New Blasting Technique to Eliminate Subgrade Drilling, Improve Fragmentation, Reduce Explosive Consumption and Lower Ground Vibrations

by

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Abstract

A new blasting technique has been developed by International Technologies, LLC. to eliminate subgrade drilling, lower ground vibrations, improve fragmentation and reduce explosive consumption. The new technique utilizes a uniquely designed borehole plug, with a bottom hole air deck and a predetermined stemming mass on top of the plug. This combination is referred to as the Power Deck™. Single holes and full scale tests were conducted by Blasting Analysis International, Inc. (BAI) to determine how the system works, the mechanisms behind its success and the best design parameters to use for the given rock conditions. Results have shown reduced or eliminated subgrade drilling, ground vibration reductions of up to 33%, reduced explosive consumption by 16 to 25%, and improved fragmentation by up to 25%. This paper summarizes the methodology, field test setups, analyzes procedures and results for one series of single hole and full-scale tests which were performed in Pennsylvania, USA.

Introduction

In today's challenging and competitive mining industry, mine operators are always striving to lower their total mining system costs and improve their bottom line. International Technologies, LLC. has assisted mine operators in achieving these objectives with the Power Deck™ blasting system.

Single Hole Characterization Tests

Hole load cross sections for the three full-scale single hole tests are illustrated in **Figures 1 to 3.** All of the single holes were 6 1/4 diameter, drilled to average depths of 48 feet and used 12 feet of 1/4 to 1/2 inch crushed rock for the top stemming. The explosives used were a consistent combination of an emulsion/Anfo blend and Anfo. Burdens were maintained between 14 to 18 feet along the bench height. **Figures 1** depicts how the holes were normally loaded at the quarry with a full column of explosives, 3 feet of subgrade and 12 feet of top stemming. The test hole shown in **Figure 2** was loaded with a smaller column of explosives, 12 feet of top stemming, a 3 foot air deck at the hole bottom and no subgrade. In **Figure 3**, the hole load consisted of two equal lengths of explosive decks separated by a 3 foot mid-column air deck, 12 feet of top stemming, a 3 foot bottom hole air deck and also no subgrade. Here both the top and bottom explosive decks were fired simultaneously. A mid-column air deck separated by two explosive decks requires precise simultaneous detonation of the two explosive decks.

Note that the total explosive quantity was reduced by 17% for the hole load with the bottom hole air deck (**Figure 2**), and by 25% for the double air deck hole (**Figure 3**), relative to the typical normal hole loads used at the quarry as shown in **Figure 1**.

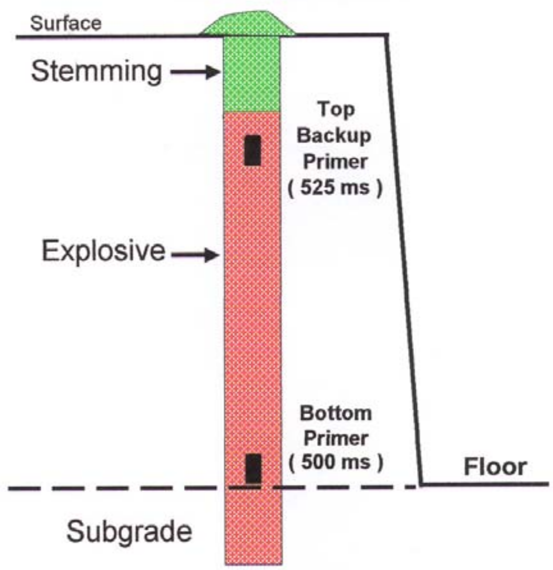

Figure 1 – Typical continuous explosive column load with subgrade drilling.

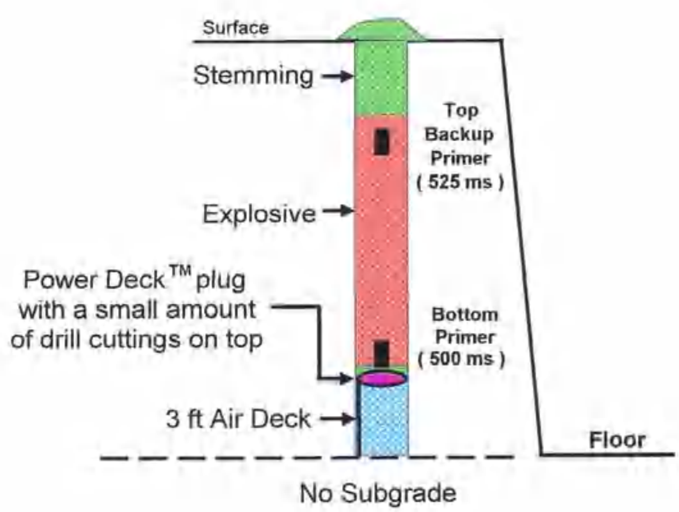

Figure 2 – Continuous explosive load with a 3-foot bottom hole air deck and no subgrade.

