PORT OF OAKLAND BERTH 22
UNDERWATER SOUND MEASUREMENT DATA FOR THE DRIVING OF OCTOGONAL CONCRETE PILES
AUGUST 2, 2004 – FEBRUARY 14, 2005

April 4, 2005

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Executive Summary

Underwater sound pressure levels were measured during the driving of octagonal concrete piles as part of the Berth 22 construction project at the Port of Oakland. Two underwater sound attenuation systems were tested to access their performance in reducing underwater sound pressures. In general, the peak sound pressure levels measured at 10 meters from the pile driving typically ranged from 185 to 192 dB re 1 µPa. The associated root-mean-square sound pressure levels ranged from 173 to 180 dB and the sound energy levels ranged from 160 to 174 dB. This report presents results of measured underwater sound pressure levels and the results of data analysis from the recordings of these sounds.

Job No: 04-115

Introduction

Underwater acoustical monitoring was preformed at the Port of Oakland, Berth 22 construction project. Certain driving periods between early August 2004 and mid February 2005 were measured. A DelMag D-62-22 diesel impact hammer was used to drive 0.61 meter octagonal reinforced concrete piles. All piles were driven straight up and down into the sloping channel floor. The data analysis presented in this report includes drive histories of each drive measured and signal analysis of selected pile strikes during pile driving. Bubble curtain systems and configurations were tested to access their noise reduction performance.

Project Description

Construction Equipment

The construction project involved the driving of 0.61 meter diameter octagonal concrete piles to support new dock facilities for Berth 22 at the Port of Oakland. The piles were driven approximately 15 to 30 meters into the substrate at the edge of the shipping channel. The channel edge has comparatively steep banks and the water depth is approximately 13 meters. Figure 1 shows a picture of the pile driving activity during underwater sound measurements.

Pile driving was conducted using a model D62-22 Delmag diesel pile hammer. The hammer operates as a large piston (5,900 kg) in a diesel combustion engine generating up to 224 kilo joules (165,000 foot lbs) of energy on each blow. The hammer has four fuel settings and several features that protect the pile and equipment. The most notable of these is the cushion block, which consists of laminated plywood that is about 1/3rd of a meter thick and separates the "pill" of the pile hammer and the pile. This "softens the blow" from the hammer to the pile, so the hammer does not directly strike the brittle concrete pile.

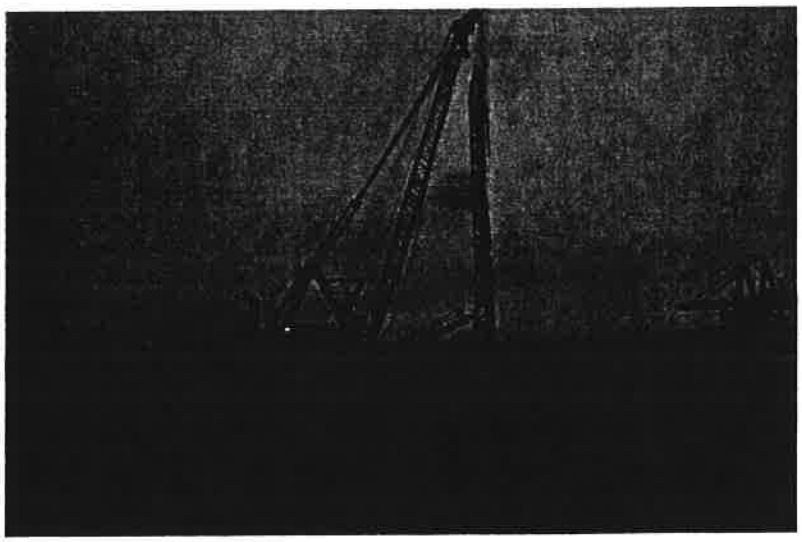

Figure 1. Driving Pile 284A in August, 2004.

Methodology

Measurement Positions

Measurements were made during the driving of A, B, C, D, and E row piles. Rows A thru D were driven in the water, while row E piles were driven on the shore with a land based pile-driving rig. Primarily, measurements were taken at 10 meters from the pile, but distant measurements were conducted for some piles to quantify the drop off rate of the underwater pile driving noise.

Measurement Equipment

Measurements were made using G.R.A.S. CT10 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 (Type 1) and Sony Model TCD-D100 Digital Audio Tape Recorders (DAT). The multi gain signal conditioner provides the ability to lower or raise the signal strength so that measurements are made within the dynamic range of the instruments used to analyze the signals.

The peak pressure and root-mean square average sound pressure levels (RMS) were measured "live" using the SLM. The Larson Davis Model 820 SLM has the ability to measure the unweighted peak sound pressure. RMS levels were measured with the SLM using the standard "impulse exponential-time-weighting" (35 msec rise time) function of the Larson Davis Model 820 SLM. 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.

Underwater Sound Descriptors

When a pile driving hammer strikes a pile, an acoustic pulse is created that propagates through the pile and radiates sound into the water and the ground substrate as well as the air. The sound pressure pulse represented in the time domain 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 for the pulse is calculated by computing the average of the squared pressures over the time that comprise the portion of the waveform containing 90 percent of the sound energy.[1] This RMS term is described as $RMS_{90\%}$ in this report. This can be approximated for pile driving by measuring the signal with a precision sound level meter set to the "impulse" RMS setting (RMS). 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 described using various terms. Assuming the "total energy flux" can be equivalent to the un-weighted sound exposure level (SEL), a common unit of sound energy used in airborne acoustics to describe short-duration events. The unit is dB re $1\mu Pa^2$-sec. In this report, peak pressures and RMS sound pressure levels are expressed in decibels re 1 μPa.

Underwater Sound Measurement Data Management

Data were collected from hydrophones in two ways: (1) measurement of peak and RMS sound pressures for each second; and (2) digital audio recording of the sounds for subsequent signal analysis. Following each day of measurements, digital data captured by the SLMs were

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[1] Richardson, Greene, Malone & Thomson, *Marine Mammals and Noise,* Academic Press, 1995 and Greene, personal communication.

downloaded to computer systems. These data were converted and stored in raw ASCII format. The SLMs were primarily used to provide accurate live readings. These readings were recorded in field notebooks from time to time. Digital audio tape recordings were analyzed for selected pile driving events. The sound pressures measured from the tapes were compared to the "live" measurements to avoid any data processing errors. At the same time, the technician listened to the signals to ensure that high quality tape recordings were made (no noise interference) and the source was pile driving noise.

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 145.3 dB (re 1 μPa) tone 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 audiotapes that were 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 on tape. Tape analysis included the measurement of the calibration tone at the beginning and end of tape recording events. 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 audiotapes were labeled and stored for subsequent analysis.

Data Presentation

This section presents measured underwater sound pressure levels. Representative pile driving sound recordings were analyzed and are also presented in this section. Peak and RMS levels reported in these sections were measured directly from SLMs used in the field. The $RMS_{90\%}$ and SEL were calculated based on signal analysis of representative pile driving strikes. Examinations of the analyzed pile strikes found that the RMS measured with impulse setting of the SLM closely approximated the $RMS_{90\%}$ level; therefore, the RMS was used to describe the $RMS_{90\%}$ measure of the pile driving pulses.

