

Analysing Accuracy and Blast Hole Loading Techniques To Reduce Vibration 2008

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Abstract

Macmahon Contractors have been the preferred mining contractor at the Newmont, Waihi Gold Mine since 1999. Macmahon perform all mining tasks in the open pit from Drill & Blast to the final reclamation of the Embankment site some three kilometres away. The open pit 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. Current mining rates in stage two have reduced to 85,000BCM per month as opposed to 180,000BCM per month in stage one some months prior.

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 three parts to this paper, firstly we reflect on the work done by Blair Jackson & Tjaart Louw in 2003. Blair and Tjaart presented a paper to the International Society of Explosives Engineers titled "The Evaluation of Electronic Detonators at Martha Mine, New Zealand". Secondly we look at the accuracy testing of three separate electronic detonators on the market today. Thirdly we present the Particle Vector Sum results of eleven signature blast holes fired with various charge weights and loading techniques.

Introduction

Martha Open Cut Gold Mine is located at the heart of the Waihi township. 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.

Pre Electronic Initiation System – Track Record

(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 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 and 50 holes in sensitive areas.

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.

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.

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 under ground 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.

Explosive distribution: Hole 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.

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.

Restrictions on Blasting

Local Authorities and Blasting Consultants stipulate a higher sample rate for Martha Mine when measuring ground vibration. The new sample rate increases from one sample every three milliseconds to one sample every millisecond. This single change has a significant impact on blast design and raises questions regarding the accuracy of our original electronic detonator. 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 1300 blast holes which in turn eliminates the use of some electronic systems as their capacitors 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.

Particle Vector Sum (PVS) Waveforms

With the more accurate sample rate in the seismographs a higher number of vibration “spikes” are recorded. In the past we suspect that some spikes may have been inaccurately 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 identified the optimal delay between holes for the Martha Mine to be 19ms (milliseconds), frequency was not considered at this time. The data shows that 1 – 2 milliseconds either side of this 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 \pm a given percentage it can not 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 before dropping to the next best optimum inter hole delay which for Martha

Mine is 10ms but from experience increases vibration by approximately 0.5mm/sec at 4.0mm/sec.

Misfires

The very high numbers of misfires were also a concern for the site. Misfires consume a considerable amount of time and interrupt production with the greatest risk being the excavation of the detonator & primer as most electronic detonators contain lead azide.

The positive aspects of electronic detonator misfires is that the shot-firer can pin point where the misfire is located and the identification number of the misfired detonator can be recorded, the location can be surveyed and some systems actually identify the potential misfire while allocating the delay to the detonator prior to final stemming being added which allows the shot-firer to eliminate the hazard by removing the faulty detonator or re-priming the hole prior to blasting.

New Initiation System (Detonator “B”)

In May 2007 a new initiation system was brought onto site. This new system had far superior accuracy but 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.

This system was used for approximately two months on site. Predicting blast vibrations became slightly easier as the PVS waveforms became more consistent, possibly through the supposedly superior accuracy of the detonator components.

Detonator Accuracy Trials (Detonators “A” & “B”)

After many years of trying to identify the reasons for large blast induced vibration “spikes” it was decided to eliminate one of the many variables that come with vibration which was the detonator accuracy or inaccuracy. In the past, some four years ago 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 $\pm 0.1\%$ of the programmed delay 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 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 blast box would lose 1500ms prior to initiation of its first detonator.

The more modern SEED waveform analysis suggested we need a more precise detonator so tests began on detonator “A” to find out the actual accuracy or inaccuracy. 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 with attached bell wire.



Seismograph and sensor block.

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.

Results of accuracy trials on detonators “A” & “B”

Trail date and time	Measured time of Nominal Time 0ms delay	Measured time of Nominal Time 3000ms delay	Measured time of Nominal Time 6000ms delay	Measured time of Nominal Time 9000ms delay
Trial #1 Det “A”	0 ms	3005.6 ms	6017.1 ms	9026.7 ms
Trial #2 Det “A”	0 ms	2999.8 ms	6011.5 ms	9020.5 ms
Trial #3 Det “A”	0ms	3009.0 ms	6019.5ms	9029.8 ms
Trial #4 Det “A”	0 ms	3008.3 ms	6013.9 ms	9027.6 ms
Trial #5 Det “A”	0 ms	3007.3 ms	6023.9 ms	9031.5 ms
Trial #6 Det “A”	0 ms	3006.6 ms	6016.4 ms	9024.4 ms
Trial #7 Det “A”	0 ms	3006.8 ms	6016.6 ms	9025.4 ms
Trial #8 Det “A”	0 ms	3006.3ms	6020.8 ms	9024.2 ms
Trial #9 Det “A”	0 ms	3006.6 ms	6016.1 ms	9027.8 ms
Trial #10 Det “A”	0 ms	3010.7 ms	6016.1 ms	9021.0 ms
Trial #11 Det “A”	0 ms	3004.6 ms	6011.2 ms	9016.6 ms

