines. This method gives a fragmentation better than that obtained when using concussion blasting but is still not the ideal.

Possible improvements to the method

Possible improvements to this method would be investigating the possibility of remote charging, and if found viable the implementation thereof. The operators of the drill rig and the miner in charge could also be taught as to where the most effective positioning of a drill hole would be so as to maximize the effect of the blast.

Conclusions

Although utilizing the same principles as concussion blasting, this method is far more effective, with the use of far less explosives, as well as these being confined to blast holes. Unfortunately, though there is a high capital cost involved in the purchase of expensive equipment. This method is only applicable to the blasting of boulders that are on the draw point floor as well as boulders that are firmly hanging up in the draw point mouth. This method is far safer than concussion blasting but still lacking the desired levels of safety, and still has a very high cycle time.

Emulsion secondary breaking method

Emulsion has traditionally been used on Koffiefontein mine for the charging of long holes in ring blasting. A new project together with AEL (African Explosives Limited) bulk systems division, has seen this type of blasting being used for the secondary blasting of large boulders and hang-ups in draw points. It is a very versatile method and is being used together with drill and blast methods as well as for high hang-ups and lay on type blasting. The emulsion unit is mounted on to a frame that is able to fit onto the back of mostly all carriers and can be pneumatically, electrically or hydraulically driven, with the size of the unit being constructed by AEL to the customers specifications, therefore making for a versatile charging unit.

Emulsion is a mixture of oil and greases and as such has no explosive characteristics. It is only once the emulsion is mixed in the correct ratio with the gassing mixture that an explosive is generated. Gassing is a mixture of ethylene glycol, water and sodium acetate. The gassing and the emulsion are mixed in the right ratio by valves or venturi applications just prior to coming out of the nozzle and therefor results in a high safety orientated charging method.

This method may be used with both drill and blast applications as well as concussion blasting of hang-ups. When used to combat hang-ups the charging nozzle is partly removed allowing the emulsion mixture to be sprayed into the drawpoint from a safe area. A pentolite booster is used in both cases for detonation. A schematic of the basic layout of the emulsion car may be seen in Figure 5.

Time study

The following average times were calculated from observation whilst working with the concussion blasting crews:

- Time for drill and blast method = 60 minutes
- Time for blasting of hang-ups = 63 minutes.

These times are found considering a set of steps required to perform the required outcome, and are found taking the average time for each step then summing this. It is important to note that this includes a standard re-entry period of 15 minutes whereas conventional times for the other methods investigated at Finsch mine are 10 minutes re-entry.

Quantities

The following average quantities of explosives required per blast are calculated from observation, it is to be noted that these are averages calculated to the nearest explosive unit. Emulsion is measured in kilograms used as dispensed by the computer controlled dispenser.

- Boulder - 2 kg of emulsion
- Hang-up = 13 kg of emulsion
- Detonation devices.

Labour and equipment requirements

This method of secondary blasting is highly labour intensive. It requires three personnel as well as three vehicles. That is a drill rig, an emulsion cart and the miners LDV.

Costs

The following are the average costs associated with this method of secondary breaking. To obtain these the values, average values from the above sections were taken and multiplied by average costs obtained from the mining industry for the year 2000.

- Capital cost = R 1556 000
- Operational costs (servicing, fuel etc.) = R361 700/annum
- Personnel costs = R162 500/annum
- Explosive costs - Concussion bomb = R35/hang-up
  - Drill and blast = R 13/boulder.

Advantages

The following are the positive aspects associated with the emulsion method of secondary breaking.

- It is easy to use.
- Safe -The emulsion is not explosive until it mixed with the gassing mixture.
- The charger is able to charge from under the brow, and does not have to enter the draw point, due to the range of the spray nozzle. This means the method is perfect for use with hang-ups, as you are able to spray the emulsion from a distance onto a sapling with the magnum and cortex. This emulsion forms a concussion pack and fills into cracks, in the hang up, for maximum blast effect.

Disadvantages

The following are the negative aspects associated with the emulsion method of secondary breaking.

- Due to the huge amount of gasses produced a 15 min re-entry period is required, causing operation delays.
- A large amount of emulsion is wasted prior to charging until the correct gassing of the mixture is obtained. Also after charging when the pipes require cleaning out. This is between six and 12 kilograms.

Figure 4—AEL secondary breaking emulsion cart

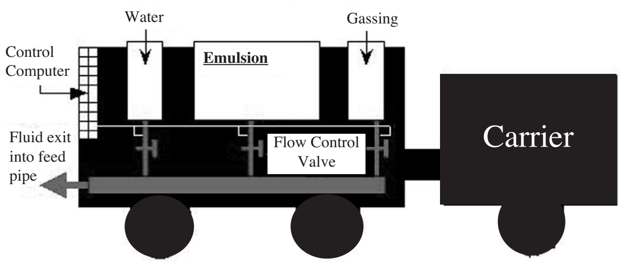

Figure 5—Diagram of AEL emulsion cart

- Crystallization of the emulsion occurs if it is allowed to stand for too long a period
- Once gassed the emulsion must stand for at least half an hour for effective results.
- Ineffective on medium to small boulders as it blows out of the short holes drilled.
- High capital costs are involved in the purchase of the equipment (emulsion carrier and cart) required.