Measurements conducted during August 2004 were part of a caged fish study, where fish were exposed to pile driving noise. Results of these exposures are reported separately. Other measurements conducted in December, January, and February measured bubble curtain performance. An air bubble curtain system, often referred to as the bubblator, was used to attenuate underwater sound pressures.

Drive History Analysis

Entire driving periods were recorded using an SLM either live in the field or from a tape recording in the office. These data tell us how underwater sound pressures varied over an entire driving period. Both peak and RMS sound pressures are obtained from these analyses. All reported data were measured at a distance of 10 meters from the pile unless otherwise stated.

Measurement depth was 8 meters for measurements conducted in August 2004, and 3 meters deep thereafter. These figures are presented in Appendix A.

Acoustic Signal Analysis

Representative pile driving acoustical pulses from selected driving periods were analyzed to obtain waveform, narrow band frequency spectra (i.e., 6 Hz resolution), and accumulated sound energy. The analysis was also used to calculate acoustical descriptors such as the RMS over 90% of the energy and the total sound energy or SEL of the impulse event. These data analyses are for 10 meters positions unless otherwise stated in the figures. These figures are presented in Appendix B.

August 2, 2004 - Pile 277B

The first set of pile driving measurements were conducted on August 2, 2004 when Pile 277B was driven. Measurements were made at 10m from the pile and at two unattended positions 100 meters from the pile. The first was 100 meters to the northeast of the pile, and the second 100 meter position was southwest of the pile (at the Maersk Dock). All hydrophones were positioned at a depth of about 8 meters, where water depths were about 10 meter to 13 meter deep. The 10 meter position DAT recorded failed to record during driving; and therefore, signal analysis for pile #277B is not available. Continuous SLM measurements were successfully made at all positions for the pile. At 10 meters, sound pressure levels ranged from 183 dB peak (173 dB RMS) at the beginning of the drive to 191 dB Peak (178 dB RMS) around the middle of the drive. Levels were fairly consistent for the last 5 minutes of the approximate 10-minute drive. The RMS level was about 10 to 12 dB lower than the peak sound pressure and the SEL was about 10 dB lower than the RMS pressure level. At the distant positions, sound pressure levels were 15 to 20 dB lower. There may have been some shielding between the 10 meter and 100 meter southwest positions. Levels 100 meters northeast were about 5 dB higher than those measured at 100 meters to the southwest.

August 3, 2004 - Pile 277A & Pile 284B

Pile 277A was driven during the early afternoon of August 3, 2004. Measurements were made at 10 meters and at the 100 meter position to the southwest. During the entire driving period, sound pressure levels at 10 meters from the pile ranged from 182 dB Peak (171 dB RMS) to 190 dB Peak (176 dB RMS). The SEL was about 165 dB. Sound pressure levels were highest near the middle and end of the drive. Average sound pressure levels at 100 meters southwest were 167 dB Peak, 156 dB RMS and about 146 dB SEL. It is evident that there may have been acoustic shielding between the 10 meter and the 100 meter positions. Sound pressure levels were about 20 dB lower at 100 meters to the southwest than at 10 meters from the pile.

Pile 284B was driven late on the afternoon on August 3, 2004. Measurement distances were the same as for Pile 277A, which was driven earlier that day. This pile was installed further east than the other two piles that were driven previously. During the entire driving period, sound pressure levels at 10 meters from the pile ranged from 182 dB Peak (171 dB RMS) to 190 dB Peak (178 dB RMS). The SEL was about 164 dB. Average sound pressure levels at 100 meters southwest were 174 dB Peak, 163 dB RMS and about 152 dB SEL. Sound pressure levels were highest near the beginning and end of the drive. Sound pressure levels were about 12 dB lower at 100 meters to the southwest than at 10 meters from the pile.

August 4, 2004 - Pile 284A

Pile 284A was driven during the morning of August 4, 2004. Measurement distances were similar to those made during the driving of Piles 277A and 284B. The 100 meter southwest position was further east, near the edge of the existing Maersk dock. During the entire driving period, sound pressure levels at 10 meters from the pile ranged from 183 dB Peak (170 dB RMS) to 192 dB Peak (177 dB RMS). The SEL was about 166 dB. Average sound pressure levels at 100 meters to the southwest were 174 dB Peak, 162 dB RMS and about 152 dB SEL. Sound pressure levels were highest during the beginning and end of the drive. Sound pressure levels were about 14 dB lower at the 100 meter southwest position than at 10 meters from the pile.

December 3, 2004 - Piles 285D, 286D & 281B

Two D-row piles and one B-row pile were measured on December 3rd, 2004. Measurements were made 10 meters from the pile. The air bubble curtain attenuation system, which consisted of an open steel frame with holes drilled to let air pass through, was turned off at times during each pile for testing. With the air bubble curtain on, the average underwater sound levels in the D and B rows were roughly 188 dB peak (178 dB RMS) and 180 dB peak (167 dB RMS) respectively. With no bubbles present, the average underwater sound levels in the D and B rows were 191 dB peak (179 dB RMS) and 184 dB peak (172 dB RMS) respectively. The air bubble attenuation system appeared to be more effective in the B row than in the D row, and that the attenuation devise was more effective at reducing peak pressure than RMS pressure.

December 7, 2004 – Piles 285B & 281A

One B-row pile and one A-row pile were measured on December 7, 2004. The air bubble curtain attenuation system was turned off during each pile for testing. With the bubble curtain on, the average underwater sound levels in the B and A rows were 181 dB peak (170 dB RMS) and 180 dB peak (169 dB RMS) respectively. With no bubbles present, the average underwater sound levels in the B and A rows were 184 dB peak (174 dB RMS) and 187 dB peak (177 dB RMS) respectively.

December 20, 2004 – Piles 287C & 287B

Measurements were made for one C row and one B row pile on Monday, December 20, 2004 when the air bubble curtain system. This system was modified by adding a larger diameter ring at the bottom to ensure that air bubbles surrounded the pile from the bottom to the water surface. The top rings were not considered necessary due to the lack of currents. This was confirmed from visual observations.

Underwater sound levels were measured at 10 meters from the pile at a depth of 3 meters below the water surface. Measurements were made from the deeper water at the edge of the Hagar Barge. The picture below shows the C Row pile being driven. The picture was taken from the measurement position 10 meters from the pile when the bubblator airflow was set at about ¼ flow or less.

The bubble curtain attenuation devise was turned off during each pile for testing . With the air bubble curtain system on, the average underwater sound levels in the C and B rows were 181 dB peak (169 dB RMS) and 177 dB peak (167 dB RMS) respectively. With no bubbles present, the average underwater sound levels for both C and B rows were 183 dB peak (171 dB RMS).

Figure 2. Air Bubble Curtain Attenuation System in Operation.

Reducing the airflow did not appear to affect the air bubble curtain system performance in reducing sound pressures. The performance based on reduction between ON and OFF conditions varied from about 0 to 5 dB. Subsequent use of the modified air bubble curtain system was at about ¼ airflow in the bottom ring only.

