A review of the benefits being delivered using electronic delay detonators in the quarry industry

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Abstract

Programmable electronic delay detonators have been available for several years. The take-up rate of this technology has been high in some sectors of the mining industry, particularly open pit coal mining and underground metalliferous mining.

The quarry industry has had exposure to electronic blasting systems, but the take-up of the system has been relatively modest to date in Australia. The cost of the system over conventional non-electric delay detonators presents the most significant hurdle in a quarry manager's mind, but it is also true that examples of the overall benefits of the technology are poorly understood in the industry.

While most quarries that have converted to electronic blasting systems have done so on the basis of ground vibration control, few have understood the potential the system has in increasing productivity and reducing overall costs.

This paper serves to update the industry on the use and benefits of electronic blasting systems in quarries today, and includes a number of examples of the overall cost benefits that this technology can potentially deliver to the industry.

Introduction

The quarrying industry in Australia is highly competitive. Aggregates have generally maintained or reduced in constant dollar price over the past 20 years, despite increasing labour, equipment and energy costs, as well as industry demands for even more stringent product specifications, environmental and safety controls. End user market growth based on unprecedented levels of construction, especially in Western Australia and Queensland, the states most affected by what has been termed the mining "super-cycle", has resulted in quarry operators looking for ways to differentiate themselves and get an "edge" on their competition.

An area that has historically been scrutinised as part of the overall quarry process is the drill and blast component. At a typical quarry operation, drill and blast can account for approximately 15% of total quarrying costs.

Drilling and blasting costs are generally highly transparent to a quarry operation, particularly with an increased propensity to adopt the use of contractors. This transparency often exposes drill and blast as an obvious target for cost reduction. After all, savings are readily available through measures such as powder factor reductions and elimination of second primers. However, to do this without analysis of the downstream effect is to ignore the pivotal part that drill and blast plays in the total cost of aggregate production. This is due to the fact that it is positioned at the very beginning of the rock breakage and crushing process. Consequently, sub-optimum blasting practices inevitably lead to increased total production cost per unit tonne of final product. The reality is that with some careful analysis, it can readily be shown that optimising the drill and blast program can transform any quarry operation.

The introduction of electric delay detonator systems around 50 years ago and non-electric detonator systems during the 1970's allowed quarry operators to develop flexible blasting solutions to assist them in their operations, to a point. The shortcoming of both systems is that the delay in these detonators is governed by the burning time of pyrotechnic compounds (Figure 1). Very slight differences in burning rates and the amount of the compound contained within the detonator itself limits the accuracy of the detonator versus its nominated delay time. Generally non-electric delay detonators fire within approximately 1% nominal delay time; this is known as "cap scatter". It is now known that a quantum reduction in cap scatter is the key to unlocking a huge array of benefits to quarry operations using blasting.

