# Muck Pile Shaping for Draglines and Dozers at Surface Coalmines

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## ABSTRACT

This paper presents three case studies from three surface coalmines. The first case study is from a coalmine where a dragline operates in 60 m wide and 1 km long strips. Typical overburden height ranges from 30 m to 50 m. The base case blast was modelled using an advanced blasting model (Distinct Motion Code – DMC) to establish the baseline using the blasting parameters in use before optimisation. DMC was used to model the alternative blasting scenarios to obtain the following key objectives:

- the post blast muck pile profile was required to have an optimum height of ~28 m
- optimise cast percentage
- achieve a well-fragmented muck pile for the dragline
- the muck pile profile should be appropriate for the dragline entry into the strip.
- Achieving these objectives would optimise the dragline performance through reducing rehandle and improving advance along the strip. DMC modelling resulted in the following outcomes:
- the required muck pile profile could be achieved
- the cast percentage increased from 21.1 to 25.1 – a four per cent increase
- rehandle volumes were reduced.

Establishing a good quality assurance / quality control (QA/QC) process was essential to delivering a blast that could achieve these outcomes. The blast was fired successfully and the dragline completed the strip approximately two weeks ahead of the time taken for the previous strip.

The second case study is from a coalmine where D11 dozers are used to move the blasted material to the spoil. An optimum profile was required for the dozers for this low-cost mining operation. To achieve this, an electronic blasting system (uni tronic™ 600) was introduced to optimise the muck pile profiles being delivered. The new muck pile profiles showed improved cast percentage from 10.6 per cent to 17.8 per cent. The changes in the muck pile centre of mass displacement improved dozer efficiency as a result of pushing material shorter distances to its final position. Dozer productivity (bcm/h) statistically did not change but coal was being exposed at a faster rate.

The third case study summarises the results from a site where dozers are used to minimise the total mining cost. Traditionally, excavators had been used on-site with conventional blast designs. After firing the first cast shot, the blasted material was found reasonably well-fragmented. Although dozing productivity hasn't been quantified on-site, operators were providing positive feedback (easier push) due to the reasonably good muck pile profile suiting to the dozers. This site also realised significant savings with the dozing as compared to their truck/shovel operation.

## INTRODUCTION

Over the last three years the coal mining industry around the world has seen a large reduction in the price being paid for coal. This has led to each mine facing the age old challenge of reducing the cost of production to remain profitable. This leads to the age old issue of choosing between options to reduce the cost inputs or improve productivity (Lumley and McKee, 2014). This paper looks at the methods to improve productivity and reduce the cost of production that has been implemented at three coalmines around Australia.

The first case involved changing the blast parameters for a dragline operation to achieve a post blast muck pile profile with an optimum height of ~28 m at the low wall and an increased cast percentage. This change in muck pile shape resulted in a reduction in rehandle, maintained fragmentation and reduced the need for ancillary equipment to aid in clean up, pad preparation, etc.

The second case involved changing the drill and blast parameters for a dozer operation to improve the post blast

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muck pile profile, increase cast, increase the centre of mass displacement and achieve the required fragmentation. The aim was to reduce the average dozer push distance of the blasted muck pile to reach final position.

The third case involved changing the drill and blast parameters for a truck and shovel operation to improve the post blast muck pile profile, achieve increased cast, reduce the amount of material moved by the truck/shovel excavation fleet and maximise the amount of material moved by dozers.

In each case, the ability to achieve the resultant productivity improvements was based upon improving the understanding of what was required to increase the rate of advance of the digging/dozing equipment. Each method involved changes in drill and blast parameters to provide the excavating equipment the optimum post blast muck pile profile. Blast movement modelling and blast design software were used (Distinct Motion Code – DMC and SHOTPlus™ 5 Professional) to assist in evaluating a variety of options. This uses a scientific method instead of the usual trial and error approach to identify the optimum solution. Combined with changes in operational practices at each site the approach proved to be successful in improving productivity and reduce the cost of production.

To implement the required changes a team based approach was required with the involvement of mine site technical services and operational personnel and Orica. This paper discusses the drill and blast changes and some of the operational changes.

