Microphone Height Effects on Blast-Induced Air Overpressure Measurements

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ABSTRACT

Blasting Seismographs use microphones to measure air overpressure from blasting. The microphone height above the ground has been the object of some controversy. The current ISEE "Field Practice Guidelines for Blasting Seismographs" specify microphone placement within 1.2 inches of the ground or over 3 feet above the ground. In this study, air overpressure measurements were taken at different height intervals and compared. Blasting seismographs constructed to the ISEE "Performance Standards for Blasting Seismographs" were used to monitor construction, quarry, and coal mine blasting. Near and far field measurements were taken to obtain representative spectral and amplitude ranges. The comparative analysis shows that microphone height has negligible impact on air overpressure measurements.

INTRODUCTION

All blasting seismographs currently measure blast induced ground vibration and air overpressure levels. The accuracy of measurement is dependant on how the unit is constructed and how it is deployed in the field. While operators have no control over construction of the blasting seismographs, they do have control over field deployment.

In 2000, the International Society of Explosives Engineers (ISEE) published two standards that address these two issues:

- "Performance Specifications for Blasting Seismographs"
- "Field Practice Guidelines for Blasting Seismographs"

The first has cemented the accuracy of the blasting seismographs from a mechanical perspective. The second recommends field deployment practices and if followed should result in accurate field measurements.

The field practice guidelines were developed based on the literature available at the time. In particular for air overpressure measurements (airblast) the microphone height recommendation was set at greater than 3 feet or less than 1.2 inches from the ground. These recommendations were based on RI 8508 and ANSI S12.8 and S12.9. This paper explores the impact of microphone height measurements between 1.2 inches and 3 feet by members of the ISEE Blast Vibration and Seismograph Section.

METHODOLOGY

In this study, air overpressure measurements were taken at different height intervals ranging from 0 to 5 feet (0 1.5 m) and compared to each other. Blasting seismograph microphones were used to monitor construction, quarry, and coal mine blasting. Near and far field measurements were taken to obtain representative spectral and amplitude ranges. The comparative analysis will determine if microphone height has an impact on air overpressure measurements. Comparisons are only made between the same blasting seismographs to eliminate any possible differences between microphones of different manufacturers.

WHITE INDUSTRIAL SEISMOLOGY (White) DATA

White Industrial Seismology personnel gathered data from field tests, with the Mini-Seis 1.0M seismographs. These instruments meet or exceed the ISEE Performance Specifications for Blasting Seismographs.

A series of limestone quarry production blasts were monitored using two or three seismographs per blast. The seismographs were placed close together in the field as illustrated in Figure 1. Microphones were place on the ground, one-foot (0.3 m) above the ground and three feet (0.9 m) above the ground. Each unit was setup using varying microphone heights. Various distances were used to obtain a wide range of acoustic levels.

Figure 1. White Microphone Deployment.

Test #1 – August 4, 2003

The distance from the blasting seismographs to the blast was approximately 650 feet (198 meters). The peak acoustic measurements and FFT frequencies are listed in Table 1.

Table 1. White Test 1 Data.

Description	Acoustic Psi x 10^{-5} (Pa) [dB]	Acoustic FFT Frequency (Hz)
3 feet (0.9 m)	2088 (144) [137.1]	2.00
1 feet (0.3 m)	2146 (148) [137.4]	2.00
0 feet (0 m)	2175 (150) [137.5]	2.00

The microphone on the ground had the highest amplitude while the one at 3 feet (0.9 meters) had the lowest amplitude. The overlaid frequency spectra from the microphones at 3 feet (0.9 meters) and 1 foot (0.3 meters) are shown in Figure 2. The spectra are virtually identical. The same is true for the microphone laying on the ground compared to the one at 3 feet (Figure 3). The maximum variance between measurements was only 4 percent or 0.4 dB.

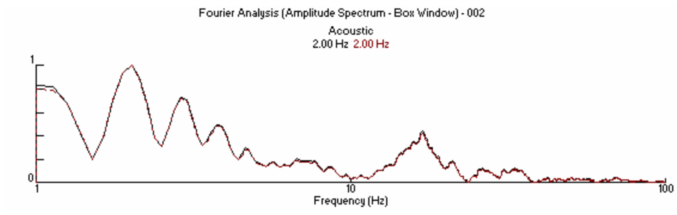

Figure 2. White Test 1 Comparison of 1 and 3 Feet.