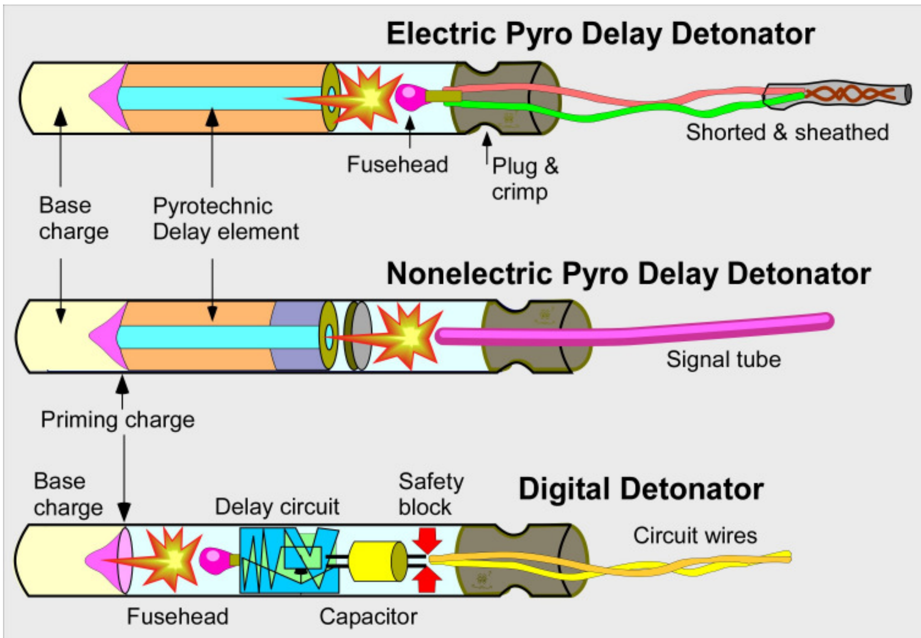


Figure 1 - Fundamental construction differences between pyrotechnic and electronic delay detonators

The idea of electronic delay detonators (electronic detonators) was raised in 1973 at the Kentucky Blasters Conference in the USA. They were first used in Australia during the mid 1980's, but were not commercially used by Orica Mining Services until late 1999. Electronic detonators remove the cap scatter by replacing the pyrotechnic compounds with a printed circuit board (PCB). The delay of the detonator is now controlled by a quartz clock contained within a central processing unit on the PCB, rather than burning of a pyrotechnic element, as is the case in non-electric detonators. This allows an electronic detonator to fire as accurately as 0.01% of its nominated delay time.

It is known within the industry that accurate electronic detonators can deliver a variety of benefits. The authors intend this paper to serve as a reference for all quarry operators and associated personnel, and to inform of them of these benefits and ultimately how they can assist with delivering real cost savings to any quarrying operation.

Acceptance of the electronic detonator

Orica Quarry Services predominantly provides two types of services for quarry customers around Australia. A "down-the-hole" (DTH) service that involves the delivery of bulk product, and a "Rock-On-Ground™" (ROG™) service. *ROG* is a complete blasting service which includes laser profiling of the free face (if any), blast design, mark-out, boretraking, dipping, loading, tie-in and finally the firing of the blast. In NSW alone, approximately 30% of all Orica *ROG* customers are using electronic detonators regularly. Note that while in the case of Orica Quarry Services' customer base, the highest usage rate of electronic detonators may be in the *ROG* sector, there are several DTH customers who are also independently harnessing the benefits of this technology.

Quarry operators are experiencing numerous benefits through the use of electronic blasting systems. These are realised through the following unique features:

- Accuracy and precision
    - As electronic detonators now fire at their nominated delay time, blast holes accurately interact with one another as designed.
    - Benefits:
        - Tailored blast designs lead to reductions in blast vibration, smaller & more uniform fragmentation, and the ability to change and improve muckpile profiles to suit any earthmoving fleet.
- Programmability
    - Orica's i-kon™ electronic detonators, for example, can be programmed in 1ms increments between 0 ms and 15,000 ms.
    - Benefits
        - This allows quarry operators to modify the delay times in the blast to best suit local geological conditions, assisting with improved fragmentation or to meet stringent environmental constraints. Larger blasts can also be fired at sites where stringent environmental constraints need to be met, that would otherwise be impossible with non-electric detonators due to cap scatter.
- Independence
    - Electronic detonators all receive their fire signal instantaneously. Therefore the notion of a burning front, that was always important to consider when using non-electric detonators, is eliminated.
    - Benefits
        - Quarry operators can fire larger more complicated blasts, over a number of levels, which would have previously been impossible to achieve, due to burning front and "cut-off" limitations with non-electric detonators.

- Communication
    - Most electronic detonator systems allow the user to communicate with the detonators at any time prior to the firing of a blast.
    - Benefits
        - This allows the user to identify any problems with the detonators, providing an opportunity to rectify the problem, prior to firing a blast, thus potentially avoiding a misfire.

While electronic blasting systems have numerous beneficial features, the greatest benefit by far is the potential it unlocks to make quantum differences to blasting outcomes. This is only possible through knowledge and an intimate understanding of global best practice that continually evolves as the industry develops new and innovative ways to sequence blasts. Many of these new initiation sequences challenge conventionally held beliefs, and are therefore often not adopted without a close working relationship to the technical blast improvement team of the explosives services provider.

