Underwater Sound Levels Associated with Driving Steel Piles for the State Route 520 Bridge Replacement and HOV Project Pile Installation Test Program

Prepared By:
Illingworth & Rodkin, Inc.
505 Petaluma Blvd., South
Petaluma, Ca. 94952

Prepared for:
Washington State Department Of Transportation
Office of Air Quality and Noise
15700 Dayton Avenue North, P.O. Box 330310
Seattle, WA 98133-9710

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EXECTIVE SUMMARY

This report presents the results of hydroacoustic monitoring conducted for the State Route 520 Bridge Replacement and HOV Project – Pile Installation Test Program. Data was collected as required by the Test Pile Noise Monitoring Task Order and Noise Monitoring Program Work Plan. The monitoring was conducted over a three-day period in October 2009. A total of 9 steel shell test piles were driven at three locations: four 24-inch piles were installed in Portage Bay, four 30-inch piles were installed north of SR 520 in the area of Foster Island, and one 30-inch pile was driven north of SR 520 between Foster Island and Edgewater Park. There were three different mitigation devices tested to assess their sound reduction properties.

- A confined bubble ring around the pile being driven,
- An unconfined bubble ring consisting of two separate rings.
- A double wall steel casing with one-inch air space and four inches of acoustical insulation.

Along with the hydroacoustic measurements airborne measurements were made at close in locations (10 - 15 meters) and distant locations (125 – 250 meters).

Table 1: Summary Table of Monitoring Results.

Pile	Date	Distance (meters)	Mitigation	Peak (dB)		Single Strike SEL (dB)[4]	Number of Strikes	Range of Reduction (dB)[5]	RMS (dB)[4]
				Range	Average				
Location C - 24-inch Steel Shell Piles With Unconfined Bubble Rings									
PB3	10/26	10m	None	170	157	144	Vibratory	N/A	144
PB1	10/27	12m	On[1]	184 - 190	187	159	77	8-14	170
			Off[1]	195 - 199	198	171			183
PB2[6]	10/27	12m	Off[1]	174 - 183	178	153	60	0-6[7]	165
			On[1]	172 - 181	181	153			165
PB3	10/27	10m	On[1]	154 - 165	161	137	334	22-31	148
			Off[1]	184 - 193	192	165			177
			On[1]	154- 164	161	136			146
			Off[1]	178 - 186	182	155			167
PB4	10/27	10m	Off[1]	172 - 194	190	164	275	24-32	176
			On[1]	157 - 161	160	136			147
			Off[1]	180 - 188	183	157			169
Location B - 30-inch Steel Shell Piles with three different Mitigation Systems									
WAB1	10/29	10m	Off[2]	191 - 196	194	169	410	36-39	182
			On[2]	156 - 162	157	135			150
			Off[2]	195 - 196	196	169			182
WAB2	10/29	13m	Off[1]	191 - 196	193	169	450	29-35	181
			On[1]	158 - 166	161	137			152
			Off[1]	190 - 196	192	165			179
WAB3	10/29	10m	DNAP[3]	181 - 192	186	163	405	9-12[5]	177
WAB4	10/29	13m	Off[2]	189 - 191	188	160	350	32-36	174
			On[2]	158 - 165	161	138			151
			Off[2]	194 - 196	196	172			185

Pile	Date	Distance (meters)	Mitigation	Peak (dB)		Single Strike SEL (dB) [4]	Number of Strikes	Range of Reduction (dB) [5]	RMS (dB) [4]
				Range	Average				
Location A - 30-inch Steel Pile with Unconfined Bubble Ring									
WAB5	10/29	10m	Off[1]	196 - 197	196	176	1,470	18-20	185
			On[1]	173 - 179	176	153			167
			Off[1]	196 - 197	196	174			185
			On[1]	177 - 180	178	153			167
			Off[1]	194 - 196	195	170			182
			Off[1]	195 - 196	196	174			181
			On[1]	175 - 180	177	153			167
			Off[1]	192 - 197	196	173			185

[1] – Unconfined Bubble Rings
[2] – Confined Bubble Ring
[3] - DNAP (Double Walled Noise Attenuation Pile)
[4] – Average Levels
[5] – Average reduction is based on the baseline pile (196 dB Peak) for pile where the DNAP was tested. All other piles the average reduction is from the same pile with the bubble curtain fully on and compared to the bubble curtain fully off.
[6] – The Bubble Rings were never fully in use due to problems controlling the airflow.
[7] – Not enough data points to be statistically valid.

On October 27, 2009 when the unconfined bubble ring was first used there were some problems with the compressors and the manifold system during the first two piles driven. The piles were driven for approximately two minutes, which did not give the crew enough time to adjust the operation. By the time the third pile was driven most of the problems had been resolved and the bubble rings became more effective. During the first two piles driven the noise levels were reduced by 3 – 11 dB and during the driving of the last two piles the reduction was 31 dB.

On October 29 the compressors and manifold worked properly for both the confined bubble ring and the unconfined bubble rings while driving at Locations B and C. The reduction with the confined bubble rings ranged from 30-35 dB and the reduction with the unconfined bubble rings ranged from 19-35 dB.

The DNAP noise reduction system was difficult and time consuming to use and was substantially less effective in reducing the noise from the pile driving. Reduction ranged from 4 – 8 dB

1.0 INTRODUCTION

This technical report presents results of underwater sound levels measured during the impact driving of four 24-inch and five 30-inch steel shell piles and the vibratory installation of one 24-inch steel shell pile at the SR 520 bridge replacement project in October of 2009.

The piles were driven at three different locations and measurements from the impact driving were made at 10 meters, 200 meters, and 500 meters for each location. Three different mitigation methods were used during the driving of the piles, unconfined bubble rings, confined bubble ring, and Doubled Walled Noise Attenuation Pile (DNAP). The bubble rings were tested with on/off cycles during each pile driving events, except on the one pile where the DNAP was tested. Results from this are discussed in the data presentation section (Section 6.2.2). The sound level from vibratory installation of one pile (PB-3) was measured at Location C. Results from this are discussed in the data presentation section (Section 6.2.1). Figure 1 shows the project area and the location of monitored piles.

Figure 1: ***Project Location***

Additionally, airborne noise levels were measured at a two locations each day. On the first day a noise shroud was used on the pile driver to test the noise reduction at a distant location. Measurements were made on the barge and at the closest receiver locations to the pile driving location. Exact measurement locations are shown in Figures 2, 3, and 4.

2.0 PROJECT DESCRIPTION

2.1 Test Pile Noise Monitoring Project.

State Route 520 Bridge Replacement and HOV Project – Pile Installation Test Program is designed to assess the different mitigation measures to reduce the noise impact from pile driving. The project consisted of driving piles in three locations. Figures 2, 3, and 4 show the exact locations where the pile sets were driven and the measurement locations. Different sized piles were driven, four 24 inch diameter steel shell piles were driven at Location C and a total of five 30 inch diameter steel shell piles were driven at Locations A and B. Three different noise attenuation systems were evaluated. Two consisted of bubble rings, one confined in a steel casing and one unconfined. The third system consisted of an outer steel casing with a one-inch air space and four inches of insulation and a inner steel casing all sealed together. This system is referred to as the DNAP system.

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Figure 3: Location B Measurement Sites

Figure 4: Location C Measurement Sites

3.0 UNDERWATER SOUND LEVELS

3.1 Characteristics of Underwater Noise

When a pile driving hammer strikes a pile a pressure pulse is created which propagates through the pile and radiates sound into the water and the ground substrate as well as the air. A plot of a sound pressure pulse as a function of time is referred to as the waveform. The peak pressure is the highest absolute value of the measured waveform, and can be a negative or positive pressure peak. The RMS level is determined by analyzing the waveform and computing the average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy.[1] This RMS term is described as $RMS_{90\%}$ in this report. This has been approximated in the field for pile driving sounds by measuring the signal with a precision sound level meter set to the "impulse" RMS setting ($RMS_{impulse}$). Another measure of the pressure waveform that can be used to describe the pulse is the sound energy itself. The total sound energy in the pulse is referred to in many ways, such as the "total energy flux"[2]. The "total energy flux" is equivalent to the un-weighted sound exposure level (SEL) for a plane wave propagating in a free field, a common unit of sound energy used in airborne acoustics to describe short-duration events. The unit is dB re 1µPa^2-sec. In this report, peak pressures and RMS sound pressure levels are expressed in dB re 1 µPa; however, in other literature they can take other forms such as a Pascal or pounds per square inch. The total sound energy in an impulse accumulates over the duration of that impulse. How rapidly the energy accumulates may be significant in assessing the potential effects of impulses on fish. Chapter 9 includes the definitions of terms commonly used to describe underwater sounds.

Researchers have indicated that high peak pressures along with the rate of change (i.e., rise time) are important considerations in assessing potential biological impacts (i.e., injury or mortality)[3]. Descriptors such as the peak pressure, $RMS_{90\%}$, and SEL are useful descriptors in describing the magnitude of these impulses. None of these descriptors adequately account for the effect of rise time for pile driving impulses. The peak pressure only refers to the magnitude of maximum pressure fluctuation, which may be only one factor causing damage. The RMS averaged over 90% of the impulse includes averaging over a relatively long period of the impulse where the pressure fluctuation is much lower. For instance, about 50% of the energy from a typical pile driving impulse accumulates in less than a quarter of the time that 90% of the energy accumulates. The SEL or "total energy flux" is basically normalized to one second and, therefore, is not as useful for discerning differences in impulses where the majority of the energy occurs within 1/10th of a second. However, SEL is useful to researchers in assessing impacts to animals. The pressure waveforms show the individual characteristics of these strikes; however, it is difficult to identify any meaningful differences in the impulses. Studying the waveforms can provide an indication of rise time; however, rise time differences are not clearly apparent due to the numerous rapid fluctuations that are characteristic to this type of impulse. A plot showing the accumulated sound energy over the duration of the impulse (or at least the portion where

[1] Richardson, Greene, Malone & Thomson, *Marine Mammals and Noise,* Academic Press, 1995 and Greene, personal communication.
[2] Finerran, et. al., *Temporary Shift in Masked Hearing Thresholds in Odontocetes after Exposure to Single Underwater Impulses from a Seismic Watergun*, Journal of the Acoustical Society of America, June 2002.
[3] Wardle, et.al. *Effects of Seismic Air Guns on Marine Fish*. Continental Shelf Research 21 (2001) 1005-1027. Pergamon. June 21, 2000.

much of the energy accumulates) appears to be the best available tool to illustrate the differences in source strength and rise time. An example of the characteristics of a typical pile driving pulse is shown in Figure 17.

The Fisheries Hydroacoustic Working Group (FHWG) representing the National Oceanic and Atmospheric Administration-National Marine Fisheries Service (NOAA Fisheries), U.S. Fish and Wildlife Service, California/Washington/Oregon Departments of Transportation, California Department of Fish and Game, and the U.S. Federal Highway Administration reached an "Agreement in Principle" for interim criteria for injury to fish from pile driving activities. The agreed-upon criteria "identify sound pressure levels of 206 dB peak and 187 dB accumulated sound exposure level (SEL) for all listed fish except those that are less than 2 grams, in that case, the criteria for the accumulated SEL would be 183 dB. In an effort to develop data with respect to these criteria, the accumulated peak pressure and sound exposure level were measured.

4.0 METHODOLOGY

4.1 Measurement Positions

Hydroacoustic measurements were made at three different positions at each location. One of the measurement positions was unattended, at distances of 200 meters at location C and 500 meters at Locations A and B. One of the positions, the near position, was located on the contractor's barge 10-13 meters from the pile Measurements were typically made at one mid-water depth. The Water depth ranged from about 3 meters (10 feet) to 7 meters (23 feet). All measurement positions reported are approximate due to fluctuations caused by weather conditions.

4.2 Measurement Equipment

Measurements were made using Reson TC4013 and TC-4033 hydrophones with PCB in-line charge amplifiers (Model 422E13) and PCB Multi-Gain Signal Conditioners (Model 480M122). The signals were fed into Larson Davis Model 820 Integrating Sound Level Meters (SLM) and Marantz Model PMD 660 Solid State Recorders (Figure 5). The multi-gain signal conditioner provided the ability to increase the signal strength (i.e., add gain) so that measurements are made within the dynamic range of the instruments used to analyze the signals.

The peak pressure and sound exposure levels (SEL) were measured "live" using the SLM's, the root-mean square average sound pressure levels ($RMS_{impulse}$ levels) was measured from recordings captured in the field and replayed in the lab. The Larson Davis Model 820 SLM has the ability to measure the unweighted peak sound pressure. Limited additional subsequent analyses of the acoustical impulses were performed using a Larson Davis Model 3000 Real Time Analyzer. The real time analyzer provides narrow-band frequency and waveform analyses.

Figure 5: Underwater Sound Level Measurement Equipment

4.3 Quality Control

The measurement systems were calibrated prior to use in the field with a G.R.A.S. Type 42AA Pistonphone and hydrophone coupler. The pistonphone, when used with the hydrophone coupler, produces a continuous 136.5 dB (re 1 µPa) hydrophone at 250Hz. The SLMs are calibrated to this tone prior to use in the field. The tone is then measured by the SLM and is recorded on to the beginning of the digital audio recording that was used in the field. The system calibration status was checked at the end of the measurement event by both measuring the calibration tone and recording the post-measurement tone. All systems were found to be within 0.5 dB of the calibration levels. The pistonphone output was certified at an independent facility.

All field notes were recorded in water-resistant field notebooks. Such notebook entries include calibration notes, measurement positions (i.e., distance from source, depth of sensor), system gain settings, and the equipment used to make each measurement. Notebook entries were copied after each measurement day and filed for safekeeping. Digital media were labeled and stored for subsequent analysis.

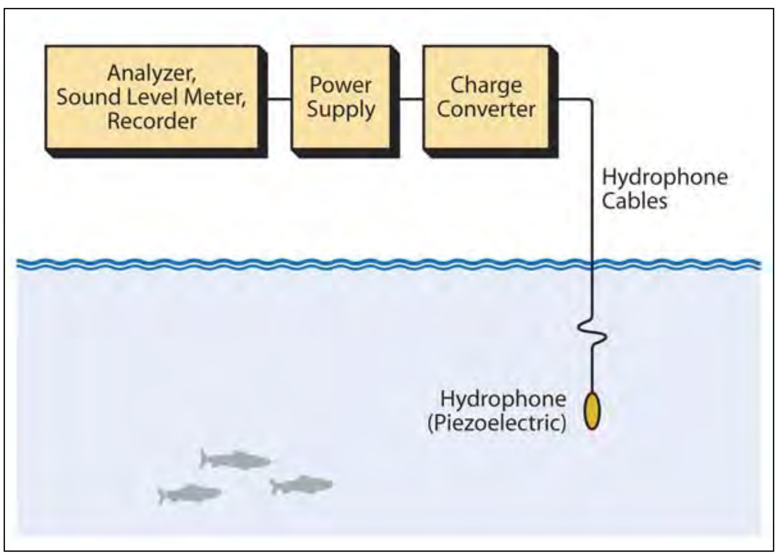


Figure 6: Diagram of hydrophone deployment at monitoring positions

5.0 MITIGATION MEASURES

5.1 Bubble Curtain Design – Unconfined Bubble Ring

The bubble curtain design that was used by the contractor for this project is similar to other bubble curtains used for projects in Washington. Figure 7 shows the design that was used on this project. The airflow to the bubble rings was regulated using a manifold system connected to two Ingersoll Rand Model XP825 compressors. This system allowed either one or both compressors to be used to supply the airflow as needed. There were two air hoses connected to each bubble ring and each set of hoses was connected to the manifold so that each ring was run off one compressor. Figure 9 shows the manifold and connectors. Table 2 shows the flow rate through the bubble curtain at each pile.

Figure 7: Photo of bubble curtain ring system used for this project and the bubble curtain hole spacing pattern

Figure 8: Photograph of the bubble curtain being deployed

Figure 9: Photograph of the air manifold system

Table 2: Summary Air Pressure and Flow in Bubble Curtain Rings.

Pile Number	Pressure (PSI) / Flow (CFM)	
	Upper ring	Lower Ring
PB-1	120/400	120/725
PB-2	120/450	120/750
PB-3	95/600	95/700
PB-4	100/450-650	100/400-650
WAB-2	110/690	115/680
WAB-5	110/700	110/690

PSI – Pounds per Square Inch
CFM – Cubic Feet per Minute

5.2 Isolation Casing with Bubble Ring

The second mitigation system tested was a isolation casing with a bubble ring. The bubble ring was similar to the rings used in the bubble curtain system; except there was only one bubble ring and it used only one air compressor. The isolation casing was a steel shell pile with a bubble ring attached near the base. Figure 10 shows the inside of the isolation casing and the configuration of the bubble ring.

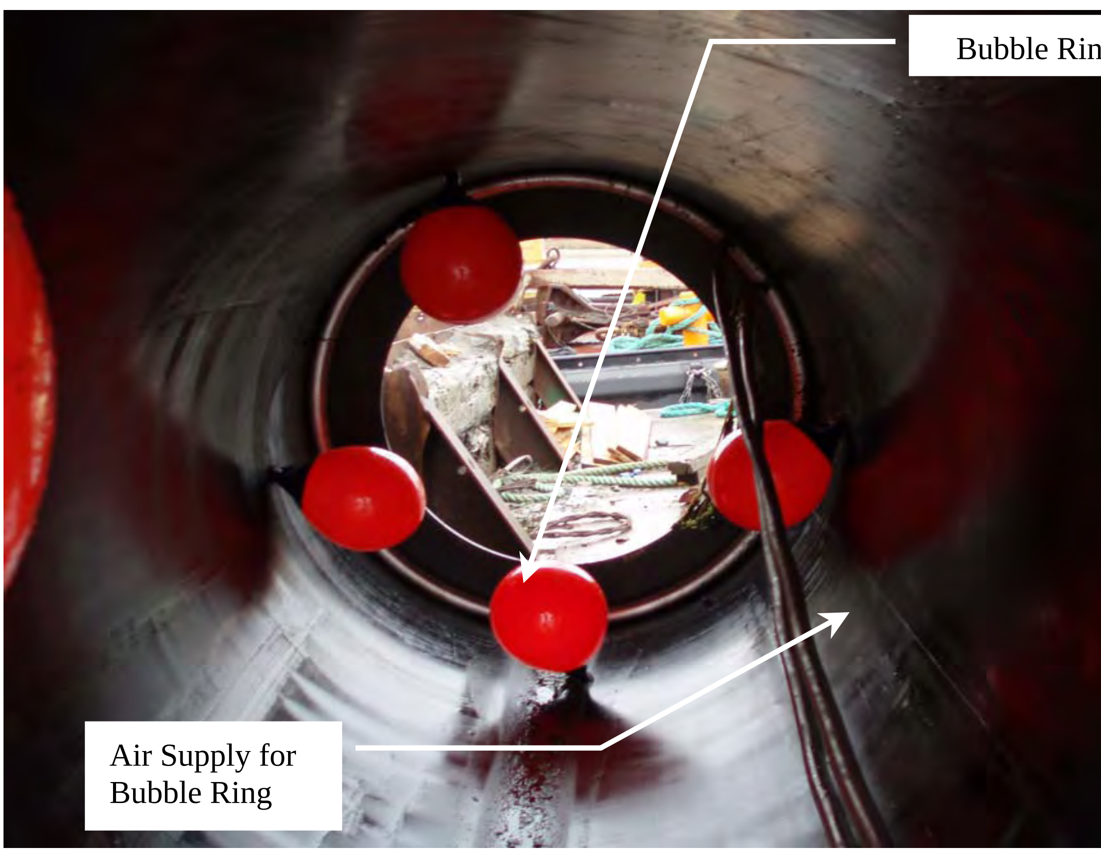


Figure 10: Photograph of inside of isolation casing

Figure 11: Photograph of bubble action in the isolation casing

Table 3: Summary Air Pressure and Flow in Isolation Casing Bubble Ring.

Pile Number	Pressure (PSI) / Flow (CFM)
WAB-1	105/720
WAB-4	115/600

5.3 Double Walled Noise Attenuation Pile (DNAP)

The third method tested was a Double Walled Noise Attenuation Pile (DNAP). The DNAP is a hollow steel pile casing filled with four inches of insulation and one inch of air space Figure 12. Figure 13 shows the actual DNAP.

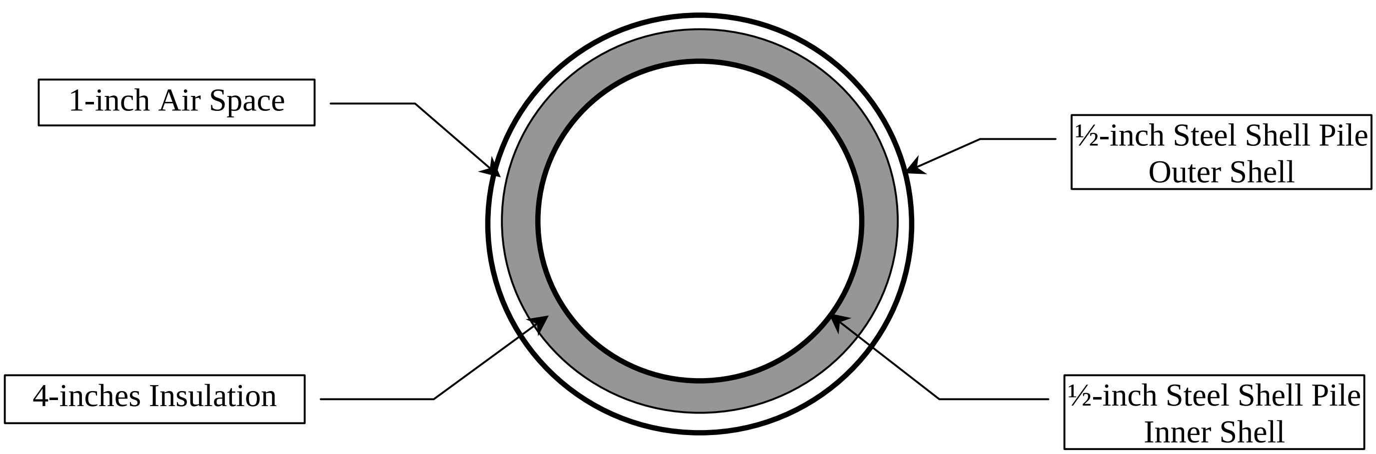


Figure 12: DNAP Details

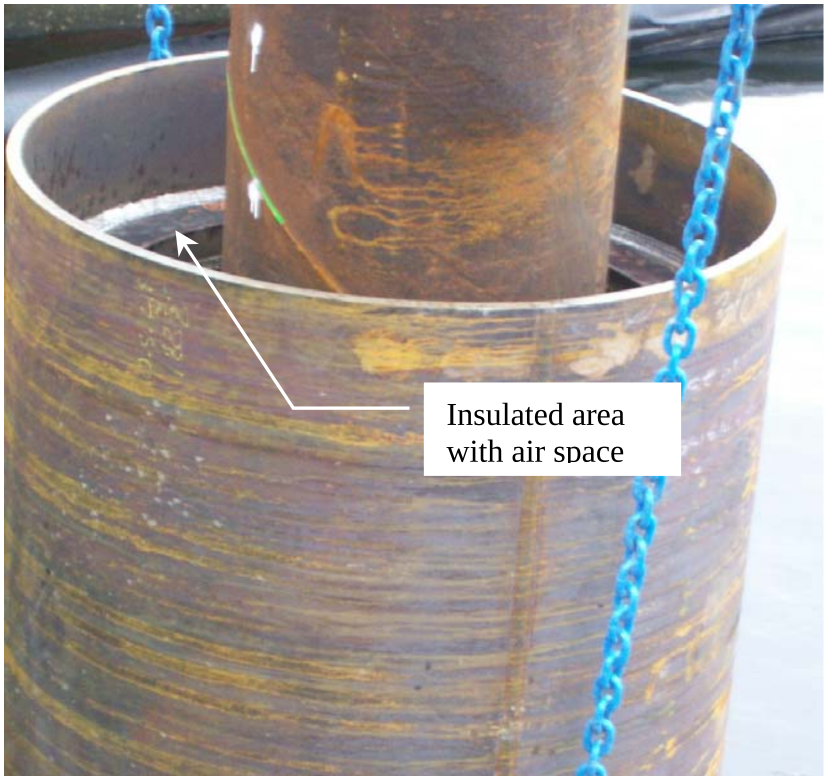


Figure 13: Photograph DNAP

6.0 DATA PRESENTATION

6.1 Introduction

This section presents measured Peak, RMS, and SEL levels. This section includes a summary presentation of the data.

Table 4: Summary of Pile ID and Mitigation Type Used

Pile	Attenuation	Location
PB-1	Unconfined Bubble Rings	C
PB-2	Unconfined Bubble Rings	
PB-3	Unconfined Bubble Rings	
PB-4	Unconfined Bubble Rings	
WAB-1	Isolation Casing with Bubble Rings	B
WAB-2	Unconfined Bubble Ring	
WAB-3	DNAP	
WAB-4	Isolation Casing with Bubble Rings	
WAB-5	Unconfined Bubble Ring	A

The complete set of measured sound pressure level data is contained in Appendix A. A list of all measurement events is provided at the beginning of the appendix. The data contained in Appendix A are presented in the order of the locations where the measurements occurred beginning at location C, Portage Bay. In the waveform figures that follow, the axes all have the same scale. This facilitates visual comparisons between piles with and without mitigation. The differences between the unmitigated and the mitigated levels are large; in some cases it is difficult to see the mitigated waveform. The following example shown in Figures 14 - 16 shows a typical comparison between a mitigated and unmitigated pile strike and the no pile driving level at 10 meters. These results would be similar with the use either the unconfined bubble rings or the isolation casing with a bubble ring. The unmitigated peak sound pressure is 5.68 E+09µPa (195 dB) while the mitigated strike has a peak sound pressure of 6.74 E+08µPa (177 dB) and the period between pile driving or no work period had peak sound pressure was 5.60 E+06µPa (135 dB). The period where there was no pile driving would be classified as background noise because it had other anthropogenic noise, i.e. small workboats and barge activity, occurring at the measurement time. The noise floor for the peak detector at the 10-meter location was approximately 150 dB re: 1µPa, at the distant locations where there was 20 dB of gain added the noise floor was about 130 dB peak re: 1µPa. The RMS noise floors were below the range of measured levels. The measured RMS levels ranged from 105 to 120 dB re: 1µPa when there was no pile driving occurring. Near the barge there was work and boat activity to the levels were higher than at the distant locations. At the 500 meter location the RMS level was slightly affected by the slap of waves on the aluminum boat.

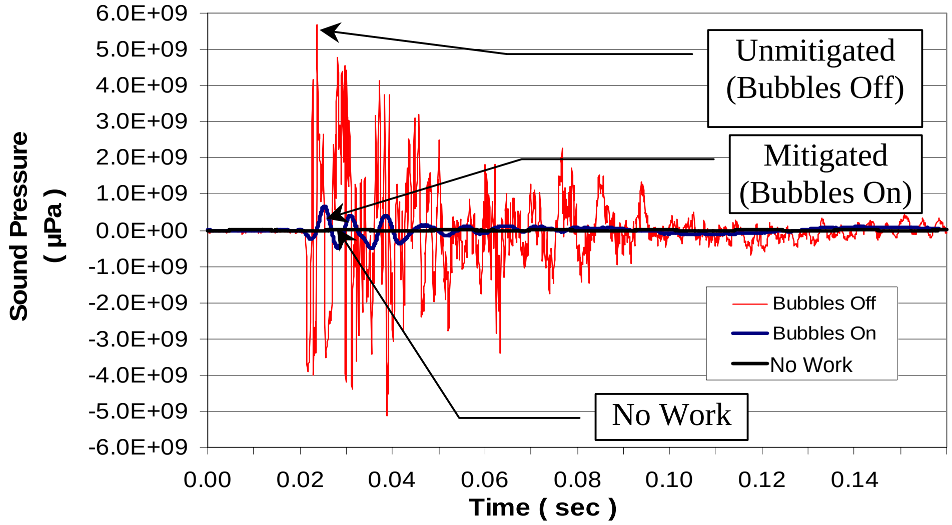


Figure 14: *Mitigated vs. Unmitigated Waveforms*

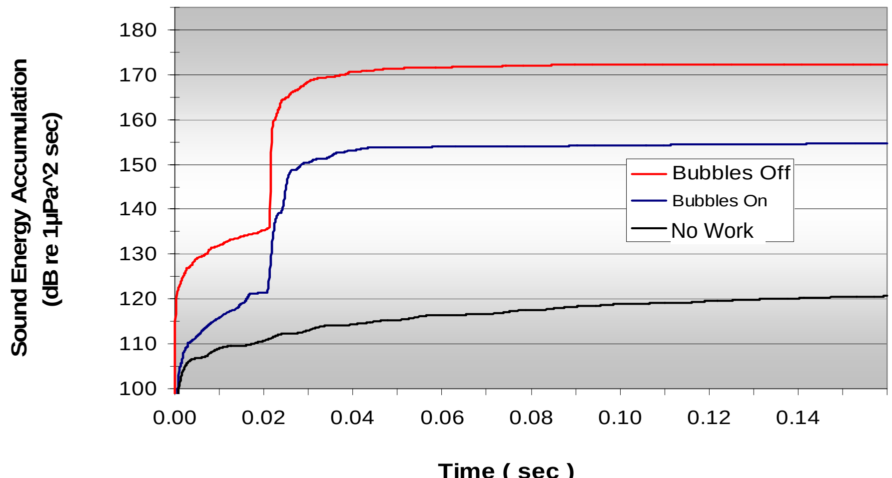


Figure 15: *Mitigated vs. Unmitigated Accumulation of Sound Energy*

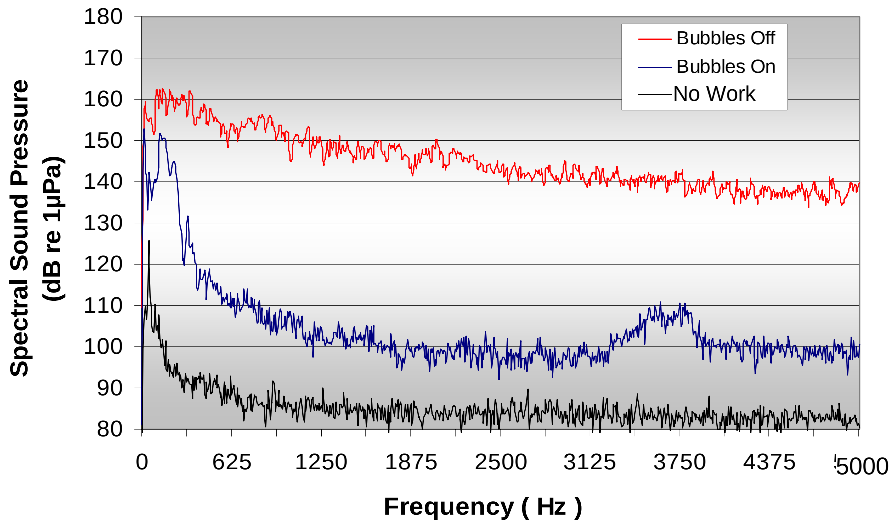
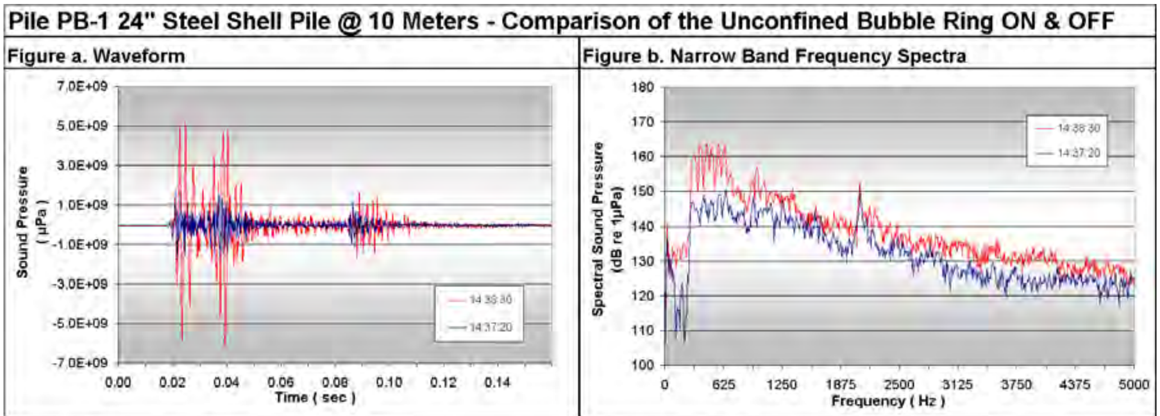


Figure 16: *Mitigated vs. Unmitigated Narrow Band Frequency Spectra*

Figure 17 shows an example waveform, narrow band frequency spectrum, accumulation of sound energy, and summary of sound pressure and sound energy levels measured at Portage Bay. The waveform is a time history of the pressure fluctuations caused by the pulse above and below zero pressure. The pulse includes sound pressures at different frequencies. The frequency analysis was conducted in 6 Hz constant bandwidths up to a frequency of 5000 Hz.



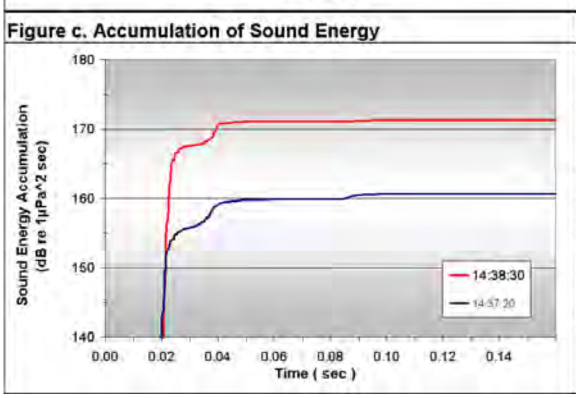


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
14:38:30	196	184	171
14:37:20	185	172	161

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Bubble Ring On	187	170	159
Bubble Ring Off	198	183	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 17: *PB-1 signal analysis of a pile driving underwater sound pulse*.

6.2 Location C – Portage Bay

6.2.1 Vibratory Driving Pile PB-3 October 26, 2009

Underwater sound measurements were made on October 26, 2009 when four 0.61-meter (24-inch) diameter steel pipe piles were installed just north of SR 520 in Portage Bay. An APE 200 vibratory driver/extractor was used to install the piles. Only one pile, PB-3 was measured.

Underwater sound levels were measured from two positions: (1) a fixed position from a raft that was 10 meters from the pile and (2) a dock that was 200 meters from the pile. The hydrophone at each position was set at mid depth, the water depth at the raft was 3 meters and the water depth at the dock was 4 meters. At the time of pile installation, there were no currents and it was calm with no wind.

Measurements were made at 10 meters and 200 meters from PB-3. The pile was installed at 13:37 to 14:32. Measurements of the sound pressure due to vibratory driving were not clear at 200 meters due to low source levels compared to background noise. Only the loudest levels from the vibratory pile installation could be measured over the background noise at 200 meters.

The measurements at 10 meters were pretty clear. Table 5 shows the peak sound pressures and the 1-second sound pressure levels or SELs from vibratory pile installation at PB-3. Figure A-1, in Appendix A shows the time history of the pile driving. Note that peak sound pressures at the 200-meter position were about 128 to 145 dB. The level of 128 dB was near the background level and the vibratory pile driving sound was barely audible on the recording. At the 10-meter position, peak pressures were generally in the range of 140 dB to 160 dB, with two peaks of 170 and 167 dB. At 200 meters, the highest peak measured was 145 dB. The highest 1-second sound levels (or SEL) measured at the 10-meter location was 151 dB, and at the 200 meter location the highest level was 126 dB.

Table 5: Summary of Measured Sound Levels for Vibratory Driving at Location C- Pile PB-3 – October 26, 2009

Pile	Time	Location	Peak dB re: 1µPa		SEL dB re: 1µPa^2-sec	
			Average	**Range**	**Average**	**Range**
PB-3	13:37 – 14:32	10 meters	157	136 - 170	144	105-151
		200 meters	133	128-145	115	102-126

Vibratory pile driving is generally much slower and quieter than impact driving and is recommended as a sound reduction measure[4]. Although peak sound levels can be substantially less than those produced by impact hammers, the total energy imparted can be comparable to impact driving because the vibratory hammer operates continuously and requires more time to install the pile. The actual time driving for PB-3 was about 12 ½ minutes out of the one-hour of time. Most of the time was spent leveling and adjusting the pile.

[4] Caltrans Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish, February 2009

6.2.2 Impact Driving – October 27, 2009

Four 24-inch piles were driven with an un-confined bubble ring attenuation system. The first pile, PB3 was driven approximately 20 feet. A summary of the underwater measurements taken at location C is shown in Table 6. There were two compressors running the air supply lines for the bubble rings. They were putting out 600- 700 CFM @ 95 PSI, causing very good bubble action around the piles. The first strike on PB3 was at 12:56:15 hours and the pile was 12 meters from the hydrophone. The last strike was at 13:08:31. There were a few stops during the drive and the blow count for the pile was 334 blows. Figure 18 shows the difference between the mitigated and unmitigated waveform and frequency distribution of PB-3.

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON and OFF 10/27/2009

Figure a. Waveform

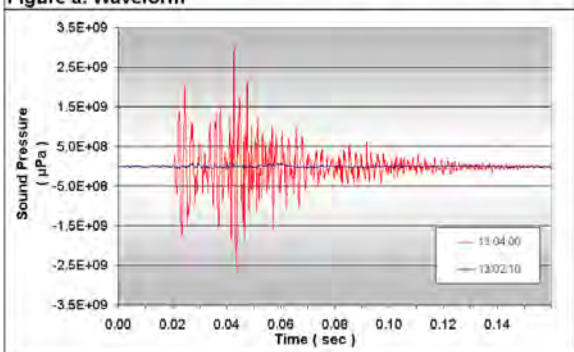


Figure b. Narrow Band Frequency Spectra

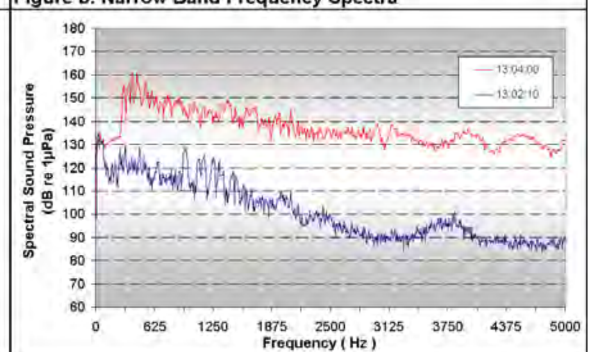


Figure c. Accumulation of Sound Energy

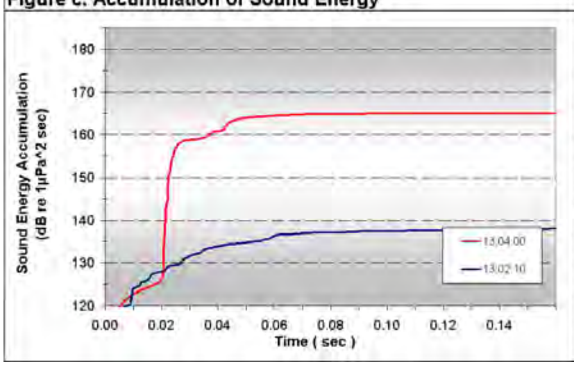


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:04:00	190	178	165
13:02:10	158	147	138

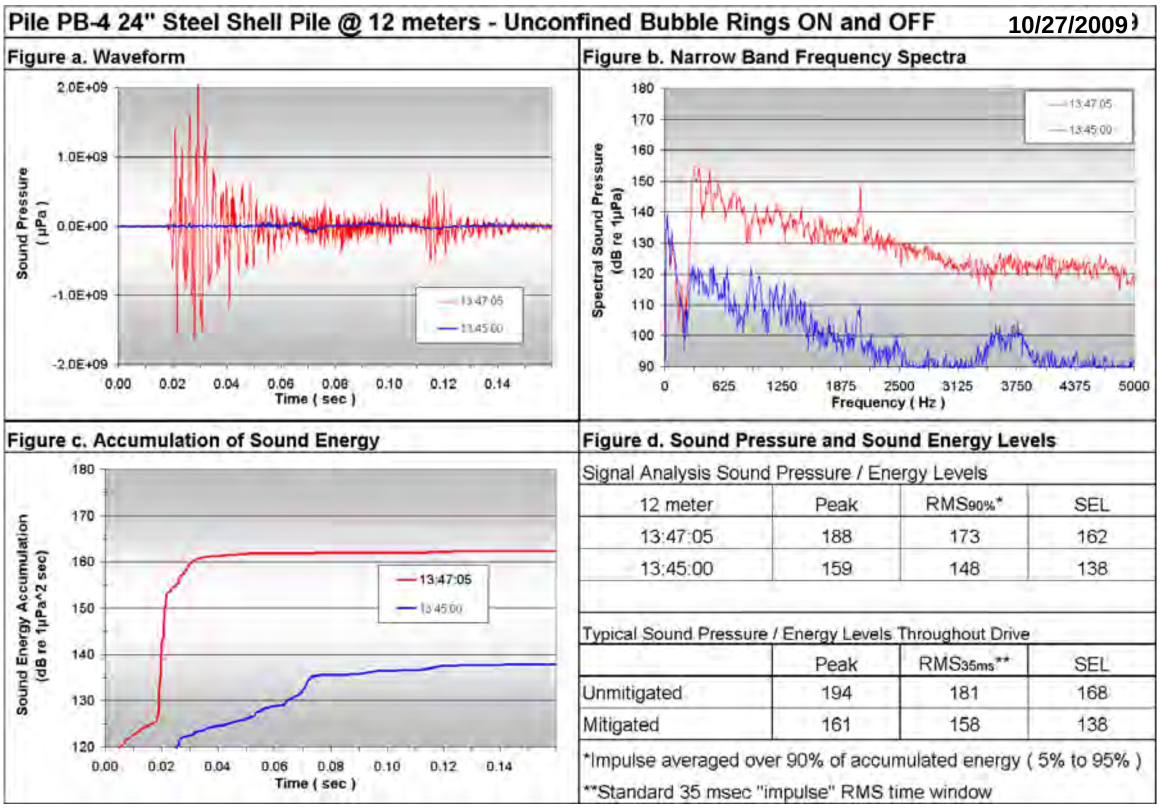
Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	193	179	167
Mitigated	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 18: PB-3 Signal Analysis With and Without Unconfined Bubble Rings

The second pile driven was PB4, was driven approximately nine feet. The drive started at 13:40:14 hours with the bubble rings off. After approximately 90 seconds the bubble rings were started. The drive was completed at 13:47:50 hours and 275 blows were used to set the pile. There was a lot of boat activity around the pile while it was being driven. Figure 19 shows the difference between the mitigated and unmitigated waveform and frequency distribution of PB-4.



Signal Analysis Sound Pressure / Energy Levels			
12 meter	Peak	RMS90%*	SEL
13:47:05	188	173	162
13:45:00	159	148	138

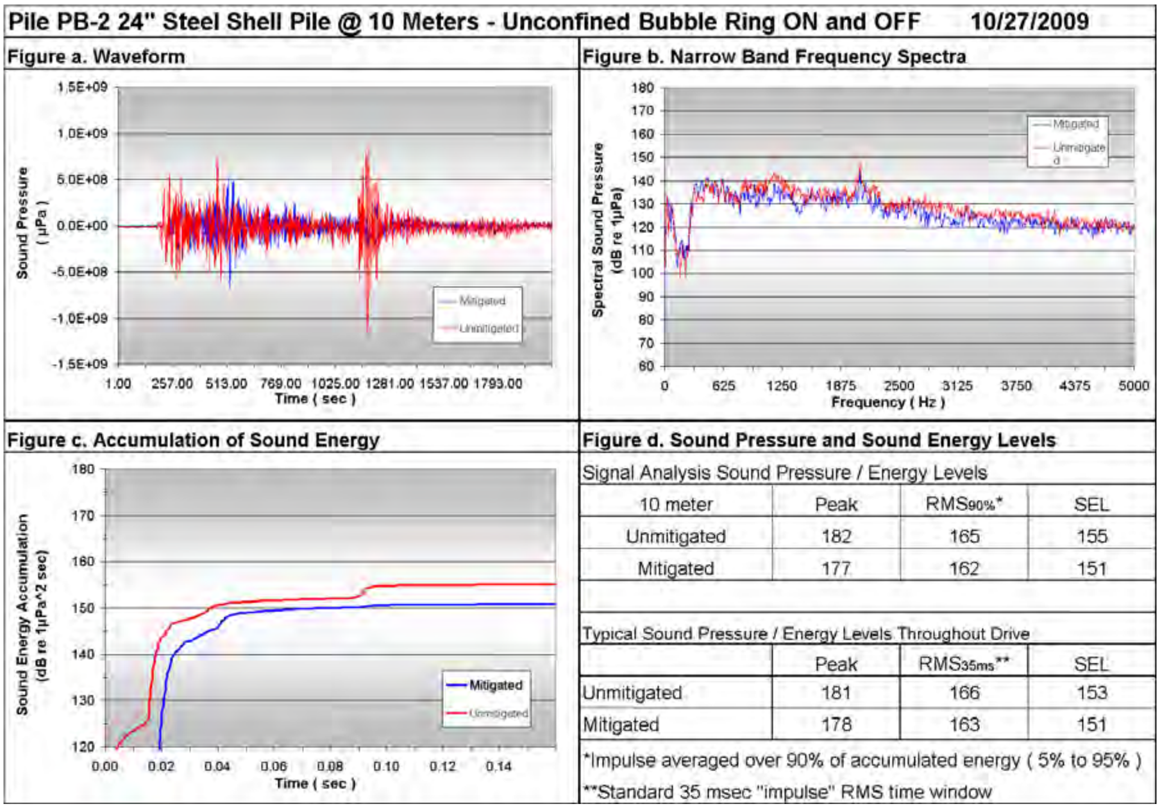
Typical Sound Pressure / Energy Levels Throughout Drive	Peak	RMS35ms**	SEL
Unmitigated	194	181	168
Mitigated	161	158	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure 19: *PB-4 Signal Analysis With and Without Unconfined Bubble Rings:*

Pile PB2 was started at 14:21:47 hours with the bubble ring turned on. The bubble ring was turned off at the end of the drive. The drive ended at 14:23:10 with only 60 pile strikes. The compressors were running at 120 PSI with one compressor putting out 450 CFM and the other 750 CFM. The contractor did not think the gages were working properly on the first compressor. It appeared that there was less bubble action when the pile was being driven. The airflow was never fully on when the driving began and by the time the air was shut off the driving was completed so there was not a time when there was either a good flow of air or a complete stoppage of air. Figure 20 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of PB-2.



Signal Analysis Sound Pressure / Energy Levels			
10 meter	Peak	RMS90%*	SEL
Unmitigated	182	165	155
Mitigated	177	162	151

Typical Sound Pressure / Energy Levels Throughout Drive			
	Peak	RMS35ms**	SEL
Unmitigated	181	166	153
Mitigated	178	163	151

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 20: *PB-2 Signal Analysis With and Without Unconfined Bubble Rings:*

PB1 was also driven for a short period of approximately two minutes. During the last 25 seconds the impact hammer was running with the fuel shut off. The compressors were again both at 120 PSI and 400 CFM and 725 CFM. There were a total of 77 pile strikes during the driving period. It appeared that there was some obstruction in the air hoses causing a higher noise level when the bubble curtain was in use, because there was such a short driving period there was not enough time to fully investigate the cause. However it could have been in the manifold and valves, similar to what happened at PB-2. Figure 21 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of PB-2.

Pile PB-1 24" Steel Shell Pile @ 10 Meters - Comparison of the Unconfined Bubble Ring ON & OFF

Figure a. Waveform

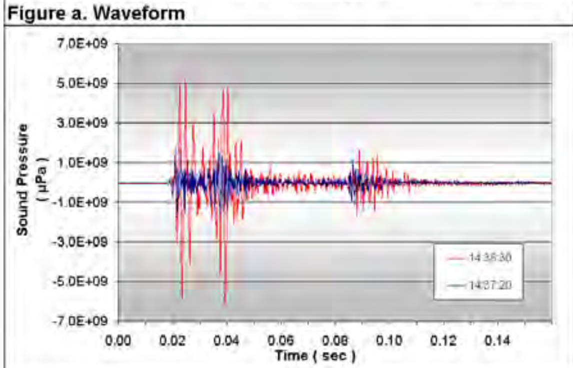


Figure b. Narrow Band Frequency Spectra

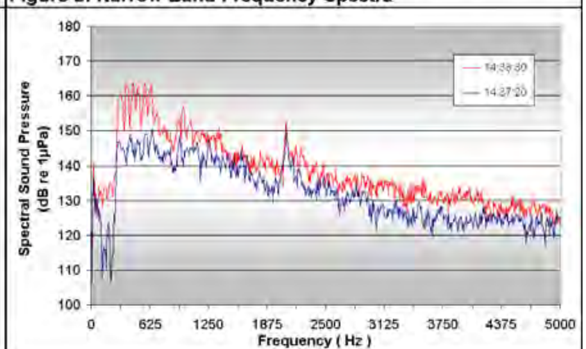


Figure c. Accumulation of Sound Energy

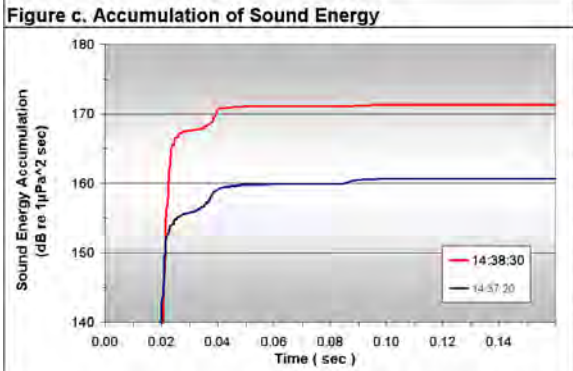


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
14:38:30	196	184	171
14:37:20	185	172	161

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Bubble Ring On	187	170	159
Bubble Ring Off	198	183	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 21: PB-1 signal analysis of a pile driving underwater sound puls**e.**

Table 6: Summary of Underwater Sound Levels for Location C, Portage Bay.

Pile	Date	Mitigation Type	Mitigation On or Off	Maximum Peak[2] (dB)	Maximum RMS (dB)	Average RMS (Pascals)	Number of Strikes	Average Peak (Pascals)	Range of Reduction (dB)	Average SEL (dB)	Cumulative SEL (dB)[2]
PB-1[1]	10/27/09	Un-confined Bubble Ring	On	190	173	316	77	2239	8-14	160	187
			Off	199	185	1412		7943		172	
PB-2[1]	10/27/09	Un-confined Bubble Ring	On	181	166	141	60	794	0-6	151	172
			Off	183	167	199		1122		153	
PB-3	10/27/09	Un-confined Bubble Ring	On	165	152	22	334	112	22-31	139	179
			Off	193	179	708		3981		165	
			On	164	155	22		112		138	
			Off	186	172	200		1259		155	
PB-4	10/27/09	Un-confined Bubble Ring	Off	194	181	562	275	3162	24-32	165	182
			On	161	158	22		89		138	
			Off	188	174	251		1413		158	

[1]The Bubble Rings were never fully in use due to problems controlling the airflow.
[2]The Peak and accumulated SEL values did not exceed the thresholds.

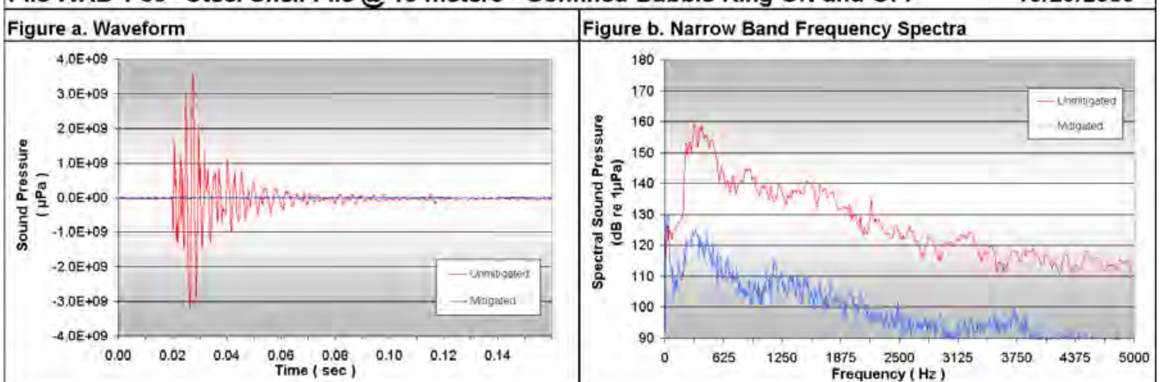
6.3 Location B – Near Foster Island

October 29, 2009

At Location B (see Location Map) the barge was 10 meters from the first row of piles. Piles were designated WAB1-4. There were three attenuation systems used, with WAB1 and WAB4 the confined bubble ring system was used, with WAB2 an unconfined bubble ring system was used, and with WAB3 the DNAP system was used. A summary of the results from the measurements is shown in Table 7.

WAB1 (30-inch pile) – The hydrophone was 10 meters from the pile and the drive began at 09:59:29 hours with the bubble ring off. After 30 seconds the bubble ring was started. The pile was driven for approximately eight minutes and 30 seconds with the bubble ring on, and then the bubble ring was turned off for the last minute of driving. The contractor needed the bubble action off so he could see his mark on the pile and know when to stop. The impact hammer would not stop when the fuel was turned off. It took approximately two minutes to come to a full stop. There were 410 blows under full operation and an additional 85 blows before the hammer stopped. There was one bubble ring in the confined casing and only one compressor was used. The compressor put out 700 CFM at 105 PSI; the bubble action in the casing was very good. Figure 22 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of WAB1.

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring ON and OFF 10/29/2009



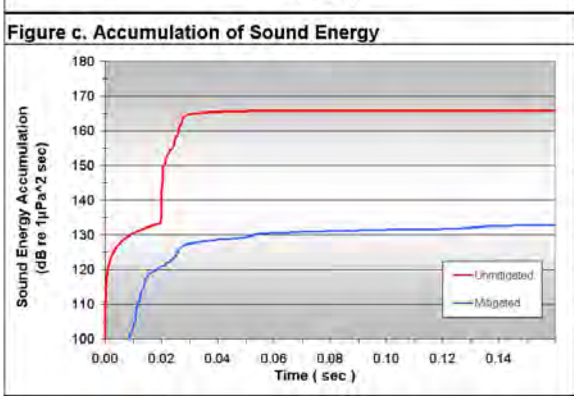


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:10:00	191	182	166
10:03:00	153	141	133

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Unmitigated	194	181	169
Mitigated	158	143	134

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 22: WAB1 Signal Analysis With and Without Confined Bubble Rings

WAB4 (30-inch pile) – The hydrophone was 13 meters from the pile. A confined air bubble ring was used at this location. The drive began at 11:32:50 hours with bubble ring off. After 30 seconds the bubble ring was started. The pile was driven for approximately six minutes with the bubble ring on, and then the bubble ring was turned off for the last two minutes of driving. The contractor needed the bubble action off so he could see his mark on the pile and know when to stop. There were 350 blows under full operation. There was one bubble ring in the confined casing and only one compressor was used. The compressor put out 600 CFM at 115 PSI; the bubble action in the casing was very good. Figure 24 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of WAB4

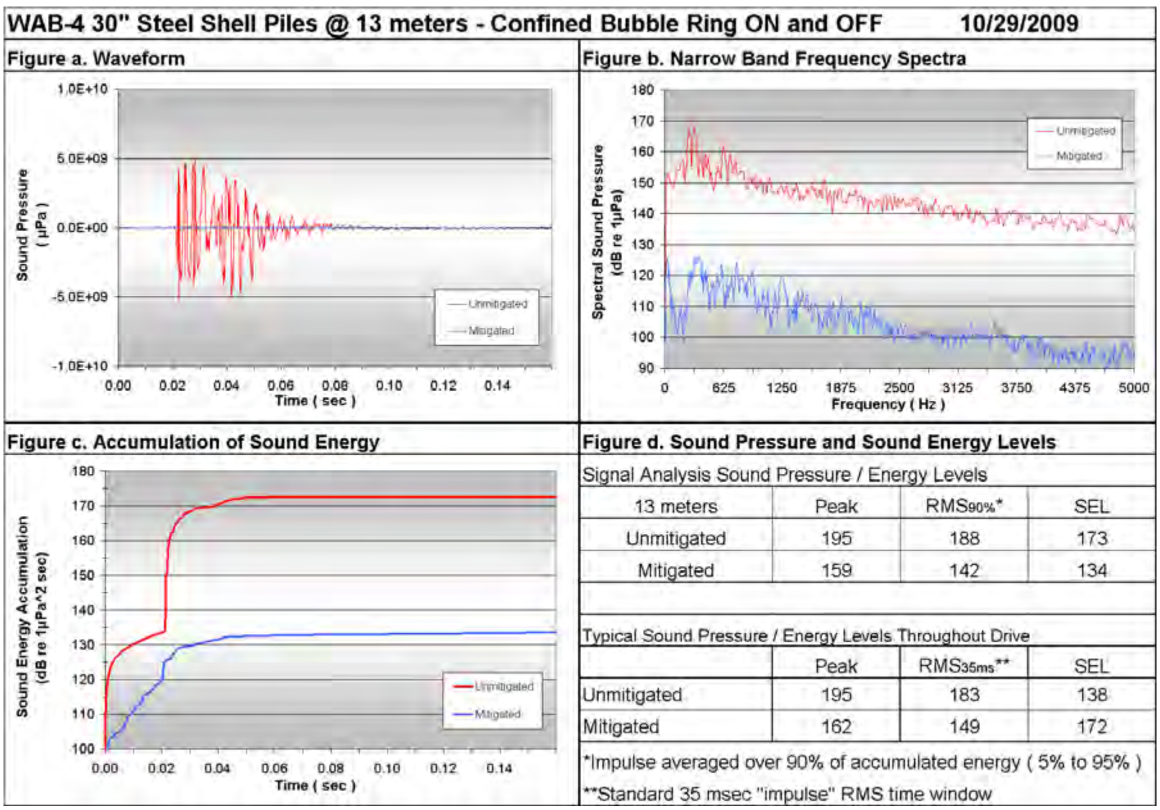


Figure 23: *WAB4 Signal Analysis With and Without Confined Bubble Rings*

WAB2 (30-inch pile)– The hydrophone was 13 meters from the pile, a set of unconfined bubble rings was used at this location. Driving started at 10:48:13 with the bubble rings off, after 30 seconds the bubble rings were started. The pile was driven for approximately eight minutes and 45 seconds with the bubble ring on. The bubble rings were turned off for the last minute of driving, the contractor needed the bubble action off so he could see his mark on the pile and know when to stop. The impact hammer would not stop when the fuel was turned off. It took approximately 30 seconds to come to a full stop. There were 450 blows before the hammer stopped. There were two bubble rings used in the unconfined system and two compressors were used, the first compressor was putting out 690CFM at 110 PSI and the second compressor was putting out 680 CFM at 115 PSI. This provided a very active bubble curtain around the pile. Figure 23 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of WAB2.

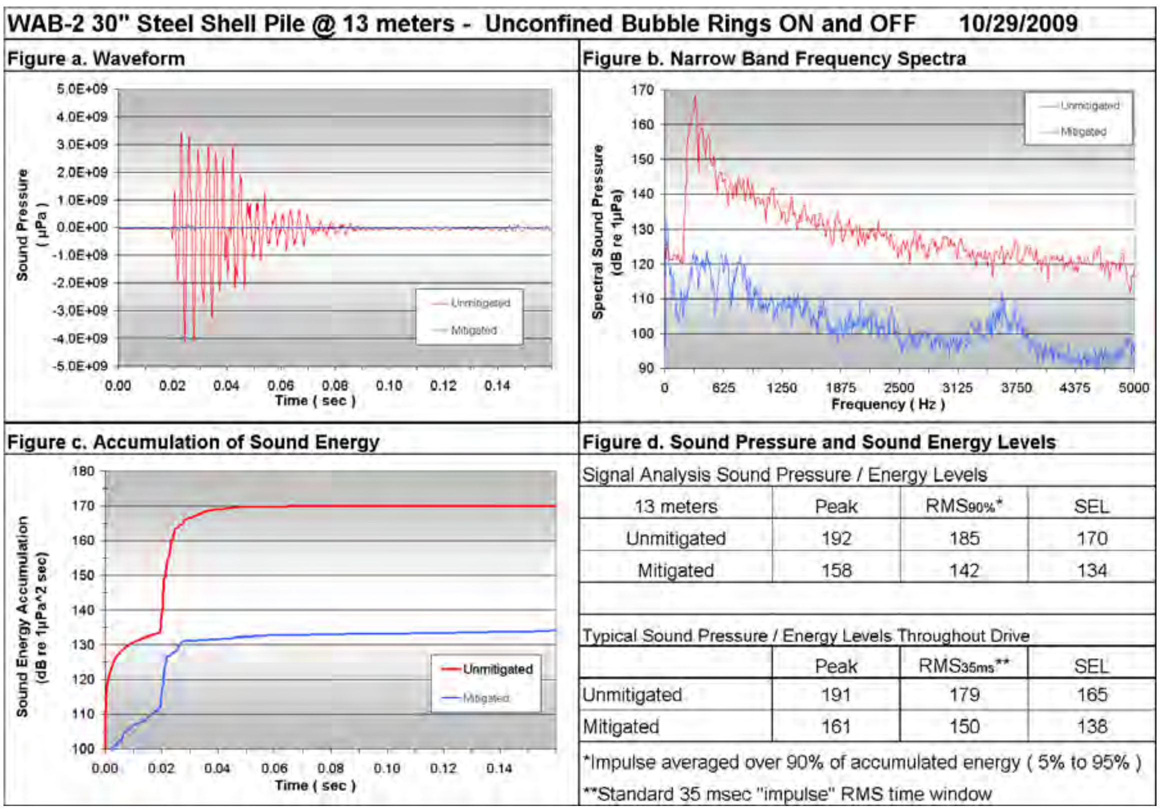


Figure 24: *WAB2 Signal Analysis With and Without Unconfined Bubble Rings*

WAB-3 (30-inch pile) – The final pile at location B used the DNAP attenuation system. The hydrophone was 10 meters from the pile and the drive began at 13:49:20. The pile was driven for approximately 12 minutes. There were 405 blows under full operation. Figure 25 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of WAB3.