December 21, 2004 - Pile 282E, 283E, 284E, & 286E

Measurements for 4 different E Row Piles were made on Tuesday December 21, 2004. Underwater sound levels were measured at two fixed locations and one mobile location. One fixed location was setup at a distance of about 10 to 15 meters from the piles and the other was set up at 20 to 25 meters. No air bubble curtain system was used during the driving of these piles since the piles were driven on or near land. The average underwater sound levels at the E row were about 191 dB peak (180 dB RMS). Considering that the piles were driven on land, the underwater sound pressure levels were considered high. The relatively high underwater sound pressure levels were suspected to be caused by ground borne vibration, in which the sound energy is reintroduced into the water column from the ground away from the pile.

Figure 3. Land Based Driving of E Row Piles on 12/21/2004.

January 25, 2005 – Piles 317D, 318D, 319D & 320D

Measurements for four D Row Piles were made on January 25, 2005. Underwater sound levels were measured at one location 10 meters from the pile and 3 meters from the surface of the water. A different bubble curtain system was used during the driving of these piles; the bubble curtain consisted of a thick PVC shell that encircled the pile underwater. This system was proven effective for another marine pile driving project in Benicia, CA. Air was then forced into the space between the PVC shell and the pile during driving. One bubble curtain On/Off/On test was performed on pile #317D, and measurements of the test show a negligible difference in underwater sound pressure levels. The average underwater sound level at these D row piles was about 190 dB peak (177 dB RMS). Ground borne sound probably limited the effectiveness of this system.

Figure 4. Driving of D Row Pile with PVC Shell Air Bubble Curtain System.

February 14, 2005 – Piles 316A &316.5A

Measurements for two D Row Piles were made on February 14, 2005. Underwater sound levels were measured at one location 10 meters from the pile and 3 meters from the surface of the water. The original open frame bubble curtain system was used, and was tested during the driving of pile #316A. With the air bubble curtain system off, the underwater noise levels at 10 meters were roughly 185 dB peak (174 dB RMS). With the air bubble curtain system on, the underwater noise levels at 10 meters were roughly 182 dB peak (170 dB RMS).

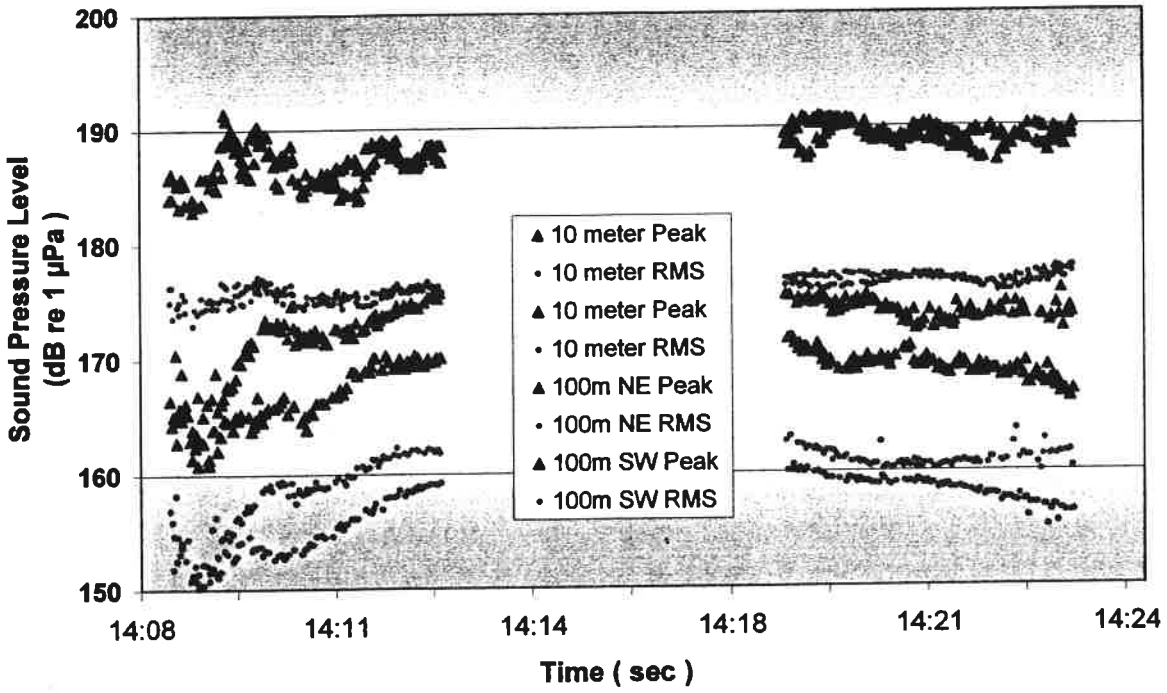
Appendix A

Drive History Figures

Port of Oakland Berth 22 Construction

Underwater Acoustical Monitoring Data

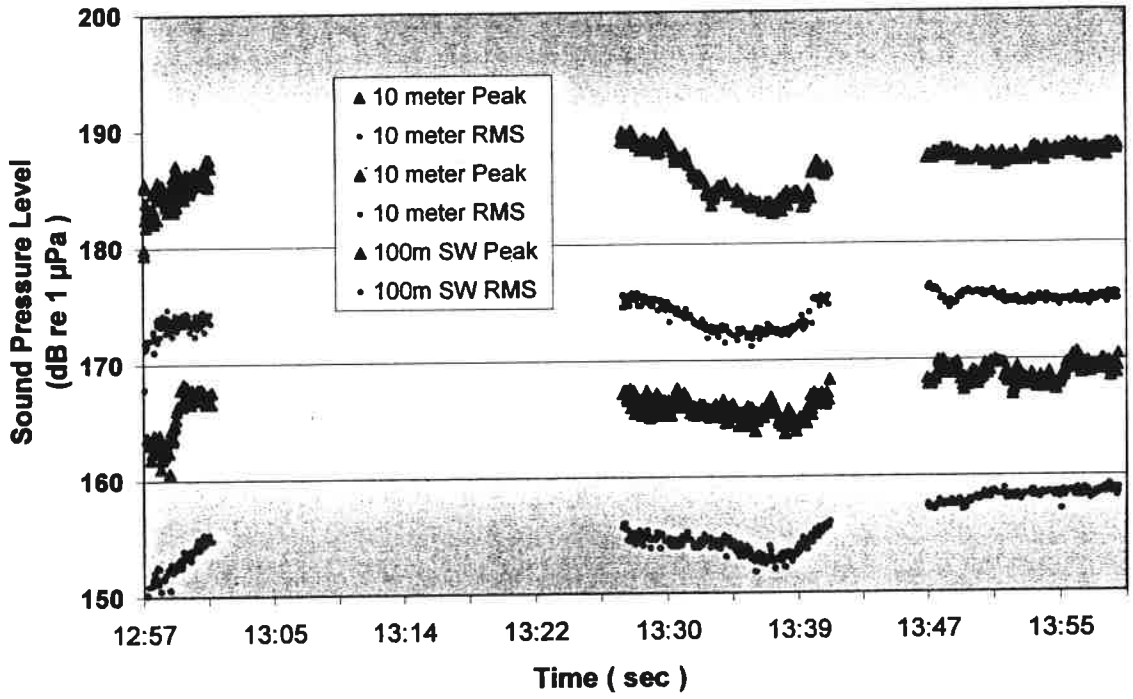
Berth 22 Underwater Sound Levels - Pile #277B - 08/02/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
14:04 - 14:52	On	-	-	-	-	-
	Off	**188**	183 - 191	**176**	173 - 177	N/A