Trial date and time	Measured time of Nominal Time 0ms delay	Measured time of Nominal Time 3000ms delay	Measured time of Nominal Time 6000ms delay	Measured time of Nominal Time 9000ms delay
Trial #12 Det "A"	0 ms	3008.0.6 ms	6010.01 ms	9026.61 ms
Trial #13 Det "A"	0 ms	3009.77 ms	6016.11 ms	9024.41 ms
Trial #14 Det "B"	0ms	3002.69 ms	6004.15ms	9007.81 ms
Trial #15 Det "B"	0 ms	3002.93 ms	6006.10 ms	9009.77 ms



Event Report

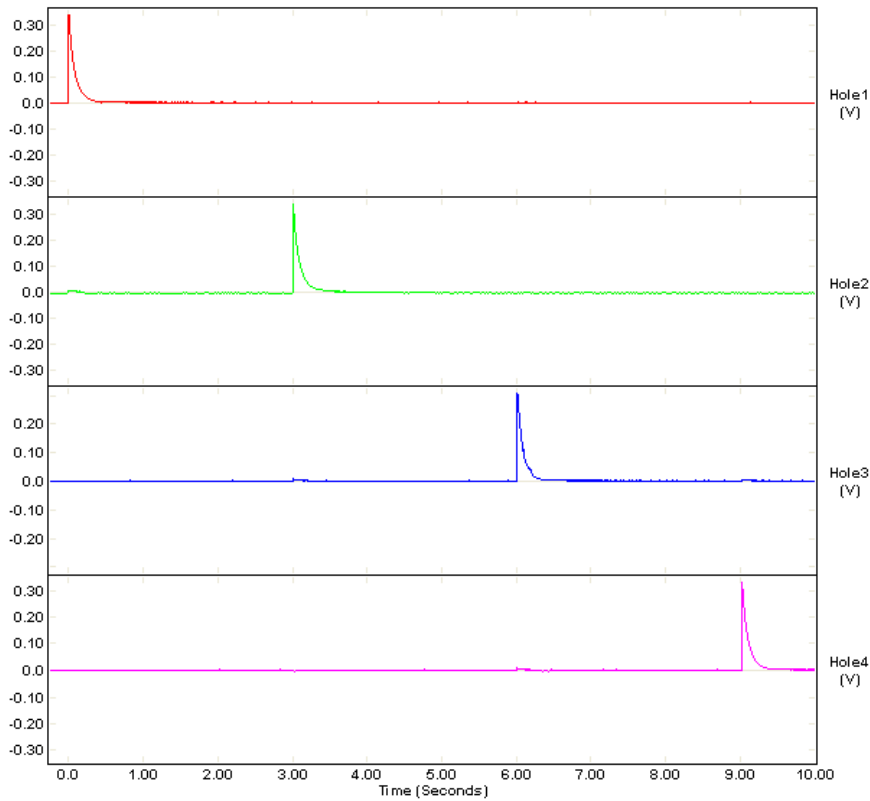
Date/Time Hole1 at 10:24:56 March 10, 2007
Record Time 10.0 sec at 4096 sps
Job Number: 1

Serial Number BE8810 V 8.01-8.0 MiniMate Plus
Battery Level 6.1 Volts
Calibration June 23, 2005 by Instanter Inc
File Name J810BKUC.XJ0

Notes
Location:
Client:
User Name:
General:

Post Event Notes

Channel	Name	Peak	Time (sec)	Trigger Level	Gain	Range	Units
1	Hole1	0.337	0.001	0.0500	1x	1.61	V
2	Hole2	0.339	3.009	0.0500	1x	1.61	V
3	Hole3	0.309	6.015	0.0500	1x	1.61	V
4	Hole4	0.331	9.028	0.0500	1x	1.61	V

