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ACKNOWLEDGEMENTS

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- Eastern Industries, Inc. (Regional Head Office)
- Eastern Industries, Inc. (Ormrod Quarry)
- Maurer & Scott, Inc.
- Power Deck Company, and
- J. Roy, Inc.

This research was sponsored under contract by International Technologies, Inc.

1.0 INTRODUCTION

Blasting Analysis International, Inc. (BAI) was commissioned by International Technologies, Inc. to test their new SuperPlug™ in full-scale blast environments. The SuperPlug is referred to in the USA as "PowerDeck" and as "Taponex" in South America. The purpose was to compare the use of the new SuperPlug in conjunction with airdecks placed within the same explosive column versus full column explosive loads. Direct comparisons were made for fragmentation, ground vibrations, subgrade drilling versus no subgrade drilling and the degree of muckpile displacement (i.e., throw).

BAI is an independent, international consulting group specializing in custom blast designs, blast diagnostics, troubleshooting, airdeck/electronic detonator applications, technical/safety audits and training. To date BAI has evaluated, monitored and/or supervised over 6,000 full-scale shots spanning 22 countries in a variety of diverse field conditions.

BAI also certifies that it is completely independent and is not associated with the manufacturing, sale and or the distribution of explosives, rock products or blasting accessories. Our services were retained strictly as an engineering consulting firm to evaluate the performance of the SuperPlug against conventional blasting techniques.

2.0 FULL-SCALE TEST SERIES

Two full-scale test series were conducted consisting of single hole characterization tests and full-scale shots at two limestone quarries. One location was in Kentucky and other location was in Pennsylvania. Both sites utilized 6 1/4 inch diameter holes with bench heights ranging from approximately 45 to 51 feet, and 3 to 4 feet of subgrade. Drill patterns averaged 12 x 14 feet.

In reference to Figures 2.01 and 2.02 the single hole characterization tests consisted of:

A. Normal hole - Full column of explosive with 3 feet of subgrade in a 52 foot hole and 12 feet of stemming.
B. Single SuperPlug hole - A 3-foot airdeck at the bottom of a 45 foot hole with no subgrade and 12 feet of stemming.
C. Double SuperPlug hole - Here a 3-foot airdeck was placed at the bottom a 52 foot hole and a 3-foot airdeck was placed in the mid-column of the explosive. This hole also had 12 feet of stemming.

The purpose of the single hole characterization tests was to:

- Establish some control measures.
- Check and verify each explosive system.
- Verify the SuperPlug functioning and reliability.
- Measure the VOD of the explosive and the resulting gas front velocity in the airdecks.

Two full-scale shots consisting of a total of 30 holes each were then evaluated as illustrated in Figure 2.03. Everything in the blast designs was kept constant for each shot, except that one of the shots used the SuperPlug with a 3-foot airdeck at the bottom of each hole, and the other shot was loaded full column. The full column load is referred to in this report as the Normal shot and the bottom hole airdeck shot is referred to here as the SuperPlug and/or PowerDeck shot.

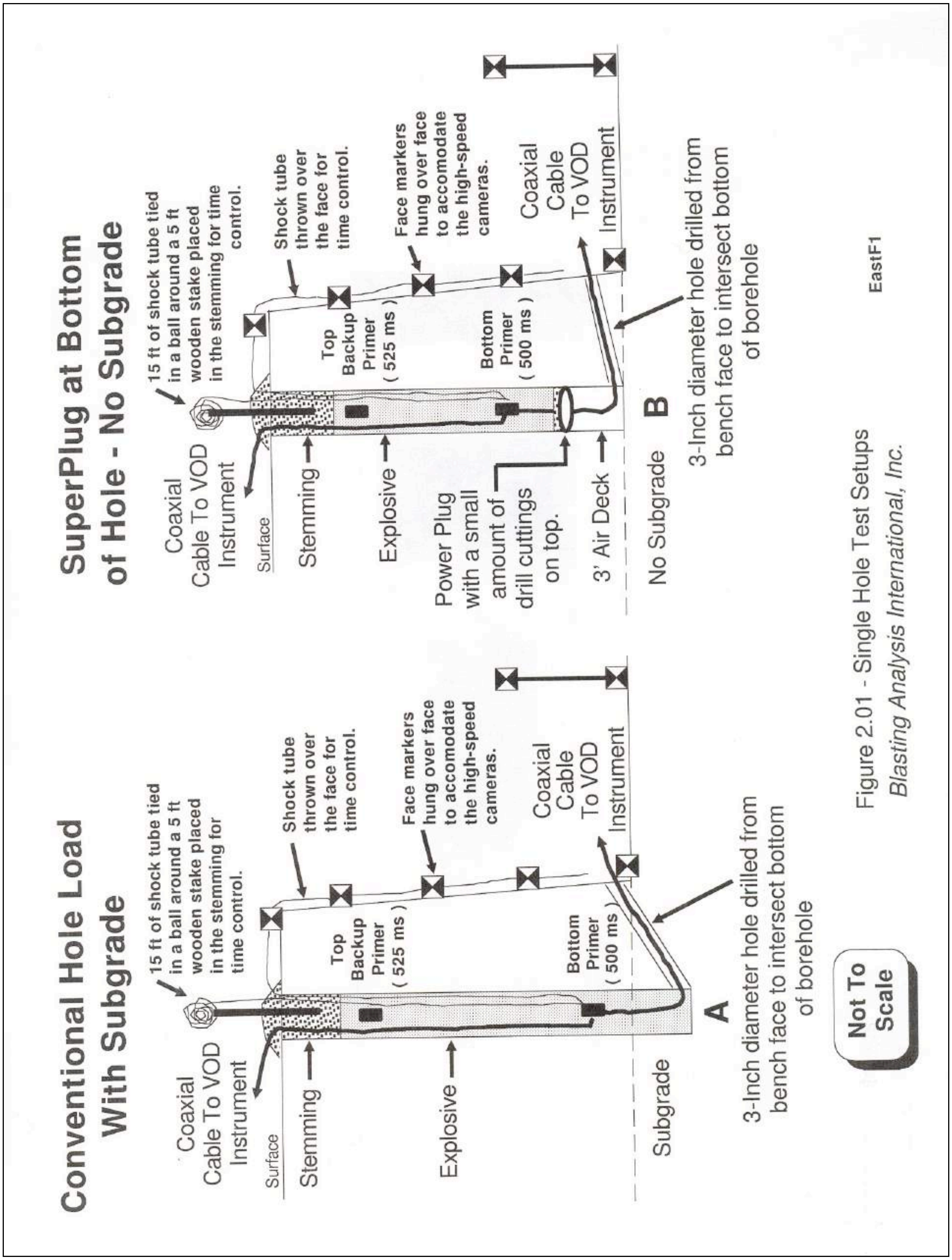


Figure 2.01 - Single Hole Test Setups
Blasting Analysis International, Inc.