Notes:	
	Pile # 277B
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 130 feet
	B Row Pile (~54 feet from shore) in 40 feet of water from MLLW

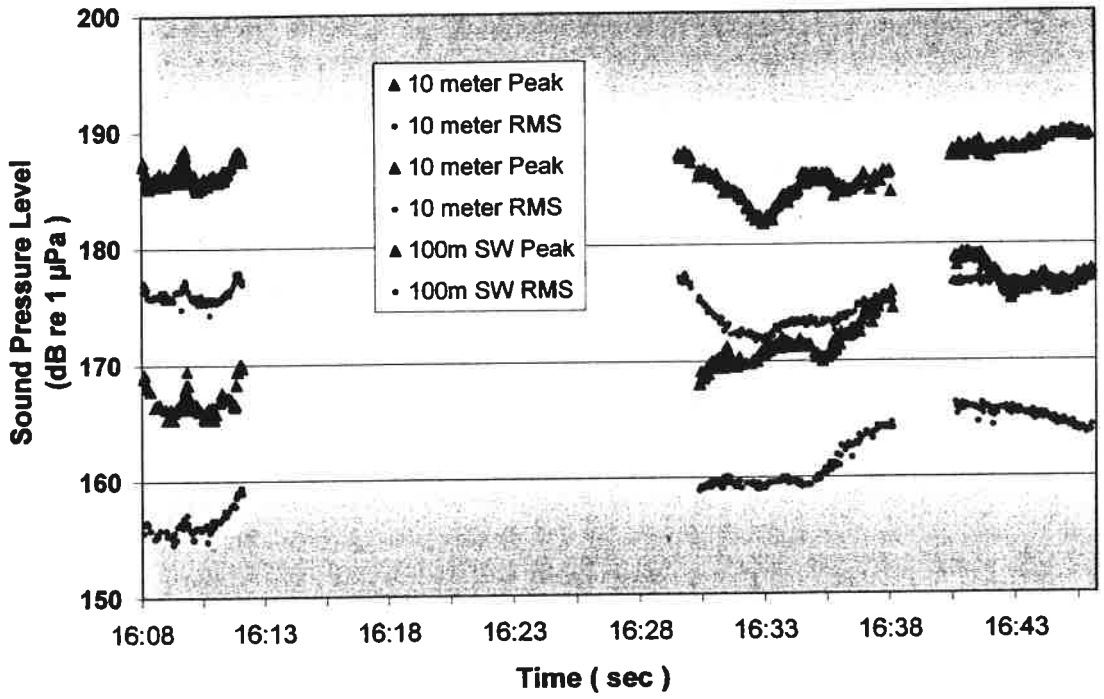
Berth 22 Underwater Sound Levels - Pile #277A - 08/03/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
12:08 - 14:20	On	-	-	-	-	-
	Off	**187**	182 - 190	**174**	171 - 176	165

Notes:	
	Pile # 277A
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 165 feet
	A Row Pile (~72 feet from shore) in 50 feet of water from MLLW

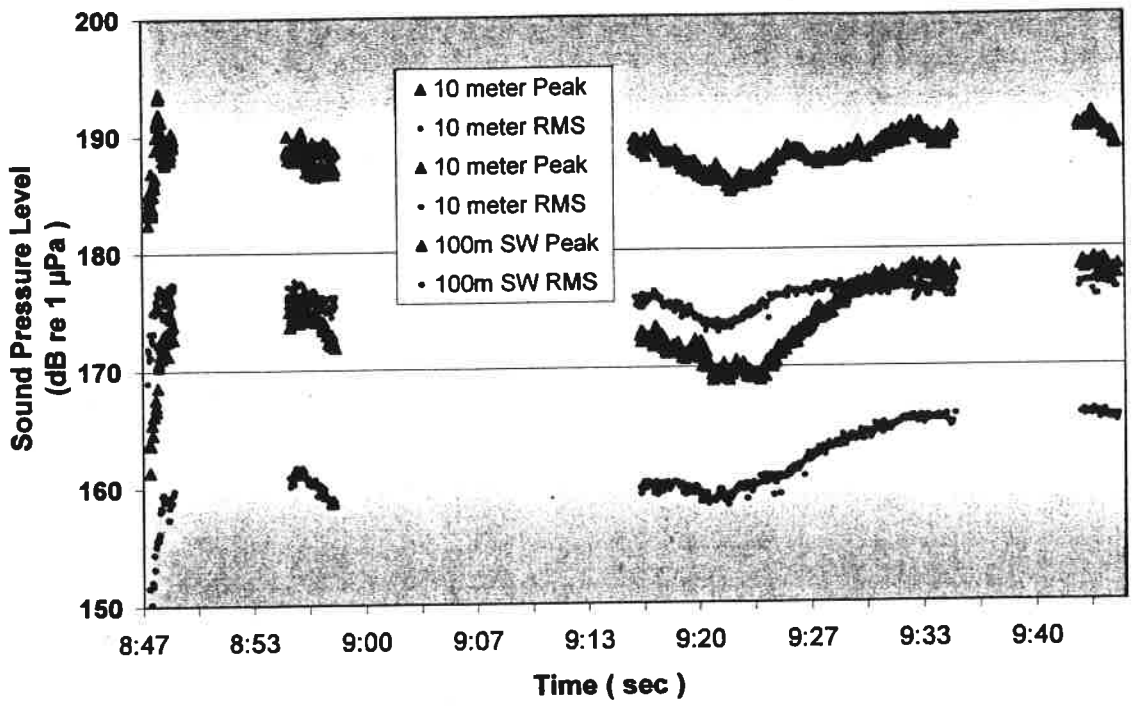
Berth 22 Underwater Sound Levels - Pile #284B - 08/03/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
16:04 - 16:49	On	-	-	-	-	-
	Off	**186**	182 - 190	**175**	171 - 178	164

Notes:	
	Pile # 284B
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 130 feet
	B Row Pile (~54 feet from shore) in 40 feet of water from MLLW