There are a few well-known blast modelling software packages that could model the blast-induced rock mass displacement. Some of the well-known models include DMC (Preece, 1993; Preece and Tawadrous, 2014), SoH (Minchinton and Dare-Bryan, 2005) and HSBM (Sellers, Furtney and Onederra, 2012). Some of the other relevant muck pile modelling and case studies were given by Chiappetta, Mammele and Postupack, 1988; Chung and Preece, 1994; Workman, 1995; Mortazavi and Katsabanis, 1999; Pereira, 2001; Brent and Noy, 2006; Preece and Chung, 2005; Chung and Mustoe, 2006; Tordoir *et al*, 2009; Goswami, Brent and Graham, 2010; Munjiza, Divic and Mohanty, 2012.

## CASE STUDY 1 – MUCK PILE SHAPING FOR DRAGLINES

### Site background

Mine X is a 24/7 strip mine operation in which the overburden is removed primarily using a dragline. The use of the dragline is maximised to ensure the lowest possible operating cost. To assist this, the standard blasting practices are to cast blast an entire strip with several subsequent coal blasts as the coal is uncovered.

The reduction in coal price required the site to review its operation with the aim being to reduce the total cost of mining. The site evaluated a number of options and identified that improving the productivity of the main digging equipment, the dragline, was the best alternative. To this end the mine operational and technical services personnel and Orica jointly developed a program to ensure the delivery of the revised target.

As a starting point a review of the drill and blast design, practices, timing and the required dragline dig design was carried out by the team. This review identified the following as key requirements to optimise dragline performance:

- establish a good QA/QC process

- the post blast muck pile profile required an optimum height of ~28 m to optimise the dragline performance by reducing rehandle and improving advance along strip
- optimise cast percentage
- identify the coal loss and implement methods to reduce coal loss
- implement changes to the drill and blast process with a continuous improvement imperative.

The initial step of establishing a good QA/QC process was essential in delivering the required results. The use of the blast modelling and blast design software were essential to analyse all the options to determine the optimum solution. The baseline blast used the following blast parameters:

- hole diameter: 251mm
- burden: 7.5 m
- spacing: 14 m
- blasthole angle: 15 degrees
- hole depths: 30–45 m
- full strip fired.

## Modelling muck pile profiles and implementation of the results

The modelling process used the baseline blast parameters and post blast profile as the starting point from which alternative designs were modelled using Distinct Motion Code (DMC). DMC is a computer program that combines discrete particle motion with gas flow to simulate blast-induced rock motion (Preece, Tidman and Chung, 1997). The base case was considered to be after the implementation of the QA/QC process. The base case and alternative blast designs are summarised in Table 1.

The base case delivered an actual cast of 23.1 per cent and the DMC model was calibrated using this cast percentage and the actual blast profile. Modelled cast result for Case 1 was 25.5 per cent. Figure 1 shows the calibrated DMC model for the base case. Figure 2 shows the simulated cases 1 to 4.

The team carried out a review of the outcomes of the modelling process and identified Case 1 as providing optimum blast profile. The team implemented the blast parameters as detailed in Case 1. Table 2 compares the actual Case 1 results to the base case and the pre QA/QC process.

The actual Case 1 post blast profile measured a cast of 25.1 per cent. The modelled prediction was 25.5 per cent. This accuracy of the model gave the team confidence with its use for any future adjustments that may be required. Figure 3 compares the pre QA/QC process and optimised post blast cast profile. The QA/QC process, implementation of electronic detonators (i-kon™ II electronic blasting system) and change in bulk product from Fortan™ Coal 12 to Aquacharge™ Coal (where required) was essential in meeting the requirement of the need to manage post blast fume and improve fragmentation and muck pile looseness. Blast timing was given to provide variable burden relief of 20–50 ms/m considering airblast and productivity requirements.

