Vibration Reduction Through Production-Signature Hole Blasting

Karl Christopherson, Austin Powder Company

&

Bryan Papillon, Austin Powder Company

Abstract

In order to improve vibrations from quarry blasting, a new technique and timing pattern was established and applied to the particular geology. By shooting a single representative borehole one full second ahead of the production blast, a signature waveform can be isolated and analyzed. Multiple production-signature blasts were performed. Encroaching residences require quarries to adjust their blasting techniques to reduce vibrations and raise frequencies. A signature hole inherently poses problems to quarries. Blasting one single hole from a production bench poses safety issues to wall stability; vibration issues to close neighbors; and budget issues to the quarry operator. Results showed that the new timing pattern reduced vibrations through timing optimization without a loss in quarry production. Therefore, this technique of vibration analysis employing a production-signature hole is successful in creating a timing pattern that meets the quarry’s goals.
Introduction

The proper blast pattern timing can significantly reduce blast-induced ground vibrations. A signature hole was necessary to improve the timing relationship between blastholes. In a competitive quarry market there often is not room in the quarry manager’s budget or time to perform a signature hole analysis. Other concerns arise when a signature hole is shot: future wall competence, loss in quarry production for a single-hole blast, and creation of unnecessary vibrations. This research was performed to eliminate these negative aspects of a signature-hole blast.

The material blasted consisted of a 2.2 g/cc density Georgetown limestone. Multiple blasts were performed using a signature hole to precede the production blast. For this bench, it was discovered that one full second between the signature hole and production blast would provide enough time to create an isolated signature waveform. This waveform could then be analyzed for timing optimization.

Multiple "production signature-hole blasts" were executed to determine the optimum timing for electronic detonation. It was observed that highwall competence was maintained throughout field trials. In addition, muckpile fragmentation was consistent and quarry production unceasing. Vibrations and frequencies from the field trial blasts were within the range of previous production blasts. Signature-hole blasts went unnoticed among production blasts. After field trials, a significant reduction in ground vibrations and an increase in peak and dominant frequencies resulted from the new timing.

Methodology

Field trials were conducted to minimize the blast-induced ground vibrations. For the isolation of the signature vibration, a 500 millisecond (ms) stagger was created between the representative hole and the production blast. This was labeled Field Trial #1 (FT1). The permanent seismograph location was approximately 1300 ft (396 m) from the blast. The signature waveform produced was indistinct from the remainder of the blast. To keep results consistent, this permanent seismograph location remained unchanged in the following trials. Therefore, the stagger interval between the signature hole and production blast was increased to 1000 ms for Field Trials #2 - #4 (FT2 – FT4). Figure 1 shows the blast pattern for FT4.

![Figure 1: Blast pattern showing delay timing per blast hole](image-url)
The blasthole design was consistent for the signature hole and production holes. Blastholes were laid out on a square pattern consisting of 14 ft (4.3 m) burden and 16 ft (4.9 m) spacing. The quarry design contract required a stone deck separation between explosive decks to split the column and reduce the explosive load. The 5.5 inch (14 cm) blastholes were loaded with an explosive deck of 25 ft (7.6 m) ANFO, with a 5 ft (1.5 m) separation deck of crushed stone, another explosives deck of 25 ft (7.6 m) ANFO, followed by 7 ft (2.1 m) of crushed stone for stemming. Figure 2 displays this blasthole design. A 10 ms interval was used for inter-deck delay timing. The representative hole is double-charged but will produce a signature waveform with which to optimize the blast design.

Figure 2: Blasthole Load
Post-blast analysis was performed using proprietary signature analysis techniques. Candidates for optimum timing from all three blasts were discovered. Inter row timing was chosen to be a simple multiple of the inter hole delay timing. Iteration of blasthole initiation was necessary due to significantly higher vibration results found when pulses overlapped. Rises in velocity occur within two ms of an optimum timing candidate. Therefore, it was determined to duplicate the optimum timing. The 14 ms timing was used in conjunction with a 10 ms inter-deck delay, replicating the signature-hole timing relationship. Figure 3 displays this new timing.

Figure 3: Blast pattern showing signature timing per blast hole
Results

FT1 consisted of a 500 ms stagger between the signature hole and production blast. A distinct waveform was not created and the test results were discarded. FT2-4 consisted of 1000 ms staggars, and were successful in creating distinct signature waveforms. Figure 4 shows an example of the isolated waveform from FT2.

Table 1 displays results from all field trials.

Table 1: Blast results from field trials

<table>
<thead>
<tr>
<th>Shot Name</th>
<th>Date</th>
<th>PPV in/s (mm/s)</th>
<th>Frequency (Hz)</th>
<th>Distance ft (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT1</td>
<td>11/29/2006</td>
<td>N/A</td>
<td>N/A</td>
<td>1265 (386)</td>
</tr>
<tr>
<td>FT2</td>
<td>12/7/06</td>
<td>0.17 (4.32)</td>
<td>24.3</td>
<td>1287 (393)</td>
</tr>
<tr>
<td>FT3</td>
<td>12/19/06</td>
<td>0.145 (3.68)</td>
<td>25.6</td>
<td>1307 (398)</td>
</tr>
<tr>
<td>FT4</td>
<td>1/8/07</td>
<td>0.15 (3.81)</td>
<td>15.5</td>
<td>1295 (395)</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>0.155 (3.94)</td>
<td>22</td>
<td>1289 (393)</td>
</tr>
</tbody>
</table>
Blasts using electronic detonators, on a typical pyrotechnic pattern, were monitored for three months prior to the signature field trials. The pyrotechnic timing pattern consisted of an inter-hole timing of 42 ms and an inter-row timing of 67 ms. Peak particle velocity (ppv) and the frequency associated with the ppv are the two most important blast characteristics to a community monitoring program. All frequency measurements in results refer to this frequency connected to ppv, also known as the zero-cross frequency. These are two of the characteristics we will examine. Table 2 displays these blast results prior to field trials.