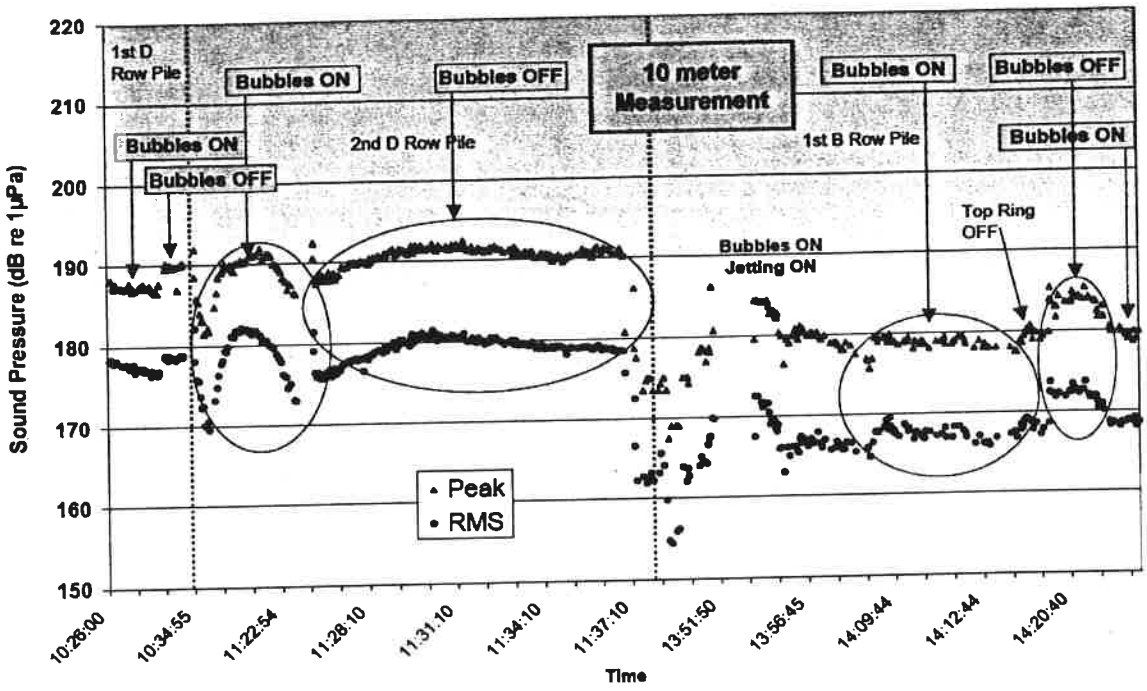
Berth 22 Underwater Sound Levels - Pile #284A - 08/04/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
08:45 - 09:45	On	-	-	-	-	-
	Off	**188**	183 - 194	**176**	169 - 178	166

Notes:	
	Pile # 284A
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 164 feet
	A Row Pile (~72 feet from shore) in 50 feet of water from MLLW

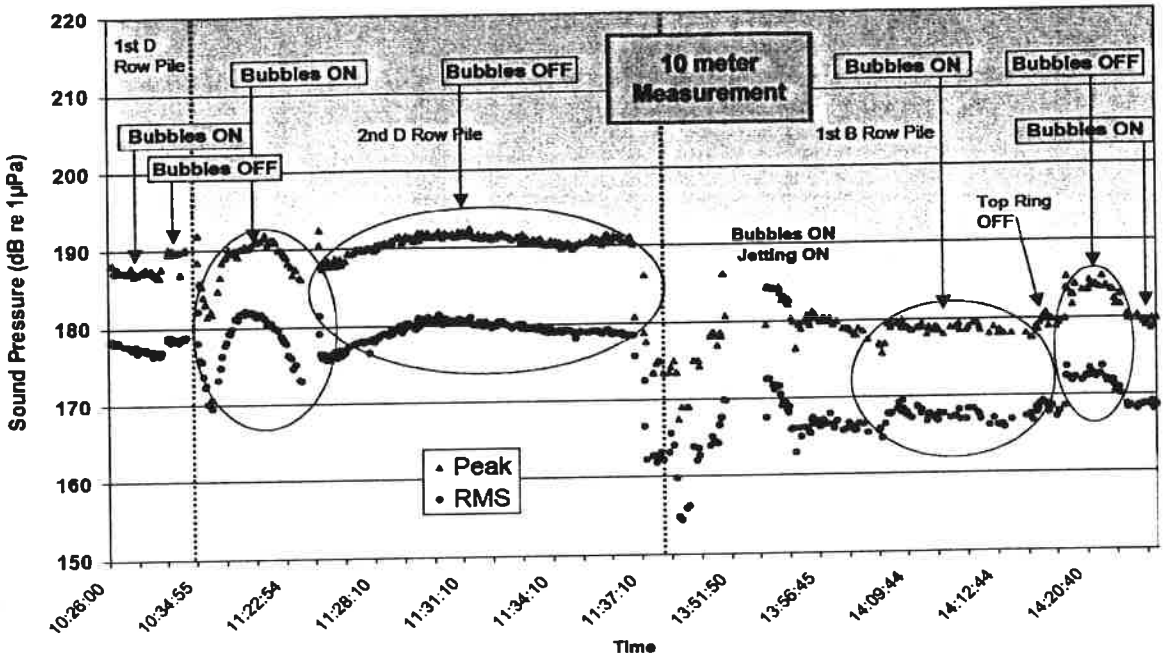
Berth 22 Underwater Sound Levels - Pile #285D - 12/03/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	Average	Range	Typical
10:26 - 10:33	On	**187**	187 - 188	**177**	176 - 178	165
	Off	**190**	187 - 190	**179**	178 - 179	166

Notes:	
	Pile # 285D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 65 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

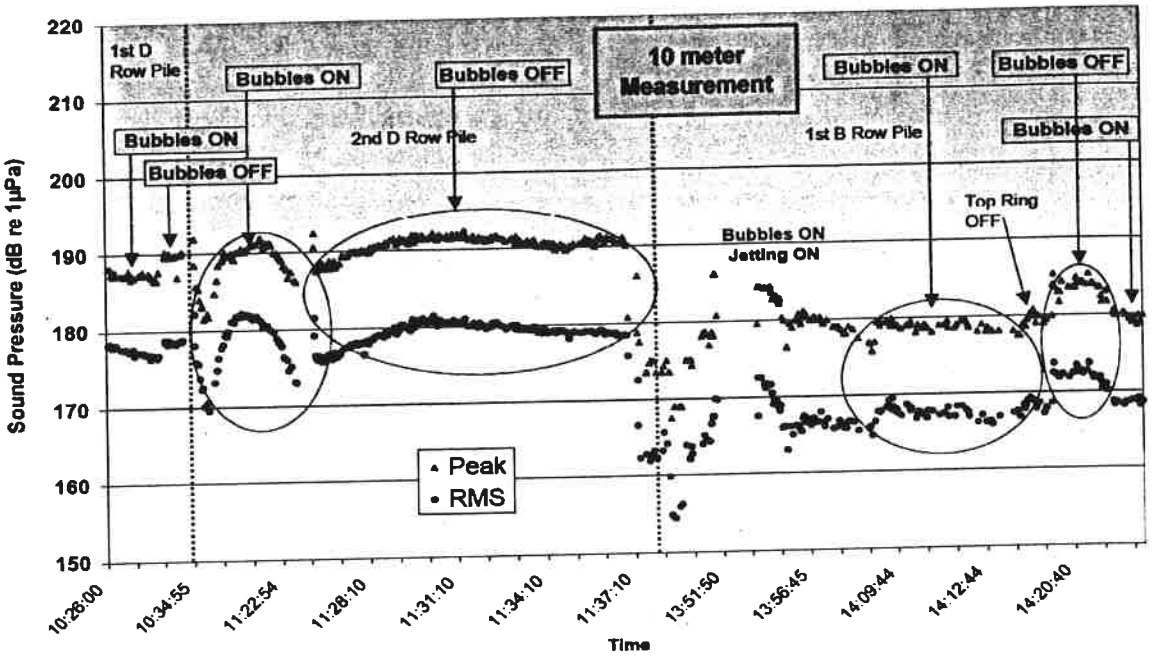
Berth 22 Underwater Sound Levels - Pile #286D - 12/03/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
11:12 - 11:35	On	**188**	181 - 192	**178**	170 - 182	164
	Off	**191**	181 - 192	**179**	176 - 181	166

