2011 Caernarfon Award Submission
New Zealand

ELECTRONIC DETONATORS
VS NON ELECTRONIC DETONATORS
AND NEW BLAST-HOLE LOADING TECHNIQUES
– YOU DECIDE

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Abstract

Inline Drilling Limited supply’s professional Drilling, Blasting & Consultancy Services to Quarrying and Mining Operations across New Zealand.

Glenn Kiernan was employed by Inline Drilling Limited in early 2008. Glenn has a significant background in Drill & Blast Operations with a particular focus on technical blast components and design improvements.

Glenn’s research began in 2001 where his drill and blast department implemented the use of electronic detonators into the Martha Gold Mine located in Waihi, New Zealand. Beyond 2001 Glenn has provided services to a large number of quarries & mines across New Zealand and in Western Australia as the growth of the electronic detonator industry and improved blasting techniques expands.

The bulk of this research was conducted at the Martha Gold Mine in Waihi until early 2008. The Martha Gold Mine Open Pit Operation is located 140km South East of Auckland, New Zealand. The perimeter of the mine is located 16 metres from the main street of the Waihi Township. Blasting and Mining activities are performed within 40 metres of the pit boundaries.

Blast induced vibration has been and still is the dominant factor when planning production rates, blast design and other related mining activities. Regulatory consents limit peak particle velocity to 5mm/sec measured at six separate monitoring locations surrounding the open pit. A 95% rolling compliance level must be maintained at all times.

There are four parts to this paper –

- Firstly it reflects on the research conducted by Glenn Kiernan, Martin Waldron and the Drill & Blast team at Waihi and the paper presented thereafter by Blair Jackson (Project Manager) & Tjaart Louw (Product designer) in 2003.
- Secondly it looks at the research Glenn conducted regarding accuracy testing of three leading separate electronic detonators on the market today.
- Thirdly Glenn presents the findings of his Particle Vector Sum results of eleven signature blast holes fired with various charge weights and basic loading techniques.
- Finally Glenn presents key learning’s around “advanced” blast hole loading techniques and loading options for Quarry Managers and Drill & Blast personnel alike.
**Introduction**

Martha Open Cut Gold Mine is located at the heart of the Waihi Township in New Zealand. Waihi has a population of approximately 4000 residents. The original underground mining began in the 1800’s. The underground mine closed in 1952.

The Martha Mine Open pit was commissioned in 1988. In 2006 the iconic Cornish Pump house was relocated to the Western end of the open pit to allow a South Wall stability cutback to proceed.

The principal mining company set a precedent in 2007 when they announced their Amenity Effects Program (AEP) where effected local residents are compensated for mine related activities eg: dust, noise or blast vibration.

**Executive Summary**

This paper was written and presented to enable Quarry Managers & Employees to understand modern aspects of the Drill & Blast component within their business or operation. The paper combines a number of blasting aspects and research spanning a ten year period within New Zealand unlike many other papers focusing on simply one component.

Firstly, the author covers the research completed at the Martha Hill Gold Mine Site in Waihi, New Zealand where Electronic Detonators were first introduced in the year 2001. Significant increases in mining production and a reduction in blasting events along with reduced vibration (PPV) enabled the Mine to continue operating and still does until this day.

Secondly, the author explains the rigorous research he conducted on three of the world’s leading Electronic Detonators and the results of each electronic detonators firing accuracy (in terms of milliseconds) as compared with each detonators Technical Data Sheet specifications. This section also provides a somewhat stumbled upon finding of the inaccuracy of one of the world’s leading seismographs and the advantage this gave to the author when dealing with the sites Peak Particle Velocity (PPV) compliance levels and the “rounding” of PPV results.

Thirdly, the author provides the results of research completed on site with regard to “simple blast-hole loading” techniques and the reduction in blast vibration or PPV because of the altered loading design.

Finally, the author provides key blast design learnings from many years of experience within the industry. These new designs will provide significant cost savings to a large number of sites, not through Drill & Blast costs along but more so through increased plant throughput which has the most potential for cost reduction. By utilising modern explosive components and products along with calculated and tested methods every site now has the opportunity to eliminate costly “oversize rock”, “toe” (unblasted in situ rock at the bottom of a blast) and high vibration results. The author shows pictures of rock that has been blasted using these designs and without the use of crushing equipment the muck pile aggregate has been utilised for forestry roading.

In closing the author/presenter acknowledges two close friends from within the Quarrying Industry who died recently within a short time of each other. One of these men was a previous Inspector and the other provided the author not only with all of his 50 years of knowledge but also life skills and an ability to work hard for what you believe in. This paper has been completed in loving and respectful memory of these two men.
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**Part 1**

**a) Pre Electronic Initiation System – Track Record:** *(Research by Glenn Kiernan and Martin Waldron, subject matter taken from Jackson & Louw)*

Mining at the Martha pit is done by mining a 5m bench in two passes of 2.5m with 180 tonne backhoe configured excavators. Blast holes have a diameter of 89mm with varying sub drill, depending on rock type. Stem height is limited to 2.2m on all blast holes.