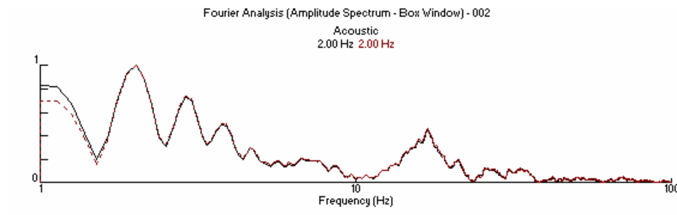

Figure 3. White Test 1 Comparison of 0 and 3 Feet.

Test #2 – August 5, 2003

The distance to the blast was approximately 750 feet (229 meters). The instruments were setup the same as the first test. The acoustic measurements obtained are listed in Table 2.

Table 2. White Test 2 Data.

Description	Acoustic Psi x 10^{-5} (Pa) [dB]	Acoustic FFT Frequency (Hz)
3 feet (0.9 m)	1624 (112) [135.0]	2.00
1 feet (0.3 m)	1682 (116) [135.3]	2.00
0 feet (0 m)	1827 (126) [136.0]	2.00

As in Test #1, the microphone on the ground had the highest amplitude while the one at 3 feet (0.9 meters) had the lowest amplitude. The acoustic measurements from the microphone heights of 3 feet (0.9 meters) and 1 foot (0.9 meters) showed insignificant variances. The microphone laying on the ground, which is within ISEE guidelines, exhibited a 12.5 percent (1.0 dB) increase in the peak overpressure compared to the 3 feet (0.9 meters) microphone height. There was only a 3.6 percent difference between the other two microphones.

The overlaid frequency spectra from the microphones at 3 feet (0.9 meters) and 1 foot (0.3 meters) are shown in Figure 4. The spectra are virtually identical. The same is true for the microphone that was laying on the ground (Figure 5).

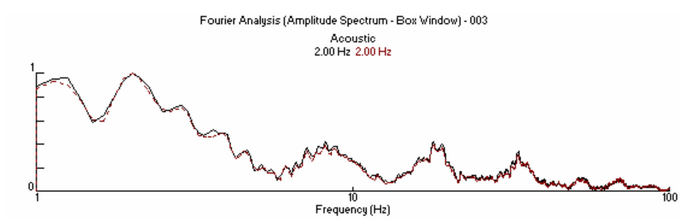

Figure 4. White Test 2 Comparison of 1 and 3 Feet.

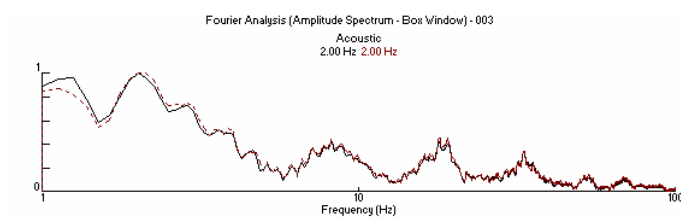

Figure 5. White Test 2 Comparison of 0 and 3 Feet.

Test #3 – August 14, 2003

The distance to the blast was approximately 1600 feet (488 meters). The instruments were setup the same as they were for the first two tests. The measurements obtained are listed in Table 3.

Table 3. White Test 3 Data.

Description	Acoustic Psi x 10^{-5} (Pa) [dB]	Acoustic FFT Frequency (Hz)
3 feet (0.9 m)	841 (58) [129.2]	1.88
1 feet (0.3 m)	870 (60) [129.5]	1.00
0 feet (0 m)	928 (64) [130.1]	1.00

Once again, the microphone on the ground had the highest amplitude while the one at 3 feet (0.9 meters) had the lowest amplitude. The overlaid frequency spectra from the microphones at 3 feet (0.9 meters) and 1 foot (0.3 meters) are shown in Figure 6. The spectra are virtually identical. The same is true for the microphone that was laying on the ground (Figure 7). There was a maximum variance of 10.3 percent (0.9 dB), but only a 3.4 percent difference between the microphones that were off the ground.

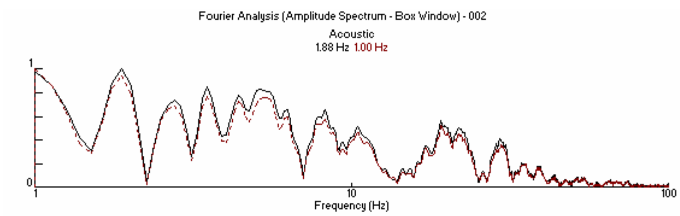

Figure 6. White Test 3 Comparison of 1 and 3 Feet.