Through the implementation of the muck pile profile project, the team delivered an increased cast of four per cent and an improved muck pile profile that reduced rehandle significantly (from 45 per cent to 30 per cent) and improved dragline rate of advance. The dragline productivity rates (bcm/h) were similar for all cases but with reduced rehandle and dozer requirement for preparation work the new post blast muck pile profile delivered an improved faster advance rate along strip with the full strip of coal being uncovered approximately two weeks ahead of schedule.
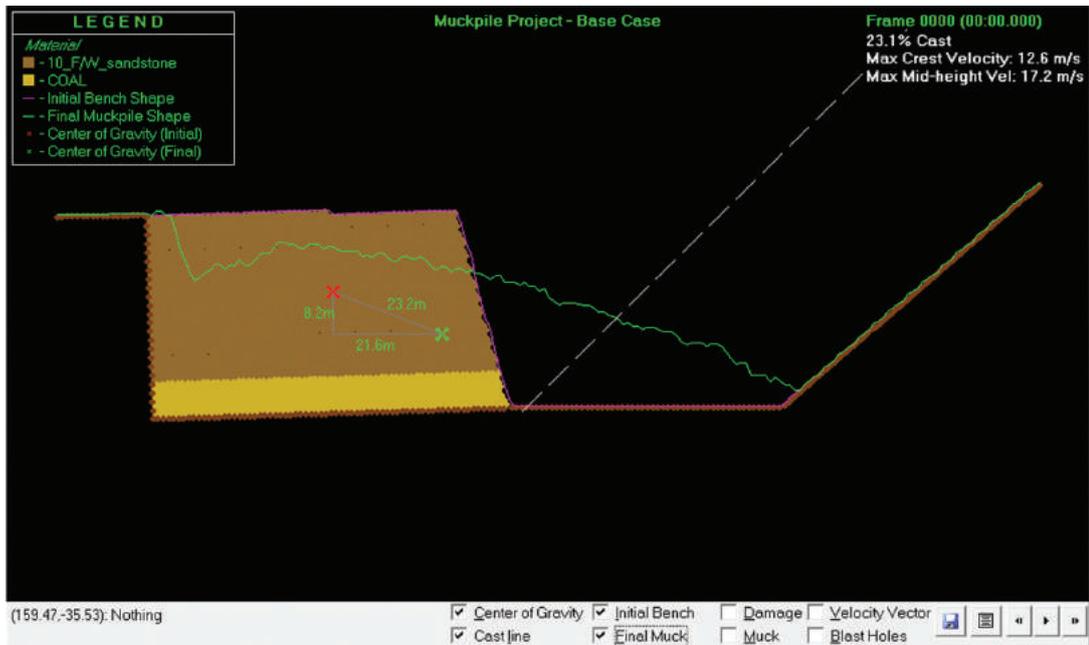
FIG 1 – Case study 1 – calibrated Distinct Motion Code (DMC) model.
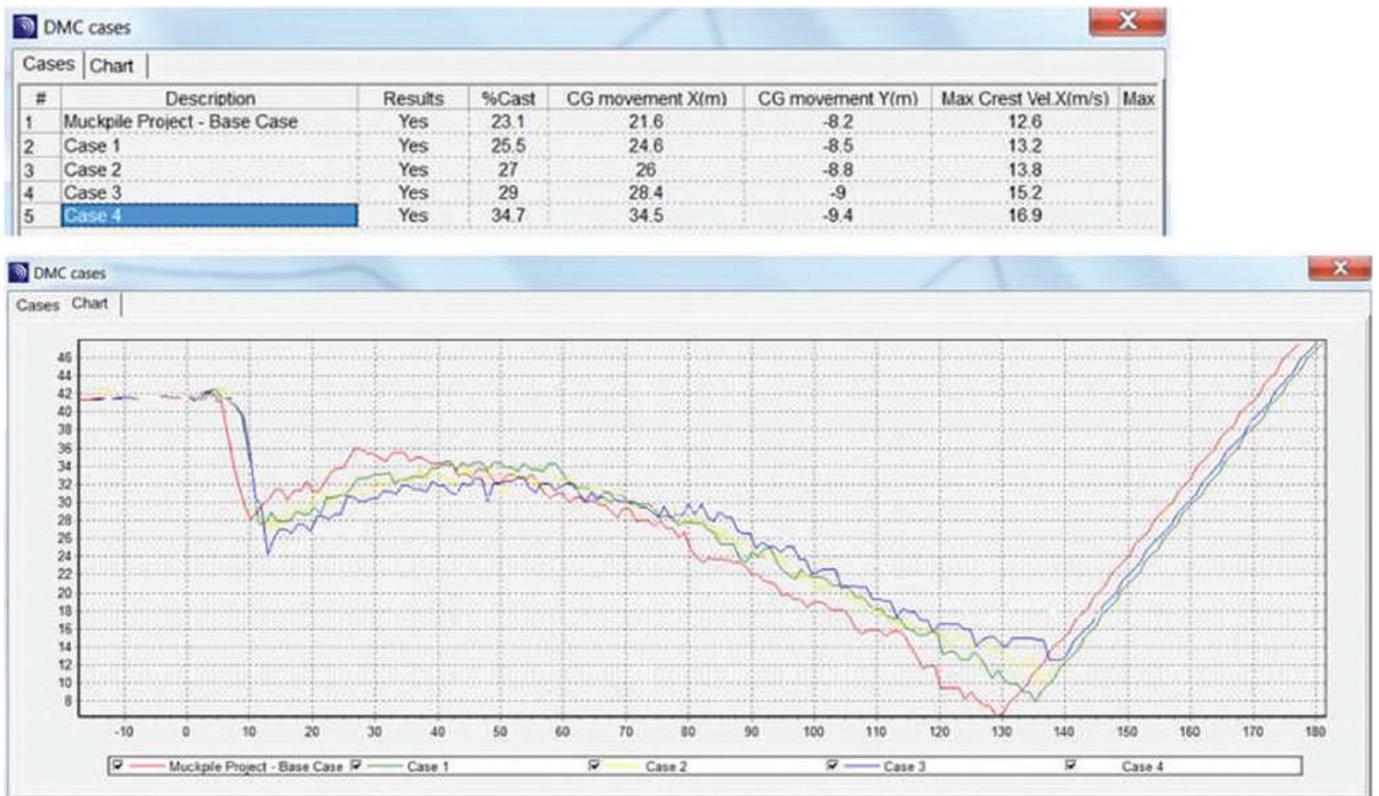