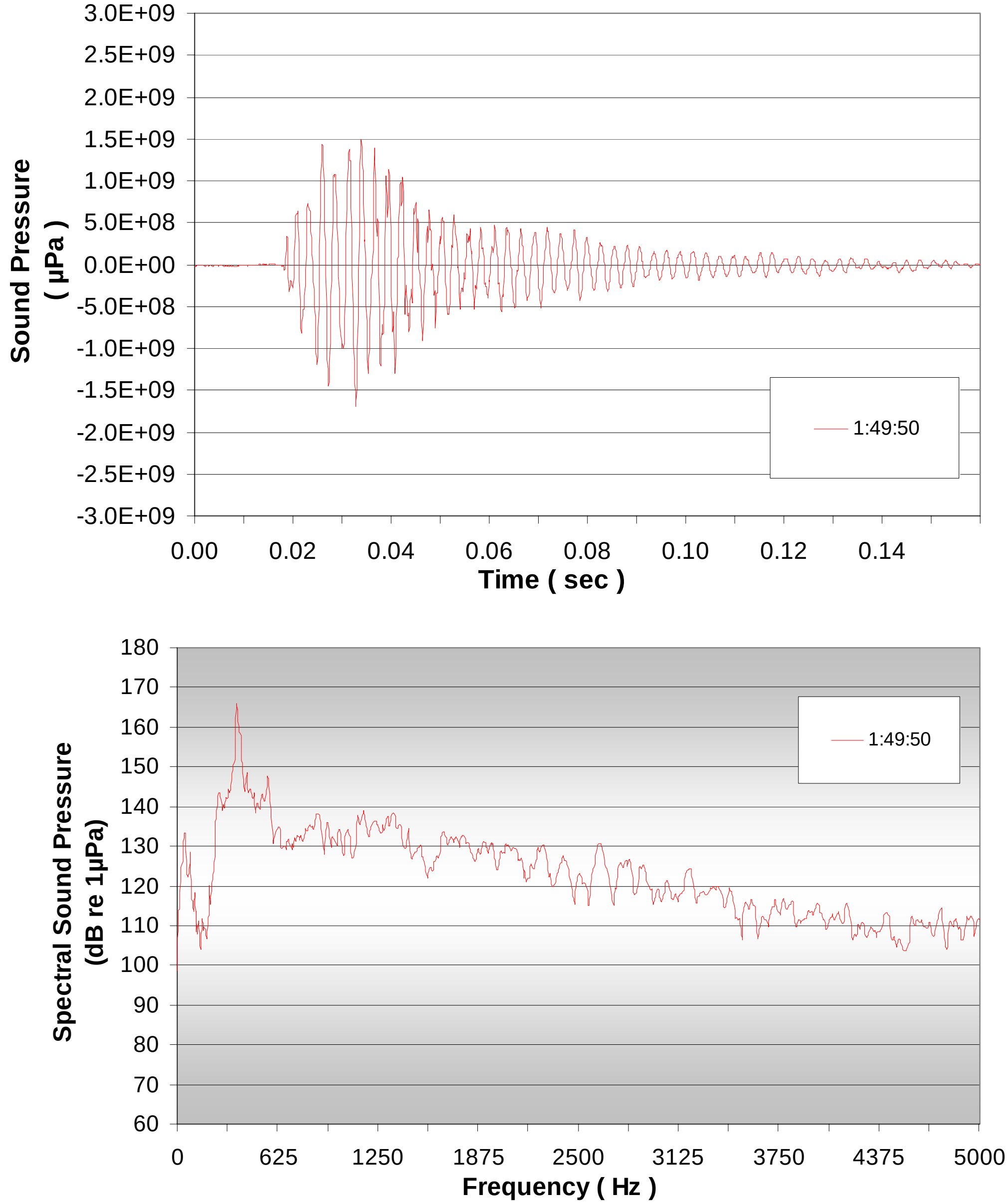


Figure 25: *WAB3 signal analysis of the DNAP System.*

Table 7: Summary of underwater Sound Levels for Location B, North of Foster Island.

Pile	Date	Mitigation Type	Mitigation On or Off	Maximum Peak[2] (dB)	Maximum RMS (dB)	Average RMS (Pascals)	Number of Strikes	Average Peak (Pascals)	Average Reduction (dB)	Average SEL (dB)	Cumulative SEL (dB)
WAB1	10/29/09	Confined Bubble Ring	Off	196	183	1122	410	5012	36-39	169	192[3]
			On	162	150	14		79		134	
			Off	196	185	1000		4467		169	
WAB2	10/29/09	Unconfined Bubble Ring	Off	196	183	1000	450	3981	29-35	168	187[4]
			On	166	163	32		112		138	
			Off	196	183	794		3162		165	
WAB3	10/29/09	DNAP	N/A	192	181	562	405	1995	9-12[1]	163	189
WAB4	10/29/09	Confined Bubble Ring	Off	191	174	398	350	2512	32-36	160	191[3]
			On	165	162	28		126		138	
			Off	196	186	1413		5623		172	

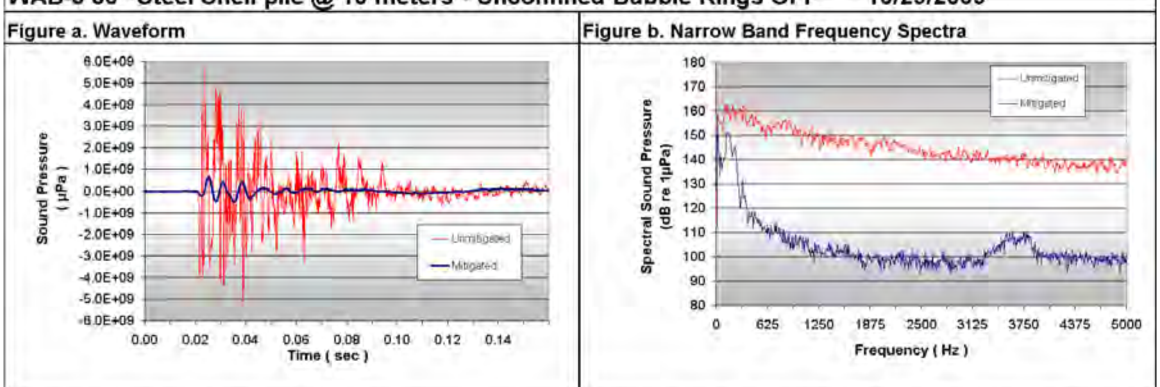
1 Average reduction is based on the baseline pile for pile where the DNAP was tested. All other piles the average reduction is from the same pile with the bubble curtain on and compared to the bubble curtain off.
2 Peak values did not exceed the threshold
3 Accumulated SEL Values would not have exceed the threshold had the attenuation system been left on
4 Accumulated SEL value did not exceed the threshold.

6.4 Location A – Between Foster Island and Edgewater Park

At Location A (see Location Map) there was one 30" steel shell pile driven. The barge was placed 10 meters from the Pile which was designated WAB5. The attenuation system used was the unconfined bubble ring system. A summary of the results of the measurements at location A is shown in Table 8.

WAB5 (30-inch pile)– The barge was moved to Location A (see Location Map) after completion of pile driving at Location "B". The water depth was 24 feet and the hydrophone was set at 12 feet depth and 10 meters from the pile. The pile driving started at 3:40:05 using an unconfined bubble ring system. The airflow was off to begin the drive. After 45 seconds the air was started and the pile was driven for approximately 10 minutes. The airflow was then turned off for two minutes and then restarted for five minutes and stopped again for 30 seconds. At that time there was an approximate 10-minute pause to allow the pile Dynamic Analysis equipment to be installed on the pile. Driving resumed at 4:07:56 with the airflow off for approximately 20 seconds. The airflow was on for 15 minutes and was turned off for the last three minutes of the drive. Two compressors were used and they both were putting out 690 -700 CFM at 110 PSI. A total of 1,470 pile strikes were used to drive the pile. Figure 26 shows the difference between the partially mitigated and partially unmitigated waveform and frequency distribution of WAB5.

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings OFF 10/29/2009



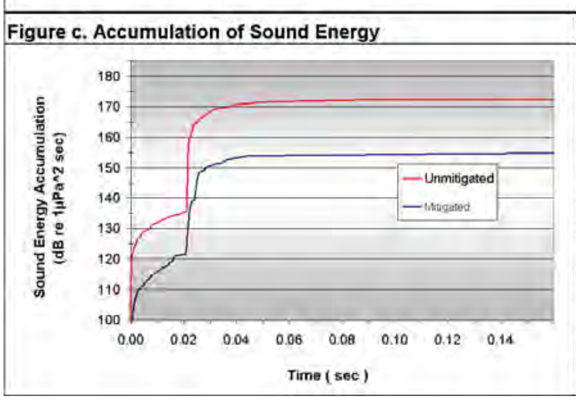


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
Unmitigated	195	184	172
Mitigated	177	164	155

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	195	182	174
Mitigated	177	165	153

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Figure 26: *WAB5 signal analysis of a pile driving underwater sound pulse*

Table 8: Summary of Underwater Sound Levels for Location A, Between Foster Island and Edgewater Park

Pile	Date	Mitigation Type	Mitigation On or Off	Maximum Peak[1] (dB)	Maximum RMS (dB)	Average RMS (Pascals)	Number of Strikes	Average Peak (Pascals)	Average Reduction (dB)	Average SEL (dB)	Cumulative SEL (dB)[2]
WAB5	10/29/09	Unconfined Bubble Ring	Off	197	185	1585	1470	6310	18-20	176	199
			On	179	168	178		631		153	
			Off	197	186	1413		6310		174	
			On	180	166	178		794		153	
			Off	196	183	1000		5623		170	
			Off	196	185	1000		6310		174	
			On	180	167	178		708		153	
			Off	197	184	1413		6310		173	

1 Peak values did not exceed the threshold

2 Accumulated SEL Values would not have exceed the threshold had the attenuation system been left on

6.5 Rise Time

Rise time is a descriptor used in waveform analysis to describe the characteristics of underwater impulses. In general rise time is the time in microseconds (ms) it takes the waveform to go from background levels to absolute peak level. There have been different definitions used in the calculation of rise time. Rise time has been calculated using the time required to go from zero, or the lowest value, to the maximum value. A different method is calculate the time it takes to go from beginning of the wave, or background level, to the maximum level. Figure 27 shows graphically how the rise time is calculated following the American National Standards Institute (ANSI) standard definition. This is the method that was used in this study and the results are shown in Table 9.

In 1973 Yelverton indicated rise time could be the cause of injury to fish. According to Yelverton (1973), the closer the peak is to the front of the impulse wave the greater the chance of injury. In other words, the shorter the rise time the higher the likelihood for effects on fish. Yelvertons studies were directed to a single blast in water.

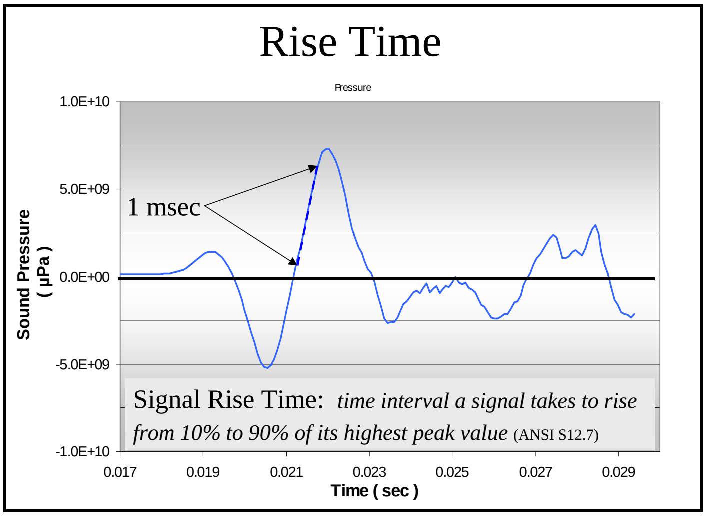


Figure 27: *Signal Rise Time*

Table 9: Summary of Rise Time for selected Piles

Pile	Date	Mitigation Type	Mitigation On or Off	Maximum Peak (dB)	Rise Time (ms)
PB1	10/27/09	Unconfined Bubble Rings	On	190	0.33
			Off	199	0.50
PB2	10/27/09	Unconfined Bubble Rings	On	181	0.31
			Off	183	0.30
PB3	10/27/09	Unconfined Bubble Rings	On	164	0.48
			Off	193	0.19
PB4	10/27/09	Unconfined Bubble Rings	Off	194	0.32
			On	161	4.53
WAB1	10/29/09	Confined Bubble Ring	Off	196	0.71
			On	164	0.42
WAB3	10/29/09	DNAP	--	192	0.63
WAB5	10/29/09	Unconfined Bubble Rings	Off	195	0.16
			On	177	0.10

Airborne Noise Measurements

Sound from a single source (i.e., a “point” source) radiates uniformly outward in a spherical pattern as it travels away from the source. The sound level typically attenuates (or drops off) at a rate of six dBA for each doubling of distance.

Usually the noise path between the source and the observer is very close to the ground. Noise attenuation from ground absorption and reflective wave canceling adds to the rate of attenuation. Traditionally, the excess attenuation has also been expressed in terms of attenuation per doubling of distance. This approximation is done for simplification only; for distances of less than 300 feet, prediction results based on this scheme are sufficiently accurate. For acoustically “hard” sites (i.e., sites with a reflective surface, such as a parking lot or a smooth body of water, between the source and the receiver), no excess ground attenuation is assumed. For acoustically absorptive or “soft” sites (i.e., sites with an absorptive ground surface, such as soft dirt, grass, or scattered bushes and trees), an excess ground attenuation value of 1.5 dBA per doubling of distance is normally assumed.

Noises generated from construction activities are considered point sources, rather than a line source such as a freeway or roadway. The area around the Alviso Pedestrian Bridge is heavily vegetative and would be considered a “soft” site. The combination of these two creates a drop off rate of 6 to 7.5 dB per doubling distance. The formula for calculating the drop off is the source level plus $10*\mathrm{Log}_{10}(D_1/D_2)$, where D_1 is the reference position and D_2 is the receiver position. For example if a impact pile driver has a reference level of 113 dBA at 50 feet the noise level at 500 feet would be calculated as follows for conditions where excess attenuation is not anticipated:

Received level = 113dBA +20Log$_{10}$(50/500) dBA

Received level =113+(-20) dBA

Received level = 93 dBA

Various descriptors are used to characterize noise levels, depending on the noise source and environment. The Department *Traffic Noise Analysis Protocol* (TNAP) and the *Technical Noise Supplement* (TeNS) contain explanations of the noise descriptors normally associated with traffic noise. Common descriptors used in environmental noise studies evaluating airborne noise are shown in Table 10.

The L_{eq} Noise descriptor is primarily used when the noise source is non-impulsive or a more steady noise. The $L_{eq(h),}$ the worst noise hour, is routinely used by the most State Departments of Transportation and the Federal Highway Administration to address impacts of highway noise on surrounding areas. The L_{max} noise descriptor is generally the most appropriate descriptor to use when discussing impulsive noise impacts, such as from pile driving. Construction noise is generally shorter in duration and the sound are more impulsive, such as with pile driving. The signal from pile driving is very short in duration and is not accurately characterized by averaging the source over a period of time. The L_{max} is the instantaneous highest level measured. Unlike the L_{eq} the Lmax does not have a time constant attached to it.

Table 10: Common Airborne Noise Descriptors

Lmax (maximum noise level)	The highest instantaneous noise level during a specified period. This descriptor is sometimes referred to as “peak (noise) level.” The use of “peak” level should be discouraged because it may be interpreted as a non- RMS value noise signal.
Lx (a statistical descriptor)	The noise level exceeded X percent of a specified time period. The value of X is commonly 10. Other values of 50 and 90 are also used. Examples: L10, L50, L90.
Leq (equivalent noise level)	The equivalent steady-state noise level in a stated period of time that would contain the same acoustic energy as the time-varying noise level during the same period.
Ldn (day/night noise level)	Commonly used to describe the community noise level A 24-hour average with a “penalty” of 10 dBA added during the night hours (2200–0700). The penalty is added because this time is normally sleeping time.
CNEL (community noise equivalent level)	A common community noise descriptor; also used to describe airport noise Same as the Ldn with an additional penalty of 4.77 dBA (or 10 Log3) for the hours 1900–2200, which are usually reserved for relaxation, TV, reading, and conversation.
SEL (single-event level)	Used mainly for aircraft noise; it enables comparing noise created by a loud but fast overflight with that of a quieter but slow overflight. The acoustical energy during a single noise event, such as an aircraft overflight, compressed into a period of 1 second, expressed in decibels.

Airborne measurements were made at two different locations during the impact driving for all pile locations. The distant sites are shown in Figures 2 and 4, they were mounted on local docks ranging from approximately 125 meters at location C to approximately 250 meters at locations A and B. The near location site was located on the front portion of the barge approximately 15 to 20 meters from the pile driver. During the pile driving at Location C, Portage Bay, there was a noise blanket tested to determine its effectiveness at reducing the potential noise impact at distant receivers. Tables 10 and 11 show the airborne Lmax and Leq values for each pile driven. There were some problems with one of the meters shutting off part way through the first day and then again at the beginning of the second day. Measurements were complete at the distant location with no loss of data. Piles PB3 and PB4 were driven with the noise blanket and PB1 and PB2 were driven without the noise blanket. A review of the limited data shows that the noise blanket was not effective at reducing the noise from the impact hammer. The main problem was that there was very short driving times without the noise blanket (one to two minutes per pile) compared to with the noise blanket (seven to eight minutes per pile). There was also some variability in the noise levels, which may have been due to the rate the piles were installed. It took less energy to install PB1 and PB2 (60 to 77 total blows) than to install PB3 and PB4 (275 to 334 total blows) this would mean that piles PB1 and PB 2 were hit softer than piles PB3 and PB4.

Table 11: Summary of Airborne Sound Levels Measured at Location C – Portage Bay

Pile	Pile Size Distance	Date	Background Levels				Pile Strike Sound Levels			
			L_{eq} (dBA)	**L_{MAX} (dBA)**	**Average L_{eq} (dBA)**	**Average L_{MAX} (dBA)**	**L_{eq} (dBA)**	**L_{MAX} (dBA)**	**Average L_{eq} (dBA)**	**Average L_{MAX} (dBA)**
Noise Levels Measured on the Barge										
PB3-Vibratory	24-inch 11 meters	10/26	89	94	78	83	95	102	88	93
PB1	24-inch 10 meters	10/27	A	A	A	A	A	A	A	A
PB2	24-inch 14 meters	10/27	79	87	74	83	A	A	A	A
PB3	24-inch 11 meters	10/27	76	95	73	87	***75***	***103***	***74***	***100***
PB4	24-inch 15 meters	10/27	78	88	75	83	***74***	***97***	***74***	***95***
Noise Levels Measured on the Dock										
PB3-Vibratory	24-inch 125 meters	10/26	72	77	71	73	76	82	71	75
PB1	24-inch 125 meters	10/27	71	72	69	71	74	81	73	79
PB2	24-inch 128 meters	10/27	72	79	71	78	72	79	71	78
PB3	24-inch 125 meters	10/27	71	80	68	73	***74***	***85***	***76***	***81***
PB4	24-inch 128 meters	10/27	72	75	69	70	***73***	***82***	***75***	***81***

[A] Sound Level Meter Failure No Data
Data that is in Bold Italics is where the noise blanket was used

Table 12: Summary of Airborne Sound Levels at Locations A and B

Pile	Pile Size Distance	Date	Background Levels				Pile Strike Sound Levels			
			L_{eq} (dBA)	**L_{MAX} (dBA)**	**Average L_{eq} (dBA)**	**Average L_{MAX} (dBA)**	**L_{eq} (dBA)**	**L_{MAX} (dBA)**	**Average L_{eq} (dBA)**	**Average L_{MAX} (dBA)**
Noise Levels Measured on the Barge										
WAB-1	30-inch 10 meters	10/29	[A]	[A]	[A]	[A]	[A]	[A]	[A]	[A]
WAB-2	30-inch 14 meters	10/29	83	84	78	79	100	109	99	105
WAB-3	30-inch 11 meters	10/29	86	84	77	79	101	110	97	106
WAB-4	30-inch 15 meters	10/29	83	92	79	78	98	108	97	106
WAB-5	30-inch 12 meters	10/29	79	80	79	80	100	109	97	103
Noise Levels Measured on the Dock										
WAB-1	30-inch 250 meters	10/29	66	68	63	63	72	81	70	75
WAB-2	30-inch 250 meters	10/29	64	65	63	63	71	83	70	75
WAB-3	30-inch 250 meters	10/29	71	72	66	67	73	83	70	75
WAB-4	30-inch 250 meters	10/29	68	69	65	66	71	80	69	74
WAB-5	30-inch 240 meters	10/29	67	72	66	66	74	83	72	80

[A] Sound Level Meter Failure No Data

The transmission loss or amount of reduction did not follow any preconceived patterns. Typically when measuring airborne noise levels the attenuation rate, or drop off rate is determined by several factors. The two easiest to define would be the type noise source, (line or point) and the type ground the noise will propagate over (hard or soft surface). Once these are determined if there are no extenuating circumstances it is fairly easy and accurate to predict the noise level at a given location. There are some variables that can make predicting noise levels and the drop off rate rather difficult and inaccurate. The most common factor is shielding between the noise source and the receiver. The amount of shielding can be relatively small and it will affect the noise levels. Another factor is other noise sources that may add to the noise level you are trying to measure. This could be some loud equipment working in the area or a freeway between the receiver and the noise source that you are concerned with. On this job there were two factors that may have added to excess attenuation to the pile driving noise.

At location C the crane was between the measurement site and the pile driving and at locations A and B the freeway was between the pile driving and the receiver. While the crane body is not that large, it may block the line of sight and therefore it may have affected the measured noise level. The freeway at location locations A and B is between the pile driving operations and the receivers, which could affect the transmission loss. .

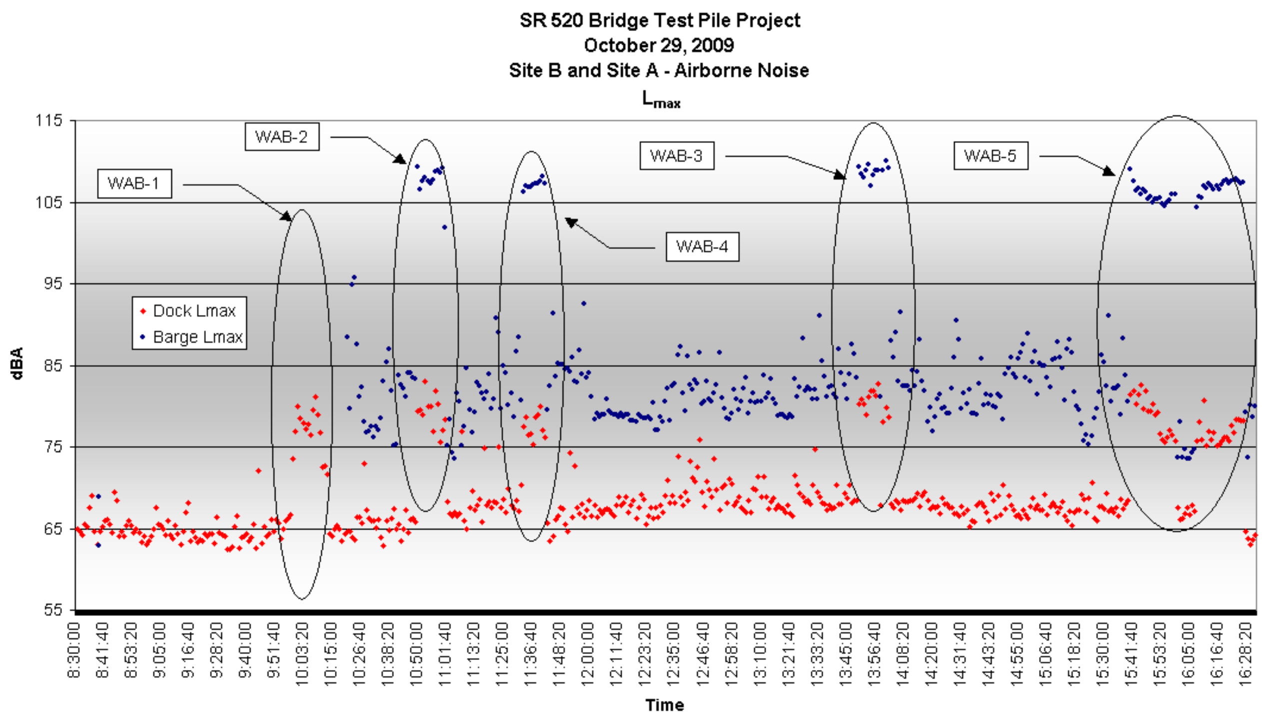


Figure 28: *Airborne noise at Location A and B-Lmax*

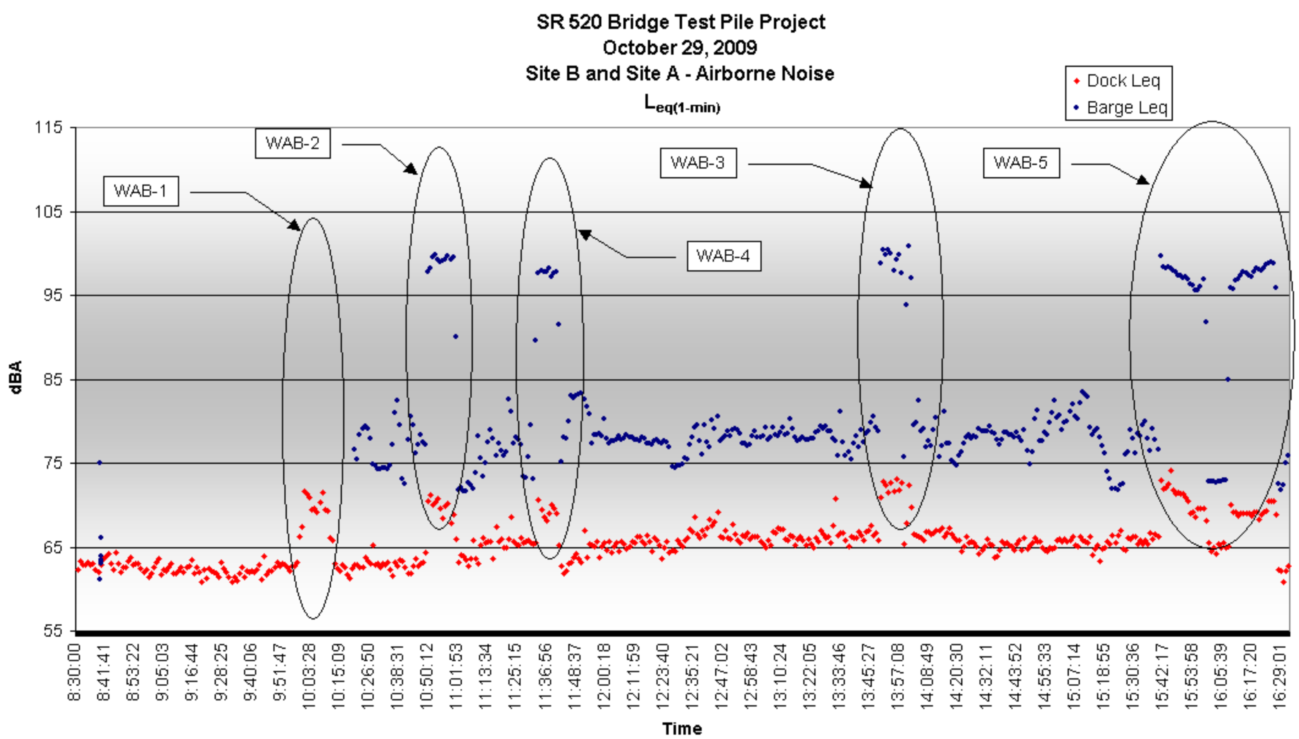


Figure 29: *Airborne noise at Location A and B -Leq*

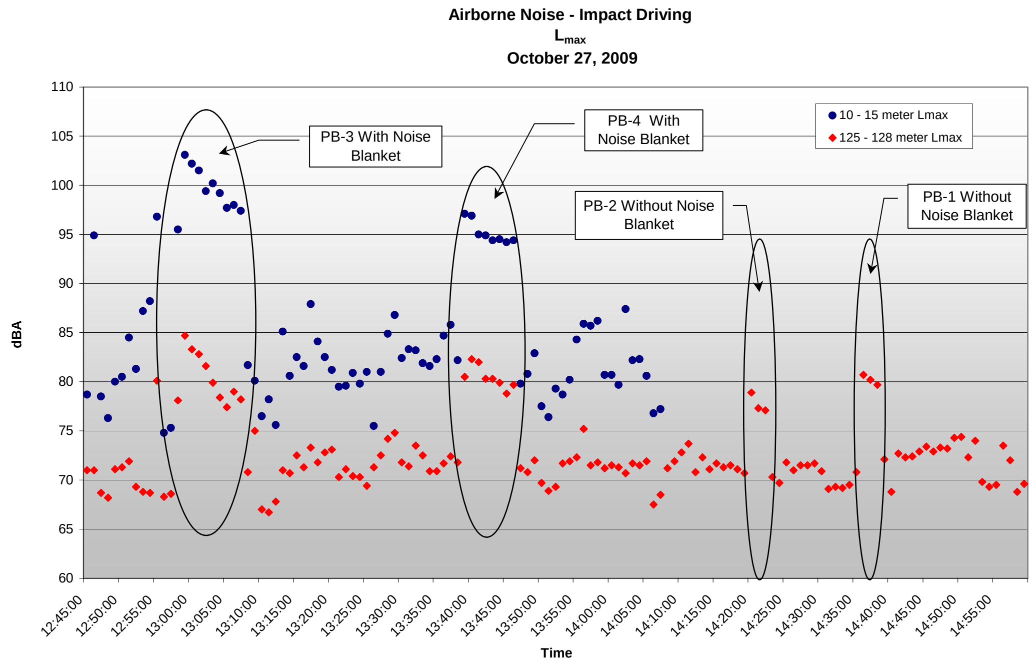


Figure 30: *Airborne noise at Locations C -Leq*

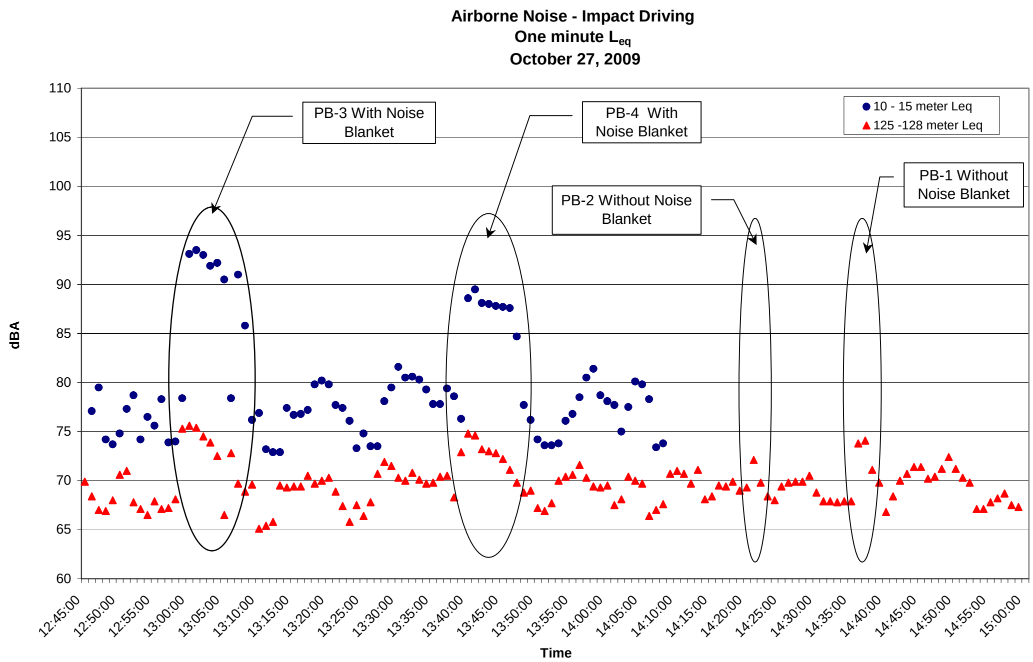


Figure 31: *Airborne noise at Locations C -Lmax*

6.7 Distant Underwater Measurements

Noise levels from the pile driving at the distant locations were very low and difficult to measure. The systems used at the 200 meter and 500 meter location had the gain in the PCB in-line charge amplifiers adjusted to amplify the signal by 20 dB. Even with this adjustment at times it was not possible to detect the pile driving above the other noises in the Lake. Table 12 shows the levels from the SLM at the unmanned 200-meter site and the manned 500-meter site at Location C. At the unmanned 200 meter location the solid-state recorder malfunctioned at 11:29:53, prior to any pile driving. The SLM continued to function normally, however it is not possible to determine what portion of the noise was solely from the pile driving at this site. At the manned 500-meter site the pile driving could not be detected above the other noises in the water, most of the noise at this site was from the wave action hitting the bottom of the aluminum boat.

Table 13: Summary of Underwater Sound Levels Measured at 200 and 500 meters October 27, 2009.

October 27, 2009									
Pile ID	Bubble Rings On/Off	200 meters				500 meters			
		Max (dB)		Average (dB)		Max (dB)		Average (dB)	
		Peak	[1]RMS	Peak	[1]RMS	Peak	[2]RMS	Peak	[2]RMS
PB1	On	134	ND	132	ND	143	ND	137	ND
	Off	136	ND	134	ND	145	ND	137	ND
PB2	Off	134	ND	131	ND	149	ND	138	ND
	On	138	ND	132	ND	143	ND	135	ND
PB3	On	140	ND	137	ND	150	ND	138	ND
	Off	136	ND	134	ND	147	ND	136	ND
	On	139	ND	134	ND	146	ND	142	ND
	Off	138	ND	136	ND	146	ND	144	ND
PB4	Off	134	ND	132	ND	149	ND	139	ND
	On	138	ND	136	ND	143	ND	134	ND
	Off	138	ND	134	ND	145	ND	135	ND

[1] Noise on solid-state recorder was from waves slapping the side of the boat, not pile driving
[2] Data recorder malfunctioned, no recorded data.

At locations A and B the equipment at both of the 200 meter and 500 meter sites functioned properly the entire day. The noise from the pile driving was recorded and samples of the signals from a selected few of the pile strikes were analyzed and are shown in the back of Appendix B. The unattenuated (bubbles off) pile strikes were clearly heard, however at the 200-meter site when the bubbles were turned on the pile strikes were no longer audible. While at the 500-meter site the attenuated pile strikes could be heard above the background noise. The unmitigated noise from the pile driving was greater at the 200-meter site, while the mitigated noise from the pile driving was greater at the 500-meter site. This difference has been observed on several different projects and is mainly due to the ground borne noise from the pile being released beyond the 200-meter location. The ground borne portion of the noise is not attenuated by the bubble ring(s). There is no obvious explanation for the higher levels measured at 500m. The sound propagation is quite complex (through the bubble curtain, bottom substrates, and water) and cannot be understood very well from these few measurements. This type of Flanking has been observed on the San Francisco Bay Bridge Project on different occasions[5]

Table 14: Summary of Underwater Peak Sound Levels Measured at 200 and 500 meters October 29, 2009.

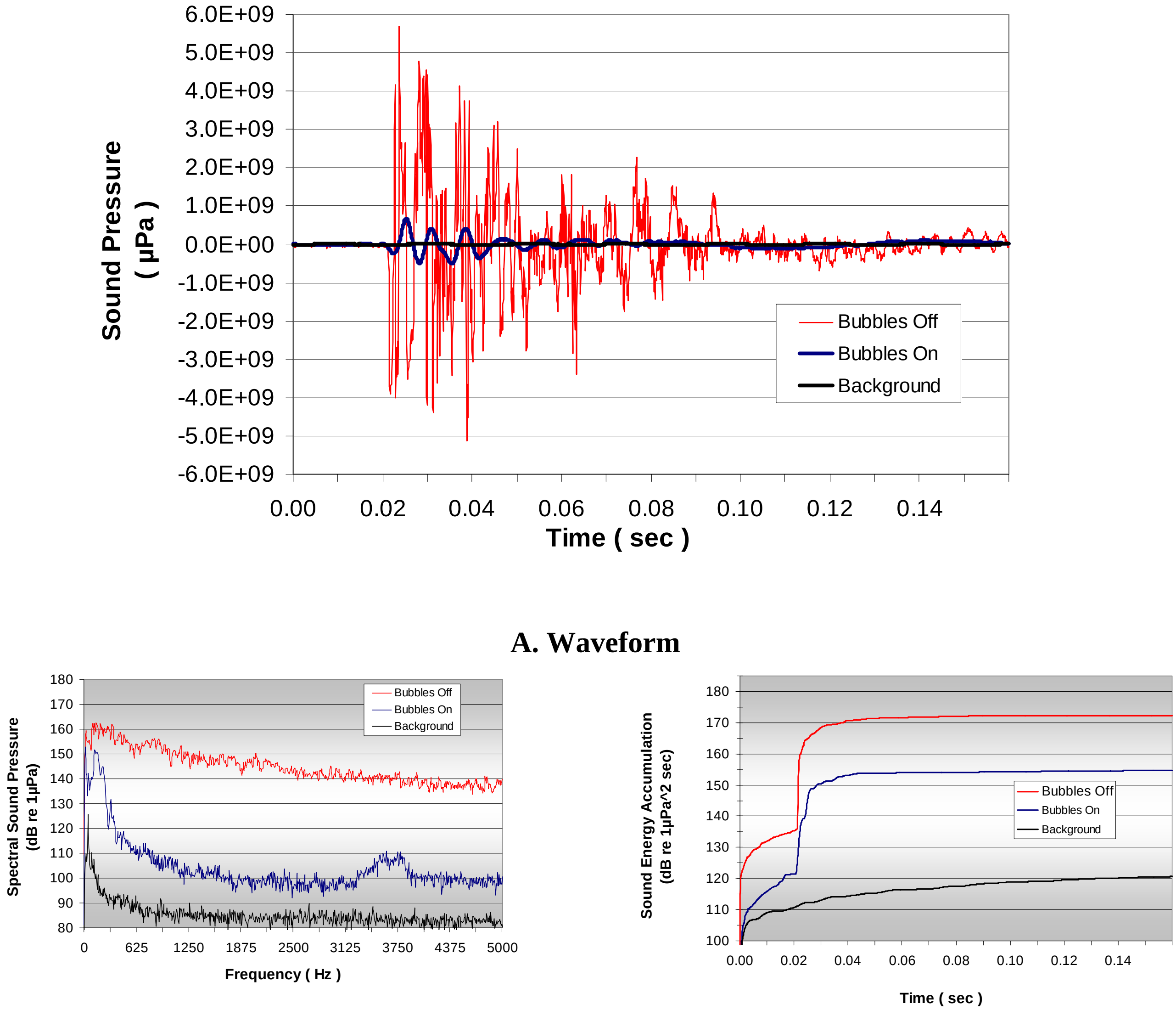
October 29, 2009										
Pile ID	Type Mitigation	Bubble Ring(s) On/Off	200 meters				500 meters			
			Max (dB)		Average (dB)		Max (dB)		Average (dB)	
			Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS
WAB1	Confined Bubble Ring	Off	165	147	157	141	160	142	154	137
		On	146	127	138	120	154	137	148	132
		Off	163	145	157	142	159	141	152	139
WAB2	Unconfined Bubble Rings	Off	161	135	150	125	161	145	153	139
		On	153	131	138	120	156	138	148	134
		Off	157	140	151	133	157	140	151	137
WAB3	DNAP	N/A	151	156	145	135	156	136	149	132
WAB4	Confined Bubble Ring	Off	141	142	135	135	152	136	146	134
		On	144	136	137	129	153	136	147	133
		Off	159	132	154	130	158	141	153	138
WAB5	Unconfined Bubble Rings	Off	177	164	175	155	163	135	158	134
		On	154	135	138	121	139	121	132	117
		Off	177	162	174	159	158	140	152	135
		On	166	146	142	124	140	118	132	130
		Off	176	160	170	155	152	134	145	116
		Off	177	161	173	159	158	137	152	134
		On	167	145	142	127	149	130	141	122
		Off	177	161	174	157	157	137	153	135

[5] Memo from James Reyff to Mara Melandry Dated July 24, 2003; SFOBB East Span Construction Pier 16E

7.0 CONCLUSIONS

Of the three types of mitigation tested, Unconfined Bubble Rings, confined Bubble rings and DNAP, the DNAP was the least effective in reducing the underwater sound levels. While all three reduced the underwater sound pressure the DNAP was the only one of the three that would have caused an exceedance of the 187 dB re1µPa^2-sec cumulative SEL threshold, had the two types of bubble ring(s) been used the entire driving period. Both of the bubble ring systems worked extremely well, once all the operational problems were resolved. The 206 dB re: 1µPa peak threshold was not exceeded, even with the mitigation turned off. Figure 32 shows the effect of a typical bubble ring(s) along with the background level.

Figure 32: *Comparison of Bubbles on and bubbles off and the background levels using an Unconfined Bubble Ring***.**



A. Waveform

B. Narrow Band Frequency Spectra

C. Accumulation of Sound Energy

The bubble ring(s) were very effective when working properly and easier to setup and use than the DNAP. Figure 33 shows the difference between the DNAP and the confined bubble ring system. The unconfined or confined bubble ring will produce similar results.

Figure 33: *Comparison of DNAP, Confined bubble Ring and Unconfined Bubble Rings*

Comparison of Mitigation Measures (Typical)

Figure a. Waveform

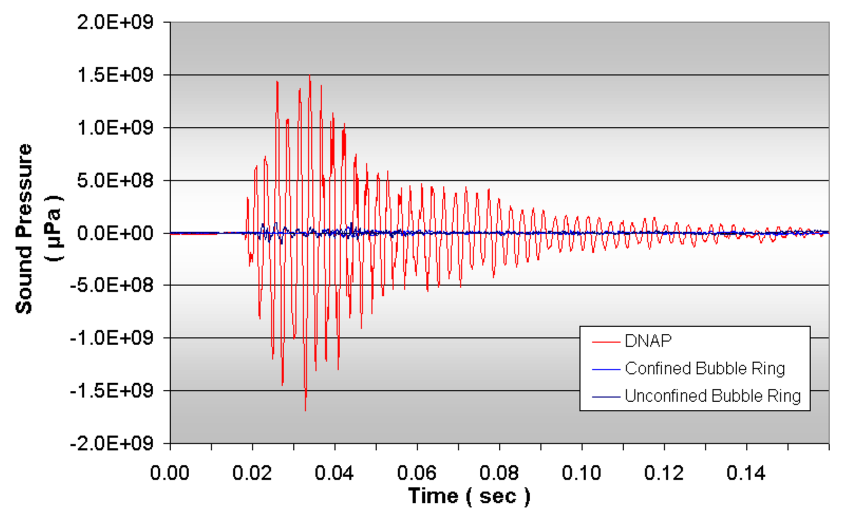


Figure b. Narrow Band Frequency Spectra

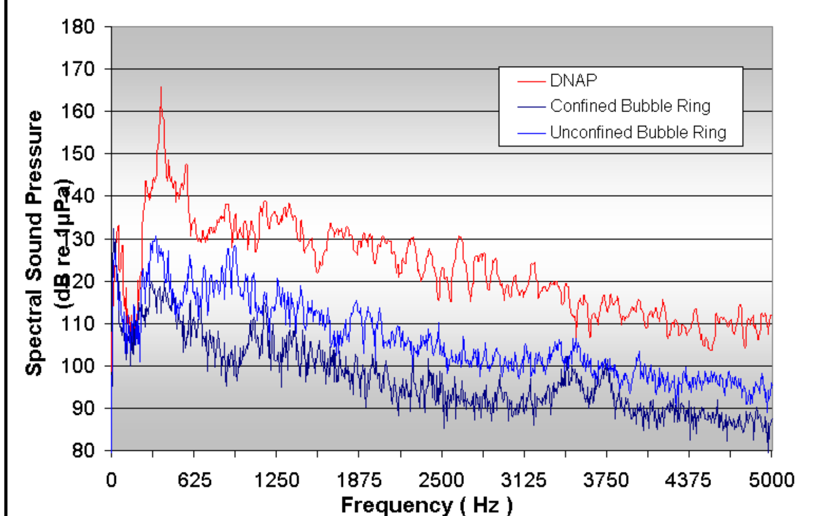


Figure c. Accumulation of Sound Energy

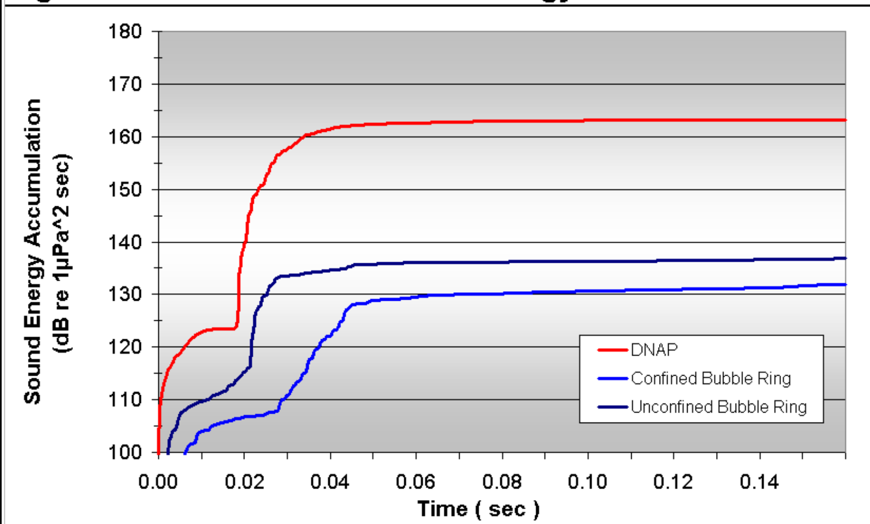


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
Typical Unmitigated	192	185	170
DNAP	185	175	163
Confined Bubble Ring	156	141	132
Unconfined Bubble Ring	160	146	137

*Impulse averaged over 90% of accumulated energy (5% to 95%

Airborne L_{max} noise measurements made at the docks indicate that the levels at the distant receptor locations will be about 10 dBA above the background levels. This is in part due to the close proximity of SR520 to the homes near the project site. The L_{eq} values were about 5 dBA above the background or no pile driving periods. The use of the noise blanket is not be recommended as it did not show any benefit and caused additional effort by the contractor in trying to drive the piles.

Monitoring was conducted at one mid channel depth at three fixed distances, including the prescribed distances of approximately 10 meters, 200 meters, and 500 meters. Data were obtained for the peak, RMS, and SEL levels. Preliminary summary reports, including measured peak and accumulated sound exposure levels, and RMS impulse levels were prepared after the completion of the driving period. Data were obtained during both vibratory and impact pile driving.

Some general conclusions from the monitoring are:

- The hydroacoustic monitoring fulfilled the objectives outlined in the Hydroacoustic Monitoring Plan. The Plan called for monitoring four piles, a total of nine piles were monitored.
- Both vibratory pile driving and impact pile driving were monitored.
- Peak sound pressures typically reached maximum levels of 199 dB at the close-in reference (nominal 10 meter) position. The 206 dB peak interim threshold was not reached.
- The maximum RMS level measured at 10 meters was 186 dB unmitigated and was 173 dB mitigated.
- The daily-accumulated SEL varied during the monitoring days, depending upon the numbers and types of piles being driven and the location. On a typical driving day, with 4 piles being driven, the distance to the 187 dB accumulated SEL threshold ranged from less than 10 meters to 60 meters. If either the confined or unconfined bubble ring(s) had been used during the entire driving time, the cumulative SEL level would have remained below the 187 dB re: 1µPa^2–sec threshold. .
- The measured noise level from the pile driving was much lower than those published in WSDOT ‘s compendium of noise measurements. The peak level shown for a 24 to 30-inch pile are 212 dB and 189 to 195 dB RMS. The measured levels were much lower than the data in the compendium, the typical unmitigated peak noise level measured was 195 dB and the RMS level is approximately 183 dB. With the use of mitigation the peak sound levels were approximately 170 dB and the RMS levels with mitigation were typically 155 dB re: µPa 1.
- The driving time at WAB-5 was substantially longer than at WAB-1 through WAB-4. This was because at WAB1 through WAB-4 the piles were vibrated in deeper and it only required between 325 to 450 blows to reach final tip elevation, while WAB-5 it required 1,470 blows to reach final tip elevation. The Accumulated SEL for piles WAB-1 through

WAB 4, if the mitigation had been used during the entire drive would have remained below 150 dB re: 1µPa^2-sec not have accumulated, while at WAB-5 the Accumulated SEL would have been approximately 185 dB re: 1µPa^2-sec. It is not clear what part of the higher level can be attributed to the pile not being vibrated in to the same depth that WAB-1 through WAB –4 were or was there a difference in the substrate that caused the

- Based on the measurements predictions can be made for future pile driving on this project. These predictions would be based on the assumptions that the piles will be driven with the same type process and the soil type will be the same as where the pile were driven for the test pile project. A conservative 20log function can be use when predicting noise levels from pile driving at 500 meters. A 25log function fits best for distances up to 200-meters. This should allow for a conservative impact assessment.

8.0 REFERENCES

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9.0 GLOSSARY OF TERMS

Ambient Sound Level - The background sound level, which is a composite of sound from all sources near and far. The normal or existing level of environmental sound at a given location.

Attenuation – A decrease in sound pressure at a receiver caused by a physical or mechanical difference in system. A physical barrier will often cause attenuation in sound pressures when place in between a noise source and a noise receiver.

Digital Audio Tape (DAT) – Underwater sounds were measured and stored digitally on digital audiotapes using a Sony Model TCD-D100 DAT Recorder for playback and subsequent analysis.

Decibel (dB) – A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for water is 1 micro Pascal (µPa) and air is 20 micro Pascals (the threshold of healthy human audibility).

Frequency Spectrum – Distribution of sound pressure vs. frequency for a waveform, dimension in RMS pressure and defined frequency bandwidth.

Hertz (Hz) – A unit of frequency. Defined as the number of complete oscillations of a quantity during a period of time. Hertz is equivalent to cycles per second. Normal human hearing is between 20 Hz and 20,000 Hz. Infrasonic sounds are below 20 Hz and Ultrasonic sounds are above 20,000 Hz.

Impulse – Impulse is defined as the time integral of a force. It recognizes that a short duration pulse may do less damage than a longer duration pulse of the same pressure. Sound pressure is equivalent to kilowatts while impulse is equivalent to kilowatt-hours. It is typically described in units of psi/msec.

Kilo Joule (kJ) – A unit of energy equal to one thousand Joules, or one Newton-meter. One kilo Joule of energy will move a body exerting one kilo Newton of resistance a distance of one meter. One kilo Joule is equivalent to 738 foot-pounds (ft-lbs).

MHU 500T – Menck hydraulic hammer, underwater series, with an energy range of 50 to 550 kilojoules and maximum blow rate of 38 blows per minute.

MHU 1700T – Menck hydraulic hammer, underwater series, with an energy range of 70 to 1,730 kilojoules and maximum blow rate of 35 blows per minute.

Micro Pascal (µPa) – A unit of pressure that is equal to one millionth of a Pascal. Most underwater acoustic sound pressure levels are reported with a reference pressure of one micro Pascal.

Monitoring Pile – A large (2.5-meter) diameter steel pipe pile. Each pile consisted of two sections. Monitoring was usually conducted only when the last section of the pile was driven. Small temporary piles were not monitored.

Acoustic near field – An area in close proximity to a noise source where appreciable variations in sound pressure may exist along a given radius or annulus to the noise source.

Pascal (Pa) – A unit of pressure equal to one Newton per square meter.

Peak Sound Pressure (unweighted), dB re 1 µPa - Peak sound pressure level based on the largest absolute value of the instantaneous sound pressure over the frequency range from 20 Hz to 20,000 Hz. This pressure is expressed in this report as a decibel (referenced to a pressure of 1 µPa) but can also be expressed in units of pressure, such as µPa or PSI.

Pier – The new East Span will consist of two side-by-side bridge structures, supported by a series of piers. Each pier will be supported by 6 piles. Piers for the Skyway, located to the east of the main span, are labeled E2 through E16. An “E” at the end of the label denotes eastbound and a “W” denotes westbound (e.g., E6E and E6W).

Pile Driving Time – The time period to drive a section of pile to its predetermined elevation.
PSI – A pressure unit, pounds per square inch.
Pulse – A brief and sudden change in a normally constant quantity.

Rise Time – Time interval a signal takes to rise from 10% to 90% of its highest peak.

Root Mean Square – The absolute average of a set of numbers, usually time variant quantity.

Root Mean Square 90% ($RMS_{90\%}$) – The root mean square over the time that comprises 90 percent of the sound energy for one pile driving pulse. Commonly used in repetitive or relatively continuous measurements such as in speech or highway noise. It is not applicable to certain transient signals such as explosions. It is used in calculating longer duration sound pulses such as pile driving pulses. RMS impulse is expressed in dB re 1 micro Pascal measured over the frequency range of 20 Hz to 20 kHz.

RMS Impulse – Maximum root mean square of a quantity measured in an interval. Measured using the standard “impulse” setting of a sound level meter, the time window is 35 milliseconds. RMS impulse is expressed in dB re 1 micro Pascal measured over the frequency range of 20 Hz to 20 kHz.

Sound level Meter (SLM) – Instrument used to measure the underwater sound pressure signals sensed by the hydrophone. A Larson Davis Model 820 precision integrating sound level meter was used to measure underwater sound pressures in the field.

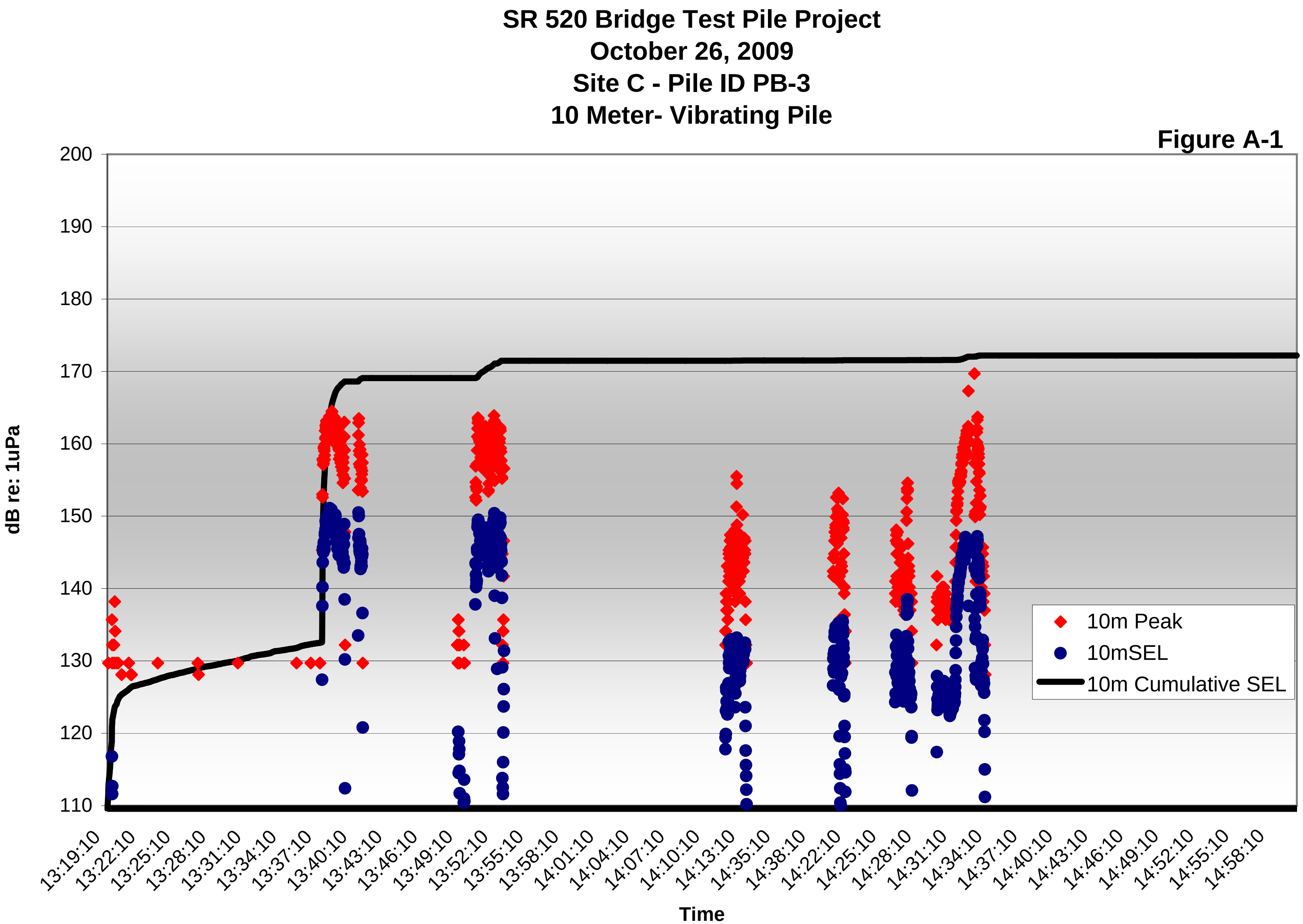
Sound Exposure Level (SEL) – A common unit of sound energy used in airborne acoustics to describe short-duration events. The time integral of frequency weighted squared instantaneous sound pressures. Proportionally equivalent to the time integral of the pressure squared and can be described in terms of μ Pa^2 sec over the duration of the impulse.

Sound Pressure Level (SPL) – Sound pressure is the sound force per unit area, usually expressed in micro Pascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The sound pressure level is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure (e.g., 20 micro Pascals) SPL = 20 log $\left\{ P_1 / 1\mu P_{\partial} \right\}$. Sound pressure level is the quantity that is directly measured by a sound level meter.

Total Acoustic Energy, dB re 1 μPa^2 sec - Proportionally equivalent to the time integral of the pressure squared and is described in this report in terms of μPa^2 sec over the duration of the impulse. Similar to the unweighted Sound Exposure Level (SEL) standardized in airborne acoustics to study noise from single events.

Waveform - A graphical representation of the time variant acoustic pressure of an individual pile driving pulse plotted with the pressure unit micro Pascal (μPa) and the time unit seconds (sec).