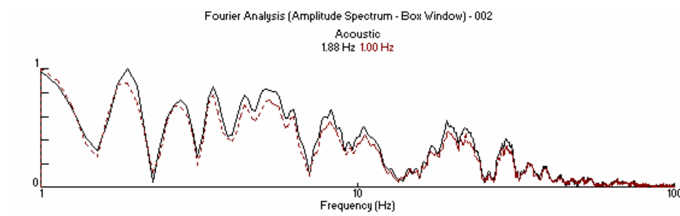

Figure 7. White Test 3 Comparison of 0 and 3 Feet.

Test #4 – August 21, 2003

The distance to the blast was approximately 475 feet (145 meters). The measurements obtained are listed in Table 4.

Table 4. White Test 4 Data.

Description	Acoustic Psi x 10^{-5} (Pa) [dB]	Acoustic FFT Frequency (Hz)
3 feet (0.9 m)	812 (56) [128.9]	1.00
1 feet (0.3 m)	928 (64) [130.1]	1.13
0 feet (0 m)	812 (56) [128.9]	1.00

This time the microphone at 1 foot (0.3 meter) had the highest amplitude. There is a maximum 14 percent (1.2 dB) amplitude difference. As with the previous tests, the overlaid frequency spectra are shown in Figures 8 and 9.

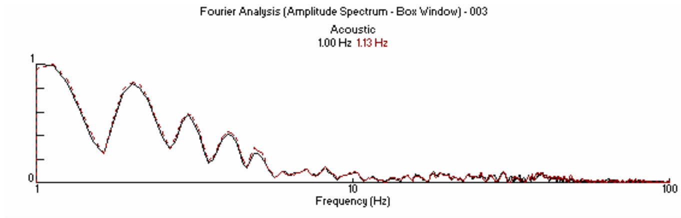

Figure 8. White Test 4 Comparison of 1 and 3 Feet.

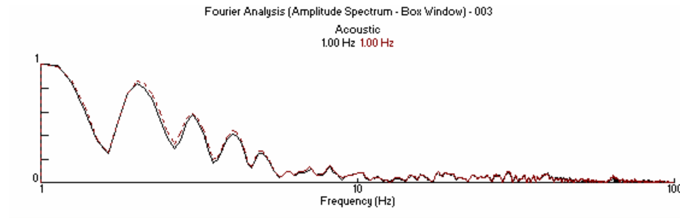

Figure 9. White Test 4 Comparison of 0 and 3 Feet.

Test #5 – September 11, 2003

For the last test, only two instruments were used with microphone heights of 3 feet (0.9 meters) and 1 foot (0.3 meters). The acoustic measurements are listed in Table 5. The overlaid spectra are shown in Figure 10. The measurements are within 9 percent (0.8 dB).

Table 5. White Test 5 data.

Description	Acoustic Psi x 10^{-5} (Pa) [dB]	Acoustic FFT Frequency (Hz)
3 feet (0.9 m)	638 (44) [126.8]	1.00
1 feet (0.3 m)	696 (48) [127.6]	1.00

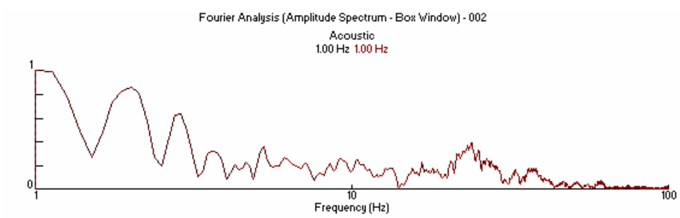

Figure 10. White Test 5 Comparison of 1 and 3 Feet.

With the exception of Test #4, all tests had acoustic variances of no more than 1.0 dB, the ISEE acoustic calibration tolerance. Test #4 had a maximum variance of 1.2 dB. It should be noted that, as with many airblasts from quarry blasting, the dominant FFT frequency was very low. However, there were higher frequency components in the spectra and these overlaid in good agreement as well.

OFFICE OF SURFACE MINING (OSM) DATA

OSM Personnel used 5 SSU Micro-Seismographs manufactured by Geosonics, Inc for the field tests. These instruments contain both the seismic sensors and microphone in one housing and comply with the ISEE Performance Specifications for Blasting Seismographs.