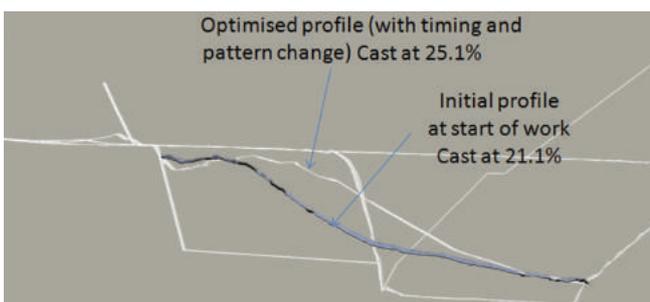FIG 2 – Case study 1 – DMC simulations. Red line shows the base case.



FIG 3 – Case study 1 – comparison of the muck pile profiles.

## Modelling for the dragline entry following the blast

One of the key considerations in managing the resources and the costs is the appropriate dragline access to the blasted muck pile. Appropriate designs can help minimise the costly and timely dragline preparation work which may delay its access to the blast. Two examples are given in this paper:

1. dragline access from the sides of the strip
2. dragline access from the middle sections of the strip.

**TABLE 1**

Case study 1 – base case and alternatives cases for blast modelling.

| Burden (m) | Base case | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|---|
| Row 1 | 7.1 | 6.0 | 6.0 | 6.0 | 5.5 |
| Row 2 | 7.5 | 5.5 | 6.0 | 6.0 | 5.5 |
| Row 3 | 7.5 | 7.5 | 6.5 | 6.5 | 5.5 |
| Row 4 | 7.5 | 7.5 | 7.0 | 7.0 | 6.0 |
| Row 5 | 7.5 | 7.5 | 7.5 | 7.5 | 6.0 |
| Row 6 | 7.5 | 7.5 | 7.5 | 7.5 | 6.5 |
| Row 7 | 6.7 | 7.5 | 8.0 | 8.0 | 7.0 |
| Row 8 | 5.2 | 7.5 | 8.0 | 8.0 | 7.0 |
| Row 9 | | | | | 7.5 |
| Average burden(m) | 7.1 | 7.1 | 7.1 | 7.1 | 6.3 |
| Spacing (m) | 14.0 | 13.0 | 13.0 | 12.0 | 11.0 |
| Powder factor (kg/m³) | 0.49 | 0.53 | 0.53 | 0.57 | 0.70 |

**TABLE 2**

Case study 1 – base case and alternatives cases for blast modelling.

| | Pre QA/QC process | Base case | Actual Case 1 |
|---|---|---|---|
| **Spacing (m)** | 14 | 14 | 13 |
| **Powder factor (kg/m³)** | 0.49 | 0.49 | 0.53 |
| **Initiation system** | Non-electric | Electronic | Electronic |
| **Bulk product** | Mostly Fortan™ Coal 12 | Mostly Fortan™ Coal 12 | Mix of Fortan™ Coal 12 and Aquacharge™ Coal |
| **Actual cast (%)** | 21.1 | 23.1 | 25.1 |

## Dragline entry from the strip end zones

In one of the strips, the dragline required access from the end of the strip. The site required a post blast profile with a ramp (with approximately ten degrees slope) at the end of the strip to minimise the dozer preparation work and minimise the lost time for the dragline. Using the calibrated DMC model, three cases were considered for modelling:

Case 1 – stand-up timing

Case 2 – stand-up timing and 5 m air deck

Case 3 – stand-up timing and 10 m air deck.