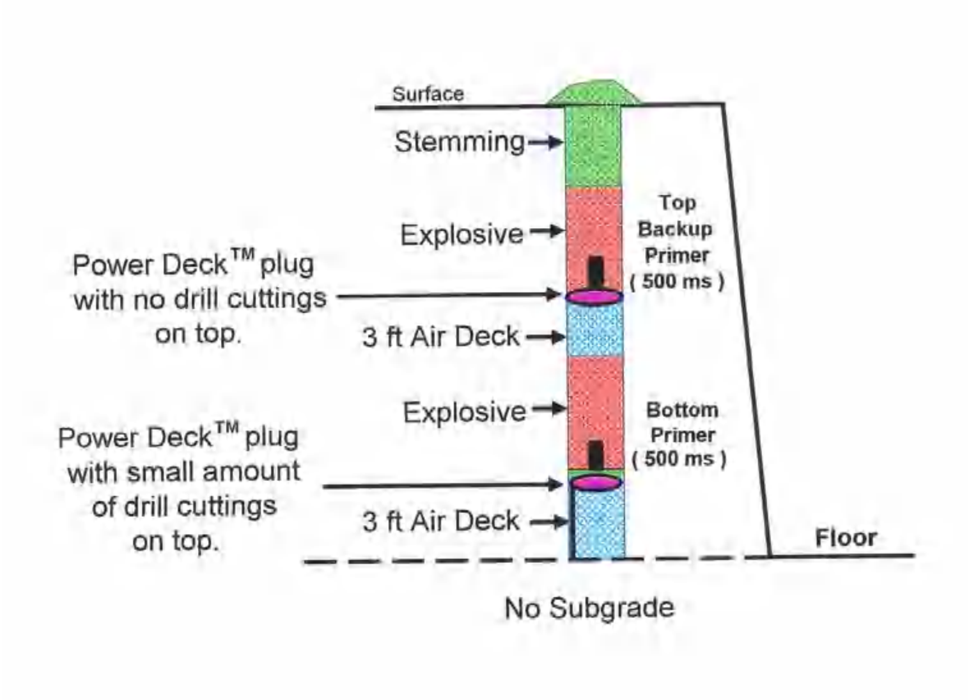

Figure 3 - Two explosive decks separated by a 3-foot mid-column air deck, a bottom hole 3-foot air deck and no subgrade.

The purpose of the single hole tests was to:

- Establish the initial control measures by eliminating many of the blast design variables inherent in full scale shots.

- Verify that the total explosive and instrumentation systems functioned as expected and,

- Verify that the Power Deck™ functioned reliably as designed and remained in place in the borehole during loading operations.

But the most important aspect of monitoring the single holes was to quantify the velocity of the Power Deck™ and the gas front velocity traveling through the bottom hole air decks. In order to achieve this, it was necessary to drill a smaller 3 inch cable hole, starting near the toe of the free face until the hole intersected the vertical 6 1/4 inch hole as illustrated in **Figure 4**. The aim was to have the small 3 inch holes break through to the bottom of the vertical holes and to the bottom of the 3 foot air decks

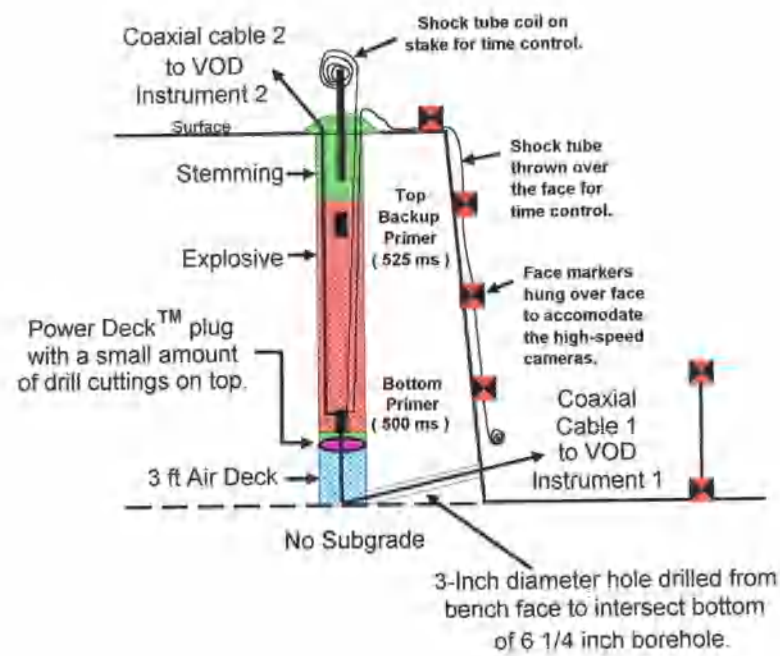

Figure 4 –– Example of a fully instrumented 6 1/4 inch diameter hole and the smaller intersecting 3 inch cable hole.

