# With Compliments

# Production Blasting with Electronic Delay Detonators at Peak Quarry

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## 1. Abstract
Peak Quarry has achieved substantial improvements to its bottom line by giving close attention to blasting practice, and in particular by introducing electronic delay detonators for routine production blasting. The precision and flexibility provided by these units has enabled the quarry to gain control over fines and curtail oversize without increasing explosive usage. In addition, the extent of nuisance from blasting vibrations has been reduced.

Cost and productivity improvements have been achieved throughout the rock handling process, from loading to secondary crushing, and face geometry has improved. While some of the improvements can be attributed to other changes to blasting practice, the precise and flexible electronic timing has been key. There have been some disadvantages with the system used, but these are expected to be reduced or eliminated with recent improvements.


## 2. Introduction
The search for improvement in quarry operations focuses on:

- safety,
- the containment of direct and indirect costs in every area,
- the raising of efficiencies, so that the available resources are optimally employed in delivering saleable product to the market place,
- finding new ways to bypass previous constraints, and
- maintaining good relations with neighbours.

Blasting impacts upon all these areas. When a demonstration blast using AEL's ExEx1000 Electronic Delay Detonator (EDD) system was taken at Peak Quarry in May 1996, management wished to increase the fraction of smaller sizes, for specialised building and construction materials. The blast was not only of general high quality, but doubled the yield of the desirable -6.75mm size fraction. This dramatic result led management to suspect that the new initiation system represented a technical break-through, with positive implications for the whole operation. Following negotiations with the suppliers, a decision was taken to evaluate the system in routine production blasting. Since the implementation of the agreement in February 1997, approximately 34 blasts have been taken with it, and 9 blasts using the conventional system. This paper reports on experience to date.

## 3. Rock Conditions
Peak Quarry is situated near Cape Town in the Western Cape, about 15 km west of Somerset West. The rock resource at Peak is hornfels, which is strong but highly folded and jointed. It forms part of the Tygerberg formation in the Malmesbury group.

Dip varies between vertical and about 75$^{o}$ west, and control of rockbreaking is made difficult by extensive folding and fracturing. This has caused significant problems with back break at the top of each bench, and excessive burden at the toe. Improvement was achieved by turning the quarry faces around by 90$^{o}$, so that the major free face runs perpendicular to the major dip. Table 1 shows the nominal characteristics for intact core.

| Parameter | Value |
|---|---|
| Density, g/cc | 2.72 |
| Uniaxial Compressive Strength, MPa | 170 - 190 |
| Young's Modulus, GPa | 68 - 77 |
| P wave velocity, m/s | 5461 |
| S wave velocity m/s | 3344 |
| Poisson's ratio | 0.2 |
| Work index | 18 |
| Abrasivity | 11.1% |

**Table 1: Characteristics of Hornfels at Peak Quarry**

## 4. Blasting Practice and Environmental Concerns

The following parameters were standard at the beginning of the exercise.

| Parameter | Value |
|---|---|
| Hole diameter, mm | 110 |
| Explosive | Powergel P100 |
| Burden, m | 3.5 |
| Spacing, m | 4.0 |
| Stemming, m | 3.0 minimum |

**Table 2: Blasting parameters**

It is usual to fire no more than eight holes per row in two rows of holes, but geometry sometimes dictates that up to five rows are necessary. Initiation employed AEL's Handidets™, with 33ms out of the hole and 500ms in the hole, and 42ms Handi Trunkline Delays ™ (HTD's) between rows. Timing was designed to achieve individual hole firing with at least 8ms between shots, in order to minimise vibrations at Penhill village next to the quarry. Vibration monitoring has been in place, and although vibration levels were within US Bureau of Mines limits, there were regular protests alleging that blasts would rattle plates or initiate cracks.

