Increasing Production Time in Continuous Mining Methods

EE Dorey
D McGinness

SYNOPSIS

The use of continuous miners in a conventional bord and pillar section results in a considerable amount of unproductive time. This is due to the roof support requirements, continuous miner configurations, and shuttle car 'change-outs'. These factors have contributed to the continuous miner having an effective cutting time of 3,5 hrs out of a possible 8,5 hrs shift.

This paper describes the initial trials with a continuous haulage behind a full face miner with on-board bolters. The use of this combination would hopefully address the unproductive time, created by the aforementioned factors.

INTRODUCTION

Khuthala Colliery will supply 1,136 million tons of coal per month to Kendal Power Station at full production. The method of mining is underground bord and pillar with continuous miners and shuttle cars.

The mine is situated approximately 19 kms off the N12 highway and some 80kms east of Johannesburg.

GEOLOGY

Khutala is placed on the Bombardie and Cologne farms and is part of the Witbank coal fields. The coal deposits are contained in the Vryheid Formations, which are part of the Karoo Supergroup and there are five coal seams present. See Figure 1

Of the five seams present only the 2,4 and 5 seams are economically viable and at this stage mining is done on the 2 and 4 seams only. Table 1 summarises the relevant information on the three coal seams.

TABLE 1

SEAM	AVERAGE DEPTH	AVERAGE THICKNESS	AVERAGE RAW CV
2	71,9m	5,34m	23,00
4	48,2m	5,71m	18,50
5	36,7m	1,98m	25,90

MINING

The Shaft System

The shaft system at Khutala consists of one 12,2m diameter downcast service shaft, an 8m x 2,5m x 15º incline belt shaft and one 10m diameter upcast shaft. In addition a further 2 x 6 diameter upcast shafts and 2 x 6m diameter downcast shafts have been constructed with a further 2 x 6m downcast shafts planned for full production.

The service shaft is equipped with a 65t Koepe type winder and a 2t Mary Anne. The 10m up cast shaft is equipped with 3 x 1250kw axial flow fans capable of handling 1500m^3 /s of air in total. The incline shaft has 2 x 1500mm wide belts 750m long running at 3,5m/s.

Coal Transport

The coal from the section feeder breakers is fed onto 1050mm section belts, operating at 2,5m/s with a design capacity of 1100tph. These belts can be extended up to 1000m, the length of a panel. They will in turn tip either into bunkers, situated in the 2 and 4 seam parting, or onto 1500mm main belts, situated on the 2 seam, which run at 3,6m/s at a capacity of 2400tph.

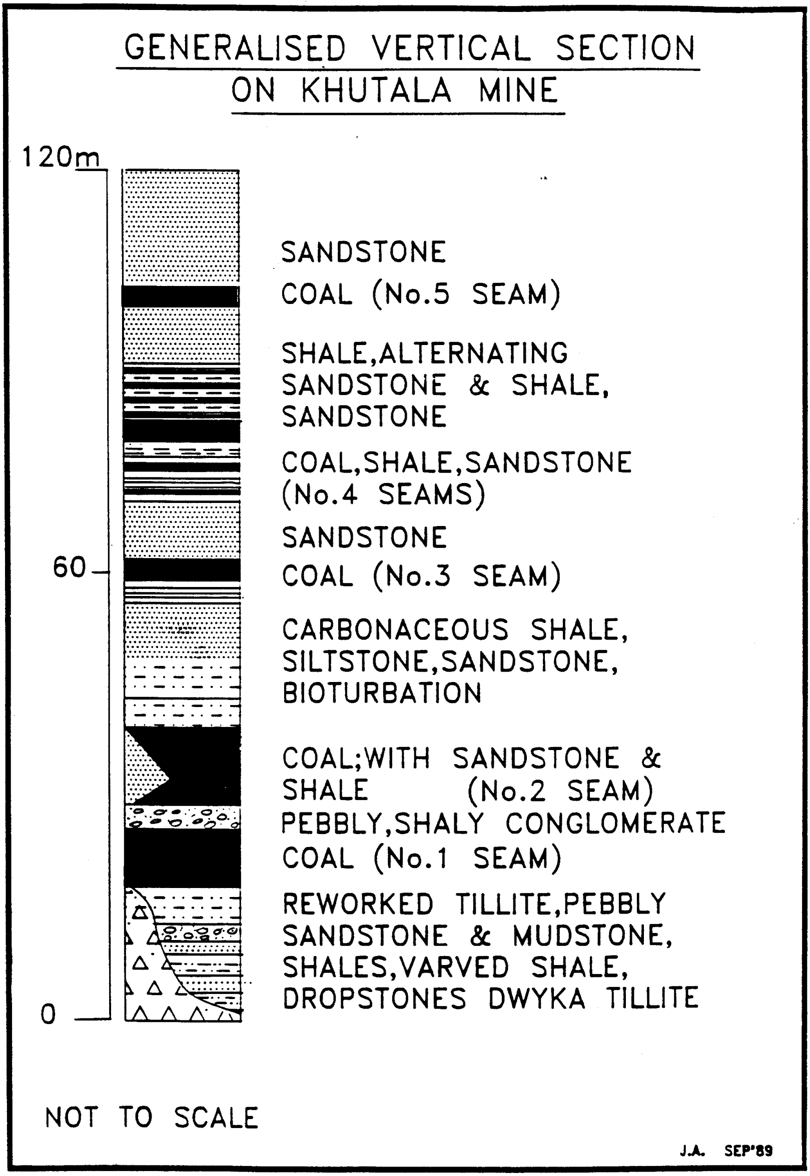

Figure 1

Vertical Section of Khutala Mine

Present Mining Method

Underground mining at Khutala is done using the conventional bord and pillar workings with continuous miners. To date the coal has been mined using double pass drum miners in a conventional application.

The development panels of Khutala are advanced on the floor of the seam leaving the topcoal to be removed on the final retreat. Panel mining is done against the roof contact while advancing, with the bottom coal being removed using a secondary advance system. In certain localised areas of the mine a very competent but thin stone band occurs in the upper band of the No 2 coal seam. The drum miners are unable to cut this effectively, and thus the panels are advanced on the floor. A secondary mining operation is then started whereby this coal is drilled, blasted and loaded using gathering arm loaders and shuttle cars. Various methods have been considered to mine this coal, however, the conventional drill and blast topcoaling has proven to be the most successful.

All panels have been laid out to extend from either the main or secondary development. Each section consists of a double header panel and the layout is designed to take into account the main geological features of the area, so as to provide adequate mining capacity. The double header section which is the basic production units at Khutala, is an 18-20 roadway panel either in main or panel development. The section is equipped with two 1050mm conveyor belts feeding onto a higher capacity district/main conveyor. Fresh air is fed to the work face via the central roadways. At the face it is split and coursed through the section returning to the main return airways along both flanks of the section. Each side of the double header is equipped with one drum miner, one roof bolter, one feeder breaker, three shuttle cars and auxiliary equipment.

Cutting Sequence

The continuous miners cuts the 6,4m bord in two lifts. The first lift is cut for 12 metres and the second lift for 15 metres, resulting in the machine having to be moved every 15 metres of face advance. The 15m face advance is then supported by the roof bolter before any further cutting can take place.

IMPROVING PRODUCTIVE TIME

Cutting and Support

To improve the non productive operation of the continuous miner, the machine must be able to cut the full width of roadway in one pass and support it as it advances.

Khutala used a Voest ABM30 continuous miner for this part of the trial. This machine has a cutting head of 5,54m in width by 1,15m in diameter. The cutting head can extend to 6m wide when cutting. There are two onboard bolters that are able to install roofbolts while the machine is cutting, and is made possible by the design of the machine.

The discharge boom, conveyor, spade and cutter head move forward independent of the main frame of the machine, enabling the cutting head to sump for a depth of one metre before the main frame has to be moved. The roof bolter rigs are mounted to the main frame and can install bolts independently of the cutting and sumping sequence.

The Voest was put on trial with three shuttle cars in July 1994, and was removed from production at the end of September 1995 for modification. In the 14 months, 786 361 tons of coal were produced, the worst month being 24 288 tons and the best month 66 021 tons. The average tonnage per month was 56 169 tons on a two shift basis.

The modifications to the machine were done to simplify the hydraulics and reduce the difficulty experienced when maintaining or repairing the machine.

The following modifications were made:

a. Reduced the electric pump motors from two to one;
b. Removed 3 of the 7 hydraulic pumps;
c. The conveyor drums were changed from hydraulic to an electric dual drive;
d. The two booster pumps for water supply were re-positioned so that only one hydraulic motor was needed to drive them both

e. A proportional solenoid was fitted on the valve bank for accurate setting of shearing speed, pressures and overload trips;
f. The hydraulic hoses were re-routed for easy access;
g. The dust curtain was made retractable for easier tramming;
h. The conveyor boom double hinge point, elevating pivot point and the spade bridge piece were redesigned and strengthened.
i. The on-board bolters were raised to reduce whip on the drill rods.
j. The valve banks and booster pups were re-positioned;
k. An "Engarde" dust suppression system was installed.

Coal Conveying

In order to effectively remove the coal produced by the full face miner/bolter in a more continuous mode than can be done by using shuttle cars, a continuous haulage was obtained for the trial. The haulage used was a Bateman snake conveyor, consisting of an inbye breaker car, eleven intermediate cars, and a delivery car.

The inbye Breaker Car

The breaker car is situated directly underneath the boom of the continuous miner and its purpose is to reduce the coal lump size. It has a 3 ton hopper with a rotary breaker and a chain conveyor, which delivers its load directly onto the connected intermediate car.