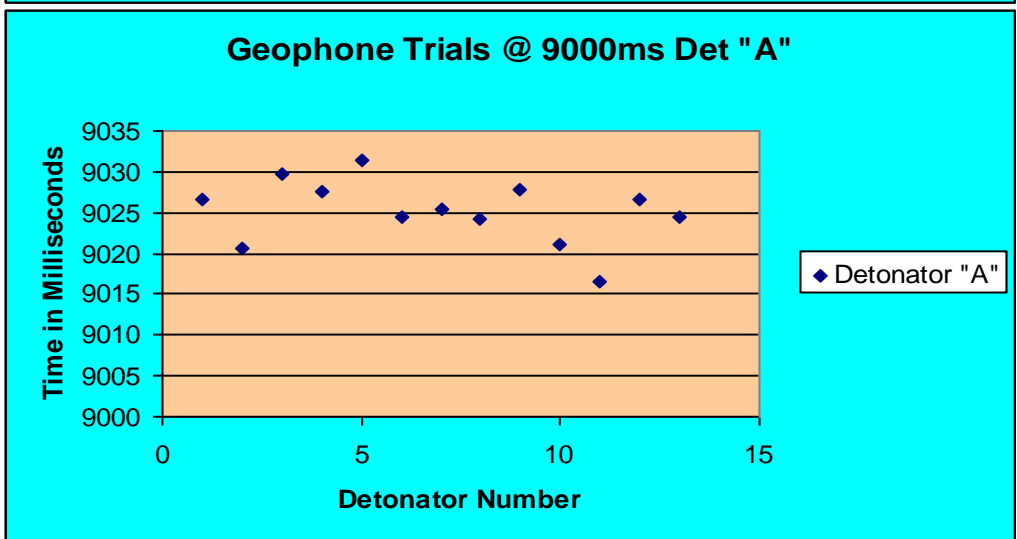
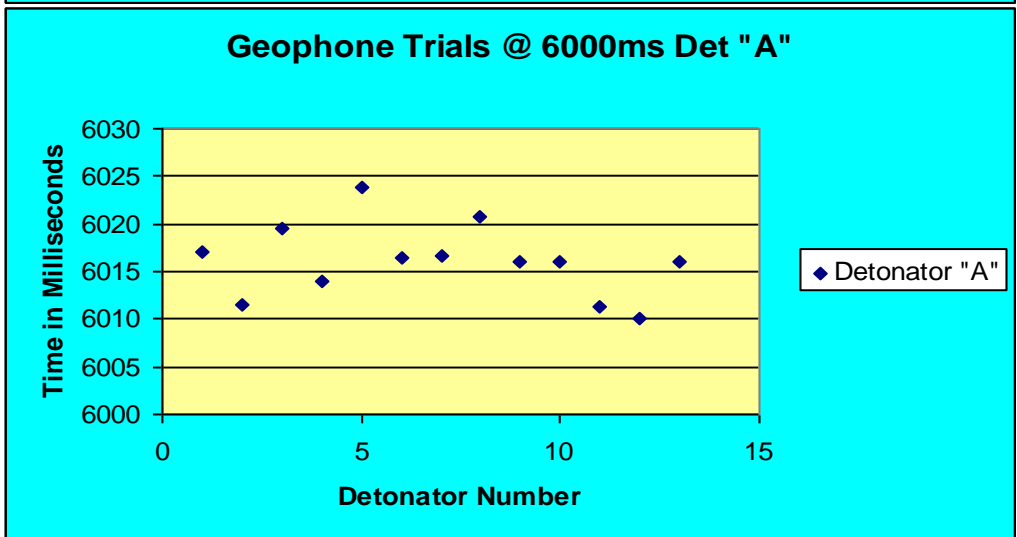
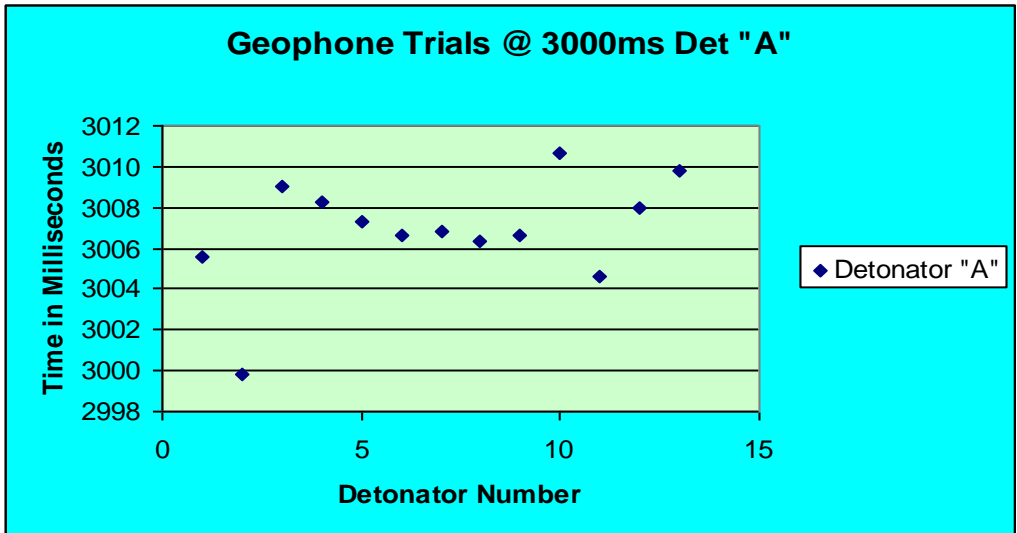


