Correlation of Highwall Damage, Muckpile Fragmentation, and Ground Vibrations North Antelope Rochelle Coal Mine,

North Antelope Rochelle Coal Mine
Powder River Basin, Wyoming

Four coal mining cast-blasts, as shown in Figure 1, using electronic and one non-electric (NE) initiation systems were studied at the North Antelope Rochelle Coal Mine in the Powder River Basin, WY. The purpose of this study was to evaluate the effects of spacing delay timing and blast-induced vibrations on highwall damage and muckpile fragmentation. The nominal burden timing of 400 ms was not significantly changed in this study.

Fig. 1 Typical cast blast shot.

Ground vibrations, detonation pressure and velocity, highwall damage, fragmentation, swell and face velocity, and rock mass characteristics were measured for each blast. Analyses were made to determine correlations among ground velocities and displacements, delay timing, damage, and fragmentation. Electronic spacing timings used in the shots were 12 ms, 17 ms (both electronic and non-electric), and 40 ms.

The location, aperture, and number of tensile cracks formed behind the newly-created highwalls were measured. In addition, muckpile fragmentation and cumulative size distributions were determined. Figure 2 shows examples of cracking formed behind the new highwall and typical muckpile fragmentation.

Fig. 2 Backbreak (left) and muckpile fragmentation (right)

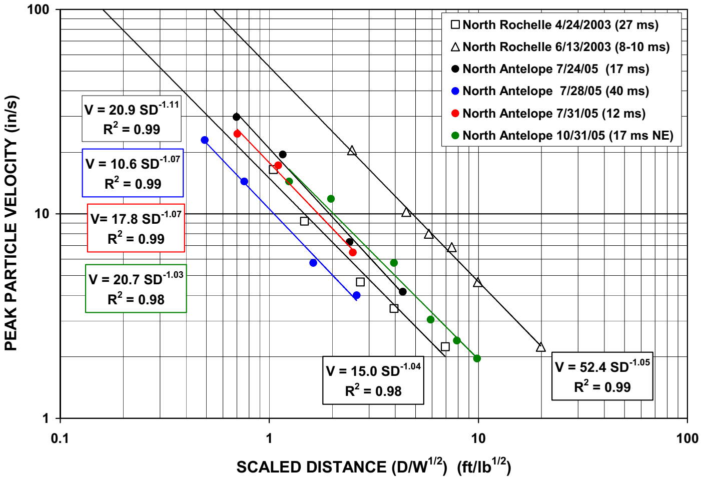
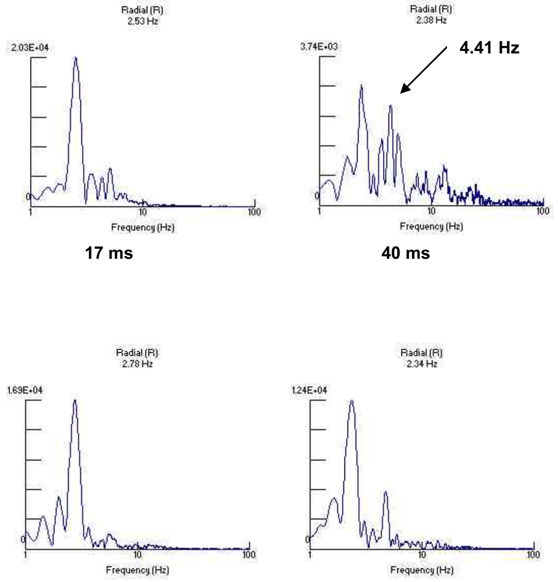


Fig. 3 Attenuation plot showing best-fit lines for North Antelope in comparison with data from North Rochelle Mines



17 ms 40 ms

12 ms 17 ms (NE)

Fig. 4 Dominant frequencies for each shot spacing delay timing at a 75 ft nominal distance behind the last row of blastholes

Results

Vibration attenuation

Figure 3 show the attenuation plots of the North Antelope data plotted in comparison with data from a previous study conducted at the North Rochelle mine (Ehlers, 2003) measured behind the last row of blastholes at similar distances from the shot point of initiation. Attenuation line best fits are provided for various spacing delay timing. In general, as spacing delay timing decreased, velocity K-factors increased, assuming that the 12 ms and 17 ms timing (for the North Antelope) behave in a similar manner. The lowest vibrations generated behind the shots were measured for 27 and 40 ms spacing timings and was independent of burden timing.