The Intermediate Car

See figure 2. The intermediate cars are the connection between the inbye breaker and the delivery car. It consists of a series of separate units linked together through which is carried the continuous belt. The continuous belt carries the coal to the end of the first unit where it discharges onto the second, then third, etc. The belt, after it discharges the coal onto the next unit, around the drive pulley and gets twisted, using a rugby ball shaped pulley. This pulley will centralise the belt and line it up for the next car. Each car is individually driven and will follow in the tracks of the car inbye or outbye of it. See Figure 3.

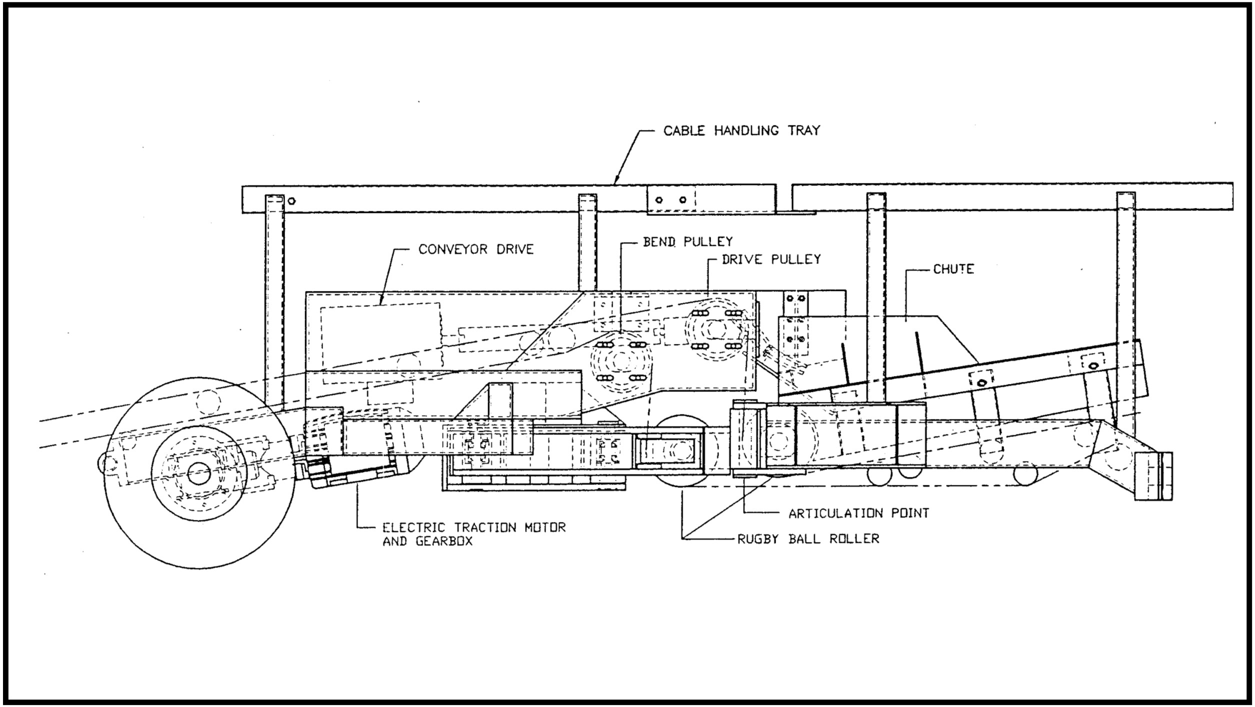

Figure 2

Intermediate Car

The Delivery Car

See Figure 4. The purpose of this car is to transfer the coal from the continuous belt onto the section belt. The unit has its own belt and is pulled behind the continuous haulage, its position maintained by a set of rails laid down 0,4m from the side of the section conveyor.

Continuous Haulage Trial

EL Bateman imported a second hand continuous haulage from Emerald Mine in the United States for the trial. Due to the lack of knowledge regarding the products, it was decided to give the Snake conveyor a test run on surface before taking it down underground. The added benefit was that if any changes had to be made to get the machine to run it would be easier to fabricate on surface.

The snake was taken to Matla Colliery stock yard for the surface trial when a converted 12HM continous miner reclaimer would be used to load the coal. Roadways were laid out using chevron tape to ensure the snake could negotiate the corners in a 6m wide roadway.

The reclaimer delivered coal into the inbye breaker car at a rate of 800 to 1000 tons per hour. Excessive coal spillage was encountered at the point where the coal was tipped onto the permanent conveyor. A shute was constructed and fitted to the cross conveyor car to solve the problem. The belt itself could carry the coal with very little spillage. No problems occurred tramming the belt in a 6m roadway or around the corners. The belting initially used on the snake was rubber belting which had to be changed to PVC flame retardant belting. The snake was fitted with a 1200mm belt of class 1000 with some of the weave removed to make it more flexible. When coal was loaded onto the belt, blockages occurred at every car shute due to runback. The belt was coated with a thin layer of rubber which stopped the problem.

Another problem encountered was spillage at the inbye breaker car where the chain conveyor was dragging fine coal back on the return side. A plate was welded onto the front end of the breaker car, which enable the chain conveyor to return the fine coal.

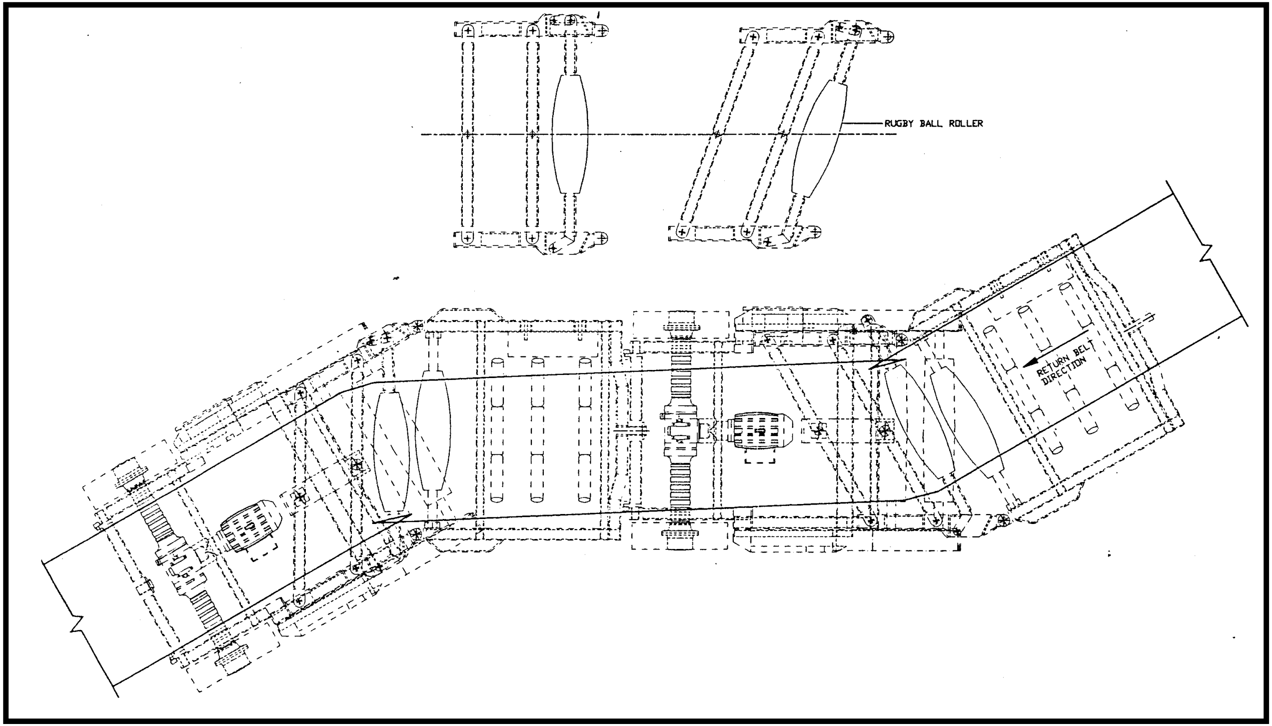

Figure 3

Intermediate Car

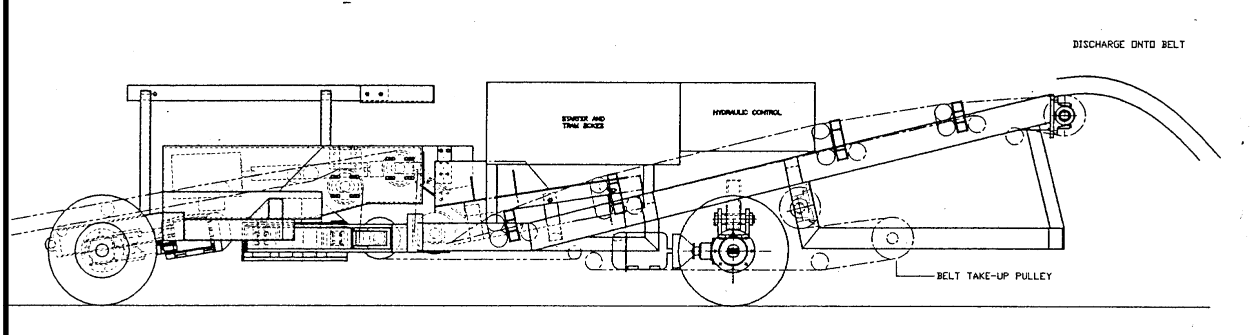

Figure 4

Delivery Car

After the surface trial, the snake was brought over to the Khutala Colliery in November 1995, taken underground and re-assembled. The divisional Mining Engineering Department inspected the machine while on trial at Matla and prior to its going into production at Khutala Colliery. SABS approval was give after an under-ground inspection.