Instrumentation Systems Used for Monitoring

A number of sophisticated, state-of the-art blast instrumentation systems were used by BAI to monitor the single holes and full-scale shots. Instrumentation consisted of an HRS-1 video borehole inspection camera system, two VODR-1 systems, a MotionMeter 1000 high-speed video system, a LOCAM high-speed film camera, the SPLIT-Desktop™ digital fragmentation analysis system, a conventional and laser surveying system, and a number of White Industrial Seismology's digital seismographs.

Full-Scale Blasts

Two 30-hole full-scale shots were then monitored to evaluate the blast result differences between the normal hole loads as shown in **Figure 1** and the hole loads as shown in **Figure 2**. The boreholes in the normal full-scale shot were drilled with a 3 to 4 foot subgrade and loaded with a full column of explosives. The boreholes in the Power Deck™ shot were drilled with no subgrade, but loaded with 16% less explosive and 3 foot bottom hole air decks. The top stemming was maintained the same at 12 feet for both shots. Floor breakage, fragmentation, ground vibrations and the muckpile profiles were the main focus of interest in the results for the full-scale blasts.

All of the other blast design variables for the normal and Power Deck™ shots were kept constant. **Figure 5** illustrates a plan view of the drill hole layout and the cumulative firing times used. The general design parameters for both full scale shots were; number of holes = 30, number of rows = 2, drill pattern (B x S) = 14 ft. x 16 ft., hole depth = 47 – 51 ft., and hole diameter = 6 1/4 in. Both shots were fired on the same bench, one behind the other, in order to eliminate any structural geology influences. Both shots were also instrumented to monitor the exact firing time of each hole and the resulting kinetics at the free face. **Figure 6** illustrates one of the full-scale shots which has been fully instrumented and readied to be fired. It is important to note that prior to firing the two full-scale shots, the blast design parameters and bench face geometry were fully optimized.

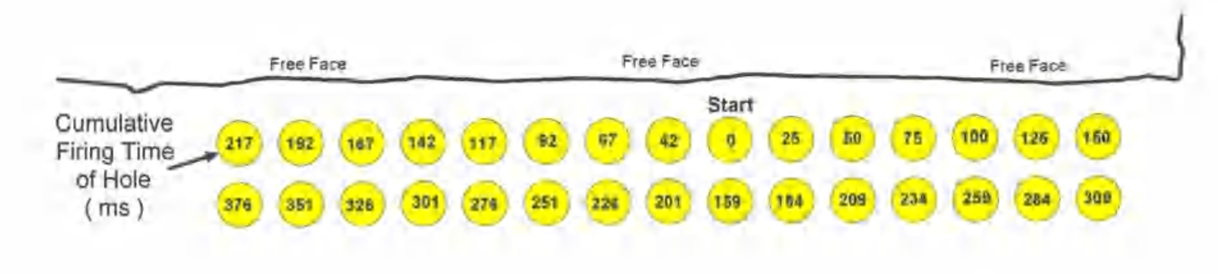

Figure 5 – Plan view of a typical full-scale shot, illustrating the cumulative firing times.

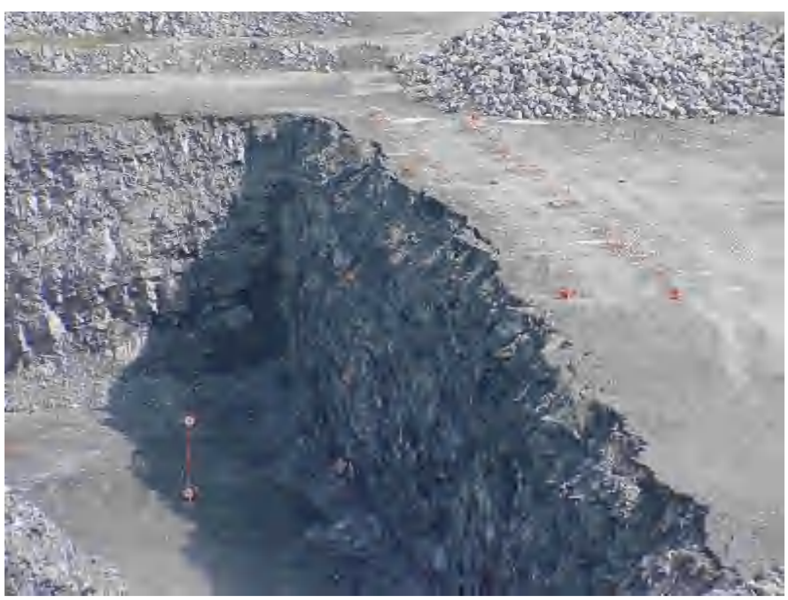

Figure 6 – Example of a fully instrumented full-scale shot ready to be fired.

Single Hole Results

The blast results from the three single holes showed no significant differences in terms of the fragmentation, breakage to the quarry floor, breakage in the collar area, the degree of muckpile throw and for the muckpile shape. This was quite significant in view of the fact that the holes containing air decks used 17% and 25% less explosive with no subdrilling.