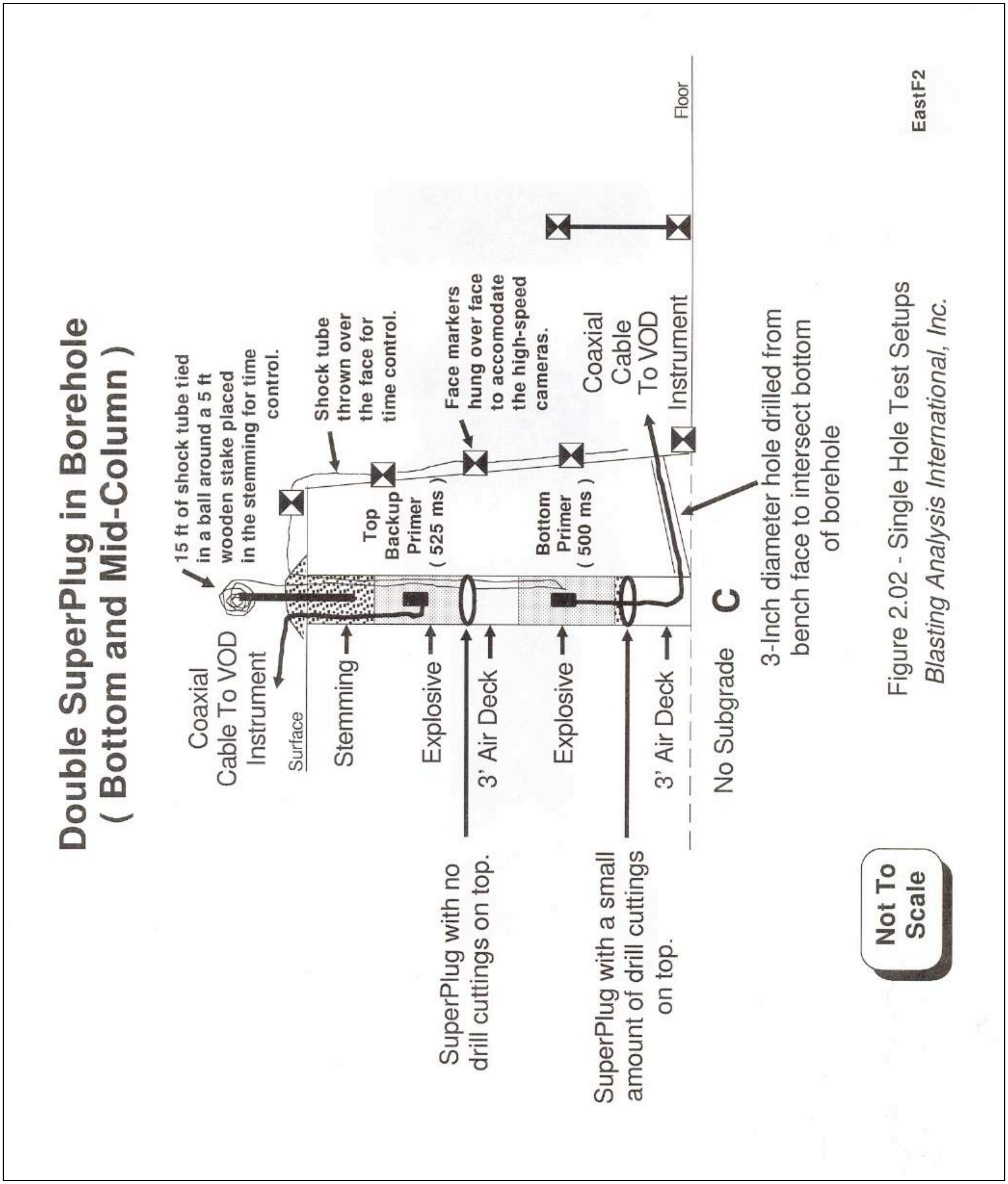


Figure 2.02 - Single Hole Test Setups

Blasting Analysis International, Inc.

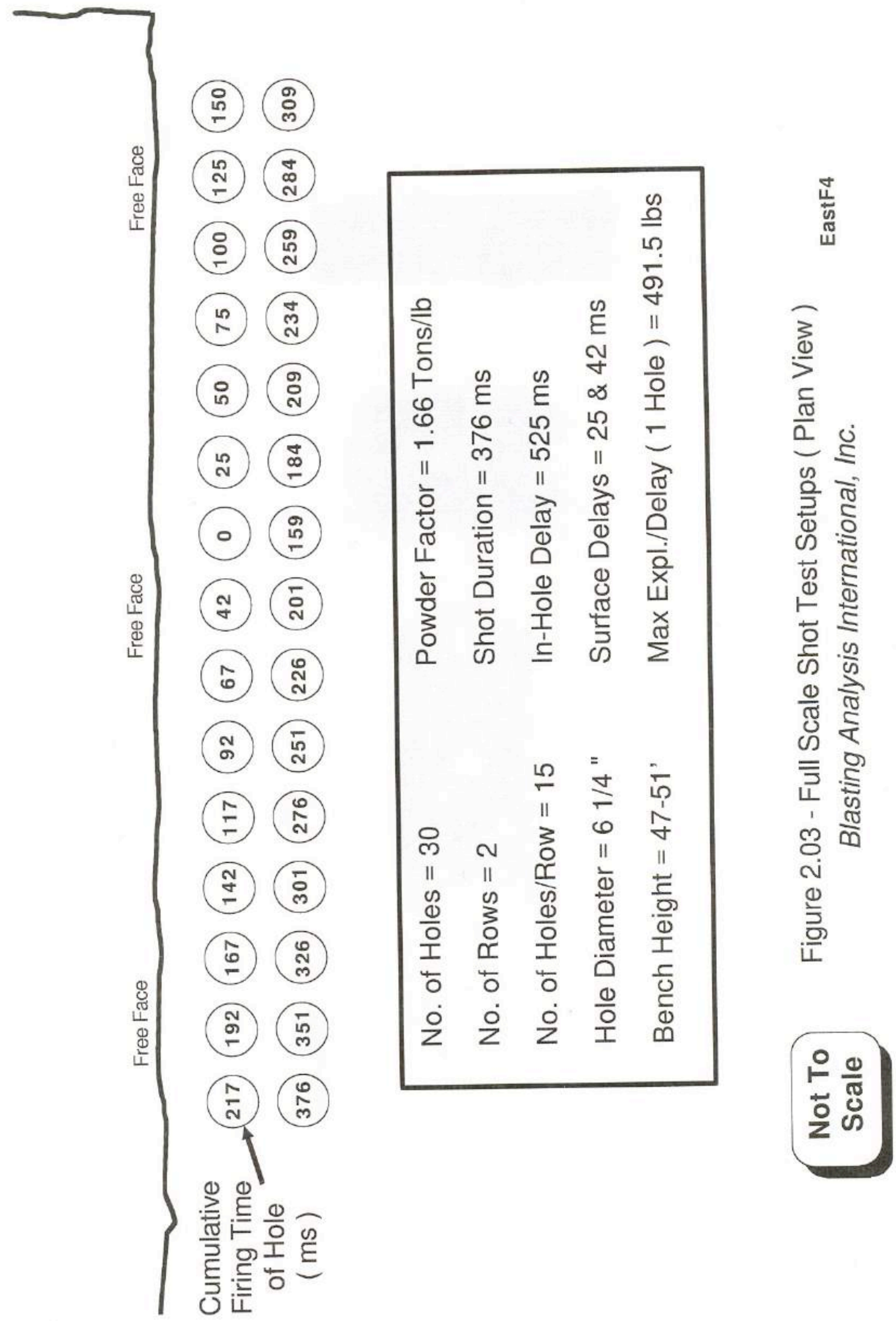


Figure 2.03 - Full Scale Shot Test Setups (Plan View)
Blasting Analysis International, Inc.

3.0 INSTRUMENTATION USED

A number of state-of-the-art blast monitoring instrumentation systems were used on all of the single hole and full-scale shots for quantitative analyses. All of the test shots were monitored and analyzed by BAI.

3.1 Borehole Inspection Camera System

Each monitored test hole was probed and recorded using a borehole inspection system. Refer to Figures 3.11 to 3.14

Figure 3.11 - Portable borehole inspection camera system used to probe and document the condition of each monitored test hole.

Figure 3.12 - Borehole camera is equipped with integral built-in lights which are adjustable for the lighting intensity required. Different camera heads can accommodate inspections in hole diameters from 2 to 12 inch diameters in B/W or color, and up to 2,000 foot depths.

Figure 3.13 - A standard camcorder is used to record the video sequence for each inspected borehole inspection for archiving and later analysis

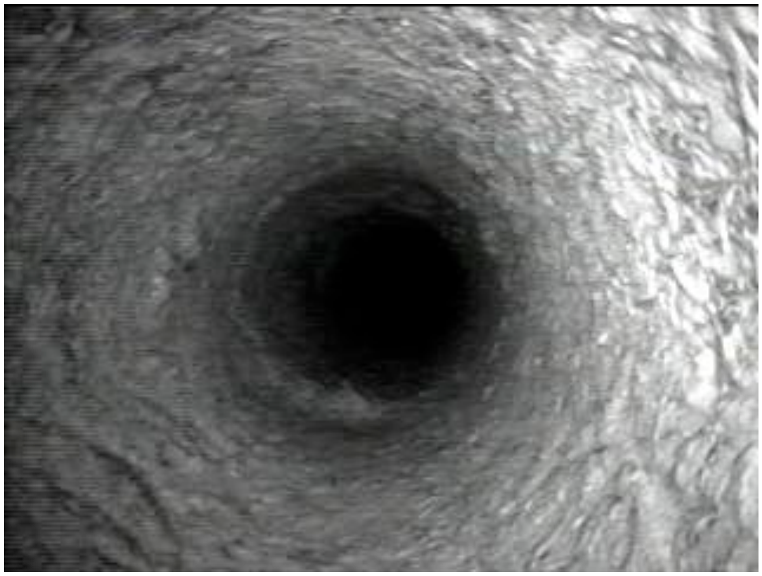


Figure 3.14 - Example of the inside borehole wall for one of the test holes.