Planned Section Layout

To keep capital cost of the investigation to a minimum, it was decided to import the minimum number of cars. This had the disadvantage of a belt extension being done every pillar advance. The pillar dimensions were designed to be 16,8m by 17,2m giving a final safety factor of 1,4 after top coaling. To enable the machine to start a split in one smooth cut and not jam its boom against the opposite ribside or have to dump coal on the floor, the split taken from the belt road would be at 60° off the line of advance.

The face line of advance had to be kept straight as the snake could not get to a face that was behind the end of the permanent belt.

The ventilation was coursed across the section with one return. The tractor road was carried in the right hand barrier and the switch road in the first right hand roadway. The first left hand roadway was kept open to allow access to the left side of the section for stone dusting and sweeping. See figure 5.

Section Conveyor

The section conveyor used was a class 1000 x 1350mm PVC belt with a 75Kw motor and 50m belt take up with an electric winch giving constant tension. The tail-end used was a return pulley in a frame, making it much easier and lighter to pull forward. The belt was carried 0,4m off the centre line to allow room for the snake. See Figure 6

Section Equipment

1 Voest ABM30
1 Bateman snake conveyor
1 LHD

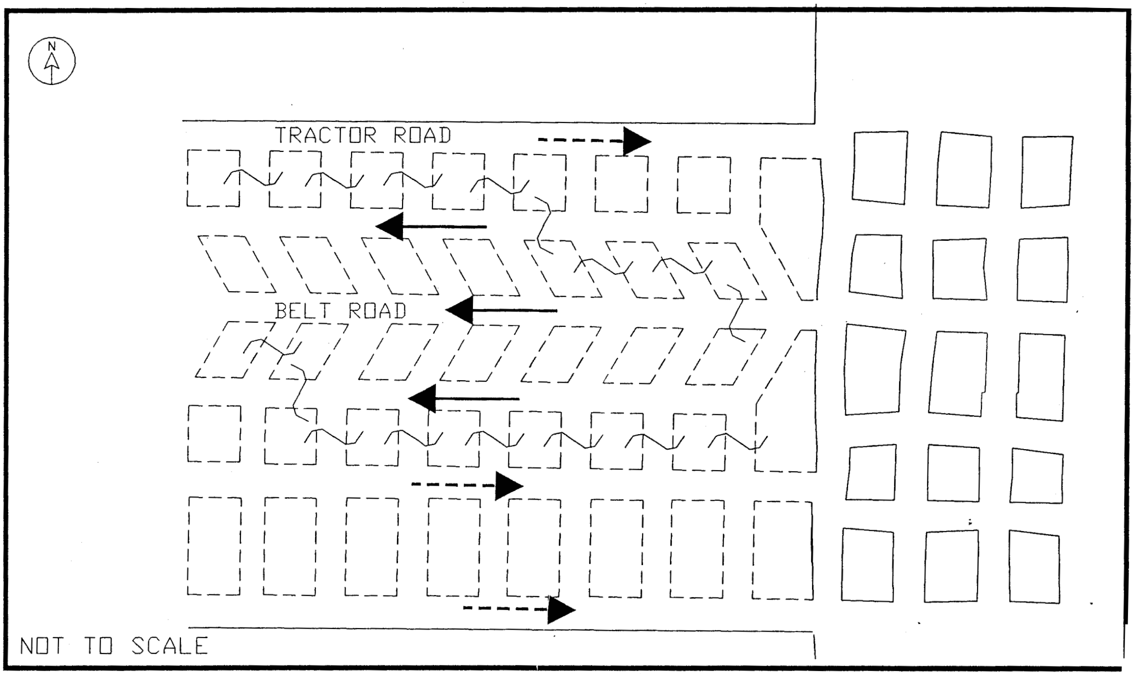

Figure 5

Section Layout

1 Bank of switches
1 Transformer
1 Oil container
1 Tool container and miner's box
2 Artisan tool boxes
1 Auxiliary fan

Section Labour

1 Miner
1 Fitter
1 Electrician
1 Voest machine operator
1 Snake Operator
2 Roofbolt Operators
1 LHD Operator
1 General worker (to assist with ventilation and relieve if anybody is sick)

A total of 9 people per shift in the section.

Production Statistics

Best production shift loaded 1800 tons
Best advance was 12m in an hour i.e. 480 tons

Problems and Solutions

- The two rugby ball pulleys failed due to bearings not packed properly.
- The conveyor drive motors were wired for 60Hz current. These were replaced with new 15Kw, 100v 50 Hz motors.
- One drive pulley shaft sheared due to metal fatigue.
- The 100v to 24v control circuit transformer failed.
- 10 of the tracking rollers failed due to lateral forces generated in keeping the belt on line. This problem was solved by installing taper roller bearings.
- The undulations in the floor next to the section conveyor either bent the positioning rails or jammed the snake. To overcome this problem the delivery car will be designed

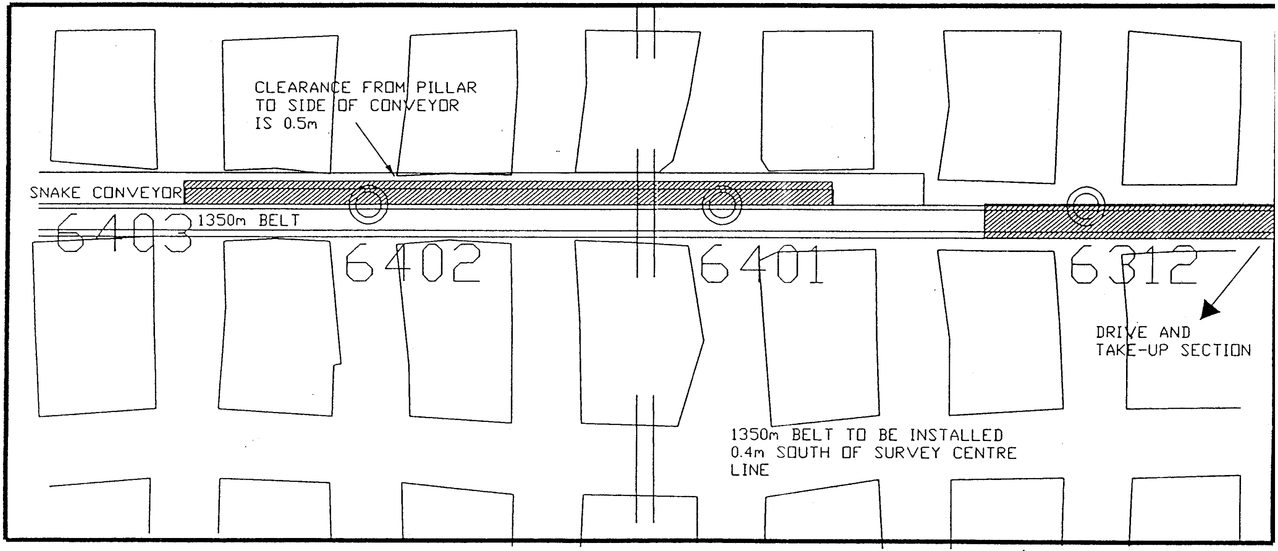

Figure 6

Tail End Layout

to run on top of the belt structure. (see figures 7 and 8)

- Carry back spillage was a major problem and caused the belt to jam. This problem would be solved by the redesign of the delivery car.
- Belt tension-the practice that if the belt slips, tension was applied. This caused the belt to deform and the mechanical joints that were being used to be pulled apart. The problem was overcome by installing an automatic tension device and on belt start up the tension applied would be 8MPA on the hydraulic take-up and the running speed 4MPA.
- The foam filled tyres travelling in the rails were being destroyed by the rail, and the car had to be trammed out of the rail to replace the tyre. The foam filled tyres were replaced with solid tyres and the redesign of the delivery car to run on top of the belt will assist.
- If the drive, bend or the rugby ball pulley moved, the belt ran against the pulley bearing which it destroyed. These pulleys can only be re-positioned when the belt is stopped and a chain block used to move the pulley. A slide block will be installed to facilitate alignment.

ANTICIPATED BENEFITS

- Increased productivity of primary coal mining machines. This will be achieved with the use of the single pass primary mining machine with on-board bolting resulting in a minimum of moves.
- Reduction in labour.
- Improved safety - less moving machines and up to date roof support.
- Mining can take place on two shifts with maintenance and belt extensions on the third shift.

ANTICIPATED REQUIREMENTS

- Good and level floor conditions.
- Greater outbye belt capacities and storage.
- The section belt should have a belt storage system to facilitate and speed up the belt extensions.

- 24 hour coal clearance capabilities.
- If a conventional double pass miner was used, a roof bolter would be required on either side of the haulage.
- Permanent LHD for clean-up in section.
- Satellite roof bolter for slips and brows.

