Monitoring and analysis of production waste blasts at the Cadia Hill Gold Mine

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Abstract

This paper presents the results of monitoring and analysis of production waste blasting trials conducted at the Cadia Hill Gold Mine in Australia. The study was part of a project aimed at assessing potential areas of cost reductions in waste blasting, without significantly affecting instantaneous loading productivity. Trial blasts were monitored over a period of approximately two months at the 685 bench level of the North Wall of the Cadia Hill open pit mine. A comprehensive data collection program was initiated which included rock mass conditions, as designed and as drilled blast designs, compliance reporting, energy distribution data, drill productivity data, drilling and blasting costs, instantaneous shovel productivity data logged by the Modular system, explosive performance and fragmentation data. A detailed comparative statistical analysis was carried out for the stemming and subdrill length data to quantify the differences in the blasts. In-hole detonation velocity and gassing length measurements for the bulk gassed emulsion product were conducted to assess the explosive performance. The diggability data was analysed for each blast considering different operators, excavator types and rock mass conditions. In this particular study, muckpile fragmentation was shown to be within acceptable limits for the range of powder factors used; and appeared to have no impact on instantaneous loading productivity. Although the targeted theoretical reduction in powder factor was not achieved in the trials, results from the study helped implement further design improvements and recommendations.

INTRODUCTION

Cadia Hill Gold Mine, wholly owned by Newcrest Mining Limited, was discovered in 1992 and is now one of the largest open cut gold mines in Australia. Cadia Hill utilises some of the most advanced mining and processing technology available and is designed to produce approximately 300 000 ounces of gold and 25 000 tonnes of copper per annum over the anticipated 13-year life of the mine. The Cadia Hill mining fleet was expanded in recent years to undertake the planned elevated waste stripping activities. The mine uses the shovel/truck system together with the modular mining system. In large open pit operations such as Cadia, the truck and excavator fleet can contribute up to 60 % of the total mining costs thus significant cost savings can be made by relatively small improvements in load and haul productivity (Onederra *et al*, 2004).

Cadia Hill Gold Mine initiated a project to assess potential areas of cost reductions in waste blasting, without significantly affecting instantaneous digging productivity. Currently, powder factors for waste production blasts are designed to deliver the required energy to produce adequate breakage and fragmentation but could be considered conservatively high in some areas. Cadia Hill identified opportunities to reduce these powder factors and suggest design improvements that can result in lower cost blasts.

As part of this project (Esen and Onederra, 2005), the Julius Kruttschnitt Mineral Research Centre (JKMRC) was commissioned to assist in the data collection and analysis over a period of approximately two months (December 2004 to February 2005). The main objective of the project was to assist in the data collection and analysis of a series of waste blasting trials to help identify drill and blast design improvements with the view to reduce costs whilst maintaining instantaneous loading productivity.

BLASTING TRIALS AND DATA COLLECTION

Description of trials

As part of the project, two benchmark and two modified blasts were initially planned to provide repetitions for comparative purposes (Esen and Onederra, 2005). The trial blasts implemented were numbers 685210, 685211, 685215 and 685220, located at the 685 bench level of the North Wall. As shown in Figure 1, three major domains delineated by three major faults were identified in the trial area. These domains were classified as hard fresh monzonite (i.e. 4N), moderately structured/slightly altered

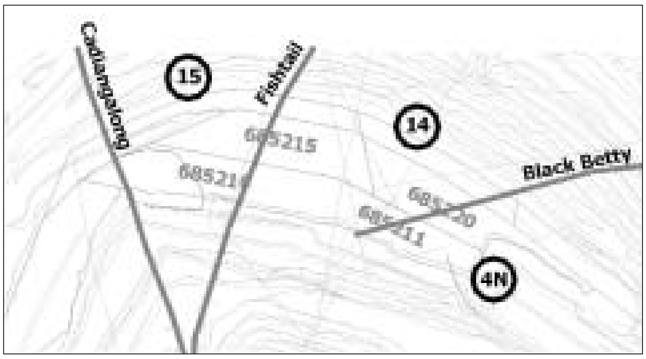


Figure 1: Locations of trials and identified blasting domains.

monzonite (i.e. 14) and highly structured/moderately altered monzonite (i.e. 15).