The microphones were placed at intervals of 0" (0 m), 2"(0.1 m), 1'(0.3 m), 3'(0.9m) and 5'(1.5 m) as shown in Figure 11. Construction, quarry and coal mine blasts were measured to obtain a cross section of spectral energy and amplitudes. Tests 1 and 2 were side-by-side comparisons of the microphones for phase and amplitude comparisons as shown in Figure 12. Throughout all the OSM tests, the same microphone was located at the specified height, e.g. Seismograph 4108 was always at 5 feet from the ground.

Figure 11. Typical OSM Setup

Figure 12. Test 1 and 2 Side-By-Side Setup.

Tests 1 and 2 – August 8, 2003

These tests were side by side comparisons to evaluate microphone performance. Test 1 was a coal mine blast and Test 2 was a quarry blast where each test was conducted in front of the free face. Both Test 1 and 2 yielded nearly identical waveforms (Figures 13 and 14), spectral components and amplitudes. The peak amplitudes were less than 5% (0.4 dB) different which is within the allowable tolerance range of the microphone performance standards. This verified that microphones from the same manufacturer respond similarly.

Table 6. OSM Tests 1 and 2.

	Test 1 @ 530' (162 m)		Test 2 @ 750' (229 m)	
Microphone	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**
0 inches	1073 (74) [131.4]	10	551 (38) [125.6]	6
2 inches	1073 (74) [131.4]		551 (38) [125.6]	
1 feet	1131 (78) [131.8]		551 (38) [125.6]	
3 feet	1073 (74) [131.4]		580 (40) [126.0]	
5 feet	1131 (78) [131.4]		551 (38) [125.6]	

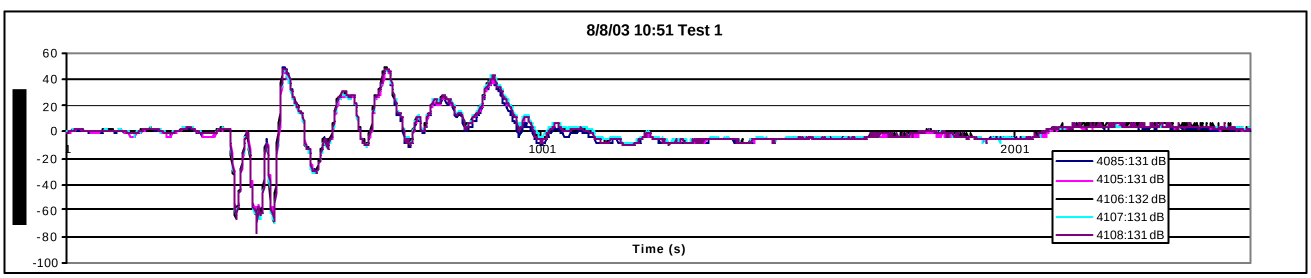

Figure 13. OSM Test 1 Waveform Comparison.

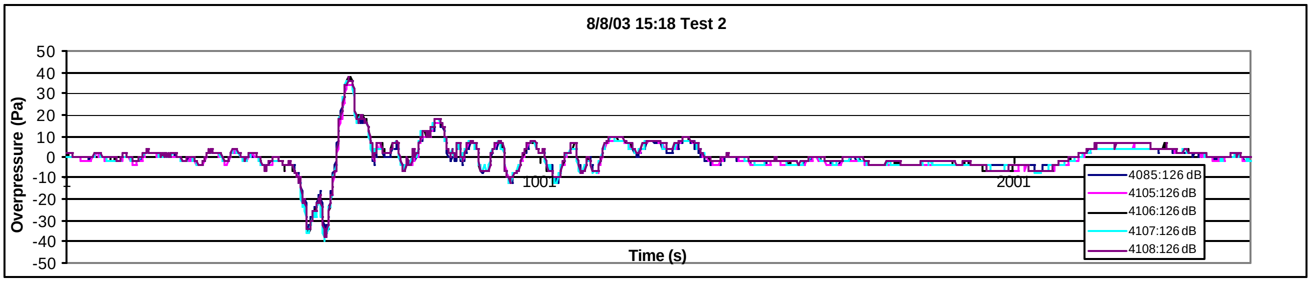

Figure 14. OSM Test 2 Waveform Comparison.