The main purpose of inspecting each borehole was to assure the integrity and consistency of the rock. Factors such as major faults, discontinuities, wall slough offs and voids could drastically alter the results. The borehole inspections were also an excellent tool to verify any major changes in the structural geology within the borehole and blast block. Any test boreholes which differed drastically from the other comparison holes were discarded and new holes were drilled. Also, each single hole test was spaced at least 50 feet apart to assure that the rock mass was not affected by the adjacent detonations.

3.2 Conventional and Laser Surveying Systems

Both conventional and laser surveying were used on each test shot/blast setup. Conventional surveying was used to line up the small 3-inch horizontal hole to intersect the vertical 6 1/4 inch face hole. Refer to Figures 2.01 and 2.02. This was accomplished by setting up a theodolite on the floor of the quarry and shooting the center of a plumbed survey rod which was placed over the center of the 6 1/4 inch vertical face hole. Once the survey rod was leveled and in-site, a vertical line was brought down to the toe near the floor level, and a collar point was established. Because it was difficult to establish a collar point on the face right at the floor level, the small intersecting hole was actually started 2 to 3 feet above the floor level. Trigonometric calculations were then performed to assure that the small intersecting hole broke through to the bottom of the vertical 6 1/4 inch hole, given the toe burden, hole depth, slope distance and how high the collar of the small intersecting hole was above the floor elevation. Refer to Figures 3.21 to 3.24.

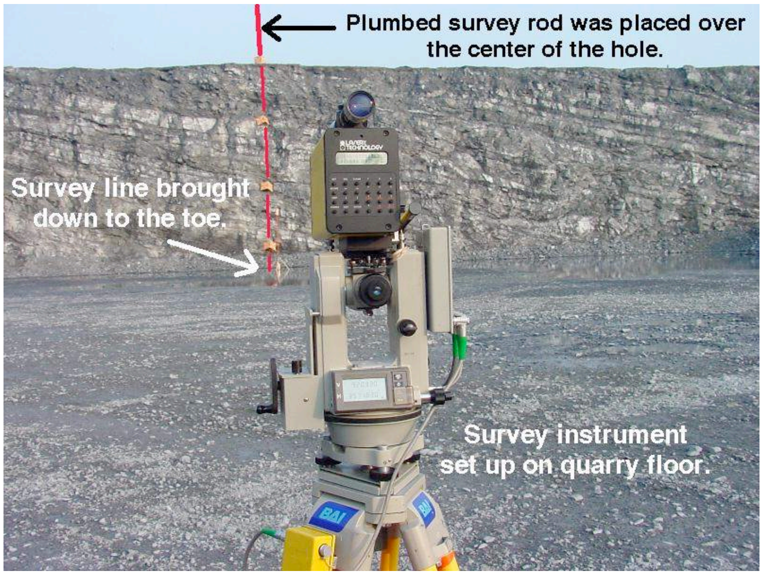


Figure 3.21 - Field setup showing how the collar of the small 3-inch intersecting hole was established to break through precisely to the bottom of the 6 1/4 inch vertical hole.

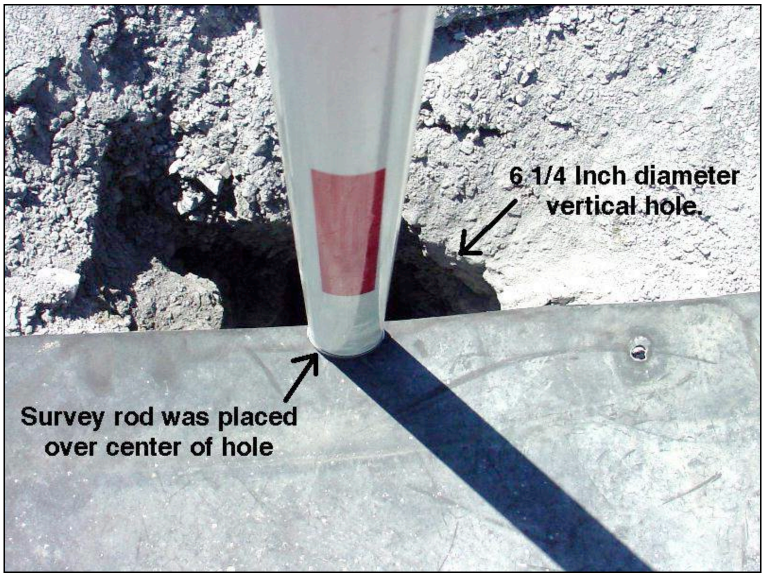


Figure 3.22 - Survey rod was placed and stabilized over the center of the 6 1/4 inch diameter vertical hole to establish a vertical control line.

Figure 3.23 - Plumbed survey rod. It was essential to have the survey rod plumbed accurately before a reference line could be shot and transferred down to the toe.

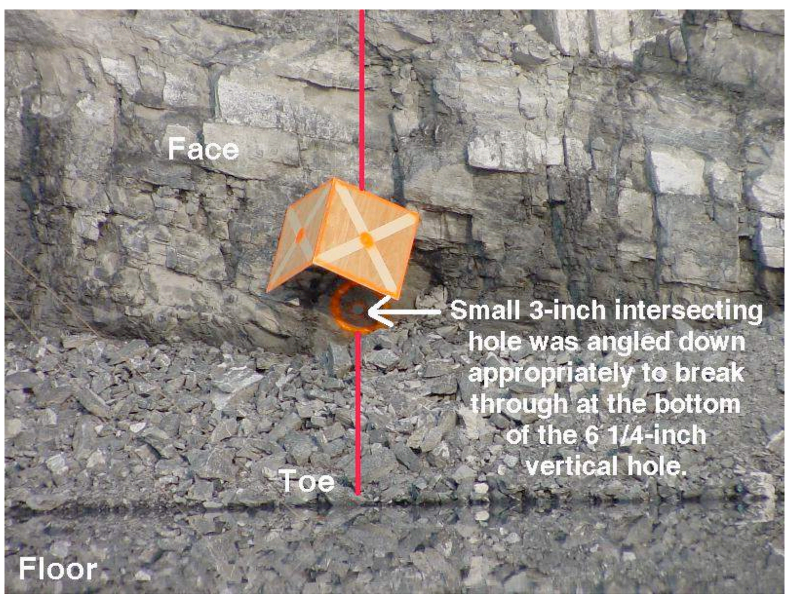


Figure 3.24 - Small intersecting hole is collared 2 to 3 feet above floor elevation and angled down appropriately to intersect the bottom of the 6 1/4 inch vertical hole.

Laser surveying was performed to establish the true burdens along the bench face from the crest to the toe. This was required in order to normalize the data results, since burdens in some areas along the bench face varied by up to 4 feet. Refer to Figure 3.25.

Figure 3.25 - Laser surveying was used to establish true burdens along the face from the crest to the toe.

Laser surveying was also used to establish where the face markers were placed on the bench face relative to the hole, bench height and true burdens. Face markers were used to accommodate the high-speed video camera for tracking purposes. Refer to Figure 3.26.

Figure 3.26 - Laser surveying was also used to establish the coordinates of the face markers relative to the vertical hole, bench height and true burdens.

3.3 High-Speed Video and Film Cameras

High-speed video cameras, high-speed 16 mm film cameras and standard digital camcorders were used on each test shot to quantify the shot dynamics, throw and the delay timing. Refer to Figure 3.31.

Figure 3.31 - High-speed video camera, high-speed 16 mm film camera and camcorder field setup.