Figure 4 shows the modelling results. This shows that the use of stand-up timing with the air-deck was required. Simply put the more the air deck is the more the post blast muck pile
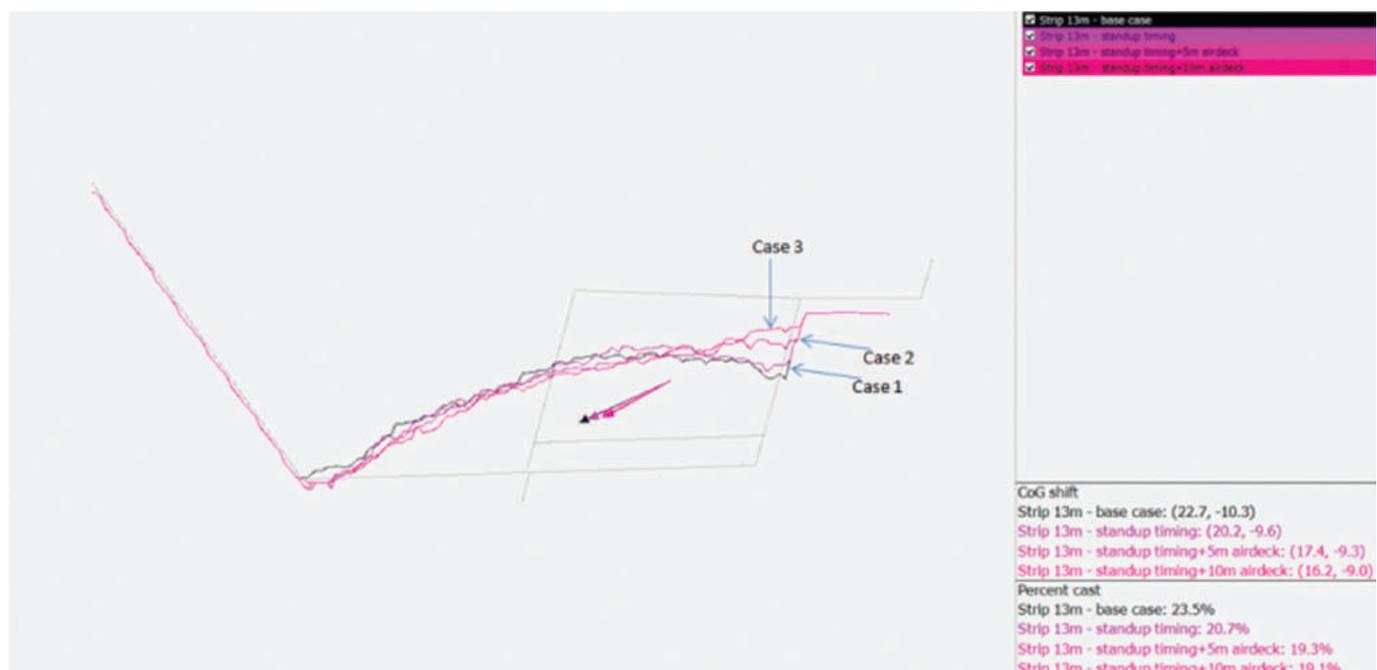


FIG 4 – Case study 1 – muck pile shaping for dragline access. Black line shows the base case.

stands up. The ramp area was approximately 100 m long and 35 m wide. Based on the modelling results, the stand-up timing with 10 m air deck in the first half of the ramp area and the rest with the 5 m air deck was used. All of this needs to ensure that the fragmentation in the area of the air deck is satisfactory for the dragline. Figure 5 shows the blast profile after the blast which confirms that the design delivered the expected results. The site found the profile reduced the amount of dozer work and the dragline downtime was reduced.



FIG 5 – Case study 1 – blast result showing the muck pile profile for the dragline's access to the shot. Arrow indicates the direction of access for the dragline.

### Dragline entry from the middle of the strip

On another occasion, the site required access for the dragline from the middle of the strip. Therefore the modelled stand-up timing and air-deck methodology was implemented as required. Figure 6 shows the post blast profile. The combination of the modelling process and the flexibility provided by the electronic blasting system were essential to the delivery of the required post blast muck pile.