Printed: March 12, 2007 (V 8.01 - 8.01)

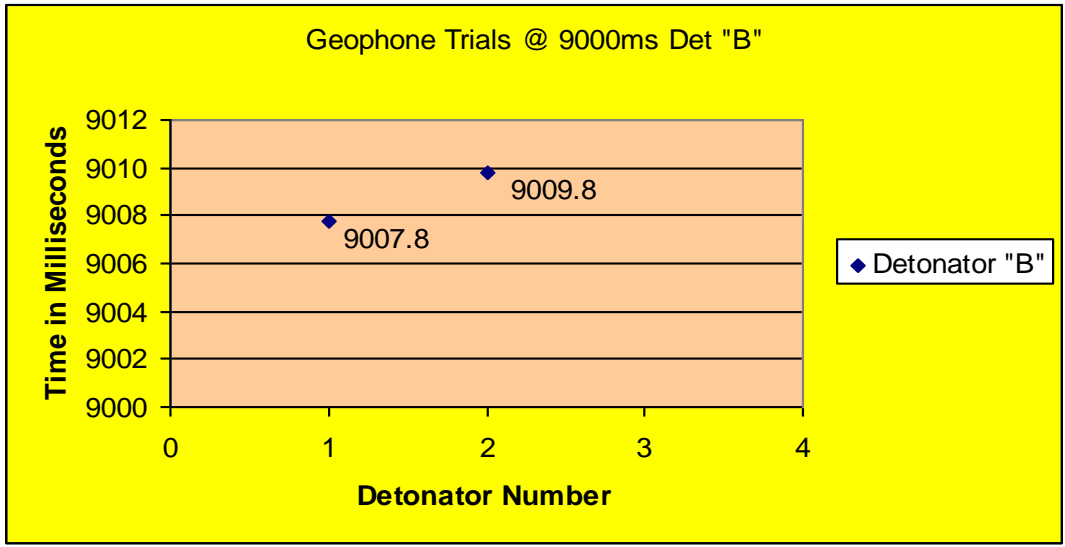
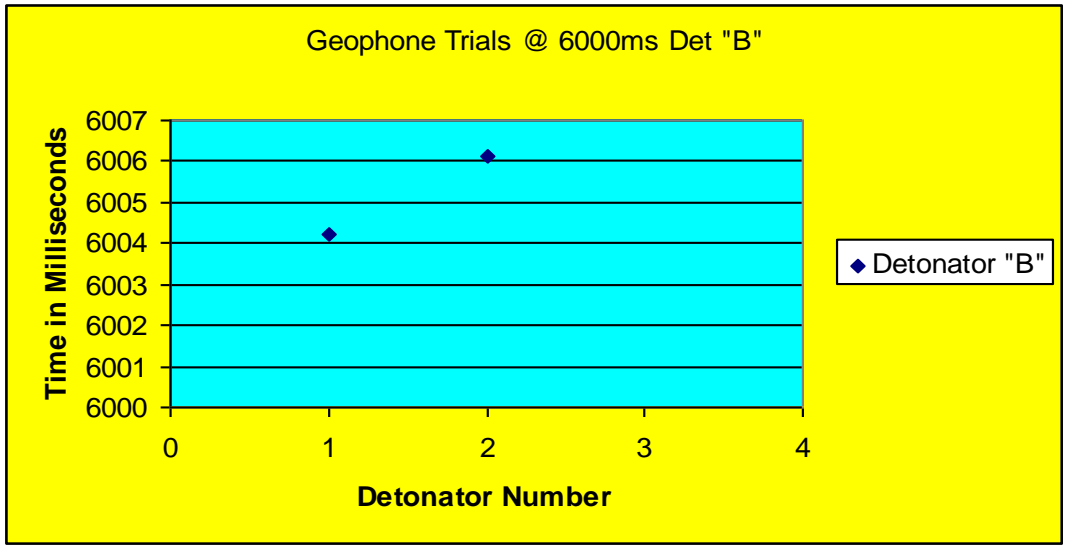
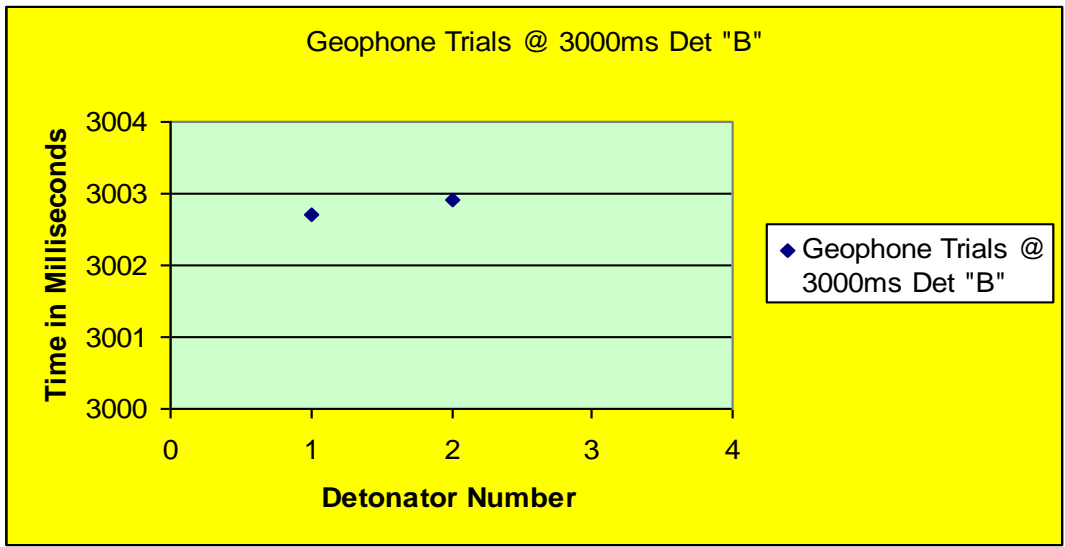
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The above report shows the signatures recorded by the seismograph for one trial. A clean vertical line signifies an accurate sample has been taken. Any disruption to this trace after the initial event has no effect on the data collected.