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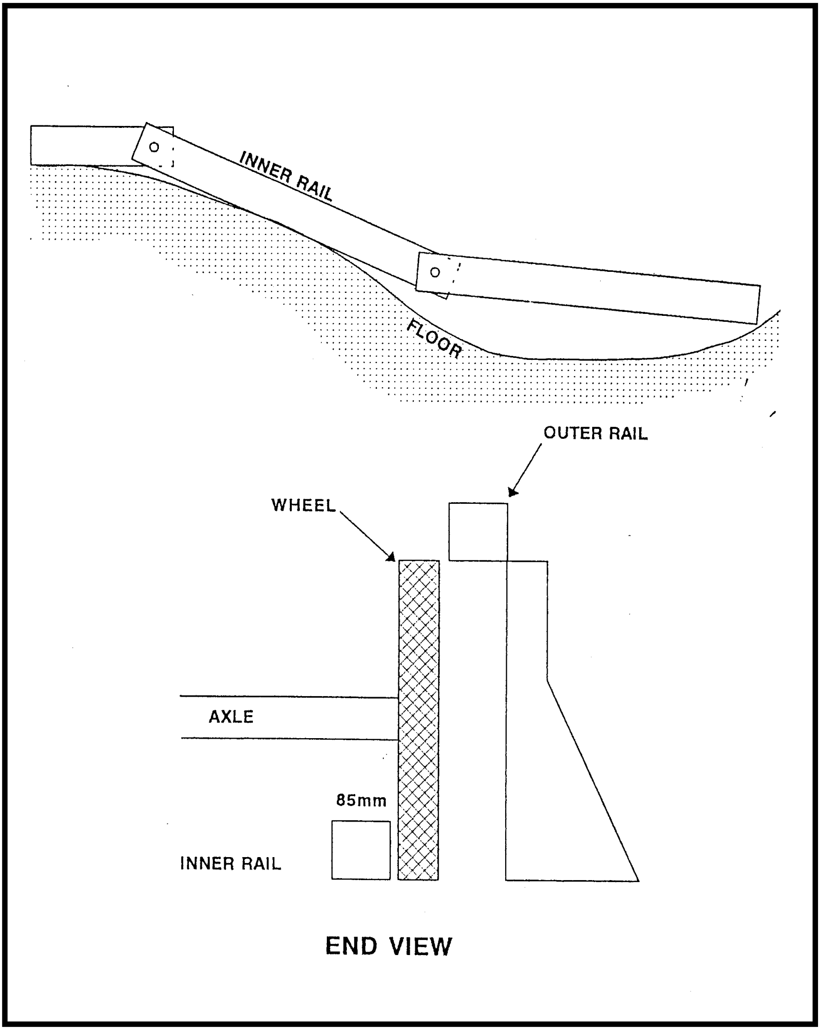

Figure 7
Discharge Car Guide Rail

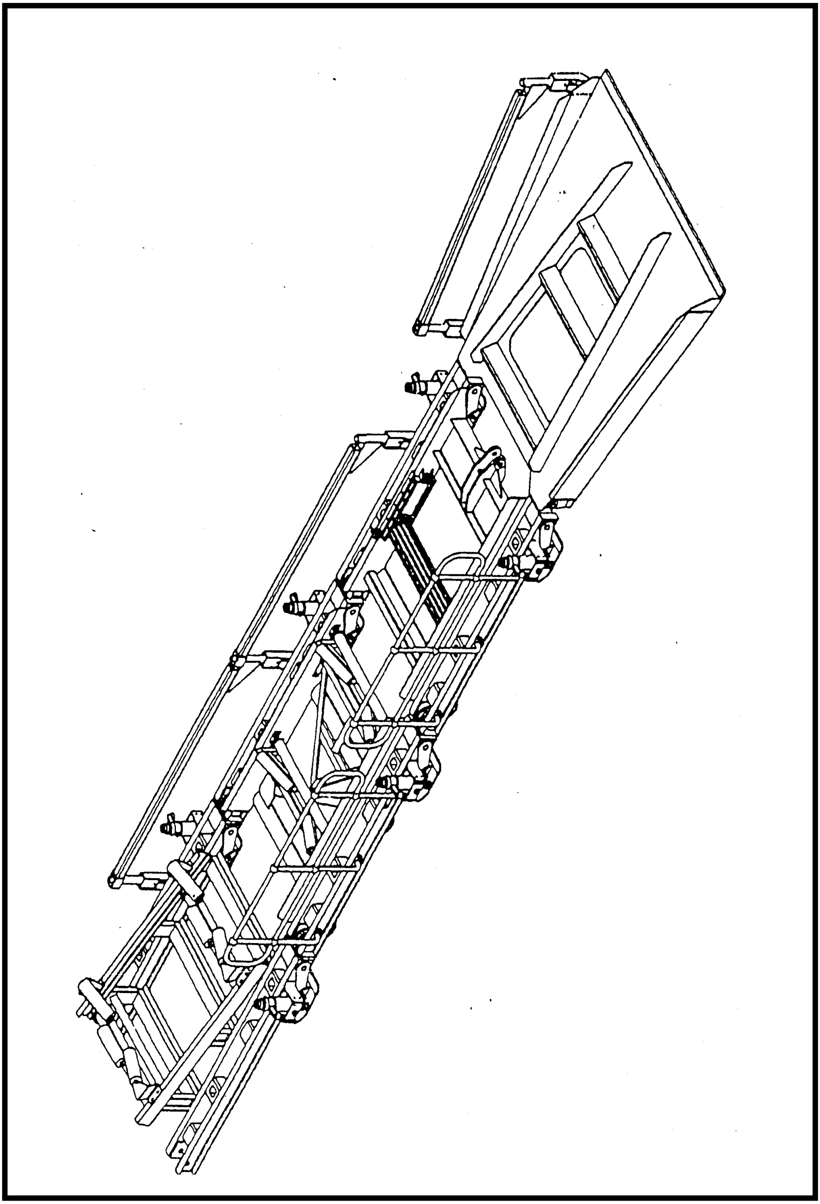

Figure 8

Low Profile Conveyor

Utilisation of Women in the Mining Industry

R Goosen (Mrs)
Syferfontein Colliery

ABSTRACT

The traditional role of women has undergone dramatic changes during the eighties and nineties. Today women are found not only in parliament but also in space. It was therefore inevitable that women would sooner or later enter into the mining environment.

The utilisation of women in the mining industry though, brings about additional aspects that need to be considered. All these additional aspects relate to the role of the woman in society and her family as well as physical and interpersonal factors. Taking all these factors into consideration, Syferfontein did however decide to break down the existing paradigm and to employ women in a production capacity in the mine. This presentation will address the decisions taken to employ women, the research done, the pitfalls that were experienced as well as the successes achieved.

STRATEGIC PLANNING WITH SPECIAL REFERENCE TO HUMAN RESOURCES PLANNING

Walt Disney made the following statement with regards to the human resources of an organisation:

> **YOU CAN DREAM, CREATE, DESIGN AND BUILD THE MOST WONDERFUL PLACE IN THE WORLD BUT IT REQUIRES PEOPLE TO MAKE THE DREAM A REALITY**
>
> **WALT DISNEY**

Planning Syferfontein gave the project team the opportunity to create, design and build the most productive and successful mine in the world. One of the critical areas regarding human resources that had to be considered in the strategic plan, was the multiskilling structure.

MULTISKILLING STRUCTURES

The information gathered from surveys conducted, indicated that job structures were mostly rigid and job descriptions were very prescriptive. Salary grading of posts were found to be determined by the production importance of the equipment rather than by the operational importance of the equpment and thus ignoring the skills required by the production operator. Syferfontein was therefore compelled to investigate alternative methods to ensure optimal labour productivity.

Labour cost, being one of the major sources of operational cost in any business had to be kept at a minimum and therefore the decision was made to adopt a multiskilling structure. Multiskilling has the result that every production operator will be trained on a minimum of two pieces of equipment and, to ensure adequate skills, the operators will only be kept competent on a maximum of six pieces of equipment. The decision to implement multiskilling resulted in a manpower complement totalling six hundred and sixty six opposed to over a thousand, should the traditional method of employment be used.

In order to reduce the number of traditional job titles in the production division, it was decided to make use of only one, namely Production Operator. To distinguish between the different categories of operators, reference is made to production operator category A, B, C, D, E or F. The first step is to appoint an operator as a trainee, after which the operator will commence his/her training on the equipment needed to qualify for category F. Once the operator has successfully completed training on all "category F equipment" he/she will be promoted to production operator category F. The process is repeated for all categories until the operator has reached category A.

TRADITIONAL JOB TITLES	CATEGORY
Dragline Operator	Category A
Assistant Dragline Operator/Groundsman	Category B
P & H Rope Shovel Operator } GD70 Drilling Machine Operator } H285 Hydraulic Shovel Operator }	Category C
789 Haul Truck Operator } 777 Haul Truck Operator } G16 Grader Operator } D9 and D11 Dozer Operator }	Category D
988 Front End Loader operator } H65 / H85 Backactor Operator } D10 Dozer Operator } 824 Frontend Loader Operator } GD35 Diesel Drill Operator }	Category E
D400 Haul Truck Operator } Water Bowser Operator } Tractor Operator }	Category F

The multiskilling structure set the framework within which all the employees in the production department, including the women, would have to function.

EMPLOYING WOMEN IN A PRODUCTION CAPACITY

Without any political pressure and even before the release of President Mandela from prison, a decision was taken that there would be no discrimination on account of race or sex at Syferfontein. That decision was in line with the Sasol Mission stating the following:

> *Sasol does not discriminate on account of race, sex or religion. It respects the dignity and rights of the individual and offers equal opportunity to all employees, on merit, to develop and realise their career aspirations.*
>
> *Affirmative action is an important part of this.*

Not only will blacks be given equal opportunity to enter into and develop meaningful careers, but women will also be given the opportunity to enter into jobs traditionally dominated by males. This will however be done in accordance to the manpower planning objectives that provide for:

- *the right number of employees;*
- *with the right level of skills;*
- *in the right job;*
- *at the right time;*
- *performing the right activities;*
- *to achieve the right objectives; and*
- *to fulfil the corporate purpose.*

The project team of Syferfontein entered unknown territory in their decision to employ women in a production capacity in the mine.