Prior to the electronic initiation system/s various blasting techniques were evaluated over a 12 month period to improve fragmentation, minimise vibration and to increase production rates, these included:

- Low density explosives (ANFO’s and non ANFO’s) to achieve an increased column height;
- Air decking holes, top and bottom, to enhance placement and distribution of the explosives;
- Numerous timing regimes - from short 8ms per delay to 400ms per delay, using pyrotechnic initiation systems;
- Reduced the hole diameter down to 76mm with tighter patterns and lower kg per hole to improve explosive distribution;
- Reduced the size of the shots to between 40 & 50 holes in sensitive areas.

**b) Low density explosives:** Minimal success has been achieved using low density explosives. This resulted from the explosive formulations used, where in the ANFO types the polystyrene beads would end up at the top of the hole, and on the low-density emulsion types where consistent performance in 89mm holes was not always achieved.

**c) Air decking:** Air decking had the biggest impact on blasting results due to the improved explosive distribution that assisted in maximising fragmentation and to a lesser extent, minimised vibration. Using air decks at the bottom of the hole, forced the explosive column higher which assisted in reducing the amount of oversize but had a negative effect on the digability of the second flitch.

**d) Delay time:** Various delay times were evaluated, using pyrotechnic initiation systems, and it was concluded that 25ms per delay was the optimal delay. *(This resulted taking into account delay time scatter of the pyrotechnic detonators and ground conditions).* Ground conditions in particular impacted on the delay time as blasting in all the designated blasting areas were on top of old underground workings with soft clay back fill or open voids. Meeting the mining consent vibration limits were made inherently more difficult, having to continuously allow for 5% delay time scatter in the pyrotechnic detonators, thus limiting the size of production blasts.

**e) Explosive distribution:** Borehole diameters were reduced to 76mm but with the softer pockets of clay within the hole, swelling of the clay made it impossible to load packaged explosives in the holes. An additional concern was the increased costs resulting from drilling tighter patterns.

**f) Reduced shot sizes:** With the reduction of the shot sizes the bcm’s yielded per shot was prohibitive of required production, as it resulted in having to blast 8 to 9 shots per day. This negatively impacting on the mine production as the pit had to be cleared while waiting for blasts to be initiated. *(All blasting has to be completed between 10am to 3pm Monday to Friday and 10am to 12pm on Saturday).*
Given the minimal success, increasing environmental and production pressures it was decided to evaluate electronic initiation systems.

g) **Electronic detonator (original) “A” trial results:**

<table>
<thead>
<tr>
<th></th>
<th>Maximum charge mass per delay (kg)</th>
<th>Distance between blast and monitor position (m)</th>
<th>Estimate of Peak Particle Velocity Mean 95% (mm/s)</th>
<th>Measured Peak Particle Velocity (mm/s)</th>
</tr>
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<tbody>
<tr>
<td>General</td>
<td>9</td>
<td>359</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>CBD</td>
<td>9</td>
<td>341</td>
<td>0.72</td>
<td>1.05</td>
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<tr>
<td>School</td>
<td>9</td>
<td>333</td>
<td>1.86</td>
<td>1.55</td>
</tr>
<tr>
<td>Pitt street</td>
<td>9</td>
<td>401</td>
<td>2.54</td>
<td>4.31</td>
</tr>
<tr>
<td>Spur</td>
<td>9</td>
<td>313</td>
<td>0.85</td>
<td>1.58</td>
</tr>
<tr>
<td>Pump house</td>
<td>9</td>
<td>408</td>
<td>0.21</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Table 2 shows the comparison between prediction levels using Scaled Distance and Signature Hole Analysis against actual measured PPV levels.

<table>
<thead>
<tr>
<th></th>
<th>Predicted PPV’s</th>
<th>Actual measured PPV’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast 15 (SW)</td>
<td>0.74</td>
<td>1.74</td>
</tr>
<tr>
<td>Blast 16 (SW)</td>
<td>0.77</td>
<td>1.70</td>
</tr>
<tr>
<td>Blast 27 (SW)</td>
<td>0.85</td>
<td>1.75</td>
</tr>
<tr>
<td>School</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast 17 (NW)</td>
<td>2.46</td>
<td>2.89</td>
</tr>
<tr>
<td>Blast 18 (NW)</td>
<td>3.01</td>
<td>3.68</td>
</tr>
<tr>
<td>Blast 19 (NW)</td>
<td>3.02</td>
<td>3.89</td>
</tr>
<tr>
<td>Blast 20 (NW)</td>
<td>2.89</td>
<td>2.04</td>
</tr>
<tr>
<td>Blast 21 (NW)</td>
<td>2.86</td>
<td>2.14</td>
</tr>
<tr>
<td>Blast 22 (NW)</td>
<td>2.94</td>
<td>2.01</td>
</tr>
<tr>
<td>Blast 23 (NW)</td>
<td>3.02</td>
<td>2.08</td>
</tr>
<tr>
<td>Blast 24 (NW)</td>
<td>2.88</td>
<td>2.04</td>
</tr>
<tr>
<td>Blast 25 (NW)</td>
<td>2.98</td>
<td>1.99</td>
</tr>
<tr>
<td>Blast 26 (NW)</td>
<td>2.72</td>
<td>1.99</td>
</tr>
</tbody>
</table>

h) **Increased production:** Blast size increase; size of the blasts prior to the trial had an average of 74 holes. By using the SMI 110 system typically 454 detonators could be fired (at a 19ms inter hole delay) per blast box without sacrificing accuracy and ensuring single hole firing.