## 5. Loading and Crushing

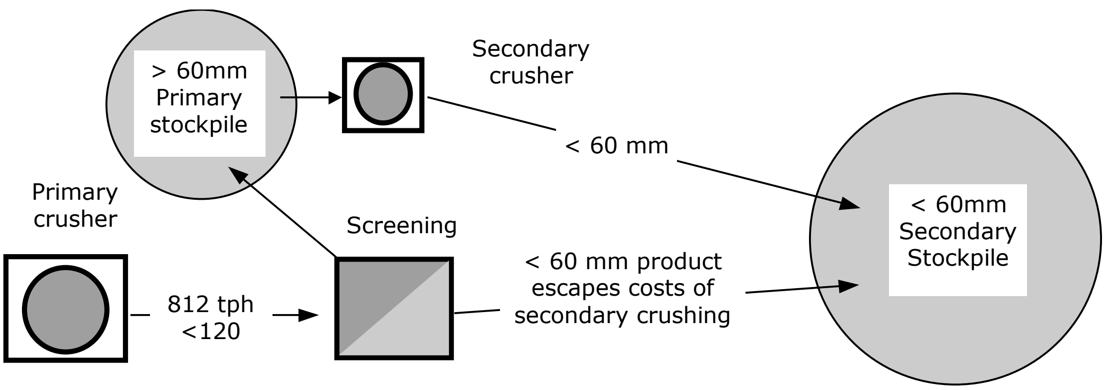



**Figure 1: Crusher Flowchart**

Figure 1 illustrates the rock flow. Two Demag H85 loaders load into CAT 769 $35^t$ dumpers, which deliver to the in-pit primary crusher. The -120mm feed from this is split into a -60mm feed which goes straight to the base plant and secondary stockpile, and the +60mm feed, which goes to the primary stockpile before the secondary crusher. It is possible to monitor tonnages by means of conveyor belt weightometers, and fragmentation phenomena by taking belt cuts.Total throughput is held at about 812 tph, and the finer the fragmentation, the more will bypass the secondary crusher, reducing operating costs.

## 6. The EXEX 1000 Electronic Delay Detonator System

The ExEx 1000 system, which is marketed in South Africa by AECI Explosives Limited (AEL), has been in wide use since 1994 and has been described at length in various papers [1]. Basically,

- the system is intelligent - that is, the detonators not only report on their own status in the hole, but are programmed by computer prior to blasting
- The detonators have six wires and hook onto a five wire surface harness through which the testing and firing instructions are given
- delays can be programmed from 1 to 15000ms in 1 ms intervals
- the blast design can be created on a PC using the Winblast software, and timing instructions downloaded directly from this.

The ability to control the firing delay of each detonator with precision has revolutionised blasting, as it opens a window of control that is closed to pyrotechnic initiation systems. These are prone to significant scatter about the nominal firing times, which means that

- the interval between shots will typically vary from nominal by up to 30ms,
- shots closer than this interval are apt to fire out of sequence, and
- if sufficient inter-shot interval is provided to ensure sequential firing despite the expected variability, then the optimum delays which would ensure efficient rockbreaking cannot be approached.

In addition, with conventional initiation systems there is no feedback to the blaster as to the reliability of units. The use of this kind of intelligent system has therefore been termed “Computer Aided Blasting”, since it represents a completely different plane of thinking and operating. The price premium has initially been set at about 30% above the price of the shock tube system it replaced.

**Safety**

Owing to a number of early mishaps with the EDD systems of various manufacturers, and the difficulty of training quarry personnel in how to handle any non-routine incidents with a system that was really a prototype, a special arrangement was negotiated between Peak Quarry, AEL and the mines inspectorate. No blasts would be taken unless an approved AEL technical specialist was present. This arrangement has ensured a beneficial relationship between explosives supplier and quarry, with both taking serious interest in the efficiency and safety of the blasting operation.

**Deployment**

Holes are primed both top and bottom, with 3ms longer delay on the top detonator. This has the benefit of ensuring that:

- If premature movement occurs during the blast, cutting off the upper part of a blasthole from the bottom primer, then the entire blasthole is likely to fire, and not just the bottom section.

  This has major benefits for the highly jointed ground at Peak Quarry.