* SURVEYS DONE IN THE INDUSTRY

Research done at various opencast mines in South Africa provided Syferfontein with only the knowledge that the traditional paradigm prevails that women were not considered for employment in a production capacity in the mining industry. America provided some examples of the successful utilisation of women in their mines. Utilisation was however limited to one piece of equipment. The steel industry in South Africa also provided some examples of women being utilised as crane drivers.

Syferfontein accepted the challenge and the first two female trainee mine surveyors in the history of the South African Mining Industry were appointed on 6 February 1989.

* RESEACH DONE BY THE HUMAN SCIENCE RESEARCH COUNCIL

Physical Factors

Not only is it expected of women operators to actually operate the mining equipment, but they are also expected to do physical work like covering blasting holes, moving cable, handling pumps, etc. This kind of activity puts a lot of physical strain on a woman and it was found that they do not always have the physical strength to perform such duties. Being an opencast mine, the workers are also exposed to the elements like rain, extreme cold and heat.

Women are more sensitive to factors like vibration, extreme heat or cold. Interviews performed indicated that a larger number of women experienced lower back pains than was experienced by men. Women found it more difficult to climb ladders and pull or carry heavy objects for long distances. The physical strength of a woman does not compare favourably with that of a man although the same performance is expected of them.

Pregnancies are a major factor for consideration when appointing female operators. A pregnant woman can not perform the physical job required from a production operator and will therefore have to be given other duties to perform that will be less strenuous.

* PYSCHOLOGICAL FACTORS

Socialising tends to play a bigger role amongst women than amongst men. Being alone in a truck or shovel can lead to feelings of loneliness that can lead to pyschological problems like depression and can also influence the level of concentration and general performance.

* JOB REQUIRMENTS

It was found that women, being trained thoroughly, can perform the required job equally as good as their male colleagues. Women tend to work safer and tend to care for their equipment better that men.

* INFLUENCE ON THE IMAGE OF THE WOMAN

The different gender roles are learnt and are dictated by the society we live in. It is therefore possible for a woman, doing a job that requires male abilities, to acquire a male role. It is however difficult for most women to perform a male role at work and change back into a female role at home and amongst friends and family.

* MALE DISPOSITION TO WOMAN OPERATORS

The research found that most men from all nationalities were more conservative regarding the role of women as the bread winner, home maker, educator etc. than were the women. Although most men accepted that women can be their equals, they still felt that they should have the authoritarian role. Most men did not want the women the become "like them" but preferred the women to remain feminine. The men showed hesitance in allowing the women to perform hard physical labour although they realised that it would increase the burden on themselves.

* CAREER EXPECTATIONS

Most women interviewed had to get a job to help support the family. It is however found amongst the younger women that they regard mining as a challenge and are considering further studies in mining. It is more difficult for a woman, after having a baby to return to work as an operator than it would be for a clerk or typist. The women interviewed realised that they must sacrifice some of the roles they needed to play in order to maintain a balance. Physical exhaustion due to demand from both work and family, may force women to choose between a family or a mining career.

* PITFALLS THAT NEED TO BE MANAGED

Being the first mine in South Africa to employ women in a production capacity, we prepared ourselves for an initial big turnover. Women did not know what to expect and information given to them was based on experiences of men.

Other pitfalls that need to be managed are:

- *Pregnancies:*

  The service regulations of Syferfontein provides for six months maternity leave for pregnant women. The maternity leave takes effect at the beginning of the last four months of pregnancy and expires two months after the birth of the child. In the event of the woman having to be taken off the mining equipment sooner than her fifth month, she has to take normal leave until her maternity leave takes effect.

- *Systems*

  It was also found that some systems do not make provision for maternity leave. That was the case with our first female apprentice that fell pregnant. When the apprentice took maternity leave, during her apprenticeship, it was found that the system at the Apprenticeship Board did not make provision for maternity leave resulting in the female apprentice being put on military leave.

- *Legislation concerning shift -and Sunday work*:

  By law, women were not allowed to work night shifts or on Sundays. Special permission had to be given for the women at Syferfontein to work night shifts and on Sundays.

* SUCCESSES ACHIEVED

- Engineering

Rebecca Mahlangu became the first woman Electrician in the coal mining industry of South Africa. Rebecca commenced duties as an apprentice Electrician on 16 July 1990. During 1991 she obtained an N5 Certificate. Rebecca completed all the prescribed modules as stipulated by the Apprenticeship Board. On 5 August 1993 Rebecca passed the prescribed trade test (Red seal) of the MIETTB (Mining Industry Engineering

Trades Training Board) and has been appointed as an Electrician on Syferfontein Colliery. To our knowledge Rebecca made history by being the first woman to complete an apprenticeship within the Sasol Group and the first in the Coal Mining Industry of South Africa.

Four female welding operators were trained to work exclusively on the dragline buckets. Although the women initially started out as just novices, they have established themselves as welders of exceptional quality.

- **Mining**

At present Syferfontein has forty four (44) female operators. That accounts for 14,6% of the total number of production operators presently employed by the mine.

Syferfontein prides itself on being the first mine in South Africa to have trained a female Dragline operator. Marinda Bekker completed her dragline training on 8 June 1994. Pam Bonthoft completed her dragline training in September 1995 making her the second female dragline operator in South Africa.

CONCLUSION

Having had the opportunity to design a new strip mine, our objective was and still is, to provide meaningful work for all our employees. This objective was mainly achieved by the use of multiskilling concepts and our commitment to equal opportunity. It is our opinion that multiskilling offers both individual employees and management the opportunity of revolutionising the way in which meaningful work and productivity can be achieved.

Air Decking at Duvha, a Technicial Evaluation

P Terrett
Middelburg Mine Services (Pty) Ltd, Duvha Section,

SA Steyn
Middelburg Mine Services (Pty) Ltd, Duvha Section,

A J Rorke
Blastinfo Africa

ABSTRACT

Air decking has become a widely practised method internationally for modifying fragmentation results and providing cost savings from reduced explosive consumption. Duvha has been applying air deck technology to overburden and midburden blasting for a few years. A thorough evaluation of air decking at Duvha has been made by instrumenting a number of blasts and analysing costs, from direct savings in reduced explosives costs to savings in improved dragline productivity.

This paper discusses the mechanics of air decking in blastholes and provides a technical evaluation of the performance of the air decks at the mine.

INTRODUCTION

Ingwe Coal Corporation was founded in 1994 and is a result of the merger between Randcoal and Trans Natal Coal. Ingwe is now South Africa's largest coal producer, supplying domestic power stations, inland and export markets. Indeed, Ingwe is now the world's largest steam coal exporter, enjoying a 41.5 per cent share of Richards Bay Coal Terminal. The 14 collieries in the group produce approximately 29.8 million tonnes of export coal, 6.7 million tonnes of coal for inland market and 38.8 million tonnes of power station coal. Ingwe employs over 16 000 people at 9 underground and 5 opencast collieries. With market capitalisation more than R5 billion, constant optimisation and research into working practices are essential to yield maximum profit for the group's shareholders.

On 1 January 1995, two of the Group's opencast collieries (Duvha Opencast Services and Middelburg Mine Services) merged to better utilise the area's coal reserves. Duvha has been power station tied and Middelburg has been 100 per cent export. Middelburg Mine is situated 20 km south east of Witbank in the Eastern Transvaal Province. Duvha Section now operates 2 Bucyrus Erie 1570W draglines and will mine approximately 40 per cento the complex's 17 million tonnes Run of Mine annual output. The geology of the complex is typical of the Witbank Coalfield where currently the 41,2 and 1 seams are extracted.

The coal is mined in a double bench strip mining operation. The overburden and midburden materials consist of closely layered sandstones with strengths ranging from 30 MPa to about 80 MPa. The overburden is often more weathered than the midburden. The mining is carried out by drilling and blasting the waste overburden which is typically about 16 to 20 m thick. Typically, 250 mm blast holes are used which are charged with ANFO and initiated using a shock tube initiation system. Draglines are used to strip the blasted material.

The dragline operation requires a pad that is next to the newly formed highwall and which is approximately at the same height as the original bench top. The blasting requirement, therefore, is for a muckpile shape that has a flat top and where casting is not excessive. This requirement, together with a need to reduce overall blasting costs, prompted a test programme in the use of the top column air decks.

The results of the tests have proved to be positive and the mine now routinely applies top column air decks to blasts in most midburden and overburden blasts. This paper discusses the results of the tests and the productivity and cost implications to the mine.

ROCK TYPES

The overburden material above the top coal seam comprises a sequence of layered sandstones and shales and can vary in thickness from a few metres to about 28 m. Often the overburden is partially weathered. The bottom coal seam is covered by a mid-burden sequence of layered sandstones and siltstones which is commonly about 18 m thick. Usually the sequence comprises a bottom sandstone layer, which is 6 m thick followed by a slightly weaker carbonaceous siltstone band in the centre of the sequence. This band is approximately 4 m wide and is overlain by another sandstone band that is about 7 m thick. Air deck testing was carried out in both overburden and midburden sequences.

MECHANISM OF AIR DECKING

Original theoretical and test work on air decks began in Russia in the 1940's. More recent work on air decking was carried out in Russia where trials on laboratory samples and in some of the open cast mines were reported by Melniko et. Al (1.2) and Marchenko (3). In these publications, the theory of air deck mechanisms and the effects on surrounding rock is covered.