In later years the SMI 200 series system unlimited numbers of detonators could be fired by simply adding additional blast boxes. Apart from the increased production, fragmentation and dig-ability also improved; refer graphs below.
Graph 1: Weekly Mining Production

Graph 2: Weekly Drill and Blast Production

Graph 3: Blast Windows per Week Pyrotechnic vs Unitronic
Reduced Oversize: Excess oversize has a detrimental effect on excavator performance normally resulting from blasting on the North wall, a large waste area of the mine which is also the mine’s most vibration sensitive area. This is a direct result of having to use small explosive charges; 2.2kg ANFO, in order to ensure that vibration consent limits are not exceeded. With the crushing system not being able to handle rocks larger than 1.3m the excavators lost up to 20% efficiency in sorting oversize during loading of haul trucks. Therefore a small reduction in the amount of oversize would have a positive effect on the following production areas:

- Excavator production;
- Crusher throughput;
- Lower secondary breakage costs;
- Less down time on crusher while breaking oversize in the jaw crusher.

Refer to Graph 4 for the oversize comparison.

Excavator Production: Excavator production is a major factor to an efficient mining operation. Fragmentation directly affects the bank cubic metres (BCM) that can be mined in a cost effective manner. At Martha the limited blasting parameters were reducing production - see tables 4 and 5.

### Table 4 Excavator production – Main Pit - BCM /hr

<table>
<thead>
<tr>
<th>Equip No.</th>
<th>Pre electronics</th>
<th>Post electronics</th>
<th>Av % increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June</td>
<td>July</td>
<td>22-Jul</td>
</tr>
<tr>
<td>1226</td>
<td>298</td>
<td>274</td>
<td>377</td>
</tr>
<tr>
<td>1292</td>
<td>266</td>
<td>263</td>
<td>302</td>
</tr>
<tr>
<td>7014</td>
<td>457</td>
<td>462</td>
<td>524</td>
</tr>
<tr>
<td>HA1</td>
<td>452</td>
<td>441</td>
<td>540</td>
</tr>
<tr>
<td>1285</td>
<td></td>
<td>487</td>
<td>515</td>
</tr>
</tbody>
</table>

Average excavator production increase, Main Pit: **13.83%**.
<table>
<thead>
<tr>
<th>Equip No.</th>
<th>June</th>
<th>July</th>
<th>22-Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Av % increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1226</td>
<td>278</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
<td>11.70</td>
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<tr>
<td>1292</td>
<td>270</td>
<td>325</td>
<td>311</td>
<td>310</td>
<td></td>
<td>20.24</td>
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<tr>
<td>7014</td>
<td></td>
<td>403</td>
<td>526</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1285</td>
<td></td>
<td>415</td>
<td>422</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HA1</td>
<td>274</td>
<td>390</td>
<td>391</td>
<td></td>
<td></td>
<td>29.84</td>
</tr>
</tbody>
</table>

Average excavator production increase, North Wall: **20.59%**.

**k) Conclusion:** The Martha Mine converted to using electronic detonators in 2002 using the SMI 110 & later the SMI 200 series systems until early 2007. In general the use of electronic detonators resulted in the following initial benefits at Martha Mine:

- Increased production without exceeding the strict vibration limits;
- Improved vibration prediction;
- Increased charge weight per delay;
- Decreased the scale distance formula;
- Reduced the number of re-drills;
- Reduced secondary breakage;
- Improved dig rates, and
- Increased production efficiency through decreased number of blasts per window.

**Part 2**

**a) Restrictions on Blasting beyond 2005:** (Research by Glenn Kiernan)

Local Authorities and Blasting Consultants stipulate a higher sample rate for Martha Mine monitoring equipment when measuring ground vibration. The new (>2005) sample rate increases from one sample every three milliseconds to one sample every millisecond. This single change has had a significant impact on blast design and raises questions regarding the accuracy of our original electronic detonator that was implemented in the year 2002.

Local Authorities suggest only one blast per day to reduce effects on local residents. Due to the very small pattern designs of typically 1.6m x 1.8m x 5m approximately 600 blast holes need to be fired each day to maintain production requirements. With an inter-hole delay of 19ms between blast holes (derived from SEED wave form modelling) blast durations extend well beyond 11,000ms (11 seconds). Some blasts patterns contained up to 1350 blast holes which in turn eliminates the use of some electronic systems as there electronic detonator capacitors inside the detonators are unable to hold a charge for this length of time.

Another problem on site is the number of misfires and the lost production due to confined work areas and the excavation of such misfires for research purposes.
b) **Particle Vector Sum (PVS) Waveforms:** With a more accurate sample rate in the seismographs located around the Open Pit a higher number of vibration “spikes” are recorded. In the past (using the old vibration sample rate) we suspect that some spikes in vibration may have been inaccurately read or miss-read as a sample may have been recorded 50% of the way up one side of a spike and the following sample taken 50% of the way down the other side of the spike therefore only displaying approximately half the actual level of vibration.