In order to analyze full-scale blasts accurately, both dimensional and time controls needed to be established for each test shot. For 2-D analysis, a minimum of four control points with known coordinates forming a distinct quadrilateral must be available in the field of view. This allows us to calculate 8 calibration constants with a system of linear equations in 8 unknowns. The calibration constants correct for vertical, horizontal and elevation coordinates of the camera's location in relation to the test location; automatically adjusts for the zoom focal length, lens aberration and screen curvature; corrects for motion towards or away from the optic axis; and also accommodates for any vibration in the recorded field of view. The analytical software (MotionTracker-2D™) was developed by BAI and it is the most accurate and easiest to use on the market today. Refer to Figure 3.32. Those in the industry who use only a single vertical and horizontal scale for analysis often end up with cumulative errors and erroneous conclusions.

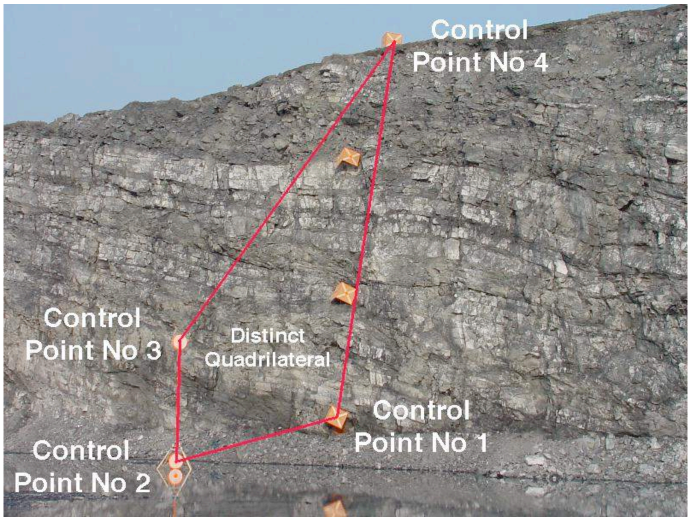


Figure 3.32 - Placement of bench face markers for tracking purposes and how the four control points were established for accurate motion analysis.

Each bench face marker which was used for tracking purposes was hung over the face with a separate line. Refer to Figures 3.33 and 3.34.

Figure 3.33 - Bench face markers were hung down the face for tracking purposes and to measure the initial velocity, ejection angle, TMIN (rock response time) and cast distance.

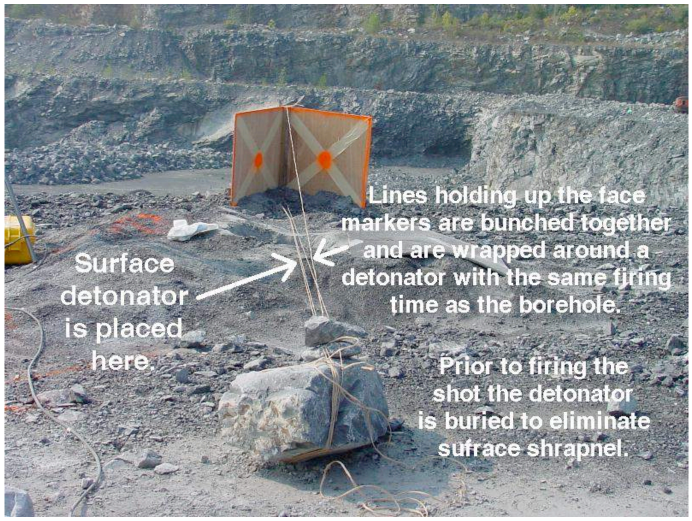


Figure 3.34 - Illustrates the separate lines for each bench face marker that were hung over the face. All of the lines are then bunched together and wrapped around a surface detonator with the same firing time as the in-hole delay. When the hole goes off, all of the lines holding up the markers are simultaneously cut, so that during motion the markers move freely and do not move as a pendulum fixed at one end (i.e., at the rock).

The second thing required for motion analysis is time control. This was established by tying shock tube to the bottom hole primer of the control hole, brought up through the explosive column and the stemming, and thrown over the face. All of the other holes had the shock tube placed on a stake in the shape of a coil. Refer to Figures 2.01, 2.02, 3.35 and 3.36.

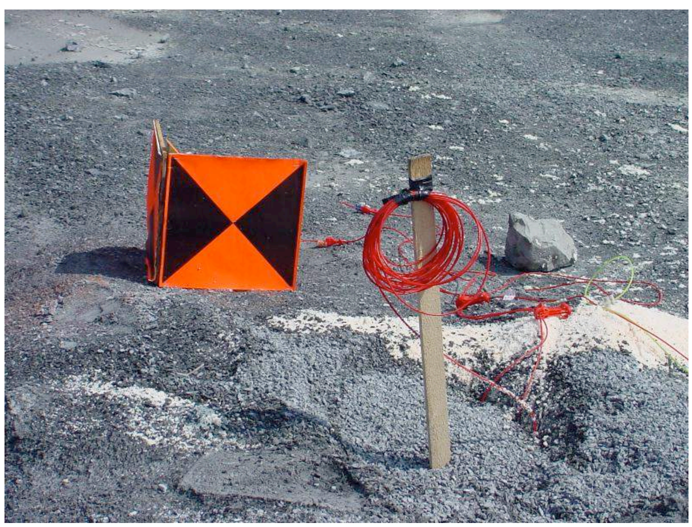


Figure 3.35 - Close-up of how the shock tube was wrapped in a coil and placed on a stake which was located at or near the hole. This setup allows accurate measurements of the firing times of each hole, when the length of shock tube and VOD of the explosive is taken into account.

Figure 3.36 - Illustrates a completed shot setup with dimensional and time controls readied for monitoring and analysis

3.4 VOD – Velocity of Detonation Instrumentation

VOD measurements were obtained using two VODR-1 systems which are TDR (Time-Domain Reflectometry) systems. Refer to Figure 3.41.

Figure 3.41 - The VODR-1 System (a TDR based VOD instrument) was used for all measurements. A special foam dielectric coaxial cable was used to measure the PowerPlug speed and gas front velocity in the airdecks. Standard RG-58 coaxial cable was used to measure the VOD of the explosive columns.

Although BAI had the choice of using the SLIFER, resistance wire or fiber-optic based VOD systems, the TDR based VODR-1 system was selected for its reliability and flexibility in obtaining field measurements. Other VOD systems, (particularly the resistance wire systems), were found unreliable, since they tended to generate more questions than answers. This was especially true for measurements involving wet hole conditions, airdecks, low order detonations and deflagrations. In addition, the other VOD systems did not provide reliable disturbance velocities through stemming.

The most critical measurements were in determining the velocity of the SuperPlug and the gas front traveling through the bottom and mid-column airdecks. For this purpose one of the VODR-1 systems used only the FSJ1-50A coaxial cable. This is a special foam dielectric coaxial cable with a low crush hold, which can measure any disturbance front in a borehole down to as low as 300 ft/sec. A typical field setup to achieve this is illustrated in Figures 2.01 and 2.02 in Section 2.0. By measuring the velocity of the SuperPlug and the mass of stemming on top of the SuperPlug, the KE (Kinetic Energy) impacting the bottom of the hole could be reliably and easily calculated.

3.5 Seismograph Instrumentation

Vibration/airblast measurements were obtained with 4-channel, full waveform, digital seismographs. A linear seismic array consisting of 5 seismographs was placed behind each test shot at distances varying from approximately 100 to 2,000 feet. Refer to Figures 3.51 and 3.52. This was necessary to establish the site-specific attenuation characteristics of the vibration and airblast from the single hole and full-scale shots. It was also very important for the single hole signature analysis when coupling airdecks with the use of precise electronic detonators.

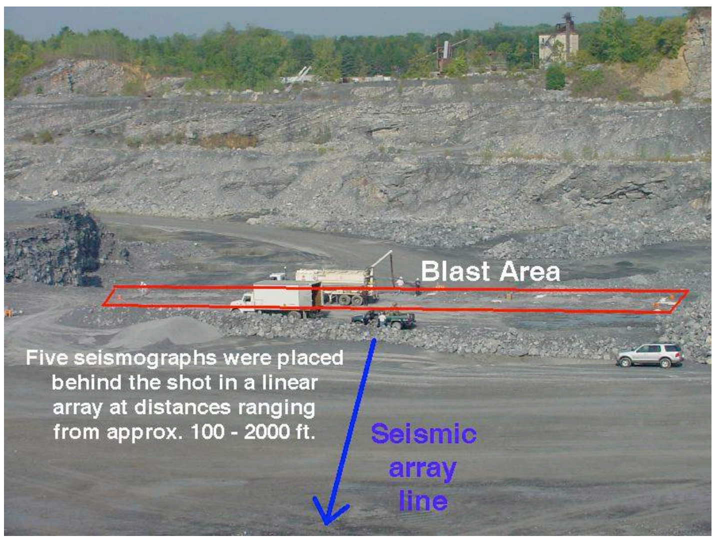


Figure 3.51 - Seismic array line in relation to the test shot area. The seismograph placed at the 2,000 foot distance was in the middle of a small residential subdivision.