Notes:	
	Pile # 286D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 65 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

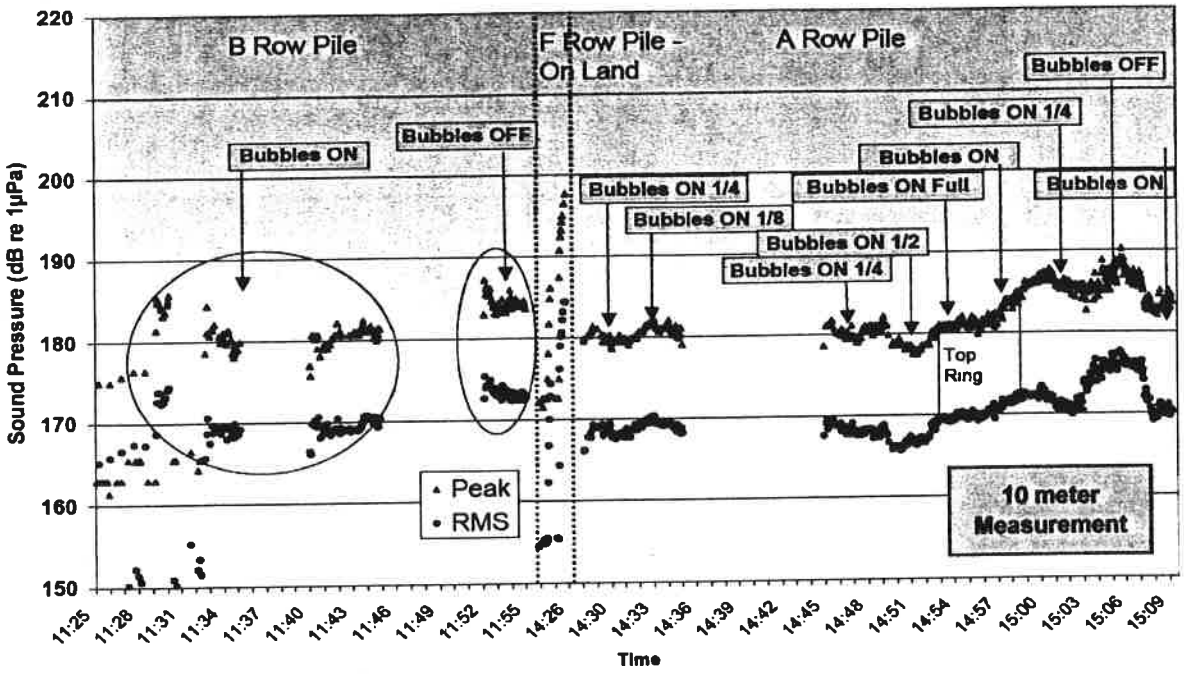
Berth 22 Underwater Sound Levels - Pile #281B - 12/03/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	Average	Range	Typical
13:48 - 14:22	On	**180**	176 - 184	**167**	163 - 173	158
	Off	**184**	182 - 185	**172**	172 - 174	161

Notes:	
	Pile # 281B
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 135 feet
	B Row Pile (~54 feet from shore) in 40 feet of water from MLLW

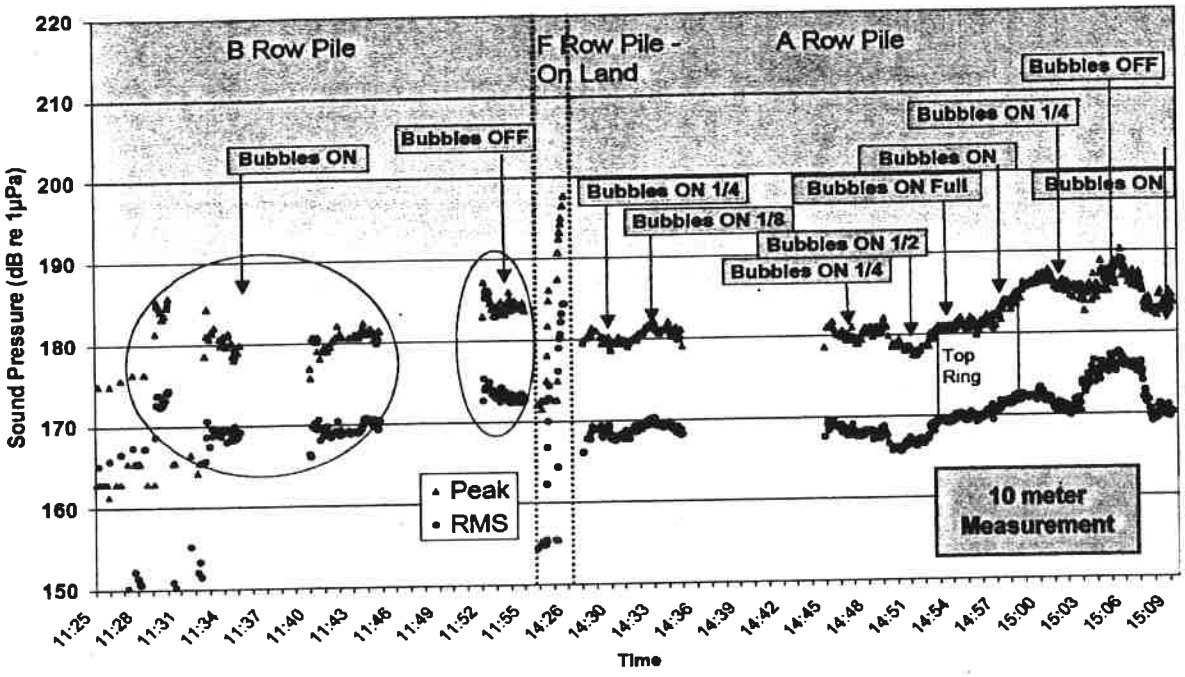
Berth 22 Underwater Sound Levels - Pile #285B - 12/07/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
11:27 - 11:54	On	**181**	179 - 184	**170**	167 - 171	159
	Off	**184**	183 - 187	**174**	173 - 175	162

Notes:	
	Pile # 285B
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 135 feet
	B Row Pile (~54 feet from shore) in 40 feet of water from MLLW