As technology evolves we learn that very precise inter-hole delays are required to maintain an evenly distributed vibration pulse. SEED waveform analysis performed by Heilig & Partners Consultants identified the optimal delay between sequentially fired blast-holes for the Martha Mine to be 19ms (milliseconds); blast induced frequency was not considered at this time.

The data shows that 1–2 milliseconds either side of this 19ms inter-hole delay is not ideal but it would not significantly raise vibration amplitudes as long as each hole fired with the same error, normally plus, eg: 3000ms nominated delay – detonator fires at say 3002ms next nominated delay is 3019ms actual det fires at 3021ms.

As most electronic detonator manufacturers Technical Data Sheets display their “detonator scatter” as ± (plus or minus) a given percentage it cannot be ruled out that during a blast some detonators maybe firing in the minus range which then would create significantly higher vibration amplitudes if the others are firing in the positive range eg: nominated delay 3040ms, actual det fires in positive range at 3042ms the following delay fires in the minus range at 3057ms, the inter hole delay between these two blast holes is now 15ms.

SEED wave form models predict these higher vibration levels once delays move further away from the optimum (19ms) before dropping to the next best optimum inter hole delay which for Martha Mine is 10ms but from experience on site the faster or shorter delay period increases vibration (PPV) by approximately 0.5mm/sec at 4.0mm/sec.

c) **Misfires:** The very high numbers of misfires on site using electronic detonator “A” or the SMI/ Unitronic detonator (for reference purposes) was also a concern for the safety on site. Misfires consume a considerable amount of time during extraction and interrupt load & haul production with the greatest risk being the excavation of the detonator & primer as most electronic detonators contain Lead Azide an extremely sensitive compound.

The positive aspects of electronic detonator misfires is that the shot-firer can pin point were the misfire is located and the identification number of the misfired detonator for cross checking after excavation. The location can be surveyed for future delineation/ excavation (if safe to do so). Some electronic detonator systems actually identify the potential misfire whilst the shot firer is allocating the delay time to the detonator prior to final stemming being added which allows the shot-firer the option to eliminate the hazard by removing the faulty detonator or re-priming the hole prior to final stemming and blasting.

d) **New Initiation System (Detonator “B” [I-Kon]):** In May 2007 a new initiation system was brought onto site. This new system had far superior accuracy and it had a maximum delay limit of 15,000ms. The new system also had many more advanced features than the previous system which allowed potential misfires to be dealt with prior to blasting as mentioned above. This system was used for approximately two months on site.
Predicting blast vibrations became slightly easier as the Particle Vector Sum (PVS) waveforms became more consistent, possibly through the supposedly superior accuracy of the electronic detonator components.

e) **Detonator Accuracy Trials (Detonators “A” [SMI/Uni-tronic] & “B”):**

After many years of trying to identify the reasons for large blast induced vibration “spikes” it was decided to eliminate or at least attempt to eliminate one of the many variables that come with vibration which was the electronic detonator accuracy or inaccuracy.

In the past, 2004 this was slightly overlooked as we were using electronic detonators that at the time were far superior to any other detonator on the market for the price (detonator “A”). We did know there was a “scatter” of ±0.1% of the programmed delay as stated on the Technical Data Sheet (TDS) which lead to us adding extra blast boxes to our blasts so each blast box was only firing up to a maximum of 8500ms (eliminates the risk of two holes firing at once).

With smaller blasts, blast boxes were distributed evenly through the blast (in a daisy chain type configuration) so the maximum duration for each blast box was only around 5000ms. Each blast box required a minimum firing duration of approximately 3000ms to configure itself and prepare to deliver the fire command to the following blast boxes. Each blast box also required a “burning front” to eliminate the potential for “cut offs” which meant each slave (a blast box that follows on after the initial “Master” or first blast box) blast box would lose 1500ms prior to initiation of its first detonator.

The more modern SEED waveform analysis suggested we needed a more precise detonator so tests began on detonator “A” to find out the actual accuracy or inaccuracy of this unit.

A method used many years ago to measure the accuracy of Pyrotechnic delays was again used for this trial. Heilig & Partners kindly supplied a seismograph that was configured to measure time, ten samples every millisecond. A sensor block was also required to connect the “bell wire” (attached to the detonator) to the seismograph port.

![Detonator "A" with attached bell wire.](image1)

![Seismograph and sensor block.](image2)

Due to the seismograph recording a very high number of samples on each trial, memory capacity is consumed very quickly. The sensor block itself only has eight terminals so only four detonators can be trialled at any one time. It was decided that four detonators would be fired with the following delays, 0ms, 3000ms, 6000ms & 9000ms. Approximately 52 “A” detonators were trialled and eight “B” detonators. There were limited stocks of the “B” detonators on site from this point on.
f) **Results of accuracy trials on detonators “A” & “B”:**