As shown in Figure 2, the preliminary design modifications adopted in order to reduce powder factor did not include a radical pattern expansion but a controlled increase in the stemming length from 4.8 m to 5.2 m; and a decrease in the sub-drilling required from 2.0 m to 1.5 m. This would bring a theoretical reduction in powder factor from 0.77 kg/m^3 to 0.71 kg/m^3.

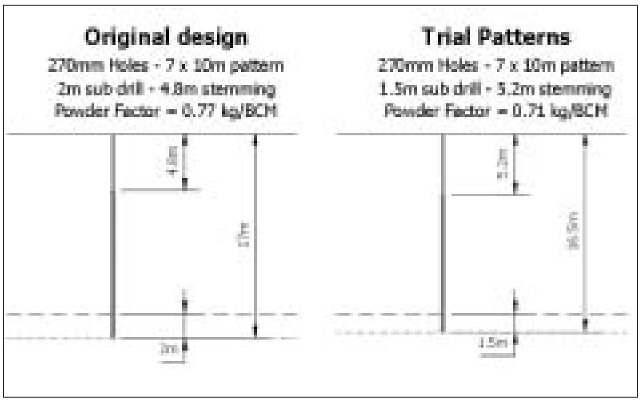


Figure 2: Benchmark and trial blast design variables.

As will be discussed in the data analysis section of this report, a detailed audit of the implemented trials was carried out. Results from this helped define the actual differences achieved and how they could be considered in a comparative analysis.

Data Collection procedures and systems applied

The data collection procedures adopted in this project were similar, and in some cases, more involved than previous diggability studies conducted at Cadia Hill mine (Onederra *et al*, 2004). The work consisted of the followings:

- Collection of data to describe the rock mass conditions of the trial areas.
- Collection and documentation of a complete set of "as designed" and "as drilled" blast design data, including blasthole position, hole length, explosive amount, stemming length and tie-up configurations.
- Generation of compliance reports for the assessment of implementation.
- Collection of drill productivity data and documentation of drilling costs.
- Documentation of costs of bulk explosive products, primers and initiation systems.
- Collection of instantaneous dig rate reports from the modular mining system.
- Collection of images from the tray of loaded trucks to estimate the fragmentation size distribution of the blasted muckpile.
- Video of each blast to allow for a qualitative assessment of overall blast performance associated with initiation, sequencing, movement and possible stemming ejection.
- Collection of a representative sample of digging and loading cycles of muckpiles using a video camera.
- Collection of explosive performance data through in-hole VoD measurements.
- Collection of gassing length measurements for the bulk explosive product used.

The tasks described above involved the application of several enabling technologies, including:

- High Precision GPS (HP-GPS) and shovel performance (productivity) data from the modular mining system
- Blast design and performance information management with the application of the JKSimBlast software
- Mobile toughbooks to collect QA/QC data
- Surpac software to create design and document survey information (as designed and as drilled data)
- MapInfo software to visualise and present HP-GPS and diggability data
- Split desktop software to analyse fragmentation images
- Microtrap VoD monitoring system to measure in-hole velocity of detonation.