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.

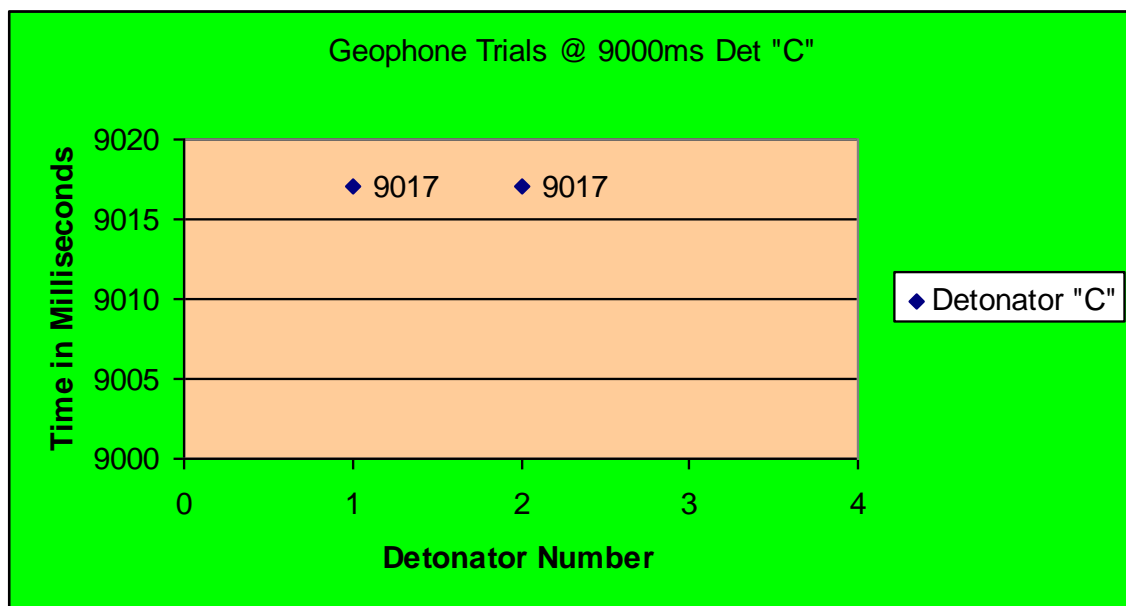


The data collected proved to us that the detonators were firing well outside there nominated delay time and they were also well outside the specifications provided by the manufacturer on their Technical data Sheets.

New Initiation System (Detonator “C”)

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



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

Alternative Method for Testing Detonator Accuracy

After discussions with 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 & Photo Diode was set up as shown below.



The picture on the left shows the Oscilloscope with the lead cord from the Photo Diode attached at the bottom. The picture on the right shows the Photo Diode mounted above the two plastic pipes that have the detonators insert 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.

Oscilloscope/ Seismograph Trial

The first trial we performed with the Oscilloscope we also attached 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.