<table>
<thead>
<tr>
<th>Trial date and time</th>
<th>Measured time of Nominal Time 0ms delay</th>
<th>Measured time of Nominal Time 3000ms delay</th>
<th>Measured time of Nominal Time 6000ms delay</th>
<th>Measured time of Nominal Time 9000ms delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial #1 Det “A”</td>
<td>0 ms</td>
<td>3005.6 ms</td>
<td>6017.1 ms</td>
<td>9026.7 ms</td>
</tr>
<tr>
<td>Trial #2 Det “A”</td>
<td>0 ms</td>
<td>2999.8 ms</td>
<td>6011.5 ms</td>
<td>9020.5 ms</td>
</tr>
<tr>
<td>Trial #3 Det “A”</td>
<td>0ms</td>
<td>3009.0 ms</td>
<td>6019.5ms</td>
<td>9029.8 ms</td>
</tr>
<tr>
<td>Trial #4 Det “A”</td>
<td>0 ms</td>
<td>3008.3 ms</td>
<td>6013.9 ms</td>
<td>9027.6 ms</td>
</tr>
<tr>
<td>Trial #5 Det “A”</td>
<td>0 ms</td>
<td>3007.3 ms</td>
<td>6023.9 ms</td>
<td>9031.5 ms</td>
</tr>
<tr>
<td>Trial #6 Det “A”</td>
<td>0 ms</td>
<td>3006.6 ms</td>
<td>6016.4 ms</td>
<td>9024.4 ms</td>
</tr>
<tr>
<td>Trial #7 Det “A”</td>
<td>0 ms</td>
<td>3006.8 ms</td>
<td>6016.6 ms</td>
<td>9025.4 ms</td>
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<tr>
<td>Trial #8 Det “A”</td>
<td>0 ms</td>
<td>3006.3ms</td>
<td>6020.8 ms</td>
<td>9024.2 ms</td>
</tr>
<tr>
<td>Trial #9 Det “A”</td>
<td>0 ms</td>
<td>3006.6 ms</td>
<td>6016.1 ms</td>
<td>9027.8 ms</td>
</tr>
<tr>
<td>Trial #10 Det “A”</td>
<td>0 ms</td>
<td>3010.7 ms</td>
<td>6016.1 ms</td>
<td>9021.0 ms</td>
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<td>Trial #11 Det “A”</td>
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<td>3004.6 ms</td>
<td>6011.2 ms</td>
<td>9016.6 ms</td>
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<tr>
<td>Trial #12 Det “A”</td>
<td>0 ms</td>
<td>3008.0.6 ms</td>
<td>6010.01 ms</td>
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<td>Trial #13 Det “A”</td>
<td>0 ms</td>
<td>3009.77 ms</td>
<td>6016.11 ms</td>
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<tr>
<td>Trial #14 Det “B”</td>
<td>0ms</td>
<td>3002.69 ms</td>
<td>6004.15ms</td>
<td>9007.81 ms</td>
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<tr>
<td>Trial #15 Det “B”</td>
<td>0 ms</td>
<td>3002.93 ms</td>
<td>6006.10 ms</td>
<td>9009.77 ms</td>
</tr>
</tbody>
</table>
The above report shows the signatures recorded by the seismograph for one trial. A clean vertical line signifies an accurate sample has been taken. Any disruption to this trace after the initial event has no effect on the data collected.
The following graphs show the “scatter” recorded when testing detonator “A” with the seismograph.
The following graphs show the “scatter” recorded when testing detonator “B” with the seismograph.

The data collected proved to us that the detonators were all firing well outside their nominated delay time and also well outside the specifications provided by the manufacturer on their Technical Data Sheets.
g) New Initiation System (Detonator “C” [Daveytronic]): In August 2007 after a series of trials and inspections the site employed a new initiation system, detonator “C”. The site did not have any product for testing until the first shipment arrived on site.

Once on site the electronic detonators were tested using the same system (seismograph). Due to increased production demands it was decided to fire only four detonators (two at 0ms & two at 9000ms) which provided the results below.

![Geophone Trials @ 9000ms Det "C"](image)

Following this trial the distributor was informed of the results which were well outside their specification of ±0.032% of programmed delay, eg: 9002.88ms.

h) Alternative Method for Testing Detonator Accuracy: After discussions with the detonator “C” manufacturer it was decided to run the test using an Oscilloscope & Photo Diode. The manufacturers of detonator “C” deployed an engineer from their factory in France to the test site in New Zealand. Once in New Zealand the Oscilloscope and Photo Diode were set up as shown below.

*Left:* The Oscilloscope with the lead cord from the Photo Diode attached at the bottom.

*Right:* The Photo Diode mounted above the two heavy duty plastic pipes that have the detonators inserted through them.
The pipes were preferred as they contained the horizontal shrapnel from the first exploding detonator from damaging the second detonator prior to initiation.

The pipe also allows the Photo Diode to record the exact initiation point when the detonator sleeve bursts and the light from this explosion is dispersed.

i) Oscilloscope/ Seismograph Trial: The first trial we performed with the Oscilloscope we also decided to attach the seismograph to crosscheck one against the other. The seismograph recorded the same initiation times as previous and the Oscilloscope recorded initiation times that coincided with the technical data sheets of the particular detonator.