FIG 6 – Case study 1 – muck pile profile for dragline access from the middle of the shot.

## CASE STUDY 2 – MUCK PILE SHAPING FOR DOZERS

This case study is from a 100 per cent dozer operation at a mine in Queensland, Australia. The site had several operating pits. In this paper, data from the largest (main) pit is presented. In this pit the strip width is 50 m and the strip length varies between 200 and 800 m. Hole diameter, angle and average hole length are 229 mm, 20 degrees and 17 m respectively. Designs consist of seven rows with a target powder factor around 0.33 kg/m$^3$. Face burden is designed at 5 to 5.5 m and the rest of the rows have 6 to 8 m burdens. Spacing is 10 m, but this varies. Bulk products used are ANFO and varying (10–40 per cent) heavy ANFO blends (Fortan™ Coal 11).

Stemming length is 4.5 m. The uni tronic™ electronic blasting system (UT600) was utilised to achieve the required timing and burden relief (20–40 ms/m).

As the primary digging equipment is the dozer, the aim was to enhance the post-blast muck pile shape to improve the dozer performance along the strip by reducing the average push distance for material to be taken to final position. To achieve this, the site personnel approached us to set up a project team to investigate alternatives. At this site the supplier was contracted to conduct drill and blast designs and were responsible for the final blast result. Using our propriety modelling and design software we delivered blasts with an increased cast percentage and a post blast muck pile optimised for dozer push operation.

Figure 7 shows the cast percentage and dozer productivity over a five year period. All data compiled between 2005 and 2010 was compared to see the differences in the cast percentage and dozing productivity. As shown in Table 3, there was not any significant difference in the mean dozing productivity values; however, average cast percentage increased from 10.6 per cent to 17.8 per cent.
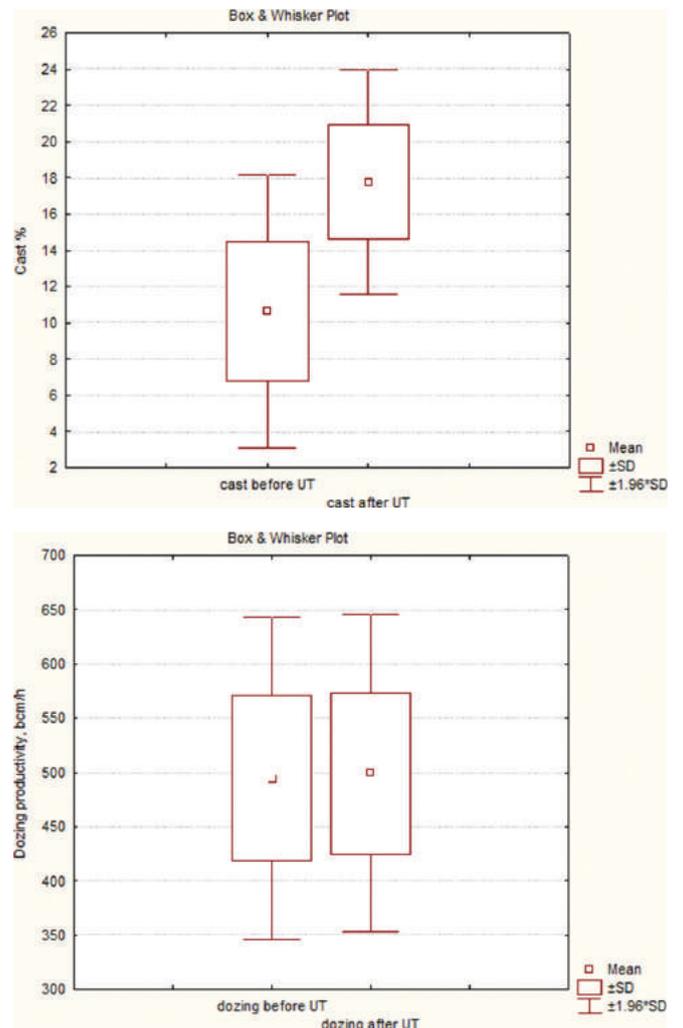


FIG 7 – Case study 2 – cast percentage and dozing productivity.