Test 3 and 4 – October 20, 2003
These tests were both at the same coal mine and each hole contained 4 explosive decks. The microphones were placed behind the free face of the blast. The peak amplitudes in Table 7 are nearly identical. The waveforms are also nearly identical as shown in Figures 15 and 16. The high resolution of the graph and low amplitude event result in a "fuzzy" waveform appearance because of the electronic noise in the system. The large roll at the end of Test 4 is probably an echo. Amplitudes for test 4 varied by 10% (0.8 dB).

Test 5 and 6 – October 23, 2004
These trials were at a construction site for the back slope of an access road to a new residential development. Each blast was matted to protect the nearby roadway and the microphones were place in front of the free face. The amplitudes are shown in Table 8 along with the dominant spectral frequencies. Figures 17 and 18 show the overlain waveforms. The amplitudes, waveforms and spectral components are nearly identical. However both low amplitude events do fall below the 10%/1dB criteria because of the pressure levels are near the instrument resolution of 2 Pa.

Table 7. OSM Tests 3 and 4.

	Test 3 @ 460' (140 m)		Test 4 @ 580' (177 m)	
Microphone Height	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**
0 inches	145 (10) [114.0]	2	290 (20) [120.0]	8
2 inches	145 (10) [114.0]		319 (22) [120.8]	
1 feet	145 (10) [114.0]		319 (22) [120.8]	
3 feet	145 (10) [114.0]		290 (20) [120.0]	
5 feet	145 (10) [114.0]		290 (20) [120.0]	

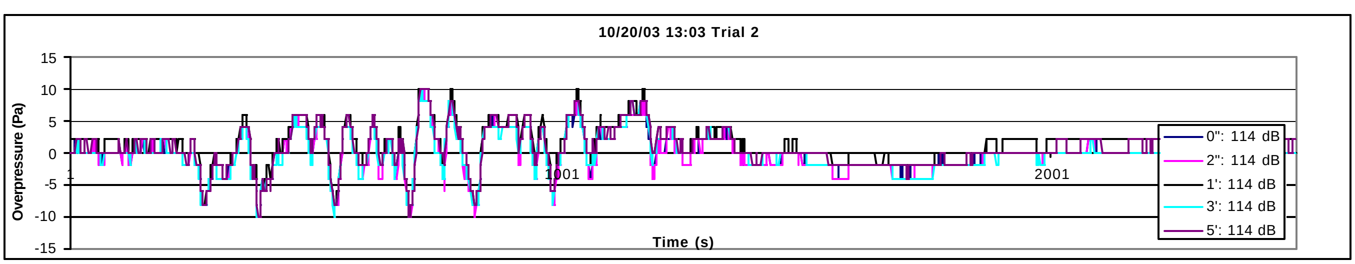

Figure 15. OSM Test 3 Waveform Comparison.

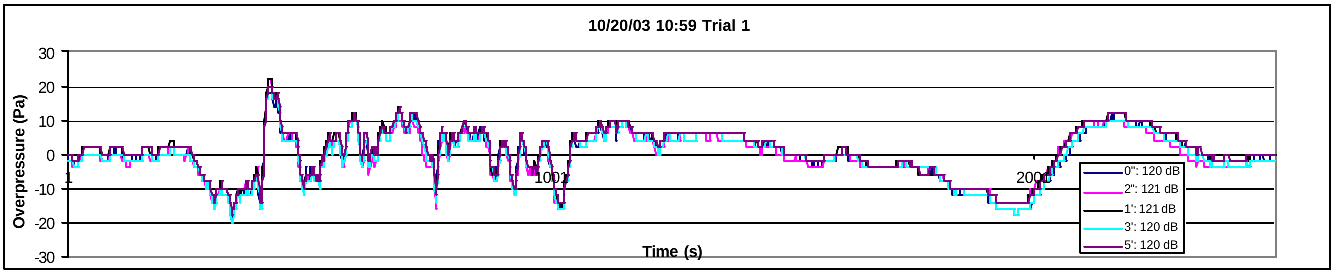

Figure 16. OSM Test 4 Waveform Comparison.

Table 8. OSM Tests 5 and 6.