Despite the benefits, there is still reluctance amongst quarry operators to adopt the use of electronic detonators, primarily due to their unit cost, and secondarily due to an aversion to what is often perceived as a "more complex" system. Those who have been in the industry long enough may well recall equivalent comments being attributed to the introduction of non-electric detonators, which went on to completely take over from electric delay detonators.

To realise the potential of electronic detonators, it is important to look at the quarrying process holistically and not simply focus on the cost of breaking rock at the face. For example, if a smaller fragmentation distribution can be achieved at the face, how will this affect the overall quarrying operation? In all likelihood,

- More material will be able to be moved through the primary crusher,
- This will improve production, and,
- More stone will be able to be moved out the gate.

If we compare the revenue and margin that is made from the sale of the extra tonnes, would it exceed the cost of the electronic detonators used in the blast? And while improved production figures is one consideration, there are many more cost savings that can be made related to,

- Less wear and tear on the crusher
- Less power draw
- Better crusher utilisation due to reduced breakdowns
- Reduced rock-breaker hours, and so forth.

In order to help quarry operators determine the value realised by the use of electronic detonators, explosives suppliers are working closely with customers to better identify and quantify these benefits. By using measurement devices already in use at the quarry (or introducing them if necessary), the difference that the electronic detonators can make compared to current blasting practices can be accurately measured. Using this data, as well as additional information provided by the quarry, purpose-built software can be used to calculate the value delivered to the quarry. Orica has developed a powerful tool that enables visual comparison of multiple scenarios on a total quarry cost model. Known as the "Value Calculator", it is being used in the blasting industry to deliver real and measurable value through a variety of Blast Based Services (BBS™).

Following are a number of case studies that best illustrate how electronic detonators are currently being used from several regions in Australia that Orica Quarry Services operate in. The case studies range from a demonstration of how electronic detonators can directly improve the bottom line of a quarrying operation in South Australia to using them to meet stringent environmental constraints in Queensland. When reviewing these case studies, readers should consider how these examples might apply this to their own operation, and the overall cost savings that could be realised.

Western Australia/Northern Territory/South Australia; using electronic detonators to improve fragmentation

Electronic blasting trials have been conducted in South Australia, Western Australia and the Northern Territory with the objective of improving fragmentation. At the beginning of 2006 two trials were conducted at the same quarry in the Northern Territory. These two blasts were used to investigate the practicalities of using an accelerated initiation sequence to promote improved fragmentation. Sizing analysis was conducted on one of the blasts, using Orica's Powersieve® software, which clearly displayed a significant improvement of the P80 sizing (Figure 2). Operators at the quarry commented that the rock "flew" through the crusher. The crusher experienced few blockages compared to the typical non-electric (or pyrotechnic) blasts, initiated with Exel™ non-electric detonators.

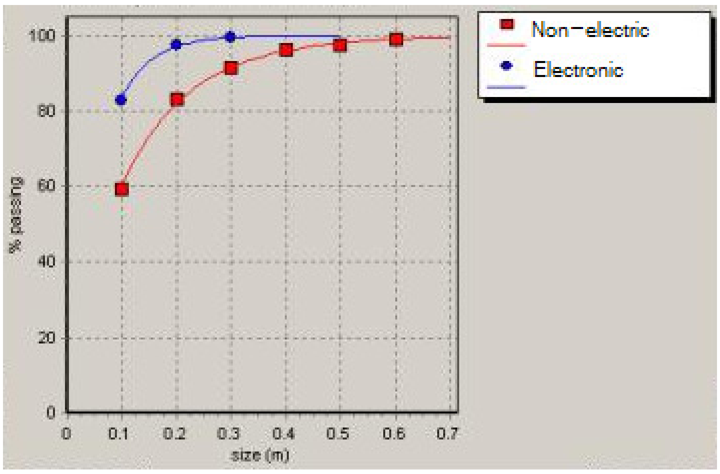


Figure 2 – NT quarry Powersieve Data

The learning from the NT trial blasts was then transferred to a regional quarry in Western Australia, where more detailed recording systems were part of the quarrying process. The trial consisted of one blast, with the results being compared to historical blasts from the same bench. The electronic blast used the accelerated initiation sequencing and was compared against conventional non-electric initiation systems and timing. The data was collated after the blast and compared to historical blast data so that trends could be examined. A 7% increase in crusher throughput was identified even with the crusher gap being reduced to stop the flooding of the secondary crushing circuit. The customer was impressed with results.