During the project, it was found that dozer muck pile profile was key to making the dozer push more effective. In 2009 the project team selected the UT600 electronic blasting system. Figure 8 shows an example of muck pile profiles before and after the introduction of the electronic blasting system. There was also an increased swell factor and centre of mass (CM) movement with the electronic blasts. The use of the electronic

**TABLE 3**

Case study 2 – summary of cast percentage and dozing productivity.

| | Mean | Minimum | Maximum | Standard deviation |
|---|---|---|---|---|
| **Cast % before UT600** | 10.6 | 3.5 | 18.1 | 3.8 |
| **Cast % after UT600** | 17.8 | 13.4 | 22.9 | 3.2 |
| **Dozing productivity before UT600 (bcm/h)** | 494.6 | 339.8 | 759.4 | 75.8 |
| **Dozing productivity after UT600 (bcm/h)** | 499.4 | 380.4 | 612.8 | 74.4 |

blasting system was critical in delivering the key change in increasing burden relief and allowing for the variable delay timing variations between the rows.

The productivity improvements delivered to the site an improved rate of coal being uncovered of two to five days ahead of schedule depending on the strip lengths and a cost reduction of approximately eight per cent in the total cost of mining.
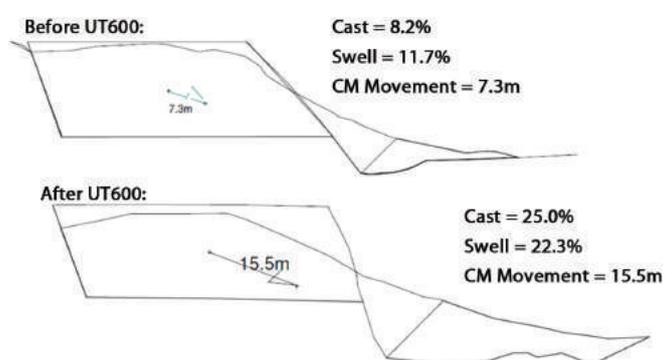


**FIG 8** – Case study 2 – muck pile profiles before and after UT600 electronic blasting system.

## CASE STUDY 3 – MUCK PILE SHAPING FOR DOZERS

This case study is from another Queensland Open Cut coalmine. This open cut operation utilises excavators, loaders, dozers and trucks to mine the coal. Only 25 per cent of the overburden is blasted with the remainder being free-dig material. The blasted portion of the overburden rock is fresh mudstone/siltstone, which is relatively competent rock that definitely requires blasting. As with the previous cases the site required to reduce their cost of mining so they set-up a project team to optimise the use of dozers by investigating changes in blast designs to deliver a change in the post blast muck pile shape. The project team decided that the post blast muck pile shape needed to have an increased cast into the void and achieve a higher dozer productivity, improving the advance along strip and the rate of coal being uncovered.

At the time of the project the site had no records of cast blasting. Therefore a calibrated DMC model from a nearby mine with similar geology was used as the base case and alternatives were analysed using DMC modelling. The optimum design was implemented using blast design software. Preblast survey (face points, crest, toe), top of coal and drill surface points were imported and front row holes were positioned according to the surveyed face profile. Average face angle was found as 58.2 ± 4.7. This face angle was very shallow for the cast blasting application. The site was using a drilling contractor to drill 165 mm diameter holes. These drills were able to drill at a maximum of ten degrees.

The heavy burdens resulting from these drill and face angle constraints were expected to limit the cast results.

A blast with 259 holes was designed at a powder factor of 0.40 kg/m³ (5 m × 7 m drill pattern with 165 mm hole diameter) with a blast volume of approximately 162 000 bcm. All holes were designed at ten degrees. Average hole length was 17 m. The uni tronic™ electronic blasting system was utilised to achieve the required timing and burden relief (20–40 ms/m). The standard non-electric system could not provide the required timing flexibility to deliver the required post blast profile so was not used.

The alternative blast design was modelled using DMC and the post blast profile is shown in Figure 9 with a predicted cast of 8.3 per cent. The blast delivered excellent fragmentation and dozers were performing well (Figure 10). Dozing productivity was difficult to quantify but operator feedback indicates that the improved muck pile looseness was giving the dozer 'an easier push' and the muck pile profile was more suited to the dozing.

The cast analysis based on post-blast survey data showed that average post blast cast was 11.1 per cent, which is slightly higher than the value predicted by the DMC model (8.3 per cent). Furthermore, the centre of prime block had moved 11.1m. Having calibrated the model with this actual result, a number of alternative designs were evaluated (see Table 4), and the following recommendations made:

- highwall angle of 70 degrees to improve cast
- increase the hole angle to 20 degrees matching the highwall angle
- increase the hole diameter to 229 mm to reduce drill and blast cost
- change to a 60 m strip width from the present 80 m to maximise the cast/centre of mass movement and improve dozing productivity.