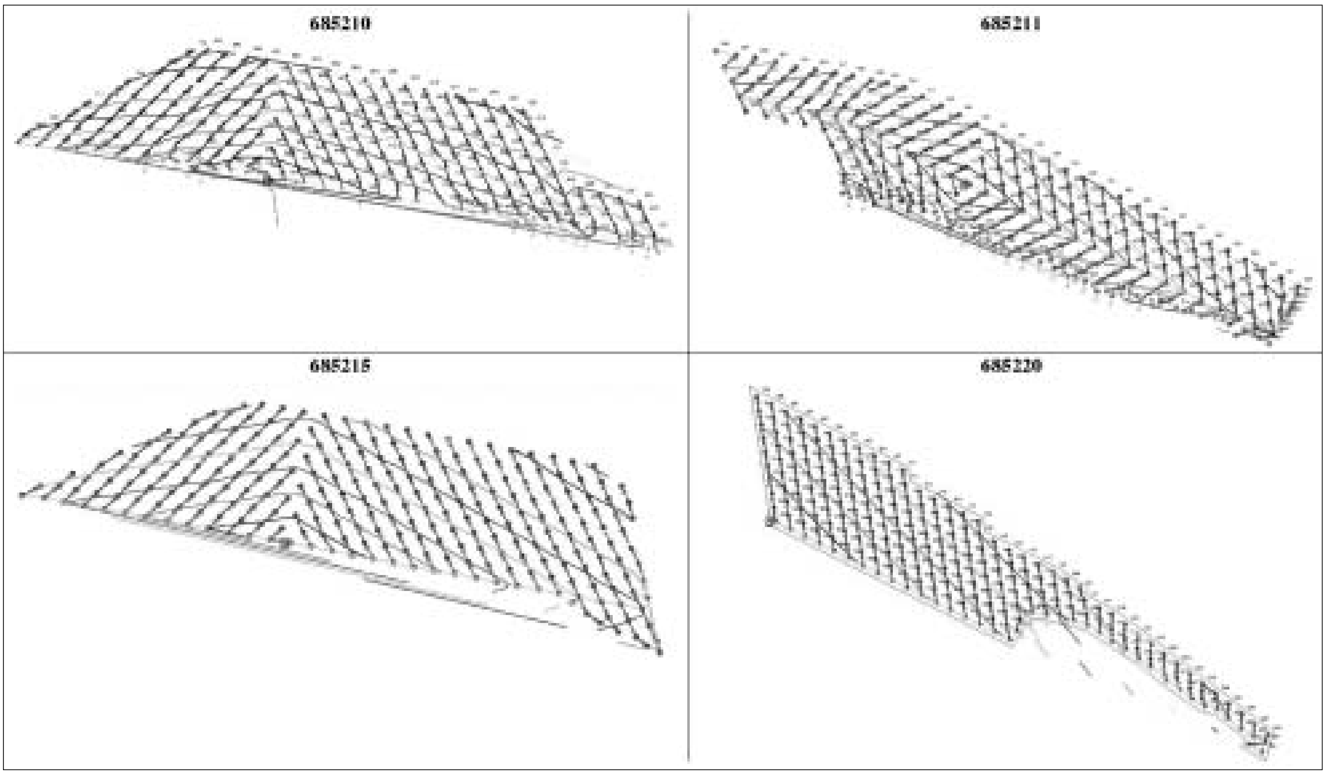
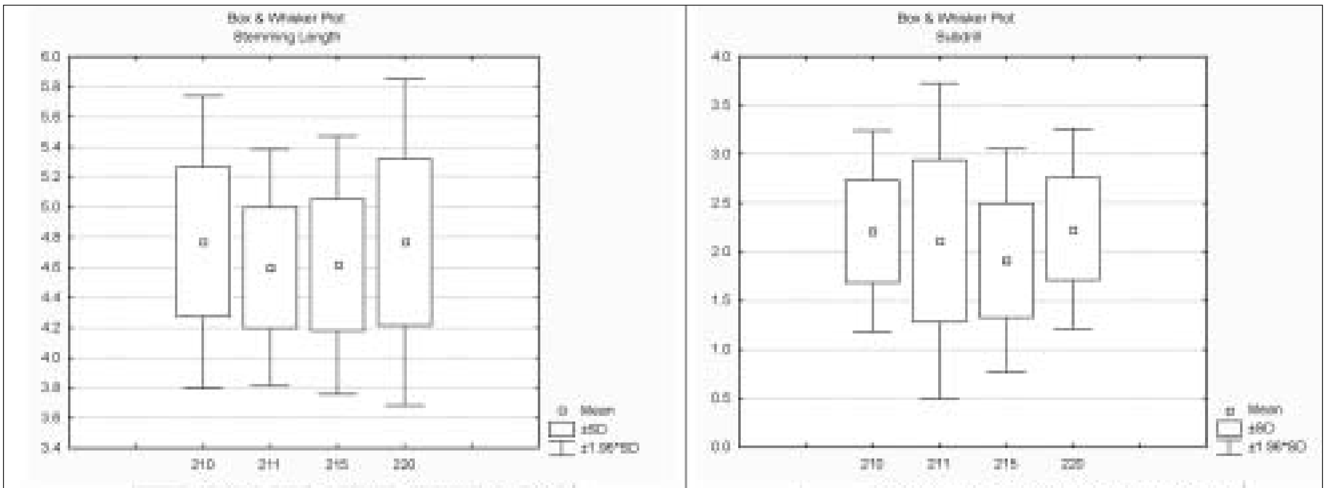


Figure 3: Shape of blast sequencing for each trial blast.