Figure 4 shows FFT plots of frequency content for the radial component to illustrate the effect of shifting low frequency amplitudes to a higher frequency range by slowing the spacing timing to 40 ms.

Damage behind the highwall

The location, width (aperture), and frequency (number) of tension cracks formed behind the crest of the new highwall constitute “damage”. The analysis of the combined measurements is difficult, as evidenced by literature review of blast “damage”, and cannot be attempted without a large number of carefully controlled test blasts. Therefore, frequency was treated separately in this study and provided the best correlation with spacing delay timing. Average tension crack frequencies for each blast measured behind the crest at 200 ft intervals are presented in terms of histograms shown in Figure 5.

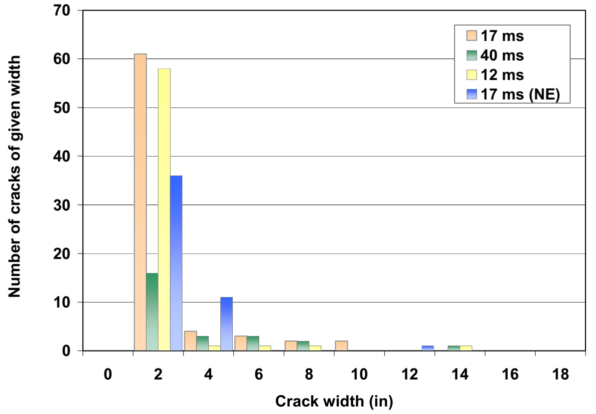


Fig. 5 Frequency plot of crack aperture

The best indicator of “damage” appeared to be the total number of “fine” cracks (e.g., cracks with apertures from 0.25 to 3 in). Using this definition, the blasts with the least densities of fine cracking “damage” behind the highwall were those with the 40 ms electronic and 17 ms NE (non-electric) spacing delays.

Other indicators of damage included the aperture of the single, most pervasive, largest crack behind the new crest, the position of this crack (as a percentage of the drilled burden, B, of 34 ft), and the average intact rock length between cracks, measured perpendicular to the highwall crack (IRL). The following table provides summary statistics for these measurements:

Spacing delay timing (ms)	17	40	12	17 NE
largest crack aperture (in)	24	13	12.5	11
largest crack position (%B)	44	51	31	80
IRL (in)	7.0	7.0	11.4	7.5
no. of “fine” cracks, N	61	16	58	36

Overall, the 40 ms electronic timing, compared with the faster timings of 12 and 17 ms, generated the lowest number of fine cracks and resulting IRL, a largest crack aperture narrower than the 17 ms electronic timing, and its position that was 51 % of the burden behind the new crest (or 17 ft behind the crest), The blast using 17 ms non-electric (NE) timing was judged to possess a similar, low overall highwall “damage” based on similar statistics.

Fragmentation

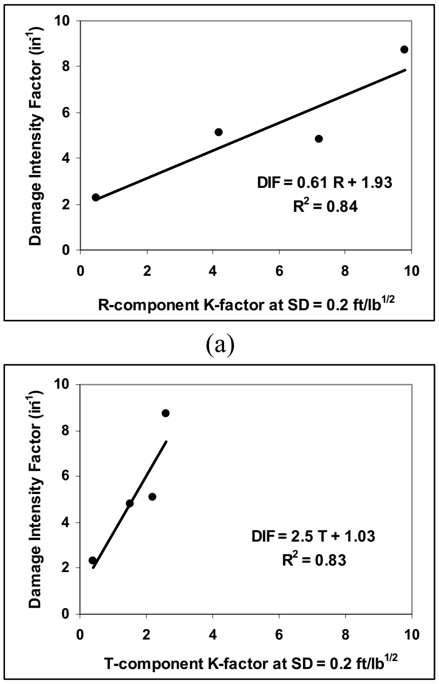
Fragmentation cumulative distribution curves were generated using SPLIT Desktop® for fragments measured at face muckpile positions coincident with highwall crest tension crack measurements. The average sizes for 80% passing (P_{80}) are shown in the table below for all four test shots.