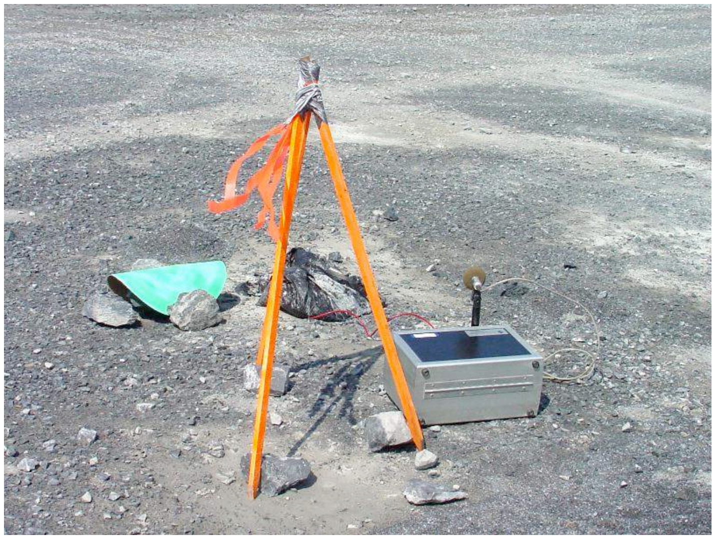


Figure 3.52 - Two types of digital seismographs were used. The close-in geophones to the test shots had a sand bag placed on top of them to assure good coupling with the ground.

Once the seismic data were analyzed, it was normalized in order to compare the normal shot against the PowerDeck shot.

3.6 Fragmentation Analysis

Digital fragmentation analysis was performed on both full-scale shots with the Split-Desktop® Software. A total of 32 to 36 digital images were taken of each muckpile to assure statistical significance when comparing the results from the normal shot to the PowerDeck shot.

In spite of what all fragmentation analysis software developers claim regarding the accuracy of their software, digital fragmentation analysis can be highly subjective unless extreme measures are taken to keep the analysis parameters consistent, particularly in the sampling technique. If this is not done properly, one could easily skew the analysis to generate any results so desired.

Thus, in this series of tests a great deal of detailed planning and testing were undertaken to minimize or eliminate the inherent cumulative errors. For each muckpile, the following analytical procedures were implemented for consistency.

Oversize generally results from the stemming area and ends up on the top of the muckpile. The thickness of the oversize in reference to a cross-sectional dig of the muckpile was approximately 25%. Thus, 25% of the total muckpile images were taken from on top of the muckpile, and the remaining 75% were taken over 4 cross-sectional digs throughout the muckpile from the beginning to the end of the digging cycle. Refer to Figures 3.61 to 3.63.

Figure 3.61 - Sampling procedure for each muckpile analysis used 25% of the digital images from on top of the muckpile, and the remaining 75% were taken over 4 cross-sections throughout the muckpile.

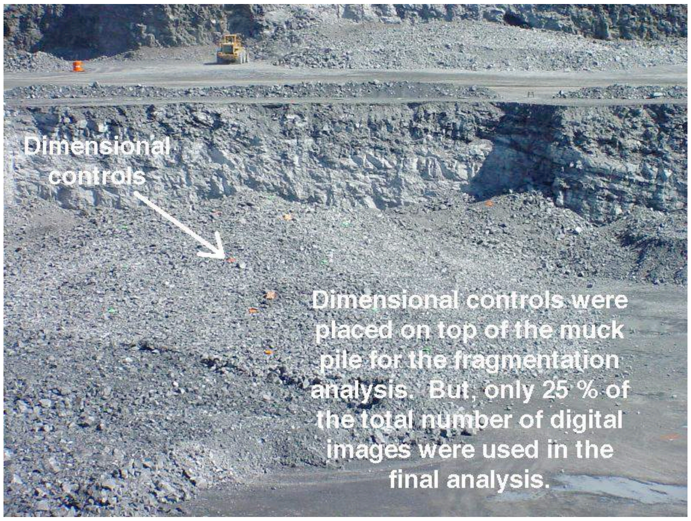


Figure 3.62 - Dimensional markers were strategically placed on top of the muckpile on a grid system. However, only 25% of the digital images encompassing the surface area of the muckpile were used in the final analysis.

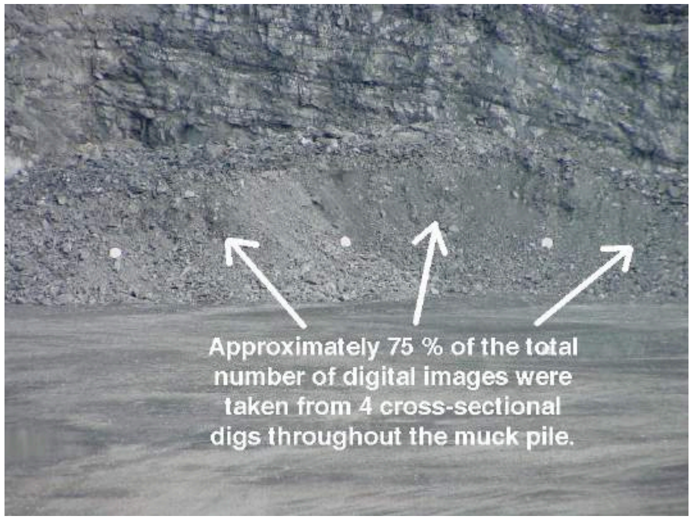


Figure 3.63 - Cross-sectional area of the muckpile. A total of 75% of the number of digital images were taken over 4 cross-sectional digs within the muckpile.

Extreme care was taken in avoiding duplicating the rock images, particularly along the top of the muckpile and along the quarry floor, (i.e., toe of the muckpile). During digging, it was inevitable that some of the oversize material from on top of the muckpile would roll down and collect along the floor. Thus, all of the cross-sectional images were strategically collected to avoid duplication counts of the oversize pieces. Refer to Figure 3.64.

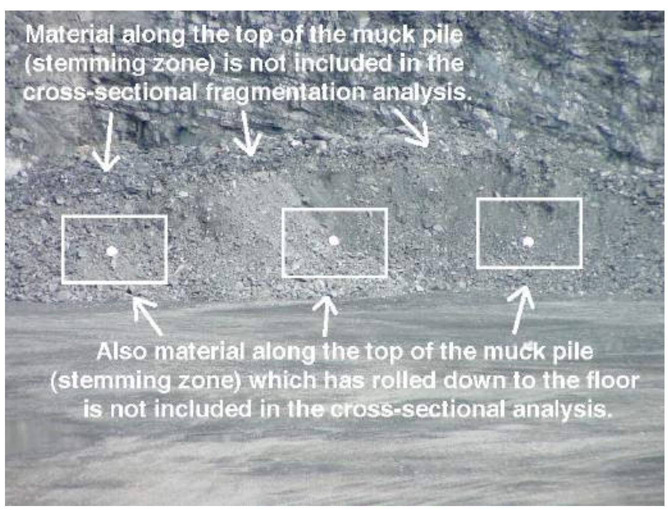


Figure 3.64 - Cross-sectional sampling technique used to avoid oversize duplication counts.

Prior to any of the fragmentation analysis, tests were conducted on a number of known but different fragment sizes of processed rock samples. The purpose was to determine the optimum dimensional control needed for measuring the rock fragmentation of interest in the muckpile. Refer to Figures 3.65 and 3.66.

Figure 3.65 - Example of poor rock size resolution for the wide angle field of view in relation to the large dimensional control size.