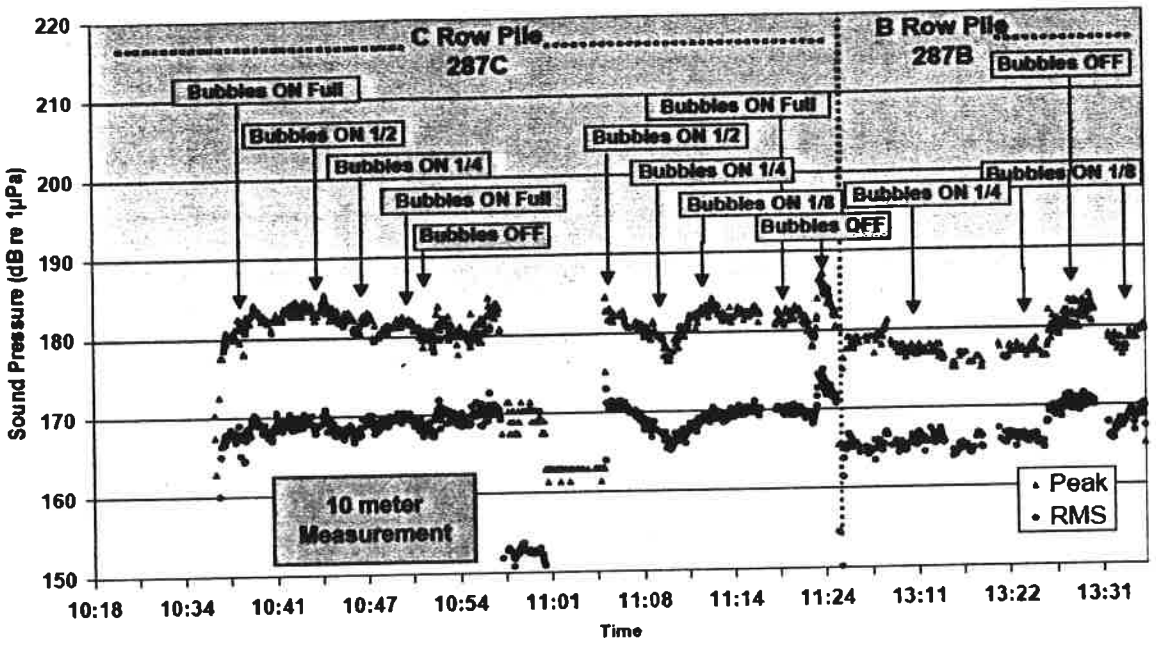
Berth 22 Underwater Sound Levels - Pile #281A - 12/07/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
14:24 - 15:20	On	**180**	178 - 186	**169**	166 - 173	160
	Off	**187**	185 - 190	**177**	175 - 178	166

Notes:	
	Pile # 281A
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 164 feet
	A Row Pile (~72 feet from shore) in 50 feet of water from MLLW

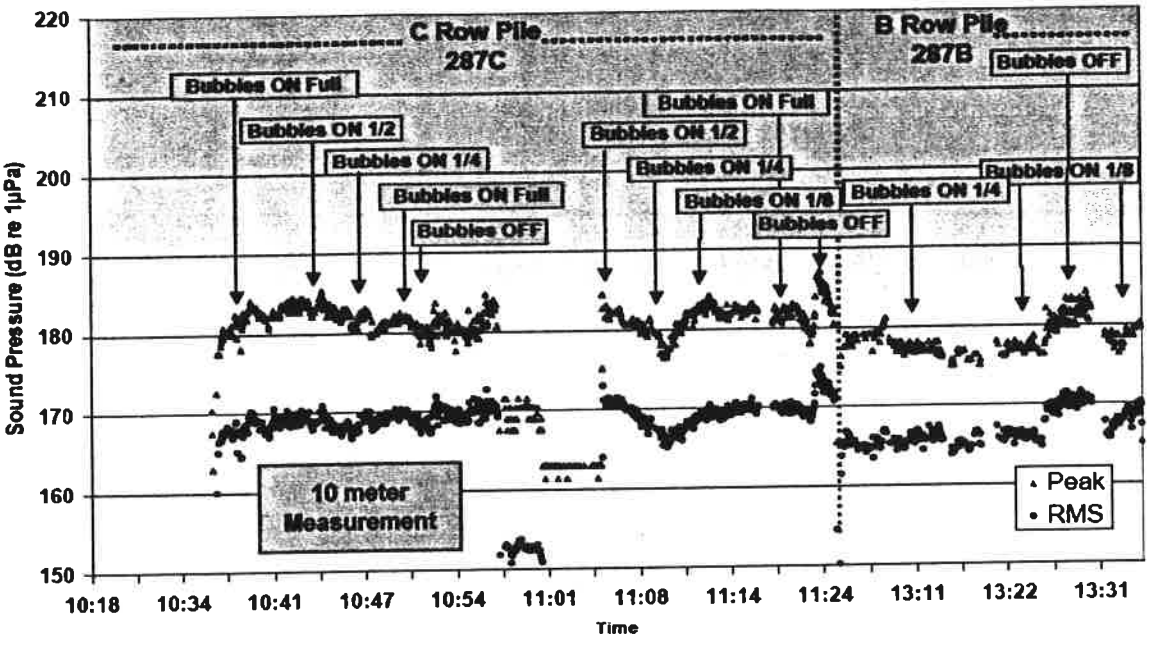
Berth 22 Underwater Sound Levels - Pile #287C - 12/20/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
10:29 - 11:24	On	**181**	178 - 185	**169**	166 - 171	158
	Off	**183**	179 - 187	**171**	169 - 175	162

Notes:	
	Pile # 287C
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 135 feet
	C Row Pile (~36 feet from shore) in 20 feet of water from MLLW

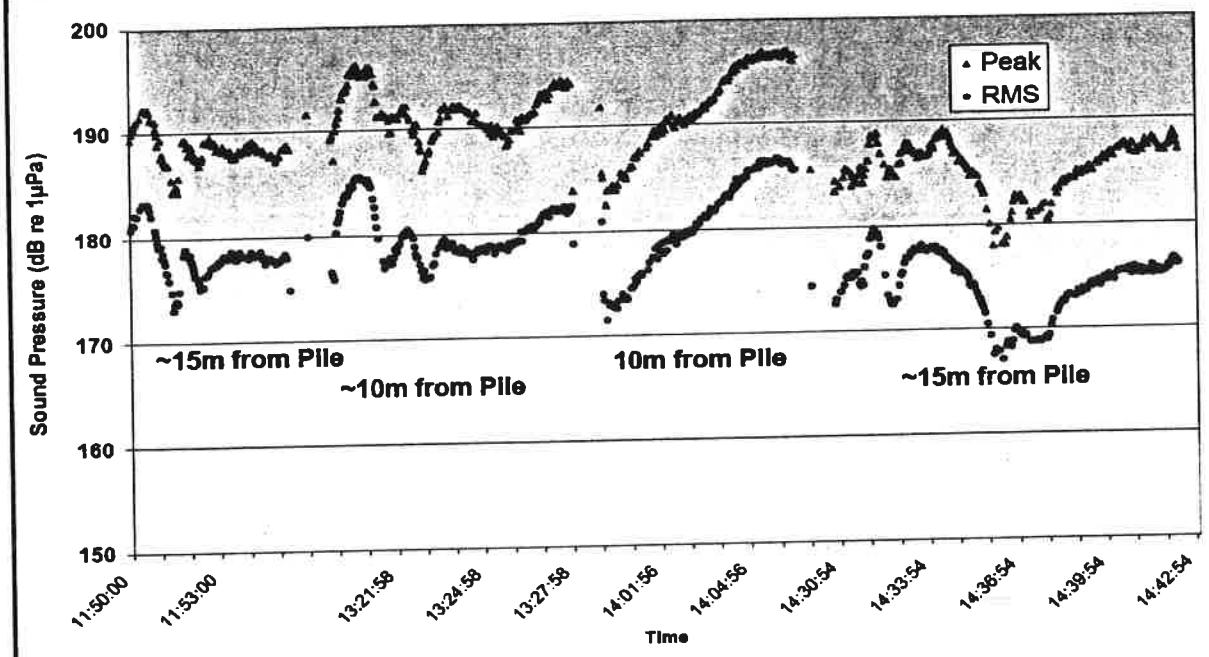
Berth 22 Underwater Sound Levels - Pile #287B - 12/20/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
13:04 - 13:33	On	**177**	175 - 181	**167**	164 - 168	155
	Off	**183**	178 - 184	**171**	168 - 172	159