The knowledge gained from the third trial blast was then applied to a quarry in Adelaide. The initiation timing was further analysed and refined using known rock mass properties to scientifically calculate an optimised initiation sequence. Electronic detonators afford this capability through their accuracy and timing selection flexibility. The blast consisted of 91,000 tonnes; one half was initiated using *Exel* non-electric detonators and the other half was electronically initiated using *i-kon* electronic detonators and partnered with accelerated initiation sequencing. The powder factors for both sections were analysed to ensure that both sections were comparable; the analysis displayed a 1.4% higher powder factor in the electronic section of the blast. After the blast the visual results clearly displayed an improvement (Figure 3 & Figure 4).

Figure 3 - Aerial view of blast, Adelaide quarry

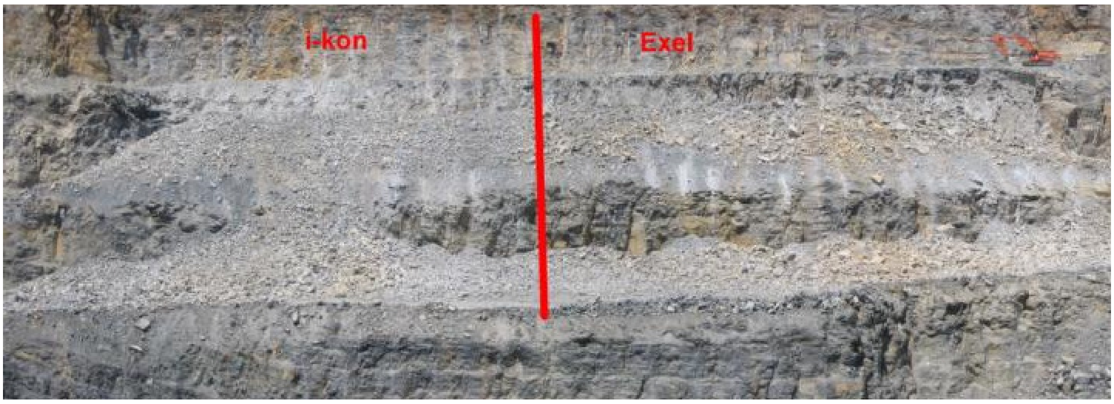
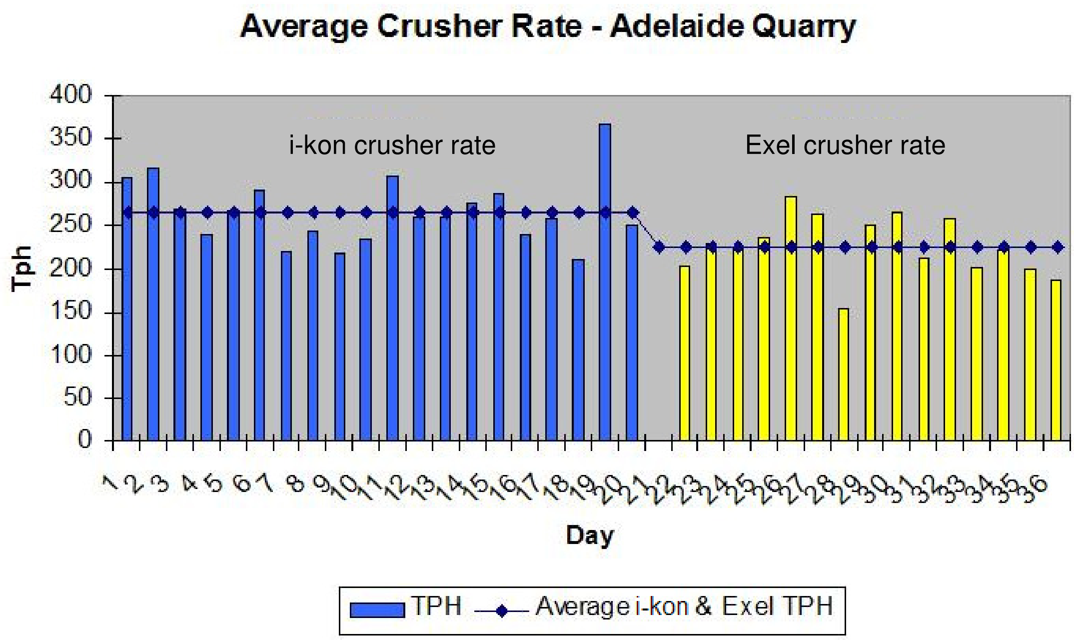