	Valid N	Mean	Minimum	Maximum	Std.Dev.
685210	236	4.77	3.80	5.80	0.496
685211	228	4.60	3.80	6.00	0.401
685215	68	4.62	2.30	5.40	0.438
685220	154	4.77	3.60	7.80	0.553

	Valid N	Mean	Minimum	Maximum	Std.Dev.
685210	234	2.21	0.83	3.82	0.526
685211	228	2.11	-1.59	5.28	0.827
685215	85	1.91	0.61	3.37	0.583
685220	201	2.23	1.03	5.29	0.524

Figure 4: Stemming length and subdrill statistics for each trial blast.

DATA ANALYSIS

Audit of trial blasts

Following the collection of both "as designed" and "as drilled" information from each trial, the JKSimBlast software was used to generate preliminary compliance reports. In terms of collar positioning, all four trials were found to be within acceptable limits. However, there were some discrepancies found in blast 685211 due to the number of in-fill holes. Tie-up configurations in each case were also documented and their differences are illustrated in Figure 3 with the use of timing contours. As shown, blasts 685210 and 685215 followed a "V-shaped" sequence, in contrast blast 685211 followed a more confined "diamond-shape" sequence whilst blast 685220 followed a typical row by row configuration. As will be discussed later, these differences have been shown to be more significant when identifying differences in loading productivity.

In order to calculate and compare the actual powder factors implemented in each trial blast, a detailed analysis of the variations in stemming lengths and sub-drilling was conducted. Figure 4 summarises the statistics associated with stemming lengths and subdrill surveys respectively. In general, average stemming lengths and subdrills achieved during the trials were close to each other and they were in the ranges of 4.6-4.8 m and 1.9-2.2 m respectively. The results show that targeted average stemming lengths of 5.2 m and average sub-drills of 1.5 m were not achieved.

As part of the auditing process, actual powder factors for each test blast were also determined. This analysis, not discussed in this paper, was used to supplement the cost versus benefit analysis of current and future blasts.

Explosive performance

Part of the performance assessment process involved the measurement of in-hole detonation velocity and column rise gassing lengths of the bulk explosive product used. The aim was to independently evaluate whether general specifications from the supplier were being met.

With regards to VoD monitoring, one blasthole from trial blast 685215 and two blastholes from blast 685220 were monitored using the continuous resistance wire VoD technique. Average VoDs were found to be 5.487 km/s and 5.314 m/s respectively, showing the explosive to perform adequately and to specifications.

The column rise (gassing length) was also measured during one of the trial blasts (i.e. 685220). 136 measurements were collected and average gassing lengths were found to be of the order of 0.8 m (Figure 5). Although the variation (standard deviation=0.33 m; experimental error=41%) appeared significant, the average length was found to be acceptable for the conditions encountered.

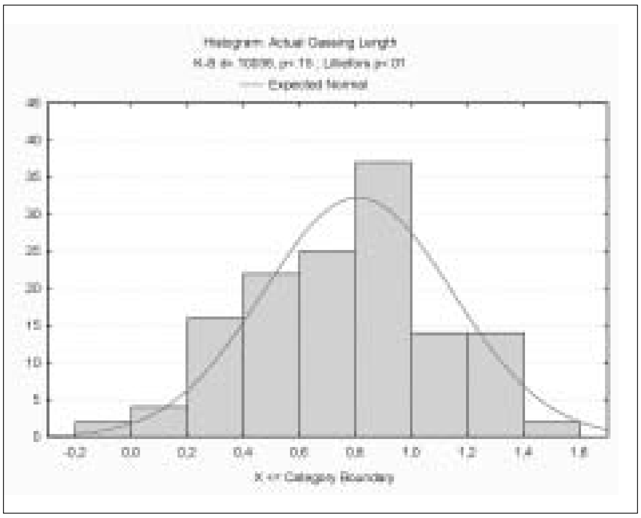
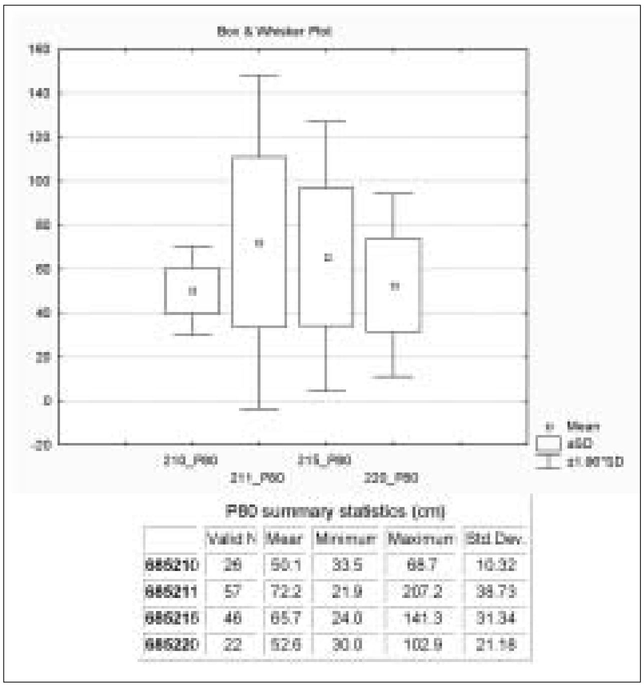