[1] Cunningham, CVB and Jones M: Commissioning of Production Blasting with the ExEx 1000 Electronic Delay Detonator System. Proc EXPLO 95: Australian IMM, Carlton, and Victoria. pp 119-126

- If a mid-hole cut-off does take place, then with shock tube systems, the top deck only fires 25 to 50ms later, which puts the timing well beyond the planned range. The top EDD's are timed to go only 3ms later, so bottom priming is achieved with no timing penalty for the top primer in the event of a cut-off.
- In the event of one detonator malfunctioning, a back up is in place.

The tendency to use one detonator per hole in order to save money carries with it a high hidden cost. The argument that "every detonator should fire, and poor quality should not be condoned by doubling the initiators", ignores the fact that there are many valid reasons why a second detonator in the hole may be vital, and puts at risk significant fragmentation benefit.

## 7. Blast Timing with Computer Aided Blasting

Without resorting to elaborate designs, Figure 2 contrasts firing patterns using shock tube systems with what is achieved using CAB. Shock tube systems are constrained by the units, which are (a) manufactured and (b) in stock, and can also be constrained by such mundane considerations as tube length. In contrast, programmable EDD's need only one item stocked. With true CAB electronic systems, the inter shot delays are infinitely variable to provide for even minor, albeit desirable, adjustments to the blast timing. These timing adjustments are made particularly meaningful by the fact that the desired timing is actually achieved, and is not merely nominal. This level of control results in a high and valuable rate of learning by the blast crew, on how to achieve desired outcomes. The interest level generated motivates attention to quality blasting and pride in expertise, which in itself is highly desirable.

Having described the quarry and its operations, the influence of CAB on quarrying operations can now be considered.

## 8. Effect of Cab On Quarry Conditions

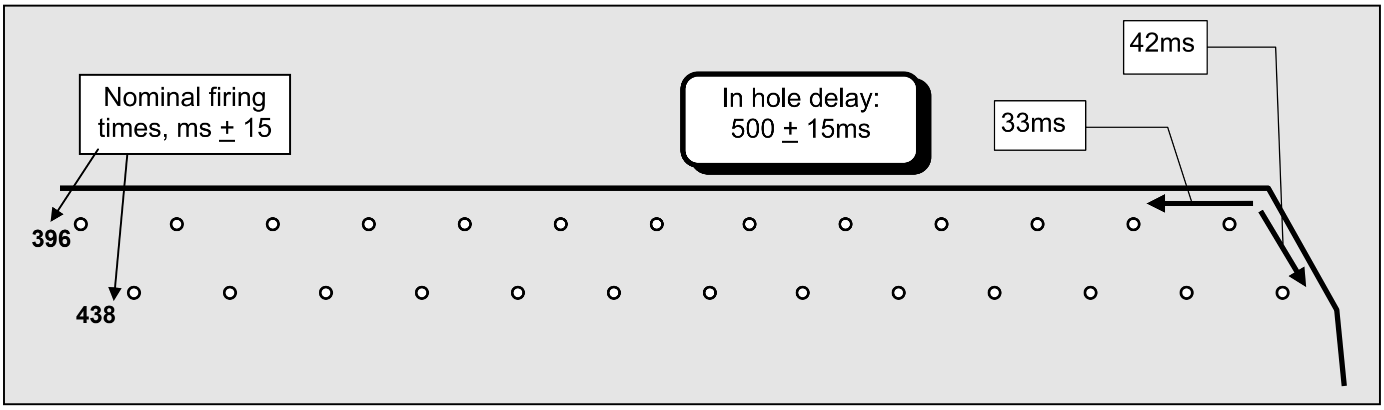
The following areas have been positively impacted by the move to Computer Aided Blasting

- Fragmentation
- Oversize
- Load and Haul efficiencies
- Crusher efficiencies
- Ground vibration
- Backbreak
- Toes