Figure 4 - Front view of blast, Adelaide quarry

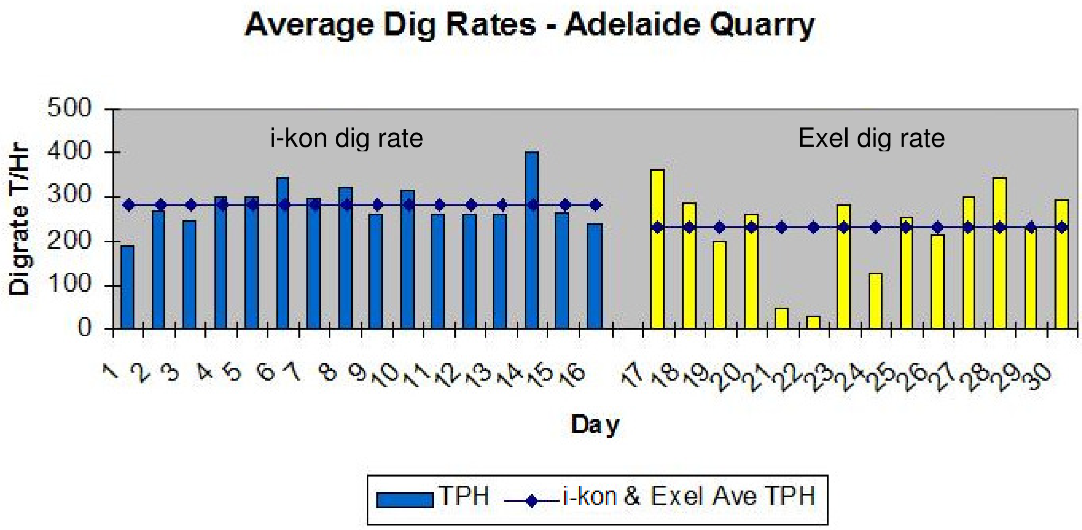
Approximately one month after the blast was fired, all of the corresponding data was collected through the quarry's data recording system. The quarry recorded load and haul daily total tonnes, crusher throughput and the amount of oversize removed from each section of the blast. All of the production data was analysed with the following results.

- Load & haul rates measured a 23% increase in average tonnes quarried per shift, favouring the electronic section of the blast.
- The crusher rates (t/hour) displayed an increase of 18%, favouring the electronic section of the blast.
- The oversize measurement displayed a 43% reduction in the electronic section of the blast.

Displayed below are the production rate graphs (Figure 5 & Figure 6).



<u>Figure 5</u> - Average crusher rates following electronic blasting trial, Adelaide Quarry



<u>Figure 6</u> - Average dig rates following electronic blasting trial, Adelaide Quarry

Using the operating costs supplied by the quarry to calculate a total operating cost, a reduction of 13% was determined for the electronic section of the blast. This included the following operating costs,

- Drill and blast
    - This included the additional cost of the electronic detonators which increased the cost of the drill and blast component by 17%
- Rock breaking
- Load and haul
- Crushing
- Screening
- Stockpile management.

The overall cost reduction is not the only benefit that can be realised by the quarry, as the improved equipment efficiencies allow more available time to quarry and crush rock. This cost reduction was calculated using Orica's Value Calculator software.

If all of the additional time, which was made available through the improved quarrying and crushing efficiencies, was converted to producing additional product in this particular quarry, an additional 18% of quarry product could be produced and sold. Even assuming only a 50% conversion of the additional operating hours liberated, the quarry could have the capability of producing approximately 10% additional saleable product with a cost reduction of 13%. All of these benefits can be realised with no additional capital investment, an easy solution that can readily be implemented by the right team.