Figure 7 illustrates a typical velocity record as a displacement versus time plot for the Power Deck™ plug and gas front velocity traveling through a typical 3 foot bottom hole air deck in the 6 1/4 inch diameter vertical hole, and then continuing on through the smaller 3 inch intersecting bench face hole. In this case, the Power Deck™ plug velocity was 11,000 ft./sec., and the expanding gas front through the smaller 3 inch intersecting bench face hole was approximately 1,500 ft./sec. Given an explosive type, borehole diameter, rock type in terms of its integrity and strength, air deck length, and the amount of stemming mass on top of the plug, the plug velocity (or gas front velocity) through the bottom hole air deck can be made to vary from approximately 1,000 to 12,000 ft./sec. The gas front velocity through the smaller 3 inch bench face hole can vary from just under 1,000 to 4,000 ft./sec. To our knowledge, this is the first time anyone has made these types of measurements in a full-scale blast environment. The significance of these measurements will be explained later.

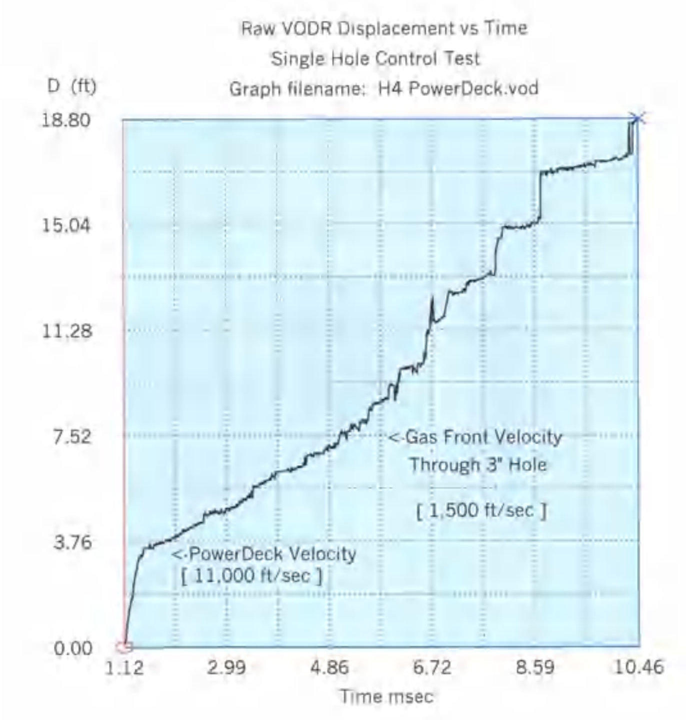

Figure 7 – Displacement versus time graph. Recording starts at the primer which was located on top of the Power Deck™ plug (0.0 feet), progresses through the 3-foot bottom hole air deck and continues on through the smaller 3-inch intersecting face hole.

Fragmentation Results

Fragmentation from the two full-scale shots in terms of the standard cumulative percent passing sizes are listed in **Table 1**.

TABLE 1 – Fragmentation Results for the Normal and Power Deck™ Shots

	Normal Shot	Power Deck™ Shot	Percent Reduction with the Power Deck™ Shot
Number of Combined Images	32	37	
Minimum Size Measured	2.50 in	2.10 in	—
P20 size	2.86 in	2.17 in	24%
P50 size	6.53 in	4.90 in	25%
P80 size	11.33 in	8.97 in	21%
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 Power Deck™ 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 Power Deck™ shot. No significant difference was found in both shots for the larger size range between 24 to 25 inches, because the top size was heavily dictated by the major structural joint system. For our sampling setup, the digital fragmentation system was insufficient to resolve the fines content below 2 inches.

Digital fragmentation analysis is extremely subjective and is prone to numerous experimental, systematic, sampling and analysis errors. To minimize these errors, over 2 1/2 months were spent in calibrating the fragmentation analysis system. Calibration took into account the ratio of merged images from the top of the muckpile and cross sections during the digging phase, comparisons against known stock pile sizes, the muckpile characteristics, the image size relative to the dimensional controls and the weather effects.

Ground Vibration Results

Ground vibration results comparing the Normal and Power Deck™ shots are illustrated in **Figure 8** 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 slightly. Seismic locations from the shots varied from 200 to 2,000 feet in a linear array.

Vibration amplitudes were reduced by an average of 33% for all locations, given a distance and maximum weight of explosives per delay for the Power Deck™ shot. A 33% reduction in the amplitudes is quite significant in view of the attenuation characteristics over distance. Also, the Power Deck™ shot did not trigger the seismograph which was stationed farthest from the shot at 2,000 feet away, while the Normal shot did.