Figure 5: Histogram of the actual gassing length of the explosive.

Fragmentation assessment

In order to compare the performance of each blast in terms of breakage and fragmentation, image analysis of loaded truck trays was conducted with the use of the Split Desktop image processing program. After each blast, photographs of tray backs were taken when they were full. To scale the images, the width of each tray was used. In this analysis, the Split Desktop results were assumed to represent the fragmentation encountered by the shovel during the complete truck loading cycle. A total of 151 photographs were analysed during the study period. The major aim of this analysis was to obtain coarse fragmentation statistics given principally by relative changes in the P_{80} (80% passing size) of each trial blast.

Figure 6 summarises the resulting descriptive statistics of measured P_{80} (in cm) for each blast.



	Valid N	Mean	Minimum	Maximum	Std Dev.
685210	26	50.1	33.5	68.7	10.32
685211	57	72.2	21.9	207.2	38.73
685215	46	65.7	24.0	141.3	31.34
685220	22	52.6	30.0	102.9	21.18

Figure 6: Fragmentation analysis of truck trays using Split Desktop.

As shown in Figure 6, the coarsest and most variable fragmentation was found to be from trial blast 685211 followed by blast 685215. The reason for this variability was believed to have been mainly caused by the rock mass condition, explosive energy distribution and delay timing (tie-up configuration). Table 1 summarises qualitatively the conditions encountered in the blasts as well as fragmentation and powder factor data.

As seen in Table 1, Blasts 685210 and 685215 lie in the structurally controlled rock domains whilst blasts 685211 and 685220 are mainly in the hard massive monzonite. When blasts 685210 and 685215 are compared, it appears that blast 685210 has better energy distribution (Figure 7) and longer inter-row delay time. It is believed that these conditions lead to better fragmentation results under this specific rock mass conditions, i.e. structurally controlled rock mass. Chiappetta's (1998) findings are in-line with this.

On the other hand, when blasts 685211 and 685220 are compared, it appears that blast 685220 has better energy distribution (Figure 7), shorter inter-row delay time and better tie-up configuration (V-sequence). It is believed that these conditions lead to better fragmentation results under this specific rock mass conditions, i.e. massive hard rock. Chiappetta's (1998) findings are in-line with this.

Instantaneous loading productivity analysis

Specific to this project was the need to identify the main factors influencing instantaneous loading productivity in the

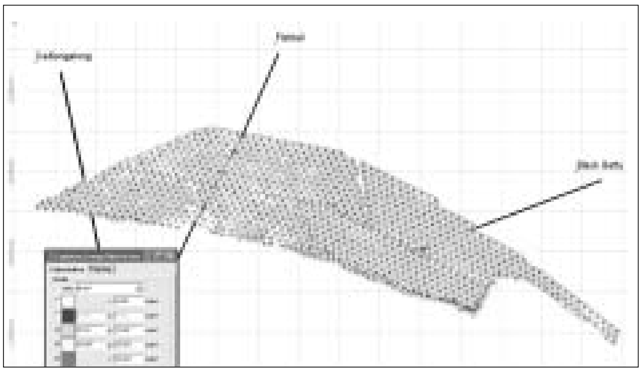


Figure 7: Energy distributions of the trials calculated at the 5695 level.

implemented waste trial blasts. Fragmentation versus loading productivity performance was first analysed in order to establish its potential impact. The analysis focussed on assessing the relative impact of coarse fragmentation defined by P_{80} statistics. For all blasts, P_{80} versus instantaneous loading productivity (ILP) is shown in Figure 8. As shown, there is no direct correlation between P_{80} and ILP. As a general trend however, when P_{80} increases, ILP appears to decrease. This analysis was extended into individual blasts and operators; however, similar findings were observed.