Adding to these recommendations, the site implemented changes in mining practice increasing the use of dozers in pushing blasted material to final position. A comparison to the previous truck and shovel showed the site achieving significant cost savings from cast shots excavated by dozers. This method has been adopted at this site with cast percentage and centre of mass movement results varying from 10.1 to 13.2 percentage and 10.1–13.5 m, respectively. Due to operational issues, hole diameter was not changed.

## CONCLUSIONS

These three case studies have shown that productivity improvements can reduce the total cost of mining and the importance of changes in drill and blast that can be used to achieve this step change. The basis of any change requires an improved understanding of the post blast muck pile profile required to improve the rate of advance of the digging/dozing equipment.

As detailed in each case study the required post blast profile was specific for each site due to site issues. In each case, it
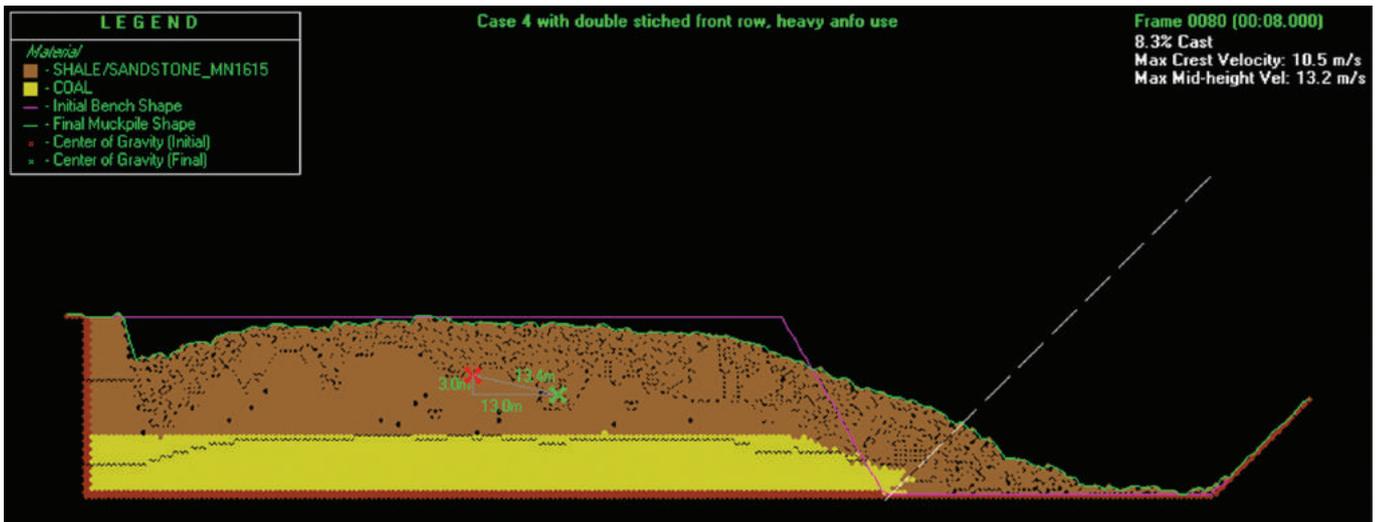
**FIG 9** – Case study 3 – muck pile shaping using the DMC model.

**TABLE 4**

Case study 3 – cast simulations for different alternatives.

|  | Hole diameter (mm) | Face angle | Hole angle | Cast (%) |
|---|---|---|---|---|
| **Base case** | 165 | 60 | 10 | 11.4 |
| **Simulation 1** | 165 | 70 | 10 | 13.6 |
| **Simulation 2** | 165 | 70 | 20 | 16.9 |
| **Simulation 3** | 229 | 70 | 20 | 20.4 |



**FIG 10** – Case study 3 – two dozers operating at the blasted muck pile.

was important to measure the baseline, jointly consider all alternatives, use modelling tools to assess all the alternatives, implement the optimum design that closely matches the required result and measure the post blast results. To achieve the end result required, a team-based approach was followed where the mine technical and operational personnel worked together with Orica personnel. Changes in operational practices were required and it was crucial for people to take ownership and provide appropriate feedback. In these three case studies, cost reduction via productivity improvement using drill and blast changes to deliver a reduction in the total cost of mining was the key driver.

## ACKNOWLEDGEMENTS

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