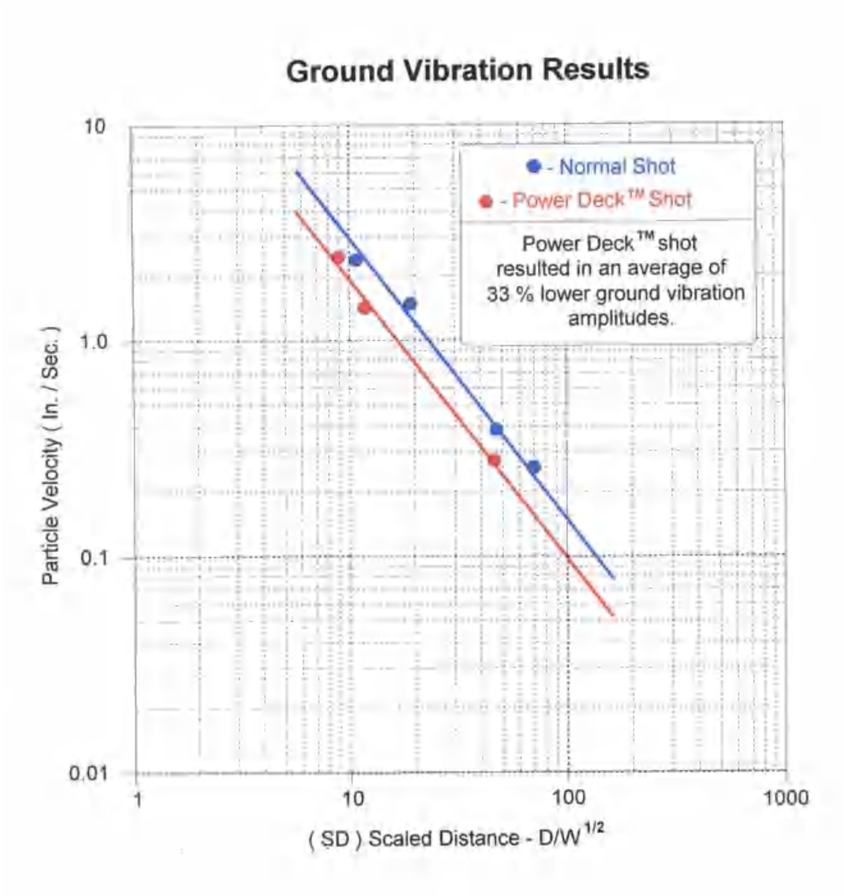

Figure 8 – Peak Particle Velocity versus Scale Distance graph for the two full-scale shots.

Muckpile Displacement

The muckpile shapes and cast distances were measured for both the normal and Power Deck™ shots. The comparison results are illustrated in **Figure 9**. The normal shot spread the muckpile over a distance of 300 feet, and the Power Deck™ hot spread the muckpile over a distance of 280 feet. Basically, there was no significant difference in the muckpile throw between the normal and Power Deck™ shots even though the Power Deck™ shot used 16% less explosives per hole.

The center of gravity for each muckpile was basically the same at approximately 80 feet. Although the muckpile profiles varied slightly, the maximum height of each muckpile was basically the same, although the Power Deck™ shot produced a little more of a power trough against the highwall.

Figure 9 – Muckpile profiles for both full-scale shots.

Level of Quarry Floor

Both the normal and Power Deck™ shots resulted in flat floors with no significant differences. But, it was very significant that the Power Deck™ shot used no subgrade (i.e., 3 to 4 feet less drilling per hole) and 16% less explosives in each hole. In addition, the Power Deck™ shot did not disrupt the collar zone of the next underlying bench.

The Power Deck™ System Design and How it Works

The Power Deck™ concept was developed by International Technologies, LLC. over three years ago. Based on many field trials and feedback from around the world, it has undergone many unique modifications to its present design, which is illustrated in **Figure 10**. The Power Deck™ plug is very simple, easy and quick to use in any hole ranging from 2 1/4 to 12 inch diameters. For underground use, the principle of operation is the same, but the Power Deck™ plug design is somewhat different. Basically the Power Deck™ plug is attached to a precut length of wooden stick that defines the bottom hole air deck length, and a small amount of drill cuttings or crushed rock is placed into the Power Deck™ plug 's specially designed holding chamber. This assembly is dropped into the borehole without any other accessories as shown in **Figure 10**. Unlike airbags which possess extremely high buoyancy, the Power Deck™ plug works equally well in wet or dry holes. Once dropped into a borehole, an appropriate calculated amount of stemming is placed on top of the Power Deck™ plug to satisfy the blasting objectives. Refer to **Figures 11 and 12**.

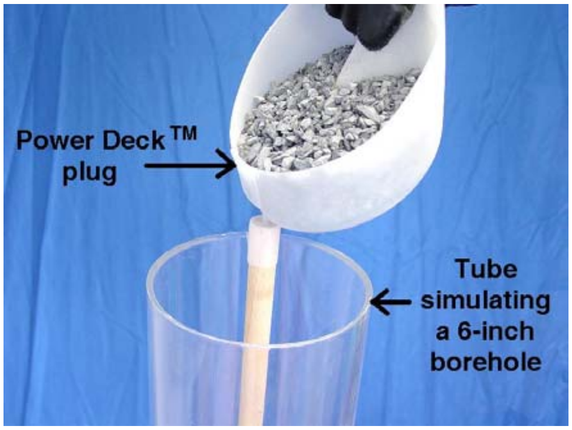

Figure 10 – Power Deck™ plug design and assembly prior to loading in a borehole.