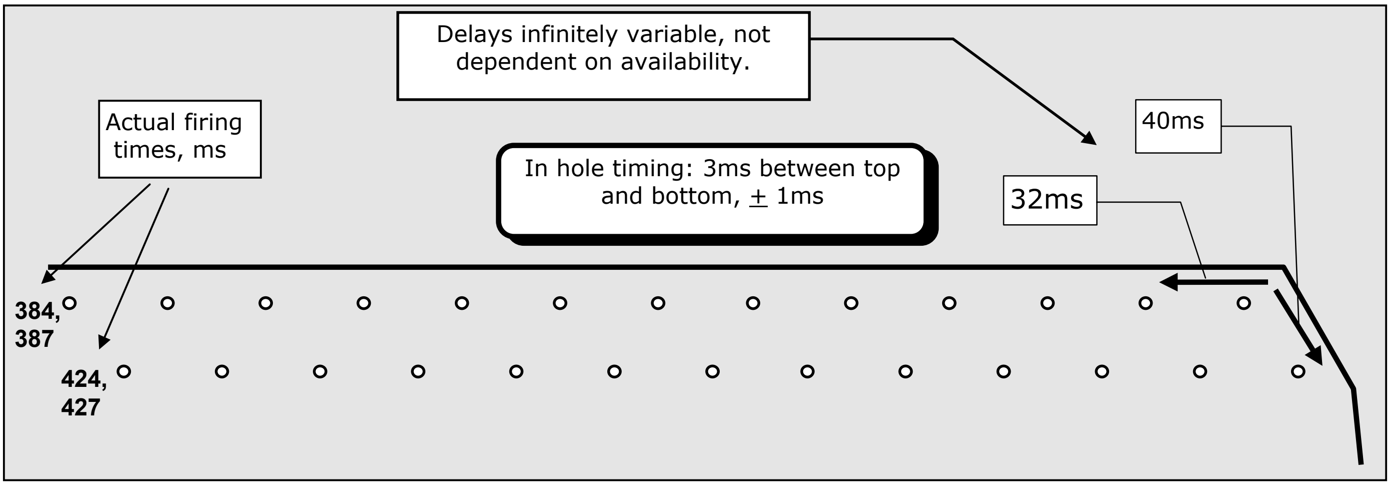
**Fragmentation**

Prior to introducing CAB, the plant was producing the desirable -6.75mm fraction at an average of 6.5% by mass. With the first blast using CAB, this increased to 14%, and the average over the months is shown in Figure 3. The plots indicate that there is a fragmentation improvement simply from using accurate delays which mimic the nominal shock tube delays. The greatest benefit arises however from CAB - that is, using the programmability of the delays to optimise results. Although it is difficult to put a figure on the benefit, the finer fragmentation is reducing operating costs all the way to the secondary stockpile, and is supplying more of the fine product, which enhances the objectives and profitability of the quarry. The areas of benefit are considered below.