From this point on we realised that the first method used to perform this test on electronic detonators had become inferior but for the purpose of recording the accuracy of Nonel MS delays in the past (when Heilig & Partners conducted such testing) it would have provided reasonably accurate data due to the short delay period of the Nonel detonators.

Contact was made with the seismograph manufacturer. The seismograph manufacturer tested the seismographs and the seismograph was found to have a scatter of its own of ±6%.

j) Oscilloscope Trials Only: We continued to trial detonators “A” & “C”. Detonator “A” showed some scatter but the data was consistent with the Technical Data Sheet for the product. Detonator “C” showed superior accuracy and consistency.

The graph belows show the data collected from the Oscilloscope trials.

Detonator “B” was unavailable for trial.

k) Conclusion: Detonator Accuracy - Detonator “C” (Daveytronic) proved to have superior accuracy and was very consistent given the long delay period. Even though limited numbers of detonator “B” & “C” were trialled, none of these fired in the minus range, in fact only one detonator fired in the minus range over all the trials performed and this was recorded on the seismograph with an inaccuracy of 6%.

Detonator “C” continues to be used on site today as the option of choice with very good results in terms of misfires (currently 1: 22,000 ratio) and vibration amplitudes.
Detonator “B” (I-Kon) seems to be as accurate as detonator “C” if not better and detonator “B” only had one misfire recorded against its name while on site. It would have been interesting to trial these detonators with the Oscilloscope but there were no detonators available for trial at the time.

Detonator “A” (SMI or now known as Unitronic) is a unique system and is the only system we have known to be able to fire over the 16,000ms (16 seconds) blast duration. Misfires were a major concern with this system and in a very vibration sensitive location the detonator was too inaccurate.

In my opinion to date having used all three initiation systems, detonators “B” and “C” are the two most advanced electronic detonators on the market today. The decision comes down to product support, training & system features in relation to your site and of course price.

As part of this research the site submitted a letter to the local authorities seeking approval to use a form of rounding up to 0.5mm when reporting Peak Particle Velocities (PPV) blast amplitudes due to the “scatter” within the seismographs monitoring the vibration at Martha Mine in Waihi, NZ. An example of this is if a blast records 3.24mm/sec PPV it will be rounded to 3.00mm/sec PPV, if a blast records 3.25mm/sec it will be rounded to 3.5mm/sec PPV.

Approval was given some months later and remains in place today.

**Part 3**

a) **Simple Blasthole Loading Techniques/Signature Blasthole Analysis:**

Eleven 89mm, 6m “signature” holes were drilled on the 1112.5 RL. These holes were surveyed in at 10 metres apart. Each hole was drilled vertically. The in-situ material was predominately acid forming (PAF) andesite.

The signature holes were dipped with a tamping rod to ensure design parameters were met. Each hole was loaded with ANFO that was weighed with scales prior to been added to the blast hole.

Three separate charge weights were used with four holes containing two air decks as the decoupling effect from this was expected to lower vibration and maybe an option when loading sensitive areas in the future for Quarries and Mines.

The “signature” borehole layout is shown below.
Each signature hole was initiated using Nonel 9.6 second long period (6m) detonators. On the surface we used one Nonel 9.6 second long period detonator (6m) and one 3.6m surface connector (42ms). This long duration between holes allowed the seismographs time to reset ready for the next event and gave any remaining particle movement’s enough time to dissipate.

Heilig & Partners had eight separate seismographs set up around the signature blasthole area. The borehole coordinates were forwarded to Heilig & Partners and a scaled distance equation was completed for each hole/monitor and the data below show the results of this research.

Scaled Distance Scatter Graphs
b) **Conclusion:** The signature holes containing the bottom and top air decks reduced vibration amplitudes when compared to standard holes loaded with the same Maximum Instantaneous Charge (MIC). The signature holes containing the air filled tubes reduced vibration amplitudes by 8% over standard holes loaded with the same MIC. The signature holes containing the blasthole “wads” reduced vibration amplitude by 22% over standard holes loaded with the same MIC.

**Part 4**

a) **Advanced Blast Hole Loading Techniques:** Obviously in any Quarrying or Mining operation the highest profitability will come from increased plant throughput. To ensure we achieve this we need to look first at what is happening within our blast as this is our initial primary crusher.

To achieve this we need to look at:

a) Drilling accuracy or inaccuracy within our blast design.
b) The energy distribution in the rock mass we are about to blast.
c) The timing and controlled release of explosive energy within the rock mass.
The picture above shows the amount of oversize generated in the final stemming area of a blast by using a poor blast design.

The photo above shows the oversize generated in the final stemming area of a blast which has “riled” down slightly but you can see the bottom portion of the blast containing the bulk explosives shows excellent fragmentation.

Reducing Final Stemming

Normal Stemming  Decreased Stemming  Hi Risk Stemming

There are definite limits as to how much the final stemming can be reduced before fly rock occurs.
Let’s look at final stemming lengths within blast holes - in the diagram above, on the left we have a normal stemming length which contains the bulk explosives energy well and has no risk of stemming ejection or fly rock from the stemming area. In the middle we have slightly reduced final stemming which will offer increased fragmentation in the final stemming area and reasonable control of stemming ejection and no potential fly rock from the final stemming area.