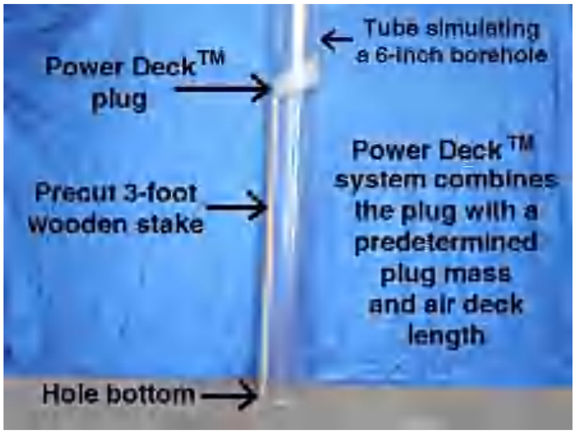

Figure 11 – Power Deck™ plug when dropped down a borehole. A precut 3-foot wooden stake in conjunction with the Power Deck™ plug design holds the assembly in place.

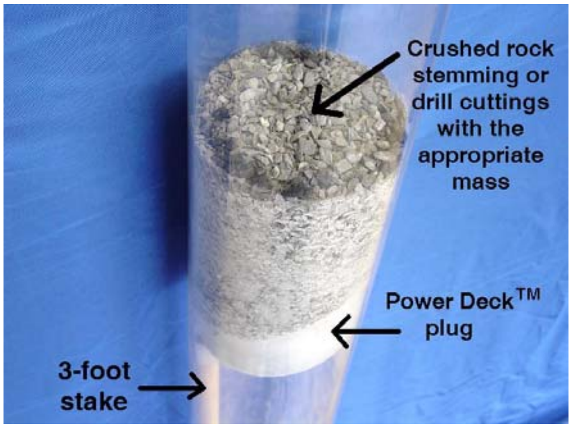

Figure 12 - An appropriate amount of stemming mass (drill cuttings or crushed rock) is placed on top of the plug prior to explosives loading. The stemming mass is selected based on the blasting objectives and how much pressure or KE is required at the hole bottom.

What happens at the bottom of a hole with the Power Deck™ system can be explained in terms of the pressure and/or Kinetic Energy. When an explosive detonates in a borehole, the high temperature by-products of the detonation will always take the path of least resistance. The bottom hole air deck will first be subjected to an intense shock wave traveling through it. When the initial shock wave front hits the bottom of the hole, the shock wave speed decreases, reflects from the hole bottom and increases the pressure at that point. At this instant of time, a separate secondary impact from the explosion products adds another impulse to the bottom of the hole. The combined effect is that the resulting pressure P_2 at the hole bottom can be increased from 2 to 7 times relative the initial pressure, P_1. . Refer to **Figure 13**. The increased point source pressure is sufficient to create a planar split and fragmentation at the hole bottom. In essence, the sum of the primary shock wave energy and secondary explosion products are much more efficient than a concentrated continuous cylindrical charge at the hole bottom, but only when the bottom hole air deck length and Power Deck™ plug mass are properly designed for the given field conditions and explosives system.

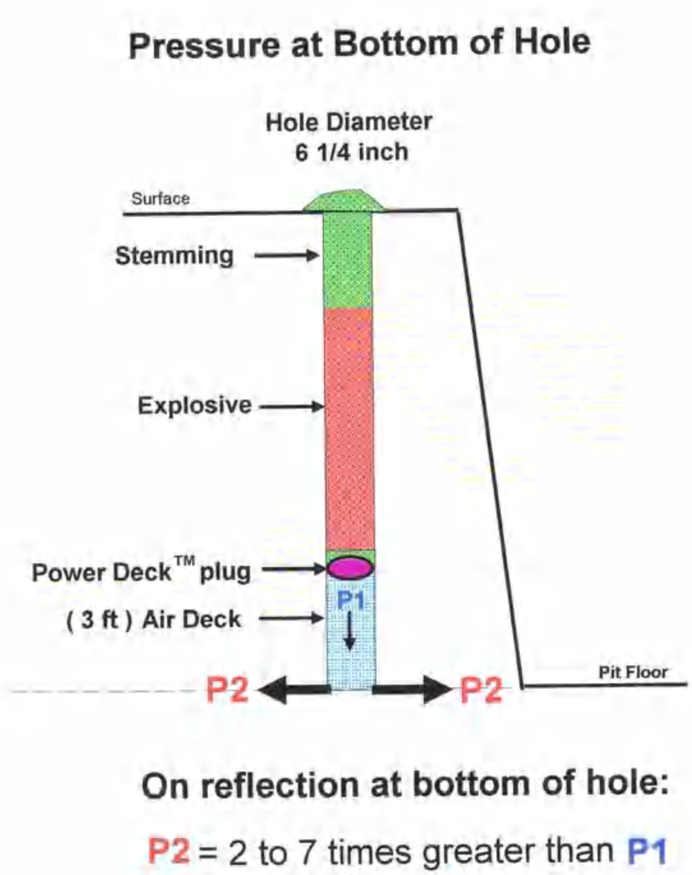

Figure 13 – Pressure increase illustration of what happens at the bottom of a borehole with an air deck.