Figure 3.66 - Example of good rock size resolution for the close-up view in relation to the dimensional control size. Here the white circular dimensional control was an 18 inch disk and the known rock size was 4 to 5 inches. Fragmentation analysis on this frame produced a P50 passing size of 4.4 inches with a very narrow (i.e., steep) cumulative percent passing curve.

Based on the fragmentation calibration tests, it was determined that the length/width of each image view should be somewhere between 5 to 12 times the size of the dimensional controls.

Given this criteria, the field of view per image was limited to approximately 7 to 18 feet. This approach worked very well for the expected rock size distribution which was the feed to the primary crushers. An example of this sampling technique is illustrated in Figure 3.67, and the accompanying rock size is shown in Figure 3.68.

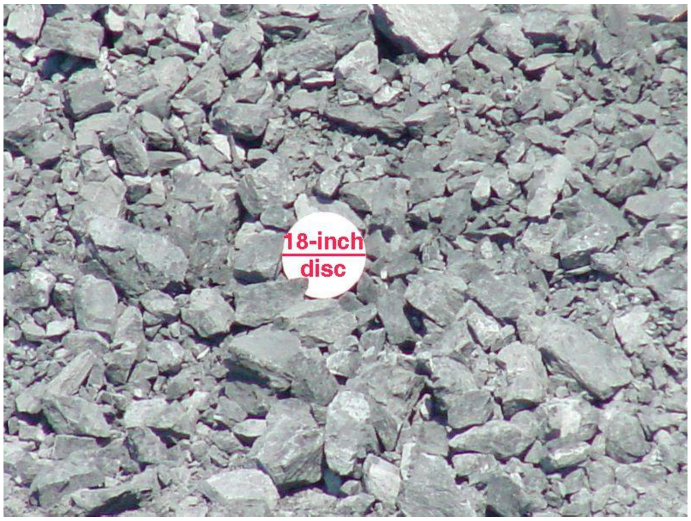


Figure 3.67 - Illustrates the sampling technique which was used to achieve the correct ratios of the image field of view to the dimensional control (disc size) and desired rock size resolution.

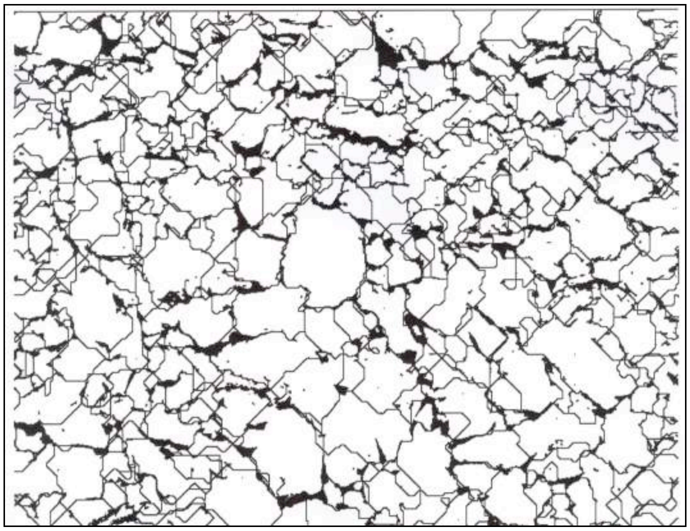


Figure 3.68 - Example analysis of the rock image shown in Figure 3.67

Another thing that was seriously considered before any of the fragmentation measurements was the rock shadows from sunlight. To minimize this error, all digital images of the muckpiles were taken at the same time of the day between 3:00 to 4:00 P.M. Once all of the individual rock images were analyzed, they were merged together to develop a histogram and cumulative percent passing curve for the entire muckpile. The circular disc which was used in each rock image was not counted in the fragmentation analysis.

4.0 TEST RESULTS

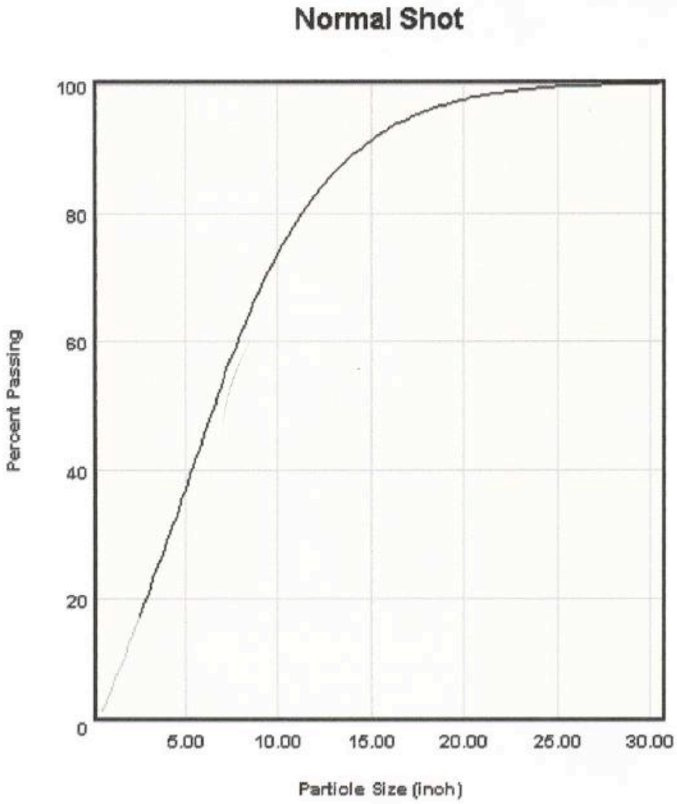
The main test results focused on the two full-scale shots (Normal vs. the SuperPlug). Once the data were analyzed, direct comparisons could be performed for the fragmentation, vibration and muckpile throw.

4.1 Fragmentation Results

Fragmentation results are presented in the form of a cumulative percent passing versus particle size and histogram curves. The cumulative percent passing curves for the Normal Shot and the PowerDeck Shot are illustrated in Figures 4.11 and 4.12, respectively. The histograms for the Normal Shot and the PowerDeck Shot are illustrated in Figures 4.13 and 4.14 respectively. The numerical results from the graph comparisons are summarized as follows:

	Normal Shot	PowerDeck Shot
Number of Combined Images	32	37
Minimum Size Measured	2.50 in	2.10 in
P20 size	2.86 in	2.17 in
P50 size	6.53 in	4.90 in
P80 size	11.33 in	8.97 in
Top size measured	25.13 in	24.86 in

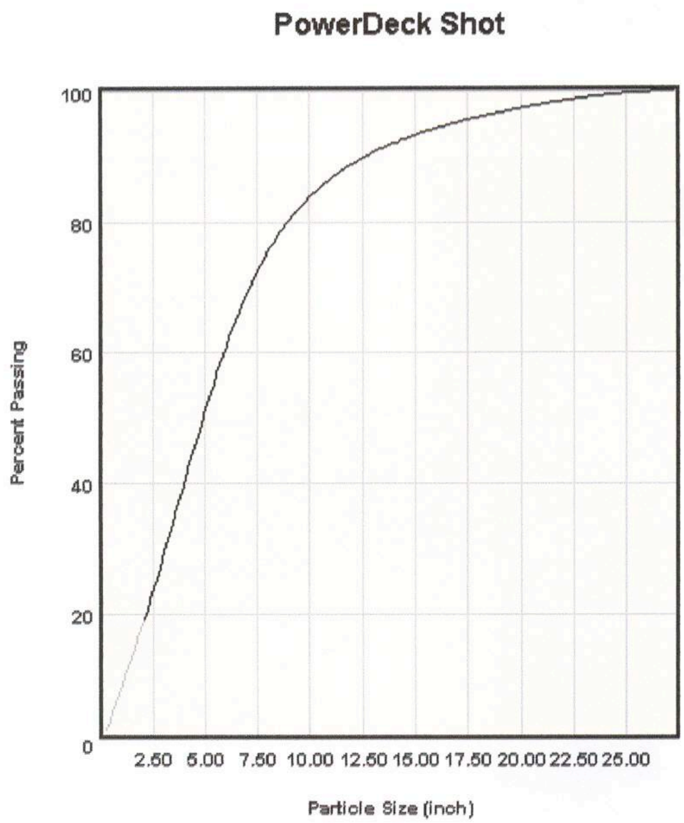
The greatest significant difference in the fragment size distribution was found in the P20, P50 and P80 passing sizes. In all cases, the PowerDeck shot resulted in a fragment size reduction of approximately 24% for the P20 passing size; 25% for the P50 passing size; and 21% for the P80 passing size. Thus the fragment size distribution was reduced substantially for the PowerDeck shot. No significant difference was found in both shots for the smaller size range below 2 to 3 inches or the top size at 24 to 25 inches.