Once this trial ended, further opportunities to trial the accelerated initiation timing were explored. Up to this point in time, the accelerated electronic initiation sequencing had only been trialled at quarry sites with no environmental limits, or sites that were recording very low or no readings for airblast and ground vibration whilst blasting.

BGC The Lakes Quarry is serviced by Orica Quarry Services on a *ROG* basis. The site is currently a large user of *i-kon* electronic detonators, which are used to reduce ground vibration associated with blasting. BGC Quarries management has introduced a pro-active policy aimed at reducing blast-induced ground vibration and airblast, measured at the closest residential property. This approach is to ensure that a good relationship can be maintained between the quarry and the surrounding residents and that they can co-exist with minimal disturbances.

Since the introduction of electronic detonators, the average peak particle velocity (PPV) has been reduced by 25% compared to the previously used non-electric system. BGC management invited Orica to trial the accelerated timing to assist with oversize reduction in a particular blocky section of the quarry, which typically produces low vibration readings. The blast reduced the oversize that was characteristically experienced in this section of the quarry, along with improved wall conditions (Figure 7).

Figure 7- BGC The Lakes blast result

Despite the accelerated timing, the environmental results display a minimal increase in PPV levels. This provided Orica with the confidence to trial in another area of the quarry using the same accelerated electronic initiation timing.

BGC The Lakes Quarry and Orica are continuing to work together to investigate the benefits that can be realised by using the geotechnical properties of the rock mass to formulate an initiation sequence that promotes improved fragmentation, whilst maintaining ground vibration levels.

Orica has assisted BGC The Lakes Quarry with implementing new blasting technology, providing an overall cost benefit that is not being realised by other quarry operators in the same market. The quarry is located approximately 35km further away from the metro market than any competitor's quarries, which adds additional cartage cost to the final product. In addition to this, the adoption of electronic blasting systems has increased the initiation component cost.

However, despite the two higher input costs, the quarry is able to supply competitively priced material into the Perth metropolitan market. BGC quarry management's ability to analyse and understand the effects of specific input costs on the total quarry operating cost has allowed the quarry to establish its position as the largest quarry in the Perth market. The BGC Managers' key objectives are to manage a quarrying operation that has minimal impact on the surrounding community, combined with maintaining a low cost operation. By leading the market with the implementation of new technology to their operating systems and processes, BGC has become a market leader in the Perth quarrying industry.

New South Wales; using electronic detonators to avoid damage to close proximity infrastructure

In mid 2006 Orica Quarry Services was engaged to conduct some work for a quarry in Sydney, due to close in 2008. In preparation for the final sale of the quarry, the western wall of the quarry needed to be remediated. It was expected that some blasting would be required to achieve this. However, situated at the top of the western wall of the quarry were three water storage tanks; two were constructed of concrete and had 2 ML and 38 ML storage capacities. The third tank was constructed of steel and had a 4 ML storage capacity (**Figure 8**, **Figure 9** & **Figure 10**).

Figure 8 - **Concrete wineglass tank, 2ML storage capacity**

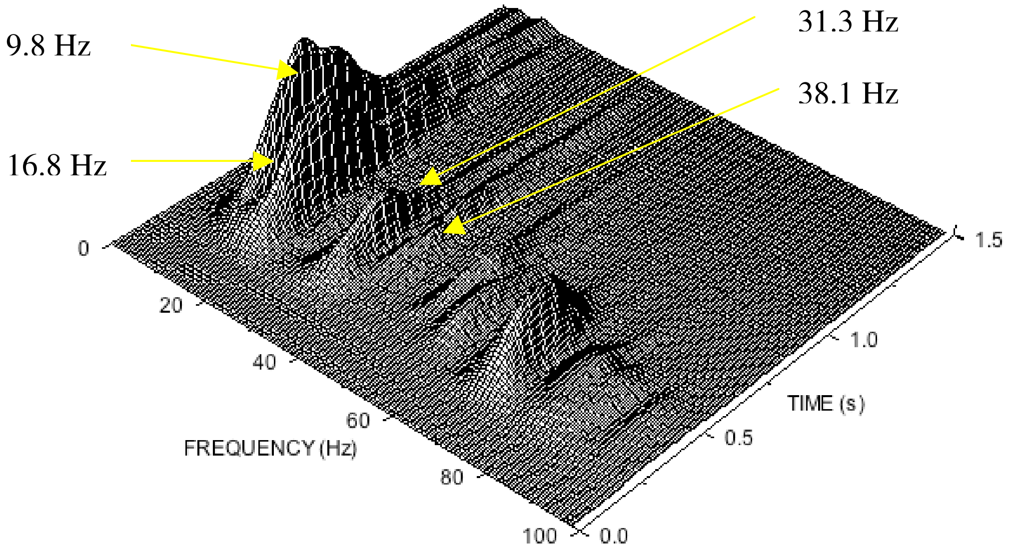
Figure 9 - **Steel wineglass tank, 4ML storage capacity**