Appendix A
Daily Time History Charts of Measured Sound Levels


SR 520 Bridge Test Pile Project
October 26, 2009
Site C - Pile ID PB-3
10 Meter- Vibrating Pile
Figure A-1
dB re: 1uPa
200
190
180
170
160
150
140
130
120
110
10m Peak
10mSEL
10m Cumulative SEL
13:19:10
13:22:10
13:25:10
13:28:10
13:31:10
13:34:10
13:37:10
13:40:10
13:43:10
13:46:10
13:49:10
13:52:10
13:55:10
13:58:10
14:01:10
14:04:10
14:07:10
14:10:10
14:13:10
14:35:10
14:38:10
14:22:10
14:25:10
14:28:10
14:31:10
14:34:10
14:37:10
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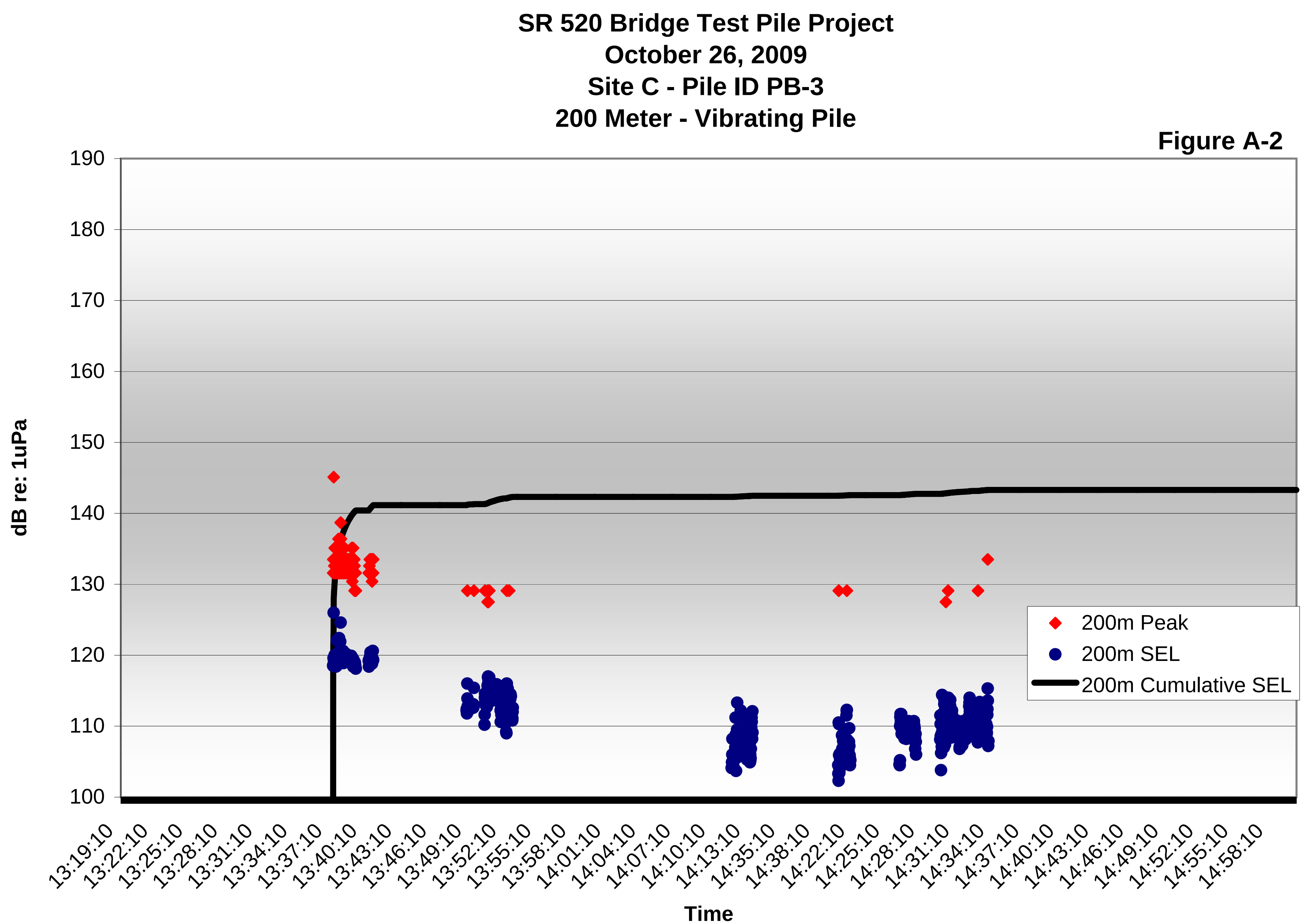
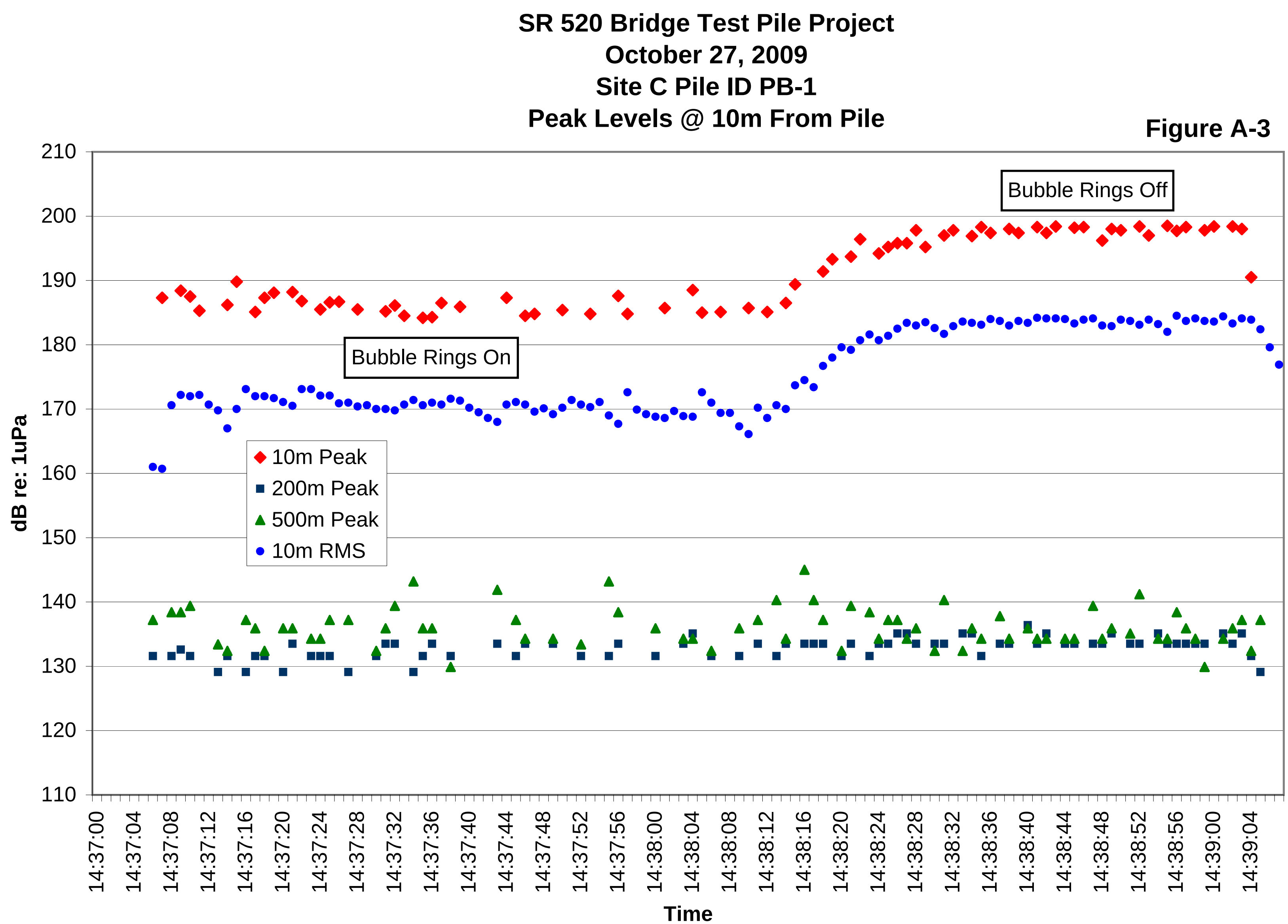
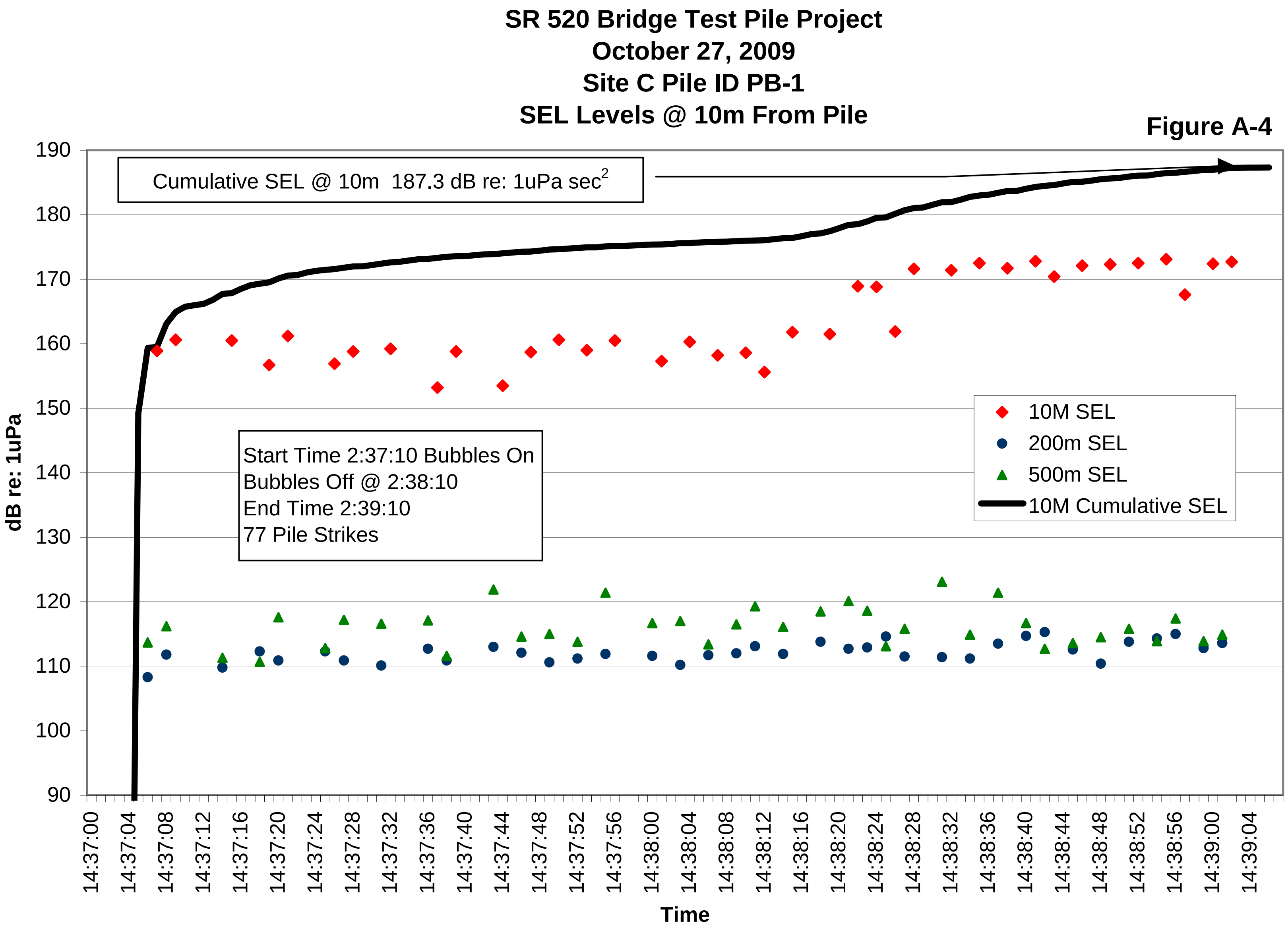
14:43:10
14:46:10
14:49:10
14:52:10
14:55:10
14:58:10
Time


SR 520 Bridge Test Pile Project
October 26, 2009
Site C - Pile ID PB-3
200 Meter - Vibrating Pile
Figure A-2
dB re: 1uPa
190
180
170
160
150
140
130
120
110
100
13:19:10
13:22:10
13:25:10
13:28:10
13:31:10
13:34:10
13:37:10
13:40:10
13:43:10
13:46:10
13:49:10
13:52:10
13:55:10
13:58:10
14:01:10
14:04:10
14:07:10
14:10:10
14:13:10
14:35:10
14:38:10
14:22:10
14:25:10
14:28:10
14:31:10
14:34:10
14:37:10
14:40:10
14:43:10
14:46:10
14:49:10
14:52:10
14:55:10
14:58:10
Time
200m Peak
200m SEL
200m Cumulative SEL



SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-1
Peak Levels @ 10m From Pile
Figure A-3
Bubble Rings Off
Bubble Rings On
10m Peak
200m Peak
500m Peak
10m RMS
dB re: 1uPa
210
200
190
180
170
160
150
140
130
120
110
14:37:00
14:37:04
14:37:08
14:37:12
14:37:16
14:37:20
14:37:24
14:37:28
14:37:32
14:37:36
14:37:40
14:37:44
14:37:48
14:37:52
14:37:56
14:38:00
14:38:04
14:38:08
14:38:12
14:38:16
14:38:20
14:38:24
14:38:28
14:38:32
14:38:36
14:38:40
14:38:44
14:38:48
14:38:52
14:38:56
14:39:00
14:39:04
Time


SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-1
SEL Levels @ 10m From Pile
Figure A-4
Cumulative SEL @ 10m 187.3 dB re: 1uPa sec2
Start Time 2:37:10 Bubbles On
Bubbles Off @ 2:38:10
End Time 2:39:10
77 Pile Strikes
10M SEL
200m SEL
500m SEL
10M Cumulative SEL
dB re: 1uPa
Time
190
180
170
160
150
140
130
120
110
100
90
14:37:00
14:37:04
14:37:08
14:37:12
14:37:16
14:37:20
14:37:24
14:37:28
14:37:32
14:37:36
14:37:40
14:37:44
14:37:48
14:37:52
14:37:56
14:38:00
14:38:04
14:38:08
14:38:12
14:38:16
14:38:20
14:38:24
14:38:28
14:38:32
14:38:36
14:38:40
14:38:44
14:38:48
14:38:52
14:38:56
14:39:00
14:39:04

SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-2
Peak Levels @ 10m From Pile

Figure A-5

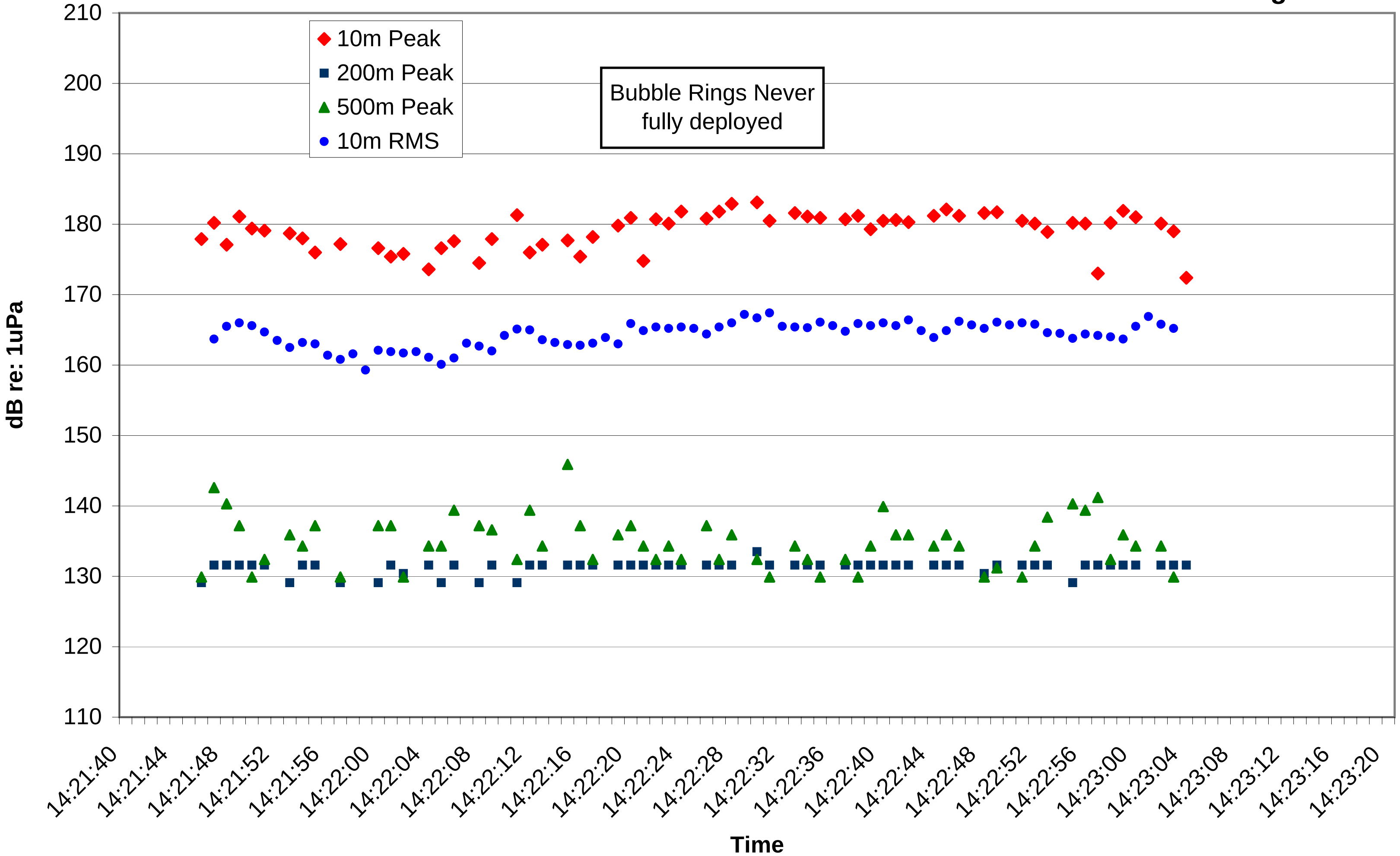
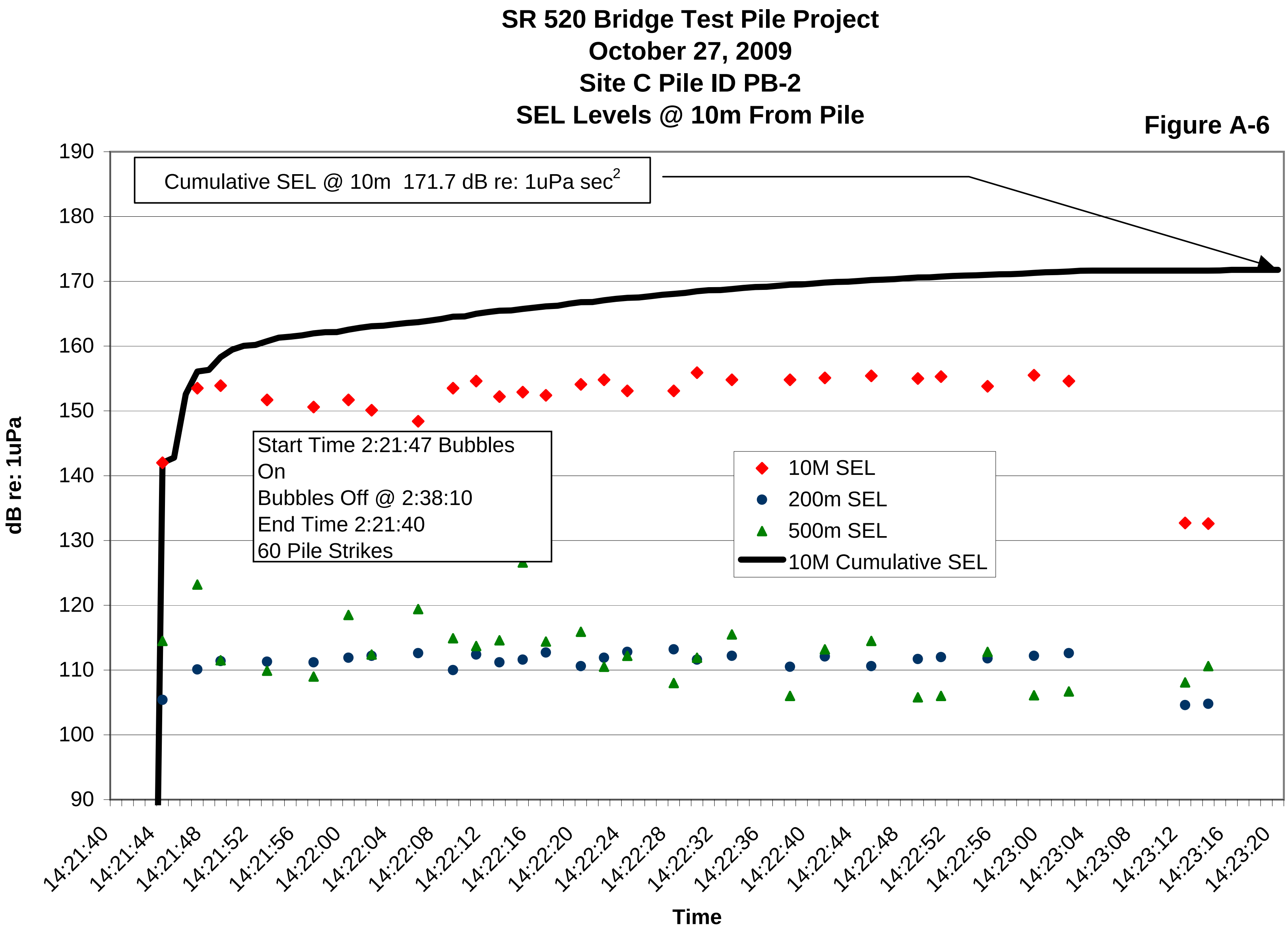
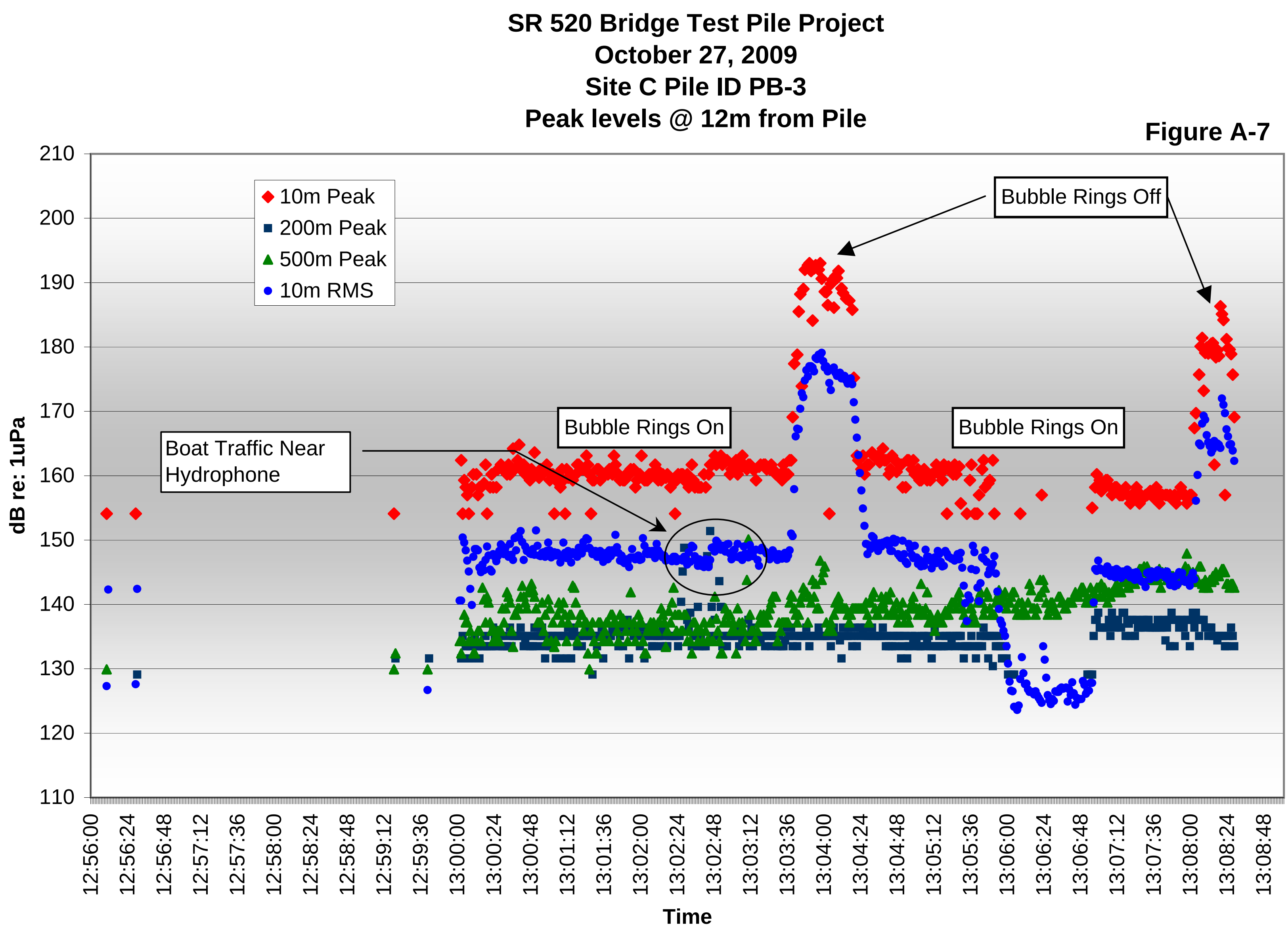


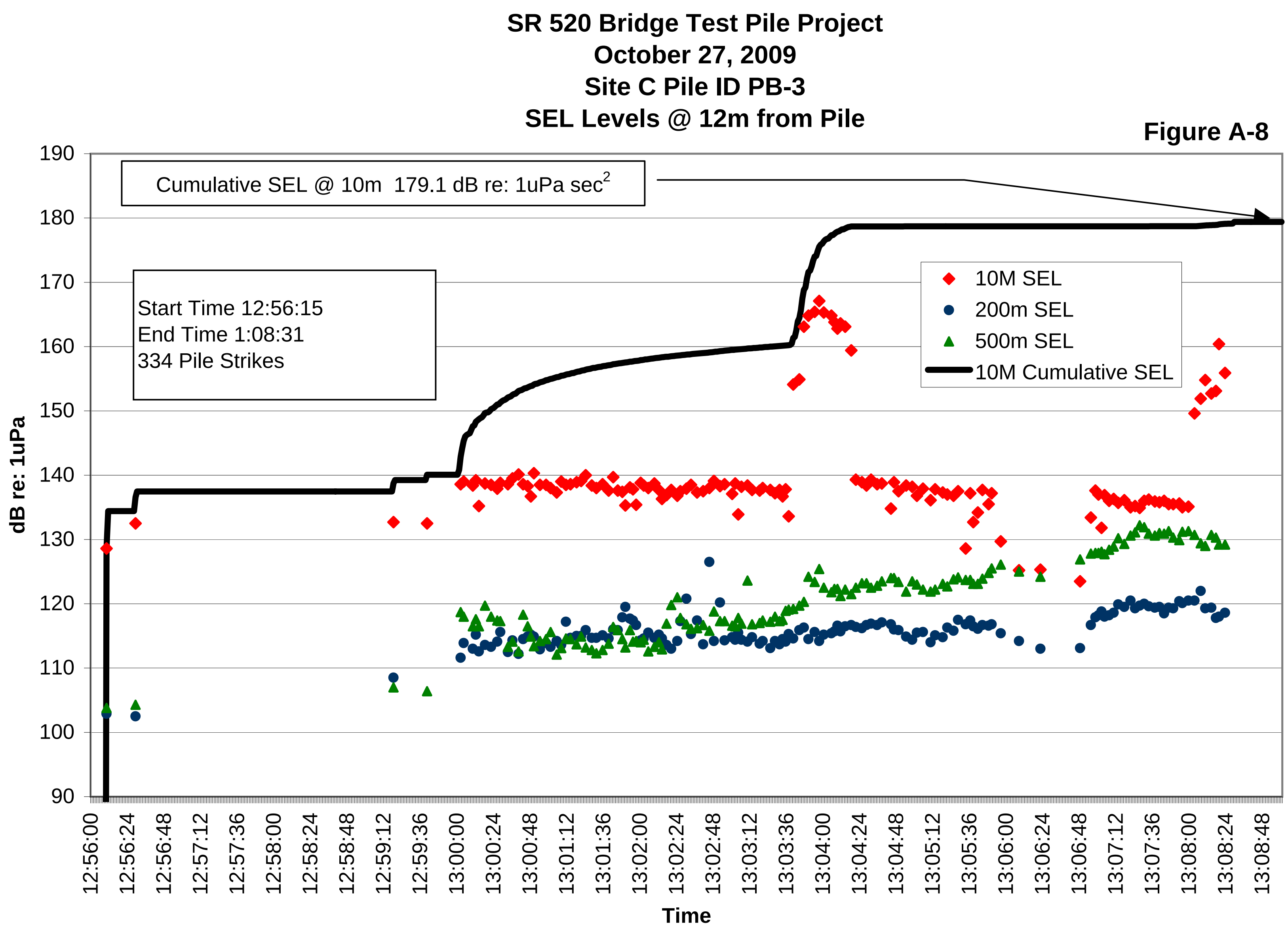
Figure A-6



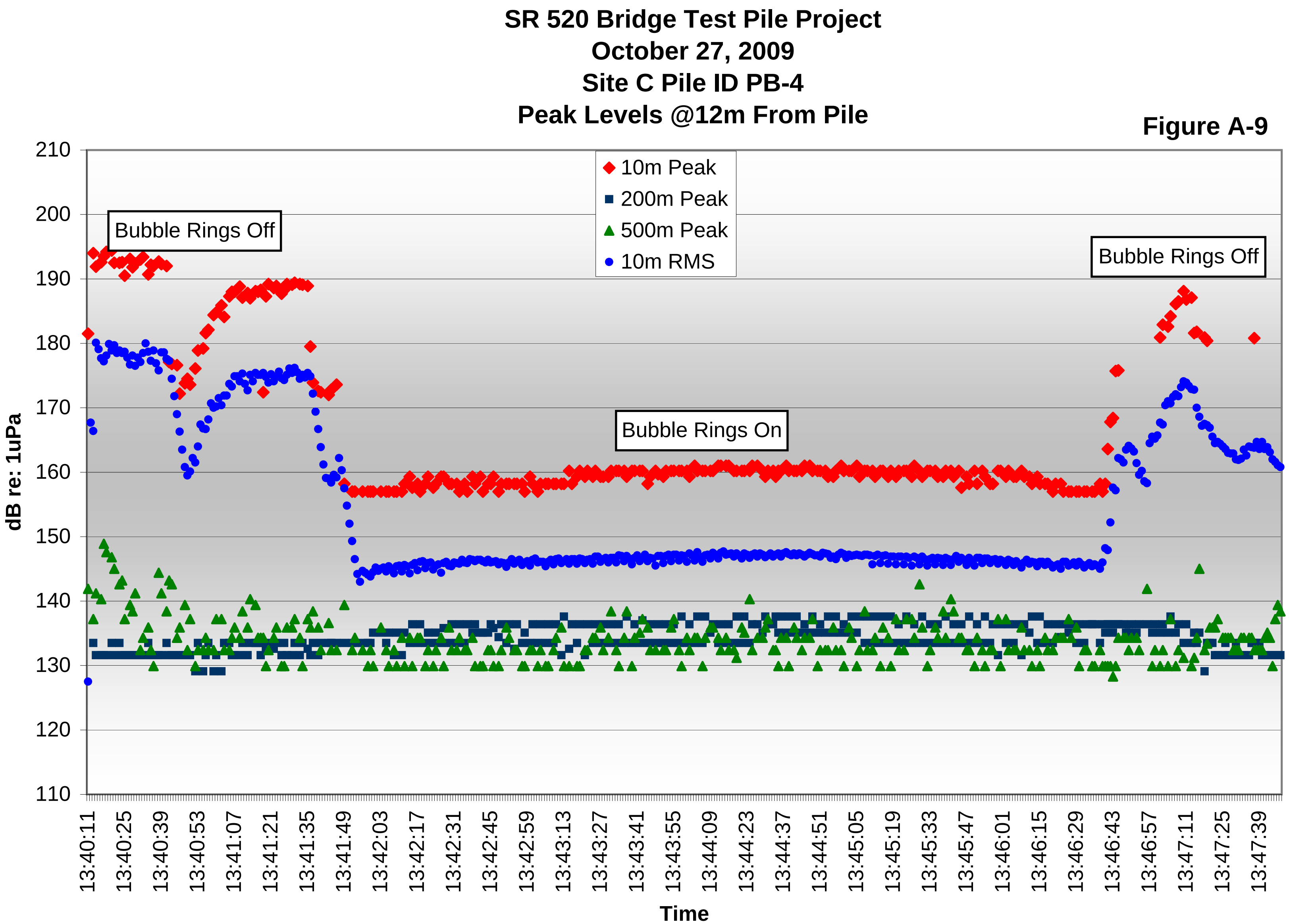
SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-2
SEL Levels @ 10m From Pile
Cumulative SEL @ 10m 171.7 dB re: 1uPa sec2
Start Time 2:21:47 Bubbles On
Bubbles Off @ 2:38:10
End Time 2:21:40
60 Pile Strikes
10M SEL
200m SEL
500m SEL
10M Cumulative SEL
dB re: 1uPa
Time
190
180
170
160
150
140
130
120
110
100
90
14:21:40
14:21:44
14:21:48
14:21:52
14:21:56
14:22:00
14:22:04
14:22:08
14:22:12
14:22:16
14:22:20
14:22:24
14:22:28
14:22:32
14:22:36
14:22:40
14:22:44
14:22:48
14:22:52
14:22:56
14:23:00
14:23:04
14:23:08
14:23:12
14:23:16
14:23:20

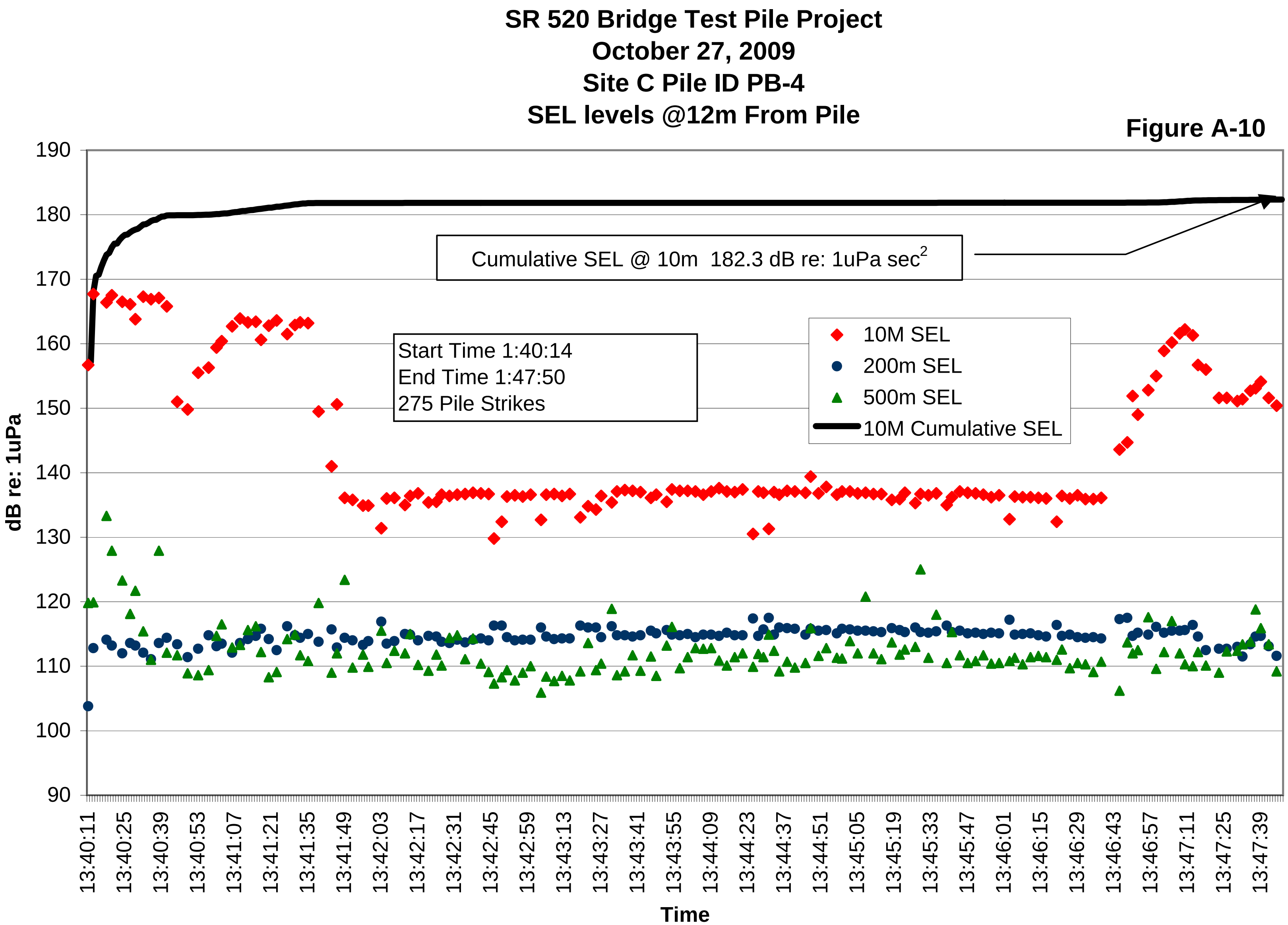


SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-3
Peak levels @ 12m from Pile
Figure A-7
10m Peak
200m Peak
500m Peak
10m RMS
Bubble Rings Off
Bubble Rings On
Bubble Rings On
Boat Traffic Near Hydrophone
dB re: 1uPa
Time
210
200
190
180
170
160
150
140
130
120
110
12:56:00
12:56:24
12:56:48
12:57:12
12:57:36
12:58:00
12:58:24
12:58:48
12:59:12
12:59:36
13:00:00
13:00:24
13:00:48
13:01:12
13:01:36
13:02:00
13:02:24
13:02:48
13:03:12
13:03:36
13:04:00
13:04:24
13:04:48
13:05:12
13:05:36
13:06:00
13:06:24
13:06:48
13:07:12
13:07:36
13:08:00
13:08:24
13:08:48



SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-3
SEL Levels @ 12m from Pile
Figure A-8
Cumulative SEL @ 10m 179.1 dB re: 1uPa sec2
Start Time 12:56:15
End Time 1:08:31
334 Pile Strikes
10M SEL
200m SEL
500m SEL
10M Cumulative SEL
dB re: 1uPa
190
180
170
160
150
140
130
120
110
100
90
12:56:00
12:56:24
12:56:48
12:57:12
12:57:36
12:58:00
12:58:24
12:58:48
12:59:12
12:59:36
13:00:00
13:00:24
13:00:48
13:01:12
13:01:36
13:02:00
13:02:24
13:02:48
13:03:12
13:03:36
13:04:00
13:04:24
13:04:48
13:05:12
13:05:36
13:06:00
13:06:24
13:06:48
13:07:12
13:07:36
13:08:00
13:08:24
13:08:48
Time


SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-4
Peak Levels @12m From Pile
Figure A-9
10m Peak
200m Peak
500m Peak
10m RMS
Bubble Rings Off
Bubble Rings On
Bubble Rings Off
dB re: 1uPa
210
200
190
180
170
160
150
140
130
120
110
Time
13:40:11
13:40:25
13:40:39
13:40:53
13:41:07
13:41:21
13:41:35
13:41:49
13:42:03
13:42:17
13:42:31
13:42:45
13:42:59
13:43:13
13:43:27
13:43:41
13:43:55
13:44:09
13:44:23
13:44:37
13:44:51
13:45:05
13:45:19
13:45:33
13:45:47
13:46:01
13:46:15
13:46:29
13:46:43
13:46:57
13:47:11
13:47:25
13:47:39


SR 520 Bridge Test Pile Project
October 27, 2009
Site C Pile ID PB-4
SEL levels @12m From Pile
Figure A-10
Cumulative SEL @ 10m 182.3 dB re: 1uPa sec^2
Start Time 1:40:14
End Time 1:47:50
275 Pile Strikes
10M SEL
200m SEL
500m SEL
10M Cumulative SEL
dB re: 1uPa
190
180
170
160
150
140
130
120
110
100
90
13:40:11
13:40:25
13:40:39
13:40:53
13:41:07
13:41:21
13:41:35
13:41:49
13:42:03
13:42:17
13:42:31
13:42:45
13:42:59
13:43:13
13:43:27
13:43:41
13:43:55
13:44:09
13:44:23
13:44:37
13:44:51
13:45:05
13:45:19
13:45:33
13:45:47
13:46:01
13:46:15
13:46:29
13:46:43
13:46:57
13:47:11
13:47:25
13:47:39
Time

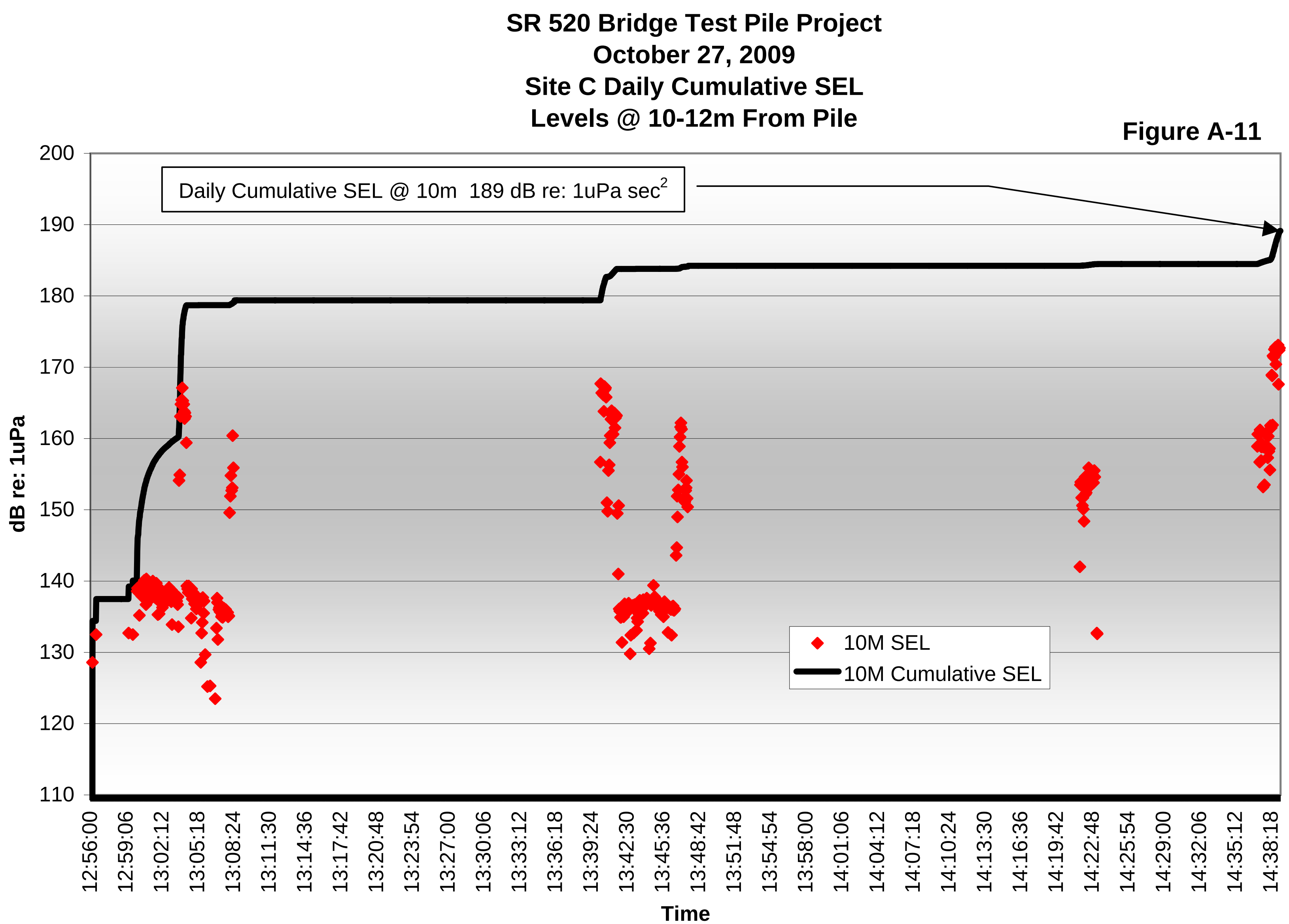
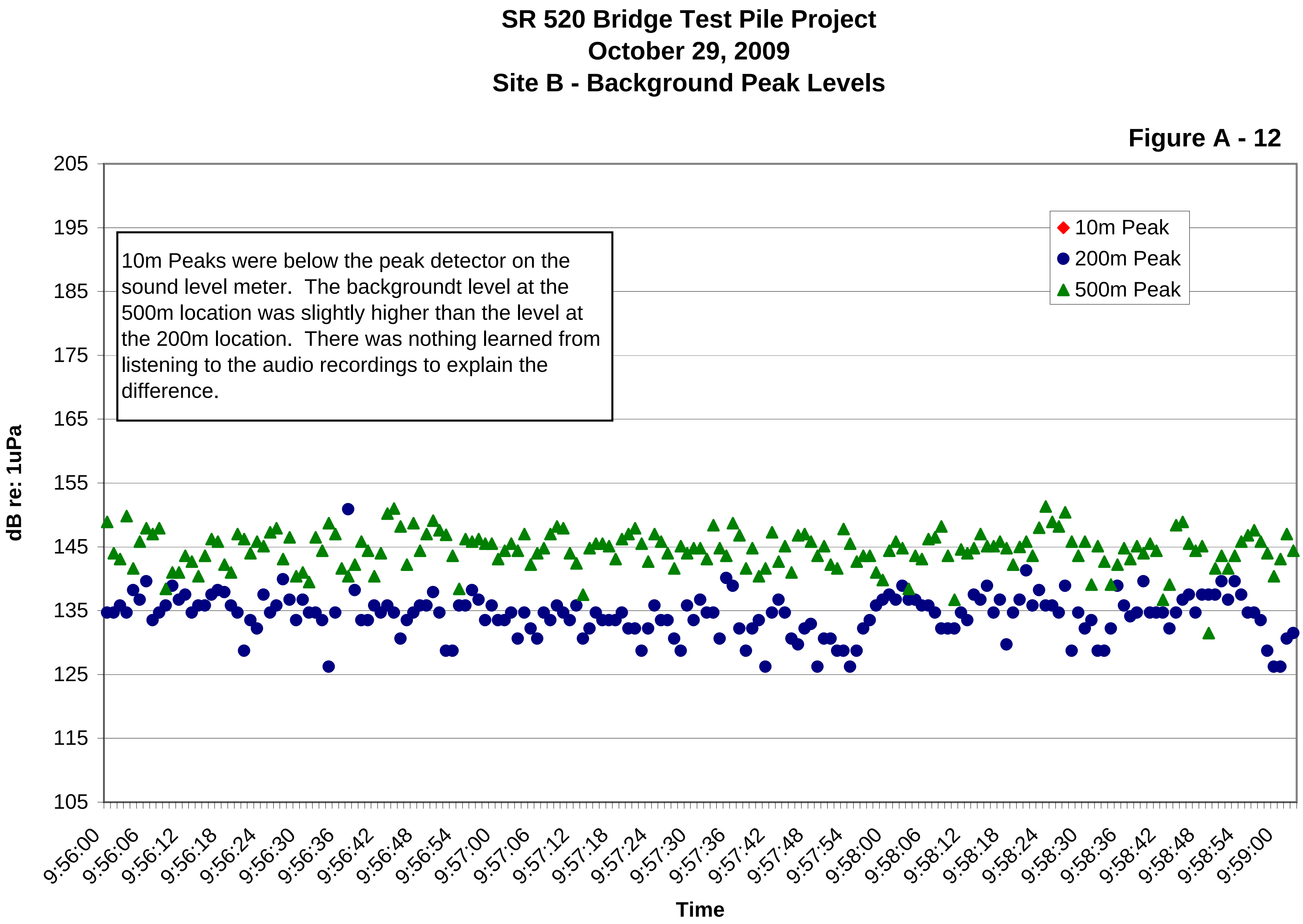
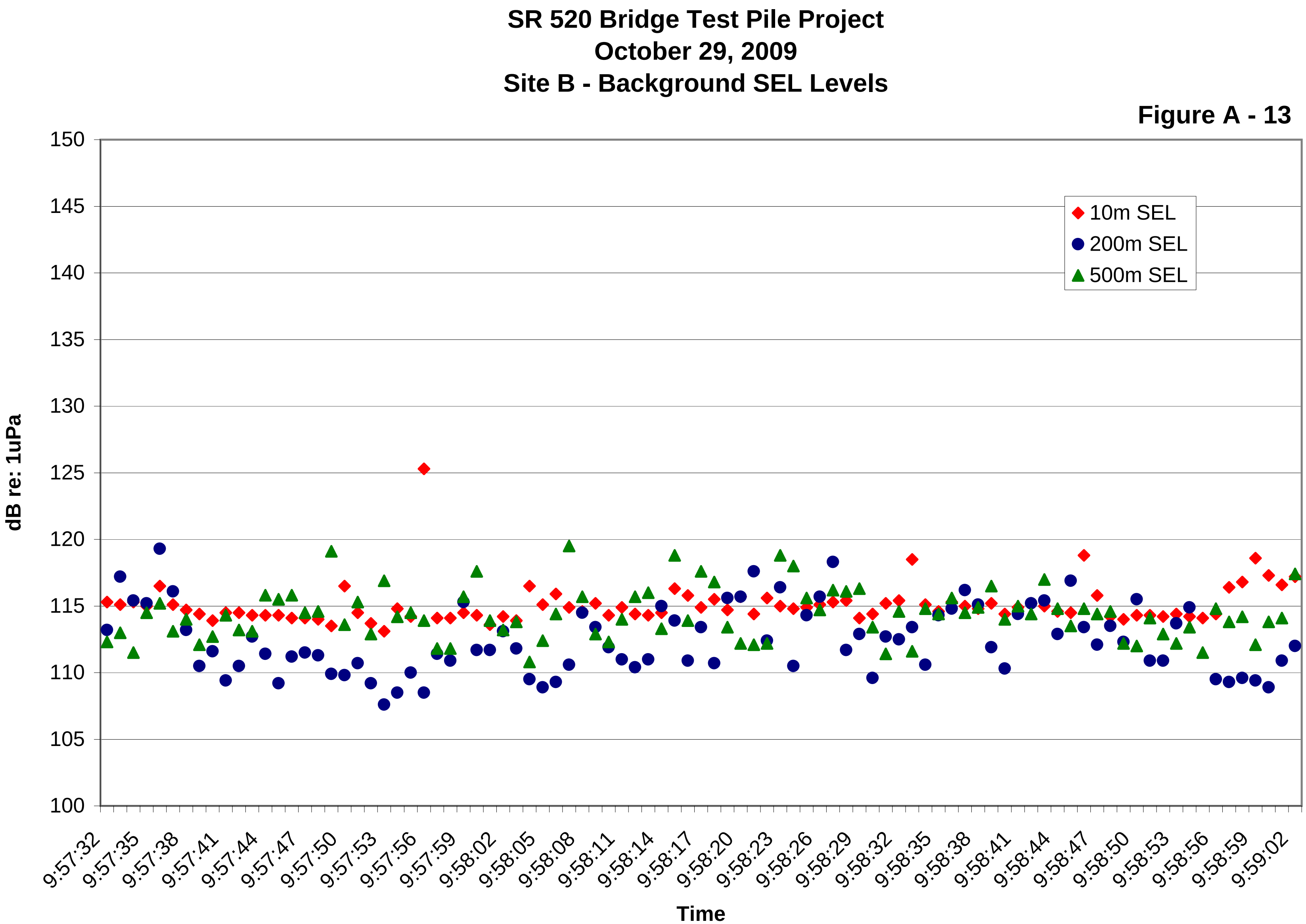

SR 520 Bridge Test Pile Project
October 27, 2009
Site C Daily Cumulative SEL
Levels @ 10-12m From Pile
Figure A-11
Daily Cumulative SEL @ 10m 189 dB re: 1uPa sec2
dB re: 1uPa
200
190
180
170
160
150
140
130
120
110
10M SEL
10M Cumulative SEL
12:56:00
12:59:06
13:02:12
13:05:18
13:08:24
13:11:30
13:14:36
13:17:42
13:20:48
13:23:54
13:27:00
13:30:06
13:33:12
13:36:18
13:39:24
13:42:30
13:45:36
13:48:42
13:51:48
13:54:54
13:58:00
14:01:06
14:04:12
14:07:18
14:10:24
14:13:30
14:16:36
14:19:42
14:22:48
14:25:54
14:29:00
14:32:06
14:35:12
14:38:18
Time

Figure A - 12

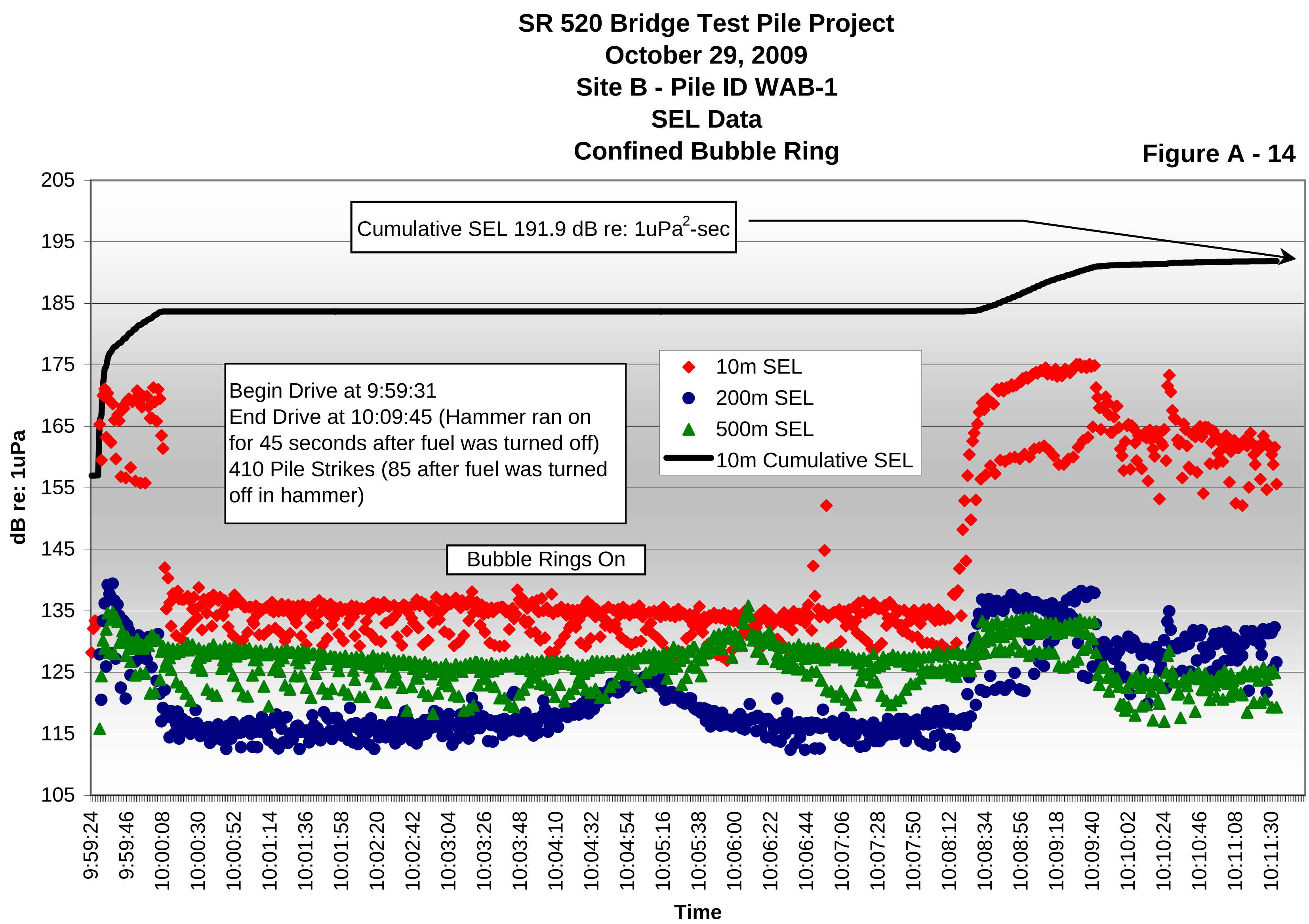


SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Background Peak Levels
10m Peaks were below the peak detector on the sound level meter. The backgroundt level at the 500m location was slightly higher than the level at the 200m location. There was nothing learned from listening to the audio recordings to explain the difference.
10m Peak
200m Peak
500m Peak
dB re: 1uPa
205
195
185
175
165
155
145
135
125
115
105
9:56:00
9:56:06
9:56:12
9:56:18
9:56:24
9:56:30
9:56:36
9:56:42
9:56:48
9:56:54
9:57:00
9:57:06
9:57:12
9:57:18
9:57:24
9:57:30
9:57:36
9:57:42
9:57:48
9:57:54
9:58:00
9:58:06
9:58:12
9:58:18
9:58:24
9:58:30
9:58:36
9:58:42
9:58:48
9:58:54
9:59:00
Time

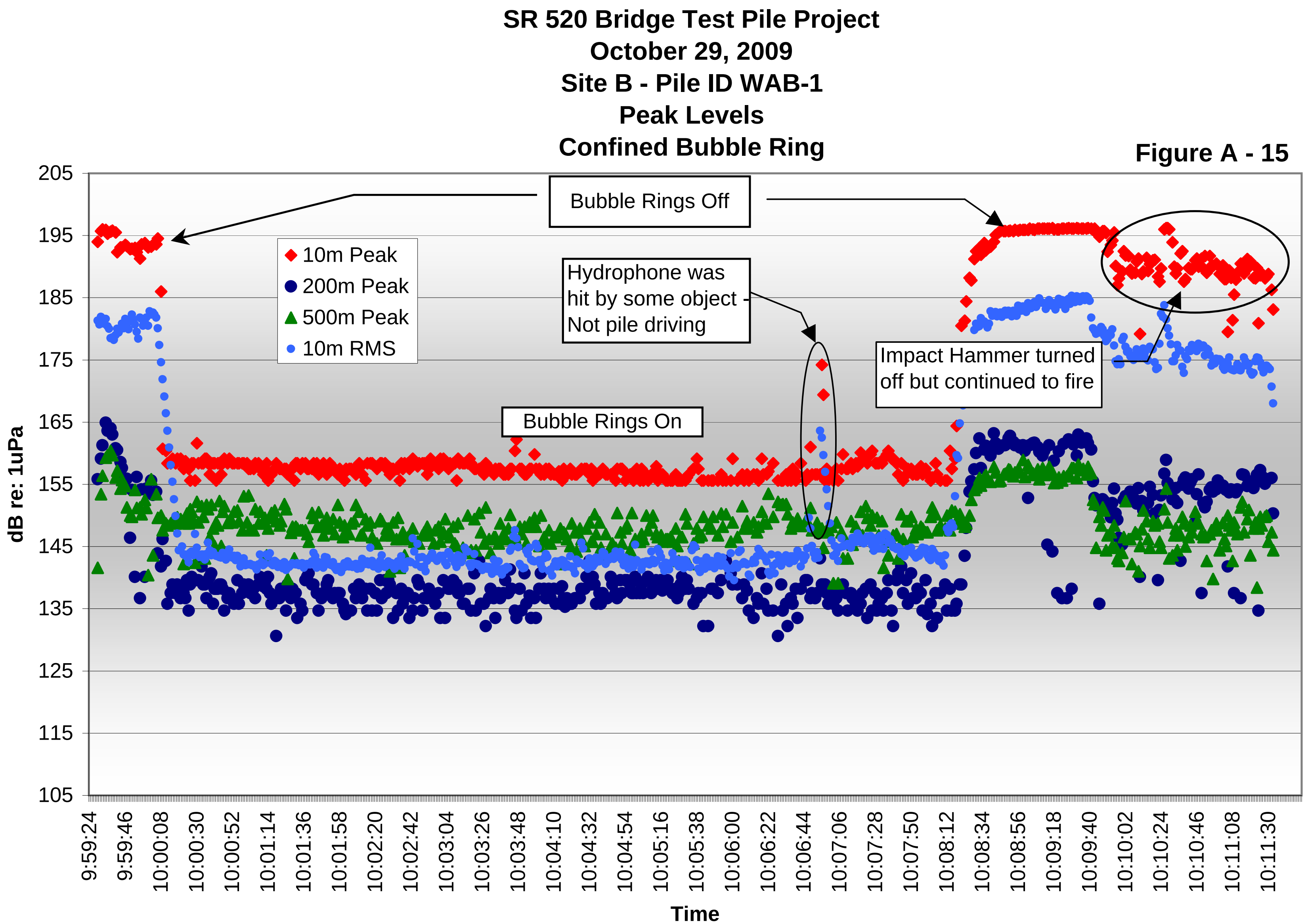


SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Background SEL Levels
Figure A - 13
10m SEL
200m SEL
500m SEL
dB re: 1uPa
150
145
140
135
130
125
120
115
110
105
100
9:57:32
9:57:35
9:57:38
9:57:41
9:57:44
9:57:47
9:57:50
9:57:53
9:57:56
9:57:59
9:58:02
9:58:05
9:58:08
9:58:11
9:58:14
9:58:17
9:58:20
9:58:23
9:58:26
9:58:29
9:58:32
9:58:35
9:58:38
9:58:41
9:58:44
9:58:47
9:58:50
9:58:53
9:58:56
9:58:59
9:59:02
Time

Figure A - 14

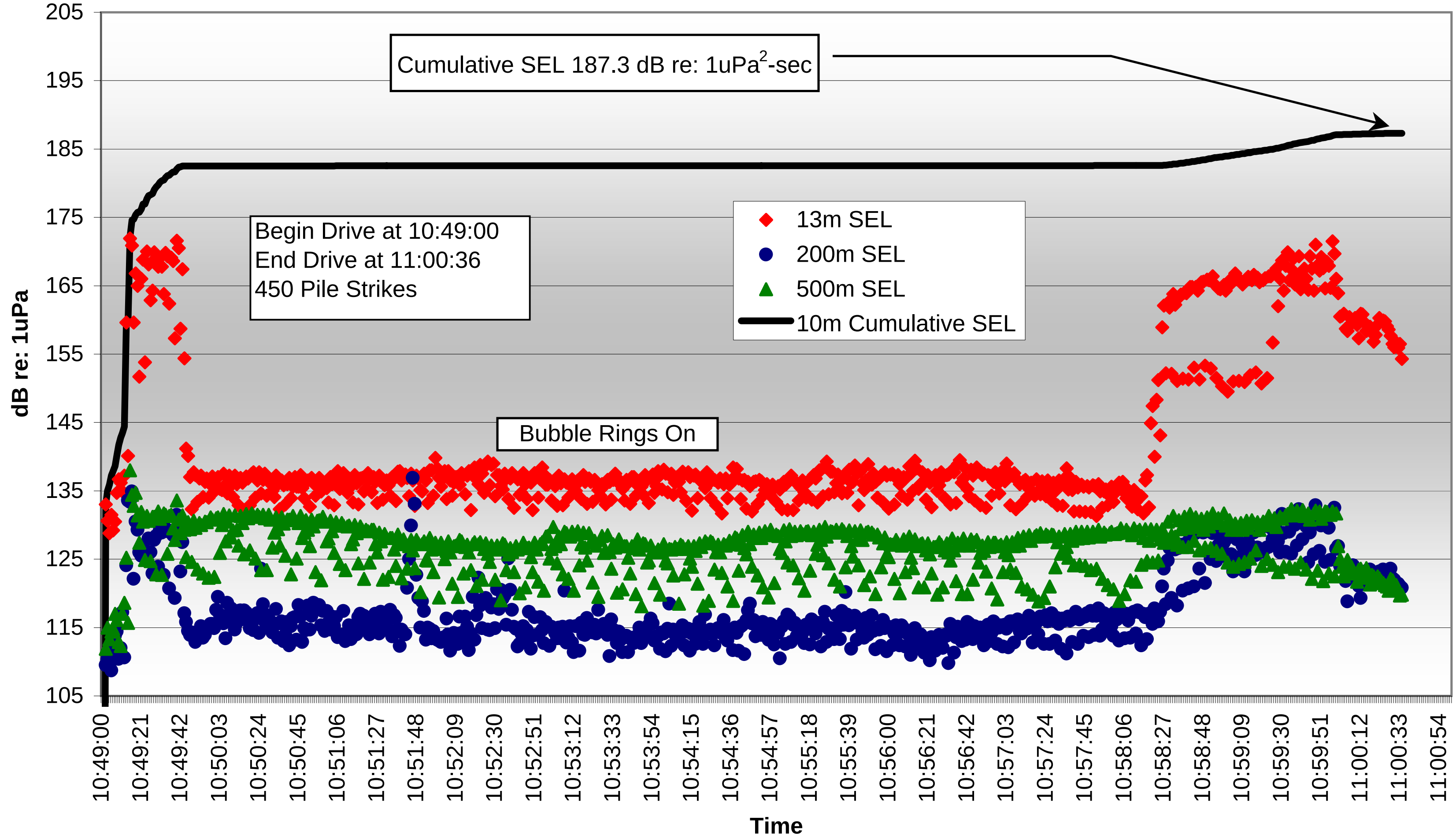


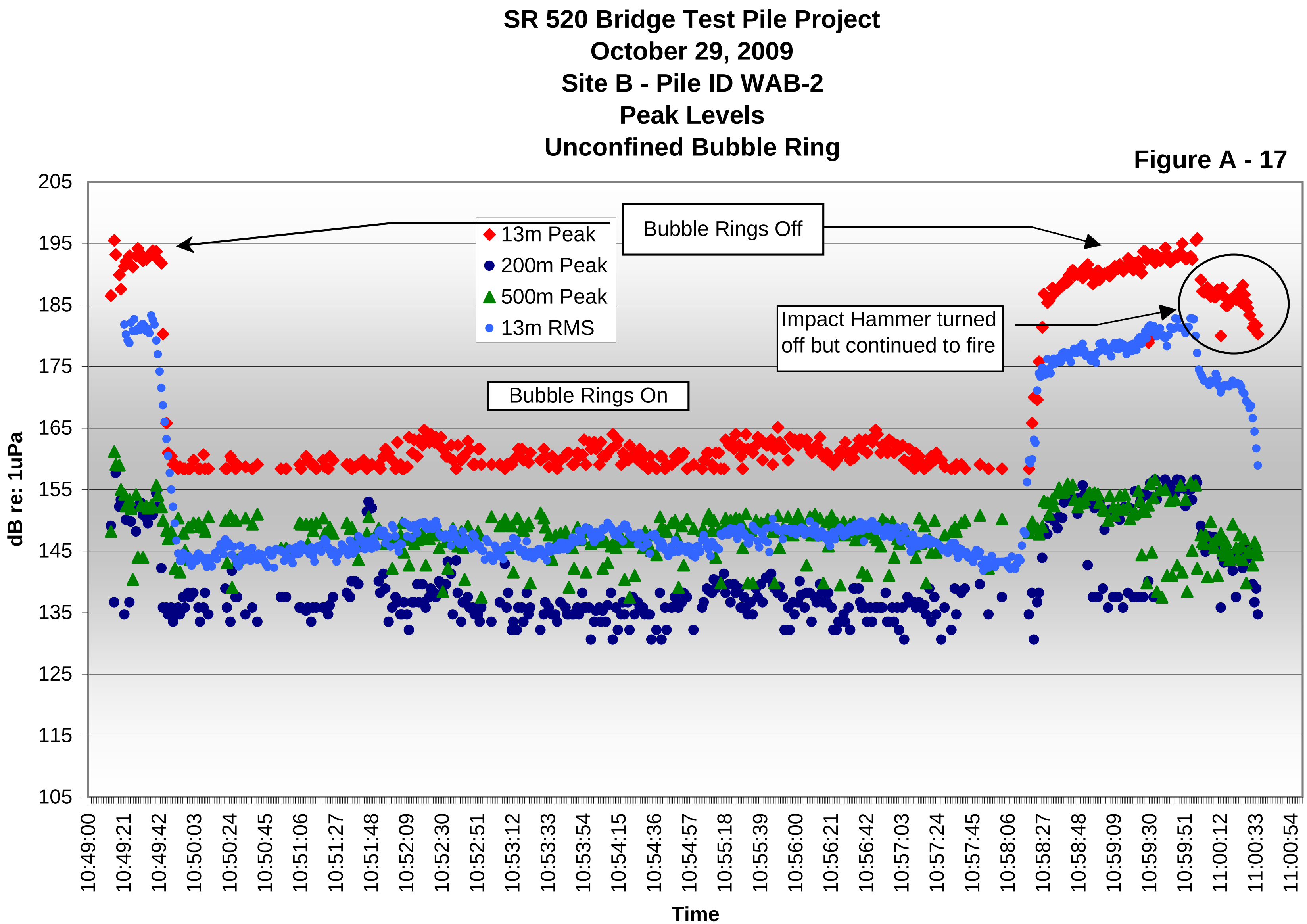
SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-1
SEL Data
Confined Bubble Ring
Cumulative SEL 191.9 dB re: 1uPa2-sec
Begin Drive at 9:59:31
End Drive at 10:09:45 (Hammer ran on for 45 seconds after fuel was turned off)
410 Pile Strikes (85 after fuel was turned off in hammer)
Bubble Rings On
10m SEL
200m SEL
500m SEL
10m Cumulative SEL
dB re: 1uPa
Time
205
195
185
175
165
155
145
135
125
115
105
9:59:24
9:59:46
10:00:08
10:00:30
10:00:52
10:01:14
10:01:36
10:01:58
10:02:20
10:02:42
10:03:04
10:03:26
10:03:48
10:04:10
10:04:32
10:04:54
10:05:16
10:05:38
10:06:00
10:06:22
10:06:44
10:07:06
10:07:28
10:07:50
10:08:12
10:08:34
10:08:56
10:09:18
10:09:40
10:10:02
10:10:24
10:10:46
10:11:08
10:11:30


SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-1
Peak Levels
Confined Bubble Ring
Figure A - 15
Bubble Rings Off
10m Peak
200m Peak
500m Peak
10m RMS
Hydrophone was hit by some object - Not pile driving
Impact Hammer turned off but continued to fire
Bubble Rings On
dB re: 1uPa
205
195
185
175
165
155
145
135
125
115
105
9:59:24
9:59:46
10:00:08
10:00:30
10:00:52
10:01:14
10:01:36
10:01:58
10:02:20
10:02:42
10:03:04
10:03:26
10:03:48
10:04:10
10:04:32
10:04:54
10:05:16
10:05:38
10:06:00
10:06:22
10:06:44
10:07:06
10:07:28
10:07:50
10:08:12
10:08:34
10:08:56
10:09:18
10:09:40
10:10:02
10:10:24
10:10:46
10:11:08
10:11:30
Time

SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-2
SEL Data
Unconfined Bubble Ring

Figure A - 16

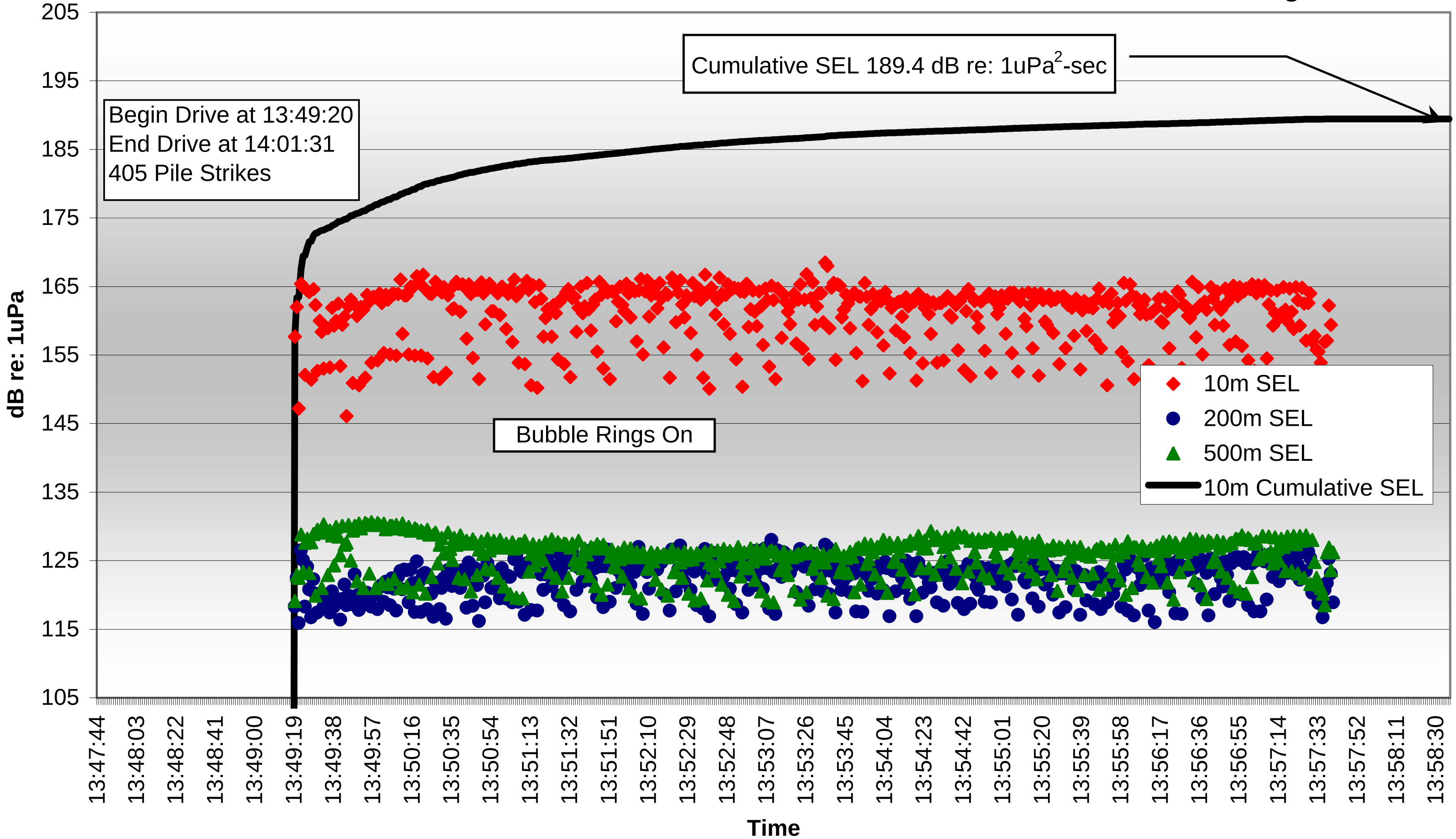


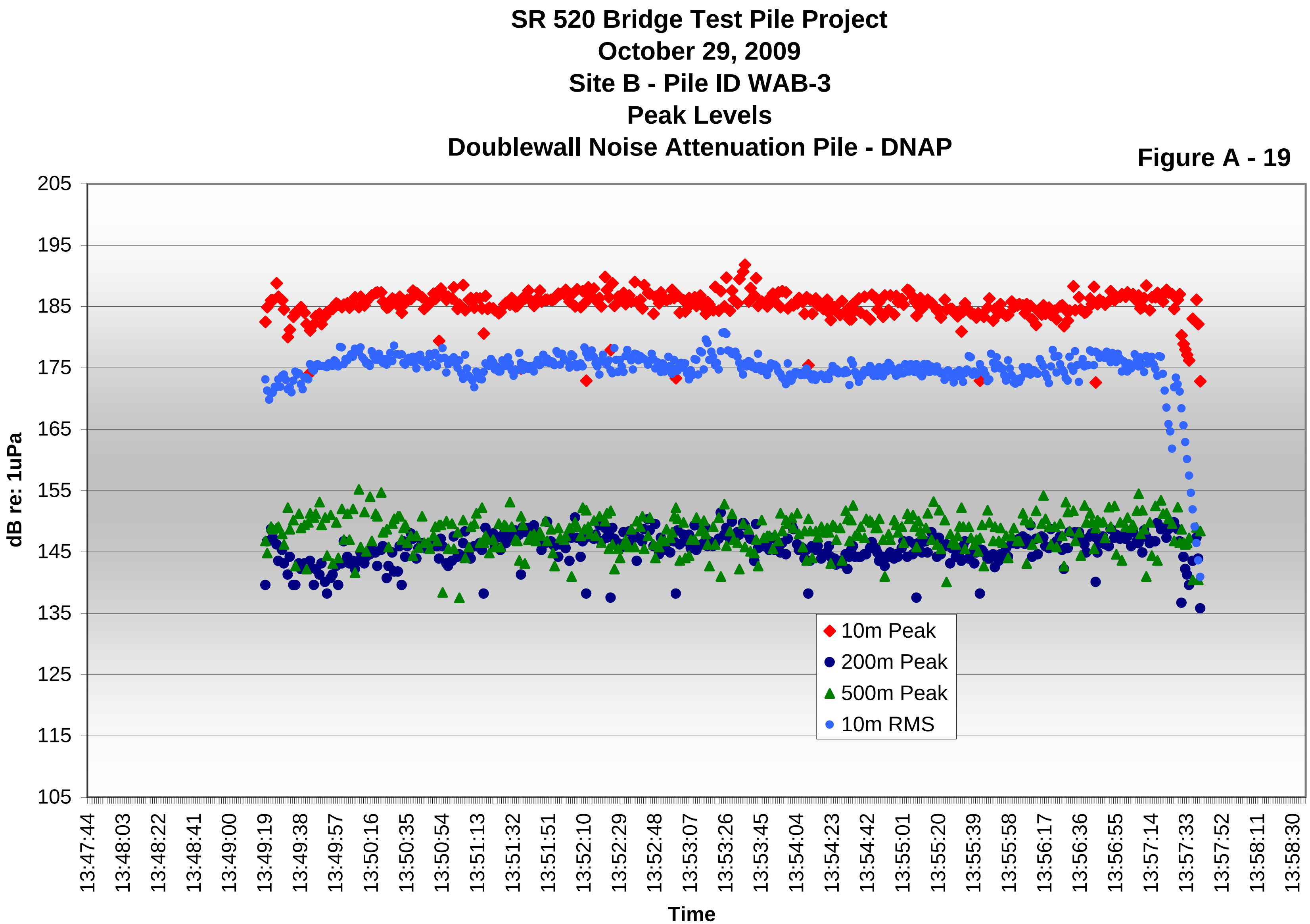


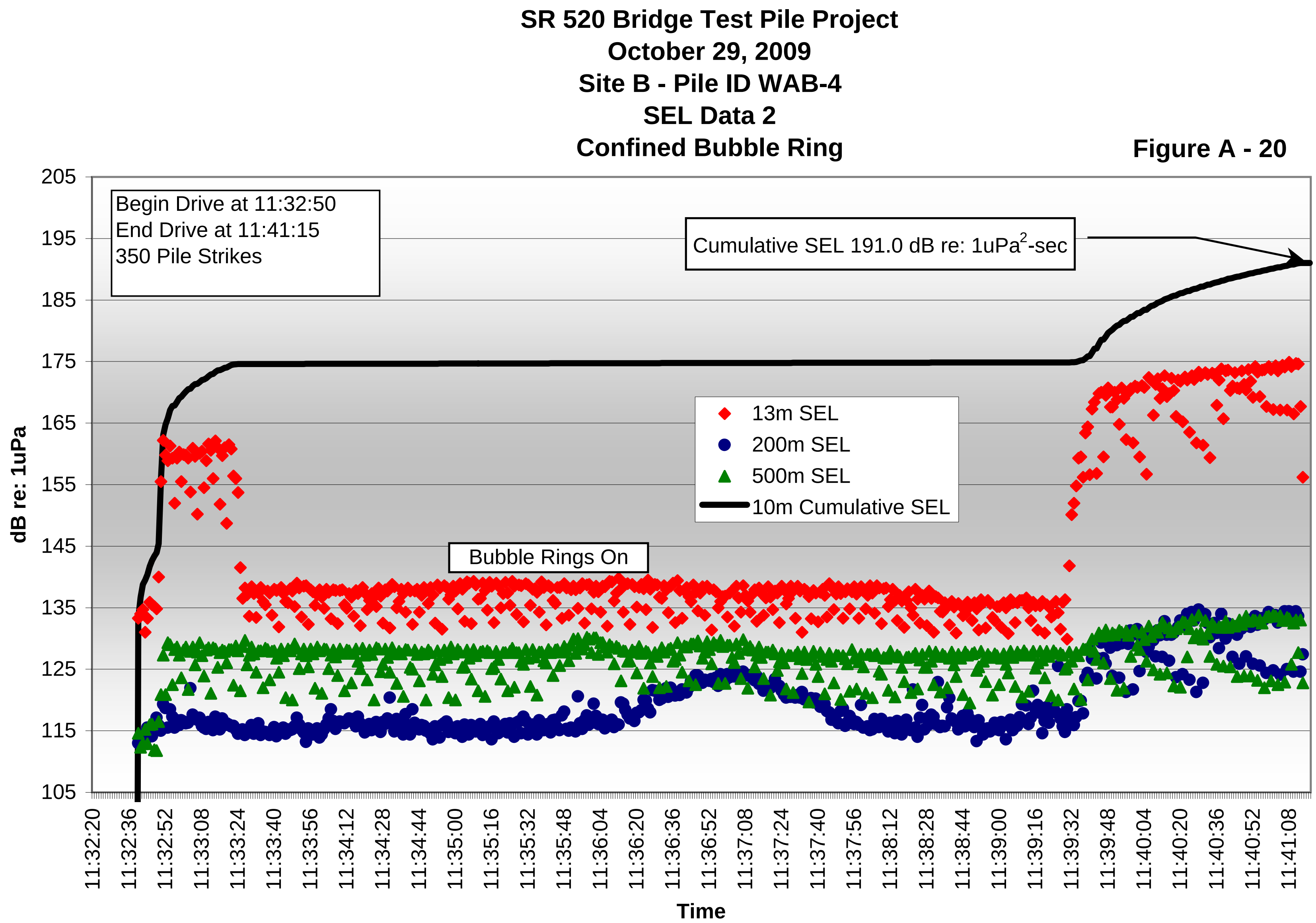
SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-2
Peak Levels
Unconfined Bubble Ring
Figure A - 17
13m Peak
200m Peak
500m Peak
13m RMS
Bubble Rings Off
Bubble Rings On
Impact Hammer turned off but continued to fire
dB re: 1uPa
Time
205
195
185
175
165
155
145
135
125
115
105
10:49:00
10:49:21
10:49:42
10:50:03
10:50:24
10:50:45
10:51:06
10:51:27
10:51:48
10:52:09
10:52:30
10:52:51
10:53:12
10:53:33
10:53:54
10:54:15
10:54:36
10:54:57
10:55:18
10:55:39
10:56:00
10:56:21
10:56:42
10:57:03
10:57:24
10:57:45
10:58:06
10:58:27
10:58:48
10:59:09
10:59:30
10:59:51
11:00:12
11:00:33
11:00:54

SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-3
SEL Data
Doublewall Noise Attenuation Pile - DNAP

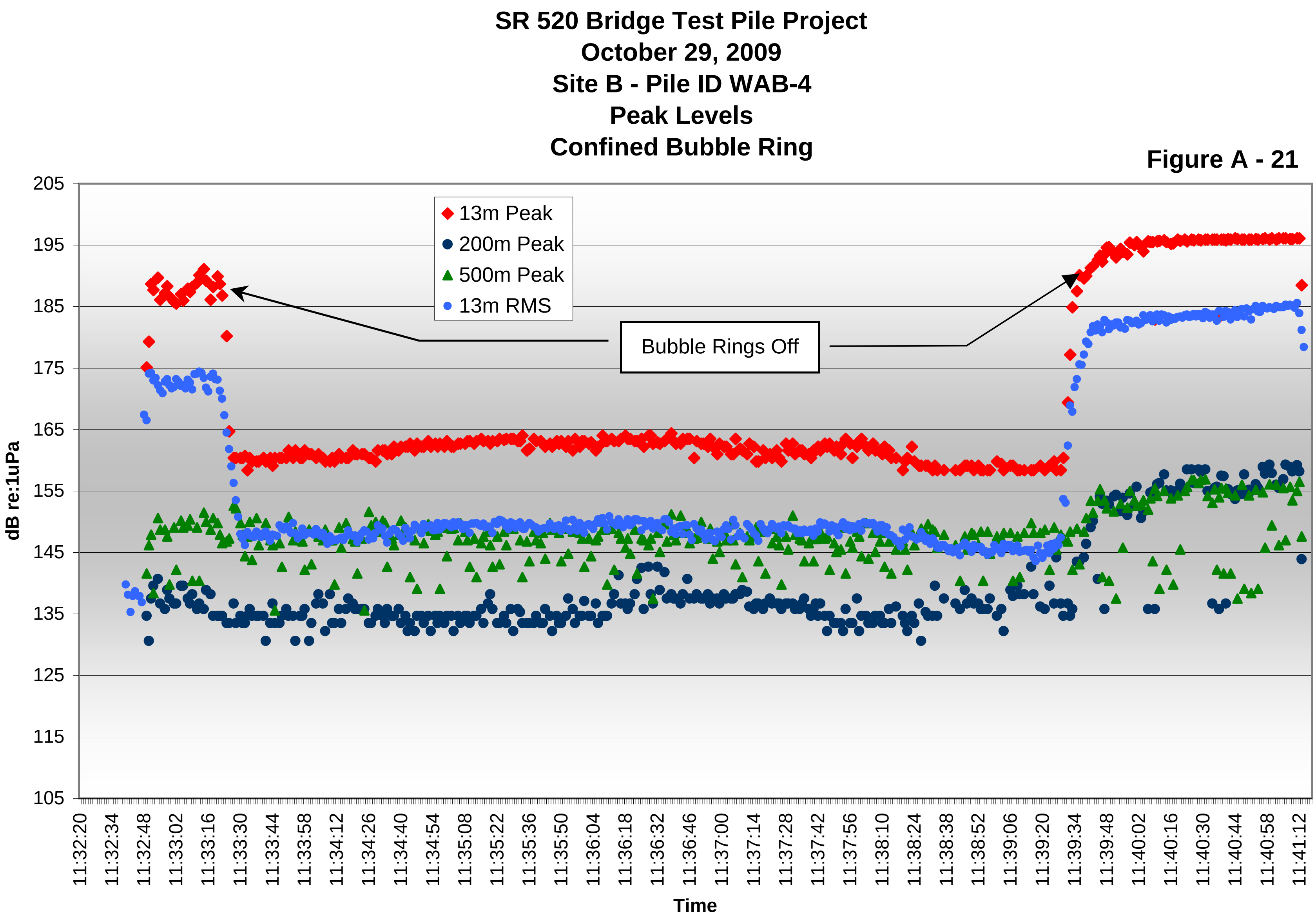
Figure A - 18

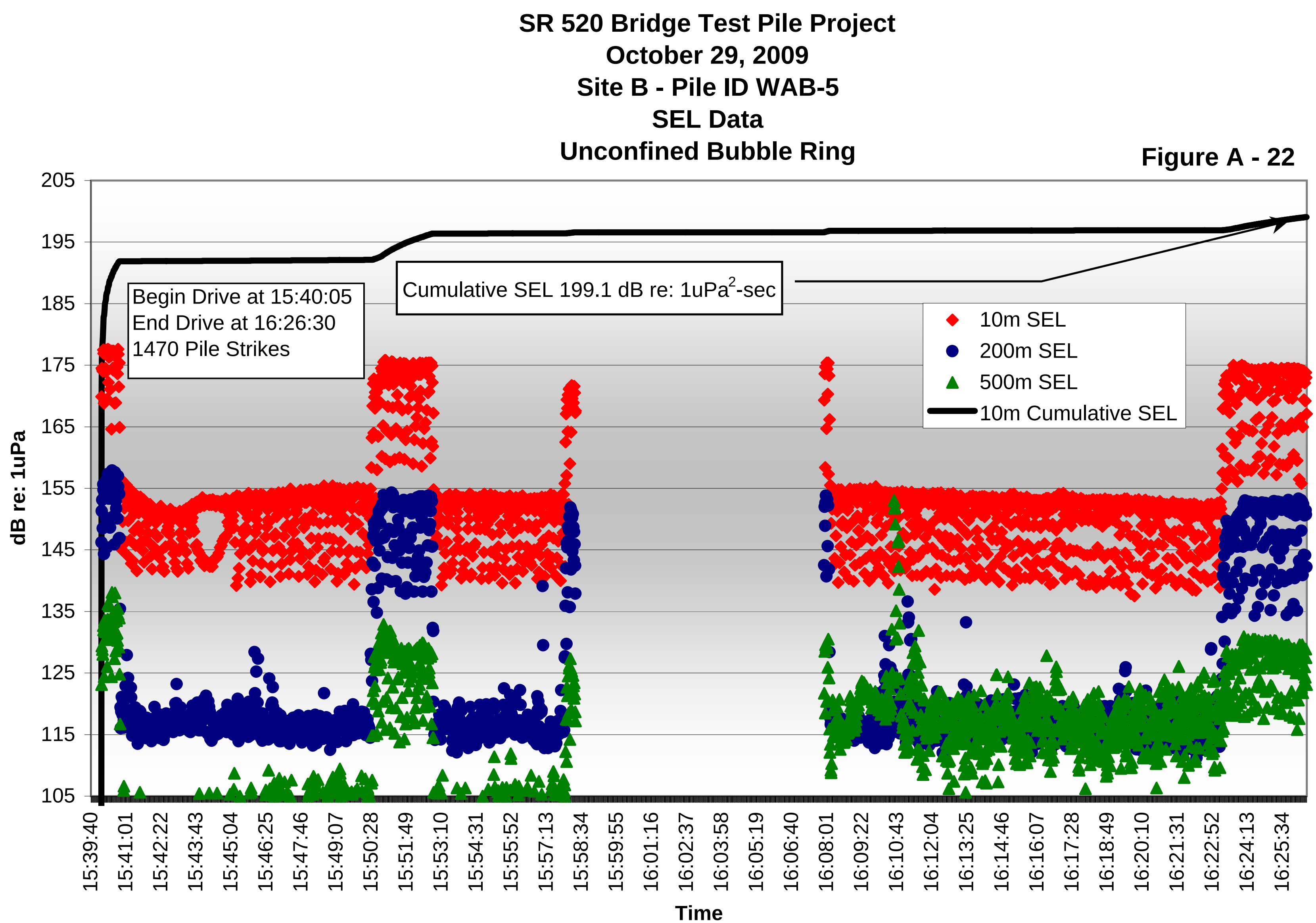



SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-3
Peak Levels
Doublewall Noise Attenuation Pile - DNAP
Figure A - 19
dB re: 1uPa
205
195
185
175
165
155
145
135
125
115
105
10m Peak
200m Peak
500m Peak
10m RMS
13:47:44
13:48:03
13:48:22
13:48:41
13:49:00
13:49:19
13:49:38
13:49:57
13:50:16
13:50:35
13:50:54
13:51:13
13:51:32
13:51:51
13:52:10
13:52:29
13:52:48
13:53:07
13:53:26
13:53:45
13:54:04
13:54:23
13:54:42
13:55:01
13:55:20
13:55:39
13:55:58
13:56:17
13:56:36
13:56:55
13:57:14
13:57:33
13:57:52
13:58:11
13:58:30
Time



SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-4
SEL Data 2
Confined Bubble Ring
Figure A - 20
Begin Drive at 11:32:50
End Drive at 11:41:15
350 Pile Strikes
Cumulative SEL 191.0 dB re: 1uPa2-sec
13m SEL
200m SEL
500m SEL
10m Cumulative SEL
Bubble Rings On
dB re: 1uPa
Time
205
195
185
175
165
155
145
135
125
115
105
11:32:20
11:32:36
11:32:52
11:33:08
11:33:24
11:33:40
11:33:56
11:34:12
11:34:28
11:34:44
11:35:00
11:35:16
11:35:32
11:35:48
11:36:04
11:36:20
11:36:36
11:36:52
11:37:08
11:37:24
11:37:40
11:37:56
11:38:12
11:38:28
11:38:44
11:39:00
11:39:16
11:39:32
11:39:48
11:40:04
11:40:20
11:40:36
11:40:52
11:41:08

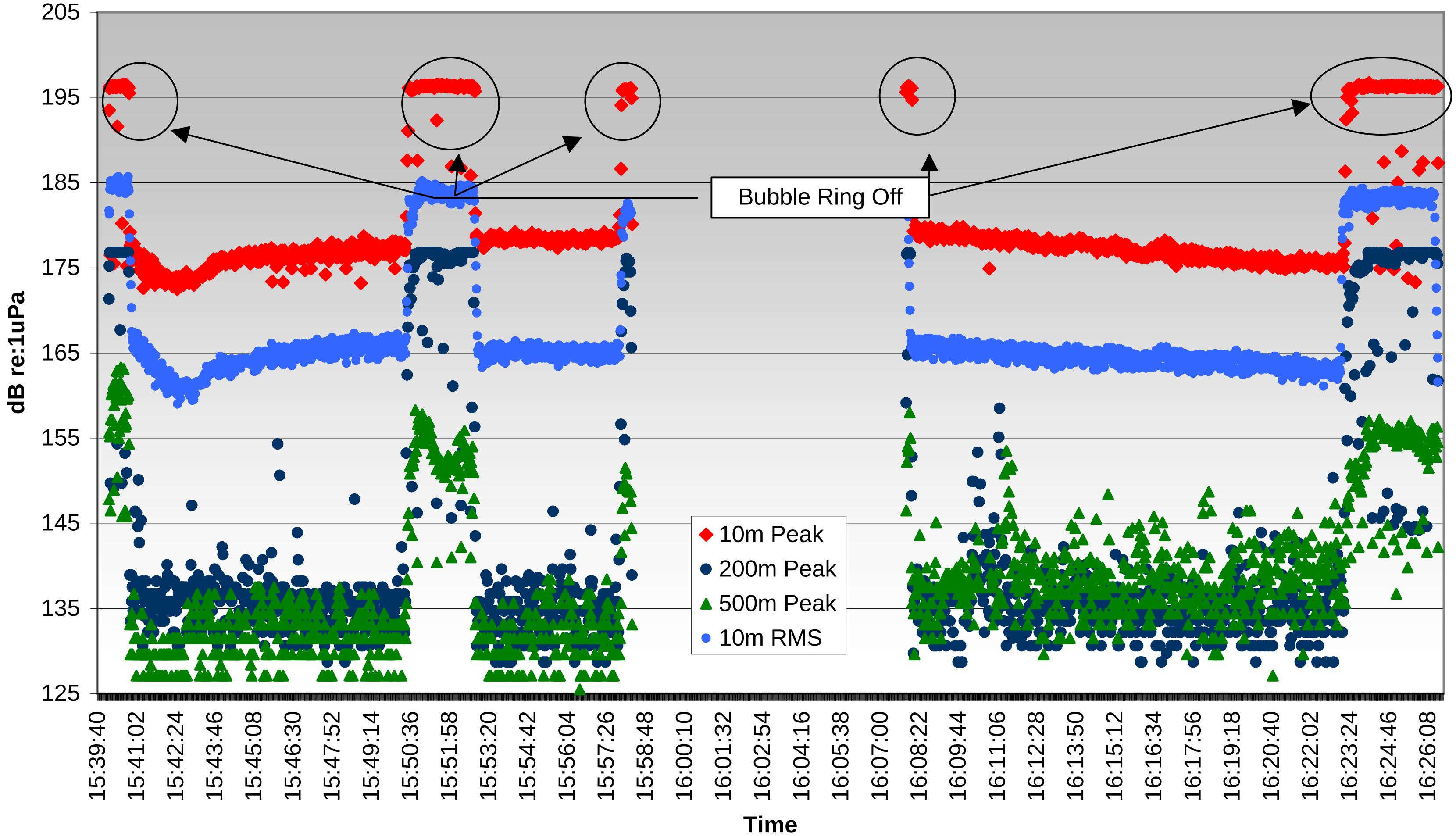

SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-4
Peak Levels
Confined Bubble Ring
Figure A - 21
13m Peak
200m Peak
500m Peak
13m RMS
Bubble Rings Off
dB re:1uPa
205
195
185
175
165
155
145
135
125
115
105
Time
11:32:20
11:32:34
11:32:48
11:33:02
11:33:16
11:33:30
11:33:44
11:33:58
11:34:12
11:34:26
11:34:40
11:34:54
11:35:08
11:35:22
11:35:36
11:35:50
11:36:04
11:36:18
11:36:32
11:36:46
11:37:00
11:37:14
11:37:28
11:37:42
11:37:56
11:38:10
11:38:24
11:38:38
11:38:52
11:39:06
11:39:20
11:39:34
11:39:48
11:40:02
11:40:16
11:40:30
11:40:44
11:40:58
11:41:12



SR 520 Bridge Test Pile Project
October 29, 2009
Site B - Pile ID WAB-5
SEL Data
Unconfined Bubble Ring
Figure A - 22
Begin Drive at 15:40:05
End Drive at 16:26:30
1470 Pile Strikes
Cumulative SEL 199.1 dB re: 1uPa2-sec
10m SEL
200m SEL
500m SEL
10m Cumulative SEL
dB re: 1uPa
Time
205
195
185
175
165
155
145
135
125
115
105
15:39:40
15:41:01
15:42:22
15:43:43
15:45:04
15:46:25
15:47:46
15:49:07
15:50:28
15:51:49
15:53:10
15:54:31
15:55:52
15:57:13
15:58:34
15:59:55
16:01:16
16:02:37
16:03:58
16:05:19
16:06:40
16:08:01
16:09:22
16:10:43
16:12:04
16:13:25
16:14:46
16:16:07
16:17:28
16:18:49
16:20:10
16:21:31
16:22:52
16:24:13
16:25:34

SR 520 Bridge Test Pile Project
October 29, 2009
Site A - Pile ID WAB-5
Peak Levels
Unconfined Bubble Ring

Figure A - 23



Appendix B

Summary of Signal Analysis of Pile Driving Underwater Sound Pulses

Pile PB-1 24" Steel Shell Pile @ 10 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

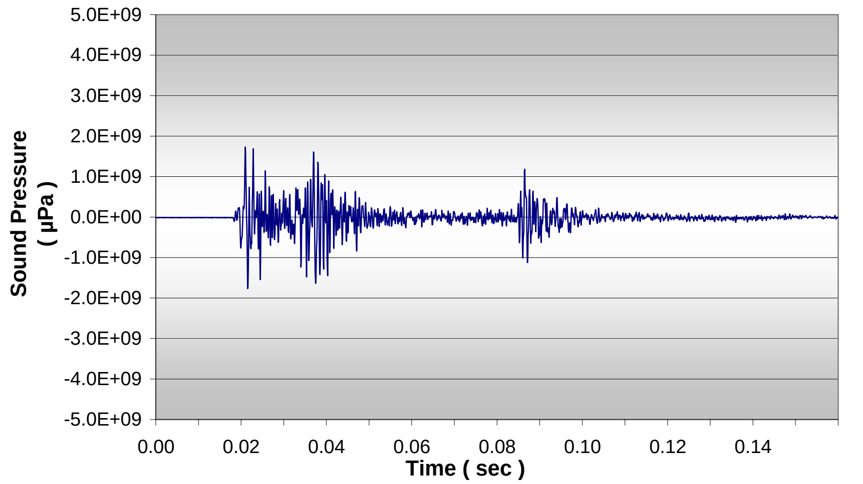


Figure b. Narrow Band Frequency Spectra

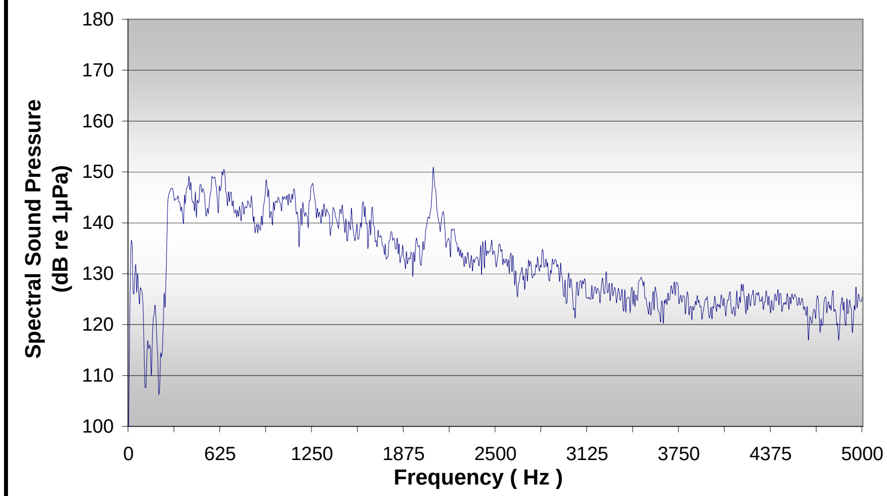


Figure c. Accumulation of Sound Energy

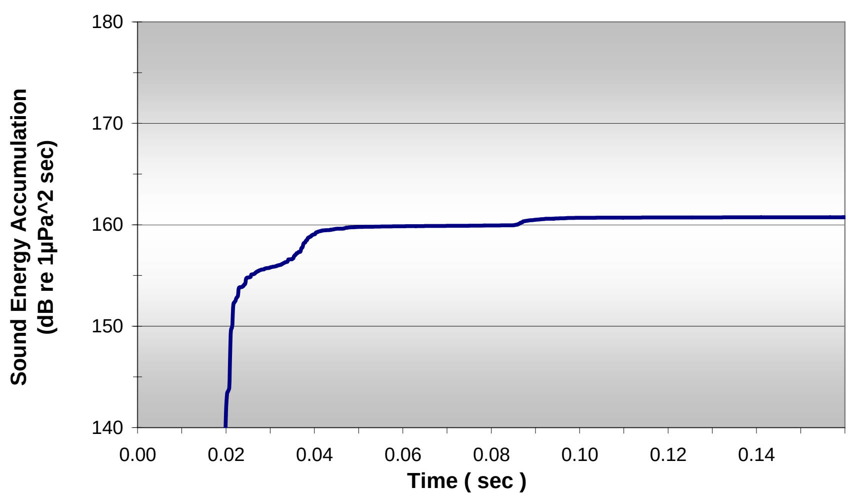


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
14:37:20	185	172	161

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Reported Average	187	170	159
Reported maximum	190	173	161

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 1

Pile PB-1 24" Steel Shell Pile @ 10 Meters - Unconfined Bubble Ring OFF 10/27/2009

Figure a. Waveform

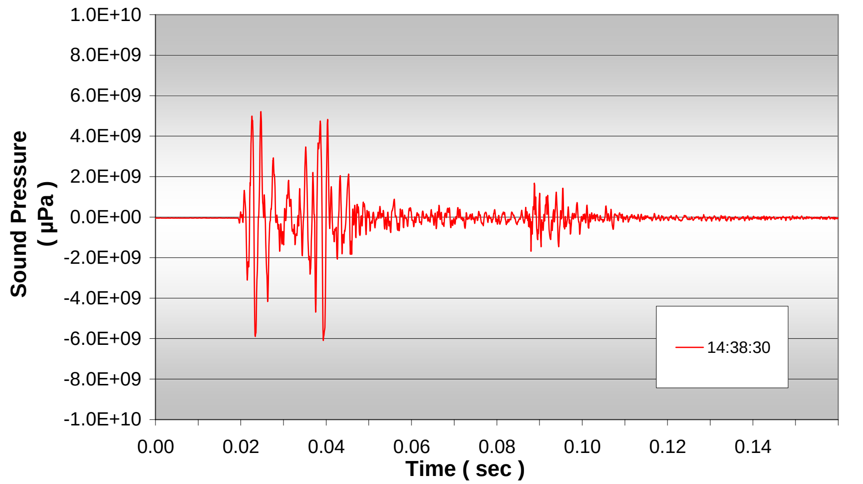


Figure b. Narrow Band Frequency Spectra

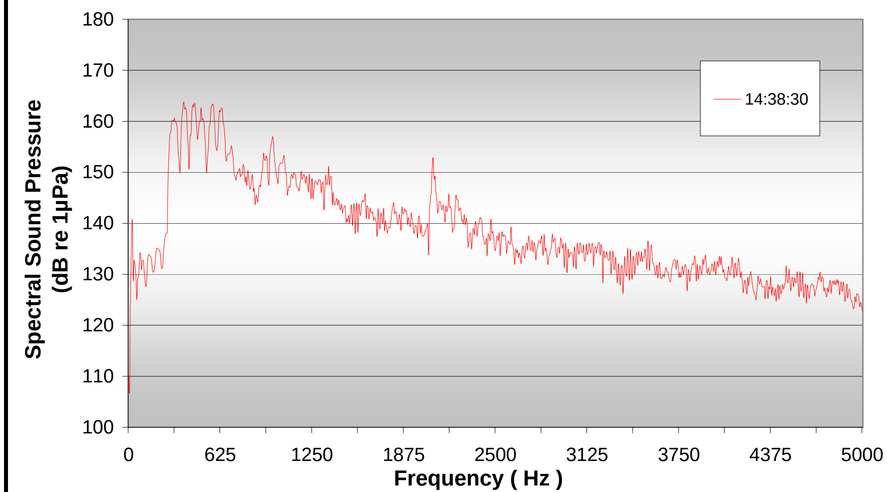


Figure c. Accumulation of Sound Energy

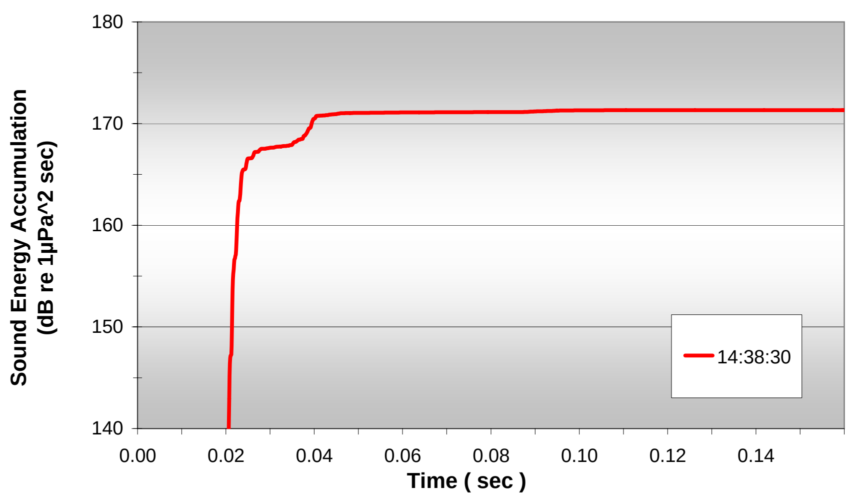


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
14:38:30	196	184	171

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Reported Average	198	183	172
Reported maximum	199	185	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 2

Pile PB-1 24" Steel Shell Pile @ 10 Meters - Comparison of the Unconfined Bubble Ring ON & OFF

Figure a. Waveform

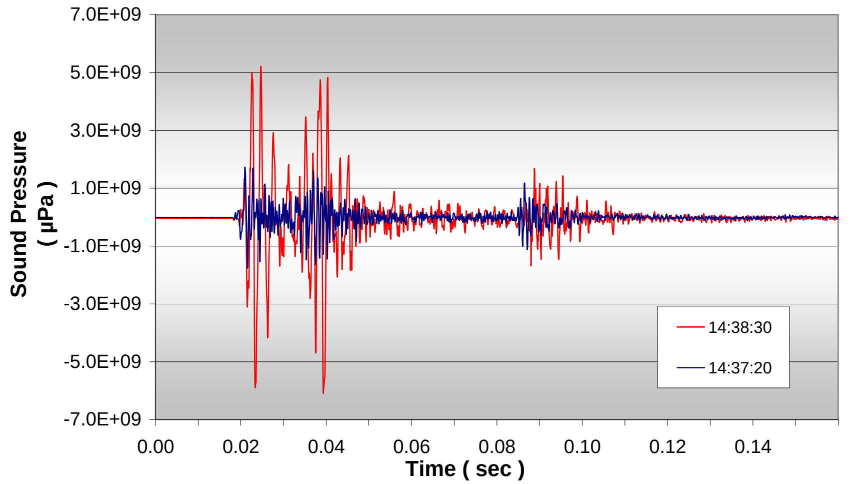


Figure b. Narrow Band Frequency Spectra

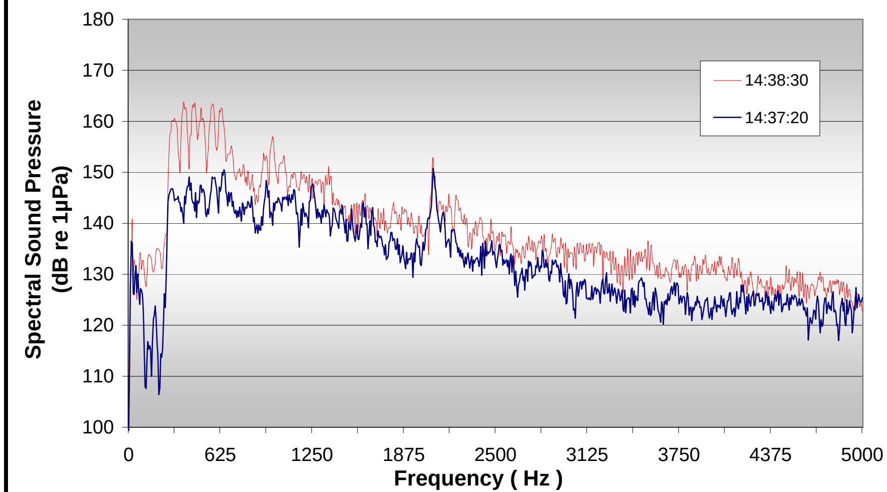


Figure c. Accumulation of Sound Energy

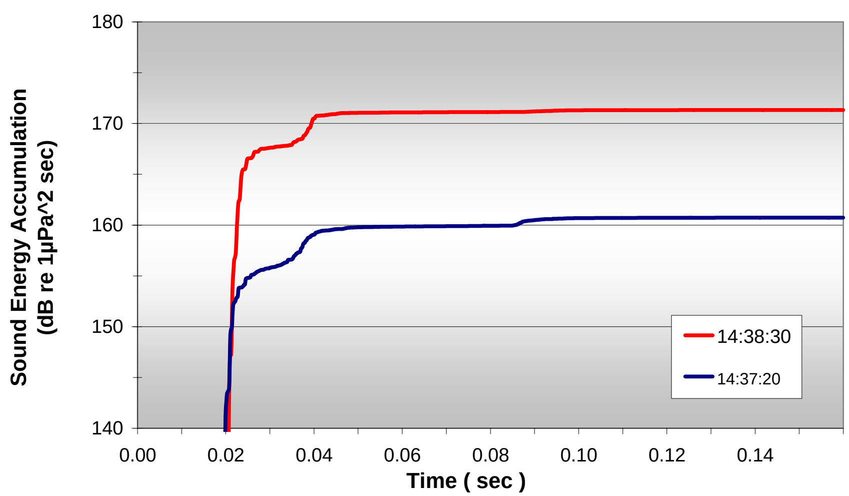


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
14:38:30	196	184	171
14:37:20	185	172	161

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Bubble Ring On	187	170	159
Bubble Ring Off	198	183	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B -3

Pile PB-2 24" Steel Shell Pile @ 10 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

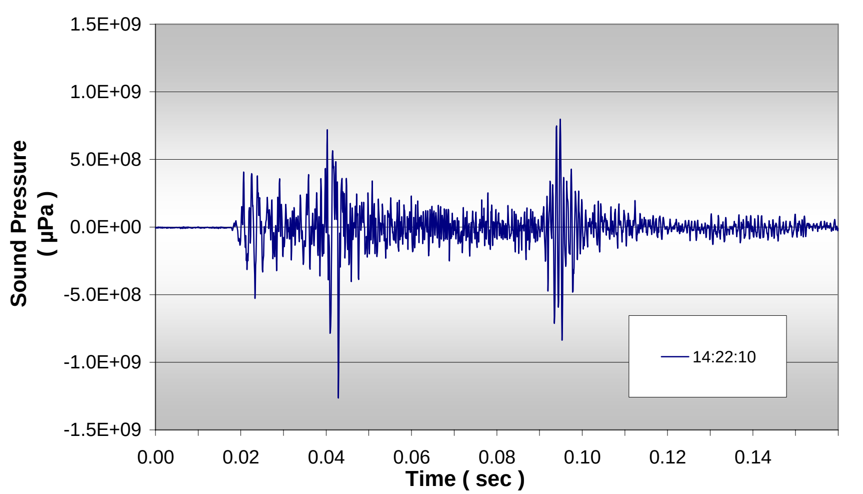


Figure b. Narrow Band Frequency Spectra

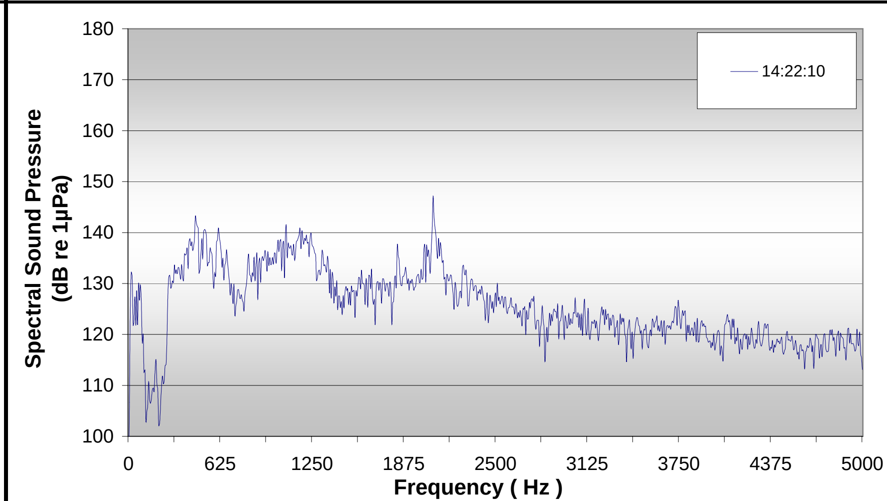


Figure c. Accumulation of Sound Energy

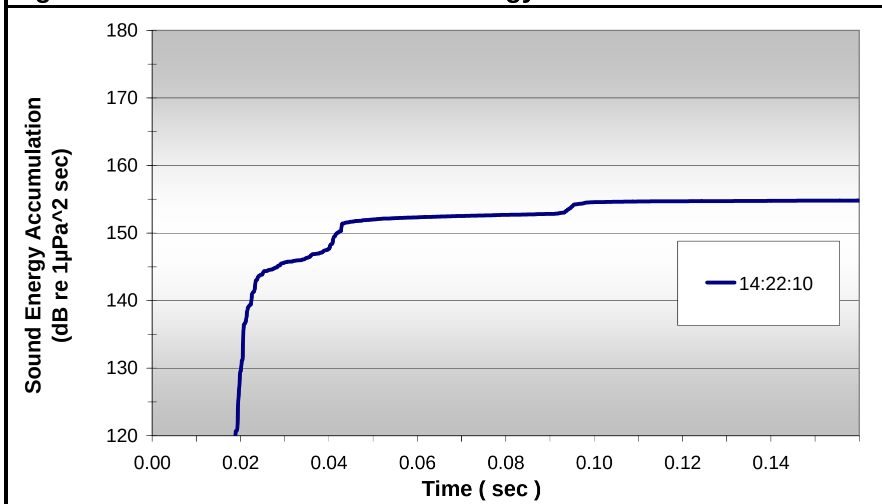


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
14:22:10	182	165	155

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Reported Average	181	166	153
Reported maximum	183	167	156

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 4

Pile PB-2 24" Steel Shell Pile @ 10 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

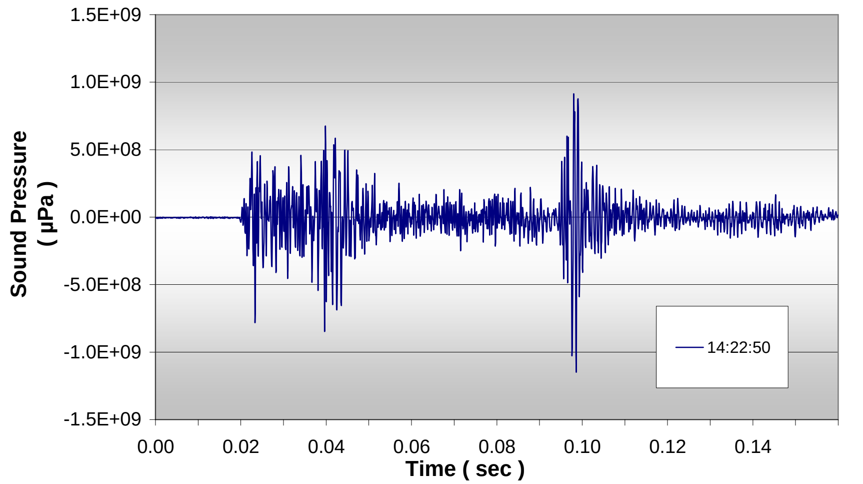


Figure b. Narrow Band Frequency Spectra

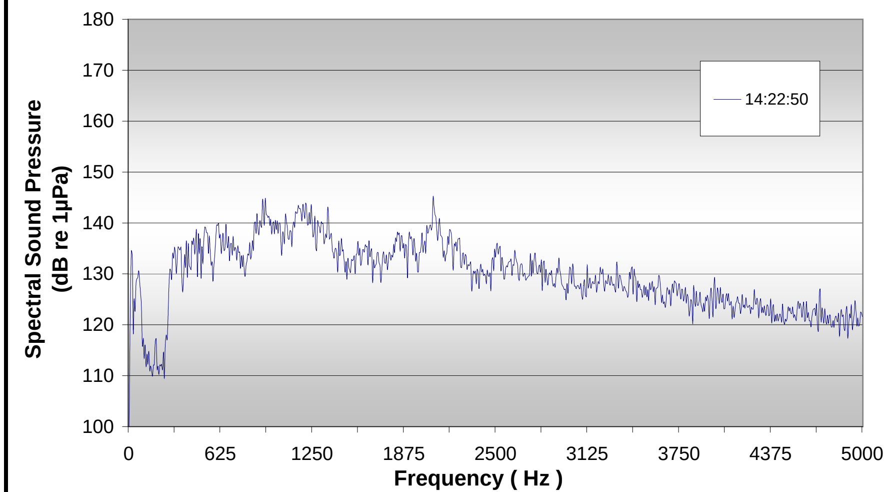


Figure c. Accumulation of Sound Energy

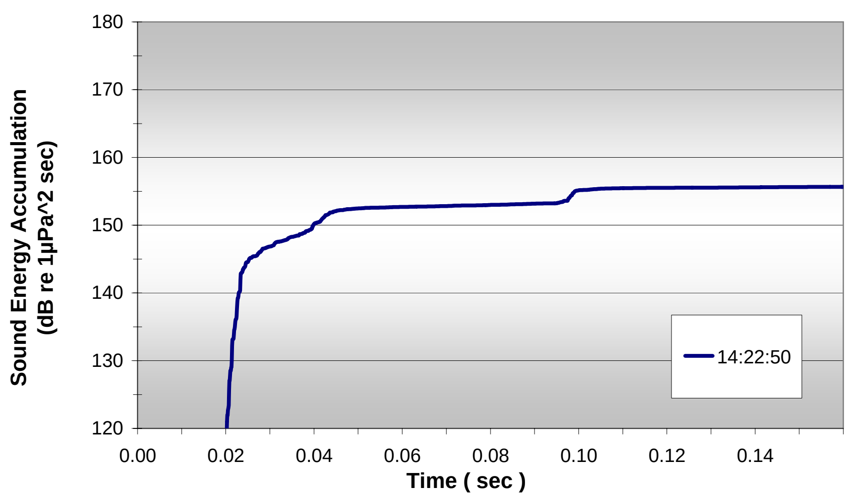


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
14:22:50	181	166	156

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Reported Average	181	166	153
Reported maximum	183	167	156

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 5

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

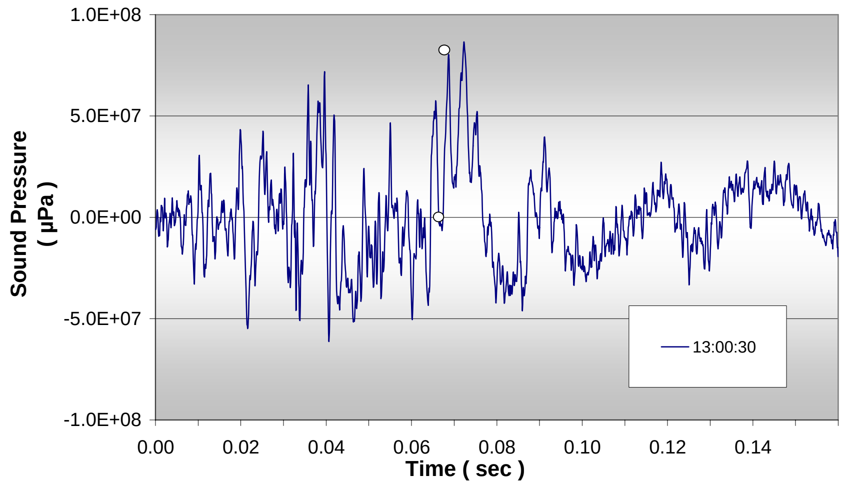


Figure b. Narrow Band Frequency Spectra

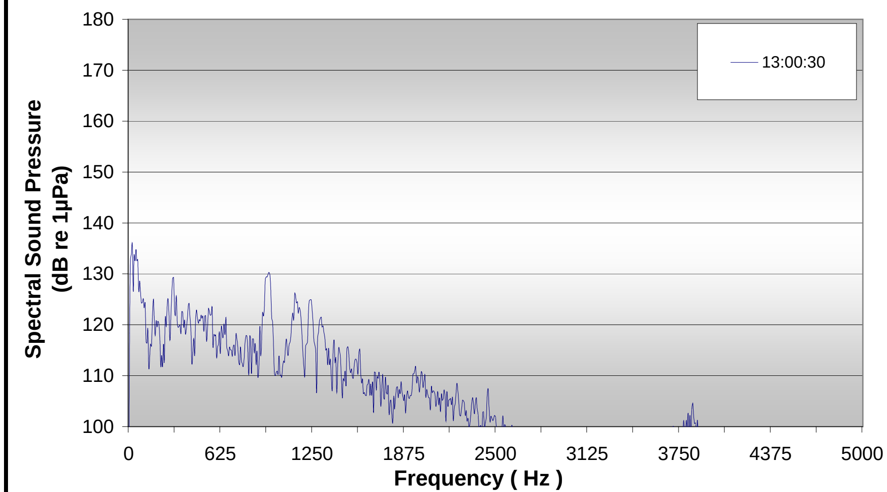


Figure c. Accumulation of Sound Energy

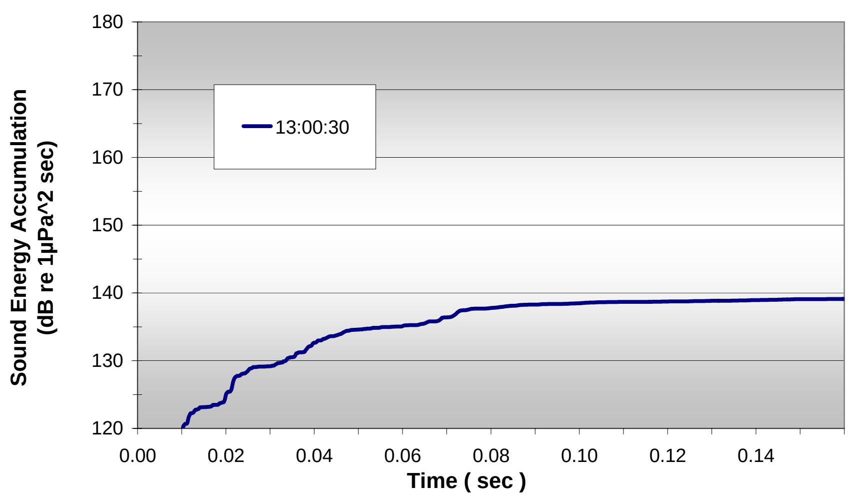


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:00:30	159	148	139

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	161	147	139
Reported maximum	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 6

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

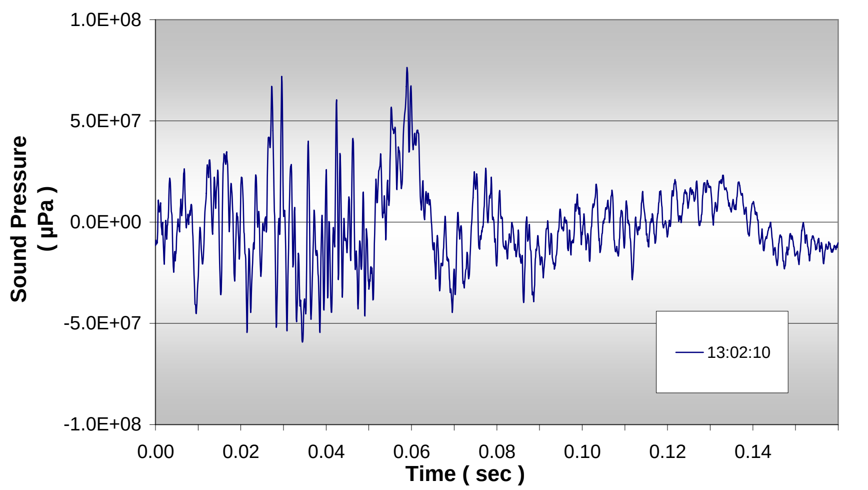


Figure b. Narrow Band Frequency Spectra

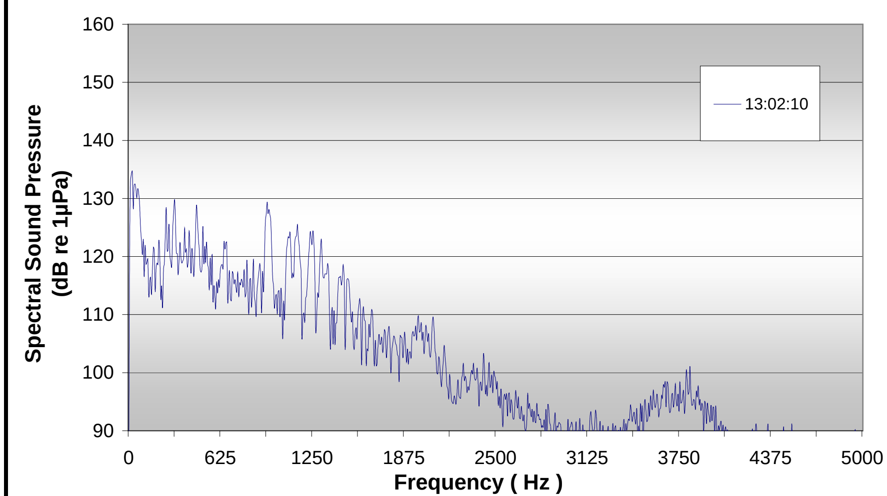


Figure c. Accumulation of Sound Energy

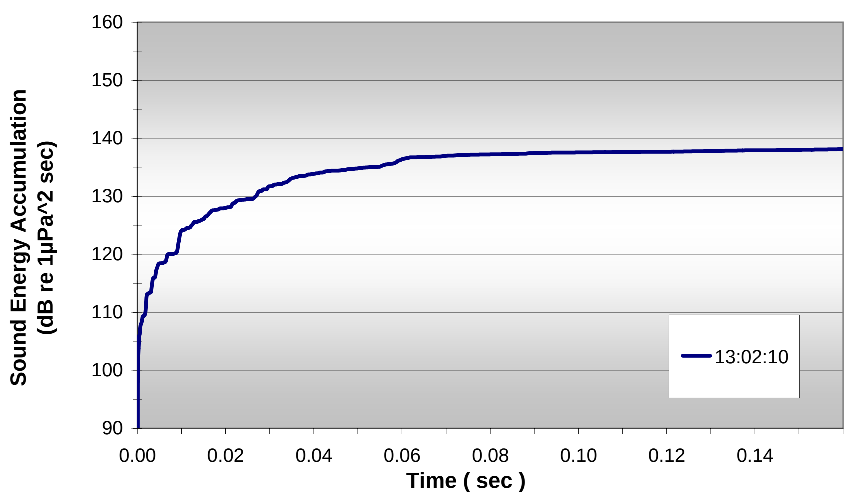


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:02:10	158	147	138

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	161	147	139
Reported maximum	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 7

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring OFF 10/27/2009

Figure a. Waveform

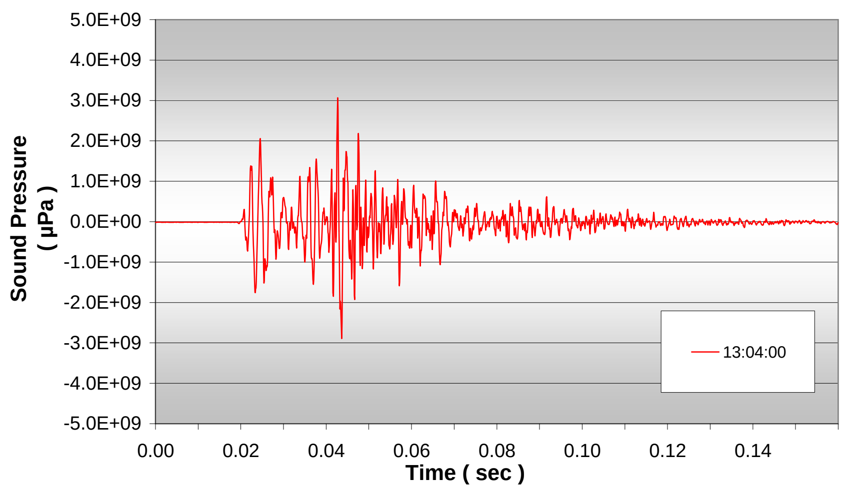


Figure b. Narrow Band Frequency Spectra

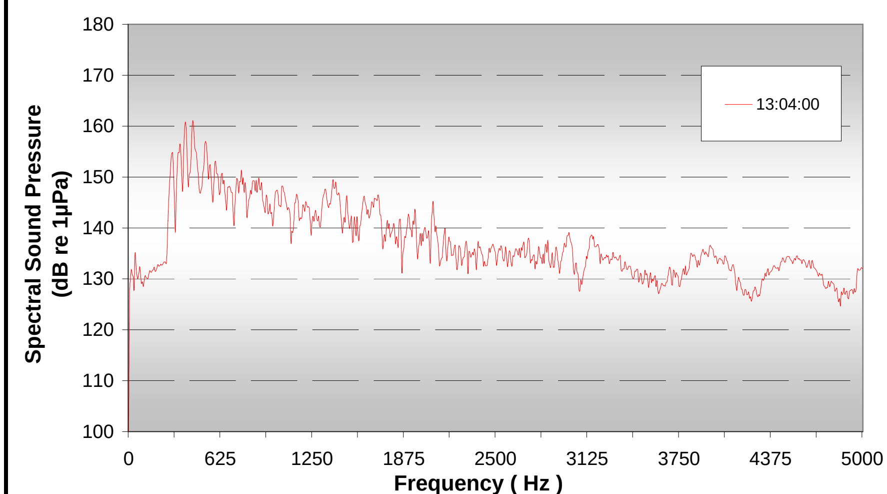


Figure c. Accumulation of Sound Energy

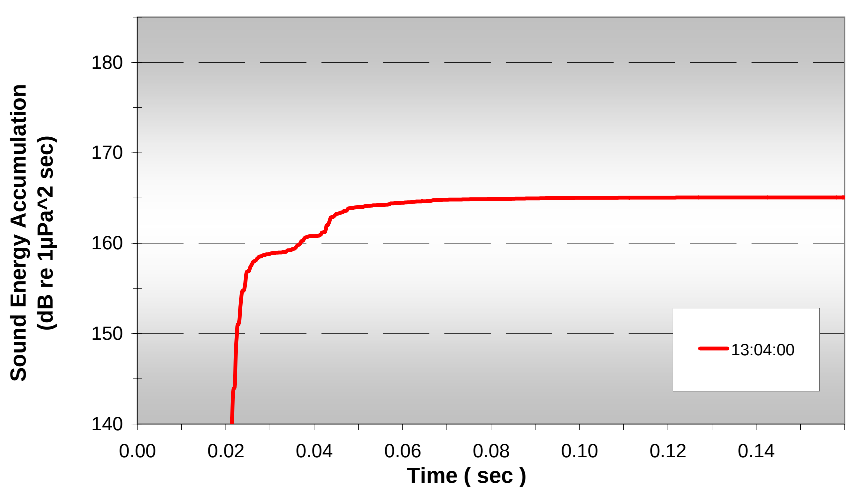


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	RMS90%*	SEL
13:04:00	190	178	165

