Further Field Applications of Electronic Detonator Technology

By

Douglas A. Bartley, DBA Consulting
Robert McClure, AIS, Inc.

Abstract

The increasing use of the Daveytronic digital programmable detonators is continuing to yield data reinforcing earlier studies concluding that accurate timing will provide substantial performance and economic benefits. This study quantifies performance increases as they relate to fragmentation, excavation, vibration control and productivity in a limestone aggregate mining operation.

High levels of field controls were adhered to during the drilling and blasting process as they related to blast design, bench preparation, pattern layout, drilling and blasthole loading. Following each blast, the fragmentation composite of the post blast muckpile was quantified. The excavation and crushing procedures were then studied to quantify any down stream advantages due to improvements in fragmentation.

This study will help provide the industry with more information as to the advantages of high accuracy electronic blasting systems over conventional pyrotechnic systems.

Introduction

The measure of the potential effectiveness that the available explosives energy has to both break and displace the rock mass is directly proportional to the effective burden that energy must overcome. This relationship is a crucial element in basic blast design. An accurate controlled sequence of blast detonation is a fundamental design parameter having a major direct effect on overall blast performance. Any variation in hole detonation timing results in that hole being fired prior to or after its nominal firing time. The hole-to-hole detonation could still remain properly sequenced, or holes could potentially detonate totally out of sequence. This will result in burden to energy relationships that can have adverse impacts on the performance of a blast. The results of these impacts have been witnessed in the past as:

- poor rock fragmentation.
- large amounts of oversize.
- high ground vibration levels.
- high air blast levels.
- flyrock incidents.
- high downstream processing costs.

The testing procedures conducted at the Commercial Stone Rich Hill Quarry were designed to provide data to quantify the detonator's performance within the following parameters:

- Rock fragmentation
- Crusher throughput
- Ground vibration control and predictability

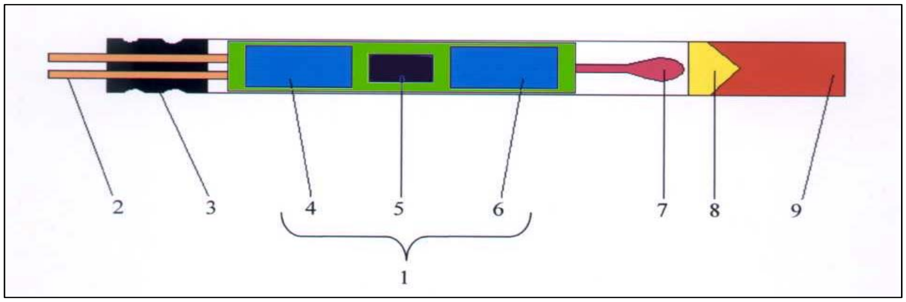
The scope of the testing program is as follows:

A series of test blasts would be detonated throughout an extended period of time during the production season at the quarry site. These blasts would be located in Bartley permit of the quarry. The maintenance of a high level of field controls during drilling, blasting and data collection processes to insure integrity of data was extremely important throughout the testing procedures.

The test blasts would be symmetrical to one another in terms of their geometry and loading parameters. They would, however, differ in the method and type of detonation system used. The initial blasts would be initiated using conventional non-electric system. The data from these blasts would serve to provide baseline information used for performance analysis comparisons with blasts initiated using the Daveytronic programmable blasting system.

The Daveytronic

DAVEYTRONIC® Cross Section of detonator.



1. Circuit board IED assembly.
2. Duplex detonator wire.
3. Crimped plug.
4. Logic capacitor.
5. ASIC processor.
6. Firing capacitor.
7. Fuse head.
8. Primary charge.
9. Base charge.

The steady advance in the proximity of the quarry to residential homes has resulted in increasing vibration levels. The typical solution to minimize ground vibrations results in a scaled down blast program that is often more costly and less efficient in terms of productivity and increased time required to mine the same volume of stone.

Previous electronic studies have established that simply programming the digital detonators with traditional pyrotechnic nominal firing times will yield increased fragmentation. These studies have also shown that optimized digital blast designs have repeatedly increased blast performance while minimizing impacts on neighboring structures.

This information coupled with a heightened need to maintain ground vibration levels within state mandated limits, the quarry management and blasting contractor opted to immediately invoke digital timing schemes that would yield minimized vibration levels that potentially could simultaneously improve rock fragmentation.

Following each blast, the muckpile dimensions were documented and an optical fragmentation analysis was conducted throughout the excavation of the shot rock.