<u>Figure 10</u> - Concrete in-ground tank, 38 ML storage capacity (note the two wineglass tanks adjacent)

The aim was to determine what effect, if any, blasting would have on the tanks given that very strict environmental limits had been applied to the tanks; a 0.16g acceleration limit and a 25mm/s vibration limit. Blasting would have to take place up to 65m away from the tanks.

In order to determine how the tanks would react when exposed to blast-induced vibrations, or the blast frequencies that needed to be avoided, baseline data was collected. This involved placing several accelerometers and geophones (generally used for monitoring blast acceleration and vibration) on and around the tanks. Single blast holes containing a known charge weight and located at a known distance from the tanks were also drilled.

The frequencies at which the tanks responded were found by plotting data into a time-frequency plot. The frequencies that were of interest were those that had a long time response ie. the tanks shook for an extended period of time. In Figure 11, a time-frequency plot has been created for the information collected from the monitoring station located at the top of the 2 ML concrete tank. The frequencies that need to be avoided so as not to excite the tanks were in this case 9.8 Hz and 16.8 Hz and to a lesser extent 31.3 Hz and 38.1 Hz. This type of analysis was completed for all 3 tanks.



<u>Figure 11</u> - A time frequency plot created from data collected at the top of the concrete wineglass tank

Once this had been completed, this data was used to conduct a Monte Carlo statistical analysis to determine the effect that full-scale blasting on the western wall of the quarry would have on the tanks. It was determined that small blasts utilising a maximum instantaneous charge (MIC) of 4 kg, with a burden and spacing of 1.3m and 1.5m respectively and a bench height of 3.5m could be fired no closer than 71m from the tanks. More practical blasting could take place no closer than 220m from the tanks, using a 2.4m burden and 2.7m spacing and a 5.6m bench height.

Assuming that blasting was to go ahead with the conservative MICs, and the need to satisfy the strict vibration and acceleration limits, it was determined that electronic detonators would be have to be used. The accuracy of the detonators and programming flexibility of the detonators would allow each hole to be fired when designed and facilitate the choice of initiation sequences to avoid the frequencies at which the tanks respond. Due to the cap scatter in non-electric detonators and the relatively inflexible delay range, non-electric detonators would not be suitable.

The complexity of meeting the onerous acceleration limit could only be achieved with accurate electronic timing but also very low MICs. As a result of the close patterns and low MICs and the resulting expensive nature of the blasting, the quarry owners made the decision to lobby the owners of the tanks to increase the vibration and acceleration limits. Their attempts were unsuccessful, leaving the quarry to consider other options. The quarry have now made the decision to secure the western wall where required using mechanical rock bolting methods.

Queensland; using electronic detonators to control both airblast and vibration

Boral West Burleigh quarry is located in Brisbane, surrounded by a number of housing estates, a light industrial area and the Brisbane-Gold Coast Highway. Prior to March 2002, the quarry was firing buffer-style blasts, where the muckpile of the previous blast remained in front of the blast to be fired. While the quarry was able to adhere to the environmental limits imposed on the site (115 dBL and 5 mm/s), the quarry was still receiving complaints from neighbours and to compound the problems, muckpile looseness and fragmentation were suffering.