	Test 5 @ 210' (64 m)		Test 6 @ 220' (67 m)	
Microphone Height	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**
0 inches	203 (14) [116.9]	8	290 (20) [120.0]	4
2 inches	203 (14) [116.9]		261 (18) [119.1]	
1 feet	203 (14) [116.9]		261 (18) [119.1]	
3 feet	174 (12) [115.6]		232 (16) [118.1]	
5 feet	203 (14) [116.9]		232 (16) [118.1]	

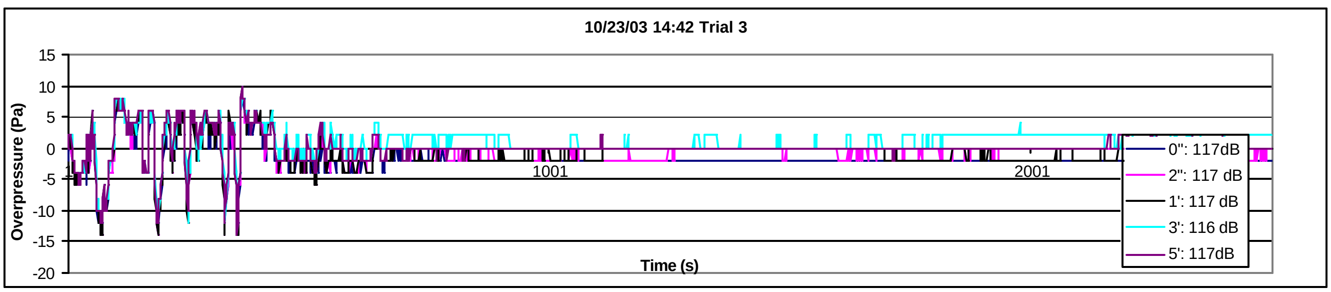

Figure 17. OSM Test 5 Waveform Comparison.

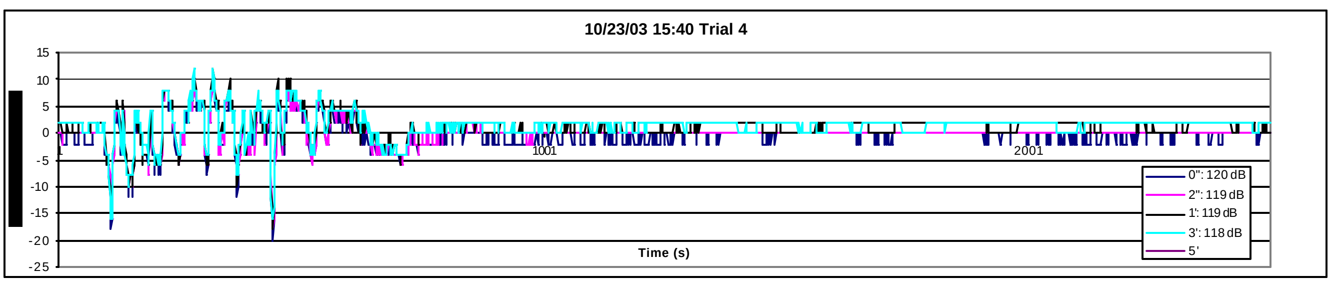

Figure 18. OSM Test 6 Waveform Comparison.

Test 7 and 8 – December 4, 2003

Test 7 was a limestone quarry blast and Test 8 was a coal mine blast. The results are shown in Table 9 and waveform comparisons in Figures 19 and 20. Both tests show a significant difference in waveform appearance for the microphone at 5 feet. This indicates a microphone problem.

The microphones for the limestone blast were placed in front of the free face. The microphone normally placed at 0 inches was placed at 2 inches because of spoil hardness. The range of amplitudes was 24% (1.9 dB), significantly more than previous trials. The two side-by-side microphones had a 12 % difference and the 5' microphone waveform varied from the others indicating an error in the recording. Eliminating the data at 5 feet because of the waveform appearance yields an amplitude range of 15% (1.3 dB). The waveform appearance and spectral energy components of the other measurements were similar.

The microphones for the coal blast (Test 8) were also placed in front of the free face. The range of amplitudes was 15%. Again the microphone waveform at 5' varied from the others indicating some form of error in the recording. Eliminating that data yields an amplitude range of only 9% (0.7dB). The waveform and spectral components were similar.

Table 9. OSM Tests 7 and 8.