An air deck is essentially an air gap situated in a column of explosive. Air decks can comprise up to 40 per cent by volume of the total column length under certain conditions They can be located at the top of the charge, between the stemming and explosive, somewhere in the explosive column, or at the base of the explosive column. The size and position of an air deck will affect the fragmentation and heave results of a blast.

The work published by Melnikov (1.2) and others suggests that the presence of an air deck increases the duration of action of the shock wave on the surrounding rock by a series of pulses due to reflections of pressure waves within a hole after detonation. In the air deck portion, the peak stress applied to the surrounding rock is lower than the extremely high stress applied by explosives in direct contact with the rock. The air decks therefore reduce the initial pressure applied by a detonating explosive charge but increase the duration of the pressure pulse. This effectively reduces the energy used in crushing the rock close to the borehole while increasing the amount of energy transmitted farther into the rock.

Tests carried out at the University of Maryland by Torrence et.al. and reported by Moon et.al. (4) support the Russian theory. It was found that the fracture network resulting from the lower, but prolonged impulse is not as intense as that produced next to an explosive charge. However, the effective stress wave does extend over a larger volume of rock.

Alternative methods such as foam plugs or suspended plugs have not been used due either to cost or reliability considerations.

HEAVE AND FRAGMENTATION EFFECTS

The main consideration in introducing air decks at Duvha was to contain blasting costs and limit heave. A number of trials were carried out using different air deck length and stemming length combinations. Air decks were varied between 3 and 5 metres whilst stemming lengths were varied between 3 and 6m. High-speed films were taken of a number of blasts to examine face velocity profiles. Figure 3 shows a typical charge configuration with face target positions used for monitoring the face velocities. Figure 4 shows the face velocities typically achieved and the face profiles with respect to time.

It was found that the face velocities in the portion of rock containing the air decks were similar to the face velocities in the stemmed portion of the blast. The face velocities in the rock portion containing explosive were about double the velocities in the air decks. The air decks, therefore had the effect of significantly containing horizontal heave in the top portion of the blast. This effect is well demonstrated in the measured face profiles from one of the blasts at Duvha (Figure 4).

It was found that there were critical air deck lengths, which provided a guideline for limits in air deck length and stemming length combinations at the mine. These are summarised in Table 1. It has been found that a 4 m air deck with 3 m of stemming gives the best results in most areas of the mine. In areas where the capping sandstone is particularly hard, the air deck length is reduced to 3m.

Table 1

Air deck and stemming length limiting combinations at Duvha

(The data is taken from a number of different test blasts and is general. Different areas of the mine were found to give heave result specific to the rock in the area.)

Stemming Lenght	Air Deck Lenght	% Air deck of combined air deck alnd charge length	Result
3 m	*3 m*	*25*	*Fine surface fragmentatin. Power trough and crest of muckpile higher than original bench height.*
3 m	*4 m*	*33*	*Coarse surface fragmentation. Nopower trough and 40 % of muckpile width at original bench height and flat on top.*
3 m	*5 m*	*42*	*Coarse surface fragmentation. No power trough and 60 % of muckpile width at original bench height and flat on top.*
4 m	*4 m*	*36*	*Coarse surface fragmentation. No power trough and 60 % of muckpile width at original bench height and flat on top.*
4 m	*5 m*	*46*	*Surface of muckpile slignthly cracked. Very little heave and bulking. Digging difficulties became evident.*

Effect on Fragmentation

An air deck lowers the peak stress wave applied to the immediate rock surrounding a blasthole and thus reduces the level of very fine crushing that occurs in this area. The energy imparted to the rock is used more effectively therefore, over a longer time to extend a fracture network over a larger volume around the air deck. The fracture network thus generated is not as intense as the fractures generated directly by explosive. The work carried out at the University of Maryland has shown that air decks increase the duration of the action of the shock wave on the surrounding material by 2 to 50 times.

In effect, a slightly coarser, but more even fragmentation should occur in the material next to an air deck.

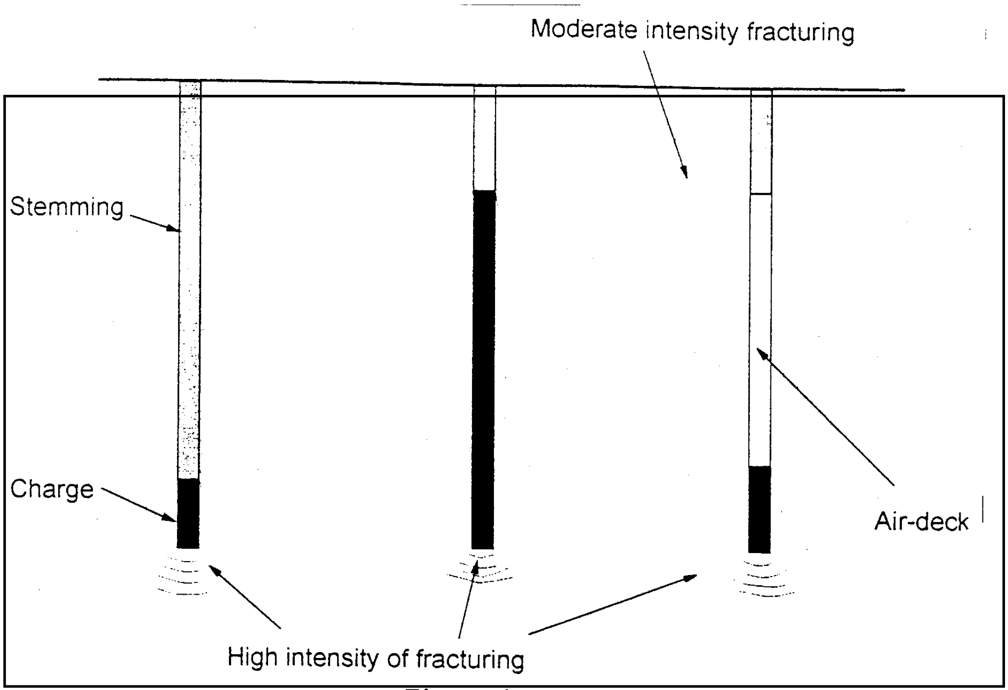

Figure 1

Fracture and stress profiles resulting from different charge geometries (redrawn after Chiappetta and Mammele (5). The influence of the air decks on improving fragmentation in the collar section of blast holes can be seen.

POSITIONING AND SIZE OF AIR DECK

Initial work (2) provided basic guidelines for air deck lengths related to charge length as follows:

$$L_{ad} = a.L_c \qquad \text{...............[1]}$$

Where **a** is a factor between 0.15 and 0.35, L_{ad} is the length of the air-deck in metres and L_c is the length of the charged column including air-deck in metres.

Regarding diameter, the following relationship was given:

$$L_{ad} = b.D_c \qquad \text{...............[2]}$$

Where b is a factor between 8 and 12 and D_c is the charge diameter in metres.

These broad guidelines will have different effects in different rock types, and trials were necessary at Duvha to optimise the performance. To prevent bad blast results, initially smaller more conservative values of **a** and **b** were tried.

Moxon et.al [4] and Mead et.al.[6] have carried out a number of laboratory test blasts on concrete blocks and some field monitoring exercises to determine the effect of air deck size and position on fragmentation. A number of practical observations were made:

- ♦ The air deck volume as part of the total air-deck charge volume appeared to reach a critical value at about 40% after which fragmentation coarsened rapidly. This is illustrated in the curve shown in Figure 2b.
- ♦ As a rule, the volume of the air-deck should decrease with increasing rock strength.
- ♦ Air decks can be effectively used to increase fracturing in the capping area of a blast, especially if some of the stemming material is replaced with air.
- ♦ The position of an air deck will result in different effects. Figure 2a illustrates the effect of air deck configuration on fragment size distribution. Generally, a mid-column air deck produced more fine fragmentation that did an air deck

at the top of an explosive column or an air deck at the bottom. Also heave effects were highest for mid-column air-decks. Better heave and fragmentation can be expected in mid-column air-decks where higher pressures and a longer duration pressure wave will tend to occur as the result of repeated collision and oscillations between the shock wave fronts and the borehole ends.

CREATING AIR DECKS AT DUVHA

Various commercial alternatives are available for generating air decks in explosive columns. Two of these are in current use at Duvha to create an air deck at the top of the explosive column and support approximately 3 to 4 metres of drill chippings above the air deck. These are briefly described.

Effect on Heave

The borehole pressure is reduced in an air decked charge and, therefore, the burden heave velocity near an air deck will be reduced. Recent trials in Australia (4) and at Duvha (the subject of this paper) have shown that the air decked portion of the blasts gain little forward momentum compared to the charged portion. Therefore, when maximum casting is an objective, the use of air decks is not likely to provide improved results.

Effect on Stemming

With the lower borehole pressures in an air decked hole, there is a lower pressure pulse applied on the stemming when the air deck is located directly beneath the stemming material. As a result the stemming material should be less readily ejected, and it should be possible to use shorter stemming lengths to achieve the same stemming retention times. A better distribution of explosive energy in the rock is thus possible. Detailed high speed photography measurements carried out by Chiappetta and Mammele (5) have illustrated that improved fracturing occurs in the stemming region of top air decked holes. This is illustrated in Figure 1.