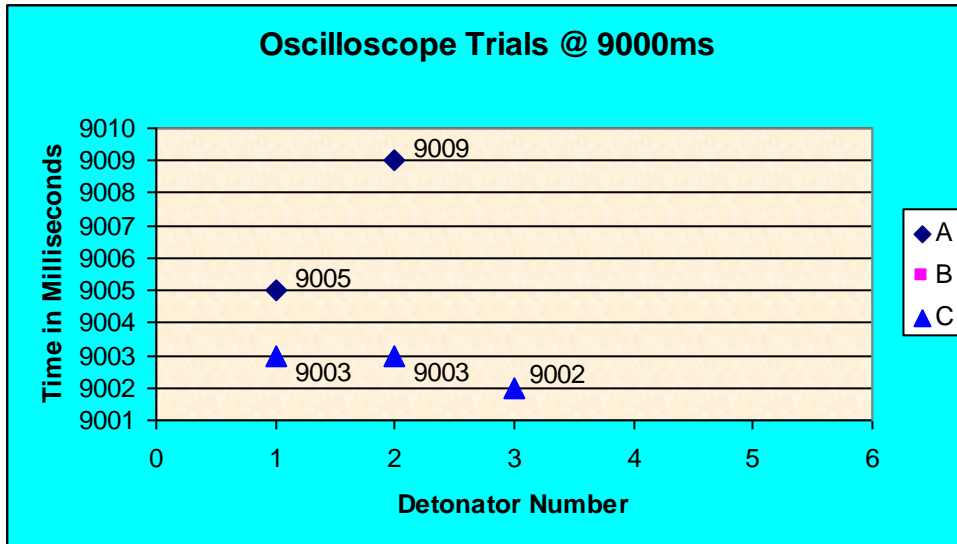
From this point on we realised the first method used to perform this test had become out dated but for the purpose of recording the accuracy of Nonel MS delays in the past it would have provided reasonably accurate data due to the short delay period.

Contact was made with the seismograph manufacturer and the seismograph was found to have a scatter of its own of $\pm 6\%$.

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 graphs below show the data collected from the Oscilloscope trials.



Detonator "B" was unavailable for trial.

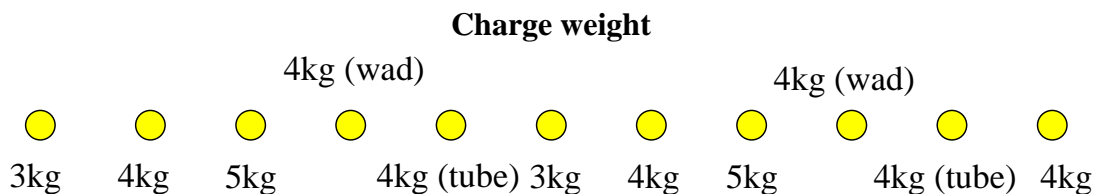
Signature Hole Analysis

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

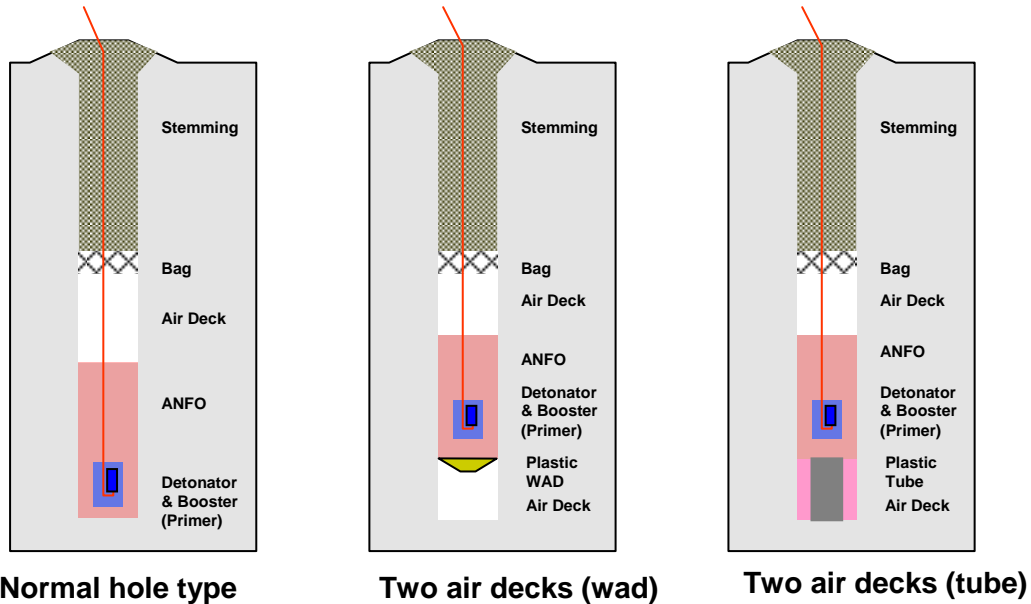
The signature holes were dipped with a tamping rod to ensure design parameters were met. Each hole was loaded with ANFO that was weighed with scales prior to been added to the blast hole.