size (in)	%
75.00	100.00
50.00	100.00
25.00	99.48
15.00	91.20
10.00	73.65
8.000	61.25
6.000	45.62
4.000	28.99
2.000	13.37
1.500	9.61
1.000	6.03
0.750	4.33
0.500	2.71
0.375	1.95
0.250	1.19
0.187	0.89
0.0787	0.37

P20 size (in) 2.863
P50 size (in) 6.533
P80 size (in) 11.33
Top size (in) 25.13

Figure 4.11



size (in)	%
75.00	100.00
50.00	100.00
25.00	99.54
15.00	93.13
10.00	83.73
8.000	75.37
6.000	60.97
4.000	39.97
2.000	18.36
1.500	13.56
1.000	8.85
0.750	6.53
0.500	4.26
0.375	3.15
0.250	2.05
0.187	1.51
0.0787	0.62

P20 size (in) 2.171
P50 size (in) 4.895
P80 size (in) 8.972
Top size (in) 24.86

Figure 4.12

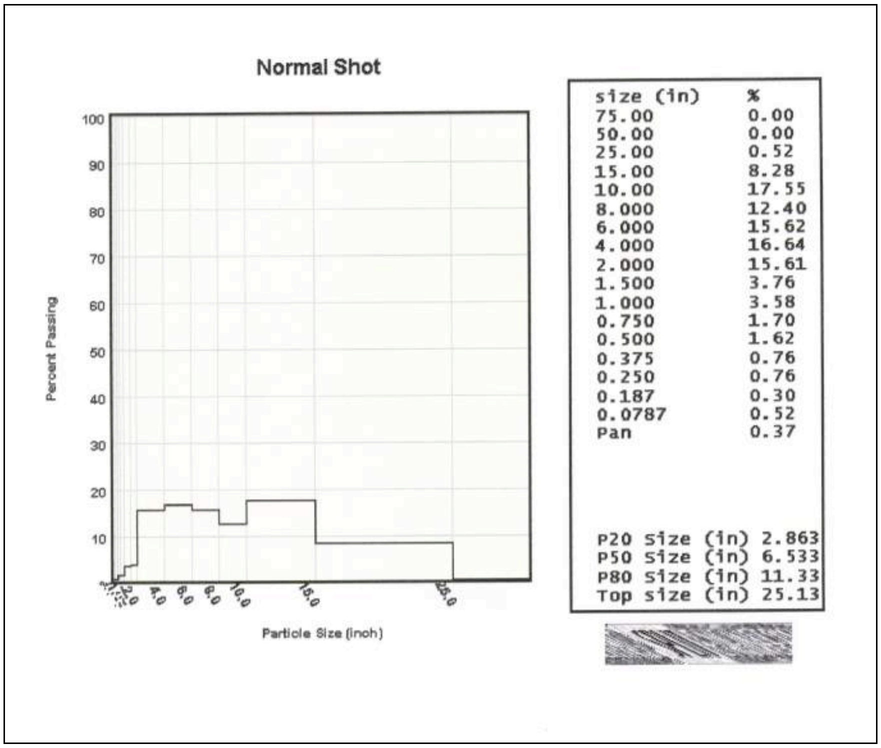


Figure 4.13

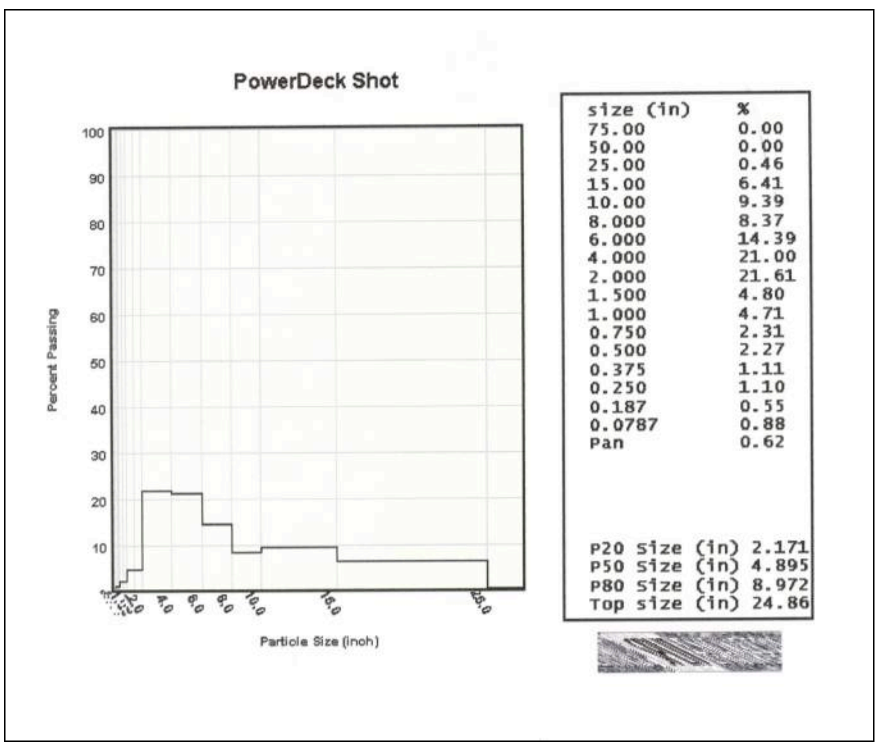


Figure 4.14

4.2 Ground Vibration Results

Ground vibration results comparing the Normal and PowerDeck shots are illustrated in Figure 4.21 as a plot of particle velocity versus scaled distance. Scaled distance here is defined as the distance divided by the square root of the maximum amount of explosives per delay. This plot is a very good way to normalize the data for comparison purposes since the distances from the test shots to the seismograph locations, and the maximum weight of the explosives varied.

The vibration amplitudes were reduced by an average of 33% for all locations, given a distance and maximum weight of explosives per delay. A 33% reduction in the amplitudes is significant in view of the attenuation characteristics over distance. Also, the PowerDeck shot did not trigger the seismograph which was stationed farthest from the shot, while the Normal shot did.