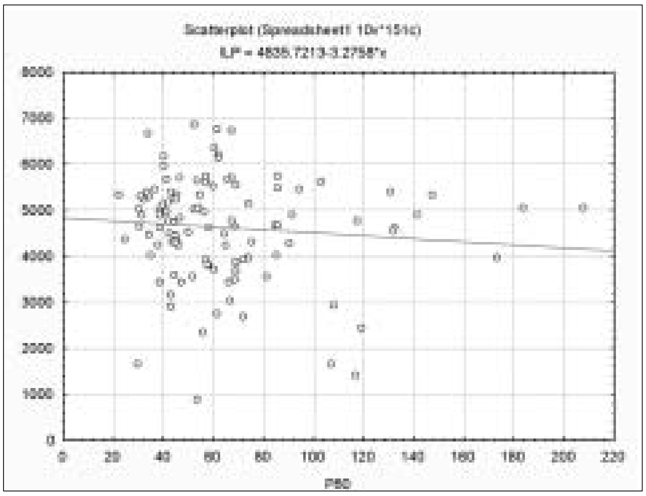


Figure 8: Instantaneous loading productivity (t/h) versus P80 (cm) for all trials.

As with previous studies (Onederra *et al*, 2004), operator experience, digging strategy, muckpile shape and looseness were believed to have a more significant impact than relatively small changes in coarse fragmentation.

In order to further assess and adequately compare differences in instantaneous loading productivity between the trial blasts, high precision GPS (HP-GPS) and instantaneous shovel productivity data logged by the Modular system were collected and analysed. Cadia Hill

Table 1: Summary of blast conditions.

Shot no	Rock mass	Energy distribution	Delay (inter hole-row)	Tie-up	Powder factor	P80
685210	structured	good	17/109	V	average	Finest
685211	mainly massive, hard	average	42/109	Diamond	Highest	Coarsest
685215	structured	average	42/67	V	Lowest	average
685220	mainly massive, hard	good	42/67	V	average	average

mine has the ability to generate "muckpile diggability reports" on a blast by blast basis. Analysis of this data was carried out with the application of both JKSimBlast and the GIS based software, MapInfo.

Analysis with Modular's HP-GPS diggability data requires some specific filtering to eliminate what can be considered to be unreliable records due to for example GPS reliability or data transmission issues. A number of constraints were used using the SQL query facility of the MapInfo software to filter the raw diggability data. These were established by statistical analysis of diggability data and by considering the practical range of data.

In general, the analysis was carried out in two stages; the first was visualising and determining average instantaneous loading productivity clusters in space for each trial blast and given equipment; the second was identifying the most representative set of data given by an individual operator and equipment, in order to reduce the inherent variability given by differences in experience and digging tactics.

The type of analysis conducted is illustrated in Figure 9 for blast 685210. This case shows productivity clusters and average performance of Shovel FS01 combining all operators. Figure 10, on the other hand, is used to identify the operator that could best represent the digging conditions of the muckpile by working in different regions. In this case, two operators were identified and their performances separately analysed.

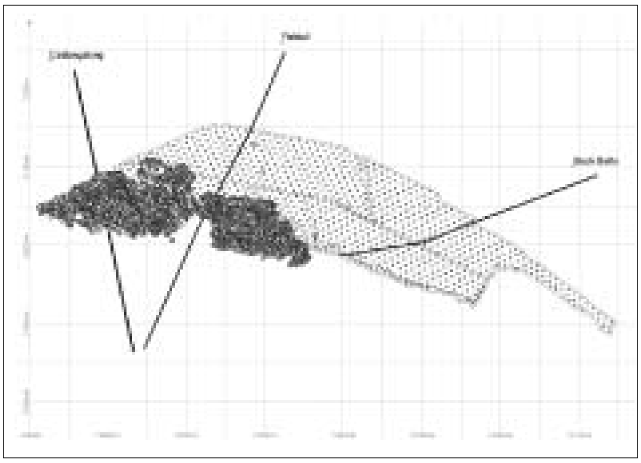


Figure 9: Instantaneous loading productivity for shovel FS01 in blast 685210 (all operators combined).