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.

The signature hole layout is shown below.



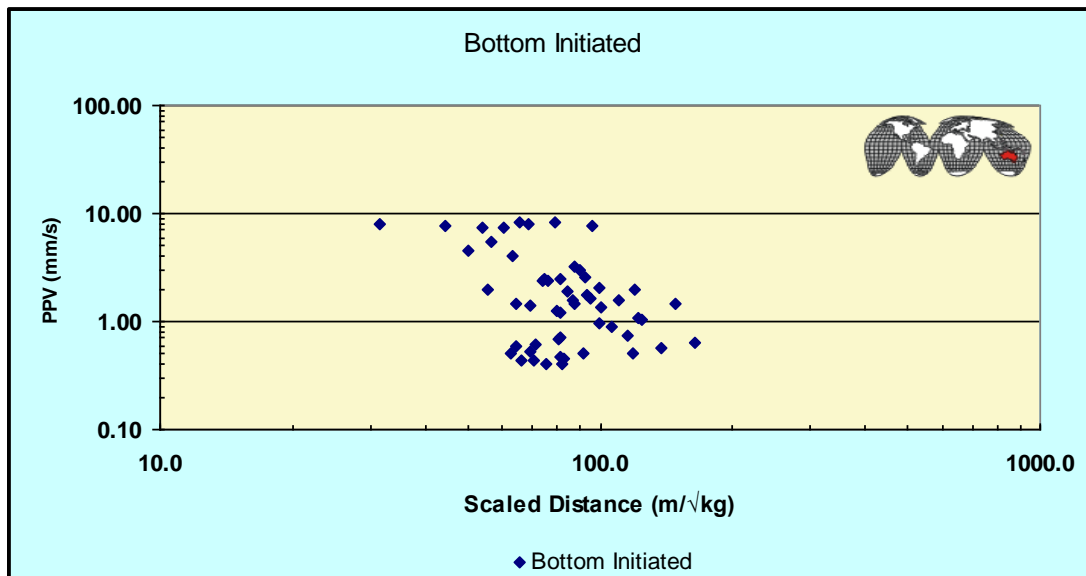
Three types of blast hole loading techniques

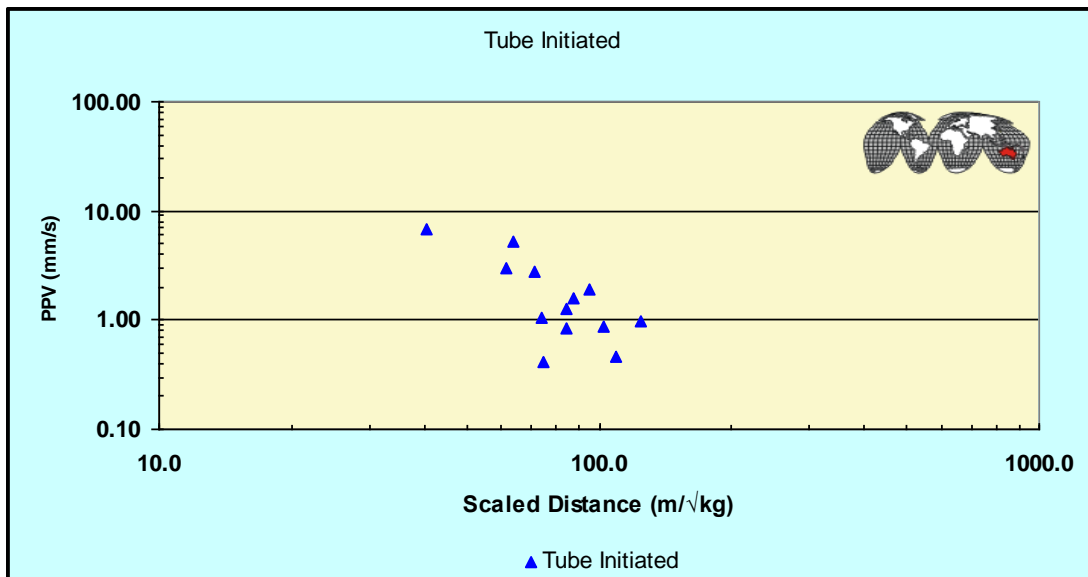
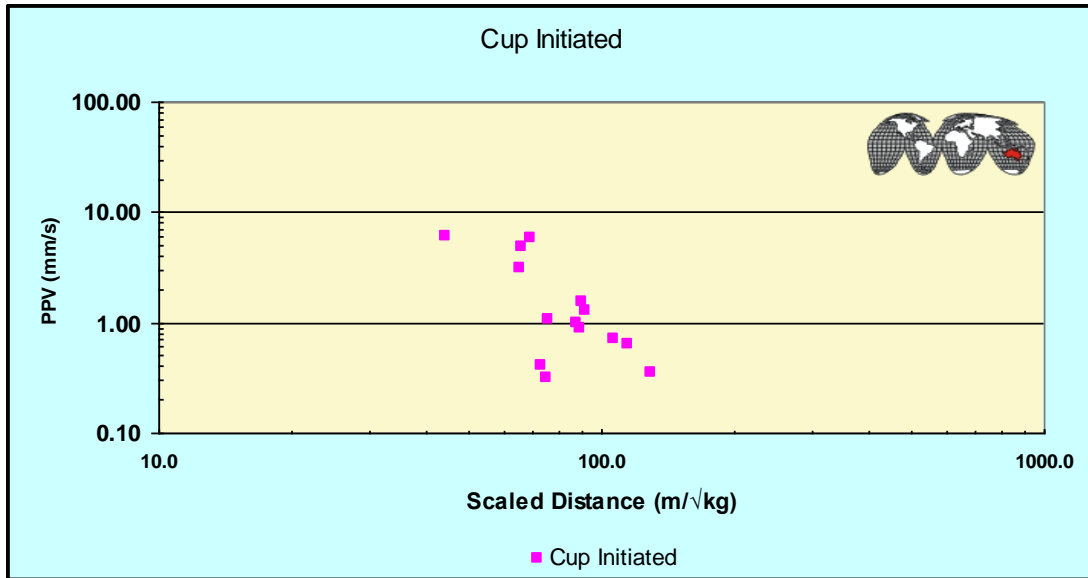