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	187	173	160
Reported maximum	193	179	167

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 8

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

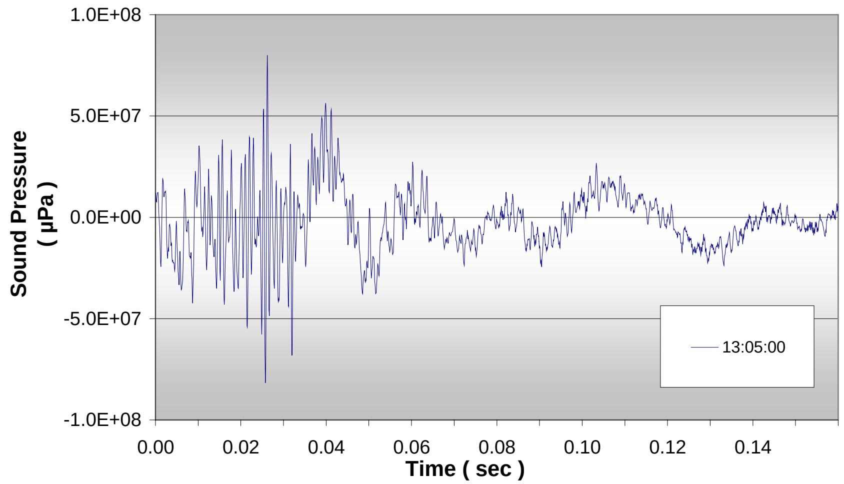


Figure b. Narrow Band Frequency Spectra

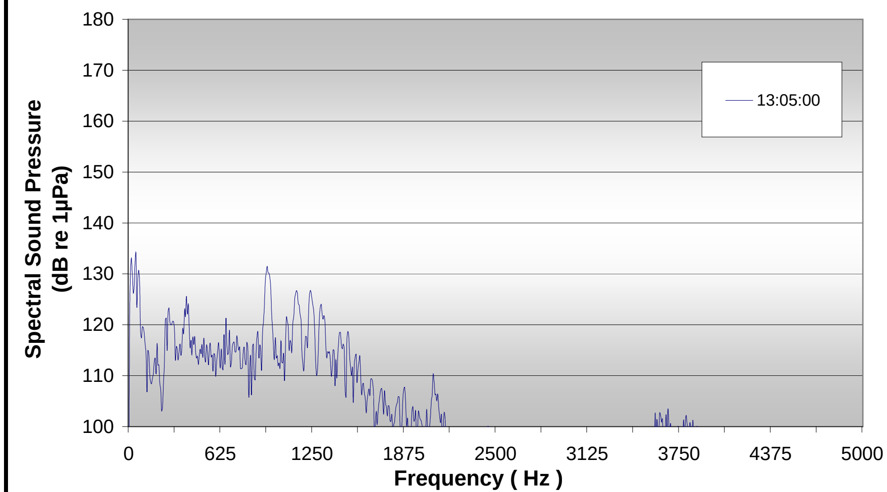


Figure c. Accumulation of Sound Energy

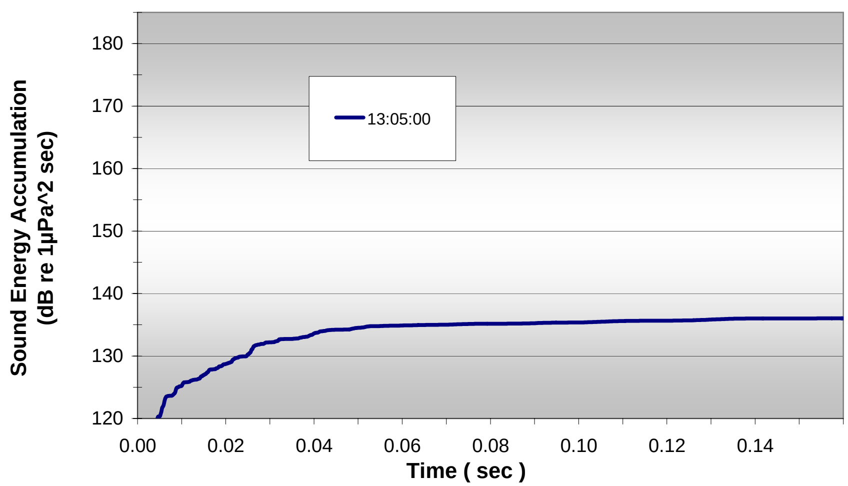


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:05:00	158	145	136

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	161	147	139
Reported maximum	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 9

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring OFF 10/27/2009

Figure a. Waveform

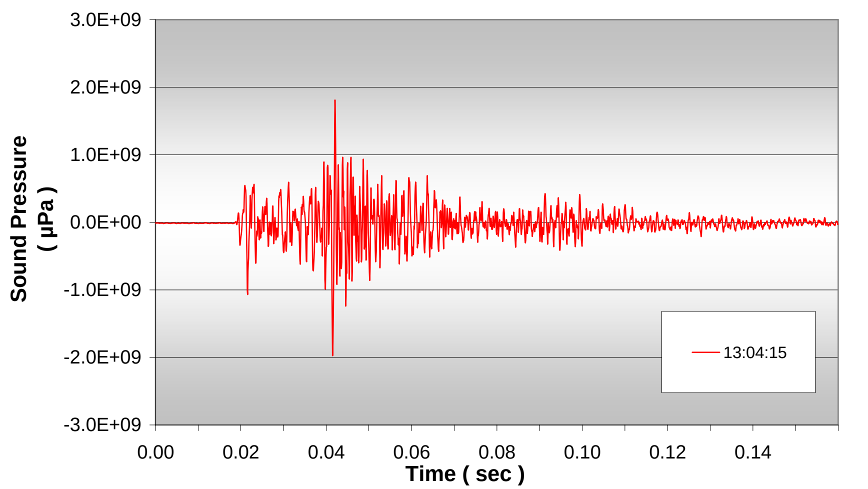


Figure b. Narrow Band Frequency Spectra

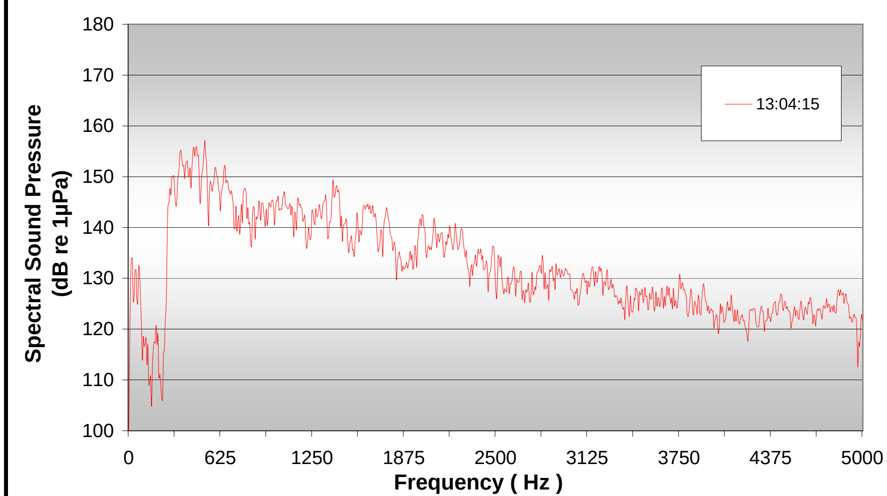


Figure c. Accumulation of Sound Energy

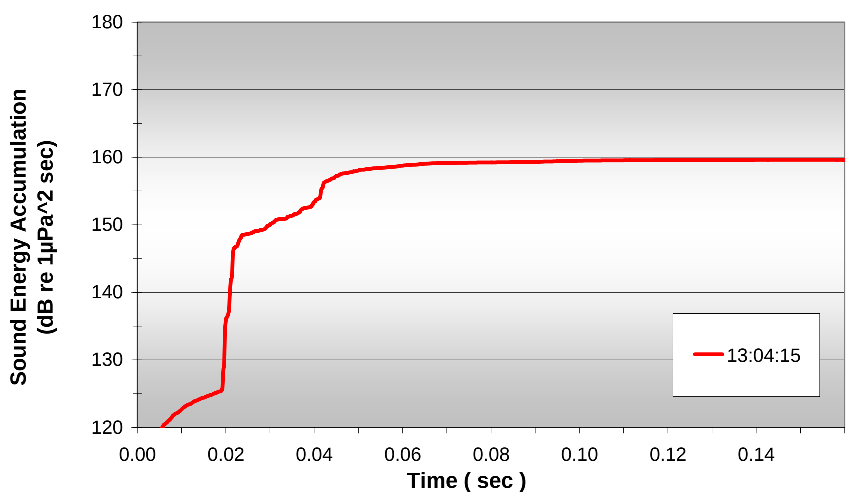


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	RMS90%*	SEL
13:04:15	186	171	160

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	187	173	160
Reported maximum	193	179	167

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 10

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON 10/27/2009

Figure a. Waveform

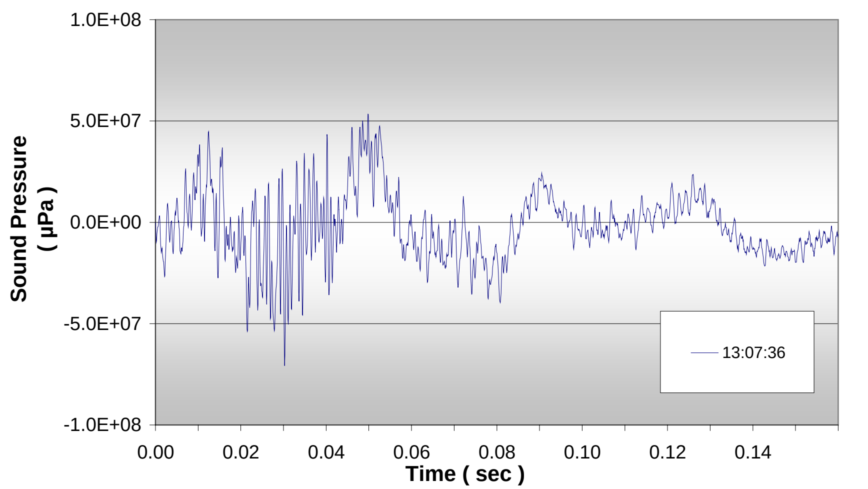


Figure b. Narrow Band Frequency Spectra

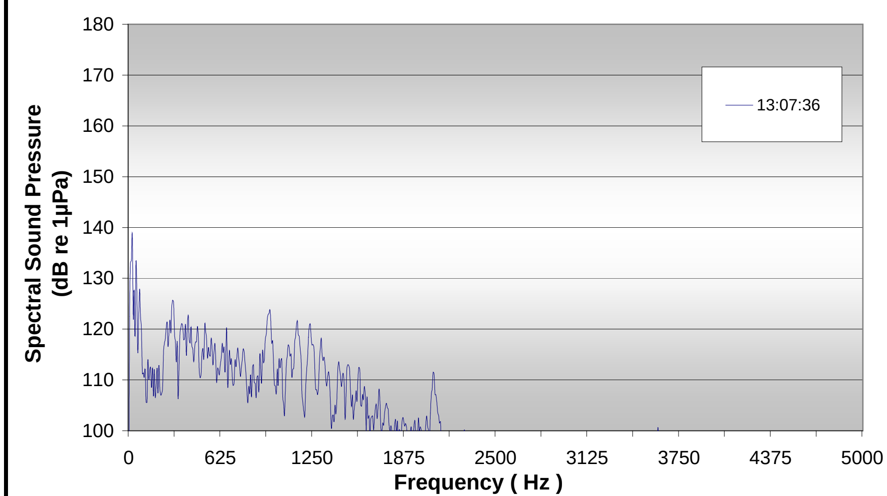


Figure c. Accumulation of Sound Energy

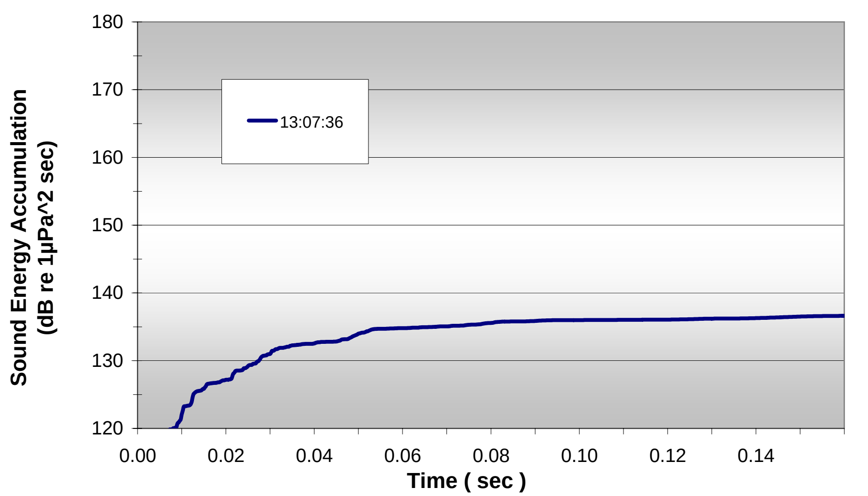


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	RMS90%*	SEL
13:07:36	157	145	137

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	161	147	139
Reported maximum	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 11

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring OFF 10/27/2009

Figure a. Waveform

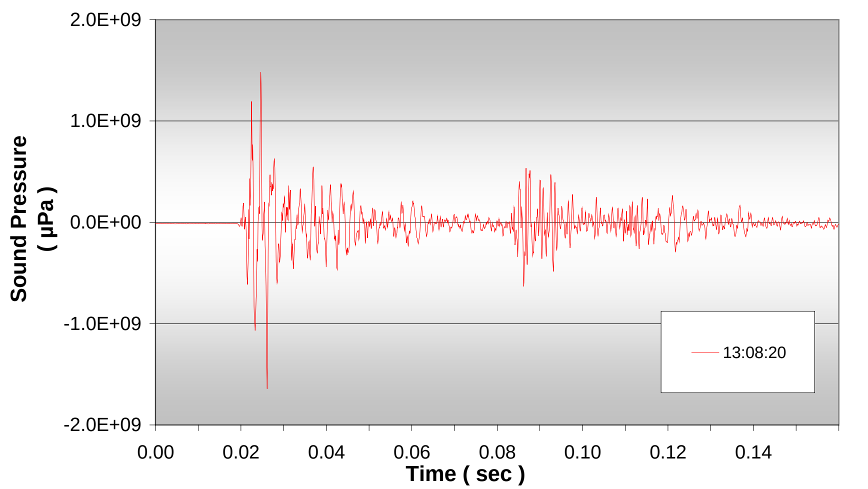


Figure b. Narrow Band Frequency Spectra

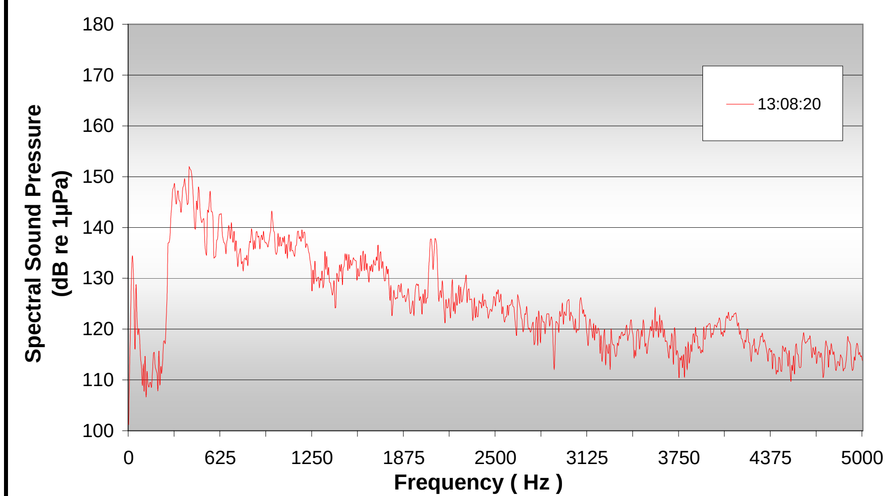


Figure c. Accumulation of Sound Energy

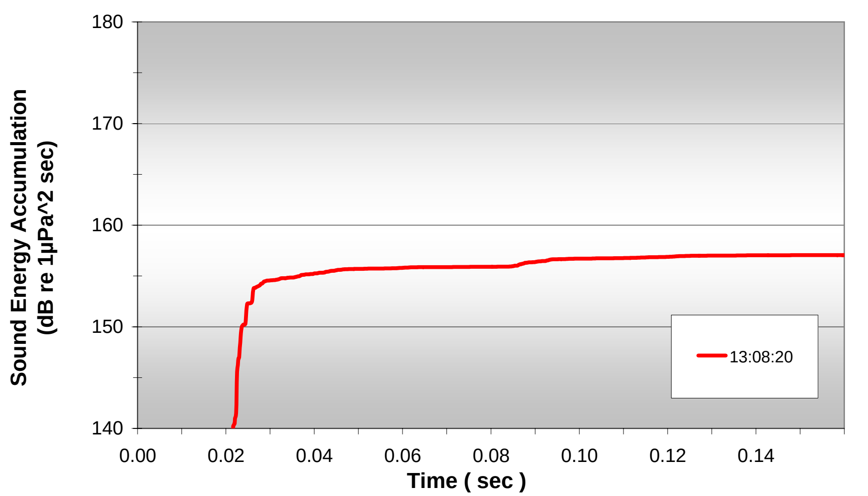


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:08:20	184	167	157

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	187	173	160
Reported maximum	193	179	167

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 12

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring On and OFF 10/27/2009

Figure a. Waveform

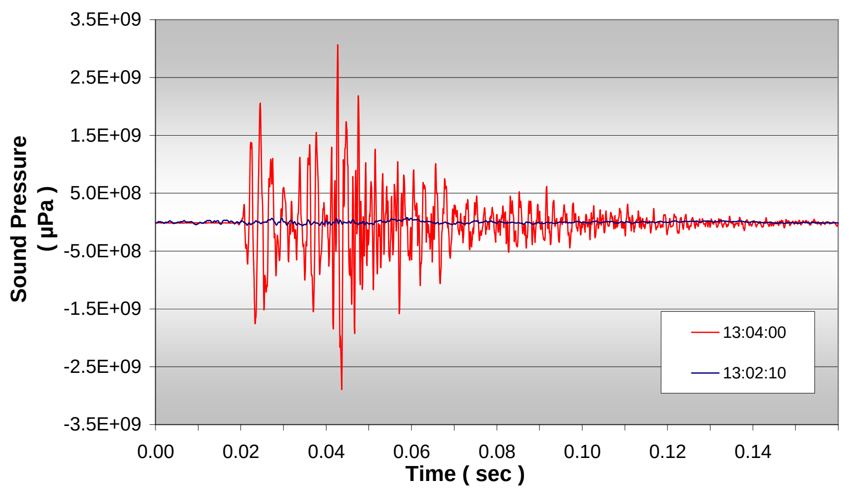


Figure b. Narrow Band Frequency Spectra

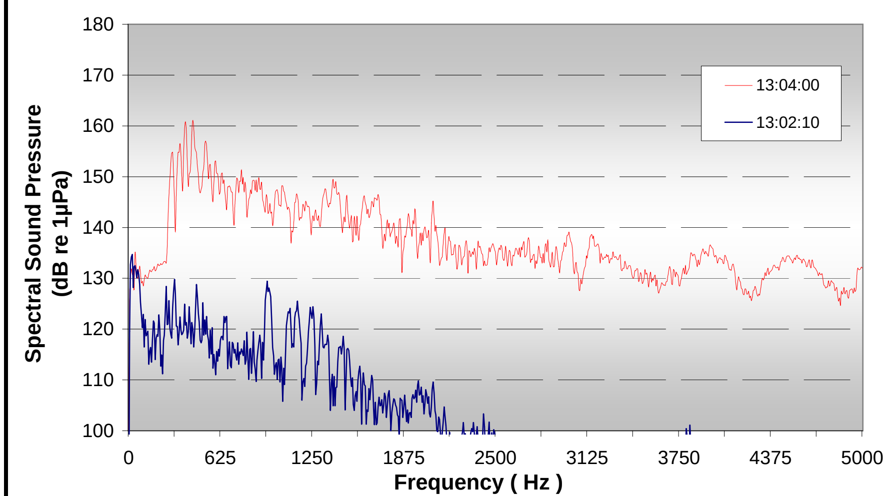


Figure c. Accumulation of Sound Energy

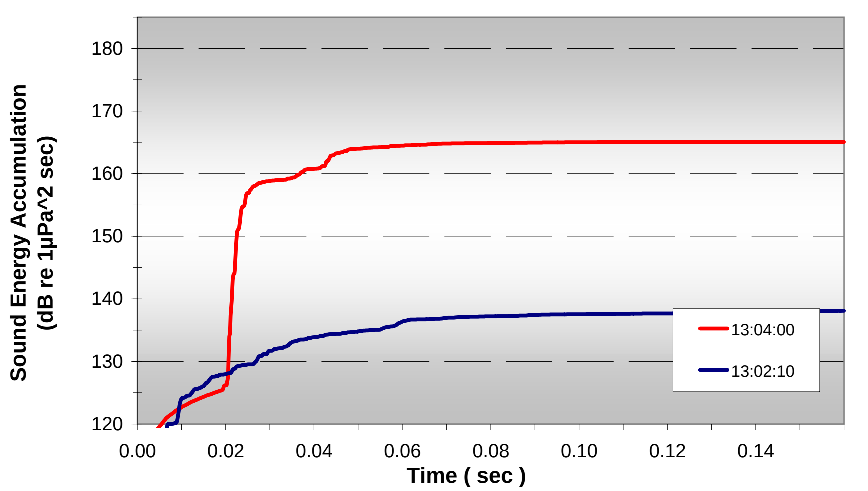


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:04:00	190	178	165
13:02:10	158	147	138

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	193	179	167
Mitigated	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 13

Pile PB-3 24" Steel Shell Pile @ 12 Meters - Unconfined Bubble Ring ON and OFF 10/27/2009

Figure a. Waveform

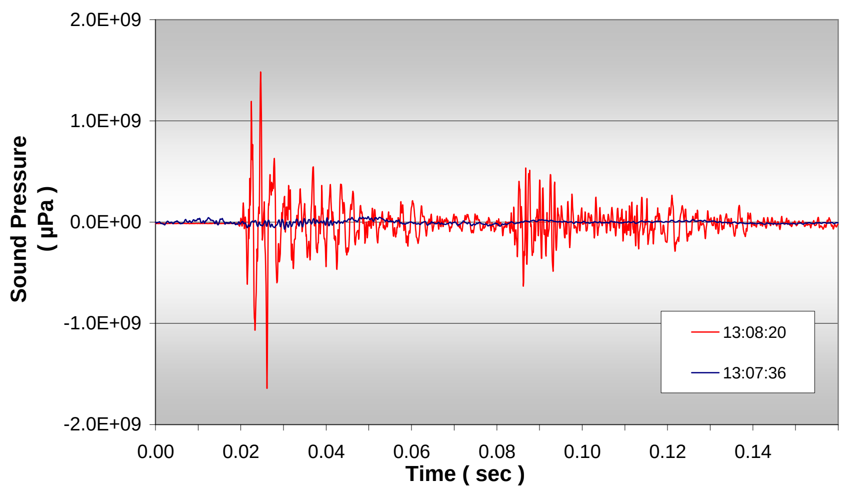


Figure b. Narrow Band Frequency Spectra

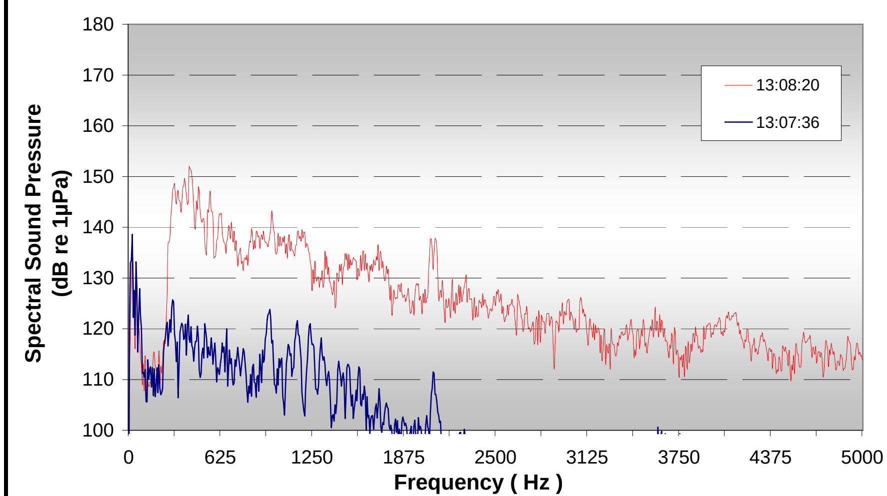


Figure c. Accumulation of Sound Energy

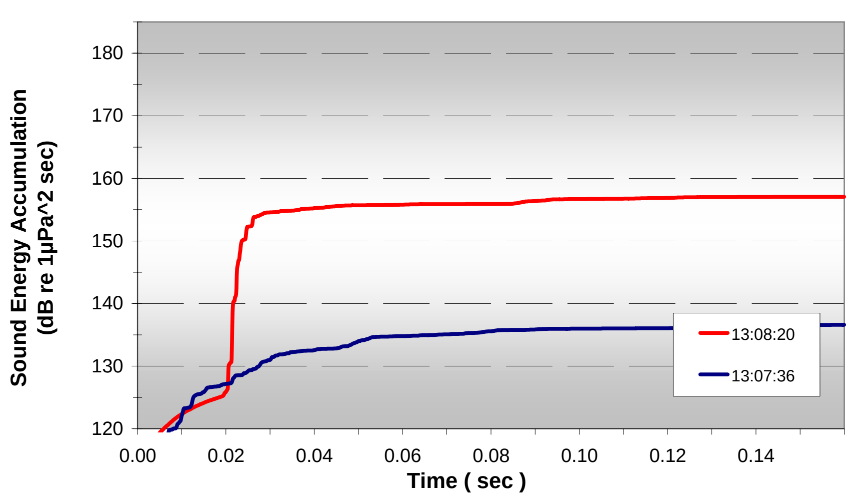


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:08:20	184	167	157
13:07:36	157	145	137

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	193	179	167
Mitigated	165	153	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 14

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings OFF 10/27/2009

Figure a. Waveform

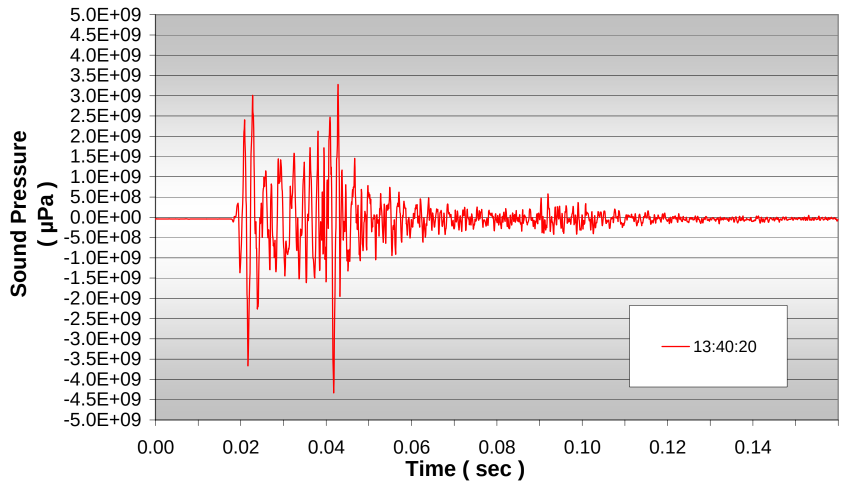


Figure b. Narrow Band Frequency Spectra

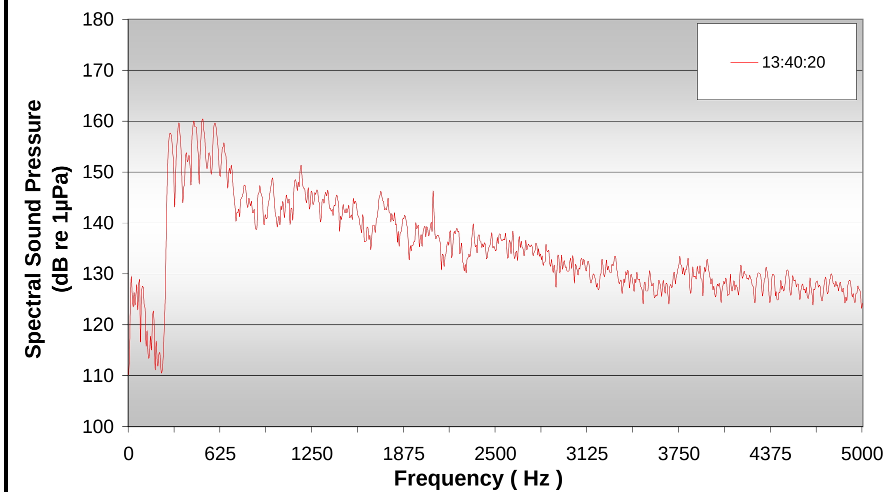


Figure c. Accumulation of Sound Energy

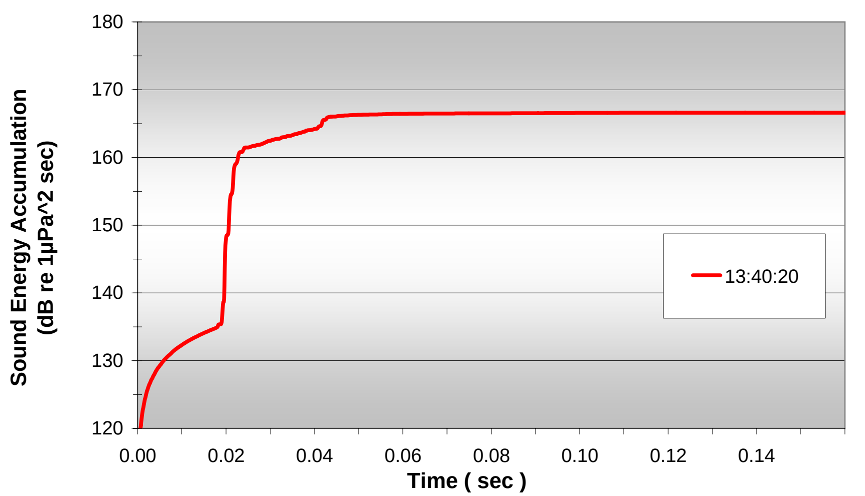


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:40:20	193	181	167

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	187	172	162
Reported maximum	194	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 15

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings OFF 10/27/2009

Figure a. Waveform

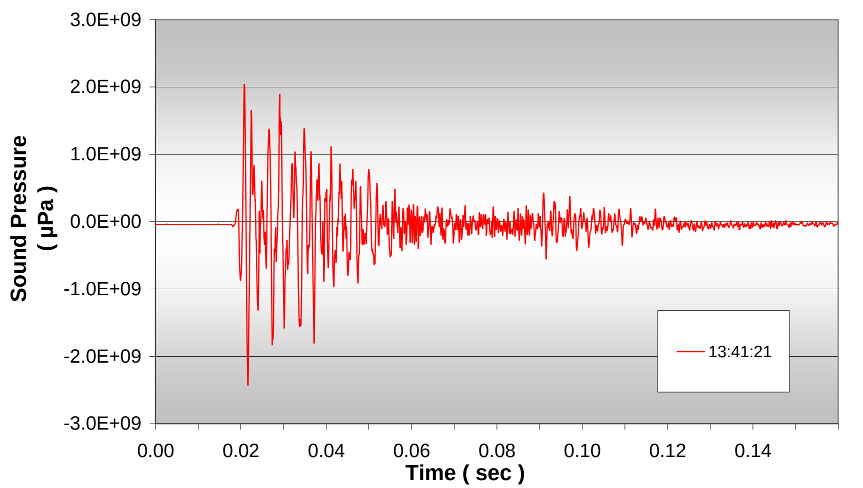


Figure b. Narrow Band Frequency Spectra

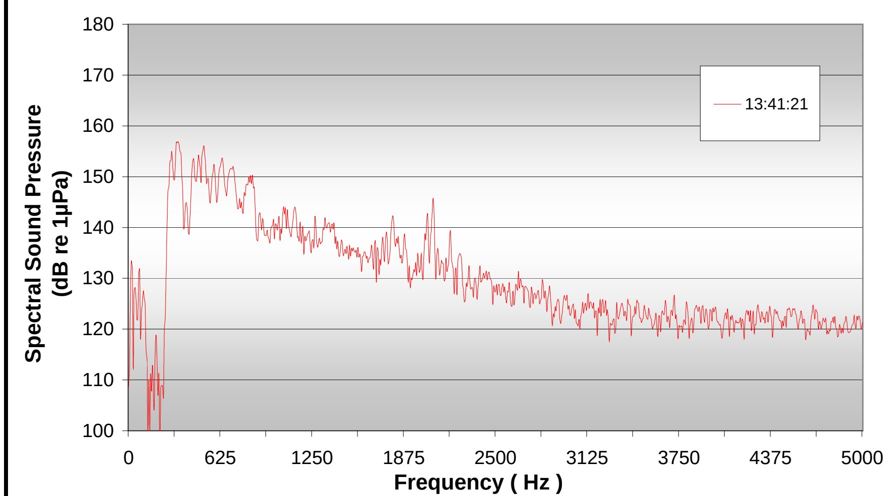


Figure c. Accumulation of Sound Energy

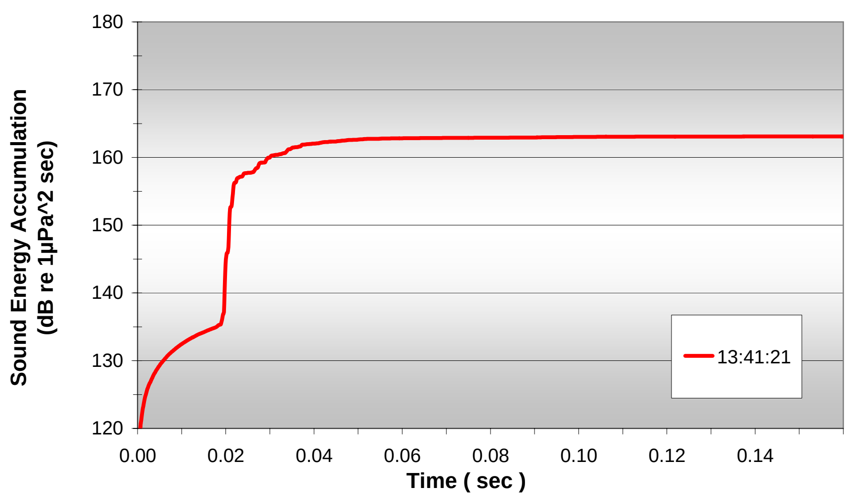


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:41:21	188	176	163

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	187	172	162
Reported maximum	194	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 16

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings ON 10/27/2009

Figure a. Waveform

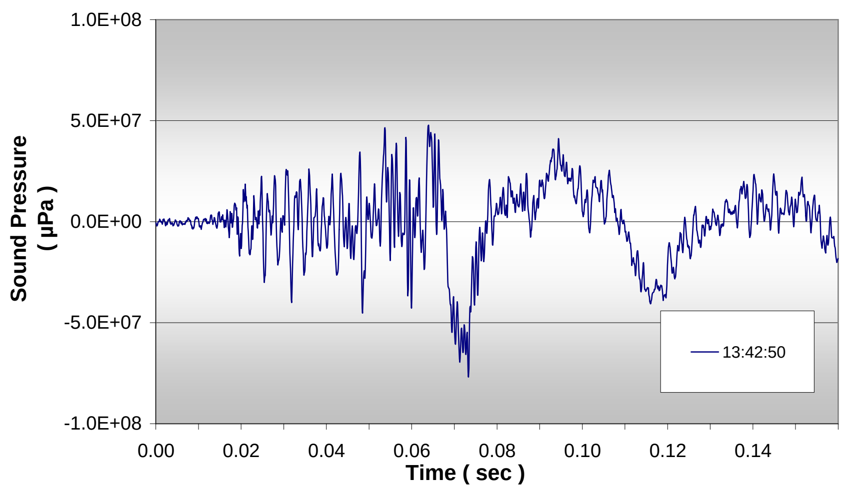


Figure b. Narrow Band Frequency Spectra

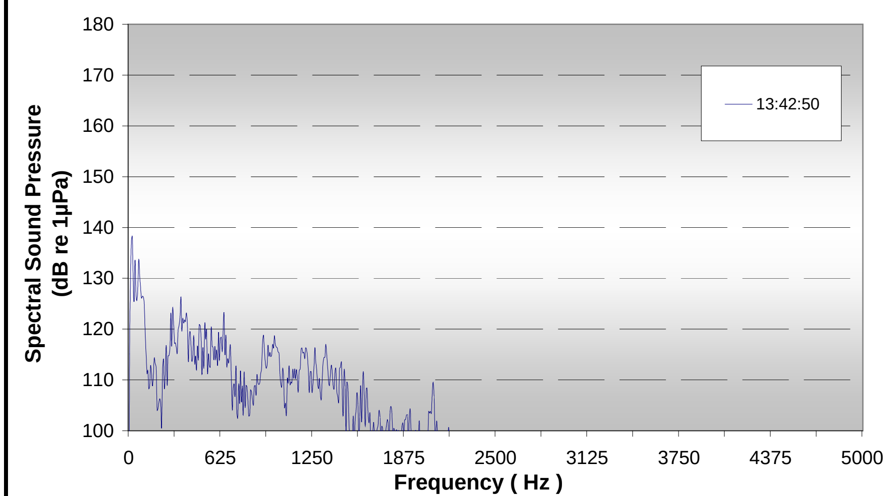


Figure c. Accumulation of Sound Energy

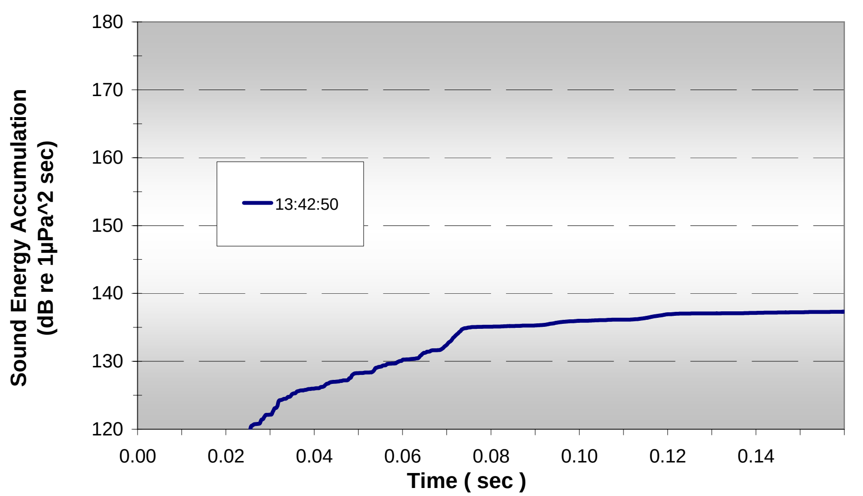


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:42:50	158	147	137

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	160	147	138
Reported maximum	161	158	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 17

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings ON 10/27/2009

Figure a. Waveform

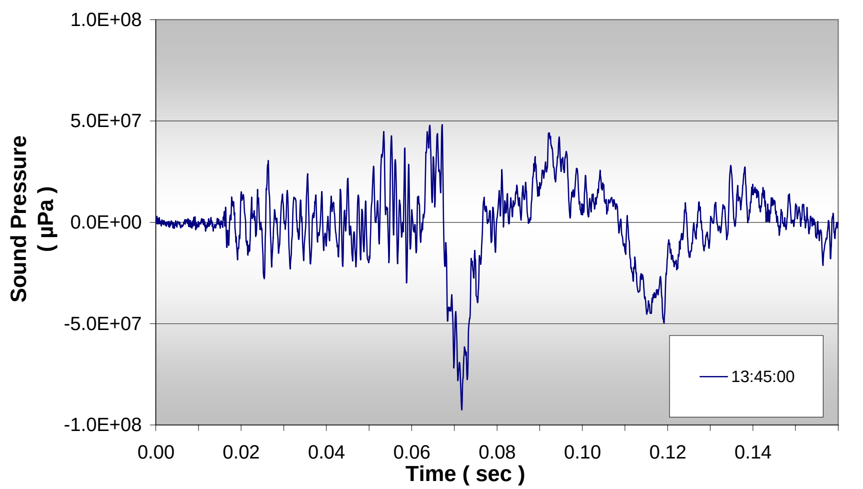


Figure b. Narrow Band Frequency Spectra

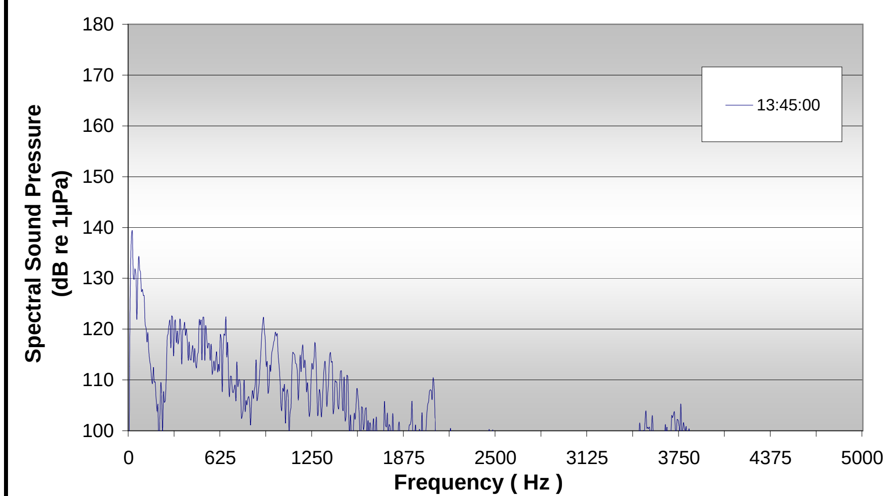


Figure c. Accumulation of Sound Energy

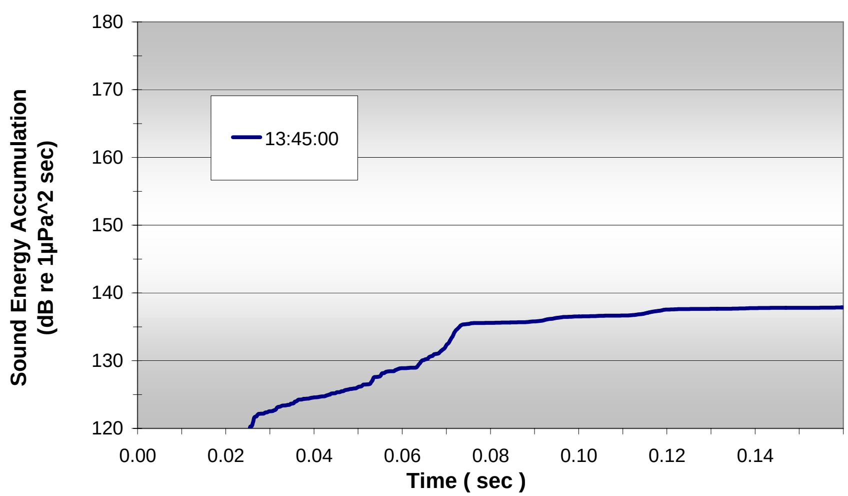


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:45:00	159	148	138

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	160	147	138
Reported maximum	161	158	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 18

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings OFF 10/27/2009

Figure a. Waveform

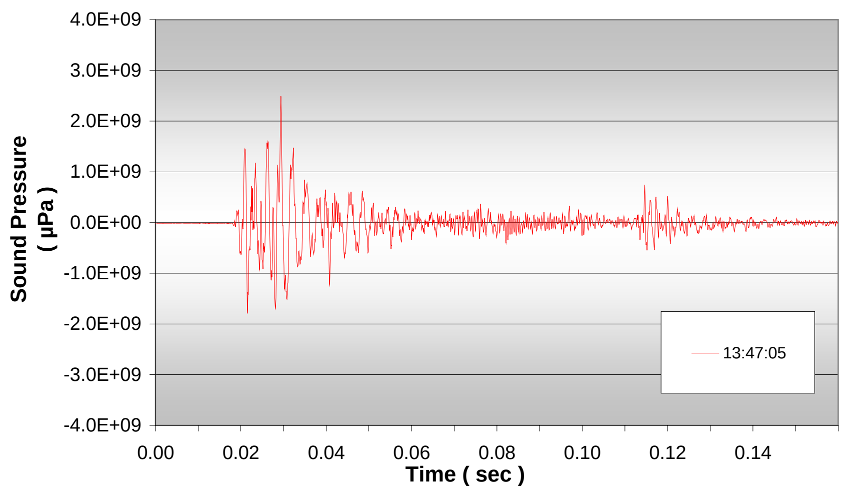


Figure b. Narrow Band Frequency Spectra

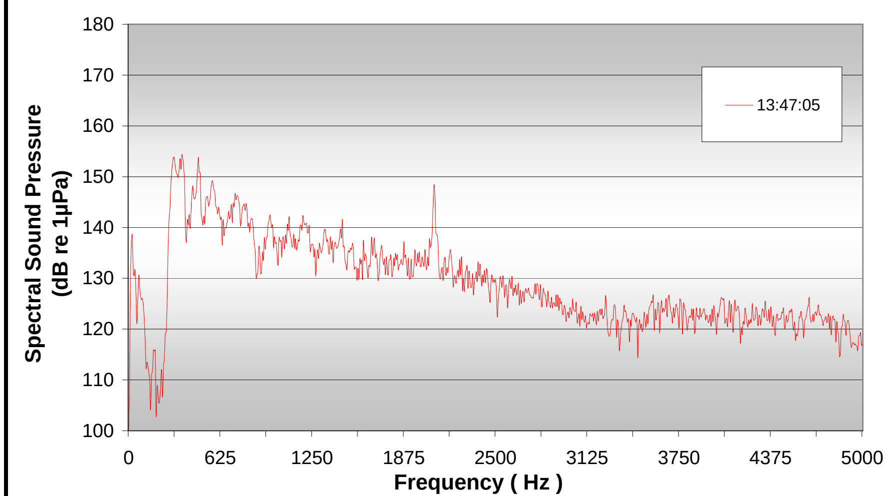


Figure c. Accumulation of Sound Energy

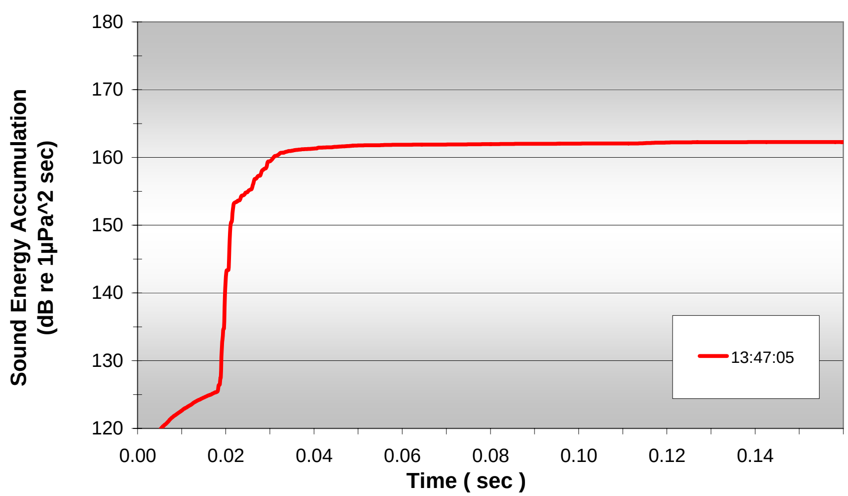


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	RMS 90%*	SEL
13:47:05	188	173	162

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS 35ms**	SEL
Reported Average	187	172	162
Reported maximum	194	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 19

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings ON and OFF 10/27/2009

Figure a. Waveform

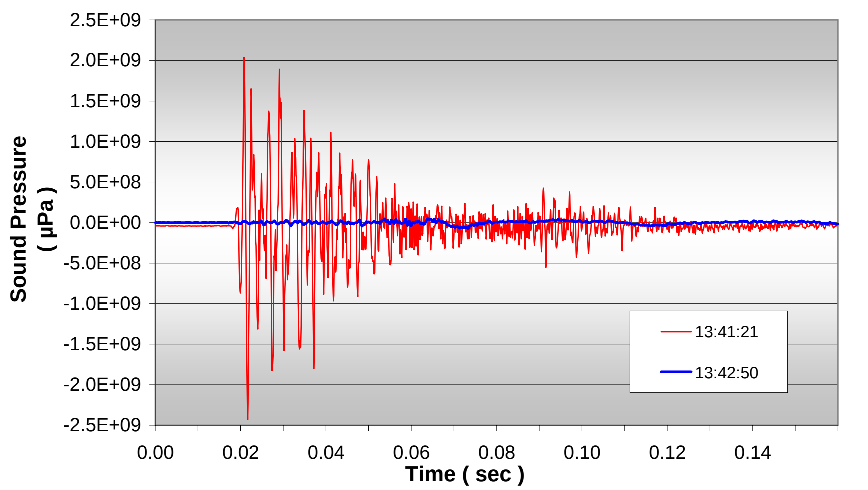


Figure b. Narrow Band Frequency Spectra

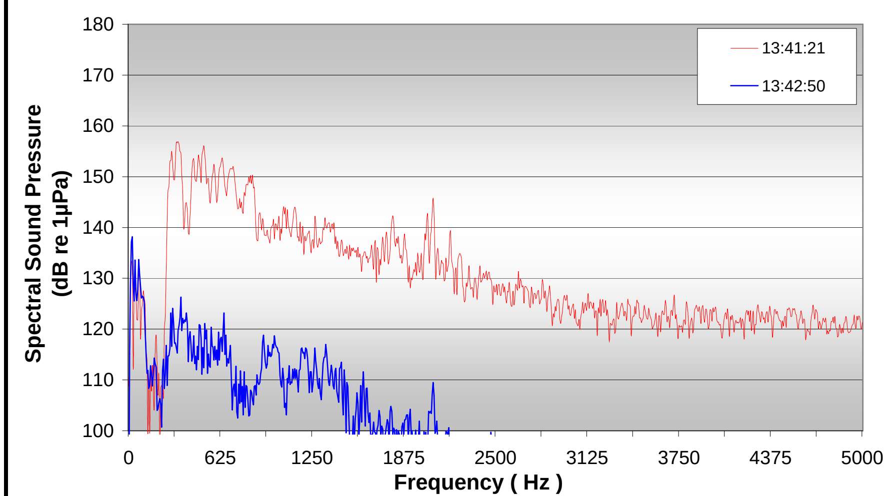


Figure c. Accumulation of Sound Energy

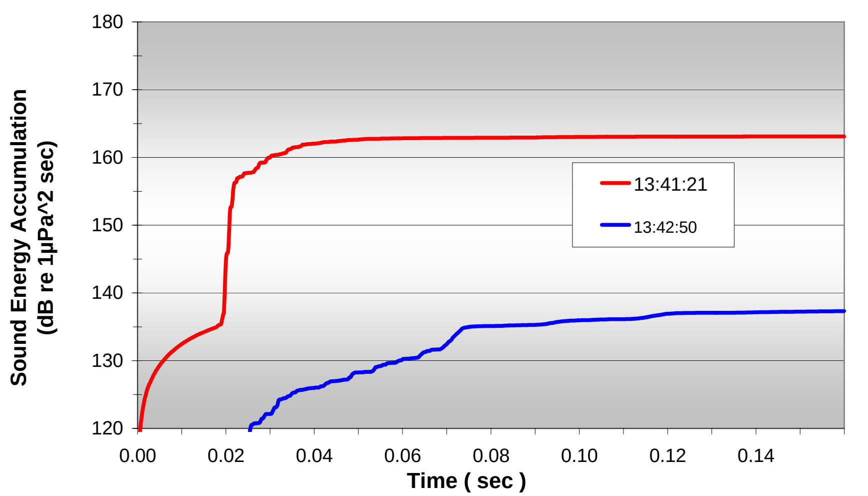


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	RMS90%*	SEL
13:41:21	188	176	163
13:42:50	158	147	137

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Unmitigated	194	181	168
Mitigated	161	158	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 20

Pile PB-4 24" Steel Shell Pile @ 12 meters - Unconfined Bubble Rings ON and OFF 10/27/2009

Figure a. Waveform

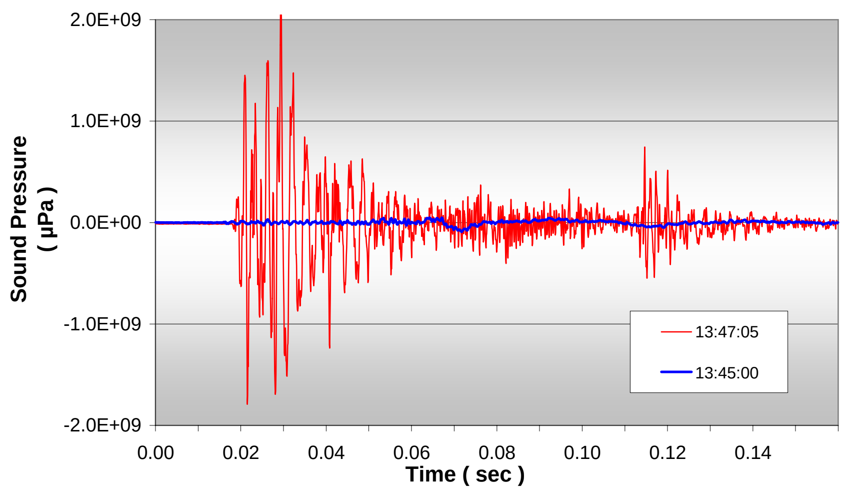


Figure b. Narrow Band Frequency Spectra

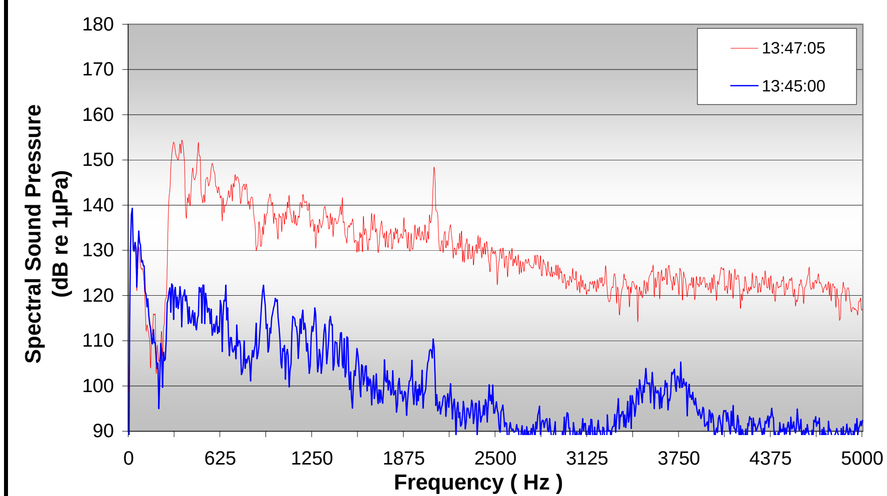


Figure c. Accumulation of Sound Energy

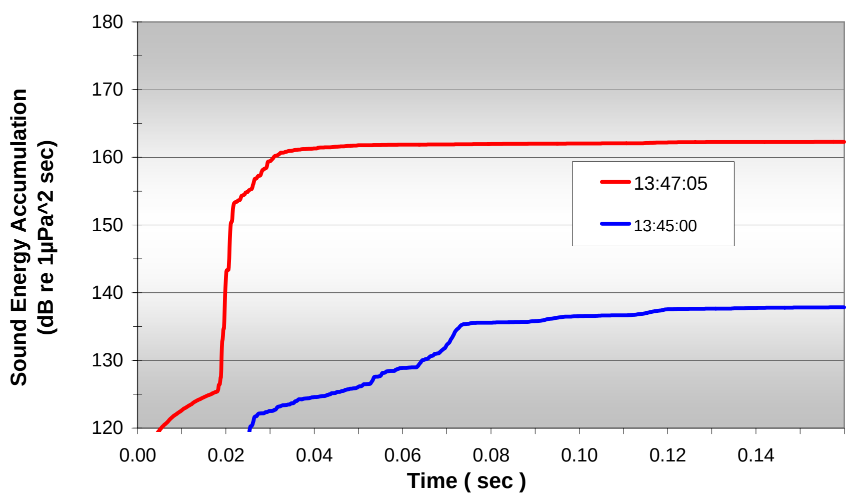


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

12 meter	Peak	$RMS_{90\%}$*	SEL
13:47:05	188	173	162
13:45:00	159	148	138

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	194	181	168
Mitigated	161	158	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 21

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

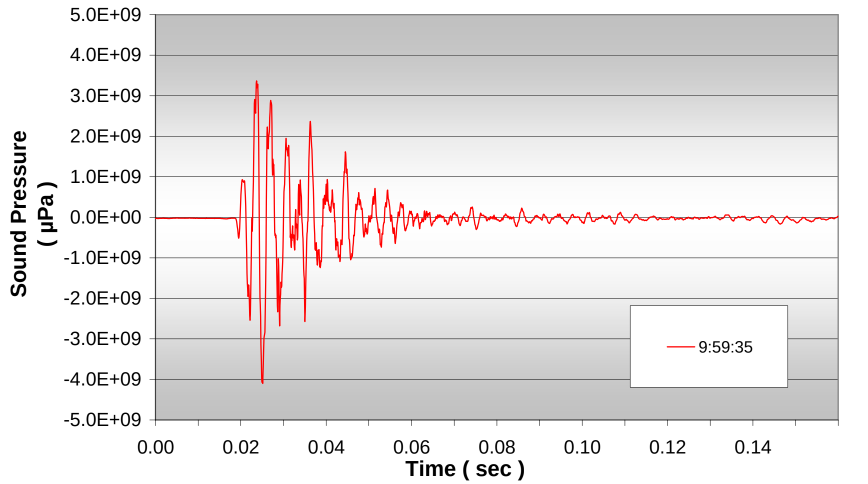


Figure b. Narrow Band Frequency Spectra

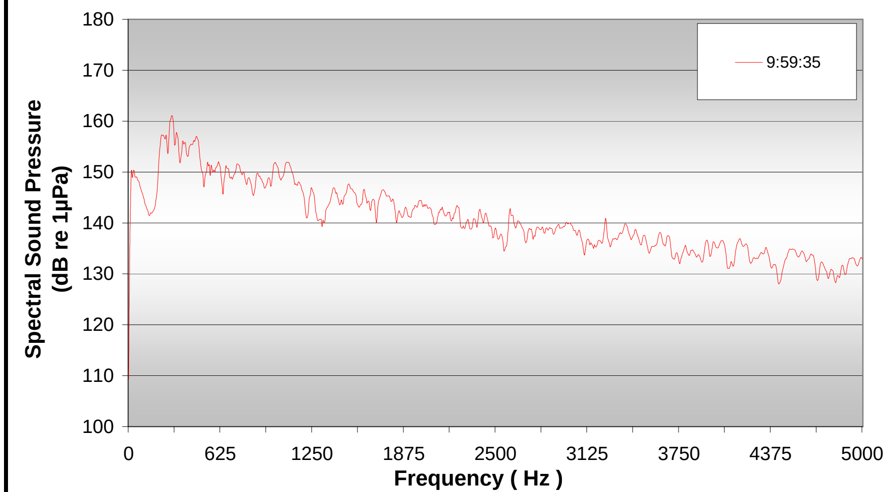


Figure c. Accumulation of Sound Energy

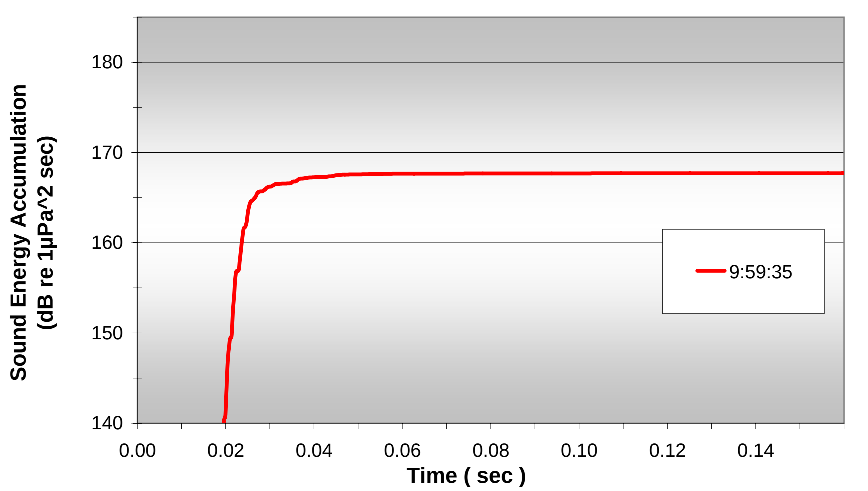


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
9:59:35	192	184	168

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	194	181	169
Reported maximum	196	185	175