	Test 7 @ 600' (183 m)		Test 8 @ 450' (137 m)	
Microphone Height	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**
0 or 2 inches	1350 (90) [133.1]		1073 (74) [131.4]	
2 inches	1160 (80) [132.0]		1015 (70) [130.9]	
1 feet	1376 (88) [132.9]	2	1073 (74) [131.4]	7
3 feet	1334 (92) [133.3]		1102 (76) [131.6]	
5 feet	1073 (74) [131.4]		957 (66) [130.4]	

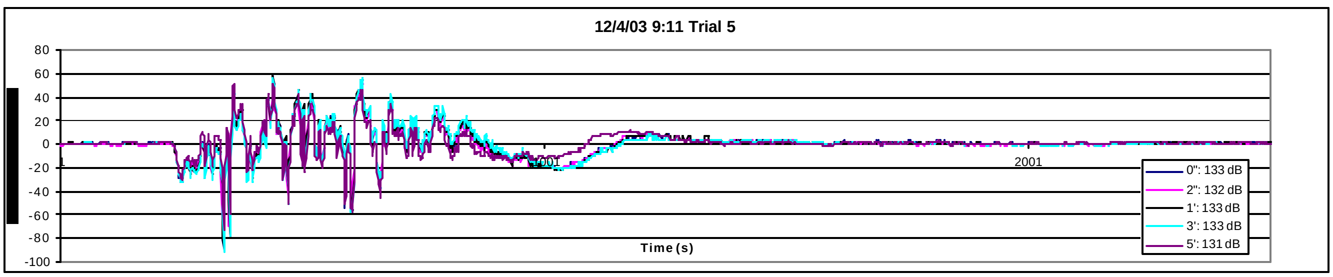

Figure 19. OSM Test 7 Waveform Comparison.

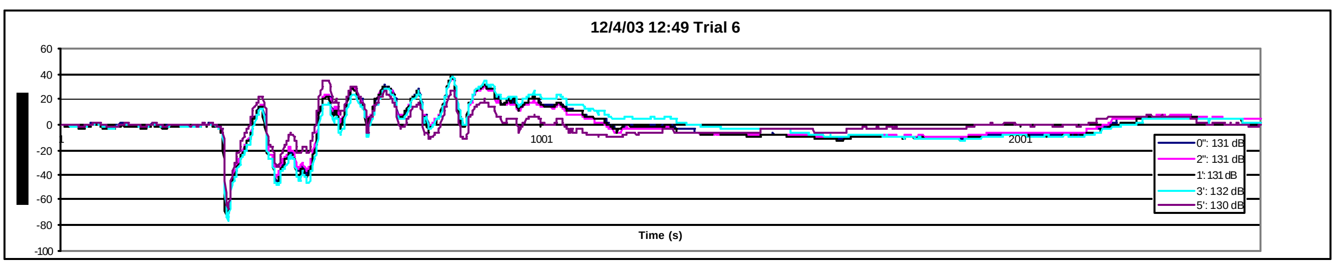

Figure 20. OSM Test 8 Waveform Comparison.

Tests 9 and 10 – March 5, 2004 and August 13, 2004

Test 9 was at a construction site for a typical excavation blast. The microphones were placed behind the free face of the blast. The waveforms are nearly identical as shown in Figure 21. The peak amplitudes in Table 10 show a 13 % (1.1 dB) variance.

Test 10 was a coal mine blast with a blowout in the front face. The microphones were placed in front of the free face of the blast. The waveforms are nearly identical as shown in Figure 22. The peak amplitudes in Table 10 show a 7% (0.6 dB) variance.

Table 10. OSM Tests 9 and 10.

	Test 9 @ 324' (98 m)		Test 10 @ 420' (128 m)	
Microphone Height	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**	**Acoustic Psi x 10^{-5} (Pa) [dB]**	**FFT Frequency Hz**
0 inches	464 (32) [124.1]			
2 inches	435 (30) [123.5]		2233 (154) [137.7]	
1 feet	493 (34) [124.6]	2	2378 (164) [138.3]	2
3 feet			2262 (156) [137.8]	
5 feet			2233 (154) [137.7]	

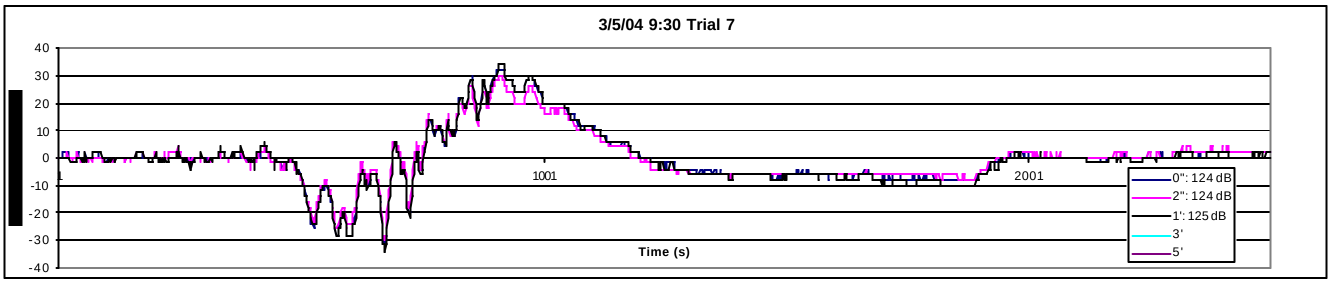

Figure 21. OSM Test 9 Waveform Comparison.