1. *Gas bags*. Gas bags have been available in South Africa for about 5 years. Modifications have been made to the

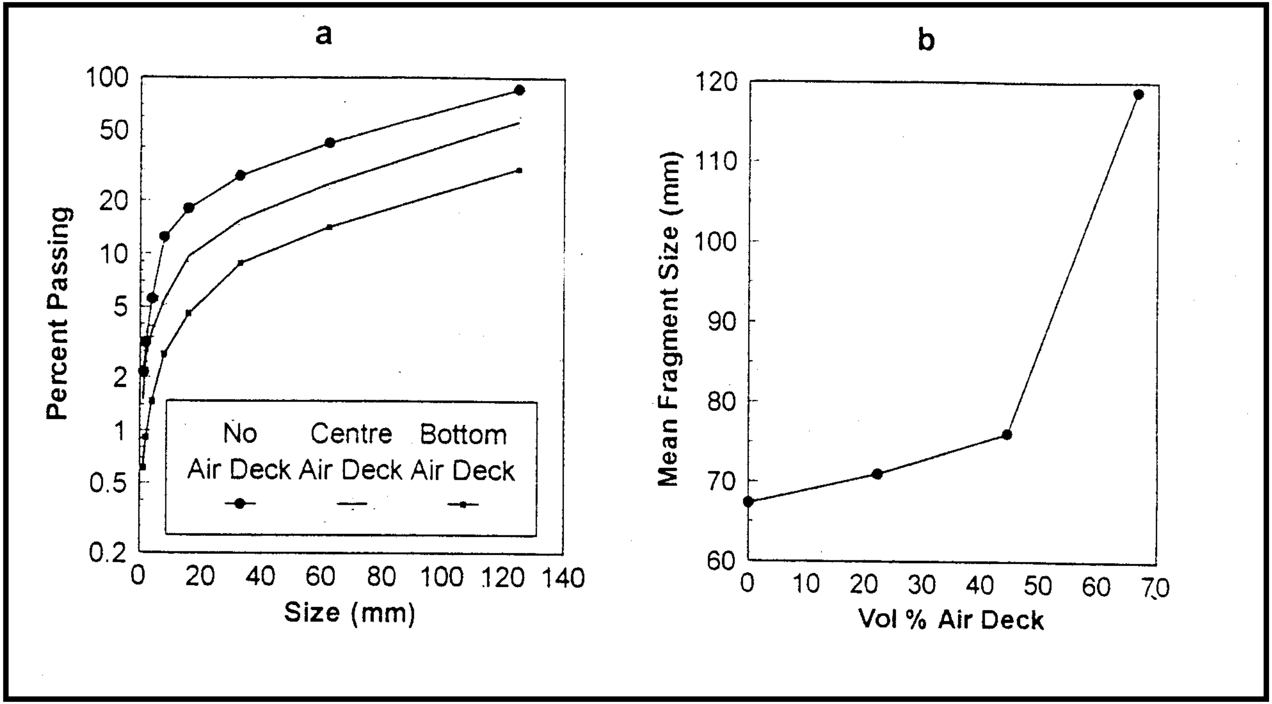

Figure 2

Effect of air deck configuration and air deck volume on fragmentation in concrete blocks (After Moxon et.al(4).

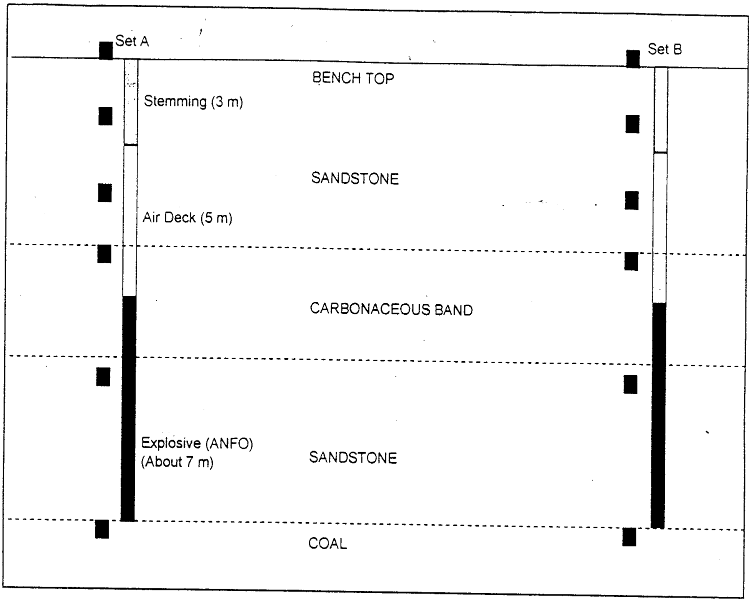

Figure 3

Typical hole configuration during air deck testing. The schematic shows the air deck position relative to charge length and stemming. Face target positions used for high speed motion analysis are indicated.

point where the units are reliable. The bag is inflated by slowly releasing the pressurised contents of an aerosol can which is packaged inside the gas bag. The slow release of air pressure is achieved by a special valve on the can that allows plenty of time to position the gas bag where required. This method is preferred to the more cumbersome alternative method for pressurising gas bags where they are inflated from a compressor on surface.

2 ***Mechanical Plugs***. Mechanical plugs in the form of spring loaded plastic disks that rely on friction with the borehole walls for anchorage are used frequently at Duvha. They are installed using rigid poles, and therefore have the disadvantage of not being practically used at large depths in blastholes. However speed of use and low cost make these units a viable option for the top column air decks at Duvha.

The mechanical plugs are more cost effective and are used preferentially, therefore, in most blasts. However, in certain areas of the mine, the holes are sleeved to prevent water infiltration into the ANFO charged holes. In such holes, the mechanical plugs are difficult to install, but the air bags work very efficiently.

AIR DECK POSITIONING AT DUVHA

The choice of positioning the air deck of the top of the explosive column rather than in the centre of the column where a softer layer of rock exists was taken firstly for practical reasons.

Mid-column air decks provide a useful method for reducing explosives cost and providing even fragmentation in a softer layer sandwiched between two harder layers. The key factor in obtaining optimum performance of the air deck, however, is to ensure that the shock front from the top and bottom charge meet approximately half way in the air deck. To achieve this, accurate detonator timing is important. The required accuracy will depend on the detonation velocity of the explosives, the speed at which the shock wave travels through the air deck and the length of the air deck. Figure 5 illustrates typical shock wave velocity measured through an

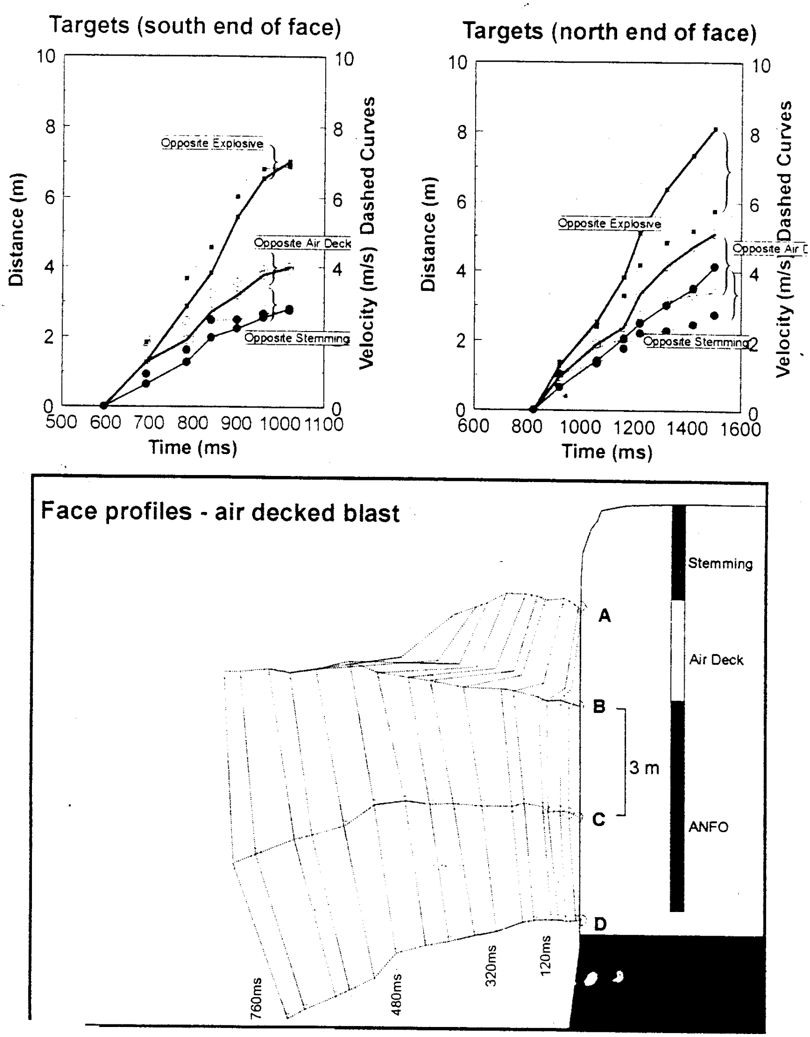

Figure 4

Face velocity curves for a trial air decked blast at Duvha. The face velocity profiles are shown in the schematic section at the bottom. The retarding effect on heave of the air deck is well illustrated.

air deck in a 250 mm diameter overburden blasthole at Duvha. Detonator placement is equally important to ensure that the travel distances will result in the shock fronts meeting in the air gap rather than in one or other explosive deck.

Davids et. al(7) carried out tests at Syferfontein Colliery on mid-column air decks. They established that the maximum time difference between the detonation of the top charge and the detonation of the bottom charge was less than the accuracy of available shock tube detonator systems. It was found that, when the shock front from one of the explosive decks impinged on unfired explosive in the other deck, it would cause sympathetic, but partial detonation. If this occurred systematically at the bottom explosive deck in a number of holes in a blast, large areas of unfragmented sandstone would remain on the coal. The need for more accurate timing in holes with mid-column air decks will only practically be satisfied when electronic detonators become commercially available and economically viable.