Safety

This method of secondary breaking is high on safety as no personnel are ever required to enter any draw point. The emulsion is also not explosive until it is mixed with the gassing and therefore, is of no danger of exploding until that stage.

Fragmentation

This method of secondary breaking gives good fragmentation of drilled and charged boulders, leaving them in manageable sized fragments that are easily loaded and pass easily through the ore pass grizzlies. This is due to the explosives having a lower energy (powder factor) than magnum cartridges and therefore the amount of fines produced, due to over-breaking, is decreased. This of course is conditional on the placement of the drilled hole in the ideal position. The charging and blasting of hang ups also results in good fragmentation, as when the emulsion is sprayed into the draw point at high pressure, it fills into all the gaps in the rock mass surrounding the area that is to be blasted. This emulsion therefore is in contact with the maximum amount of rock and detonates along with the concussion charge, resulting in the ideal collapsing of the hang up.

Possible improvements to the method

This method is currently too highly labour and equipment intensive. If the emulsion carrier could be mounted on the back of the LDV in use then a specialized emulsion cart would not be required. This would cut down on capital costs by R695 000 as well as annual costs of R210 000 per year, resulting in a more cost-effective operation.

Conclusions

This method of secondary breaking is the best for the charging and blasting of hang-ups. It is also safe and easy to use, although requiring a great deal of personnel and machinery. This method if implemented at Finsch mine could be used to charge hang-ups as well as drilled holes, with the high interruption time being minimized by blasting during the workers tea breaks as well as at the end of the shift.

Ro-Bust™ secondary breaking machine

The Ro-Bust™ is a hydro-fracturing secondary rock breaking system. It can be fitted to any suitable carrier resulting in a fully incorporated machine that has the ability to drill and break large rocks. This machine drills a hole and then using water and explosive cartridges, breaks the rock with a pulse of water.

The Ro-Bust™, that is in use on De Beers—Finsch Mine, is the result of a joint venture between Swartklip Products (a division of Denel, SA) and McCarthy Industries (Denver, Colorado). The trial Ro-Bust™ system was delivered to Finsch Mine in June 1997 and was tested underground for a period of approximately two months. It is currently applied in the production draw points and at the tips, where oversized boulders result in unnecessary delays. The system effectively and safely fragments these oversize boulders and gives satisfactory results. Continual development has been applied, since arriving on the mine, to result in the effective system that is currently in use.

Using a remote control (Figure 6) the Ro-Bust™ drills boulders, places the required number of cartridges in the drill hole, fills that hole with water, and detonates the cartridges using a pulse of water at greater than 15 Mpa. This pulse is generated and released by the pulse generator through the dispense nozzle. The machine head may be seen in Figure 7.

Time study

The following average time was calculated from observation whilst working with the concussion blasting crews:

Average time to drill and break boulder = 5 minutes.

These times are found considering a set of steps required to perform the required outcome, and are found taking the average time for each step then summing this. It is important to note that a re-entry period is not required for this method of secondary blasting, and therefore it is possible to achieve a situation of no production delays.

Quantities

The following average quantities of explosives required per

Figure 6—Ro-Bust™ remote control

Figure 7—Showing main nozzle and drill bit

blast are calculated from observation, it is to be noted that these are averages calculated to the nearest explosive unit:

Average explosive cartridges per boulder = 4 cartridges.

The used cartridges may be seen in Figure 8.

One cartridge contains 25 g of explosives and 30 of these are loaded into the cartridge dispenser (Figure 9). The water that the machine uses is service water and not drinking water. Approximately 100 litres of water per shift is used depending on how much the machine is used.

Labour requirements

This method of secondary breaking requires one operator and the Ro-Bust™ machine. This operator is directed where to go by the team leader or section miner, both of which have to be in the section. The operator of the Ro-Bust™ does not have to be the holder of a valid blasting certificate. Unfortunately a high level of operator care and skill is required from the operator in order to obtain the maximum efficiency.

Costs

The following are the average costs associated with this method of secondary breaking. To obtain these the values, average values from the above sections were taken and multiplied by average costs obtained from the mining industry for the year 2000.

- Capital cost = R3 393 750
- Operational costs (servicing, fuel, etc.) = R250 500/annum
- Personnel costs = R50 000/annum
- Explosive Costs - Cartridges = R55/Boulder.

Figure 8—Ro-Bust™ cartridge

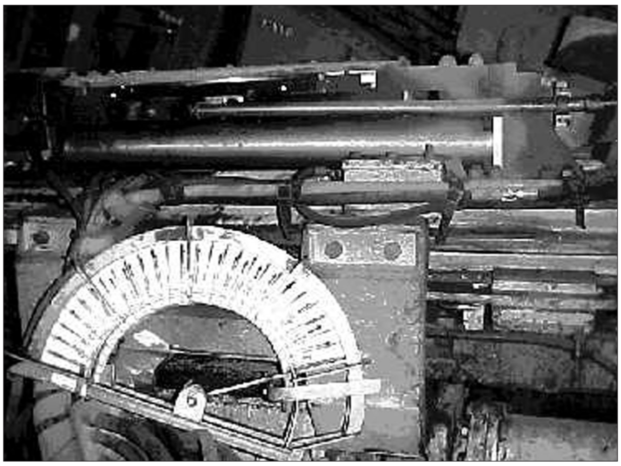

Figure 9—Ro-Bust™ cartridge dispenser

Advantages

The following are the positive aspects associated with this method of secondary breaking.