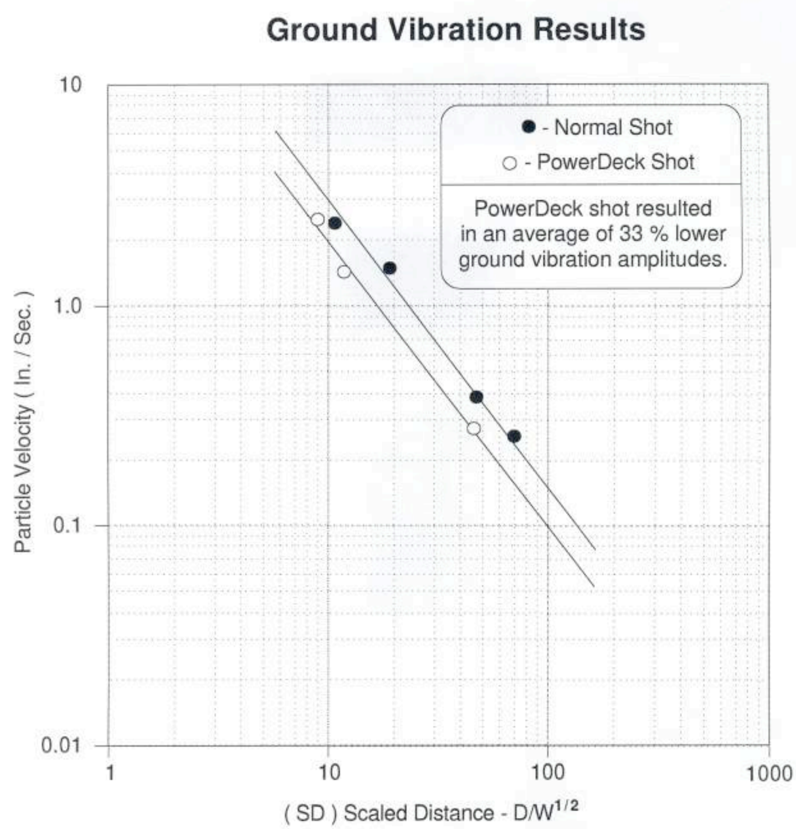


Figure 4.21 Particle Velocity vs Scaled Distance

Blasting Analysis International, Inc. EastF6

4.3 SuperPlug Velocities Through Bottom Hole Airdeck

The SuperPlug velocities traveling through the bottom hole airdeck were measured in each test hole as previously illustrated in Figures 2.01 and 2.03. As far as we know, this is the first time that anyone has successfully measured the SuperPlug velocity traveling through a bottom hole airdeck. Velocities varied from approximately 1,000 to 11,000 ft/sec. depending on the type of explosive, amount of stemming mass which was placed on top of the SuperPlug and the confining conditions of the surrounding rock mass. The gas front velocity traveling through the small 3-inch intersecting hole varied from approximately 800 ft/sec to just over 2,000 ft/sec. Figure 4.31 illustrates an unfiltered displacement versus time plot of the SuperPlug velocity in the 6 1/4 inch vertical hole and the gas front velocity traveling through the small intersecting face hole. This was the highest SuperPlug velocity recorded to date in 5 to 6 1/2 inch diameter holes with a 3-foot bottom hole airdeck. The explosive column VOD ranged from approximately 13,000 to 15,000 ft/sec.

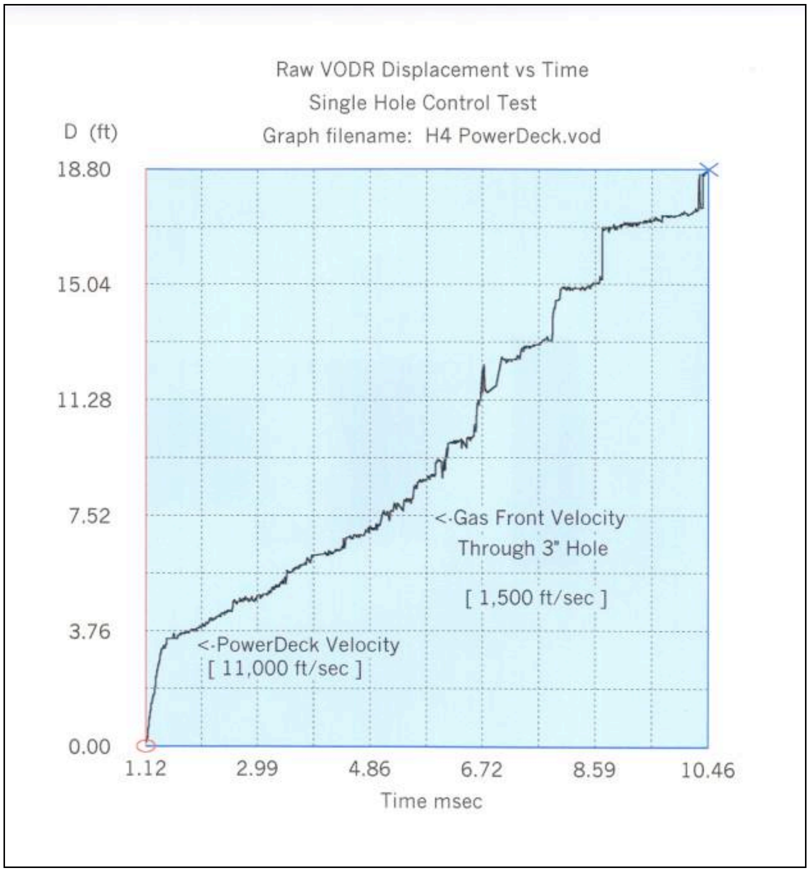


Figure 4.31

4.4 Muckpile Displacement

The muckpile shapes and cast distances were measured for both the normal and PowerPlug shots. The comparison results are illustrated in Figure 4.41. The normal shot spread the muckpile over distance of 300 feet, and the PowerPlug spread the muckpile over a distance of 280 feet. Basically, there was no significant difference between the normal and PowerPlug shot.

The center of gravity for muckpile were the same at approximately 75 to 100 feet. Although the muckpile profiles varied slightly, the maximum height of each muckpile was basically the same.

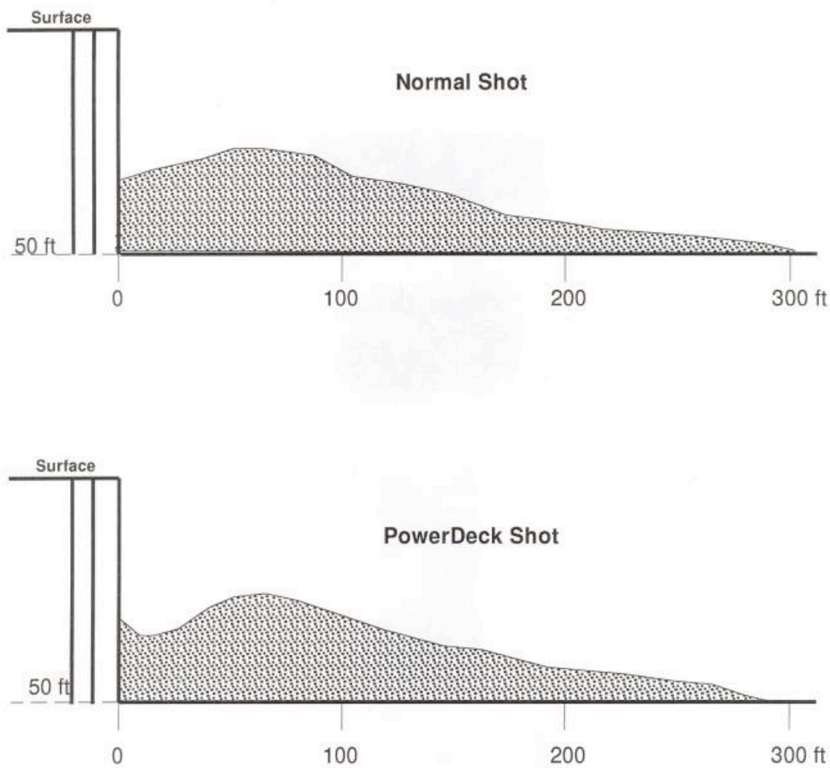


Figure 4.41 Muck Pile Profiles and Cast Distances for the Normal and PowerDeck Shots

Blasting Analysis International, Inc. EastF7

5.0 CONCLUSIONS

1. Full-scale shots were evaluated with sophisticated blast monitoring instrumentation systems. The Normal shot utilized full column explosives in each hole, and the PowerDeck shot used a 3-foot airdeck at the bottom of each hole. Results were normalized and compared for the fragmentation distribution, ground vibration amplitudes and cast distance.

2. In reference to the fragmentation, the PowerDeck shot resulted in a 21 to 24% reduction over the P20 to P80 passing sizes. The P50 passing size was 4.90 in. for the PowerDeck shot and 6.53 in. for the Normal shot. These are significant reductions which can be related to substantially lower costs in the throughputs through the primary crushers, wear and tear on the crusher linings and utility costs.

   No significant differences were found in both shots regarding the smaller fragmentation passing sizes below 2 to 3 inches or the top size 24 to 25 inches.

3. In reference to the vibration amplitudes, the PowerDeck shot resulted in a 33% reduction over all distances in the seismic array line up to approximately 2,000 feet. This was also quite significant in reducing complaints, complying with vibration regulations and/or in allowing the mine/quarry to utilize larger shots.

4. The PowerDeck shot resulted in an equivalent flat floor as that of the Normal shot. The significance of this is that a properly designed airdeck at the hole bottom with the use of the SuperPlug, appropriate stemming on top of the SuperPlug and airdeck length, could eliminate and/or reduce all subgrade drilling. This results in a direct drilling and explosives cost, without affecting the overall blast results.

5. No significant differences were found in the muckpile shape, center of gravity of the muckpile or the cast (i.e., throw distance) in both shots. The PowerDeck and Normal shots produced similar results.

6. Mine, quarry and construction operators are encouraged to utilize the SuperPlug. In most cases, the benefits are substantial with very little to loose. The main benefit has been increased productivity.

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