Table 2 summarises the ILP analysis for each trial blast separated by equipment type (i.e. FS01 vs FS02 statistics) but with all operators combined. As shown, the average ILP for shovel FS01 across all blasts varied from 4471 t/h in blast 685215 to 5174 t/h in blast 685220. The largest variability using shovel FS01 was found in Blast 685210 and the lowest in Blast 685220. Shovel FS02 appears to have performed similarly to shovel FS01 in blasts 685211 and 685215. There was however a marked difference between the performance of Shovel FS01 and FS02 in blast 685220,

Table 2: ILP analysis for trial blasts with FS01 and FS02.

BLAST ID	Shovel ID	Mean	Stdev	Mean/ Stdev*100,%
685210	FS01	4693	944	20.12
685211	FS01	4733	936	19.78
685215	FS01	4471	881	19.70
685220	FS01	5174	766	14.80
685210	FS02			
685211	FS02	4824	954	19.78
685215	FS02	4454	962	21.60
685220	FS02	4308	1035	24.03

with variation factors of 14.8% and 24.0 % respectively. When all operators are combined, it is clear that the best productivity and lowest variability (i.e 15%) was achieved with Shovel FS01 in blast 685220. For the same shovel, variability in all other blasts was of the order of 20%.

In order to minimise the impact of different operators on overall productivity statistics, regions that were considered to represent overall muckpile characteristics, and for which individual operators worked, were sampled and analysed separately. Results of this analysis are summarised in Table 3. As shown, for the same operator, there is a clear difference between blasts 685210 and 685211 with a lower productivity achieved in blast 685211. This suggests that digging conditions resulting from this blast were less favourable. Similarly, differences can also be seen between Blast 685210 and 685220, with a significantly lower productivity achieved in blast 685210. In the best performing blast (e.g. 685220), differences between operators can be clearly seen with average ILPs of 5357 t/h and 4858 t/h and a variability rating of 14 % and 16% between them.

When comparing blasts located in similar domains (e.g. 685211 vs 685220) it is evident that shovel productivity performance could be associated with the marked differences in tie-up configurations which affected the overall conditions of the muckpile and in particular looseness. The diamond shaped (confined) tie-up configuration used in blast 685211 was clearly less adequate. Its implementation in the field could also be considered less favourable, complicated further by the stitching of infill holes.

In order to evaluate whether digging across different domains would cause significant impacts on instantaneous loading productivity, further analysis was conducted for blasts 685220 and 685210. These two were chosen, as they provided an adequate region to sample across domains for the same shovel. As shown in Table 4, as a general trend, there appears to be no significant difference when digging across highly to moderate structured domains (i.e. 14 to 15) as indicated by the separation of ILP

Table 3: ILP analysis of FS01 and performance of individual operators.

BLAST ID	Shovel ID	Operator	Mean	Stdev	Mean/Stdev*100,%
685210	FS01	O	4825	714	14.80
685211	FS01	O	4680	763	16.30
685210	FS01	L	4754	901	18.95
685220	FS01	L	5139	698	13.58
685220	FS01	G	5357	750	14.00
685220	FS01	K	4858	780	16.06

Table 4: ILP statistics across rock mass domains.

DOMAIN	BLAST ID	Shovel ID	Operator	Mean	Stdev	Mean/Stdev*100,%
14	685220	FS02	ALL	4150	973	23.45
4N	685220	FS02	ALL	4382	1088	24.83
15	685210	FS01	ALL	4785	957	20.00
14	685210	FS01	ALL	4755	895	18.82

statistics in blast 685210. However, differences can be observed when digging from the moderately structured rock mass to the fresh (hardest) domain (e.g. 14 to 4N). The largest relative variation of 24.8 % by shovel FS02 was also observed in the hardest domain (i.e. 4N). This could also be attributed to equipment specific issues, as shovel FS01 performed better in this domain.

As a result, the instantaneous loading productivity can be said to be a function of the rock mass condition, drill pattern and initiation sequence, fragmentation, operator, equipment (shovel), digging strategy and muckpile shape and looseness. It is a challenging task to judge the loading productivity data obtained from different blasts as the conditions across blasts generally change and it may be practically difficult to change one variable at a time. Although we experienced this issue, the results of this project helped identify the key factors affecting diggability. The order of importance of these factors affecting diggability is still not known but could be investigated in a detailed parametric case study.