- After breaking the rocks there is no re-entry time required.
- There is no production delays due to the breaking of rocks as there are relatively no explosive gasses produced, there is also no concussion, relatively no fly rock and highly reduced noise levels.
- This method is quick and effective if the hole is placed in the correct position.
- The operator does not require a blasting certificate.
- Can blast boulders near to or on the tips.
- Totally mechanized operation.

Disadvantages

The following are the negative aspects associated with this method of secondary breaking.

- High capital costs are involved in the purchase of the equipment (Ro-Bust™) required.
- If there are any unseen cracks (i.e. the rock is not whole) then the water escapes or the pressure generated by the pulse generator is not effective enough to cause ignition of the explosive charge, and a misfire results.
- The current model in use has in the past had a very high breakdown rate, but with improvements made in the last three months this is decreasing.
- The remote batteries do not last, causing delays when batteries run flat.
- This machine is unable to drill up dip as the water runs out.
- The use of water with kimberlite is considered a disadvantage if any breaking occurs near the brow where weakness is not wanted, but this is not a disadvantage in terms of boulders broken on the footwall.

Safety

This method of secondary breakage is by far the safest of all the others investigated, if it is operated within the correct parameters. That is that the operator correctly follows procedures. The method does not require a miner with a valid blasting certificate, indicating the safety factor associated with the cartridges that are used.

Fragmentation

Fragmentation when using the Ro-Bust™ is ideal as it minimizes the amount of fines produced, which cause downstream problems, and keeps the post-blast particle size small enough to be efficiently loaded and transported to the tips where they pass, with minimal extra breaking, through the grizzlies.

Possible improvements to the method

The method currently in use is of a high enough standard so as to be effective and applicable to the requirements it has been set. The efficiency of the system could be improved through the following procedures.

- Training of more operators to ensure that this method of secondary breaking is being utilized on all the shifts. This would also prevent downtime of the machine when the usual operator is unable to be at work.
- Training of the operators where to drill in the boulders so as to attain the maximum breaking effect per hole drilled, and to minimize the necessity to re-drill a particular boulder.
- The inclusion of a dispatch system, similar to the one used on the LHDs, that can inform the Ro-Bust as to where it is required, would maximize the use of the system and avoid delays. This system would require the LHD operator to press a button on their dispatch screen that would send a signal to the control room and the Ro-Bust™ informing it where breaking is required.

These improvements would not only assist the mine to achieve better use out of the Ro-Bust system but also make operators' lives simpler.

Conclusions

This method handles boulders on the footwall with great success, and with new technology, such as the use of gel instead of water, should certainly not be discarded for dealing with hang-ups. This method is by far the safest of all the methods as well as having the lowest cycle time. Unfortunately though it has a very high capital cost. There could be further studies into this, as the production achieved during the low cycle times could pay for the high capital cost in a very short period.

Methods applicable to use in block 4

After completion of the investigation of the above four methods an in-depth comparison study was performed. As it was found that no one method meets the requirements for use with the problems of both hang-ups and boulders, a method is to be suggested for each. From the findings of this method comparison study, the following are my suggestions for a method of secondary blasting to be implemented into the block 4 project.

Blasting of big rocks or boulders

The method suggested for use here is the Ro-Bust™ Breaking System, due to it having the lowest cycle time of all the methods investigated. Therefore the high capital cost will be covered in a short period, due to production occurring in time that would normally be lost. The Ro-Bust™ Breaking System is to operate as part of the production team, being linked to the LHD dispatch system. This means that when a large rock or boulder is detected in a draw point the operator of that LHD notifies the Ro-Bust™ operator who then moves to the required position and breaks the rock.

Blasting of high hang ups

The method suggested for use here is the Emulsion Blasting System, due to the following factors.

- This system is safer than concussion blasting, with no personnel having to enter a draw point and the emulsion only being explosive when mixed with the gassing.
- The emulsion gives effective blasting by placing the explosive charge at the root of the problem. This allows for less draw point damage, as fewer blastings are required for the same effect. This is important to note, when thinking that the cost of a draw point in a block cave is approximately R260 000, for just the support.

Emulsion blasting has unfortunately a high cycle time, and it is therefore suggested that any blasting that may be required, using this method is done during tea time or at the end of the shift.

As this is only an initial study, further studies are to be conducted to find the correct quantities, etc. to be used in the actual block 4 section.

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  - Steve Kirkpatrick: Production shift boss
  - All the production miners
  - Jerry Sol: Acting mine overseer
- University of the Witwatersrand—School of Mining Engineering, especially
  - Prof H. Philips, Mr Yilmaz and all the staff.

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