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 22

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

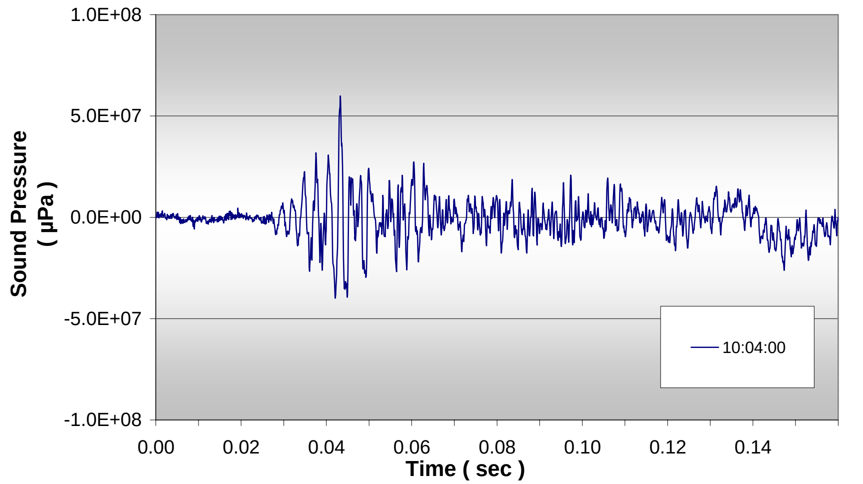


Figure b. Narrow Band Frequency Spectra

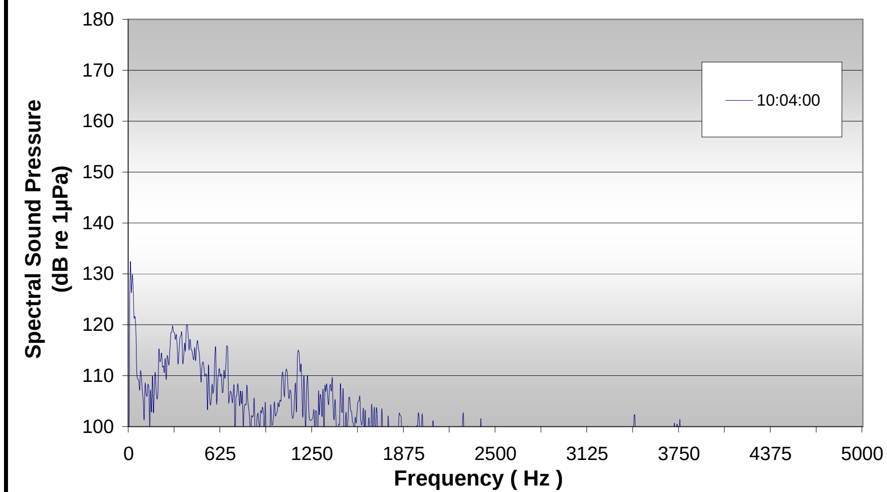


Figure c. Accumulation of Sound Energy

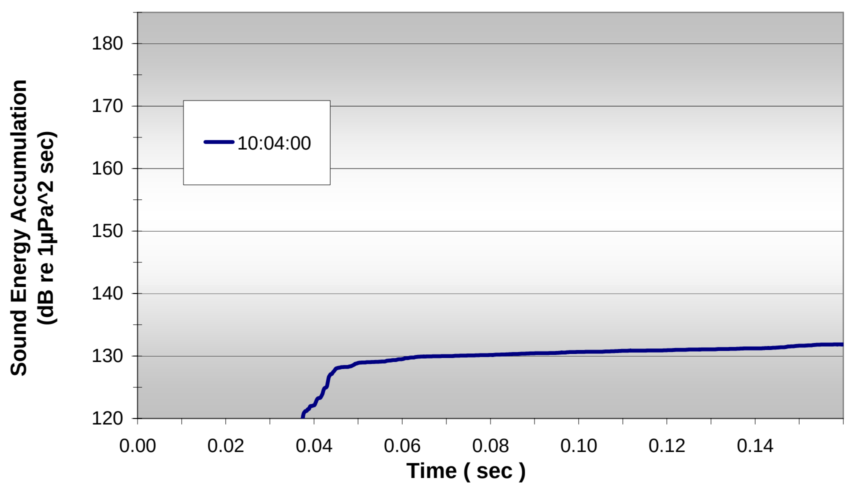


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:03:00	153	141	133

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	158	143	134
Reported maximum	164	150	152

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 23

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

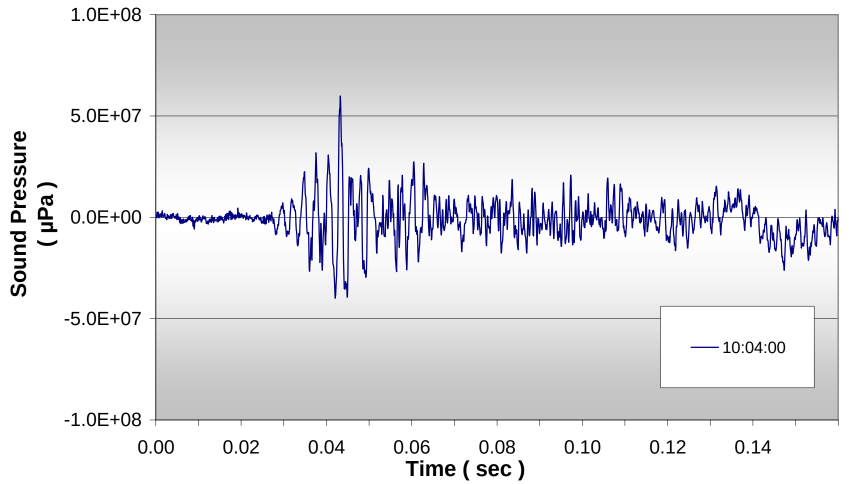


Figure b. Narrow Band Frequency Spectra

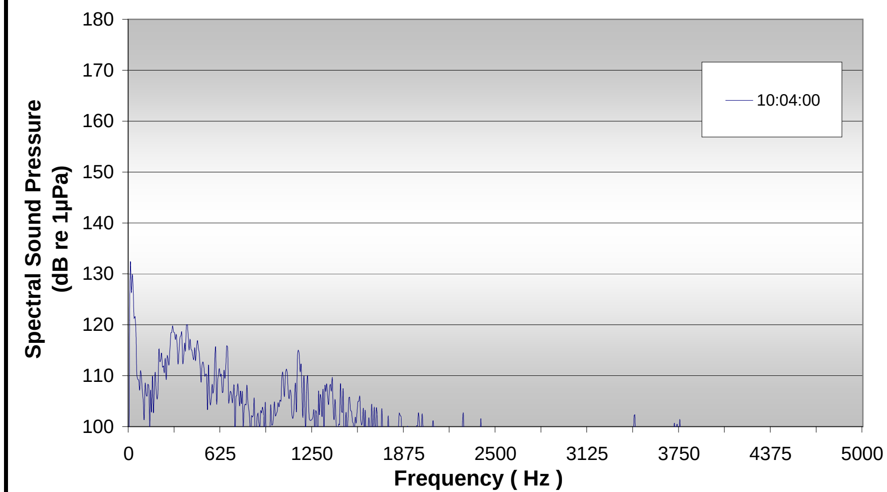


Figure c. Accumulation of Sound Energy

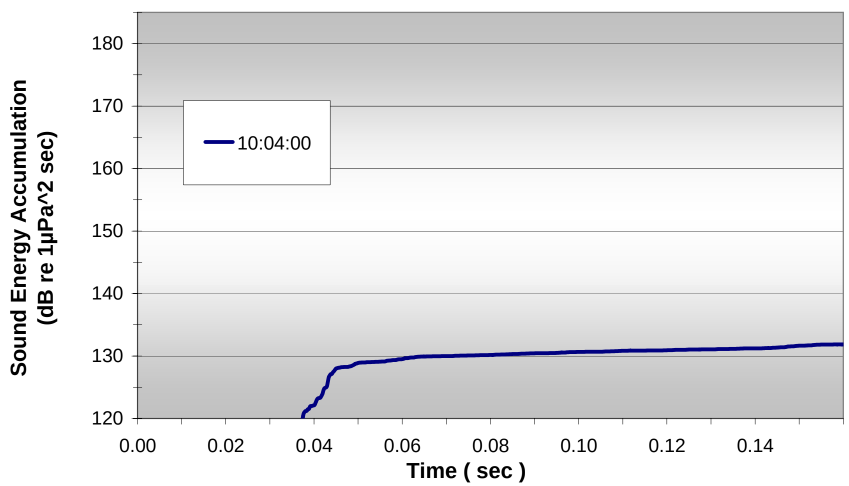


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:04:00	156	141	132

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	158	143	134
Reported maximum	164	150	152

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 24

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

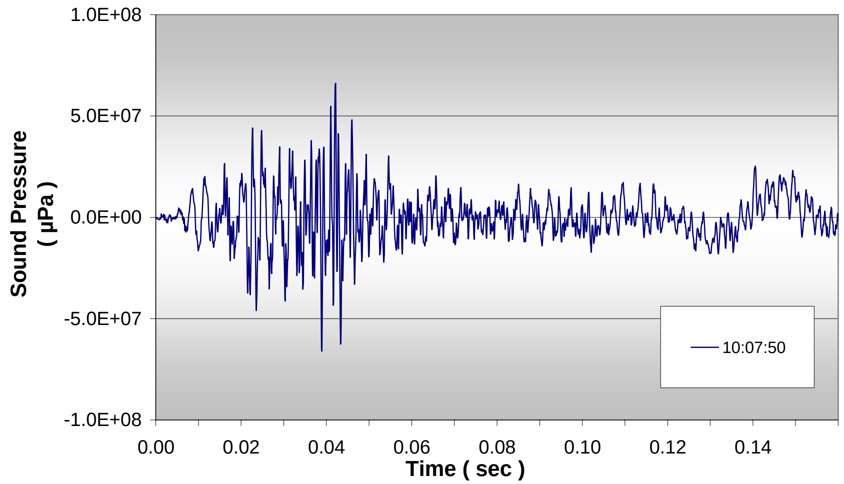


Figure b. Narrow Band Frequency Spectra

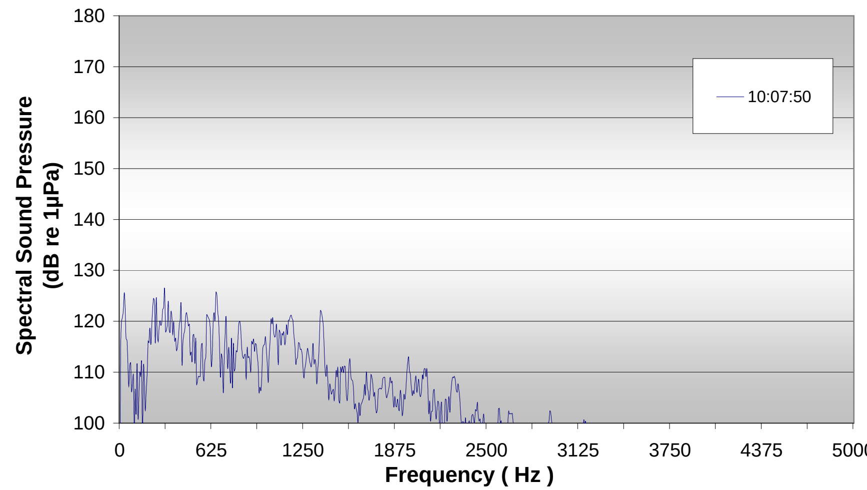


Figure c. Accumulation of Sound Energy

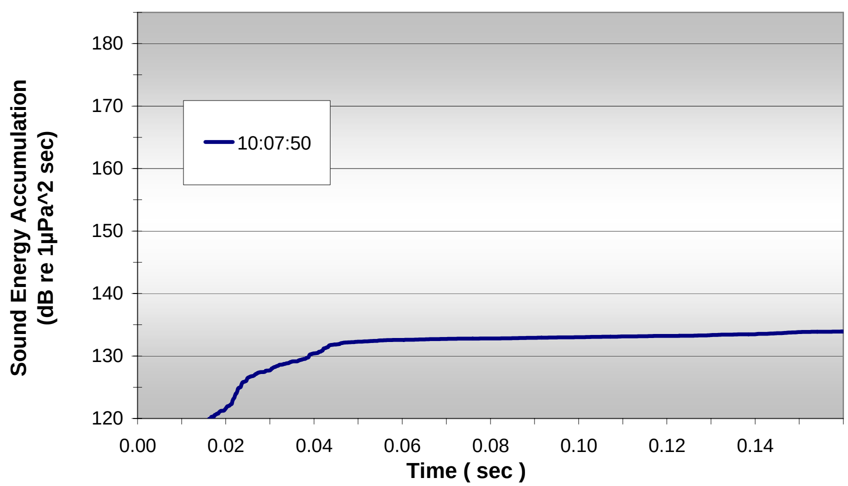


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
10:07:50	156	142	134

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	158	143	134
Reported maximum	164	150	152

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 25

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

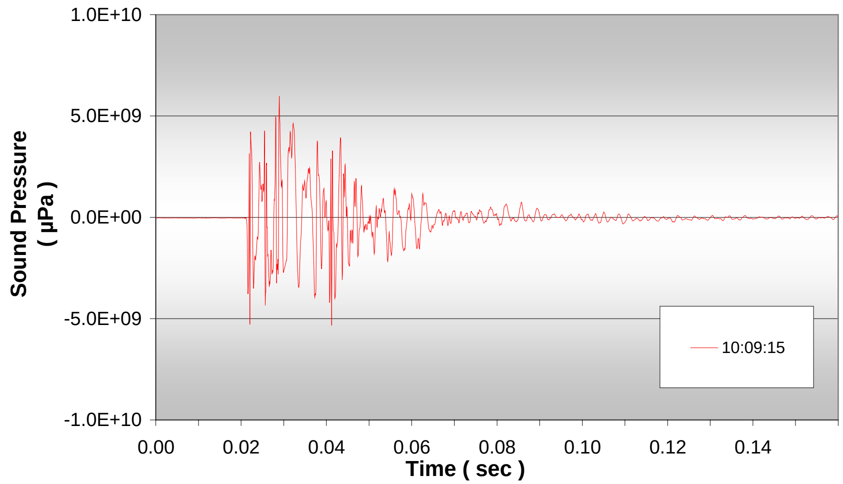


Figure b. Narrow Band Frequency Spectra

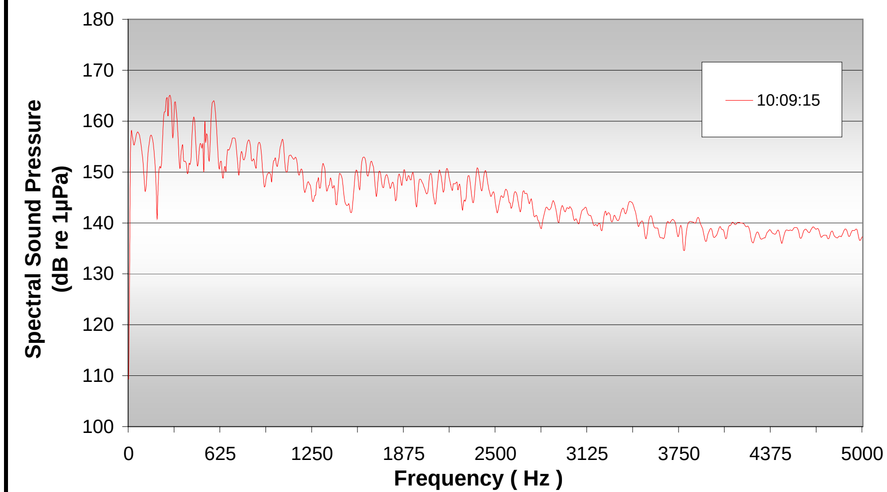


Figure c. Accumulation of Sound Energy

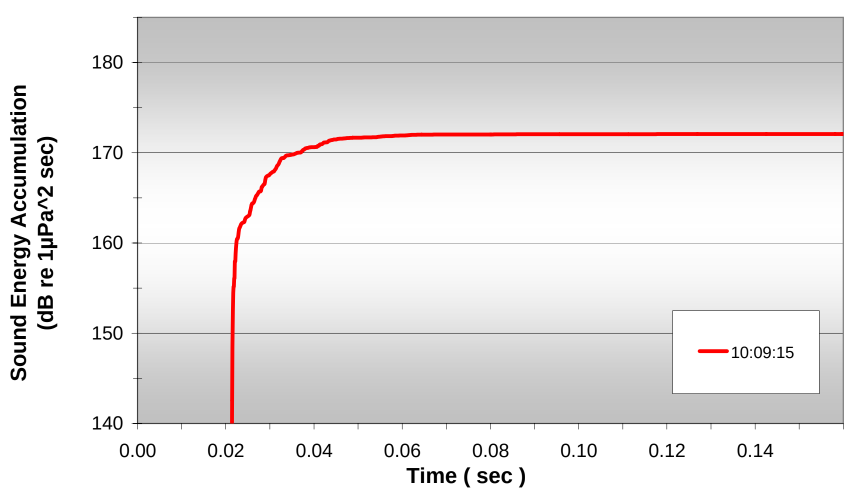


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:09:15	196	186	172

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	194	181	169
Reported maximum	196	185	175

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 26

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

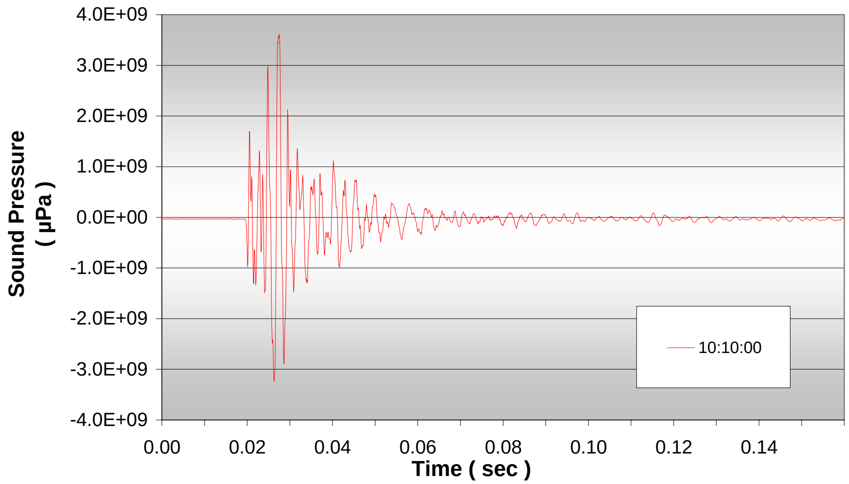


Figure b. Narrow Band Frequency Spectra

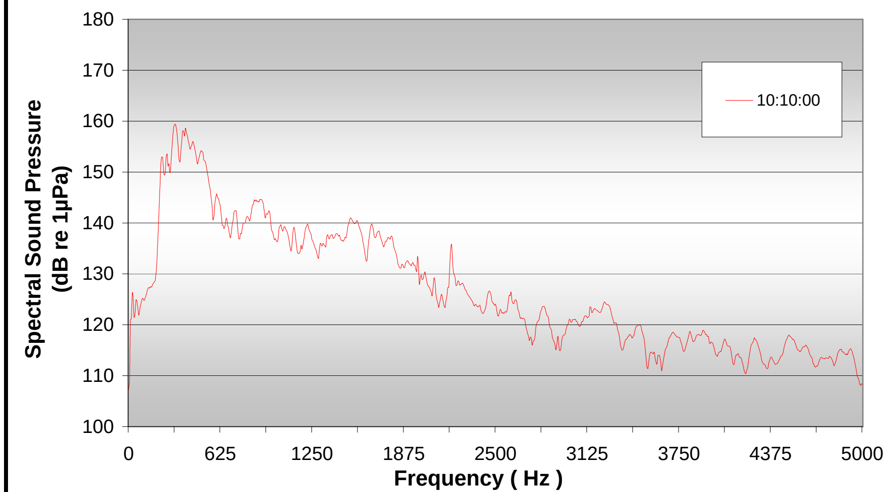


Figure c. Accumulation of Sound Energy

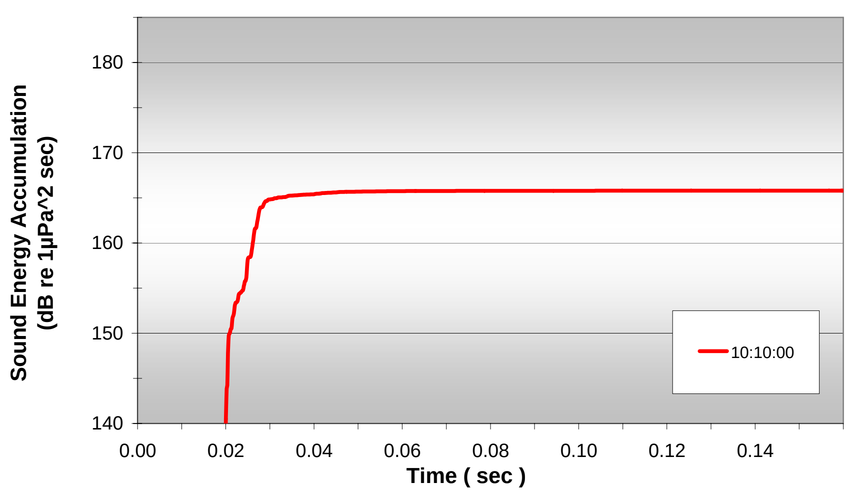


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
10:10:00	191	182	166

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	194	181	169
Reported maximum	196	185	175

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Pile WAB-1 30" Steel Shell Pile @ 10 meters - Confined Bubble Ring ON and OFF 10/29/2009

Figure a. Waveform

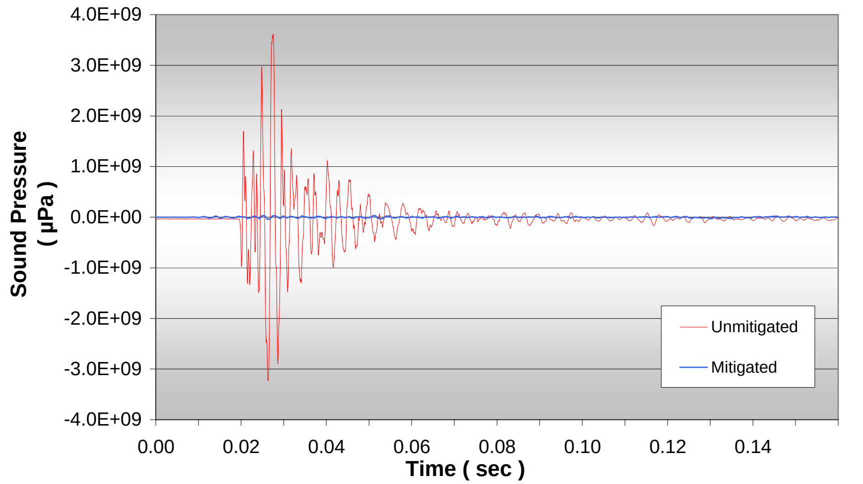


Figure b. Narrow Band Frequency Spectra

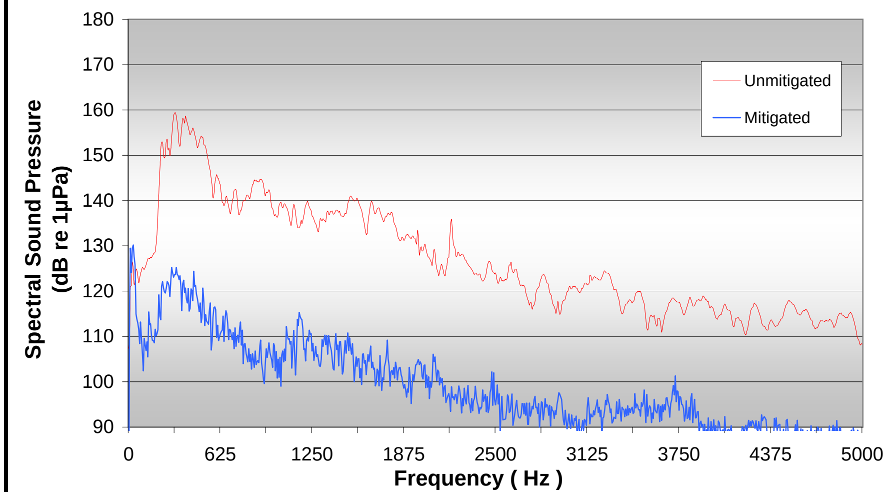


Figure c. Accumulation of Sound Energy

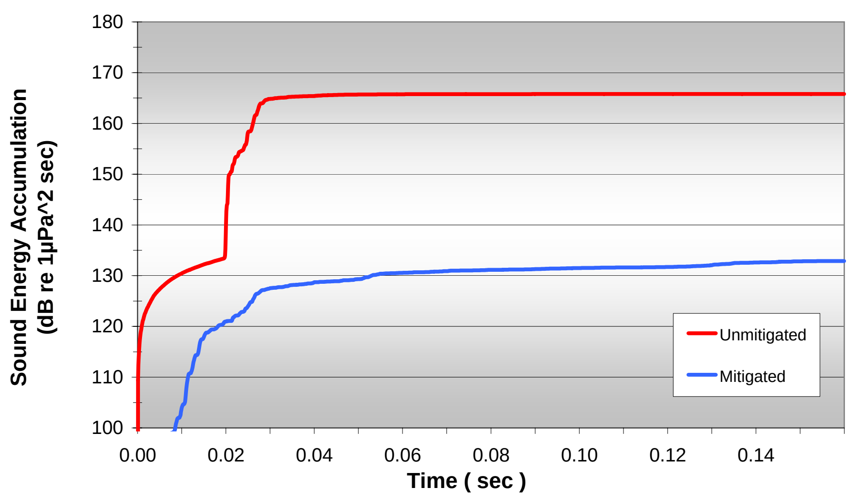


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:10:00	191	182	166
10:03:00	153	141	133

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Unmitigated	194	181	169
Mitigated	158	143	134

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 28

WAB-2 30" Steel Shell Pile @ 13 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

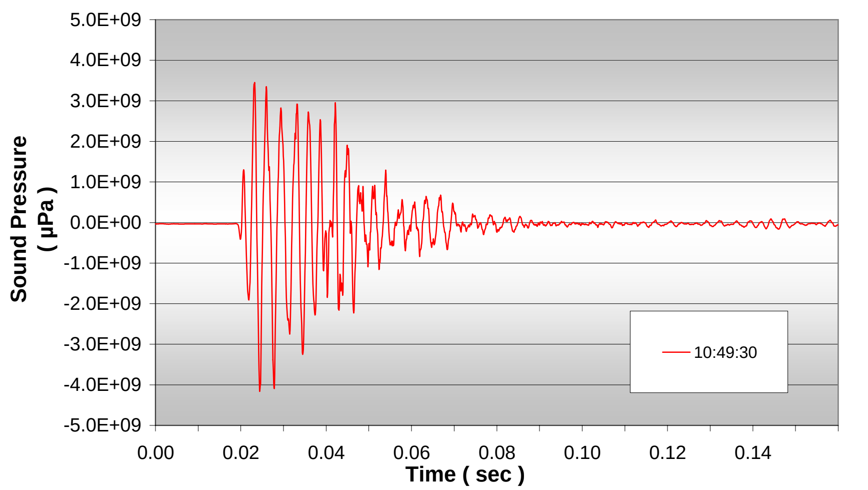


Figure b. Narrow Band Frequency Spectra

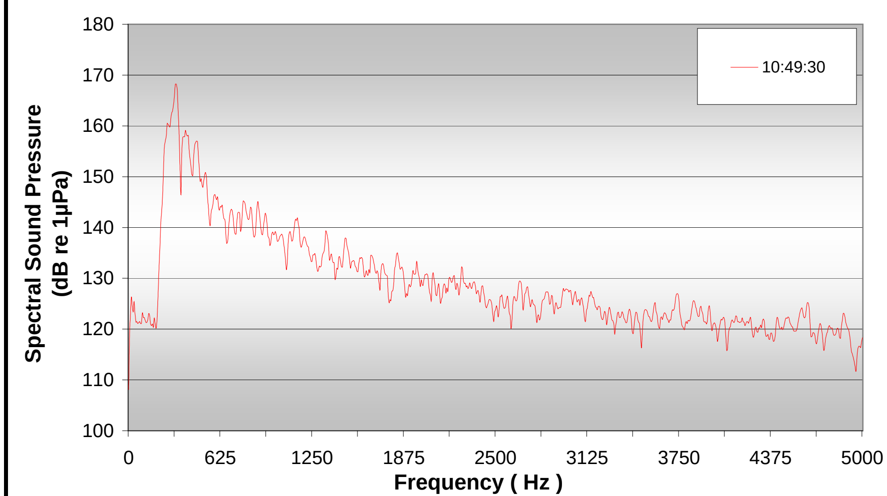


Figure c. Accumulation of Sound Energy

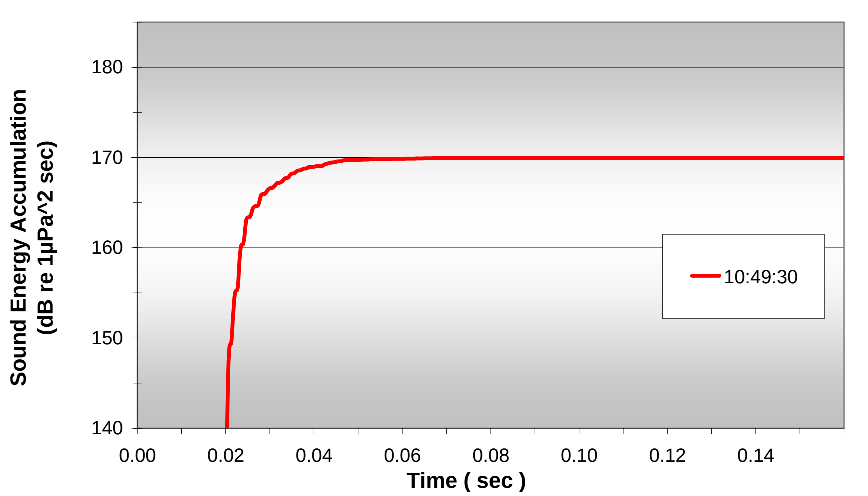


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
10:49:30	192	185	170

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	191	179	165
Reported maximum	196	183	167

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 29

WAB-2 30" Steel Shell Pile @ 13 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

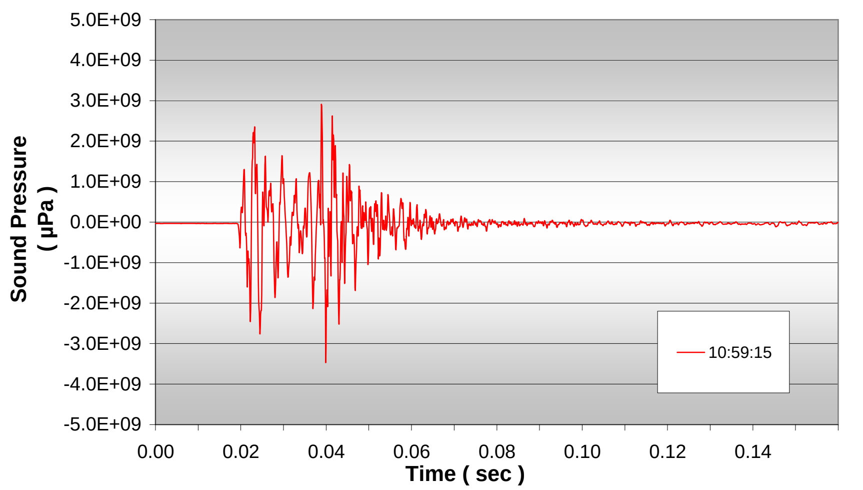


Figure b. Narrow Band Frequency Spectra

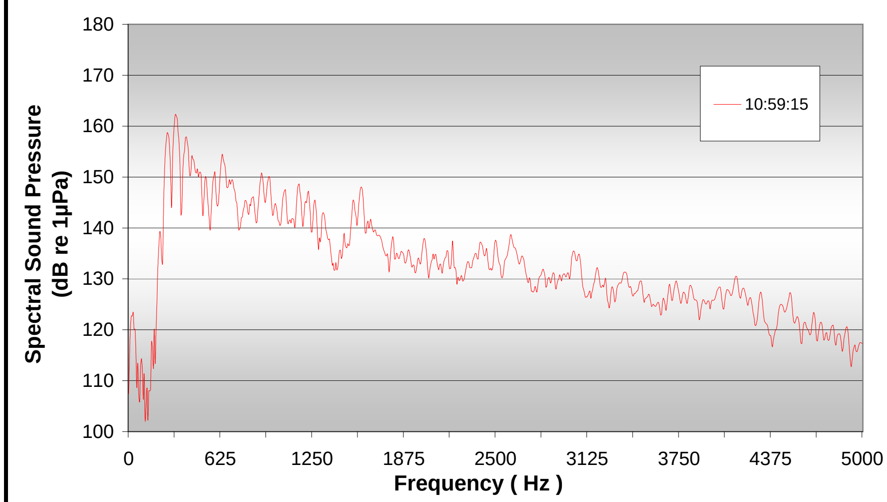


Figure c. Accumulation of Sound Energy

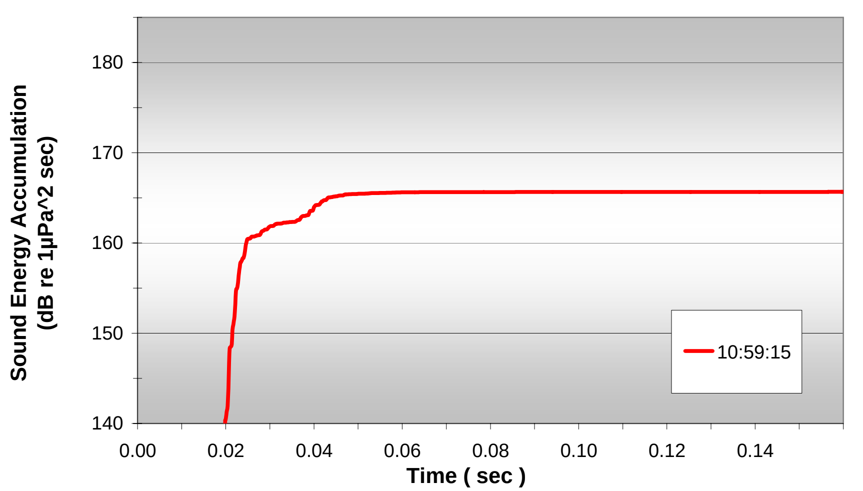


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	RMS90%*	SEL
10:59:15	191	181	166

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	191	179	165
Reported maximum	196	183	167

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 30

WAB-2 30" Steel Shell Pile @ 13 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

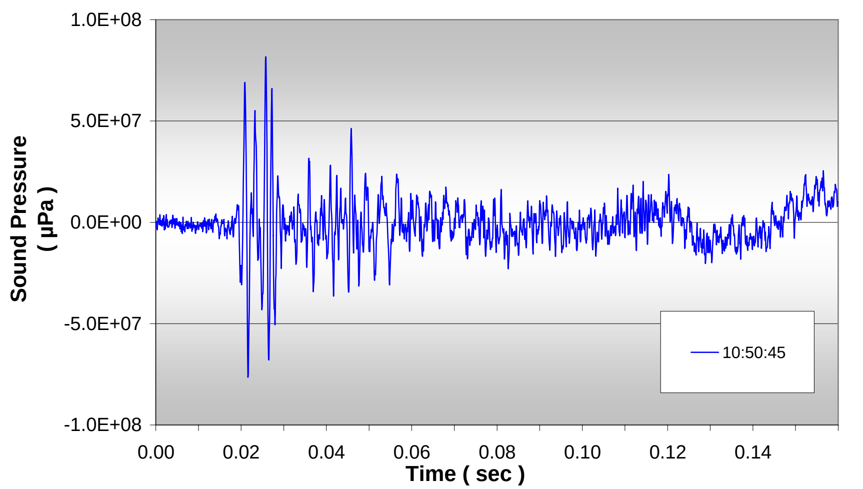


Figure b. Narrow Band Frequency Spectra

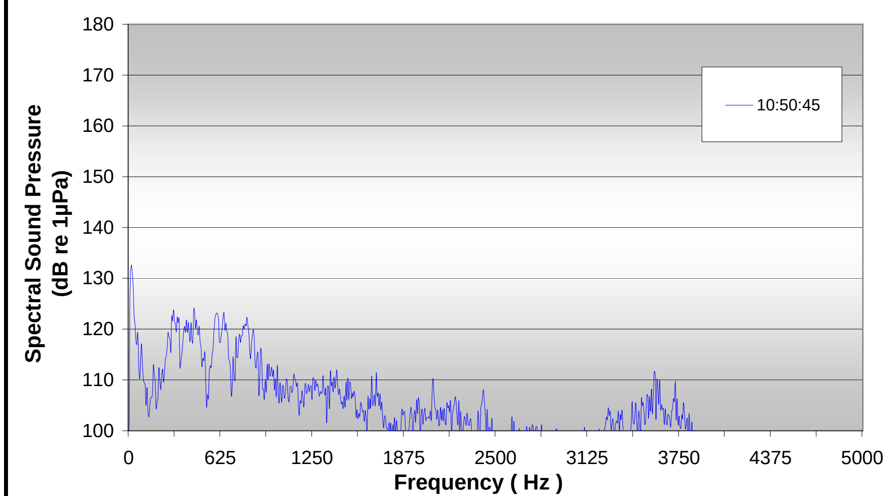


Figure c. Accumulation of Sound Energy

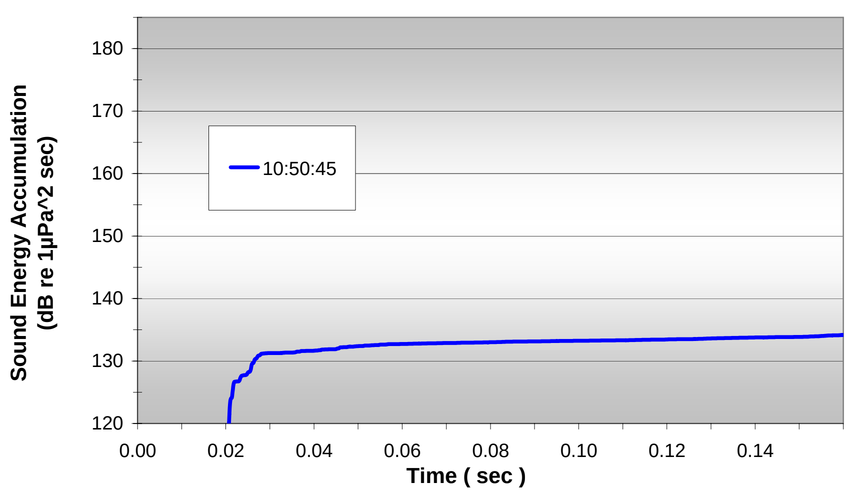


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
10:50:45	158	142	134

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	161	150	138
Reported maximum	171	163	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 31

WAB-2 30" Steel Shell Pile @ 13 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

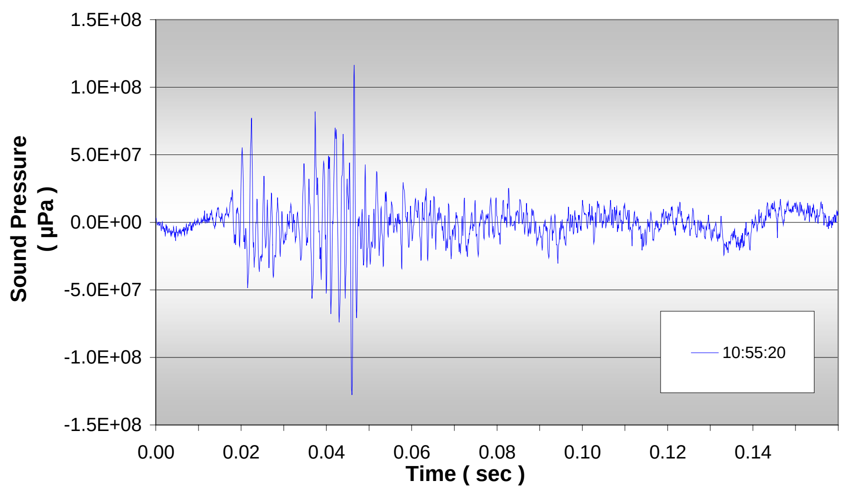


Figure b. Narrow Band Frequency Spectra

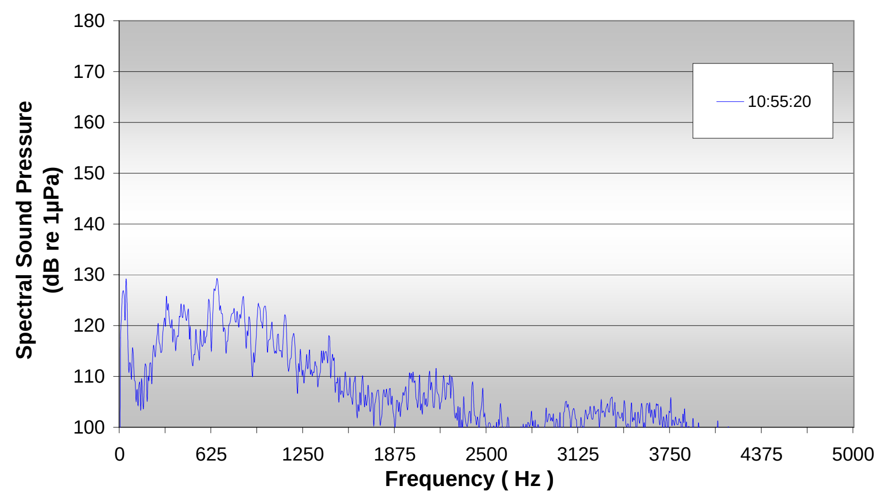


Figure c. Accumulation of Sound Energy

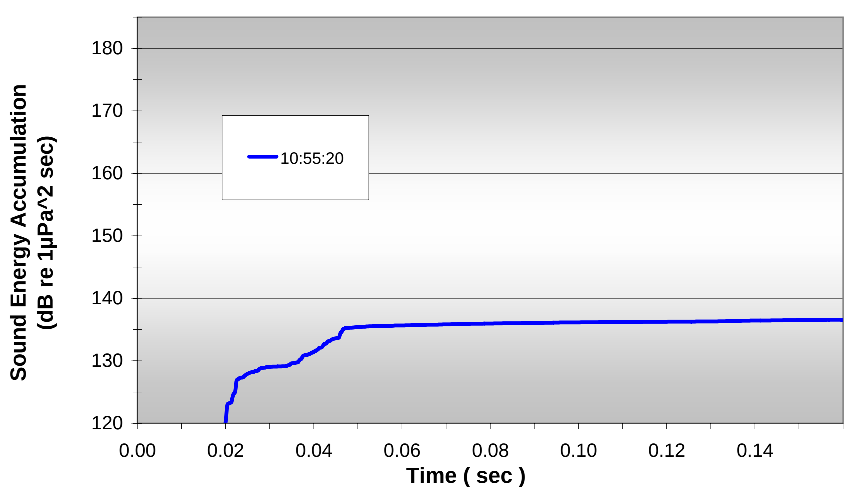


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	RMS90%*	SEL
10:55:20	162	146	137

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	161	150	138
Reported maximum	171	163	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 32

WAB-2 30" Steel Shell Pile @ 13 meters - Unconfined Bubble Rings ON and OFF 10/29/2009

Figure a. Waveform

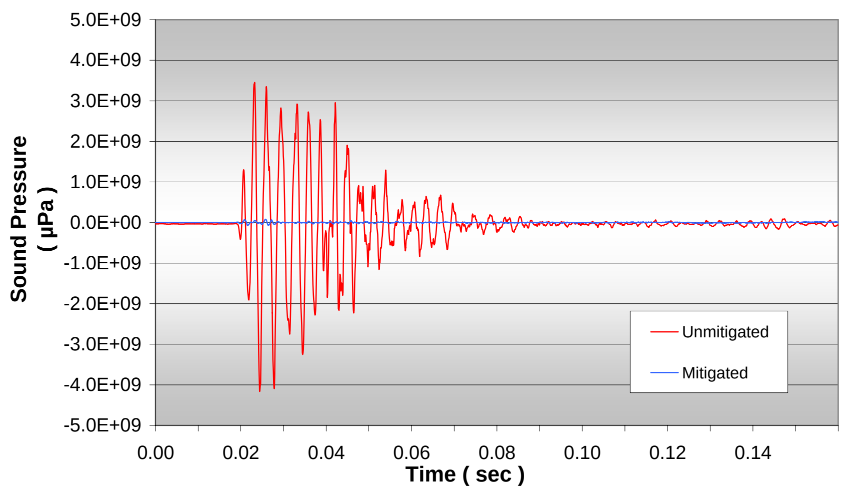


Figure b. Narrow Band Frequency Spectra

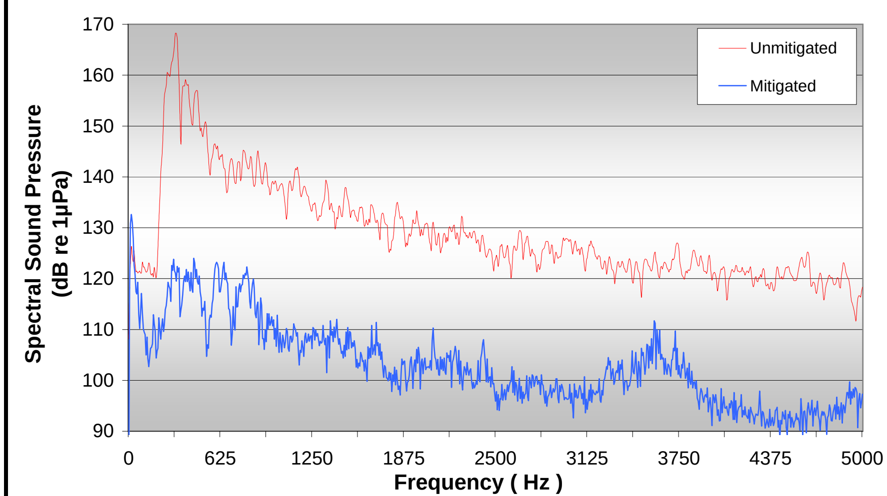


Figure c. Accumulation of Sound Energy

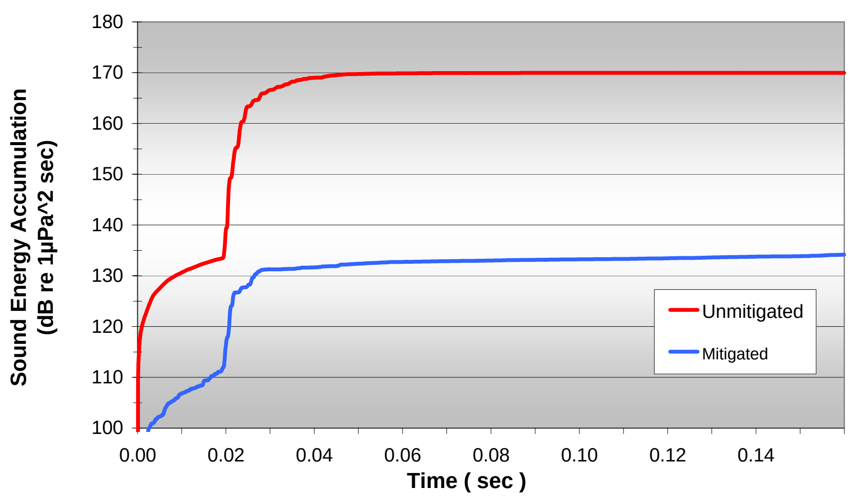


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
Unmitigated	192	185	170
Mitigated	158	142	134

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Unmitigated	191	179	165
Mitigated	161	150	138

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 33

WAB-3 30" Steel Shell Pile @ 10 meters - DNAP 10/29/2009

Figure a. Waveform

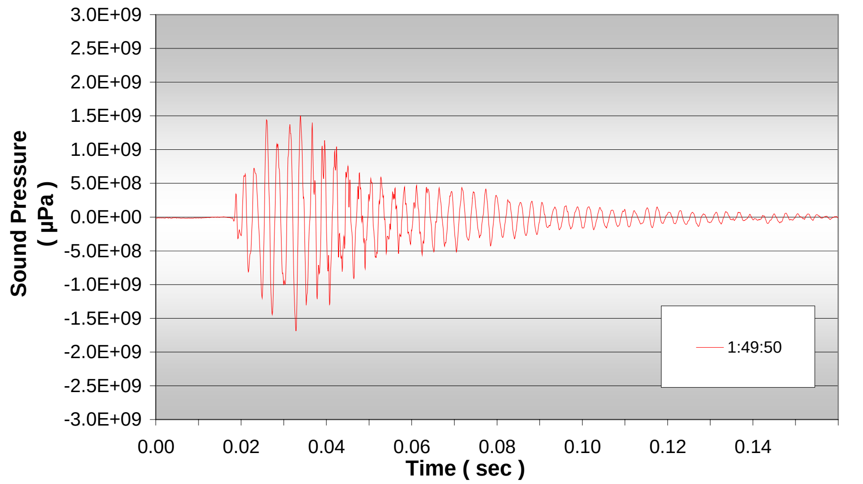


Figure b. Narrow Band Frequency Spectra

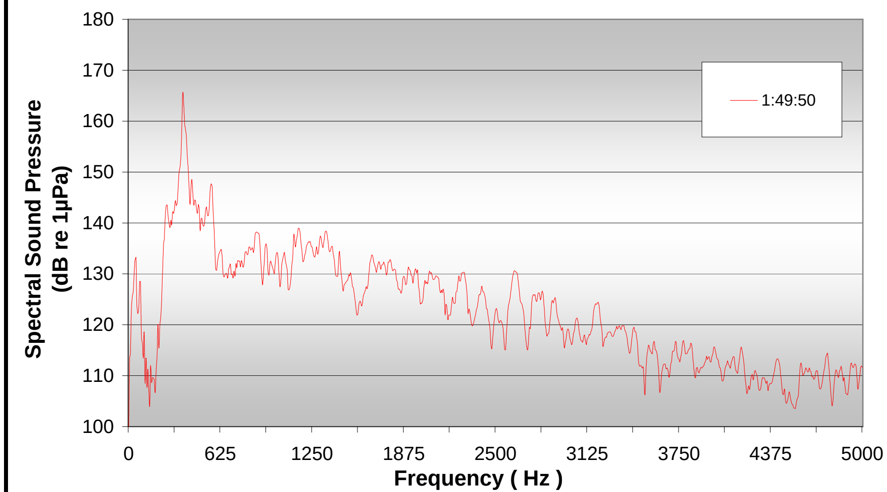


Figure c. Accumulation of Sound Energy

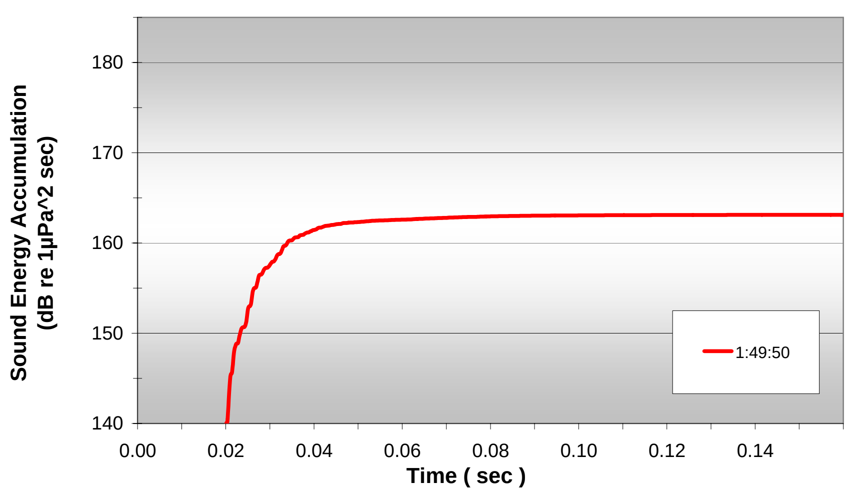


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
1:49:50	185	175	163

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Reported Average	186	175	163
Reported maximum	192	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 34

WAB-3 30" Steel Shell Pile @ 10 meters - DNAP — 10/29/2009

Figure a. Waveform

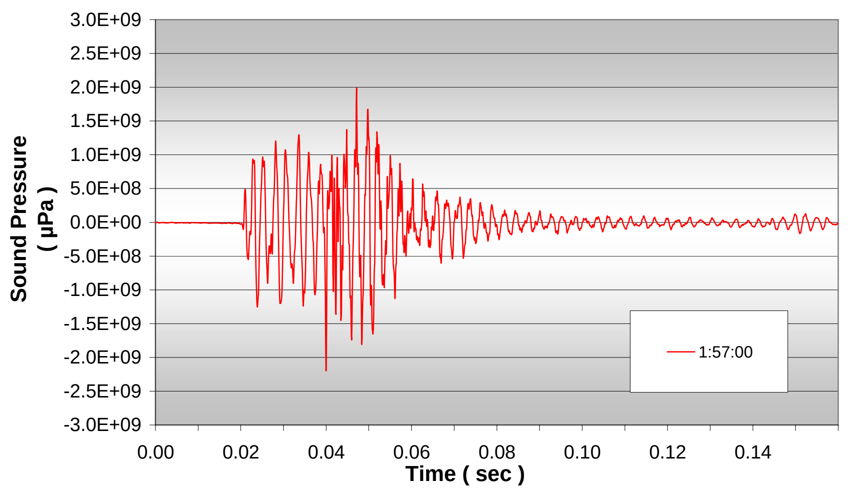


Figure b. Narrow Band Frequency Spectra

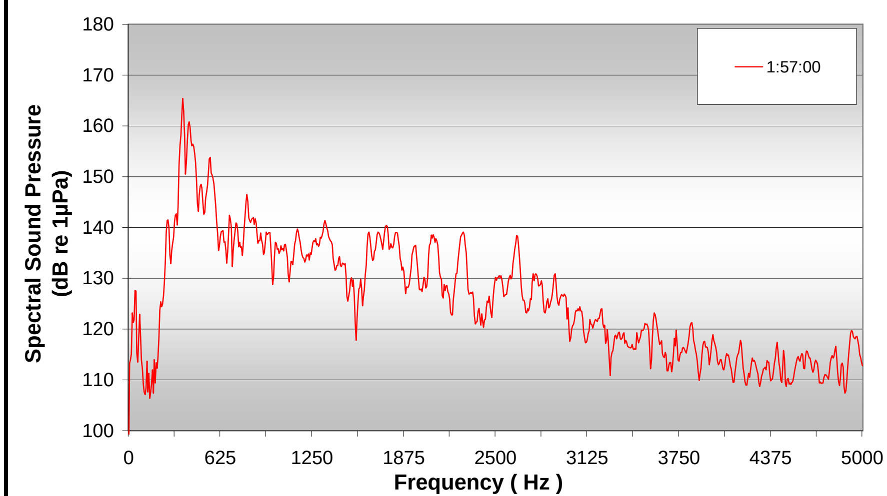


Figure c. Accumulation of Sound Energy

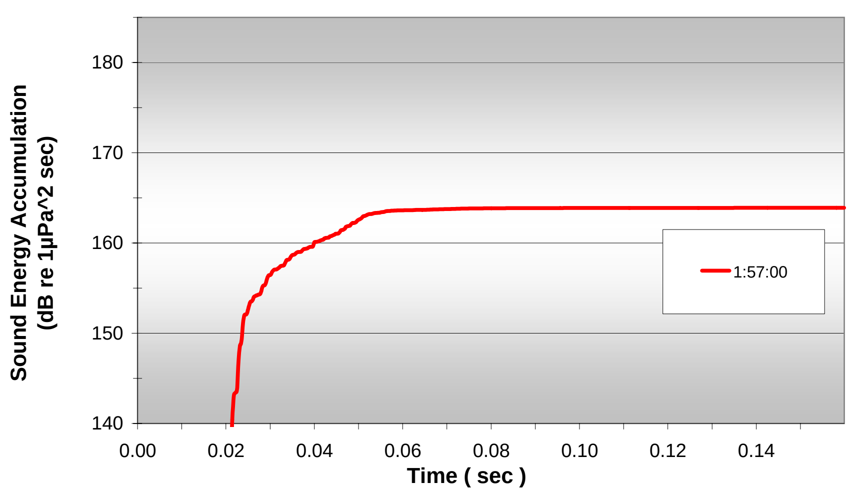


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
1:57:00	187	177	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Reported Average	186	175	163
Reported maximum	192	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 35

WAB-3 30" Steel Shell Pile @ 10 meters - DNAP — 10/29/2009

Figure a. Waveform

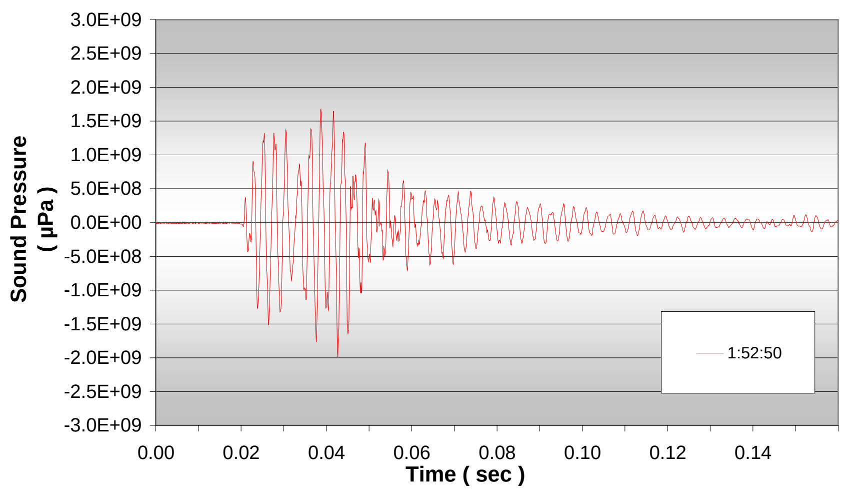


Figure b. Narrow Band Frequency Spectra

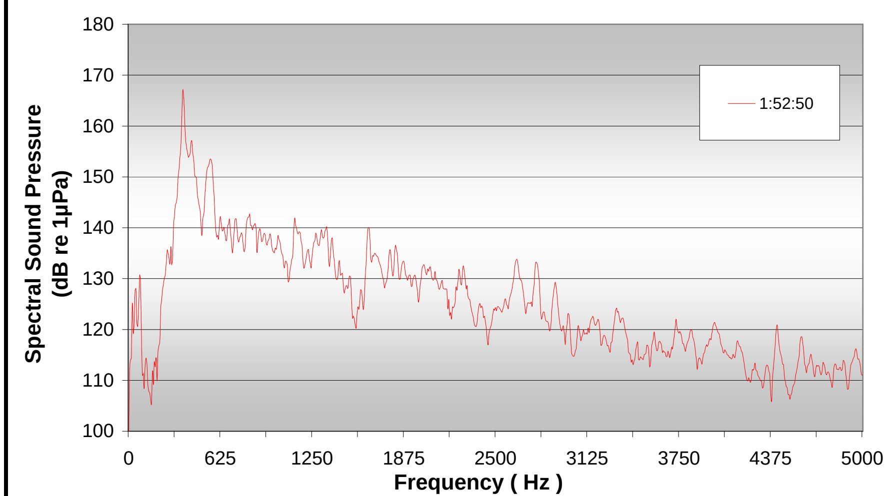


Figure c. Accumulation of Sound Energy

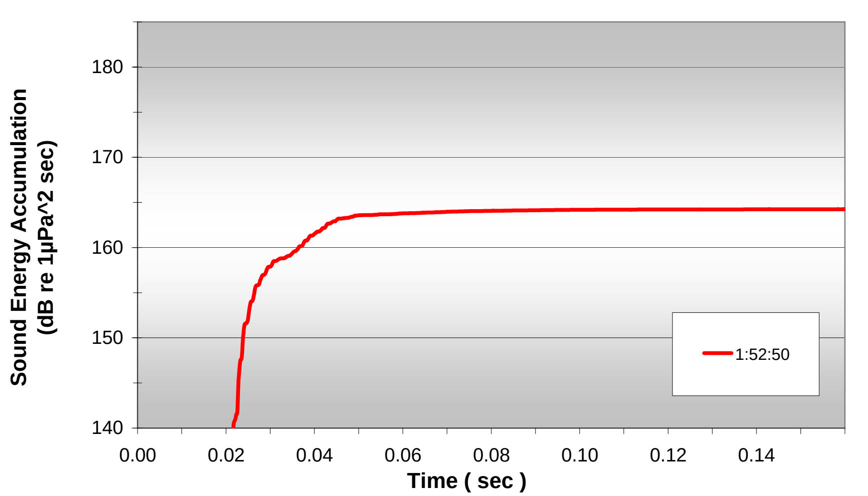


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
1:52:50	186	177	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**	SEL
Reported Average	186	175	163
Reported maximum	192	181	168

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 36

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

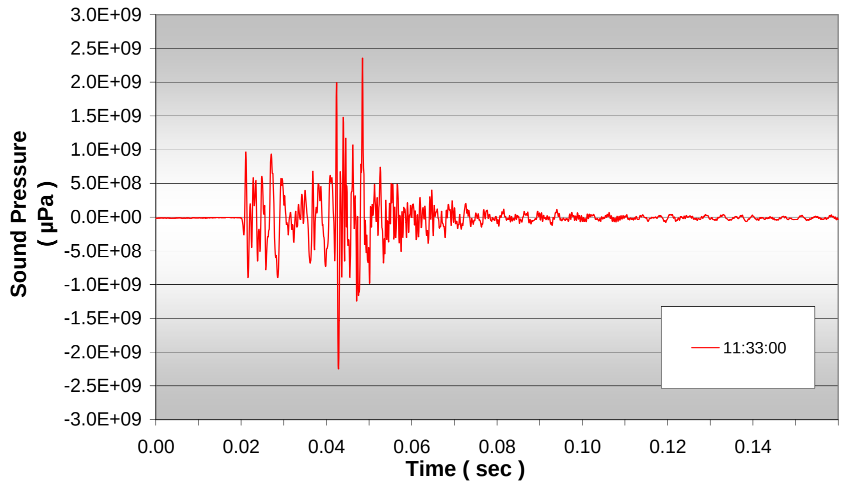


Figure b. Narrow Band Frequency Spectra

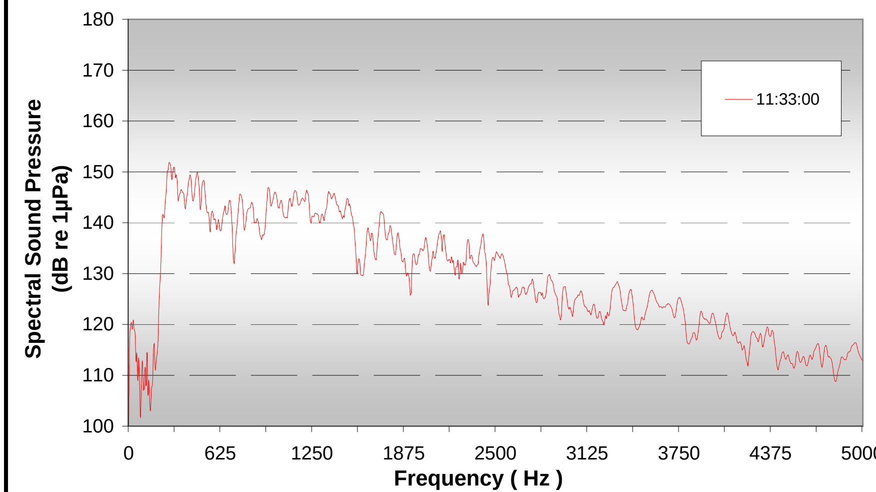


Figure c. Accumulation of Sound Energy

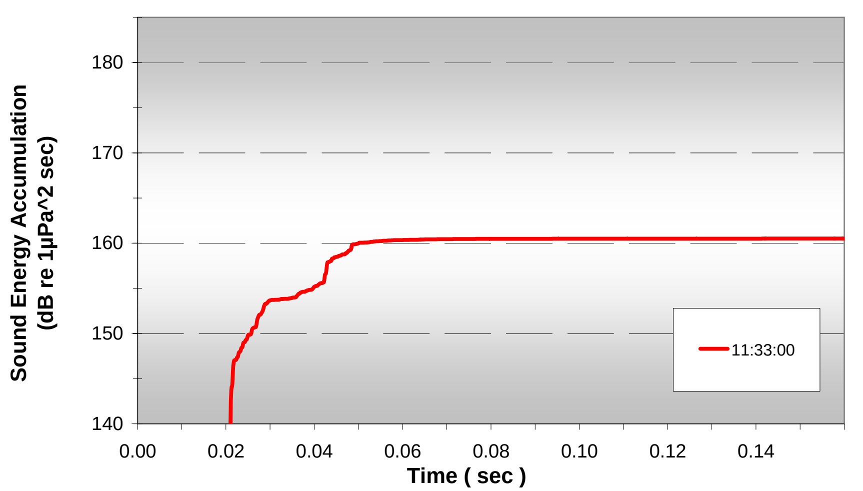


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
11:33:00	187	175	161

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	195	183	166
Reported maximum	196	186	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 37