**(a) Timing with Shock Tube**




**(b) Timing with Computer Aided Blasting**




**(c) Use of CAB to achieve specifically desired expansion time of 8ms/m.**

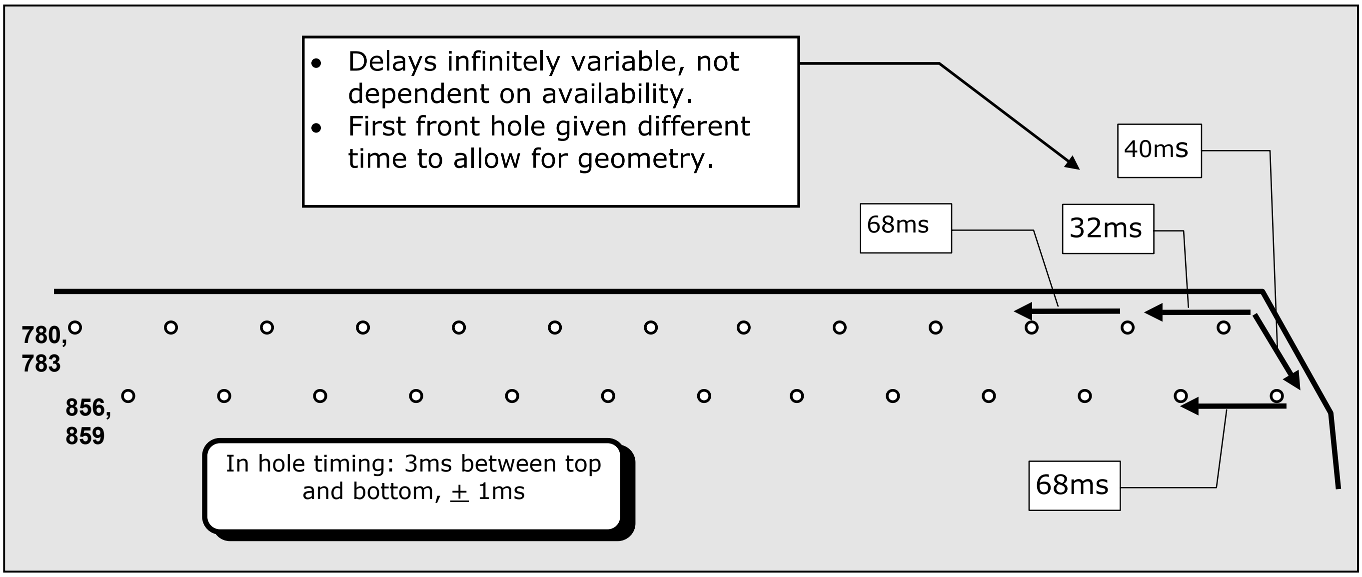



**Figure 2: Differences in timing capability with CAB**

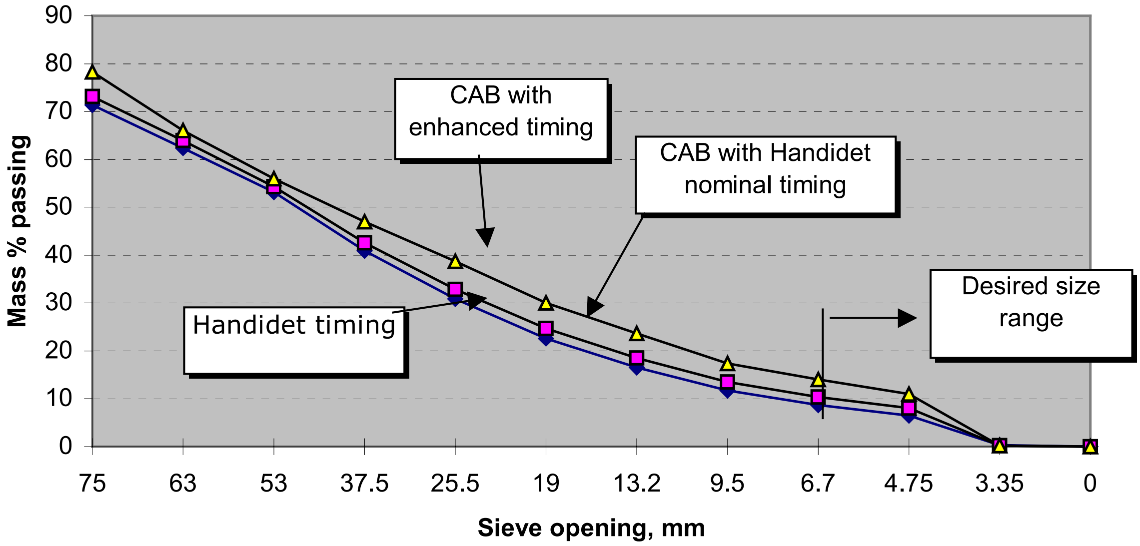



**Figure 3: Cumulative Fragmentation curve for Handidets and Computer Aided Blasting at Output from Primary Master**

### Oversize

The average boulder count has fallen from 2.5 % to between 0.9 and 1.2%, which means less than half the number of oversize fragments. The benefits of this improvement are considerable:

- Secondary breaking, whatever the method used, is troublesome, demanding time, space, labour and equipment. Half the oversize means half the expense.
- The primary loading operation progresses more quickly and with less wear on the shovel
- The face shovel loads material and does not have to dig.

### Loading and Hauling Effeciencies

The change in fragmentation has been accompanied by an improvement in digability of the muckpile, accompained by improved fill factors for the loading and hauling equipment. By careful monitoring of the conveyor belt weigher, it has been determined that the truck fill factor has increased from 27 to over 29 tons. This has repercussions through the loading cycle, as

- trucks are more quickly loaded (and therefore turned around) and
- the loader uses less passes to achieve a full load.