Close to simultaneous firing times have been achieved by connecting the top and bottom detonators with a length of detonating cord in various South African mines (7). This technique is cumbersome, however, and requires a high level of control during hole charging.

The second reason for positioning the air deck at the top of the column is the need for a muckpile with a top that is essentially undisturbed compared to the previous bench top, but is well fragmented. This could not be achieved with a top charged deck directly beneath the stemming portion of each hole.

IN HOLE SHOCK WAVE VELOCITY PROFILES

In a number of trial blasts, in-hole VODs were measured to ensure that holes were adequately pressurised. The instrument used for recording the measurements was a VODR-1 which employs time domain reflectometry to measure sensor cable length. The sensor cable used was a coaxial cable (RG58) which has a relatively high crushing threshold.

Figure 6 shows traces from VOD measurements made in a number of holes in various blasts at the mine. The clean portion of each trace represents the charged portion of each hole. In this portion,

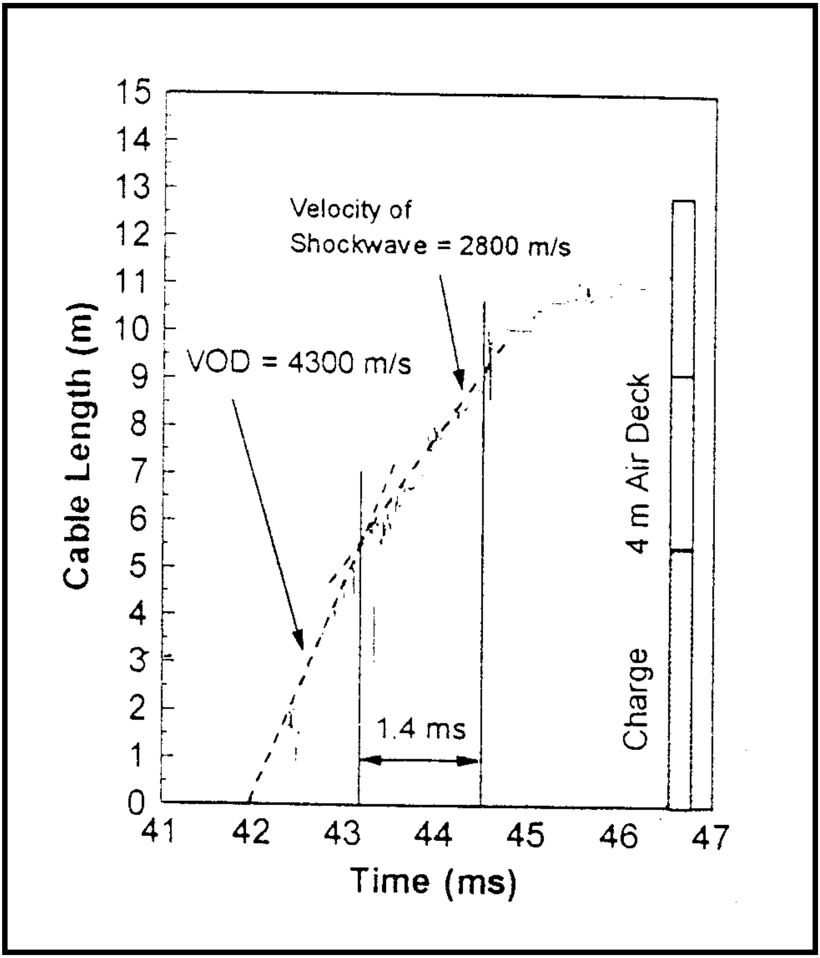

Figure 5

Continuous VOD trace in an air decked 250 mm blasthole at Duvha. The time taken for the shock wave to travel through the air deck in this case was 1.4 ms. This would be the miminum accuracy required for detonators firing two charged decks separated by an air deck

the cable was properly crushed and a relatively noise free signal was obtained. Measured VODs ranged between 4000 m/s and 4500 m/s. In the air decked portion of the hole, the speed of the shock wave was approximately half the VOD. Similarly, the pressure in the shock wave was notably lower. This can be seen in the signal traces in Figure 6 where the lower pressure crushed the RG58 cable less efficiently and thus the signal became noisier. The lower pressure in the air decks is desirable for the reduced heave and coarser fragmentation required in the top portion of the blasts at Duvha.

DAMAGE CONTROL

Presplitting is used extensively at the mine to ensure vertical highwall faces that are safe and which allow accurate drilling of front row burdens. The presplits are also blasted to dewater blocks of ground so that ANFO can be effectively used in the blastholes.

Normally, the portion of the presplit most prone to damage is the upper section where cratering from the adjacent back row of hole breaks through the presplit plane. With the top column air decks, this problem has been significantly reduced because the pressures in the top portions of the blastholes are much lower.

COST ANALYSIS

Significant savings on explosive consumption have been achieved with no detriment to Dragline productivity. Duvha Section uses 12 000 000 kg of ANFO per annum and, with the introduction of air decks, this has been reduced by about 20 %.

Dragline rehandle has been reduced by keeping the top of the blasted bench, which the dragline will traverse, as level as possible.

A significant improvement in dragline performance has been achieved in the top portion of each blast where rock displacement has been minimal. This is because rock fragments have not moved much and have remained in their relative positions. As a result, air voids normally associated with bulking are minimal and the dragline bucket fill factor has increased by about 15 % in the upper 7 m

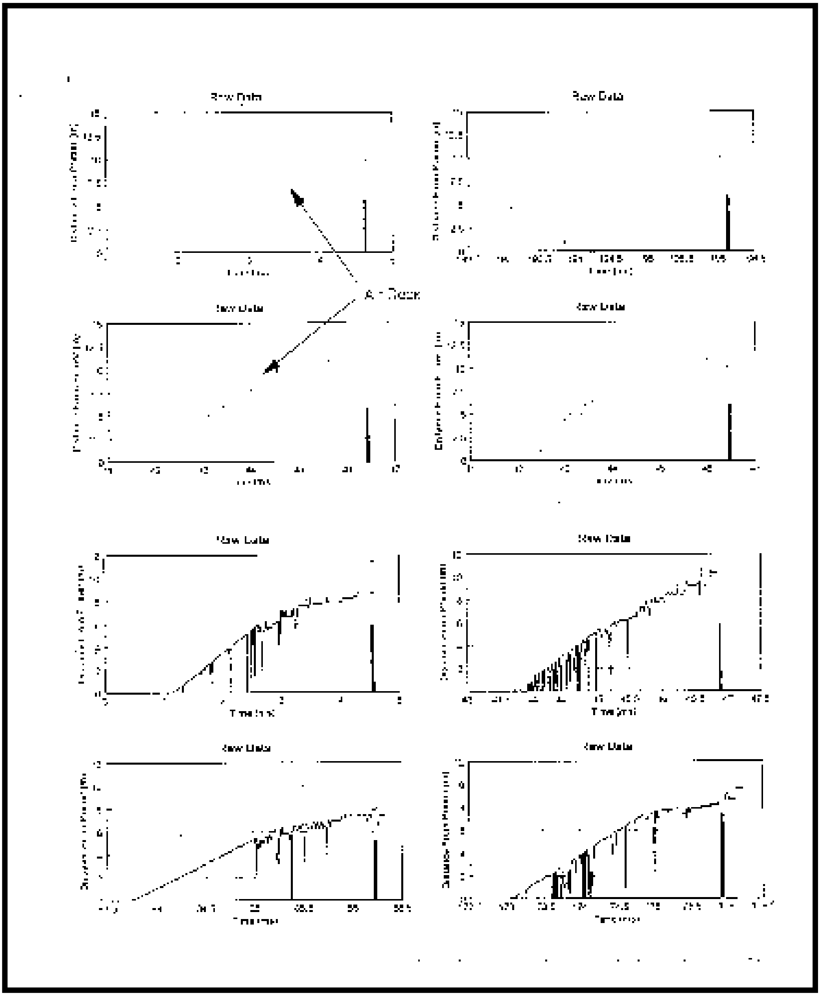

Figure 6.

VOD traces measured in a number of test holes containing air decks at the top of the explosive charge. The trace through the air decked portion of the blast represents the shock wave travelling through the air deck. The velocity of the shock wave is typically about half the VOD through the explosive column. The lower pressure in the air deck caused less efficient crushing of the sensor cable, hence the more noisy trace corresponding to the air deck.

of each blasted block.

CONCLUSIONS

For a number of years, top column air decks have been extensively used at Duvha. Typically air deck lengths between 3 and 4 m are used in a bench height of about 18 m. The stemming above the air deck is normally about 3 to 4 m long. This has resulted in a muckpile profile that is flat at the crest with the crest height being very similar to the original bench height. This significantly improves dragline performance because dragline pads do not need to be built up to the required level. This muckpile profile has been achieved because the air deck, which is located between the explosive column and the stemming at the hole collar, effectively limits horizontal and vertical heave in the top 40 % of the block being blasted.

Dragline performance has also been significantly improved by better bucket fill factors. Fragmentation in the top portion of the blast is coarser than in blasts where no air decking is used, but because fragments have not moved much relative to each other, bulking has been minimised and voids have thus been reduced.

The power troughs in the muckpiles with air decks are very small compared to blasts without air decks. This results in minimal damage to the highwall in the following block of ground thus improving safety and drilling control.

Usually, the motivation for the use of air decks is one of direct cost reduction by using less explosive. Direct blasting costs have been reduced by replacing explosive with air. However, this reduction is combined with improved blasting results and thus have confirmed the success of top column air decks at Duvha.

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