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

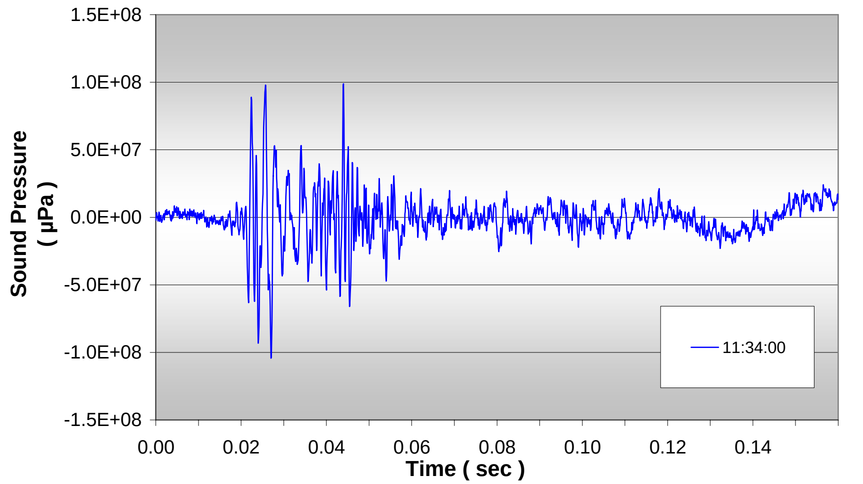


Figure b. Narrow Band Frequency Spectra

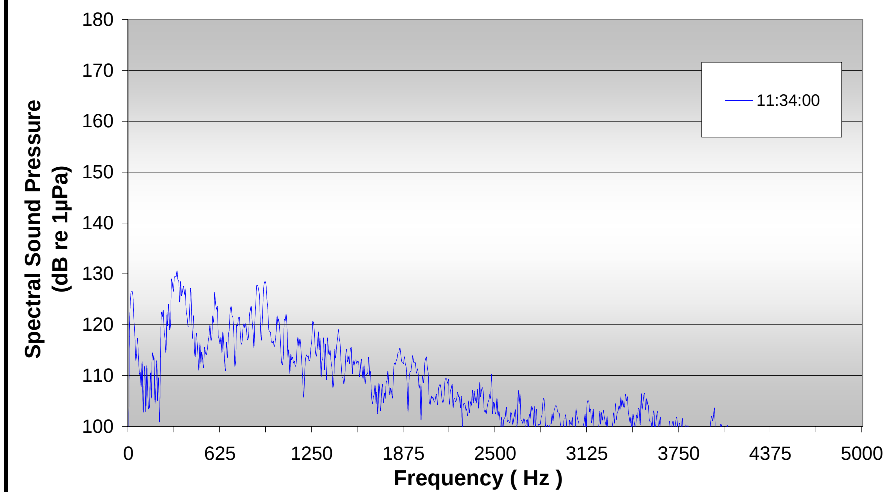


Figure c. Accumulation of Sound Energy

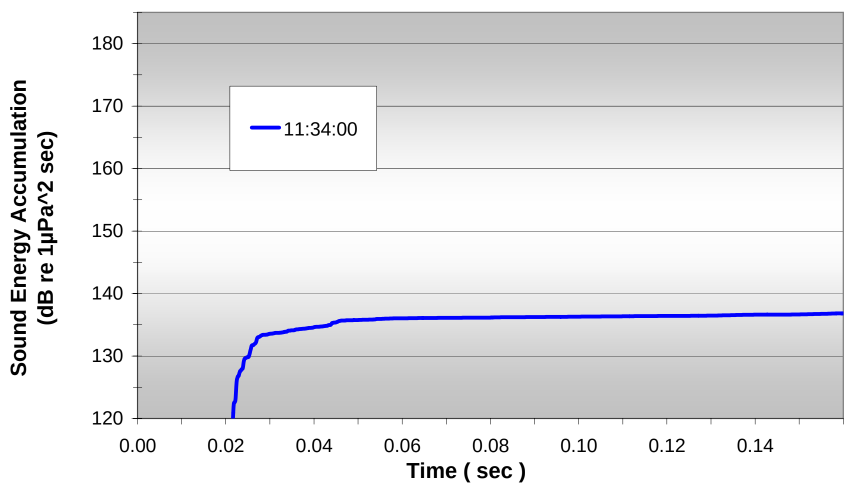


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
11:34:00	160	146	137

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	162	149	138
Reported maximum	169	162	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 38

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

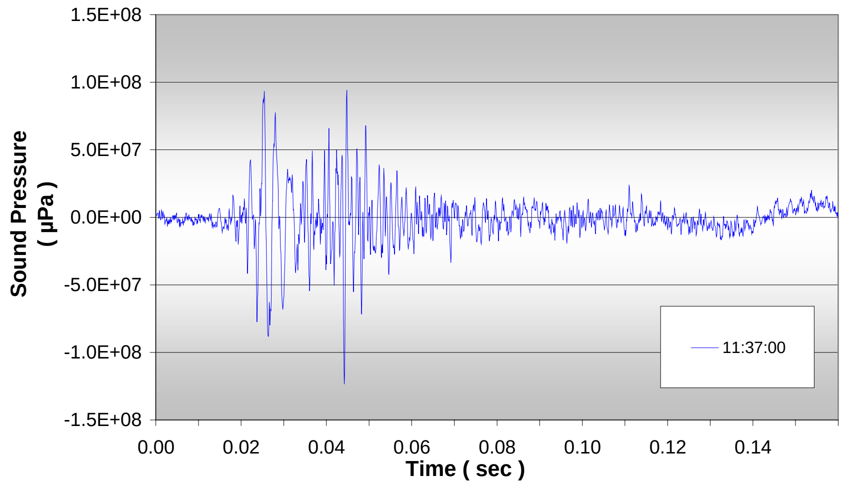


Figure b. Narrow Band Frequency Spectra

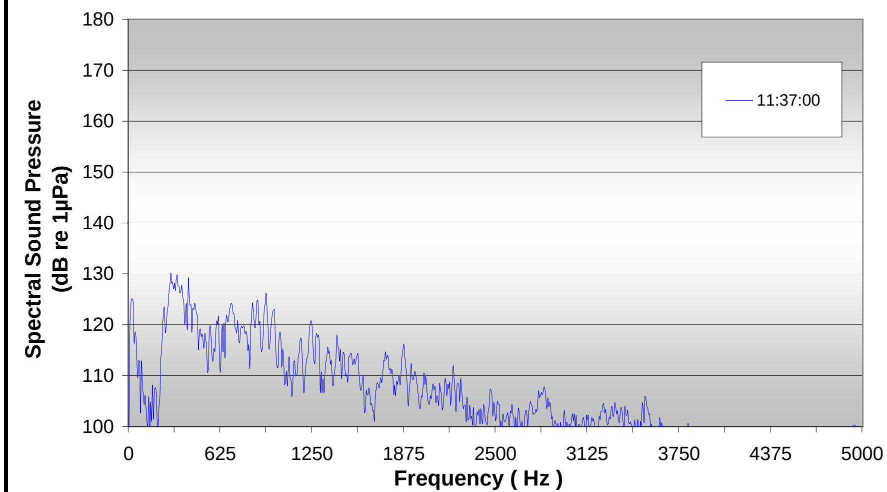


Figure c. Accumulation of Sound Energy

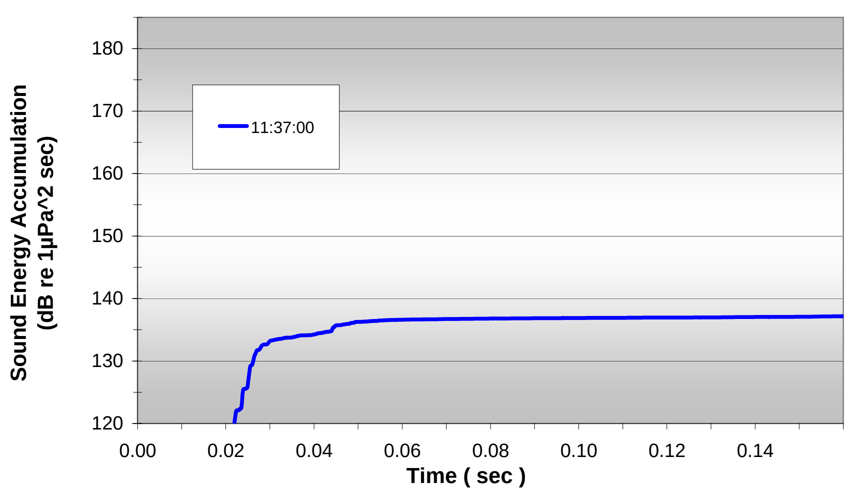


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
11:37:00	162	147	137

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	162	149	138
Reported maximum	169	162	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 39

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

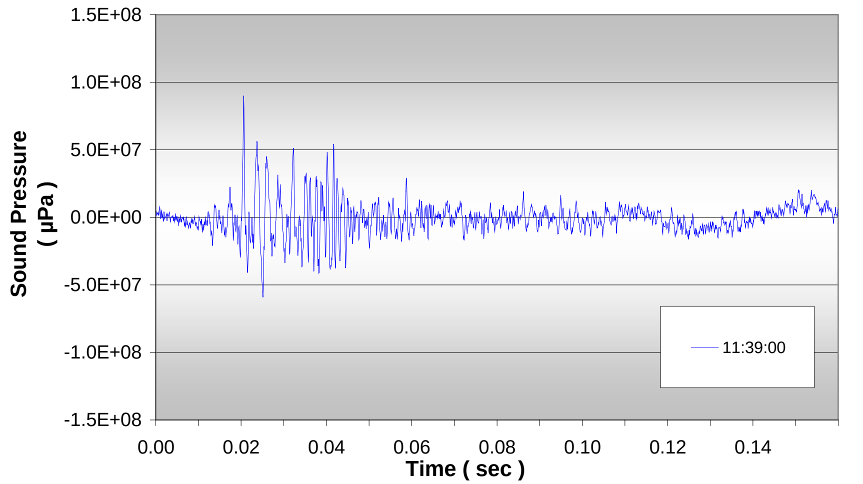


Figure b. Narrow Band Frequency Spectra

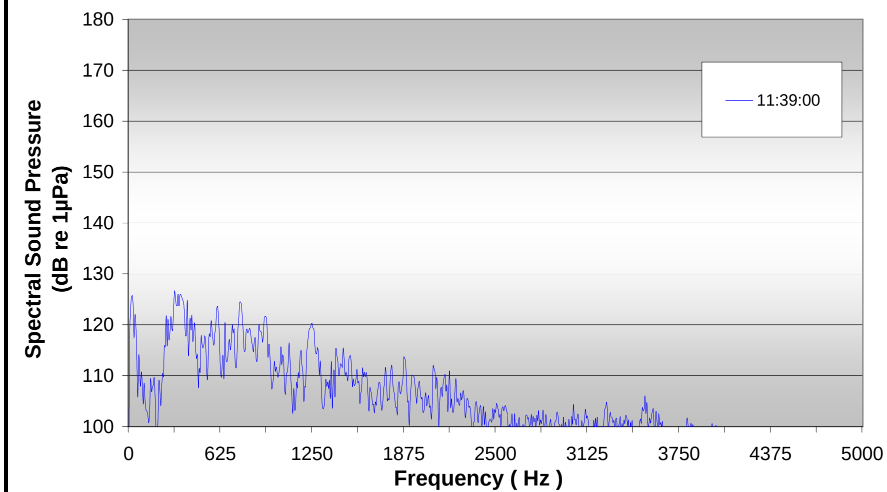


Figure c. Accumulation of Sound Energy

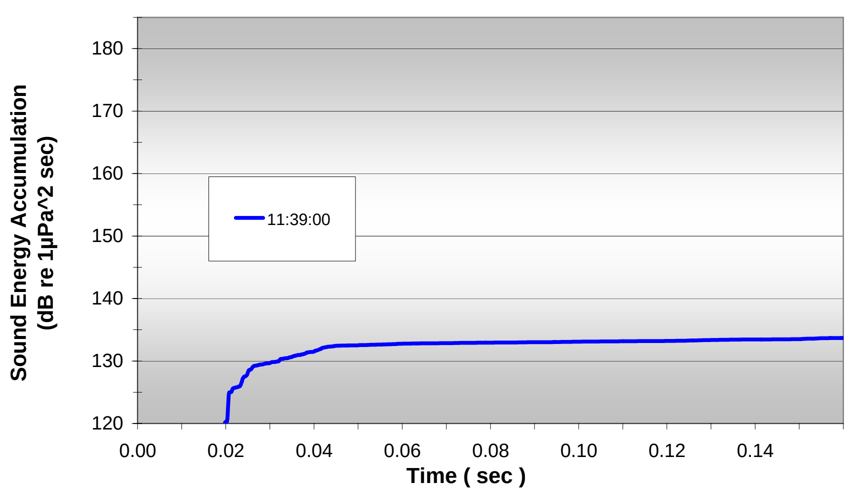


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	$RMS_{90\%}$*	SEL
11:39:00	159	142	134

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	162	149	138
Reported maximum	169	162	140

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 40

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

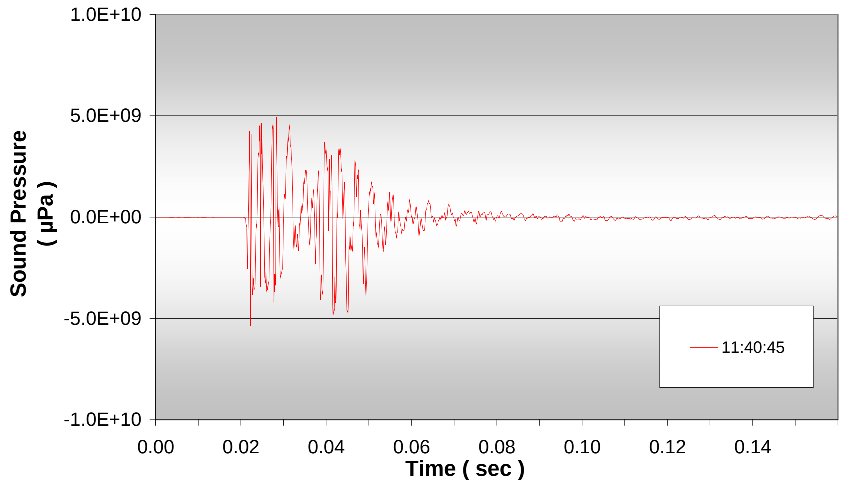


Figure b. Narrow Band Frequency Spectra

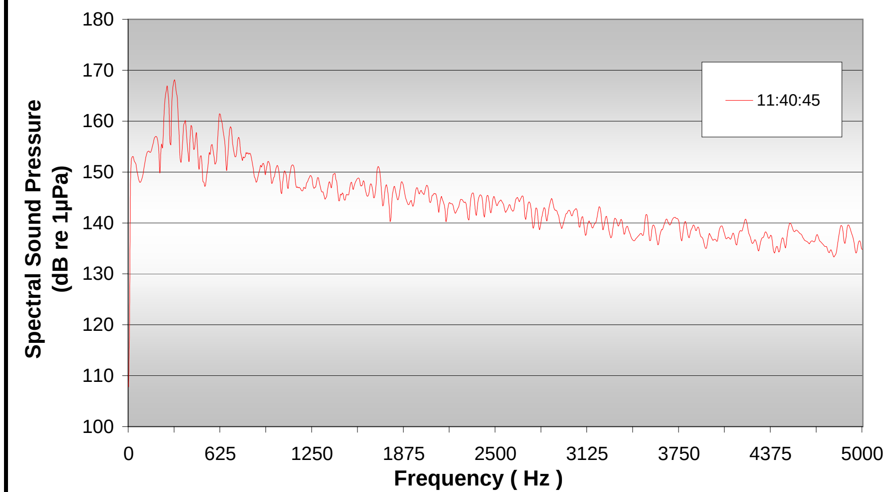


Figure c. Accumulation of Sound Energy

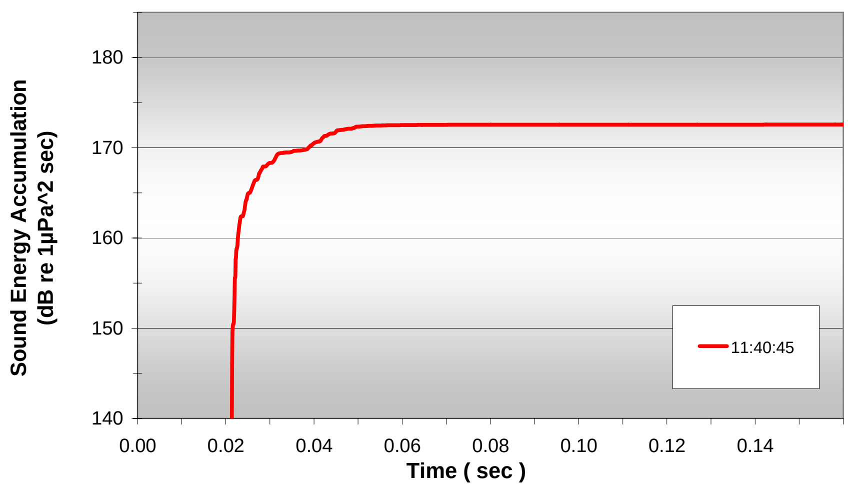


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	RMS90%*	SEL
11:40:45	195	188	173

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	195	183	166
Reported maximum	196	186	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 41

WAB-4 30" Steel Shell Piles @ 13 meters - Confined Bubble Ring ON and OFF 10/29/2009

Figure a. Waveform

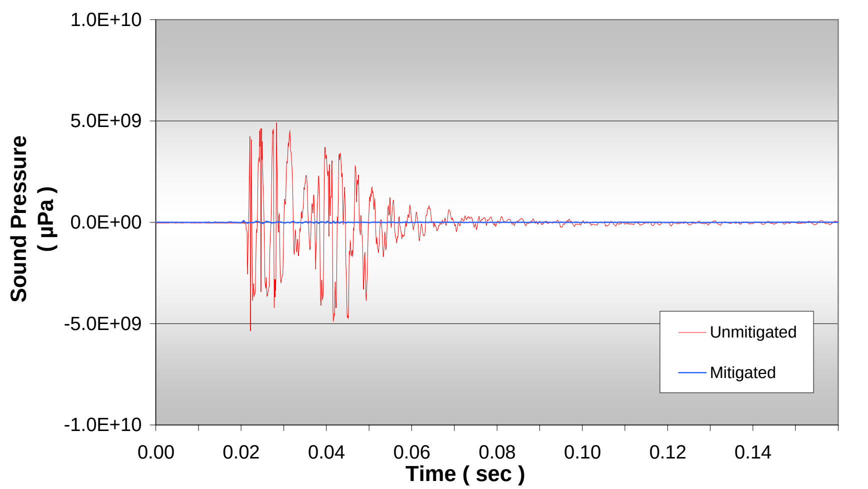


Figure b. Narrow Band Frequency Spectra

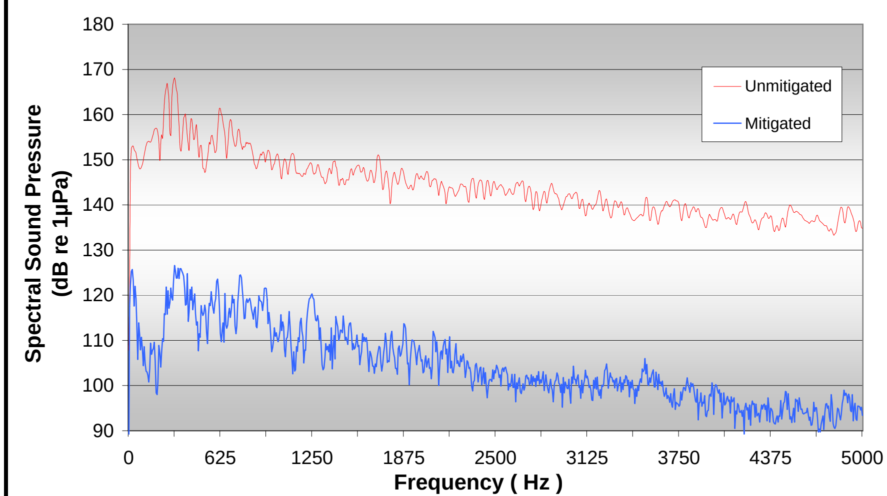


Figure c. Accumulation of Sound Energy

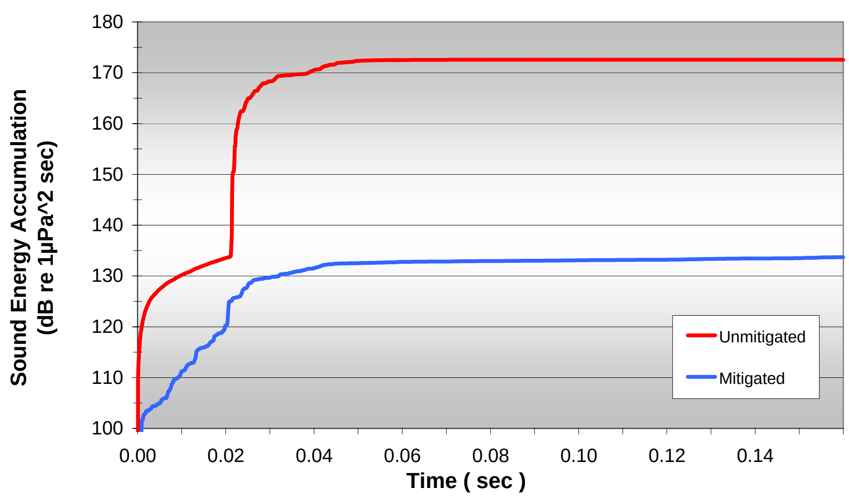


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

13 meters	Peak	RMS90%*	SEL
Unmitigated	195	188	173
Mitigated	159	142	134

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Mitigated	195	183	138
Reported maximum	162	149	172

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 42

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

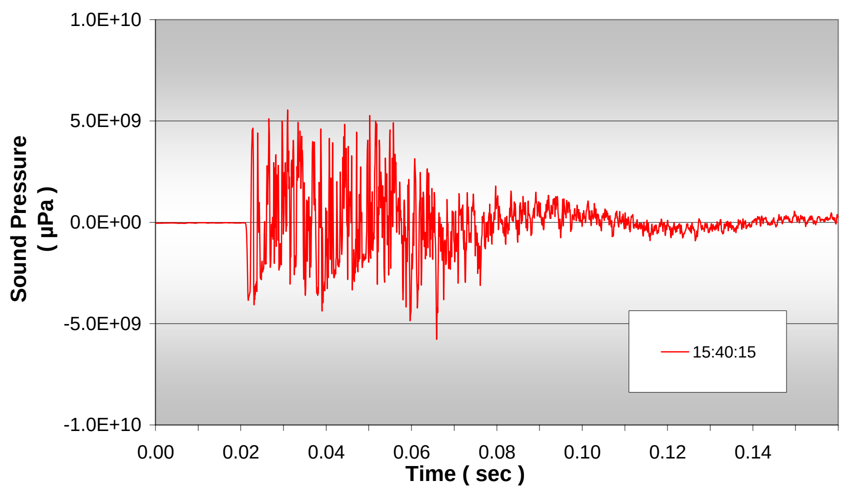


Figure b. Narrow Band Frequency Spectra

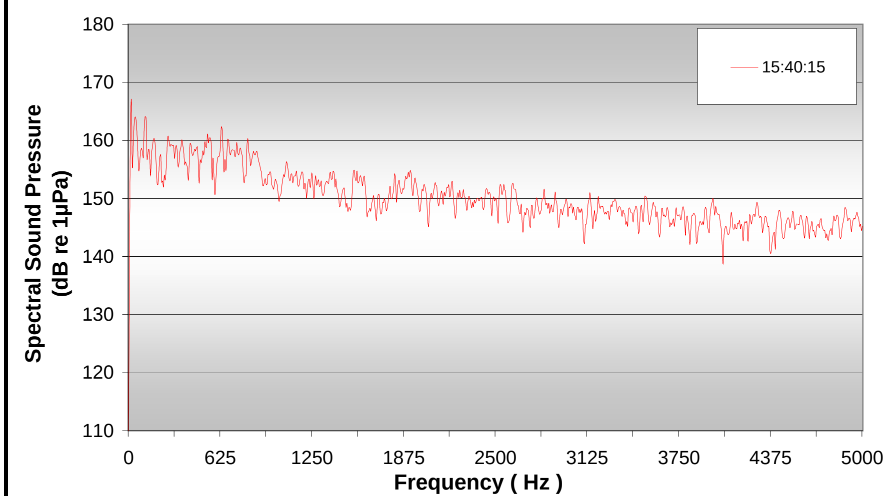


Figure c. Accumulation of Sound Energy

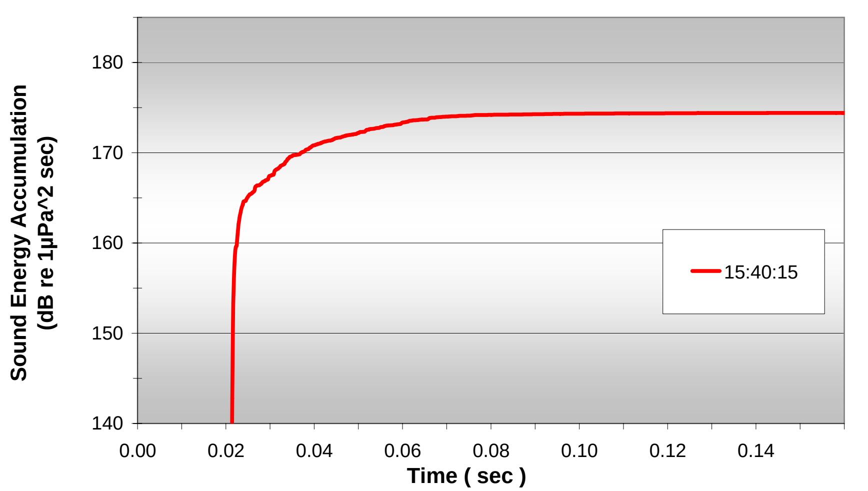


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
15:40:15	195	186	174

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	196	182	173
Reported maximum	197	186	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 43

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

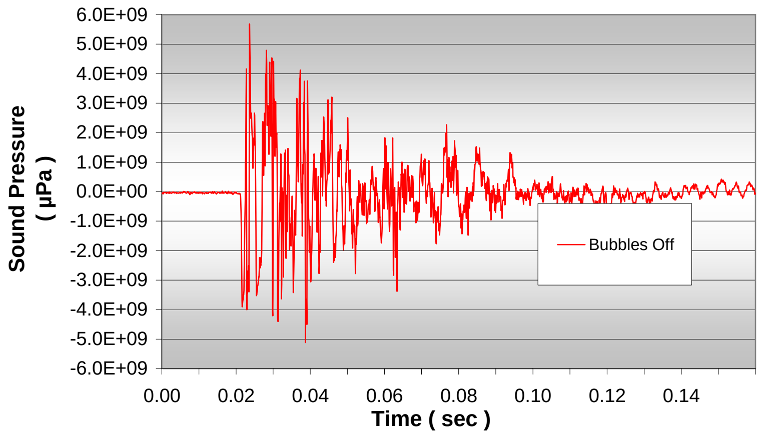


Figure b. Narrow Band Frequency Spectra

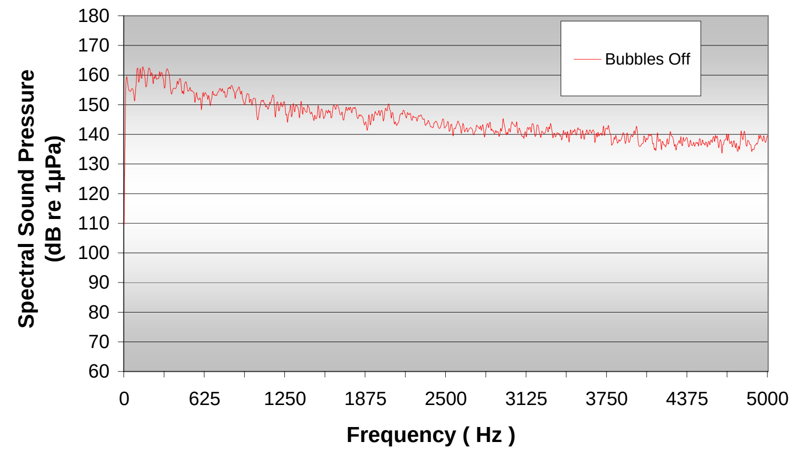


Figure c. Accumulation of Sound Energy

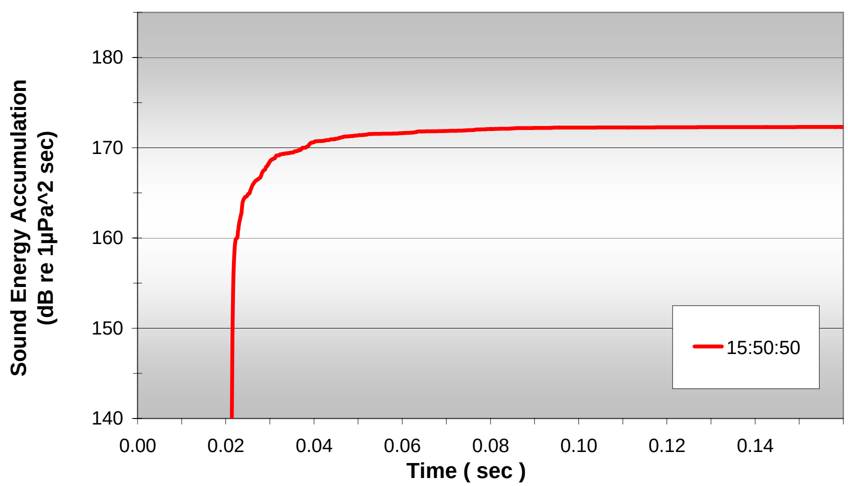


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
15:50:50	195	184	172

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	196	182	173
Reported maximum	197	186	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

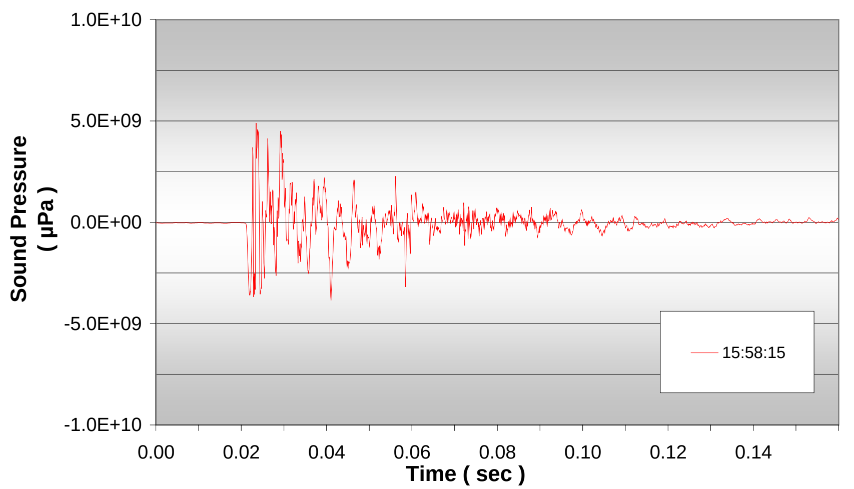


Figure b. Narrow Band Frequency Spectra

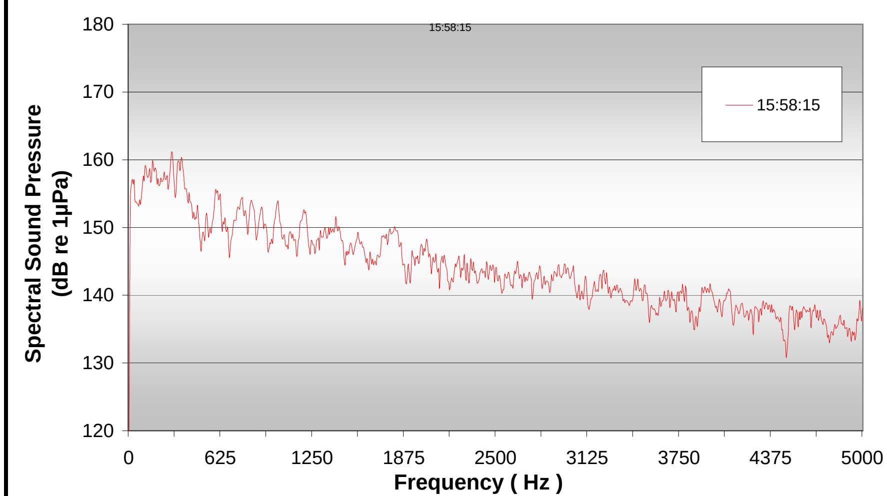


Figure c. Accumulation of Sound Energy

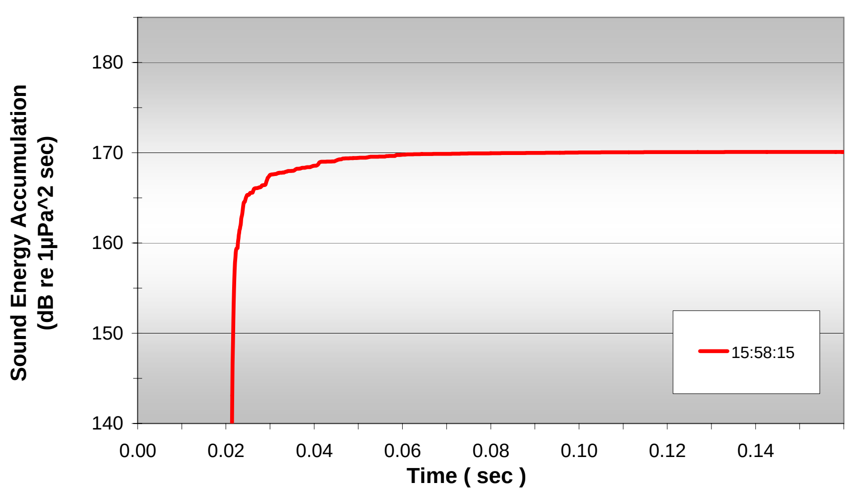


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
15:58:15	194	183	170

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS35ms**	SEL
Reported Average	196	182	173
Reported maximum	197	186	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 45

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

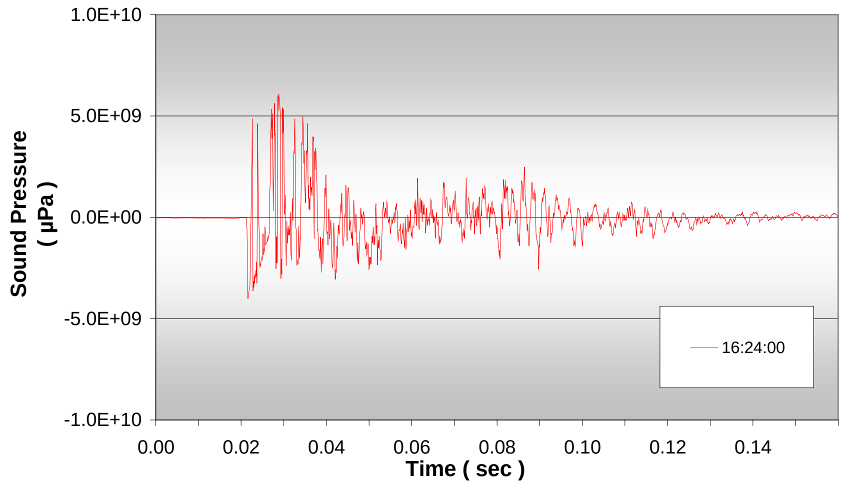


Figure b. Narrow Band Frequency Spectra

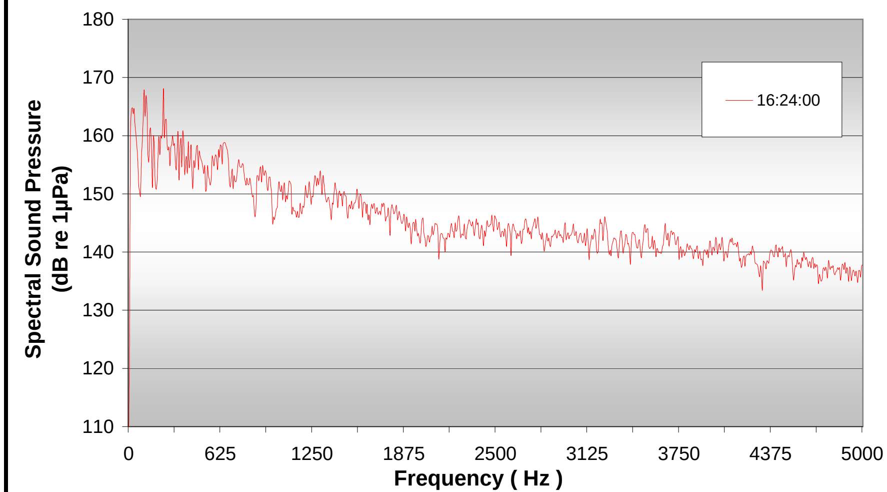


Figure c. Accumulation of Sound Energy

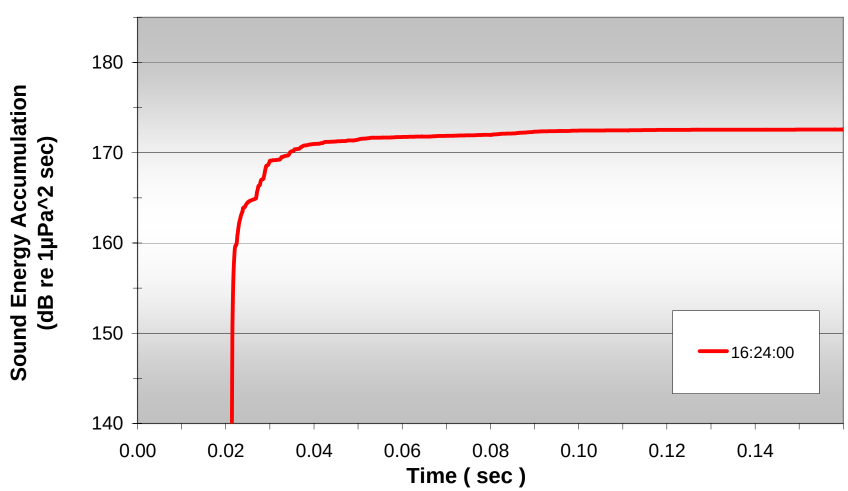


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
16:24:00	196	184	173

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak	RMS_{35ms}**	SEL
Reported Average	196	182	173
Reported maximum	197	186	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 46

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

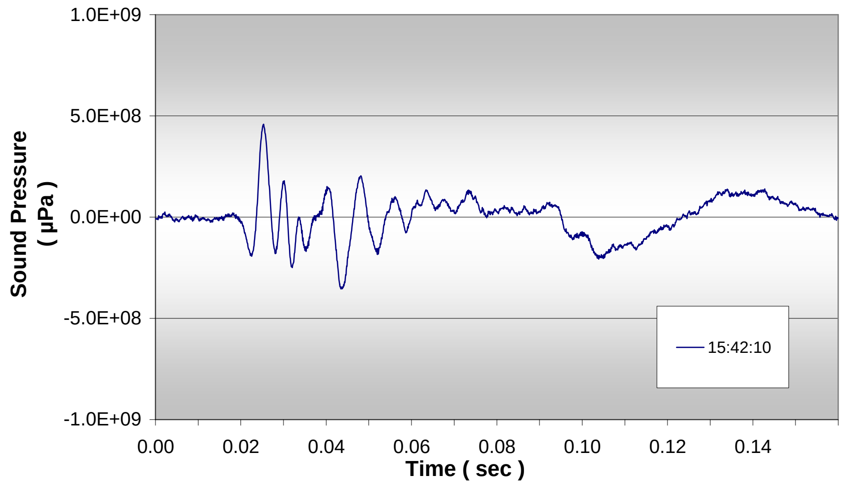


Figure b. Narrow Band Frequency Spectra

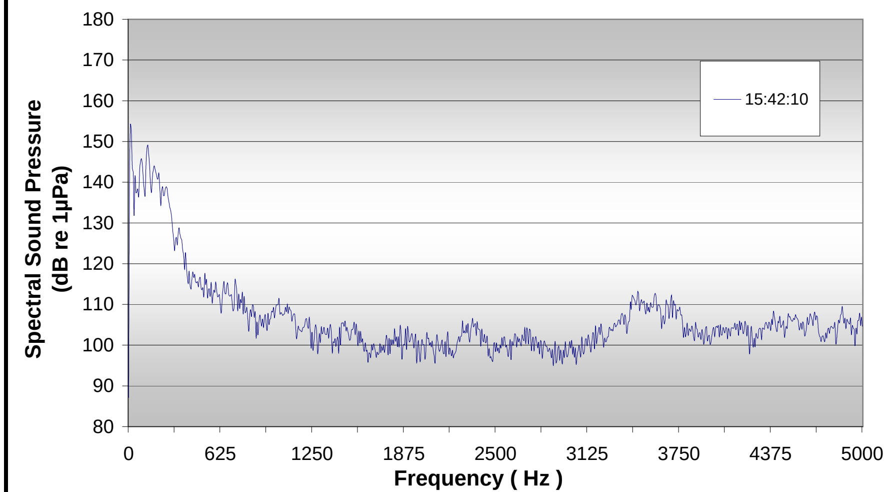


Figure c. Accumulation of Sound Energy

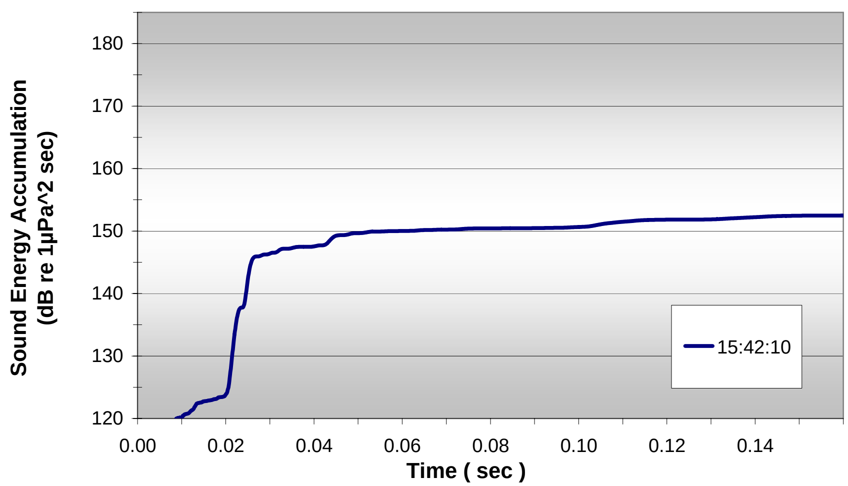


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
15:42:10	173	161	152

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS_{35ms}**	SEL
Reported Average	177	165	153
Reported maximum	186	168	155

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 47

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

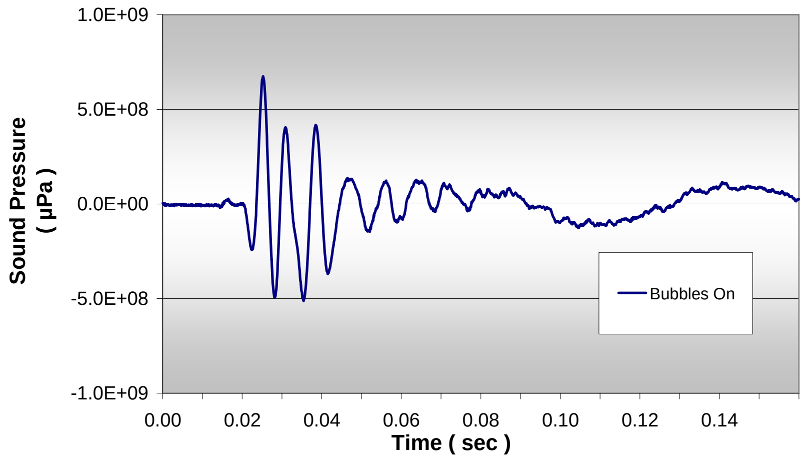


Figure b. Narrow Band Frequency Spectra

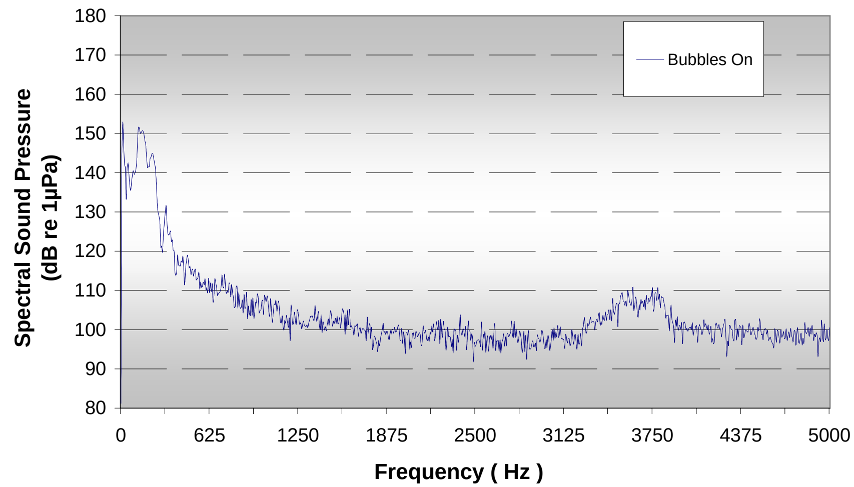


Figure c. Accumulation of Sound Energy

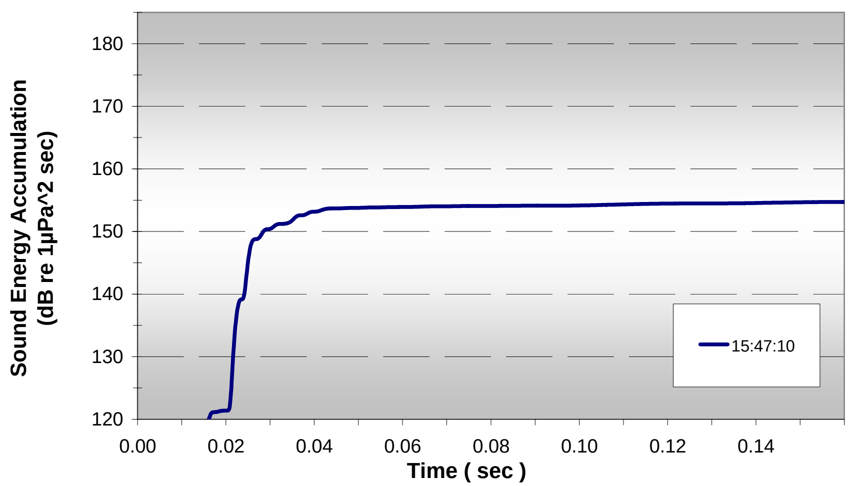


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
15:47:10	177	164	155

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	177	165	153
Reported maximum	186	168	155

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 48

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

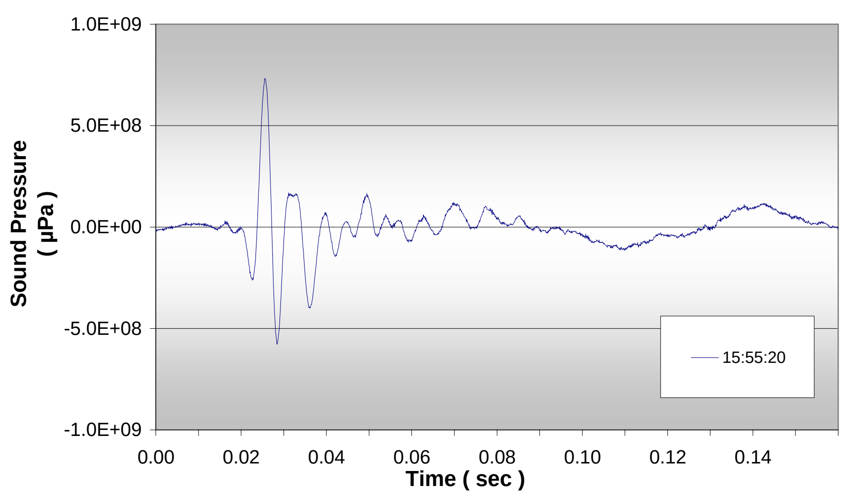


Figure b. Narrow Band Frequency Spectra

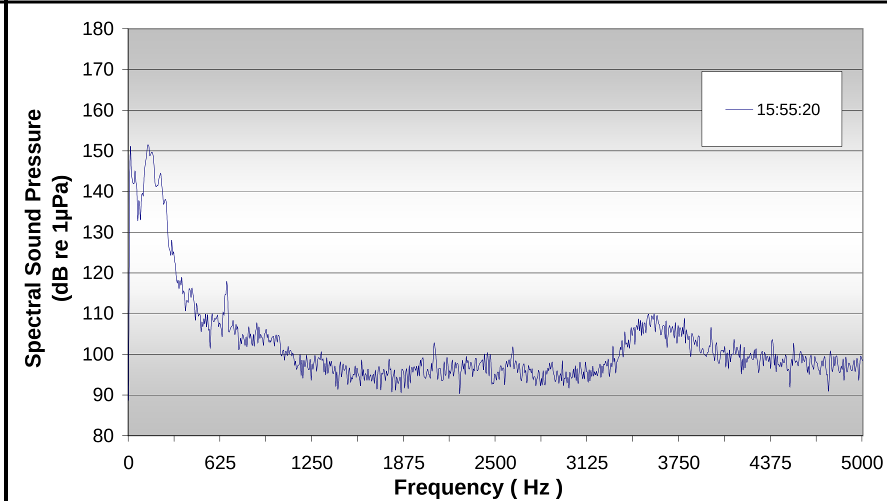


Figure c. Accumulation of Sound Energy

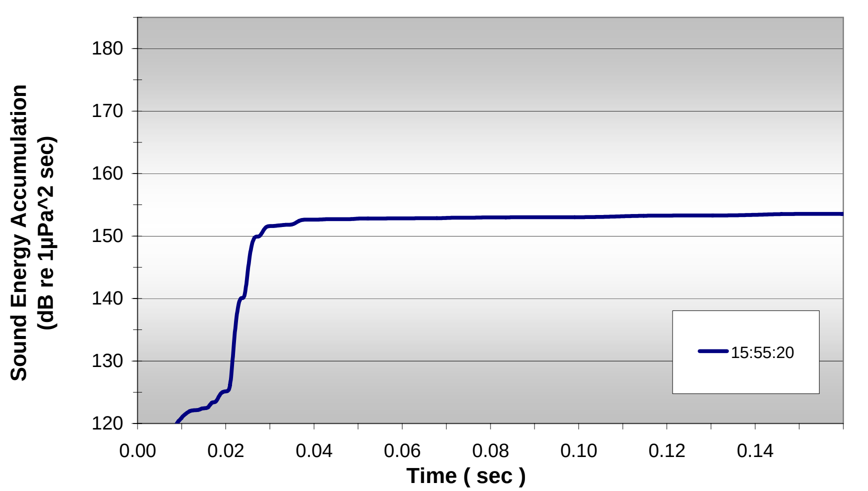


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
15:55:20	177	163	154

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	177	165	153
Reported maximum	186	168	155

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

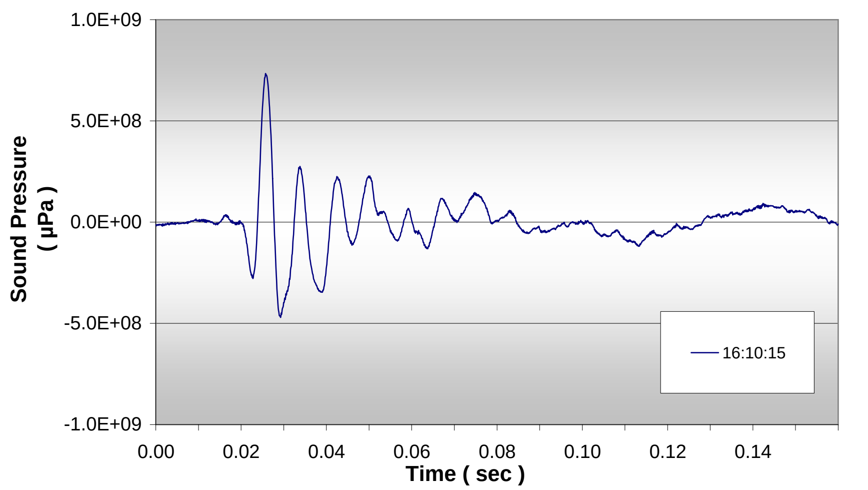


Figure b. Narrow Band Frequency Spectra

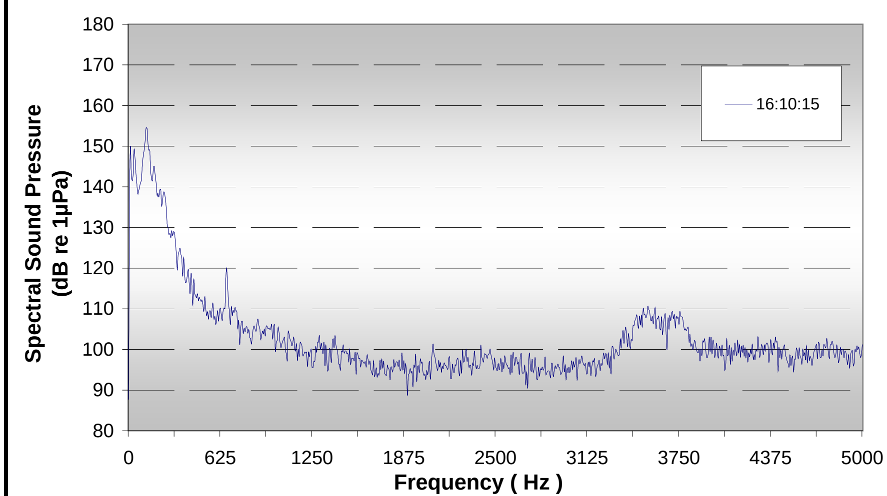


Figure c. Accumulation of Sound Energy

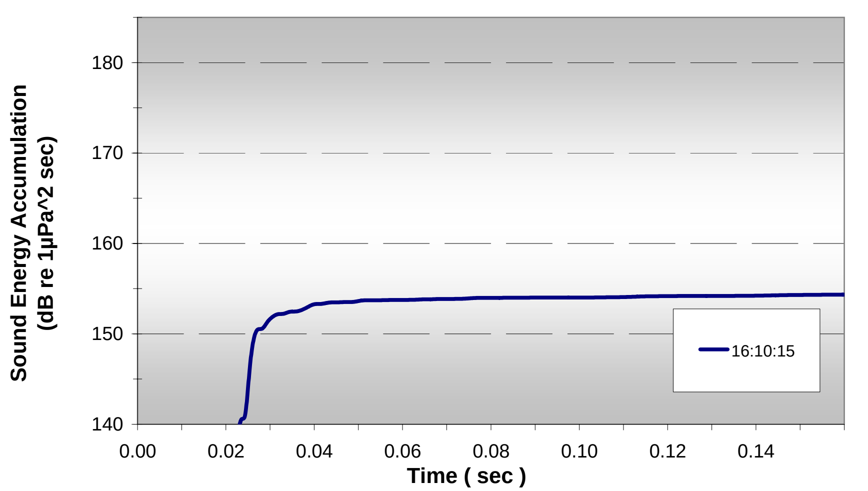


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
16:10:15	177	164	154

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	177	165	153
Reported maximum	186	168	155

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 50

WAB-5 30" Steel Shell pile @ 10 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

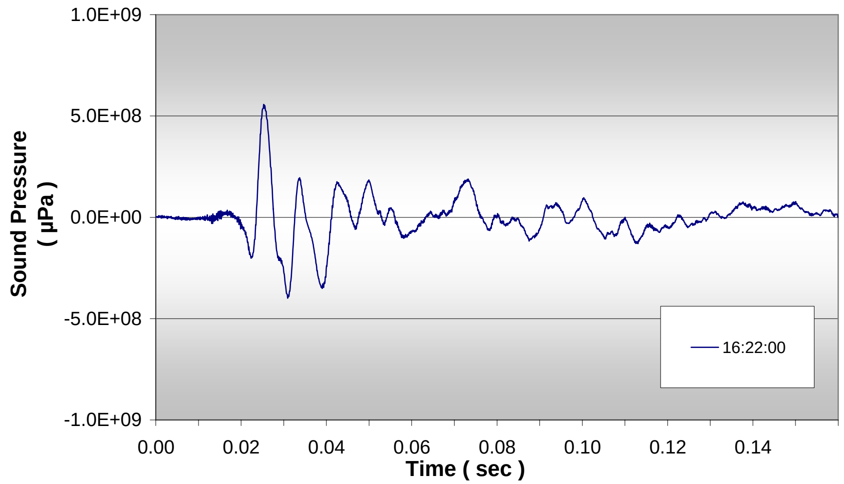


Figure b. Narrow Band Frequency Spectra

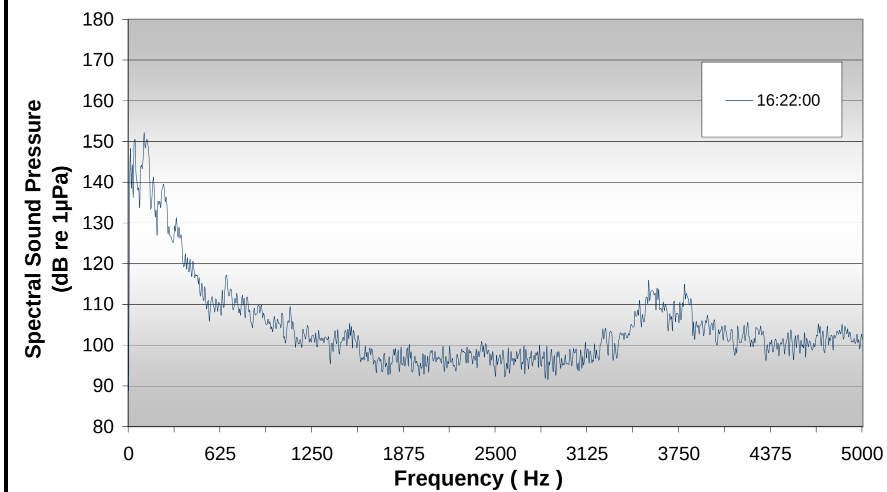


Figure c. Accumulation of Sound Energy

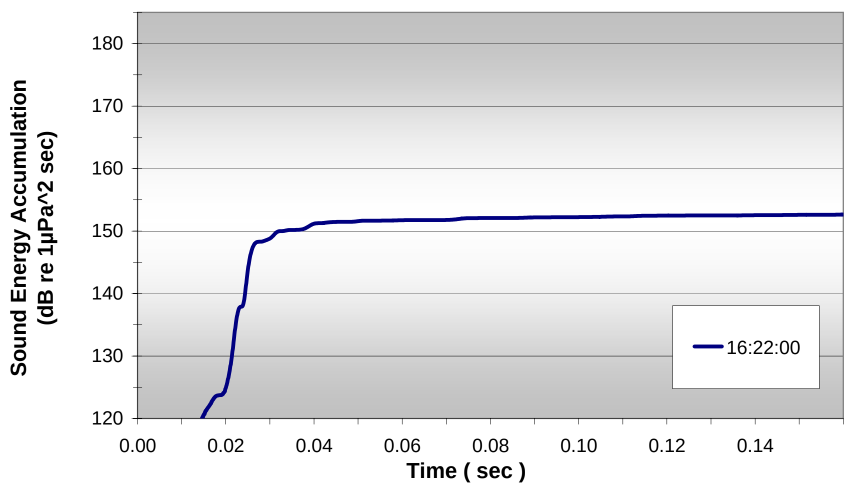


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
16:22:00	175	163	153

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak	RMS35ms**	SEL
Reported Average	177	165	153
Reported maximum	186	168	155

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 51

WAB-5 30" Steel Shell Piles Comparison of Mitigated, Unmitigated and Background Levels 10/29/2009

Figure a. Waveform

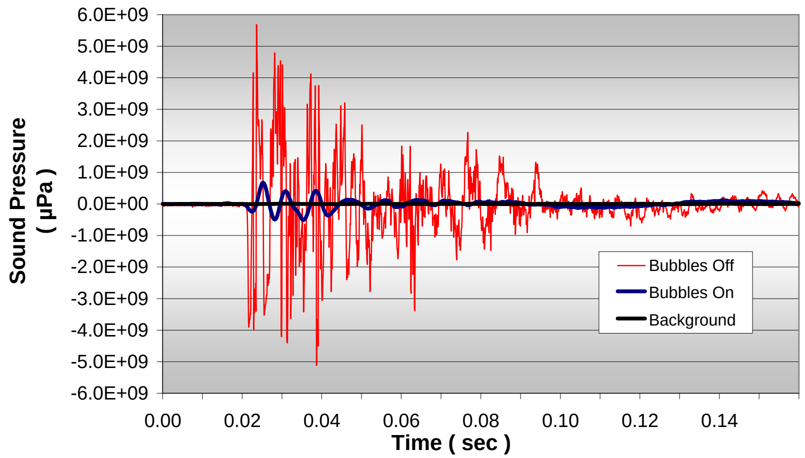


Figure b. Narrow Band Frequency Spectra

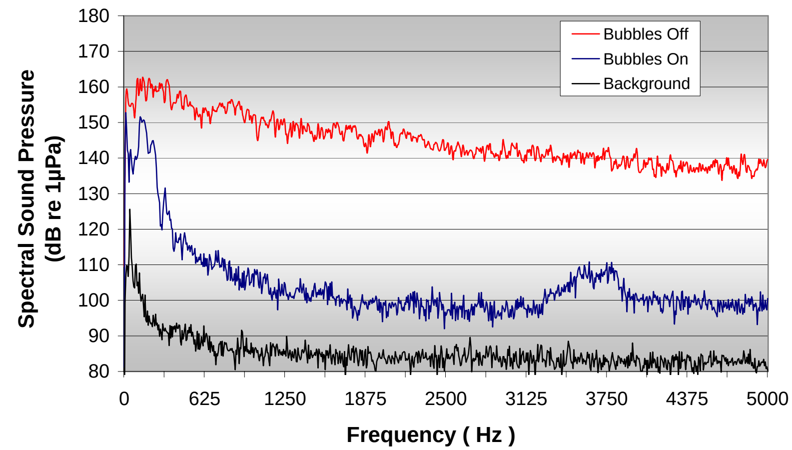


Figure c. Accumulation of Sound Energy

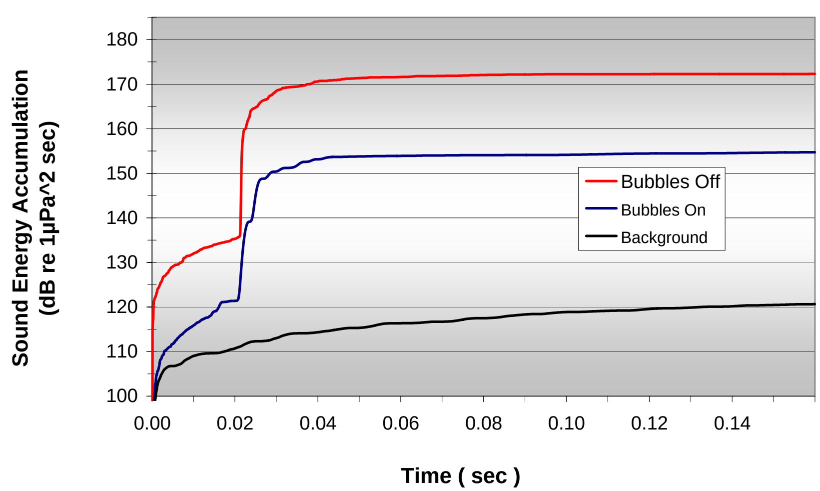


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
Bubbles Off	195	184	172
Bubbles On	177	164	155
Background	135	129	121