As a result, the fleet of four dumpers has, with some careful management, been reduced to three. This represents a significant but as yet unevaluated reduction in working costs.

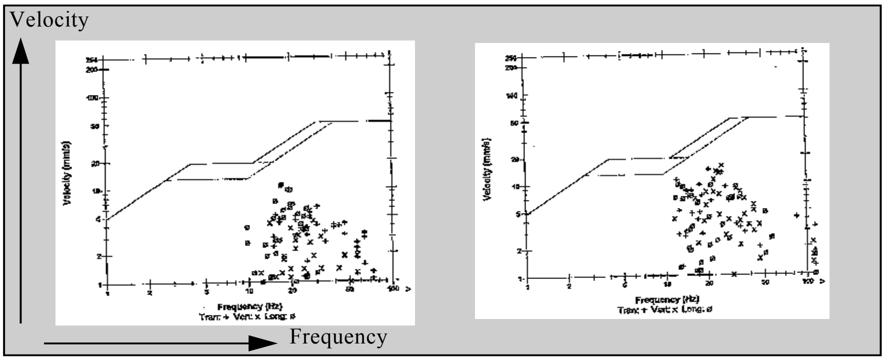
### Crusher Efficiencies

By increasing fines production in the blasting, and bypassing sections of the crushing plant, power and wear and tear can be substantially improved. On a tonnage basis, the <60mm bypass product has increased from 52% to 65%, which on a production rate of 812 tph represents a throughput reduction to the secondary crusher of 105 tph. The full benefit of this 12% reduction in crusher load is yet to be realised as adjustments are required to the plant, but it represents a large improvement in working costs. It is well known that it is cheaper to break the ground in-situ using explosives than to have to do it in the plant, after the larger particles have created extra costs in the loading cycle[2].

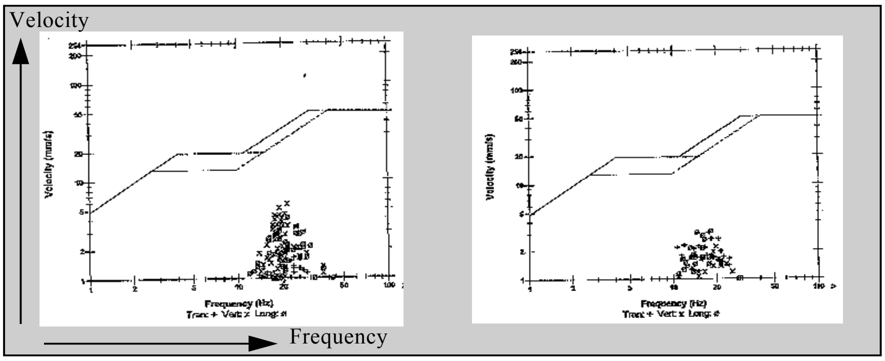
## Ground Vibration

The most crucial requirement in containing vibration complaints, is gaining predictability over the levels of vibration. If consistent vibration levels can be achieved, then technical design work can be focused on reducing the amplitude of vibration and channelling the energy into safe frequencies.

**Figure 4: Ground vibration analysis for pyrotechnic and electronic delay initiation, taken at same position.**




(a) Wide range of amplitudes and frequencies with pyrotechnic delay system




(b) Reduced amplitudes, narrow frequency range with electronic timing: Improved predictability, less impact.

Figure 4a shows typical amplitude/ frequency plots from two conventional blasts at Peak Quarry, for the three mutually perpendicular components of vibration. The wide scatter in both axes indicates poor consistency of energy distribution. The ground is shown to be experiencing shocks at irregular intervals and with very variable intensity, a sure sign that things are not under tight control.

In Figure 4b, taken at the same position, the plots of two typical EDD shots show remarkably consistent energy distribution, with maximum energy output about half that of the pyrotechnic delays, and frequencies contained to a much narrower band. Since the reduction in vibration energy is accompanied by improved fragmentation, the obvious correlation is that explosive energy is channelled from shaking the ground to

[2] Eloranta J. The Efficiency of Blasting versus Crushing and Grinding. Journal of Explosives Engineering, Cleveland, Ohio. Vol 14 No 5, Sep/Oct 1997: pp12 - 15.

breaking it when the timing of the shots is precise. This correlation has been noticed in every exercise we have undertaken with Computer Aided Blasting.
In the years ahead, this ability to both contain environmental nuiscance and improve fragmentation will become increasingly critical in urban quarries.