On the right hand side we have reduced the final stemming significantly where the bulk explosive is likely to put extreme pressure on the final stemming area and actually push a wedge of rock up and out of the in-situ rock mass which will end up flying violently through the air which in normal terms is fly rock.

Examples of violent fly rock

Expensive Oversize Secondary Breakage

The diagram on the following page looks at the top of a single loaded blast hole and shows a quick and simple calculation for “Scaled Depth of Burial”.

This calculation provides us with an S.D. (Scaled Depth) factor we can use to control the heave profile and fragmentation of our final stemming area.
In the slide above you can see we have used some Scaled Depth numbers or factors below each blast hole which provides you with the calculated outcome of your advanced blast-hole design.

Most blast designs would be looking at a scaled depth factor or S.D factor of between 0.92 & 1.40 to achieve an optimum heave profile, good fragmentation with acceptable ground vibration and air over pressure control.
This diagram shows the insertion of a “Stem Charge” on the right hand side. Stem charges have been used for many years to poor effect mainly due to the non scientific approach.

The diagram on the left shows a standard loaded blast hole with the insertion of a portion of misprinted dog biscuit bag between the bulk product and the final stemming. This is used to stop the aggregate sinking into the bulk explosive product due to its greater density and reducing the optimum detonation of the bulk product that is going to have the greatest effect on breaking the rock in our final stemming area. It’s a simple technique with a cost of approximately one cent per hole.

The above diagram shows a hard slab of rock which is located at the top of all of your blasts but here we have inserted the Stem Charge to assist us in breaking up this solid mass.
The stem charge is normally located between 50 – 65% down from the surface. A starting scaled depth calculation of 1.3 should be used. Please note if you are using Nonel initiation products you must fire the stem charge before the main bottom charge or severe fly rock may occur.

<table>
<thead>
<tr>
<th>Advantages of Using a Stem Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
</tr>
<tr>
<td>Potentially less explosives per hole, but</td>
</tr>
</tbody>
</table>

**Significantly Improves fragmentation by 5 -10 fold or more in the stemming area of the blast hole.**

Significantly increasing the normal powder factor (without the use of a stem charge) will have no significant effect on the fragmentation in the Final Stemming area.

Research has told us that increasing or doubling the normal powder factor of the blast hole without using a stem charge will have no significant effect on the fragmentation of the hard rock mass located in the final stemming area.

This is what a blast can look like when you use a main charge and a stem charge within your blast-hole. Both charges were fired with electronic detonators at exactly the same delay time.
The diagram above shows we have used a number of techniques that may be utilized by the shot-firer for different Quarrying or Mining applications.

On the left we have what is called a “Power Deck” where an air deck is placed in the centre of the explosive column and the top and bottom primers are fired at the exact same delay using electronic detonators. The charges fire towards each other with the shock pressure waves and gas pressure waves colliding in the “air deck” area creating the same or better result than a fully loaded column of explosive.

The second hole would be used in a vibration sensitive site where the three air decks minimise the PPV levels of the blast.

The third hole design is a standard loaded blast hole but we have used electronic detonators and fired the main primer and the backup safety primer simultaneously for greater effect.

The fourth hole design maybe used when Quarrying Limestone or Mining Coal. You will notice we have removed the sub-drill, installed a bottom air deck and taken some of the bulk explosive and placed it in the stemming zone as a stem charge. The shock and pressure waves at the bottom of the hole will collide with each other and eliminate any “toe” in the area and it will not disrupt or contaminate the coal seam in Mining applications.

The fifth hole shows a power deck design with a stem charge and all primers fired at exactly the same time using electronic detonators.

Finally the last design which will not only save you a lot of money it will also provide you with better fragmentation and less vibration is the use a stem charge combined with a power deck and a bottom air deck.
b) Blast Timing:

Just briefly above is a typical blast using Nonel detonators. Note timing between holes of 17 – 67 milliseconds and between rows of 25 – 109 milliseconds.

Above we look at typical timing of a blast when using electronic detonators. The timing used between holes is 1 – 4 milliseconds and between rows are 100 – 400 milliseconds which are more like cast blasting delays.
The above diagram shows that when Nonel detonators (at the top) are fired with their slow and inaccurate delays there is no interaction between blast-holes and the shock and pressure waves simply pass through the ground.

At the bottom you will notice by using short inter-hole delay times the shock and gas pressure waves interact between sequentially firing blast holes which provides greater fragmentation.

It is not shown here but the long delays between rows provide much greater heave and movement of the blast along with improved dig ability of the muckpile.