CONCLUSIONS

This study aimed at exploring the potential areas of cost reductions in waste blasting without significantly affecting instantaneous digging productivity. Trial blasts were monitored over a two month period. These were blast numbers 685210, 685211, 685215 and 685220, located at the 685 bench level of the North Wall. They were located across three distinct domains, namely a highly structured moderately altered monzonite (i.e. domain 15), a moderately structured and slightly altered monzonite (i.e. domain 14) and a fresh (hardest) monzonite (i.e. domain 4N). The main results of the monitoring and analysis of these trials can be summarised as follows:

Design and explosive performance:

- Design implementation was shown to be within acceptable limits with major discrepancies mainly attributed to the larger number of infill holes required in blast 685211.
- Detailed surveys of stemming lengths and subdrills showed that the targeted average stemming lengths of 5.2 m and average sub-drills of 1.5 m were difficult to achieve. Average powder factors ranged from 0.8 to 1.0 kg/m^3. The largest corresponded to blast 685211.
- The bulk explosive product used was shown to perform adequately and within specification.

Fragmentation and diggability:

- The coarsest and most variable fragmentation was found to be from trial blast 685211 followed by blast 685215. The reason for this variability was believed to have been mainly caused by the rock mass condition, explosive energy distribution and delay timing/tie-up.
- For all cases monitored, muckpile fragmentation was shown to be within acceptable limits and appeared to have no significant impact on instantaneous shovel productivity when considering all and individual operators.
- With regards to dig rates, the largest variability using shovel FS01 was found in Blast 685210 and the lowest in Blast 685220. Shovel FS02 appears to have performed similarly to shovel FS01 in blasts 685211 and 685215. There was however a marked difference between the performance of Shovel FS01 and FS02 in blast 685220, (i.e. 14.8% versus 24.0 %). When all operators are combined, it is clear that the best productivity and lowest variability (i.e. 15%) was achieved with Shovel FS01 in blast 685220. For the same shovel, variability in all other blasts was of the order of 20%.
- In the best performing blast (e.g. 685220), differences between operators can be clearly seen with average ILPs of 5357 t/h and 4858 t/h and a variability rating of 14% and 16% between them.
- When comparing blasts located in similar domains (e.g. 685211 vs 685220) it is evident that shovel productivity performance might be associated with the marked differences in tie-up configurations which affected the overall conditions of the muckpile (e.g. looseness). The diamond shaped (confined) tie-up configuration used in blast 685211 was clearly less adequate. Its implementation in the field could also be considered less favourable, complicated further by the stitching of infill holes.
- There appears to be no significant difference when digging across highly to moderate structured domains (i.e. 14 to 15). However, differences can be observed when digging across a moderately structured and fresh (hardest) domain (e.g. 14 to 4N). The largest relative variation of 24.8 % by shovel FS02 was also observed in the hardest domain 4N. This however, could also be attributed to equipment specific issues as shovel FS01 performed better in this domain.
- The instantaneous loading productivity is found to be a function of the rock mass condition, drill pattern and initiation sequence, fragmentation, operator, equipment (shovel), digging strategy and muckpile shape and looseness. It is a challenging task to judge the loading productivity data obtained from different blasts as the conditions across blasts generally change and it may be practically difficult to change one variable at a time. The order of importance of these factors affecting diggability is still not known but could be investigated in a detailed parametric case study.

Although the theoretical reduction in powder factor (i.e. to 0.71 kg/m^3) was not achieved in the trials, results from this analysis helped identify some key positive outcomes that support the implementation of further design improvements. For example, tie-up configurations such as the “diamond-shape” used in Blast 685211 did not appear to be favourable and affected muckpile looseness which in turn affected instantaneous loading productivity. It is important to note that this blast also had the largest powder factor. In comparison to blast 685211, the consistency and best performance achieved in blast 685220 can be attributed to its implementation and less complex tie-up configuration. In confined conditions, it appears that the diagonally oriented row by row and “V” tie-up may provide improved muckpile conditions.

The monitoring of production waste blasts at the Cadia Hill mine allowed for a better understanding of the main factors influencing instantaneous loading productivity. This in turn provided the necessary background knowledge to justify potential waste blast pattern expansions in the moderately and highly structured rock domains.

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