To combat these issues, the quarry instigated a blast improvement program in conjunction with Orica Quarry Services and Blastronics (blast monitoring instrumentation specialists). The aims of the program were to,

1. Continue to adhere to airblast and vibration limits
2. Reduce the effect of blasting on surrounding neighbours and,
3. Improve blast results, restoring a normal level of productivity to the quarry.

The airblast problem was tackled using three separate approaches. First the high airblast levels generated by the opening blast holes to fire were reduced by using a lower density/energy explosive. Next, the other high airblast levels recorded throughout the blast were treated by optimising the front row burden and adjusting the loading in the blast to suit the drilling results. Finally, to lower the general airblast level, initiation sequences were designed so that blasts were fired along the bench instead of out towards a free face.

To lower vibration levels and satisfy the vibration criteria, the MIC needed to be strictly controlled using a lower energy explosive as well as solid and air decks were also used when appropriate in order to try and minimise the MIC.

To minimise the chance of disturbing the residential neighbours, it was decided that all blasts needed to be fired in such a way that the dominant frequency content of the blasts avoided the 4 Hz – 28 Hz range. The low frequencies in this range have been scientifically proven to disrupt residents. In order to determine a non-electric initiation sequence that would avoid this frequency range, without the need for a long and exhaustive blasting campaign, a Monte Carlo statistical analysis, similar to what was completed at the quarry in Sydney, was undertaken with great success.

After 6 months of firing blasts with this initiation sequence, a decision was made to substitute *i-kon* electronic detonators, and monitor the blast results, vibration and airblast levels recorded and the neighbouring residents reaction to blasting. It was expected that that the accuracy and programming flexibility of the electronic detonators, would be ideal in further improving the blasting program. It became apparent quickly that *i-kon* system was able to lower vibration levels even further, whilst still avoiding the 4 Hz – 28 Hz frequency range.

Currently electronic detonators are still being used by the quarry in conjunction with the further refined practices developed to minimise airblast and vibration. Blasts continue to satisfy the stringent environmental limits imposed on site, and nearby residents continue to be satisfied with the approach that Boral and Orica are taking with the blasting program. The next step at the quarry will be to implement initiation sequences similar to those used and proven in the Northern Territory, South Australia and Western Australia, in order to further improve quarry production.

Conclusion

Electronic detonators have been commercially available to the Australian quarry industry since the late 1990's. Up until now, the take-up of electronic detonators within this industry has been relatively modest, traditionally only being used when the quarry operator is faced with limited blasting options often due to environmental or production constraints. This is despite a significant realisation of the benefits and uptake of the detonators within the mining industry.

The blasting industry now has access to a plentiful array of tools to measure and analyse aspects of the blasting operation. Orica has been able to adopt these modelling and measuring tools, and incorporate their use in the Value Calculator tool that compares the downstream impact of multiple blasting scenarios. The demonstrable benefits resulting from this mean that electronic detonators need no longer be used as a last resort, but as a mainstream tool to capture a competitive edge.

The flexibility and accuracy of electronic detonators mean that they are clearly beneficial in minimising airblast and vibration levels, as has been demonstrated in numerous quarries including Boral's West Burleigh operation. However, a wealth of data is now available that demonstrates that there is a significant amount of value to be unlocked in many quarrying operations not just in environmental control, but in productivity improvement as well, facilitated by the introduction of electronic blasting systems, coupled with advanced blast design capability.

Examples of productivity benefits have been detailed in this paper. By using accelerated initiation sequences, fragmentation benefits have been able to be realised at quarries in the NT, WA and SA. In the comprehensively analysed SA quarry blasting programme,

- Load & haul rates increased by 23%
- Crusher throughput rates increased by 18% and
- The over size measurement displayed a 43% reduction in quantity in the electronic section of the blast
- An overall 13% decrease in operational costs, despite the increased drill and blast cost incurred by the electronic detonators, was achieved.

The flexibility and accuracy of electronic detonators combined with the development of complex statistical models for predicting the behaviour of structures in close proximity to blast zones has also resulted in blasting potentially being able to take place where blasting with non-electric detonators would not be possible.

No matter the size or type of quarrying operation, the use of electronic detonators combined with careful measurement, has major potential to result in benefits that would otherwise be unattainable with conventional non-electric systems.

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