Optimum timing for the geology in question was found to be 24 ms inter-hole with 96 ms inter-row. Timing was implemented immediately following the trial blasts. Blast results with new timing are displayed in Table 3. Frequency shown is the zero-cross frequency recorded with the ppv.

Comparison of all blasts is displayed in a log-log plot of peak particle velocity (in/sec) versus the frequency associated with the ppv in Figure 5. As Figure 5 shows, blasts with the new timing were higher in frequency and lower in velocity than all previous blasts. Determining whether the field trials and resultant timing were successful was accomplished by comparing blast results and lbs explosive used. Referring to Table 2, blasts previous to field trials carried an average ppv of 0.15 in/s (3.89 mm/s) with a 21.2 Hz frequency, and used 9478 lbs (4299 kg) per blast with a 318 lb/delay (144 kg/delay) average. Referring to Table 3, blasts using the optimum timing carried an average ppv of 0.065 in/s.
(1.65 mm/s) with a 30.9 Hz frequency, and used 11725 lbs (5318 kg) per blast with a 641 lb/delay (291 kg) average. Post-trial blasts used more than twice the explosive lb/delay as pre-trial blasts with lower ppvs and higher frequencies. Powder factor and column loading remained the same.

Multiple blasts after the field trials were shot within the same range of the monitor as blasts prior to trials, 1400 – 1500 ft (427 m – 457 m) range. Quarry production plans designed the top bench advance away from the sensitive area, extending the monitor range to 1800 ft (549 m). When lengthened to 1800+ ft (550+ m), the average ppv predictably drops in half, but the frequency stays high. All frequencies decay with distance, but over a change of 300+ ft (91+ m) the dominant frequencies do not significantly change. Therefore, the signature timing produced higher dominant frequencies at greater distances which are less disturbing to structures and residents.

A case-by-case study shows success at similar pre- and post-field trial monitor distances:

For the monitor distance of 1453 ft (443 m) prior to field trials, the blast created a ppv of 0.16 in/s (4.06 mm/s), and a peak frequency of 25.6 Hz, using 272 lb/delay (124 kg/delay) with a total lb/blast of 13398 (6077 kg). At a monitor distance of 1466 ft (447 m) after field trials, the signature timing brought the

Figure 5: Comparison of all blasts
ppv down to 0.09 in/s (2.29 mm/s) with the same peak frequency of 25.6 Hz, using a higher lb/delay of 430 (195 kg/delay) with a total lb/blast of 12041 (5462 kg).

A monitor distance of 1561 ft (476 m) prior to field trials produced a ppv of 0.135 in/s (3.43 mm/s) with a peak frequency of 22.2 Hz, using 291 lb/delay (132 kg/delay) with a total lb/blast of 8731 (3960 kg). At a monitor distance of 1557 ft (475 m), the signature timing brought the ppv down to 0.04 in/s (1.02 mm/s) with a peak frequency of 46.5 Hz, using a higher lb/delay of 948 (430 kg/delay) and a total lb/blast of 11370 (5157 kg).

Monitor distance prior to field trials of 1288 ft (393 m) produced 0.140 in/s (3.56 mm/s) ppv, 21.3 Hz, with 323 lb/delay (147 kg/delay) and total lb/blast of 8162 (3702 kg). A monitor distance of 1301 ft (397 m) and after signature timing, ppv was 0.145 in/s (3.68 mm/s) with a higher peak frequency of 25.6 Hz, with 484 lb/delay (219 kg/delay) and total lb/blast of 10636 (4824 kg).

The production – signature hole blasting created the optimum timing for the geology without a halt in production or outside consultation. For all blasts post-trials, lbs/delay (kg/delay) was raised utilizing the signature timing. Assuming a consistent powder factor, more holes can be blasted within the old blast timing duration. This gives the quarry operator an opportunity to safely and comfortably shoot more holes near residential structures. This technique also provides the potential for an ongoing timing review within a quarry’s production blasting schedule.

**Conclusions**

The following conclusions were found:

- Production – signature hole blasting and analysis provided the optimum electronic timing while maintaining the high level of quarry production.
- Post-trial blast vibrations were reduced on average and frequencies were raised.
- For all blasts utilizing the signature timing, lbs/delay (kg/delay) was raised therefore creating an opportunity to raise total lbs/blast (kg/blast).
- This new technique provides the potential for an ongoing timing review within a quarry’s production blasting schedule.
- The field trial blasts produced vibrations and frequencies on par with previous blasting. This conclusion shows that the production-signature blasting was successful because the multiple signature-holes trials went unnoticed.
References


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