Each signature hole was initiated using Nonel 9.6 second long period (6m) detonators. On the surface we used one Nonel 9.6 second long period detonator (6m) and one 3.6m surface connector (42ms). This long duration between holes allowed the seismographs time to reset ready for the next event and gave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

John Heilig had eight separate seismographs set up around the signature blast hole area. The coordinates were forwarded to John and a scaled distance equation was completed for each hole/monitor and the data below show the results.

Scaled Distance Scatter Graph





Conclusion

Pyrotechnics to Electronics

A significant increase in production and reduced oversize when changing from pyrotechnic detonators (None1) to electronic detonators was a very important and successful event in the mines history. The numbers of blasts per week were reduced and vibration levels became more consistent.

Electronic detonator misfires were surveyed, recorded and dealt with as opposed to Pyrotechnics where misfires were only found during excavation, in the crusher or waste dumps. M.Waldron and B. Jackson must be commended for this decision as in my own opinion Martha Mine would be unable to operate efficiently without electronic detonators.

Detonator Accuracy

Detonator "C" proved to have superior accuracy and was very consistent given the long delay period. Even though limited numbers of detonator "B" and "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 our option of choice with very good results in terms of misfires and vibration amplitudes not to mention product support.

Detonator "B" looked to be as accurate as detonator "C" if not better and 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. Detonator "A" is a very 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.

To date the site has 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.

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.

Signature Hole Analysis

Martha uses the plastic blast wads to form a bottom air deck in blast holes when blasting in sensitive areas that have a bench height of five metres. Using the blast wads is not ideal as loading times are increased and some holes may be lost when placing the ridged plastic wad into the blast hole but using this technique does reduce the likelihood of being forced into blasting 2.5m bench heights.

Future Research at Martha Open Cut Mine

The accuracy of detonator “C” will allow Martha to investigate blast frequencies in the future. At present there are no requirements to target frequency even though this goes hand in hand with amplitudes when attempting to minimise blast vibration related complaints.

With new software models now on the market blast frequencies (FFT waveforms) can be analysed very easily along with very accurate delays (which Martha already have) to target the higher frequency range and to minimise the public's perception of blasting. Admittedly geology may restrict reaching these higher frequencies but until the analysis is completed and a conclusion is reached it is still an inexpensive option to investigate with potentially grand rewards.

Acknowledgements

The author would like to thank Newmont & Macmahon for allowing publication of the work completed at Martha Mine. Also acknowledgments to Blair Jackson & Tjaart Louw for their research in 2003. I must thank John Heilig of Heilig & Partners in Brisbane, Yogesh Narula of Global Seismic Solution Ltd, Auckland N.Z and Kim Greenock, Davey Bickford Australia for their time and effort put in over the past eight months to collect this data which was only intended for collection not presentation. Also a big thank you to Don Baker for presenting the paper and to Marty Waldron for the blast training and leadership provided to many of the advanced shot-firers here at Martha over the past six years. The legend still remains.



"One step ahead...together"