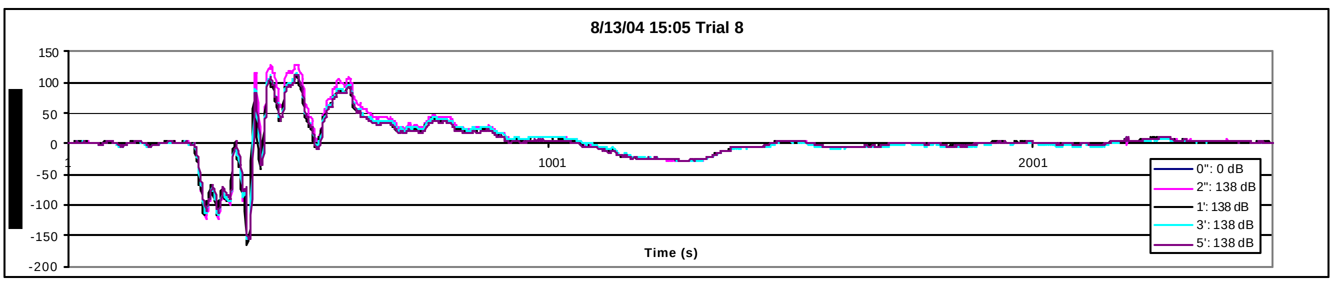

Figure 22. OSM Test 10 Waveform Comparison.

All the OSM recorded events had waveforms and spectral energy that were nearly identical regardless of microphone height. Amplitude variations showed no distinct relation to microphone height and were mostly within allowable tolerance ranges. Low amplitude events tended to have amplitude ranges greater than the tolerances specified by the performance specifications (10%), but this is attributed to the events being near the lower resolution ability of the microphone.

DISCUSSION

A summary of the peak amplitude data obtained in this study is shown in Figure 23. A wide range of measurements were taken (114 to 138 dB). The amplitudes measured from 0 to 5 feet above the ground show relatively straight line relationships that indicate minimal affect from microphone height. While some variation is apparent, no consistent trend, or arcing, of the individual lines exists. This indicates that site specific conditions and/or mounting of the microphones may play a role in consistent recordings. As discussed above, most of the amplitude variances were within the tolerance range of microphone accuracy.

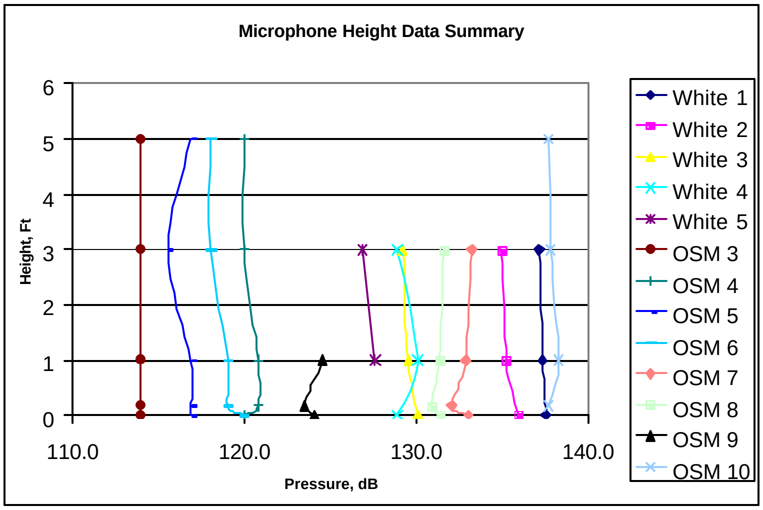

Figure 23. Data Summary of White and OSM Tests.

CONCLUSION

Air overpressure measurements at microphone height intervals from 0 to 5 feet were compared for quarry, coal mine and construction type blasts. Based on the waveforms, amplitudes and spectral energy, the comparative analysis shows that microphone height has negligible impact on air overpressure measurements.

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