**Back Break**
Prior to introduction of the EDD's, the amount of back break at the crest of the benches was excessive, requiring angled holes to try to achieve correct burdens at the toe (Figure 5).

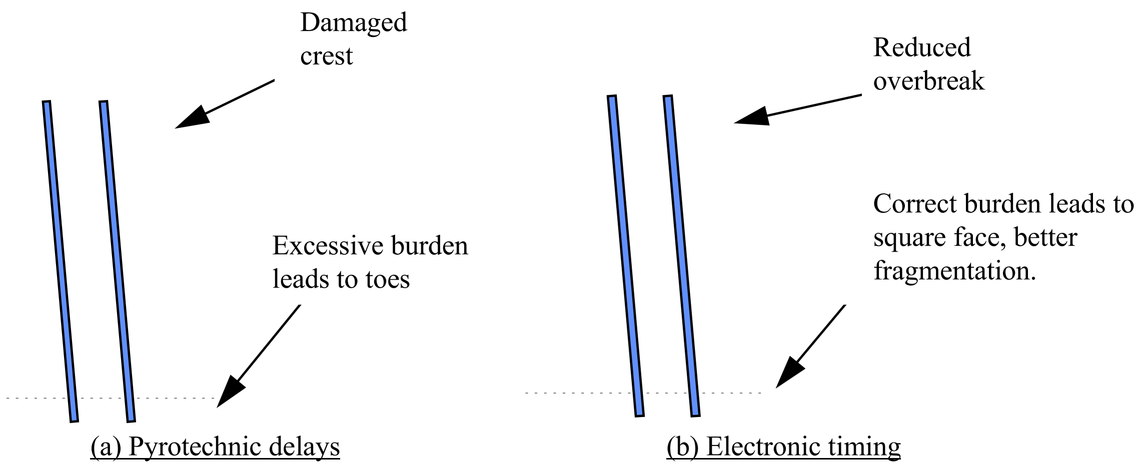



**Figure 5: Effect of precise timing on backbreak**

With the more accurate timing, a better crest has been achieved, enabling drilling to progress with standard hole angles and patterns. Figure 6 illustrates why inaccurate timing results in very ragged inter-shot intervals, which impact negatively on the backwall.

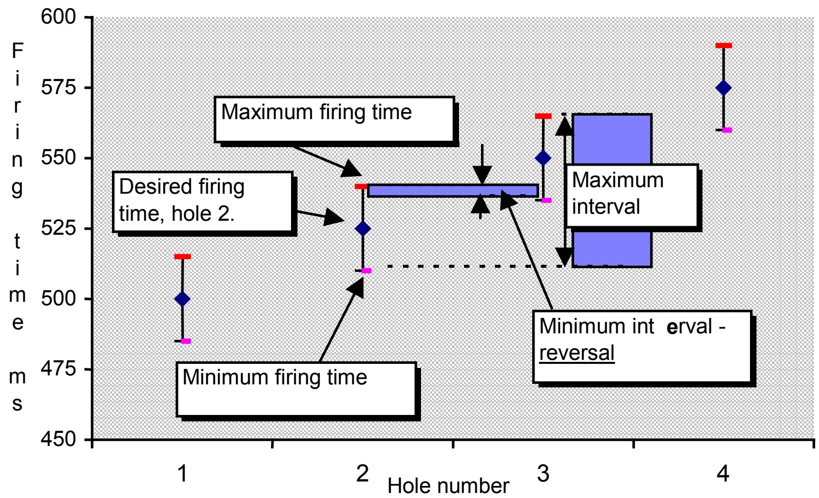



Figure 6: Effect of scatter on achieved

The timing between holes in a row was typically held at 25ms, using 500ms down hole delays. Since the timing scatter on these units is typically ± 15ms, actual delays between, say, holes two and three in Figure 6, can be anywhere between:

**(565 - 510 =) 55 ms**, which is 120% greater than planned and
**(540 - 535 =) -5 ms,** which is a reversal of firing order.