Spacing delay timing (ms)	17	40	12	17 NE
average P_{80} size (in)	12.7	17.1	13.7	13.4
K-intercept at SD=20 (in)				
radial	9.8	0.5	4.2	7.2
transverse	2.6	0.4	2.2	1.5
vertical	1.8	0.3	3.5	3.0

Fragmentation and highwall “damage” are compared in the above table with interpolated values of surface displacements calculated from velocity measurements at equal scaled distance (SD) locations behind the crest of 0.2 ft/lb$^{1/2}$ (or 20 ft from the last row of holes). With respect to delay timing, radial component values (directed into the highwall) correlate with P_{80} fragment sizes, while T component values correlate with the number of “fine” cracks and position of widest cracks for electronic delayed shots.

Damage intensity factor (DIF)

A simplified damage intensity factor (DIF) was defined by a factor $N/IRL_{(ave)}$, or the number of fine cracks divided by the average intact rock length (IRL) between fractures. The higher this factor, the more “damage” was observed along the highwall back. Correlation plots of DIF versus the R- and T-component K-factors at SD = 0.2 ft/lb$^{1/2}$ are shown in Figure 6 indicating the least damage occurred with the slowest spacing delay time of 40 ms.



(a)

(b)

Fig. 6 R- component (a) and (b)T-component K-factor at SD=0.2 ft/lb$^{1/2}$ versus damage intensity factor (DIF)

Laboratory Rock Strength Results

The overburden at the mine site was relatively weak in comparison with other rock types found in the western coal fields. Brazilian tests on seven intact rock specimens of the weakly-bedded shale and mudstone taken from the overburden resulted in an average tensile strength and standard deviation of 240 psi ± 61 psi (± 26%). Compressive wave velocities averaged 7,024 ft/s, while shear wave velocities averaged 4,516 ft/s. Lab test results compare favorably to values for weak shales reported in the literature.

Conclusions Drawn from this Study

- Large transverse (T) and radial (R) displacements measured close-in corresponded with the number of fine tensile cracks (defined as 0.25 to 3 inches in aperture).
- A spacing delay time of 17 ms generated the greatest horizontal displacements and resulted in fine fragmentation and a high measure of damage defined by the number of fine cracks divided by the average intact rock length.
- Fast spacing delay timing (12 and 17 ms) and slow burden delay times (360 and 400 ms) generated low frequency ground motions with predominant frequencies near 2.5 Hz.
- Slowing the spacing timing to 40 ms introduced higher frequency components above 4.4 Hz and reduced close-in ground displacements.
- A spacing timing of 40 ms coupled with a burden timing of 400 ms produced low displacements and minimized highwall tensile crack damage. However, this timing combination produced coarse fragmentation. A spacing-to-burden timing of 17-400 ms minimized fragmentation but resulted in larger close-in displacement and a greater number of fine cracks.

Limitations of this study

Spacing delay timings were selected by mining company personnel and specific design times employed were not done so to optimize blasting efficiency, fragmentation, and highwall “damage”. The burden timing of 400 ms was left unchanged for this study as this timing was thought by mining personnel to achieve optimal casting efficiency. The results of this study therefore do not necessarily reflect optimal blast design and only serve to characterize pre-set blast design parameters.

Acknowledgements

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Reference

Ehlers, R.Z., 2003, *Influences of Detonation Timing on Rock Response and Oxides of Nitrogen (NOx) Formation – North Rochelle Coal Mine Gillette, WY*, MS Thesis, New Mexico Institute of Mining and Technology, Socorro, NM.