When non-electric shock tube was first introduced into the industry in the 1970's, the same mechanisms in the air gap effect caused the crimp end of the shock tube which was adjacent to the detonator to blow out, causing premature detonations on many shots. Here the side blowouts bypassed the delay element by prematurely detonating the primer. Today this problem is non-existent, but the failure mechanism in the early years was identical to the effects which occur in a bottom hole air deck. Refer to **Figure 14**.

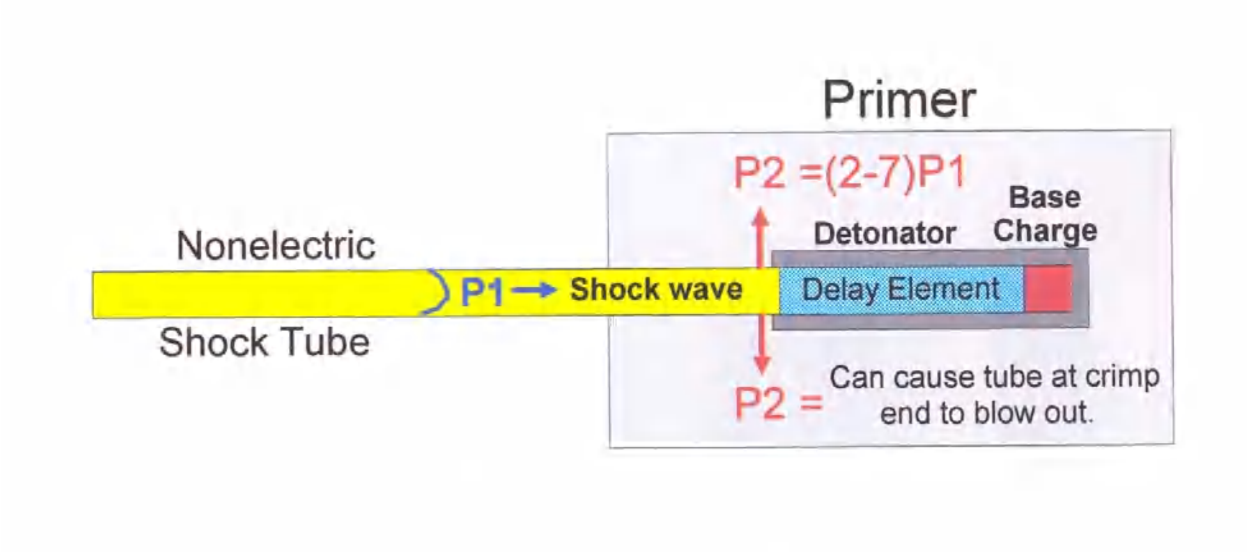

Figure 14 – Pressure increase illustration of what happens at the crimp end or at the shock tube/detonator interface for early nonelectric shock tube systems. The failure mechanisms are similar to what happens in a bottom hole air deck.

Another way to look at this phenomena is in terms of the KE (Kinetic Energy) which is imparted at the hole bottom. Refer to **Figure 15**. The KE can be calculated by measuring the mass of the stemming which is placed on top of the Power Deck™ plug and by measuring its velocity through the bottom hole air deck. This is why it was important to have drilled the small intersecting face hole in the single hole tests, which allowed measurement of the shock front velocity through the bottom hole air deck. The KE at the hole bottom can be in the order of 50 to over 100 times greater with the correct selection of the Power Deck™ plug mass and correct air deck length.