The primary crusher was equipped with belt scales to record tonnage throughput during the crushing process. Excavation records and crusher operator reports were also obtained for comparative analysis with the fragmentation and throughput data.

Blast Design

The implemented blast design during these test blasts utilized a 6.5-inch blast hole drilled to a bench depth of 55 – 60. Two rows of holes were drilled on a 15 ‘ X 19 ‘ staggered pattern. In order to insure proper toe burden dimensions, set back markers were placed prior to the detonation of each blast event to insure the proper placement of the following blasts face row of holes.

The blasting operations were conducted by personal from the Wampum Hardware Company, a DYNO affiliate from western Pennsylvania. The production blasts were loaded using an Iremix, 30% emulsion blend. Prior to the blast hole loading each of the holes were again measured to verify the correct depth and the presence of water. If water was encountered, the holes were de-watered prior to the introduction of the explosive blend. The following table provides the average blast geometry and the loading parameters of the production blasts.

Burden	15 ft.	Rock Type	Bluestone
Spacing	19 ft.	Rock Density	2.67
Bench Height	55 – 60 ft.	Explosives Type	Iremix 30%, 1.2 g/cc
Hole Diameter	6.5 inch	Tons per Hole	1,450
Stemming	8 – 10 ft.	Powder Factor	0.59 lbs. per ton
Stem Type	Crushed stone	Energy Factor	237 kcal per ton

Each of the holes in the shock tube and Daveytronic blast’s were double primed to conform to Pennsylvania State blasting regulations. The explosive column rise was carefully monitored at each blast hole to insure the proper explosive column height and the designed amount of stemming material.

Fragmentation

This study quantifies the fragmentation performance increase realized in the pit using the chemical energy (explosives) more efficiently through the use high accuracy detonators. The precisely controlled release of explosive energy in a sequence of blast holes at firing times designed to provide the optimum Δt between hole yields maximum fragmentation. Poor fragmentation with a high percentage of oversize and a non-uniform muckpile are in part a result of energy losses encountered during out of sequence or improperly timed blasts.

The data was processed using a digital image analysis system. The images were gathered using a Sony TRV-900 digital video recorder, transferred to disc and loaded into the image processor for delineation and size distribution analysis. The digital images were gathered during the excavation procedures at locations throughout the resulting muckpiles to insure the merged findings would be representative of the true level of blast induced fragmentation.

The review of the video recordings of the blasts verified that a large percentage of oversize rock originates from the cap rock above the level to which the explosives could be safely or efficiently loaded to maintain proper confinement levels. This oversize material is directly related to the geologic conditions and blast geometry. The percentage of oversize in the post blast muckpile (2%) is the same for both the pyrotechnic blasts and the Daveytronic blasts. Therefore, the fragmentation analysis was concentrated to the rock fragment sizes within the muckpile produced by the blast.

The majority of the images were obtained from inside the muckpile that were filmed during the post blast excavation of the rock. At intervals of approximately every 5 meters into the muckpile the excavator would pull back and permit the digital image recording of the exposed rock to be analyzed. This procedure was followed after each of the production test blasts, throughout the excavation of the muckpile. Digital images were also obtained at the crusher as the loads were delivered.

During the analysis of the images, the data files were saved in the system and used to create a merged analysis report. This report is very representative of the size distribution and uniformity of each of the resulting muckpiles during the testing procedures. The analysis of the merged fragmentation data yields results showing that the post blast muckpiles of the test blasts utilizing the Daveytronic detonators were composed of a higher degree of fragmented rock with a more uniform size distribution.

The following table lists the results of the fragmentation analysis. The analysis of the two pyrotechnic blasts yielded an extreme range in the data. This was largely due to the excessive amount of oversize material from the top cap rock being intermingled with the muckpile during excavation and data collection. Therefore, the second and best performing pyrotechnic blast was used as the baseline comparison during this discussion.