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 52

WAB-1 30" Steel Shell Pile @ 200M NO ATTENUATION 10/29/2009

Figure a. Waveform

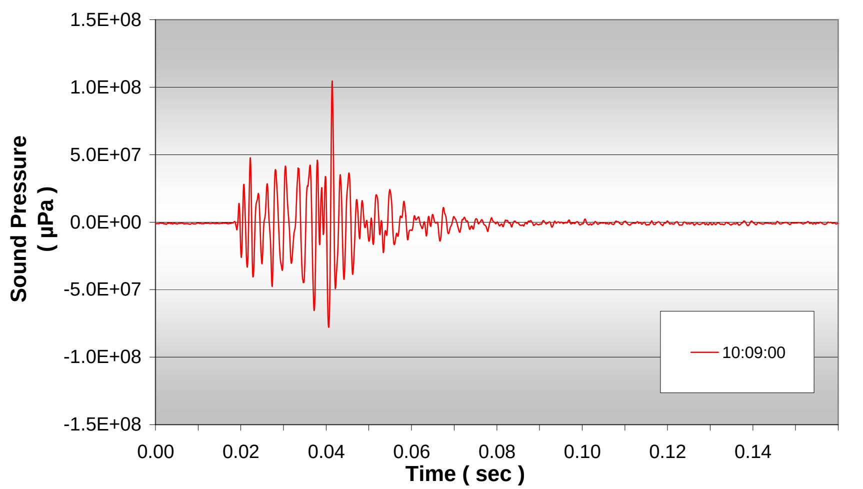


Figure b. Narrow Band Frequency Spectra

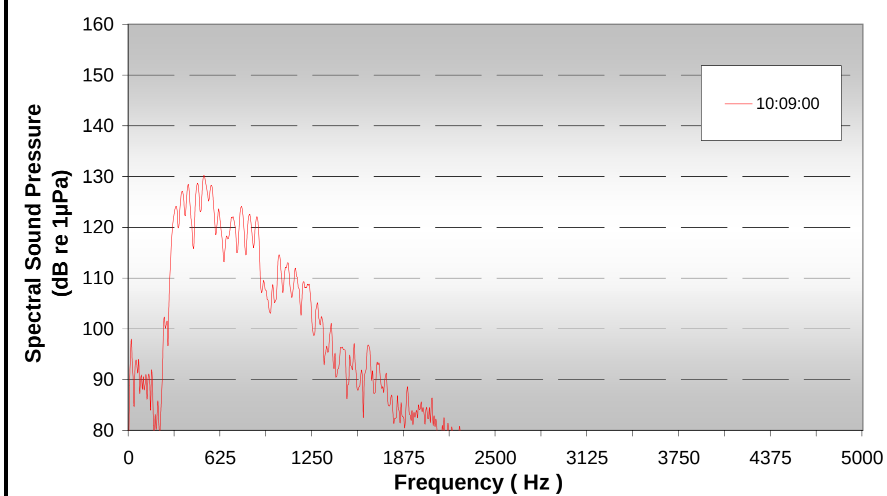


Figure c. Accumulation of Sound Energy

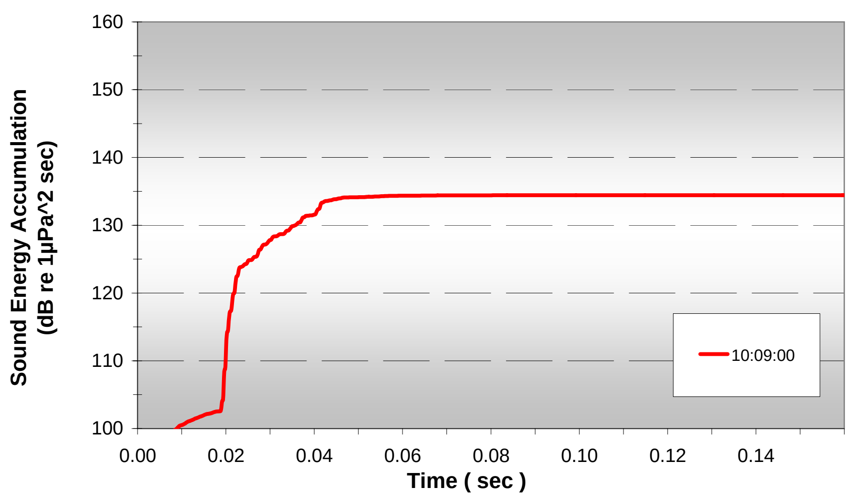


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	$RMS_{90\%}$*	SEL
10:09:00	160	149	134

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	163		
Reported maximum	157		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

WAB-1 30' Steel Shell Pile @ 500 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

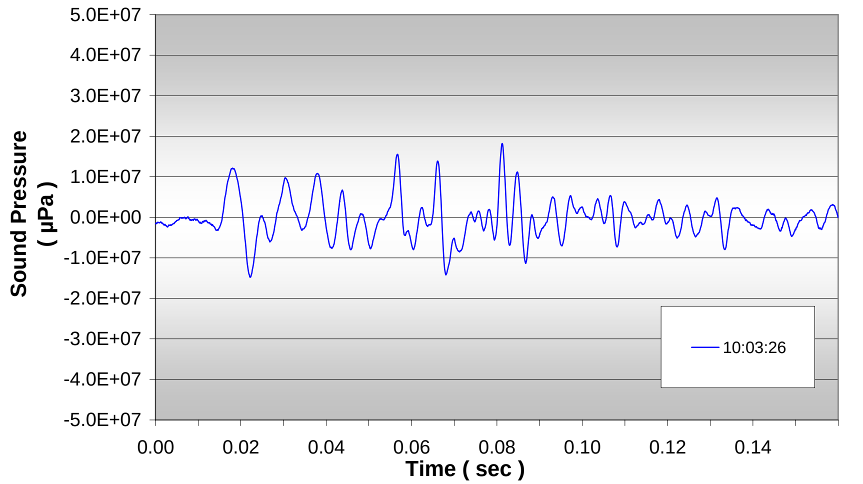


Figure b. Narrow Band Frequency Spectra

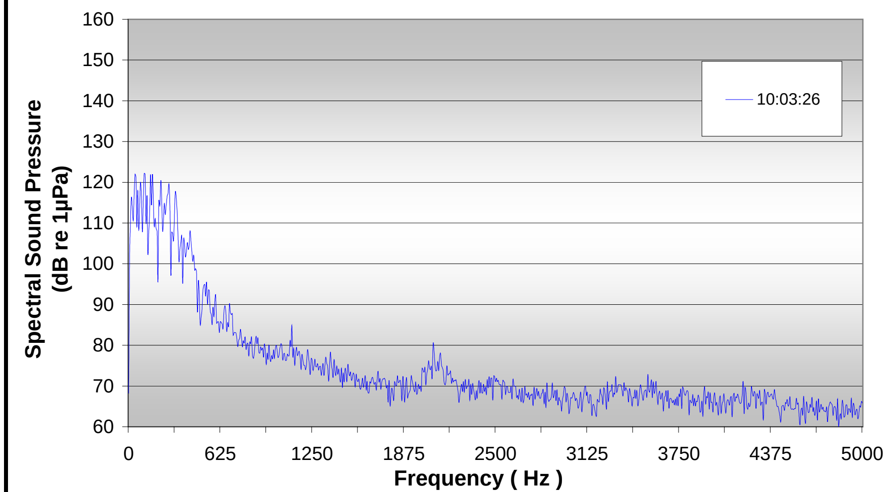


Figure c. Accumulation of Sound Energy

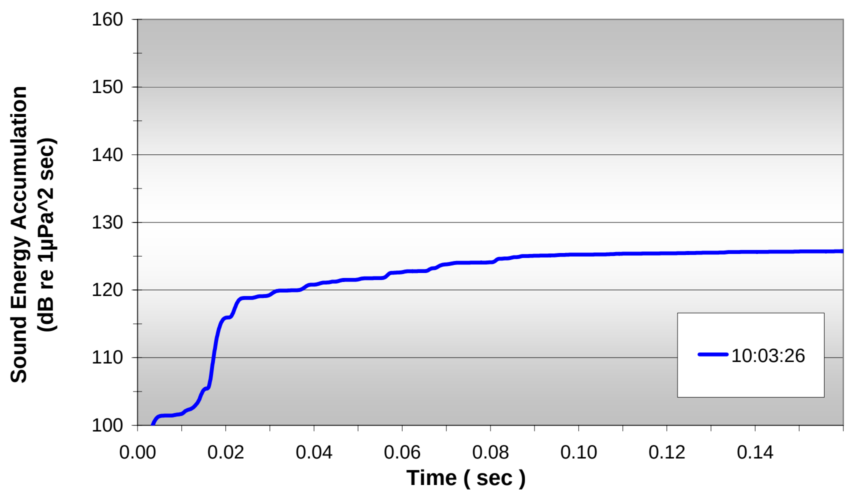


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
10:03:26	145	135	126

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	148		
Reported maximum	154		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 54

WAB-1 30' Steel Shell Pile @ 500 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

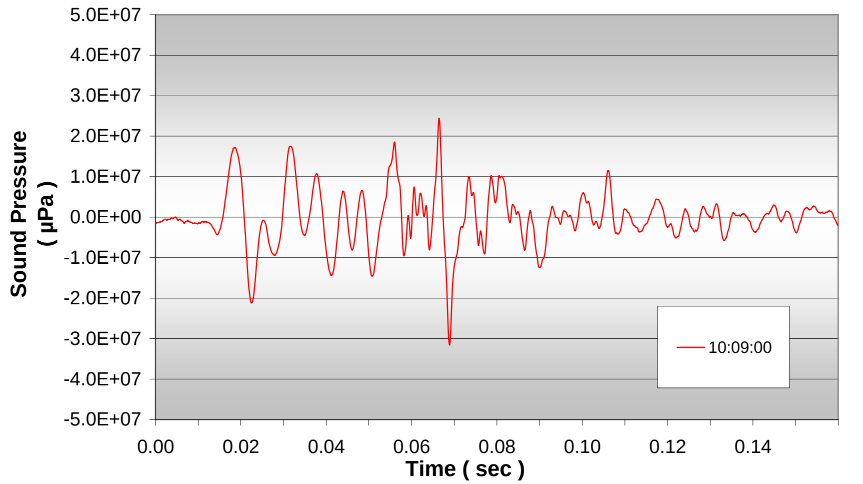


Figure b. Narrow Band Frequency Spectra

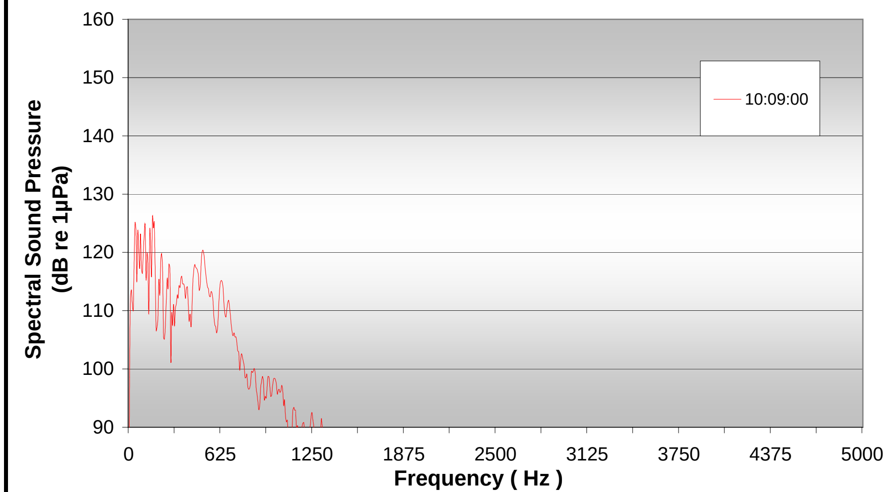


Figure c. Accumulation of Sound Energy

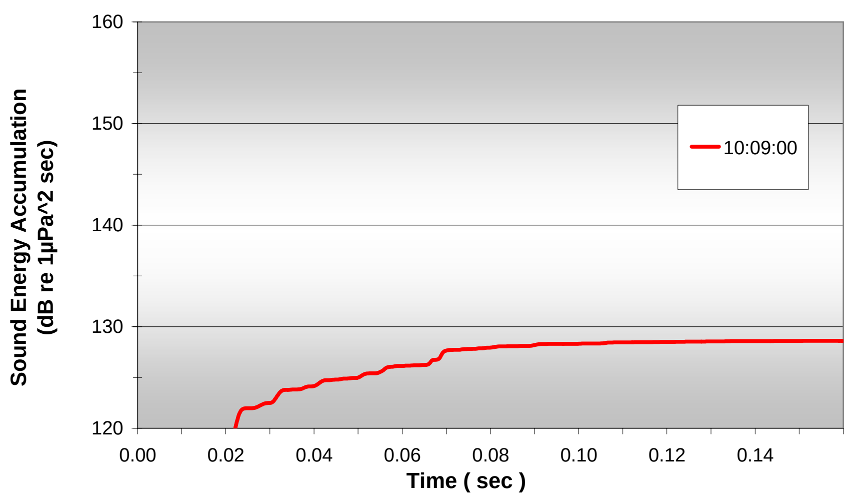


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
10:09:00	150	139	129

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	152		
Reported maximum	159		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 55

WAB-2 30" Steel Shell Piles @ 200M NO ATTENUATION 10/29/2009

Figure a. Waveform

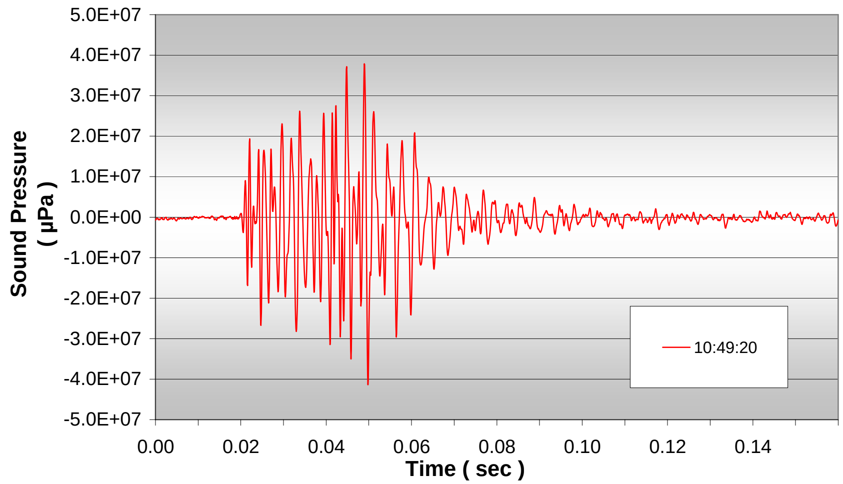


Figure b. Narrow Band Frequency Spectra

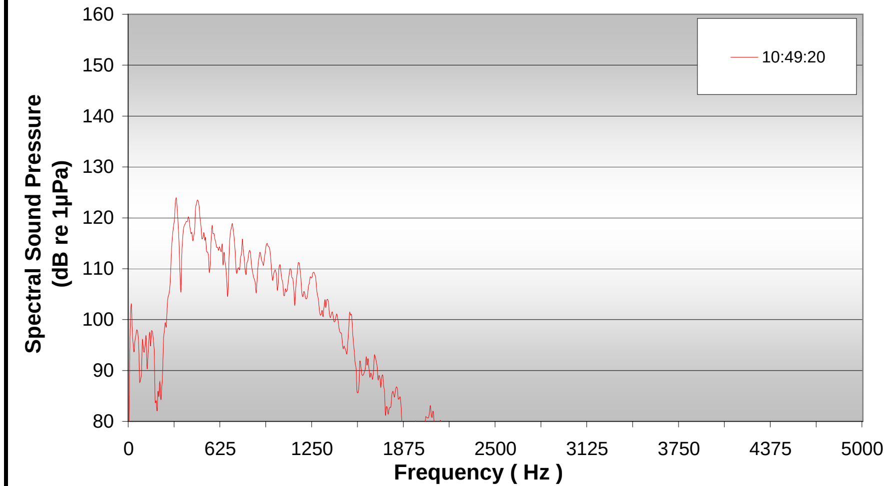


Figure c. Accumulation of Sound Energy

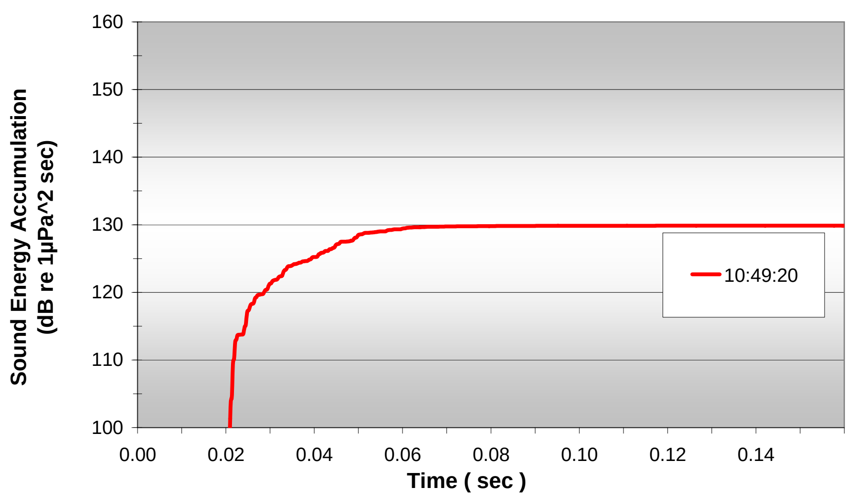


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meter	Peak	RMS90%*	SEL
10:49:20	152	143	130

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	151		
Reported maximum	157		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 56

WAB-2 30" Steel Shell Piles @ 500 meters - Unconfined Bubble Rings ON 10/29/2009

Figure a. Waveform

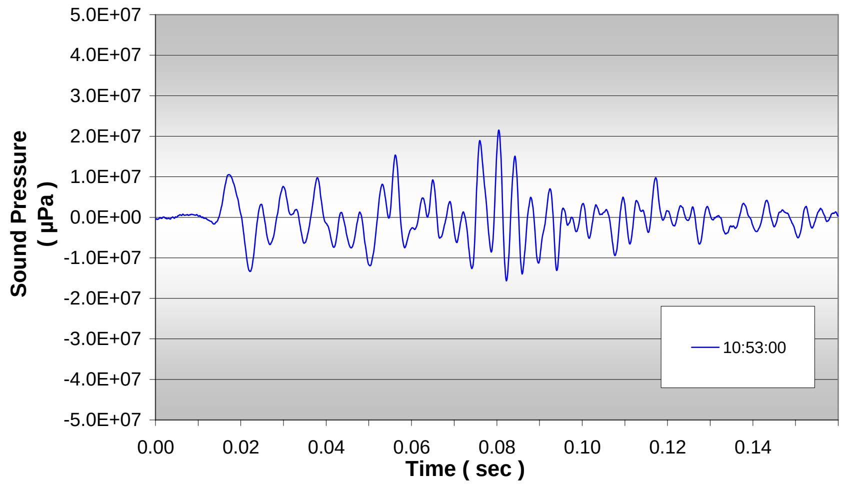


Figure b. Narrow Band Frequency Spectra

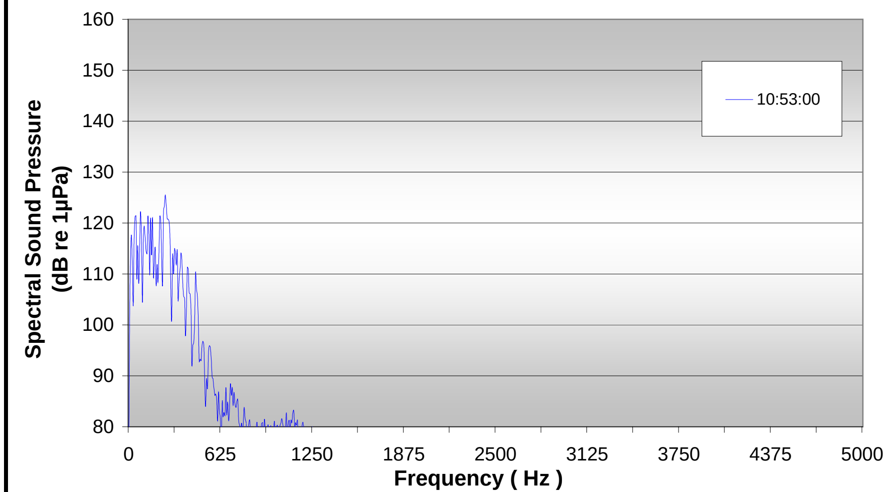


Figure c. Accumulation of Sound Energy

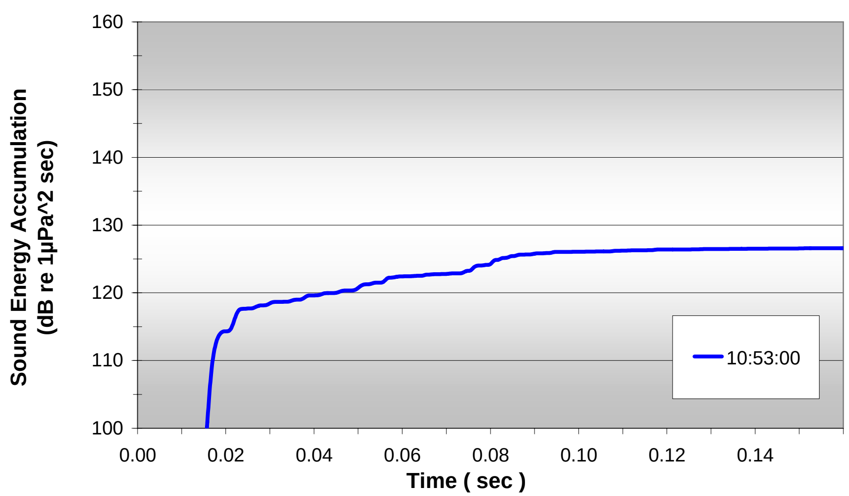


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

500 meters	Peak	$RMS_{90\%}$*	SEL
10:53:00	147	136	127

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**	SEL
Reported Average			
Reported maximum			

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

WAB-2 30" Steel Shell Piles @ 500 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

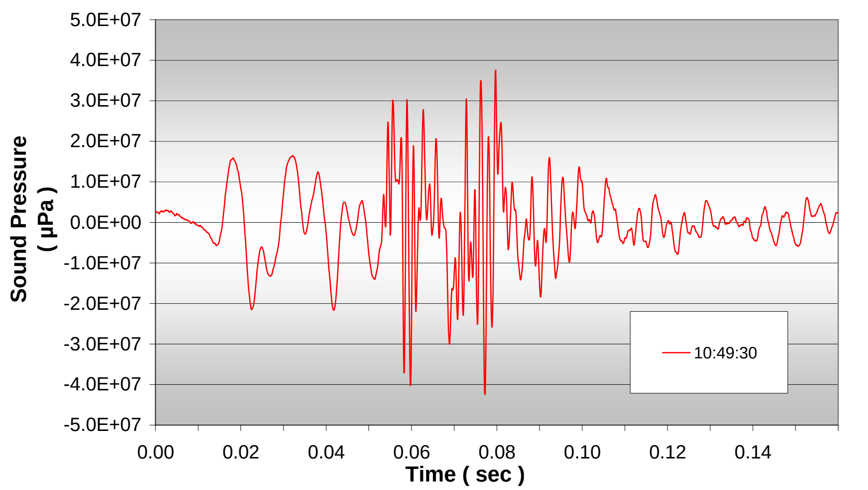


Figure b. Narrow Band Frequency Spectra

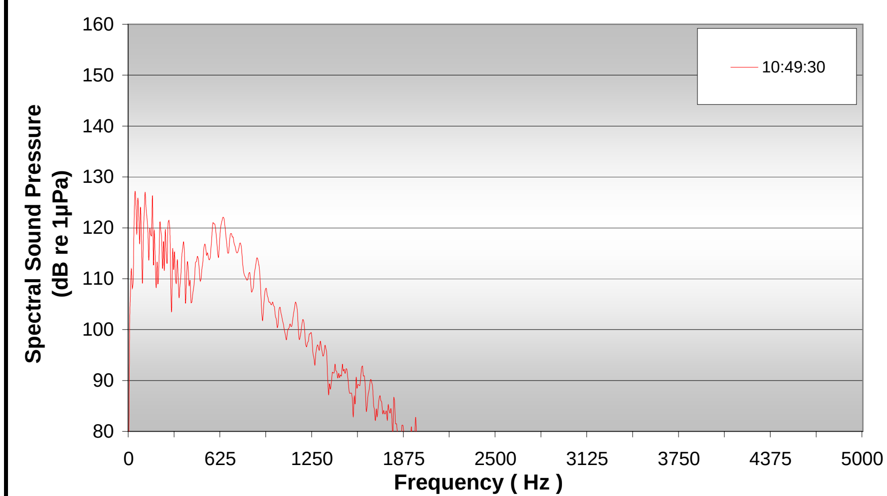


Figure c. Accumulation of Sound Energy

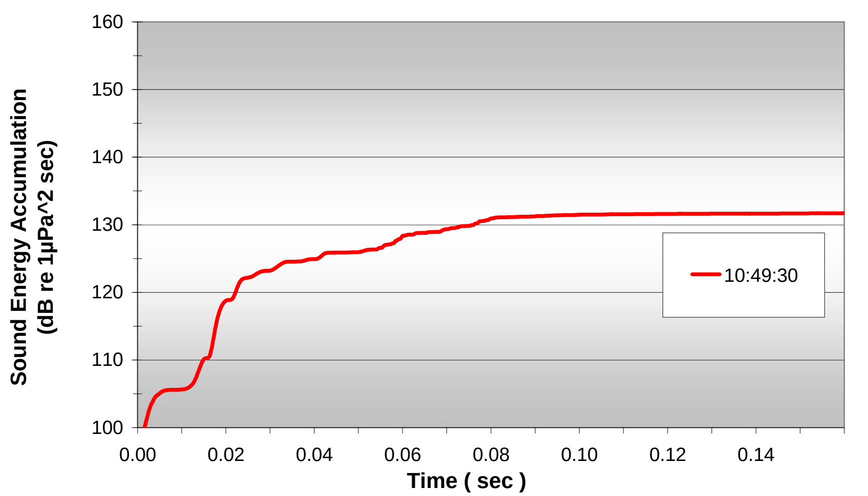


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

500 meters	Peak	RMS90%*	SEL
10:49:30	153	142	132

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	153		
Reported maximum	161		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 58

WAB-3 30" Steel Shell Pile @ 200 meters - DNAP 10/29/2009

Figure a. Waveform

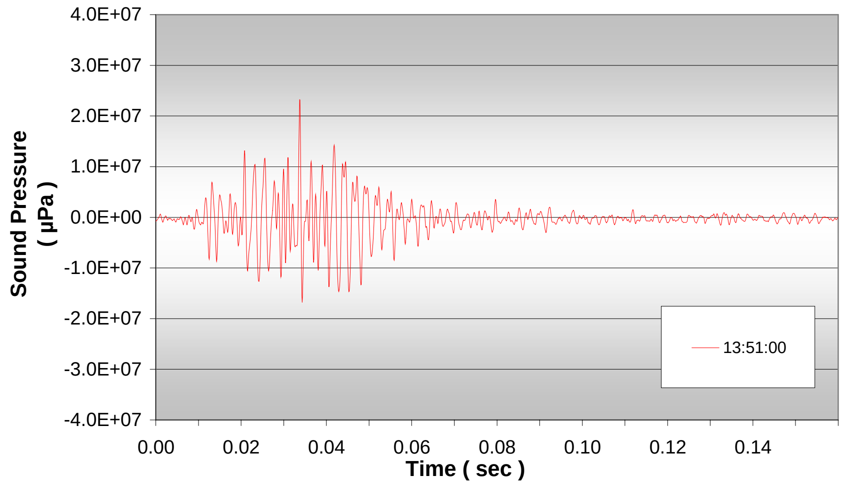


Figure b. Narrow Band Frequency Spectra

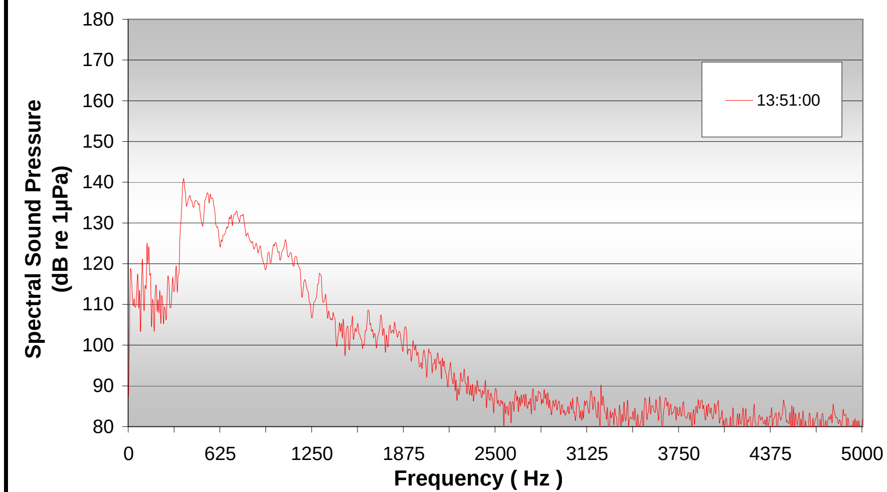


Figure c. Accumulation of Sound Energy

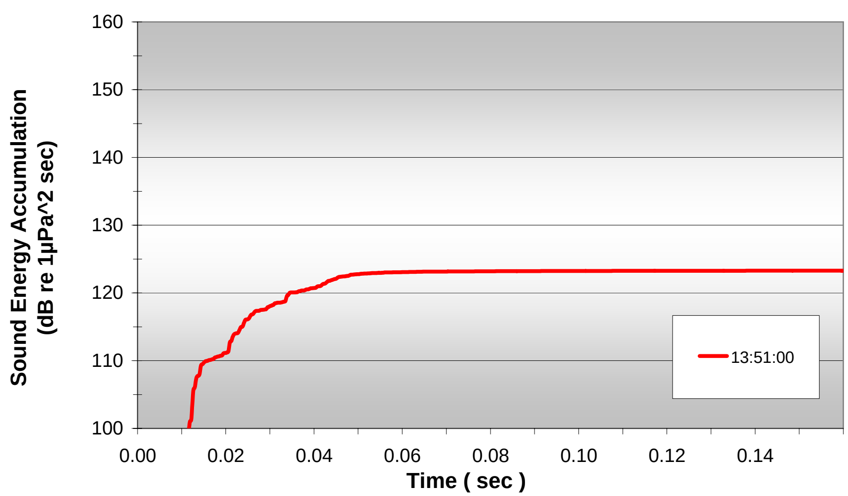


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meter	Peak	RMS90%*	SEL
13:51:00	147	137	123

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	145		
Reported maximum	151		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

WAB-3 30" Steel Shell Pile @ 500 meters - DNAP 10/29/2009

Figure a. Waveform

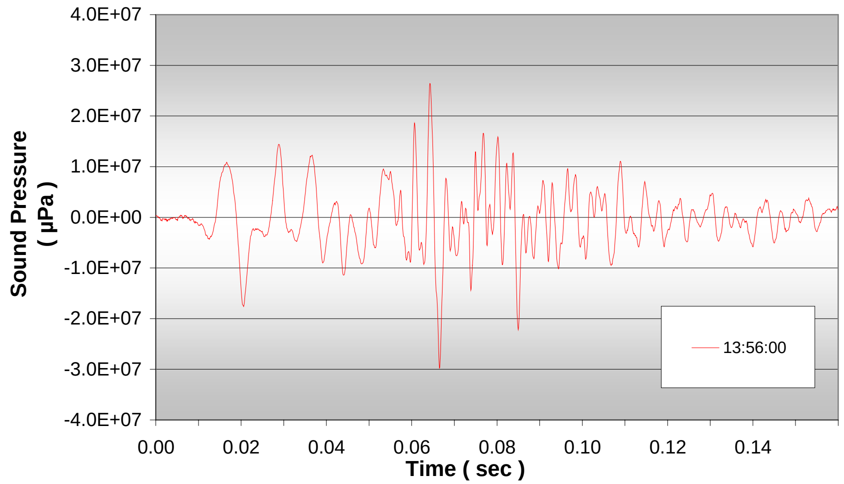


Figure b. Narrow Band Frequency Spectra

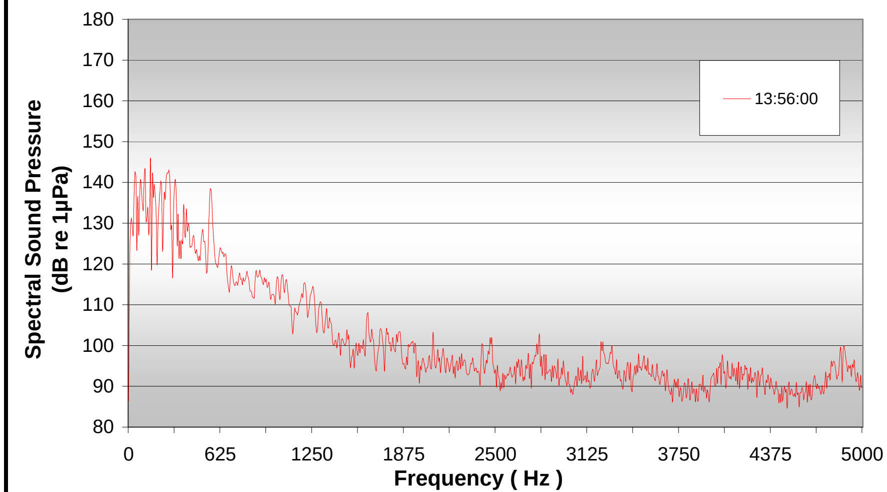


Figure c. Accumulation of Sound Energy

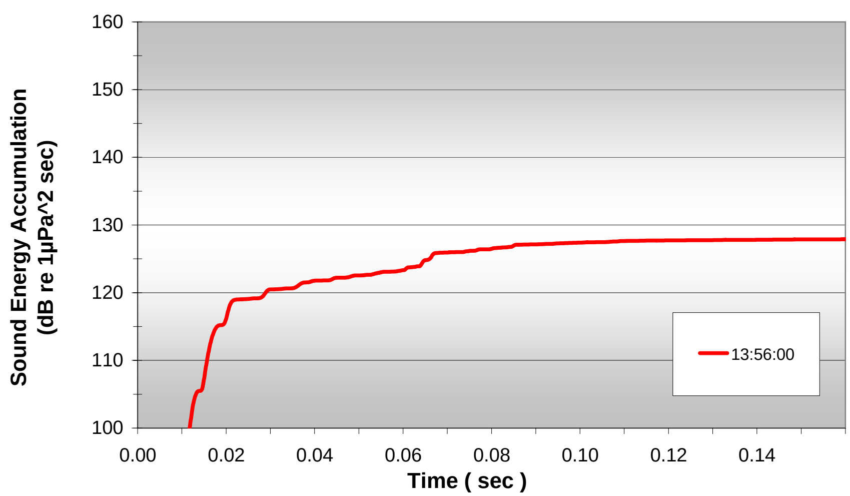


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

500 meter	Peak	RMS90%*	SEL
13:56:00	149	138	128

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	149		
Reported maximum	156		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

WAB-4 30" Steel Shell Piles @ 200 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

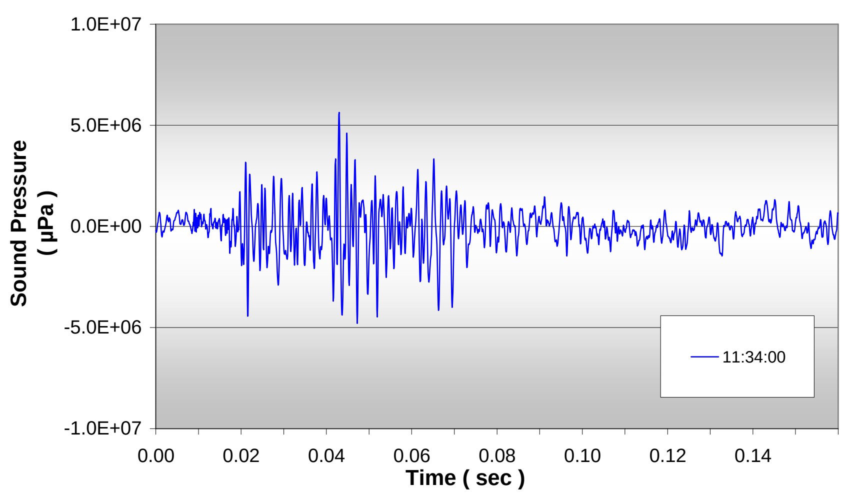


Figure b. Narrow Band Frequency Spectra

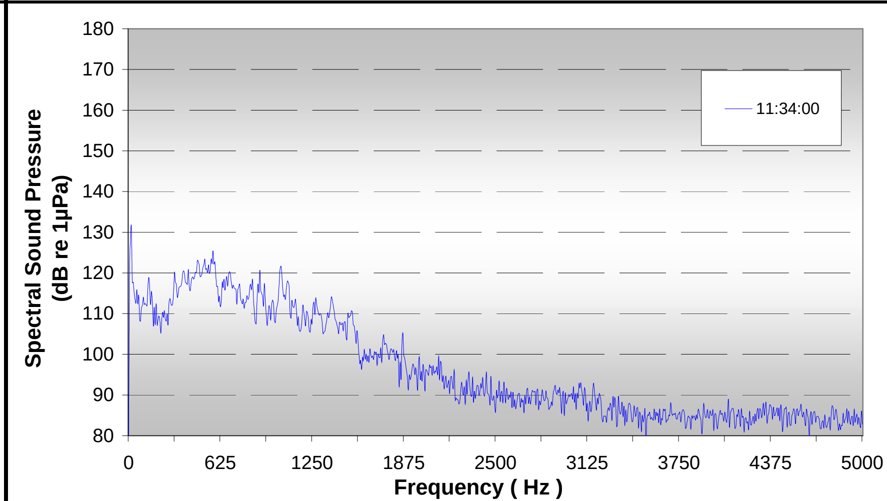


Figure c. Accumulation of Sound Energy

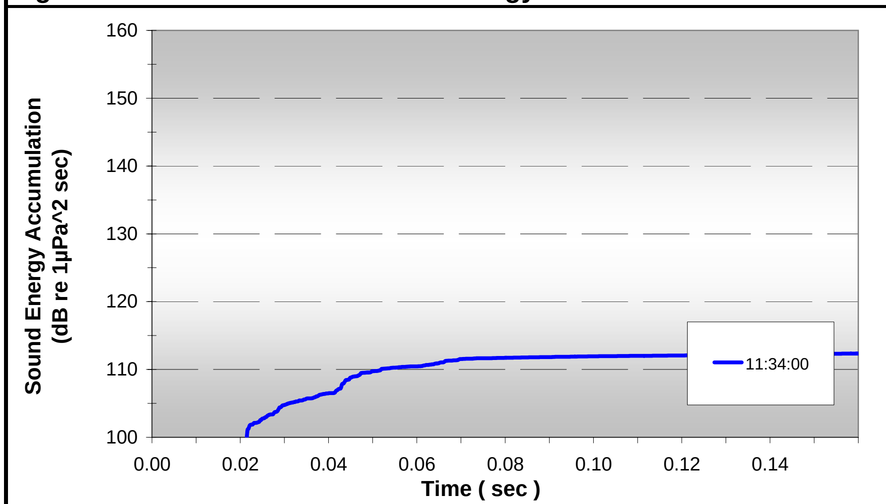


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meters	Peak	RMS90%*	SEL
11:34:00	135	122	112

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak		
Reported Average	137		
Reported maximum	144		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 61

WAB-4 30" Steel Shell Piles @ 200 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

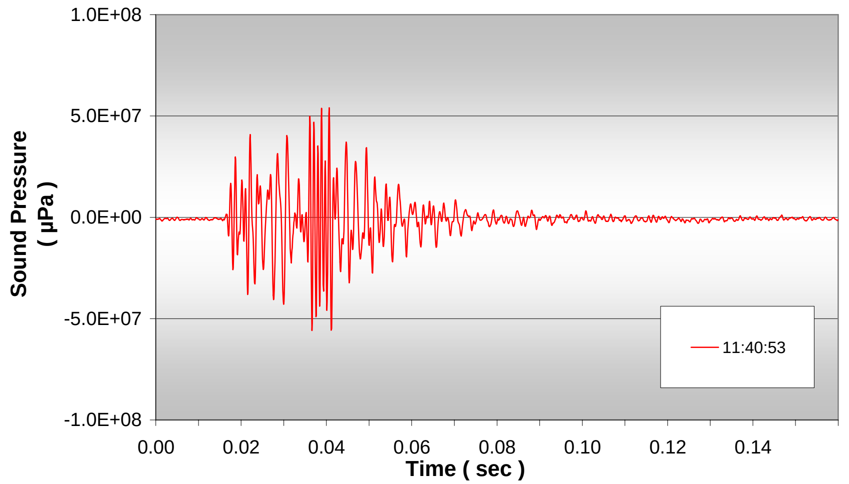


Figure b. Narrow Band Frequency Spectra

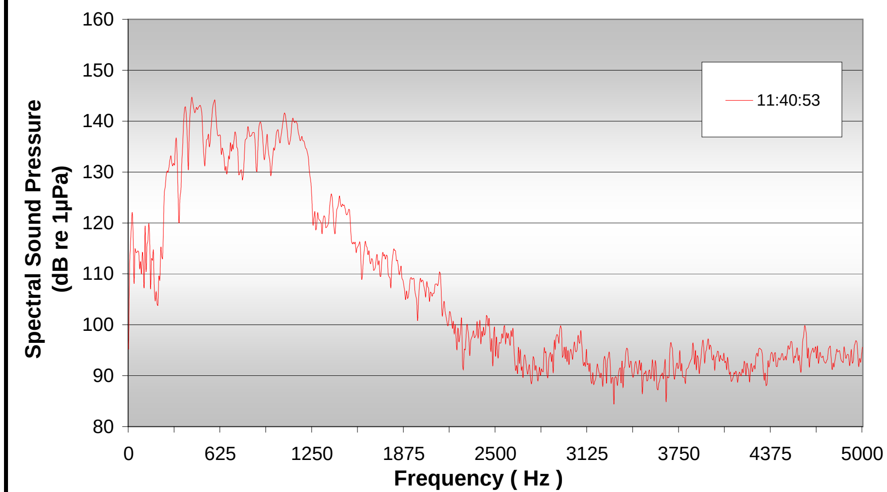


Figure c. Accumulation of Sound Energy

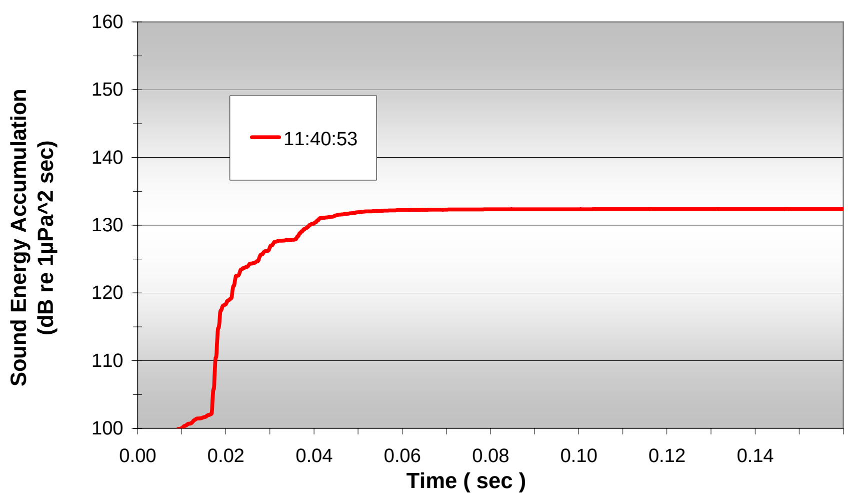


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meters	Peak	RMS90%*	SEL
11:40:53	155	146	132

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak		
Reported Average	154		
Reported maximum	159		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 62

WAB-4 30" Steel Shell Piles @ 500 meters - Confined Bubble Ring OFF 10/29/2009

Figure a. Waveform

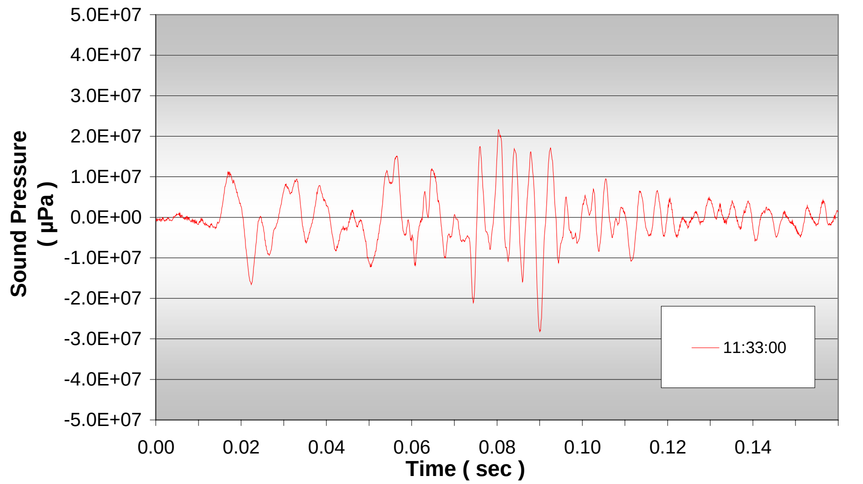


Figure b. Narrow Band Frequency Spectra

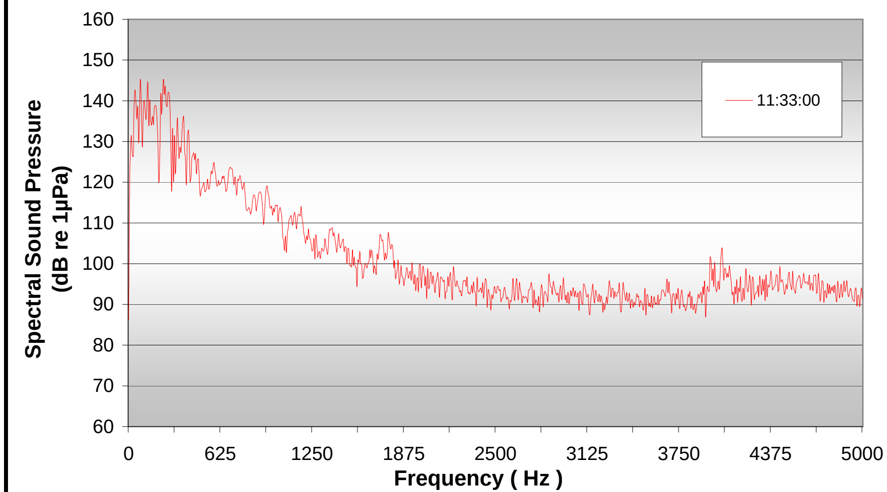


Figure c. Accumulation of Sound Energy

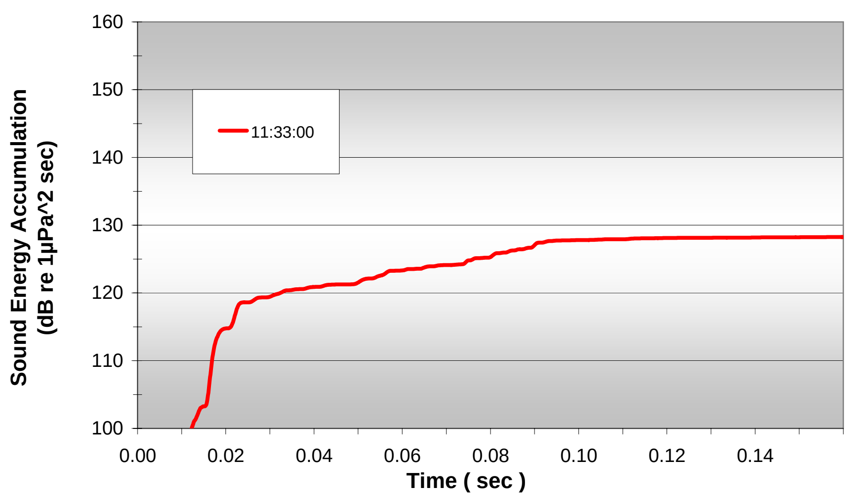


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meters	Peak	RMS90%*	SEL
11:33:00	149	138	128

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak		
Reported Average	150		
Reported maximum	158		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

WAB-4 30" Steel Shell Piles @ 500 meters - Confined Bubble Ring ON 10/29/2009

Figure a. Waveform

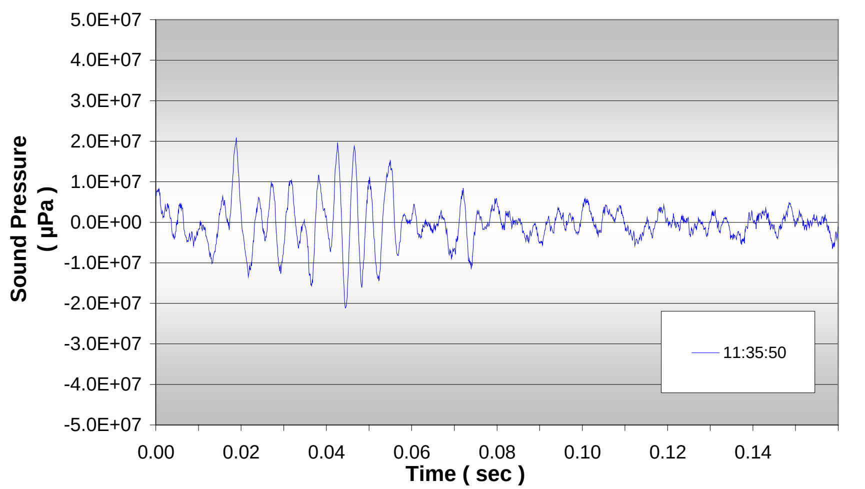


Figure b. Narrow Band Frequency Spectra

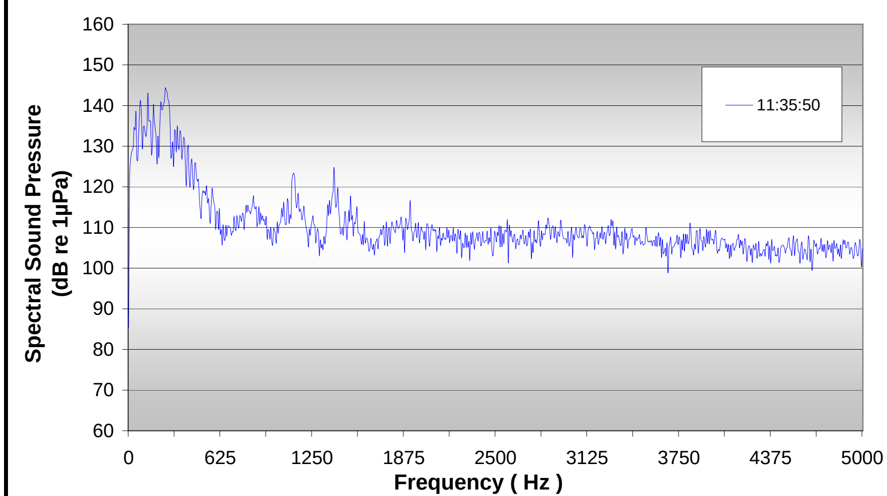


Figure c. Accumulation of Sound Energy

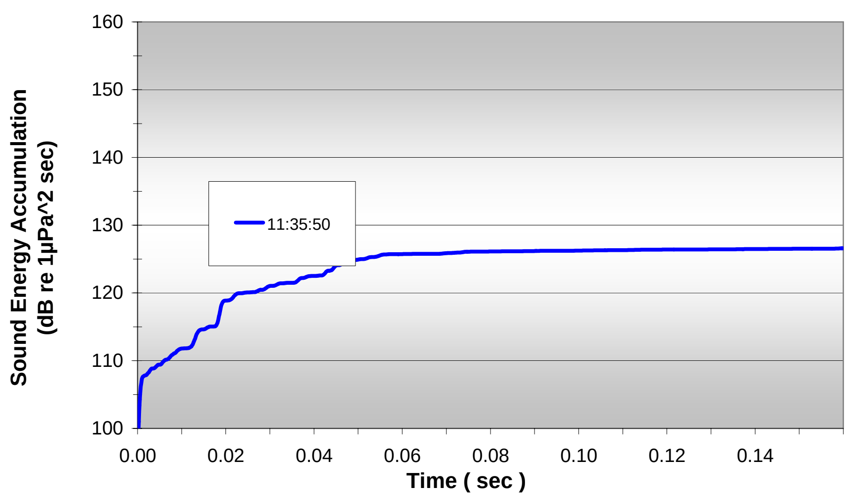


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meters	Peak	RMS90%*	SEL
11:35:50	147	136	127

Typical Sound Pressure / Energy Levels Throughout Drive

Mitigated	Peak		
Reported Average	147		
Reported maximum	153		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B -64

WAB-5 30" Steel Shell pile @ 200 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

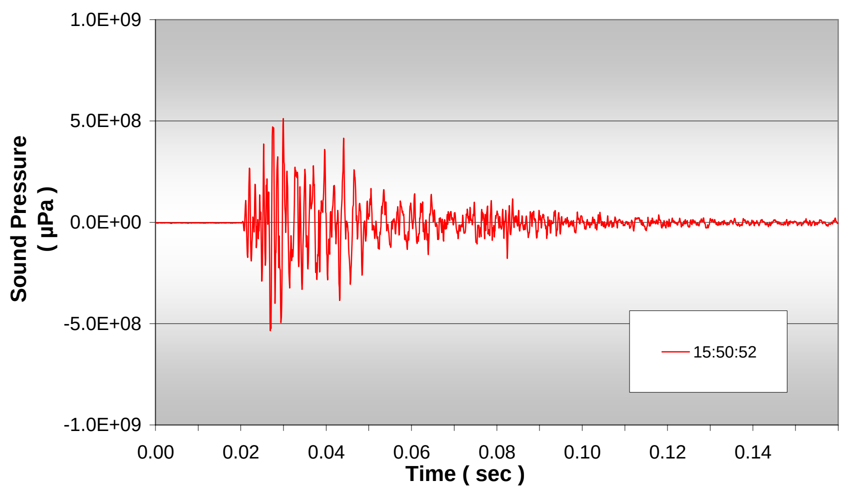


Figure b. Narrow Band Frequency Spectra

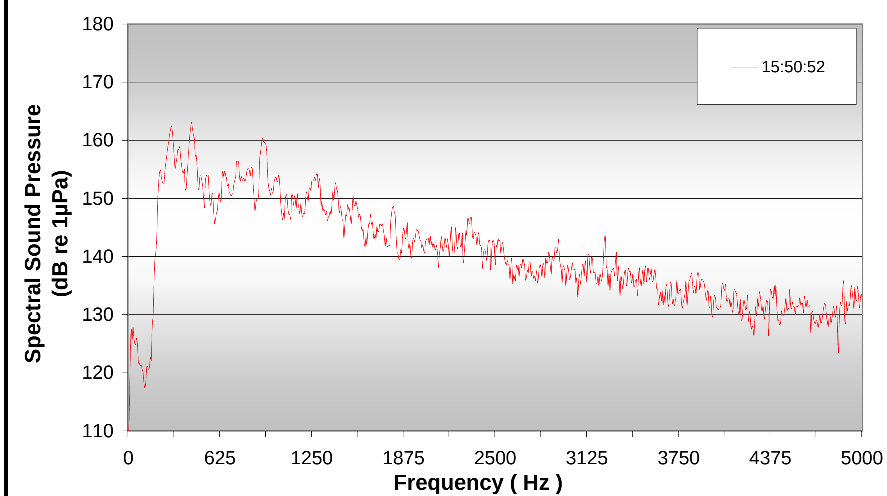


Figure c. Accumulation of Sound Energy

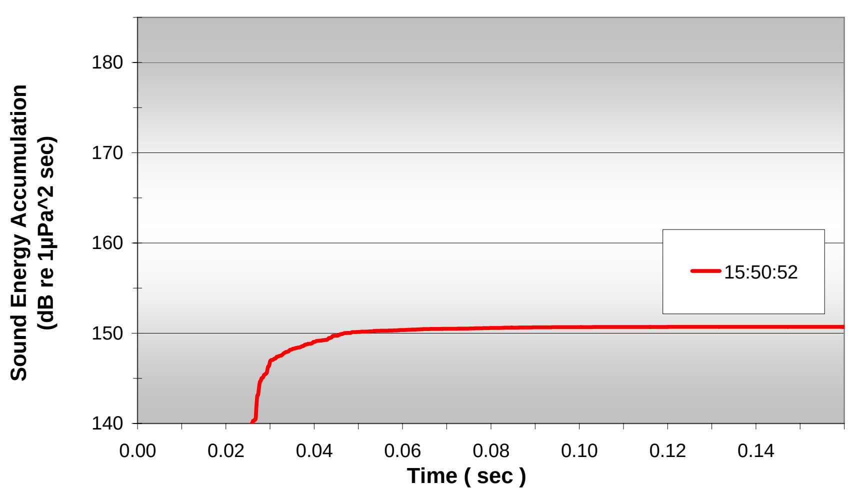


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

200 meter	Peak	RMS90%*	SEL
15:50:52	175	164	151

Typical Sound Pressure / Energy Levels Throughout Drive

Unmitigated	Peak		
Reported Average	173		
Reported maximum	177		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 65

WAB-5 30" Steel Shell pile @ 500 meters - Unconfined Bubble Rings OFF 10/29/2009

Figure a. Waveform

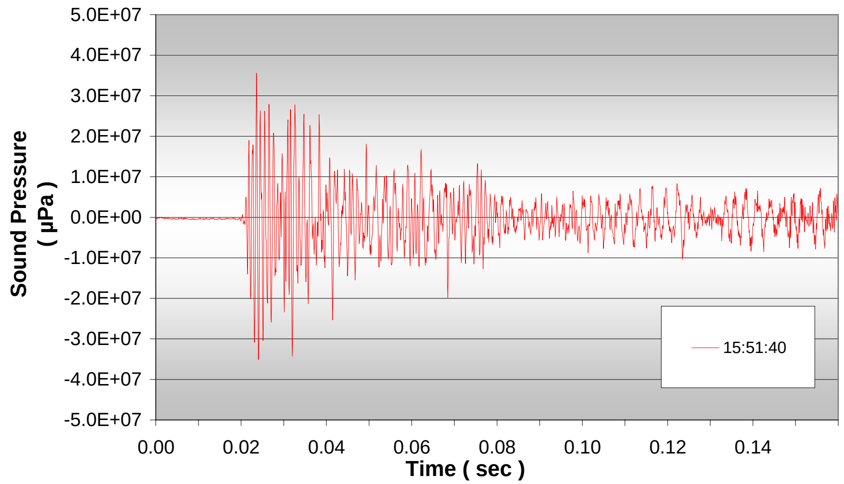


Figure b. Narrow Band Frequency Spectra

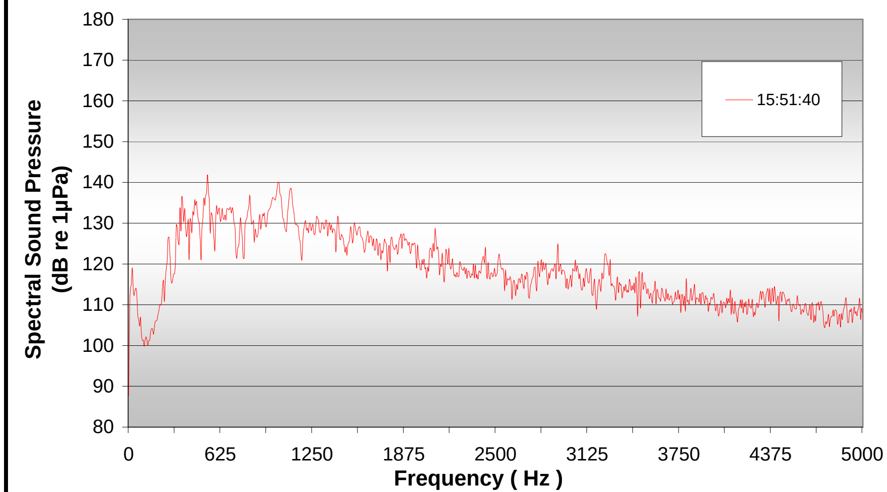


Figure c. Accumulation of Sound Energy

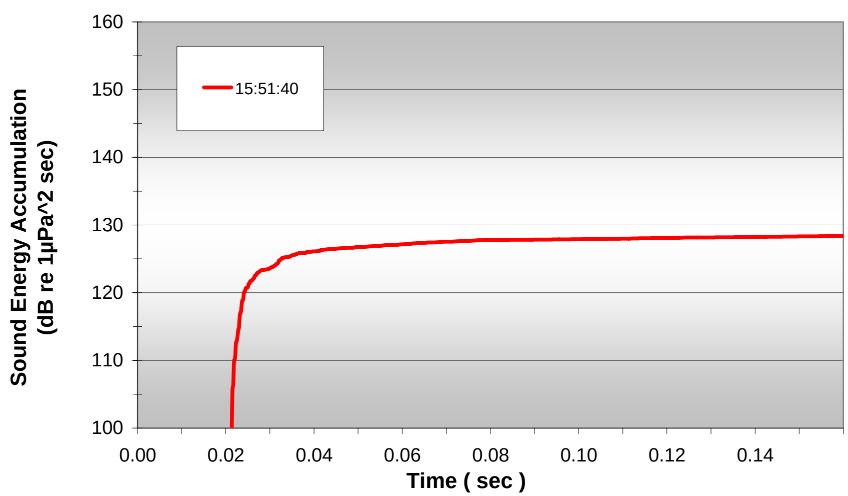


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

500 meter	Peak	RMS90%*	SEL
15:51:40	151	138	128

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak		
Reported Average	152		
Reported maximum	158		

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure B - 66