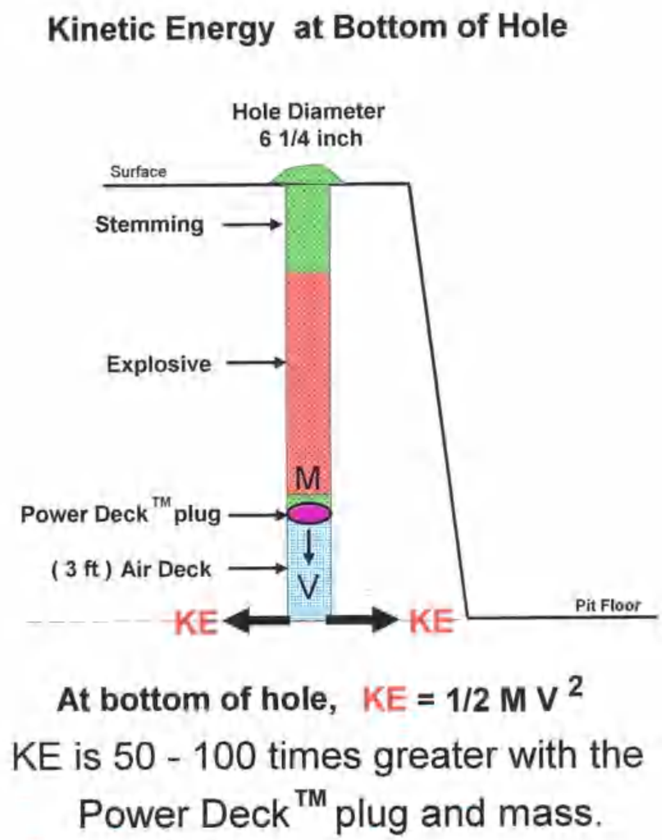

Figure 15 – Kinetic Energy increase illustration of what happens at the bottom of a borehole with an air deck.

Because this new air deck blasting technique allows one to vary and control the intensity of the pressure or KE at the hole bottom as needed, it can be used in very soft to very hard rocks, including steeply dipping formations. To date, the Power Deck™ system has been used all over the world in a variety of diverse field conditions with over a 95% success rate. The proper Power Deck™ plug mass and air deck length is dependent on the type of explosive, borehole diameter and rock strength. Failure to select the correct design parameters can lead to very poor blast results, and thus a representative to advise with the initial starting design selection is highly recommended. Once correctly implemented, the system can reap tremendous financial benefits, as many users worldwide have already realized.

Conclusions

1. No significant differences were found with the single hole characterization tests in terms of the fragmentation, muckpile throw and breakage at the toes or at the collars. But the two single holes with the single and double air decks achieved the same results with no subgrade and with 17 to 25% less explosives, respectively. This implies that both air deck loaded holes with less explosives and no subgrade were considerably more efficient than a continuous column of more explosives with subgrade.

2. In reference to the Normal and Power Deck™ full-scale blasts, the Power Deck™ shot resulted in 33% less vibrations at all of the monitored locations from 200 to 2,000 feet away. This reduction allows mine operators to maintain a higher compliance safety margin or allows larger quantities of explosive per delay while maintaining the same vibration level. In other parts of the world, ground vibrations were successfully reduced from 10 to 75%.

3. In reference to the fragmentation, the Power Deck™ shot resulted in a 21 to 25% improvement between the P20 to P80 cumulative percent passing sizes. This can result in substantial savings in utility costs, less wear and tear on the crusher linings and increased throughput. No significant differences were found between the two full-scale shots in the larger fragment sizes over 24 inches, because this was heavily influenced by the major structural joint systems in the rock mass.

4. In reference to the quarry floor, no significant differences were found between the Normal and Power Deck™ shots. Both shots achieved equivalent flat floors. The muckpile shape and maximum throw distance for both shots were essentially the same. The fact that the Power Deck™ shot used 16% less total explosives and no subgrade drilling (3 to 4 feet less per hole) clearly indicates that the Power Deck™ shot was considerably more efficient than the Normal shot.

5. For a given rock strength, explosive and borehole diameter, the total pressure at the bottom of a hole with an air deck can be controlled with the Power Deck™ system to vary from 2 to 7 times greater than that created by a full column of explosives; but only when the proper plug mass and air deck length are properly calculated. The Kinetic Energy imparted at the bottom of a hole for the same conditions can be varied from approximately 50 to 100 times greater. This allows the new blasting system to be used in very soft to very hard rock formations.

6. Since this series of tests was completed 2 1/2 years ago, mine operators around the world have realized substantial cost savings and productivity gains. Subgrade drilling has either been completely eliminated or substantially reduced, thus lowering the drilling costs and increasing the drill availability. Another significant advantage when eliminating the subgrade is that the collar zone of the next underlying bench remains completely intact. By leaving the collar intact, the risk of flyrock, airblast and dust is proportionately decreased or eliminated, allowing operators to more easily and

confidently comply with any prevailing environmental regulations. Because the subgrade can be eliminated, mine operators can target the bottom hole breakage to a specific mineralization zone (such as in coal) without damaging or diluting it.

7. The Power Deck™ blasting system has been developed for mine operators to reduce ground vibrations, improve fragmentation, eliminate subdrilling and reduce explosive consumption. In one South American mine, the explosive consumption has now been reduced by up to 50% without any significant changes in the overall blast results. But the average explosive reduction is usually between 10 to 40%.

8. Since completion of this field research, the Power Deck™ system has been successfully applied to the bottom, mid column and at the top of the same borehole. Field evaluations are now continuing with the use of multiple air decks within a single explosive column, precise electronic detonators and small strategically placed charges.

Acknowledgements

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