Pyrotechnic Blasts	Mean Size (in)	D_{90} (in)	D_{75} (in)	Roslin - Rammler Uniformity Coefficient
Blast 1 , 3/20/01	14.49	24.78	15.13	2.89
Blast 2 , 4/3/01	**8.33**	**13.43**	**7.48**	**2.64**
Best result	**8.33**	**13.43**	**7.48**	**2.64**
Daveytronic Blasts	Mean Size (in)	D_{90} (in)	D_{75} (in)	Roslin - Rammler Uniformity Coefficient
Digital , 5/10/01	5.07	8.37	6.19	2.49
Digital, 5/16/01	4.51	7.00	5.00	2.80
AVG	**4.79**	**7.69**	**5.60**	**2.65**

Daveytronic Detonator	% difference in avg. Mean size	Decrease in D_{90}	Decrease in D_{75}	% increase in Uniformity
	42% smaller ↓	**43% ↓**	**25%↓**	**1%**

The merged analysis of the Daveytronic blasts resulted in a 42% reduction in the average mean size of rock and a 43% decrease in the D90 (90%passing) screen size from the best pyrotechnic result of 13.43 inches to 7.69 inches. There is also a 25% decrease in the D75 size from 7.48 inches to 5.60 inches. These numbers typically can be directly related to reductions in excavation and crushing costs. The 2.0 plus “Uniformity Coefficient” indicates a highly uniform muckpile.

Productivity

The primary performance parameter monitored in this study was the crusher throughput. It is in this area that the Daveytronic blast’s performance was evaluated. An indicator of any increased level of fragmentation should be realized in improved excavation rates and increased bucket fill factors that should ultimately result in a shorter more efficient excavation cycle.

During the shifts while the primary crusher is operating, records were kept regarding the source of the stone and the total tonnage of stone these trucks

move to the primary during each shift. The shift reports that included stone from the underground operation were not included in the analysis.
According to the operators' records, the summary of the data is as follows:

Bluestone 6.5 inch Shock tube Blast
3/21/01

Date	Shift	Tons	Hrs	Tons/Hr
3/21/01	N	1420	2.5	568.00
3/22/01	N	4714	6	785.67
3/23/01	D	5395	6.5	830.00
3/23/01	N	4464	7	637.71
3/27/01	N	4056	7	579.43
3/28/01	N	5478	8.5	644.47
3/31/01	D	4479	7	639.86
3/31/01	N	3319	6.75	491.70
4/2/01	D	5648	8	706.00
4/2/01	N	5154	6.25	824.64
	Total	**44127**	**Average**	**670.75**

Bluestone 6.5 inch Shock tube Blast
4/03/01

Date	Shift	Tons	Hrs	Tons/Hr
4/3/01	D	6043	8.75	690.63
4/3/01	N	4179	5.75	726.78
4/4/01	N	6314	7	902.00
4/5/01	N	5125	7	732.14
4/6/01	D	6448	8.75	736.91
4/6/01	N	5728	7	818.29
	Total	**33837**	**Average**	**767.79**

The average throughput of Test Blast 1 and 2 using the shock tube system was 719 tons per hour. The following are the summaries of the data corresponding to the electronic detonator test blasts.

Bluestone 6.5 inch Electronic Blast
5/10/01

Date	Shift	Tons	Hrs	Tons/Hr
5/10/01	N	4205	4.75	885.26
5/11/01	N	5525	6.25	884.00
5/12/01	D	5467	6.5	841.08
5/14/01	D	6265	7.75	808.39
5/14/01	N	5717	6.5	879.54
5/15/01	N	2067	2.25	918.67
	Total	**29246**	**Average**	**869.49**

Bluestone 6.5 inch Electronic Blast
5/16/01

Date	Shift	Tons	Hrs	Tons/Hr
5/17/01	N	6121	7	874.43
5/18/01	N	2510	2.75	912.73
5/21/01	N	5538	7	791.14
5/22/01	N	5272	6.5	811.08
5/23/01	N	5212	6.75	772.15
5/24/01	N	5088	6.5	782.77
	Total	**29741**	**Average**	**824.05**

The average primary crusher throughput of stone during the excavation of the baseline test blasts was 719 tons per hour. The average primary crusher throughput of stone from the Daveytronic blasts was 846 tons per hour. This represents a 17% increase in stone throughput at the primary crusher.

Ground Vibration

There are many variables and site constants involved that collectively result in the formation of a complex vibration waveform. Providing a well designed blast plan has been engineered, the application of proper field controls during all steps of the drilling and blasting operation will help to minimize the adverse impacts of ground vibrations. This design would consider the proper hole diameter and pattern that would reflect the efficient utilization and distribution of the explosive energy loaded into the blast hole. It would also provide for the appropriate amount of time between adjacent holes in a blast to provide the explosive the optimum level of energy confinement.

The parameters having the greatest effect on the composition of the ground vibration waveform are:

- Geology between the blast site and the monitoring location
- Accurate timing between blast holes in a detonation sequence

Throughout this study the ground vibrations generated by the production blasts were recorded at the Glenn Hawk residence, less than 1000 feet east of the quarry site. A second seismograph was also installed at the Mark Helms residence 1000 – 1200 feet east of the blasting site.