c) Cost Comparisons

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>20 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bench Height</strong></td>
<td>10,000BCM</td>
</tr>
<tr>
<td>Drilling 89mm dia</td>
<td>$8.50 per l/m</td>
</tr>
<tr>
<td>Drilling 115mm dia</td>
<td>$13.00 per l/m</td>
</tr>
<tr>
<td>Drilling 127mm dia</td>
<td>$14.00 per l/m</td>
</tr>
<tr>
<td>Emulsion Explosive</td>
<td>$2.50 per/kg</td>
</tr>
<tr>
<td>Cast Booster 150g</td>
<td>$9.00 ea</td>
</tr>
<tr>
<td>Cast Booster 400g</td>
<td>$13.00 ea</td>
</tr>
<tr>
<td>Nonel MS, 3.6m Dowline</td>
<td>$6.50 ea</td>
</tr>
<tr>
<td>Nonel MS, 8.1m Dowline</td>
<td>$8.30 ea</td>
</tr>
<tr>
<td>Nonel MS, 24m Dowline</td>
<td>$25.00 ea</td>
</tr>
<tr>
<td>Nonel Connectadet 4.9m</td>
<td>$10.50 ea</td>
</tr>
<tr>
<td>Nonel Connectadet 6.1m</td>
<td>$11.50 ea</td>
</tr>
<tr>
<td>Connectaline</td>
<td>$0.60 per/m</td>
</tr>
<tr>
<td>Gas Bag/Step Lock</td>
<td>$14.00 ea</td>
</tr>
<tr>
<td>Labour</td>
<td>$60.00 per hr</td>
</tr>
<tr>
<td>Electronic Det (incl accessories)</td>
<td>$45.00 ea</td>
</tr>
</tbody>
</table>

Shown above are some component costs and we have used these to compare costs for a 10,000 BCM blast with a face height of 20 metres.
Above is a standard blast design using 89mm holes with a pattern of 3.0m x 3.5m and a powder factor of 0.66.

On the left the Nonel blast will cost us $2.81 per BCM and the electronic blast on the right will cost us $3.03 per BCM.

In this example we look at on the left a Nonel blast using 115mm blast holes with a pattern of 4.0m x 4.4m and a powder factor of 0.66. The Nonel blast will cost us $2.65 per BCM and the Electronic blast will cost us $2.77 per BCM.
Here we look at our last standard blast design using 127mm blast-holes with a pattern of 4.5m x 5.1m with a powder factor of 0.60. The Nonel blast will cost us $2.32 per BCM as opposed to $2.41 for the electronic blast.

Note this is a difference of only nine cents per BCM or $900.00 for the 10,000BCM blast as opposed to twenty two cents or $2,200.00 for the 89mm blast-hole design.
Now let’s look at a modified or advanced blast-hole design and its costs using the 115mm blast-hole design on a 4.0m x 4.4m pattern using a powder factor of 0.61.

As you can see we have used a “power deck” design which includes the air deck in the centre of the main charge and we have taken a portion of that bulk explosive and used it in the stemming area of our blast hole.

At the very top of the stemming area you will notice the blasted sub-drill from the previous bench, just down from that is the 7kg stem charge with a scaled depth calculation of 1.2 which will provide excellent fragmentation in our stemming zone.

When it comes to price per BCM the Nonel products are eighteen cents per BCM or $1800.00 for the 10,000 BCM blast cheaper than the electronics but if you do have a problem site and you are using a rock breaker or secondary breakage you need to look at this as an option.

We must remember our plant throughput will also be significantly improved which is our greatest profit creator.

In this example it shows the cost comparison between the advanced 127mm Nonel blast-hole design and the electronic design.

Whilst this diameter is probably to large for some Quarry operations particularly in New Zealand you will note the difference between the two designs is only 13 cents per BCM or $1,300.00 for a 10,000BCM blast.
Above is a summary of the comparisons made for the examples provided in the previous slides.

For a small Quarry operation in New Zealand transferring from an 89mm blast design using Nonel Detonators to a 115mm blast design using advanced blast hole loading techniques it will cost you 1 cent less per BCM but eliminate your secondary breakage (rock breaker), the cost of one employee as well as greatly improving your plant throughput with the added advantage of far less costs due to wear and tear on the plant and conveyors.

### Cost Comparison Summary

<table>
<thead>
<tr>
<th></th>
<th>Nonel Detonators</th>
<th>Electronic Detonators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard 89mm Blast</strong></td>
<td>$2.81</td>
<td>$3.03</td>
</tr>
<tr>
<td><strong>89mm Blast (pf 0.66)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Standard 115mm Blast</strong></td>
<td>$2.65</td>
<td>$2.77</td>
</tr>
<tr>
<td><strong>115mm Blast (pf 0.66)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Standard 127mm Blast</strong></td>
<td>$2.32</td>
<td>$2.41</td>
</tr>
<tr>
<td><strong>127mm Blast (pf 0.60)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Advanced 115mm Blast</strong></td>
<td>$2.62 (poor timing, reduced fragmentation)</td>
<td>$2.80 (Perfect Timing, Optimum Fragmentation)</td>
</tr>
<tr>
<td><strong>115mm Blast (pf 0.61)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Advanced 127mm Blast</strong></td>
<td>$2.34 (poor timing, reduced fragmentation)</td>
<td>$2.47 (Perfect Timing, Optimum Fragmentation)</td>
</tr>
<tr>
<td><strong>127mm Blast (pf 0.58)</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What’s it to be?

Electronics or Non Electric (Nonel)

It's Your Choice!
d) Acknowledgements:

The End

Thank You
Written & presented in memory of the late
Pat Wallbank & Chris Browne
RIP

This paper was written and presented in memory of two of my great industry friends who were my mentors when I first started in the Quarrying Industry twenty-five years ago.

Thank you.