When electronic timing is used, the actual interval between shots is very close to what was designed, and this results in consistent, controllable breaking results, and with a straighter back, the burdening of the holes becomes more regular, which in turn reduces back damage.

**Toes**

The presence of substantial toes has been eliminated with the introduction of CAB, probably as a result of better crests, reduced backbreak and enhanced breaking mechanisms. This means that "Snake holes" are only still necessary in the older parts of the quarry standing since before CAB was introduced. The smoother floors have benefits for running costs on loading and hauling equipment.

## 9. Discussion

An important objective at Peak Quarry has been to maximise production of fines fractions. At many operations the objective is the opposite - to minimise them. Introducing accurate timing resulted in greater efficiency of energy transfer from the explosives to the rock, and a question could arise as to whether it is therefore likely to result in more fines, where less are required. The answer is not simple, as it depends what is causing the fines, and what the definition of "fines" covers.

Basically, if the powder factor remained the same, overall fragmentation would almost certainly be finer. However, since both dust and boulders result from out of sequence firing, it is possible that both will be reduced when CAB is adopted. It is generally recognised that the fragmentation becomes more even, which ties in with this expectaton.

If fine fragmentation is not required, then adopting CAB would permit the pattern to be expanded, dropping the powder factor and reducing smaller fractions. The point is that CAB always results in greater uniformity of blasting results, so less insurance, in the form of over-design, is needed.

## 10. Disadvantages of Cab

The following disadvantages became apparent when the ExEx1000 initiation system was implemented:

- In wet weather, the connections were prone to develop faults, and required attention before a blast could be put off.

- The high fault rate encountered during hook up and testing has been an irritation. Conventional firing systems provide no feedback before firing. There is a tendency to assume therefore that everything is functional, and after the blast it is easy for a misfired hole not to be noticed. The EDD feedback can therefore put the system at a disadvantage in terms of the perception of the users. The fault rate is related in part to wire damage during charging and stemming operations, and is a function of the high number of conductors in this particular system: five on surface and six down the hole.

  The need for the presence of a supplier's representative is a negative feature: with experience to date, it is likely that permission will be obtained to blast without this.
- Owing to its complexity and flexibility, the system is prone to operator error. The blasting team need to keep their wits about them when hooking up and allocating delays.

The above problems are addressed in the new ExEx2000 system. The most obvious refinement is that only two wires are used, which greatly simplifies operation and improves the robustness of operation.
There continues to be an undercurrent of concern that these electronic systems may not be safe. This concern is entirely unfounded with the ExEx systems, which have been designed in the most basic way to only generate sufficient energy for firing once it is time to blast. There have been, and there could be, no incidents since the first wake up calls in the early days, when safety was based on electronic switches rather than physical isolation from firing voltages.

## 11. Conclusion

Each of the important production parameters considered in Table 3 have improved since introducing CAB. Improvement results both from improved accuracy of timing and the ability to fine tune the blast design. Taken together, these improvements are a powerful argument for the merits of the technology, and amount to considerable economic benefit.

| Item | Result |
|---|---|
| Fragmentation | Fines increased by at least 30% |
| Oversize | Boulder count reduced by about 50% |
| Load/ Haul | Quicker turn around, improved load factors |
| Crushing | Reduced tonnage to secondary crusher |
| Ground Vibration | Better predictability, reduced amplitudes |
| Backbreak | Better faces, reduced toes |

**Table 3: Operational achievements with Computer Aided Blasting**

Once the benefits of Computer Aided Blasting have been experienced, it is difficult to give up the exhilarating freedom of controlled rockbreaking and revert to the constraints of pyrotechnic delays. In view of the economic advantages, it has been well worthwhile the added cost and effort of using the ExEx1000 system, and the much enhanced 2000 system will render this approach even more attractive. Management at Peak Quarry continuously adjusts operations to meet new challenges, and sees this as an important part of the toolkit.
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