Research developed by the USBM (United States Bureau of Mines), universities, and others over the last 15 years in the blasting industry has concluded that residential structural response to a blast induced ground vibration is dependent on both the peak particle velocity and the frequency of the waveform. The frequency is the number of oscillations that the ground particles vibrate per second as a blast vibration wave passes by the structure's location.

Above ground structures will resonate much like a tuning fork whenever they are excited by a vibration containing adequate energy matching the fundamental frequency of the structure. This value of this frequency is mainly dependent upon the mass, height and stiffness of the structure. The maximum response of a house to blast induced ground vibration occurs whenever the frequency of the ground vibration matches the natural resonant frequency of the house. Likewise, if there is little or no energy at the resonant frequency of the structure, the structural response to the vibration will be negligible.

Further studies have also shown that there are direct relationships between the firing times of blast holes in a detonation sequence and the frequency composition of the ground vibration recorded at a particular structure in question. These studies have also concurred that a total blast sequence is simply defined as a series of single hole detonations that are separated by a given amount of time (Δt). It is the relationship between this Δt and the geology of the site that has the most effect on the amplitude and frequency composition of the ground vibration wave. The geology is generally a constant in the equation but it will change as the blasting operations move throughout the mine or quarry.

This relationship between timing and geology has led to the development of several sophisticated computer programs to predict and modify blast induced ground vibrations. These programs process a single hole blast ground vibration signature at a given production blast location, and through thousands of mathematical iterations predict the synthetic waveform, its amplitude and frequency composition for any given Δt between adjacent holes in a row and Δt between consecutive rows in a blast.

A single hole test blast was detonated at the blast site. The "Fourier Frequency Spectrum Analysis" of this blast indicated that there is a very dominant low frequency characteristic at the recording sites. The application of the vibration modeling and prediction technique using this signature hole data indicated that the dominant frequency domain could potentially be increased, outside the typical upper resonant frequency limit of residential structures. The computer analysis determined that the application of 22 ms between holes and 88 ms between rows would produce the most favorable blast induced vibrations.

The vibration levels and their corresponding frequencies are as follows:

Location	Date	T PPV	Hz	V PPV	Hz	L PPV	Hz
NonElectric							
Hawk	3/21	.55	11	.50	47	.67	21
Hawk	4/3	.46	15	.43	18	.45	13
Electronic							
Hawk	4/23	.42	27	.29	43	.54	30
Hawk	5/10	.76	14	.39	39	.69	28
Hawk	5/16	.39	22	.39	34	.39	28

As shown above, the peak particle velocities generated by the digital blasts that were closer to the Hawk recording location, have generally been reduced or maintained even as the blasting operations have become closer to the monitoring point. Their associated frequency trends have also been progressively increased to values above 20 Hertz.

The timing designs implemented with the electronics also produced a blast with a distinctively shorted duration. This coupled with the higher dominant frequency content of the vibrations has reduced the amplitude of structural response at the primary recording location.

Conclusion

The Daveytronic digital programmable electronic detonator trials that were conducted at the Better Materials Inc., Commercial Stone Operation: Rich Hill Quarry during the 2001 production season resulted in performance benefits in terms of rock fragmentation, crushing and vibration control. The findings during this study at the Rich Hill quarry provide further evidence quantifying the benefits of using of high accuracy detonators in terms of improved blast performance as typified by:

- A 43% decrease in the mean size of rock in the post blast muckpile from 8.33 to 4.79 inches.
- A 17% increase in the tonnage throughput at the primary crusher.

- A maintenance of regulatory vibration levels and improved frequency content of ground vibrations without scaling down blasting program.

The above results have been obtained without the implementation of any changes in design or optimization techniques. The potential to shoot larger blasts with reduced environmental impacts while increasing blast performance could improve public acceptance and reduce down time during blasting. Continued use of the electronics at this site combined with blast optimization techniques should yield even greater benefits.

REFERENCES

Dowding, Charles H.,1985,"Blast Vibration Monitoring and Control", Northwestern University , Evanston,IL.

Medearis, K., 1976, " Development of Rational Damage Criteria for Low Rise Structures Subjected to Blasting Vibrations", Report to the National Crushed Stone Association, Washington, DC.

Siskind ,D. E., Stagg, M. S. ,Kopp, J.W., Dowding, C.H.,1980, "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting", Bureau of Mines RI 8507, OSM Dept. of Interior Washington, DC.