Notes:	
	Pile # 287B
	DelMag D-62-22 Diesel Impact Hammer @ Setting #2
	24 Inch Octogonal Concrete Pile - 135 feet
	B Row Pile (~54 feet from shore) in 40 feet of water from MLLW

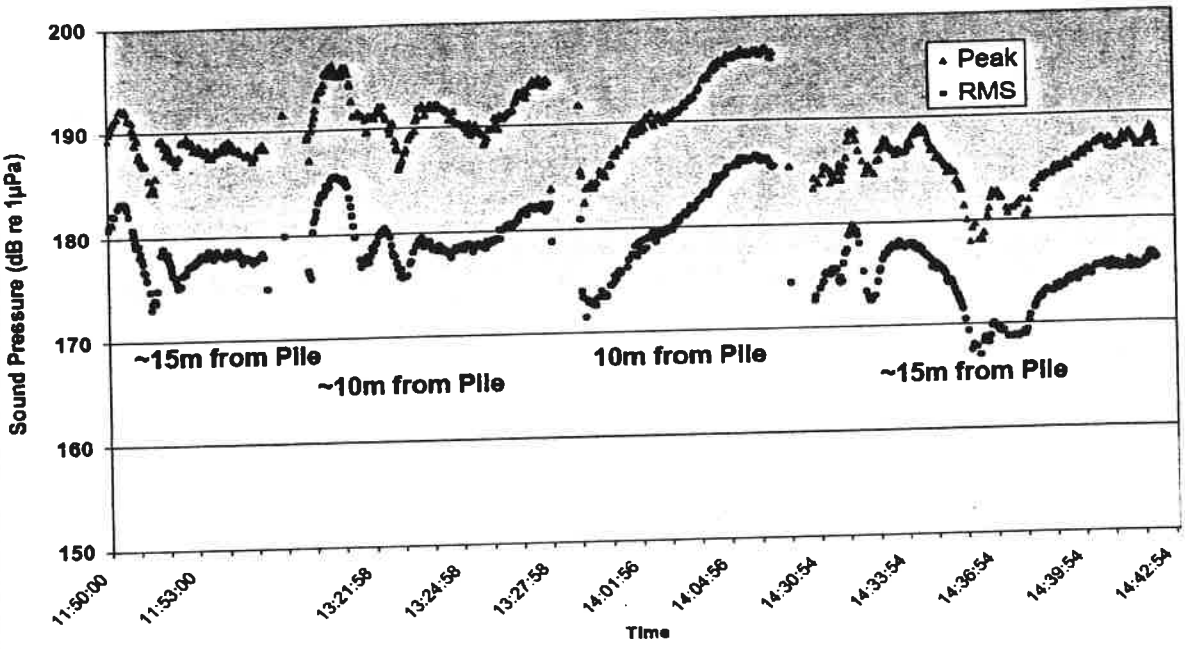
Berth 22 Underwater Sound Levels - Pile #282E - 12/21/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
11:43 - 11:56	On	-	-	-	-	-
	Off	**189**	187 - 192	**178**	175 - 182	N/A

Notes:	
	Pile # 282E
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

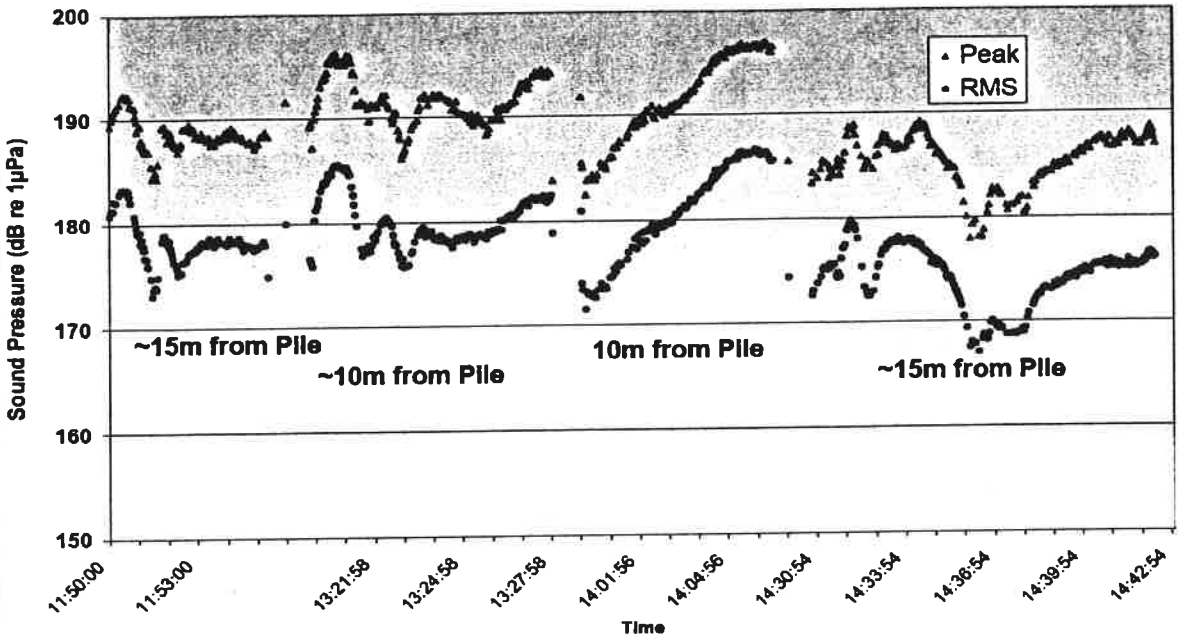
Berth 22 Underwater Sound Levels - Pile #283E - 12/21/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	Average	Range	Typical
13:15 - 13:28	On	-	-	-	-	-
	Off	**192**	188 - 196	**180**	176 - 185	170

Notes:	
	Pile # 283E
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

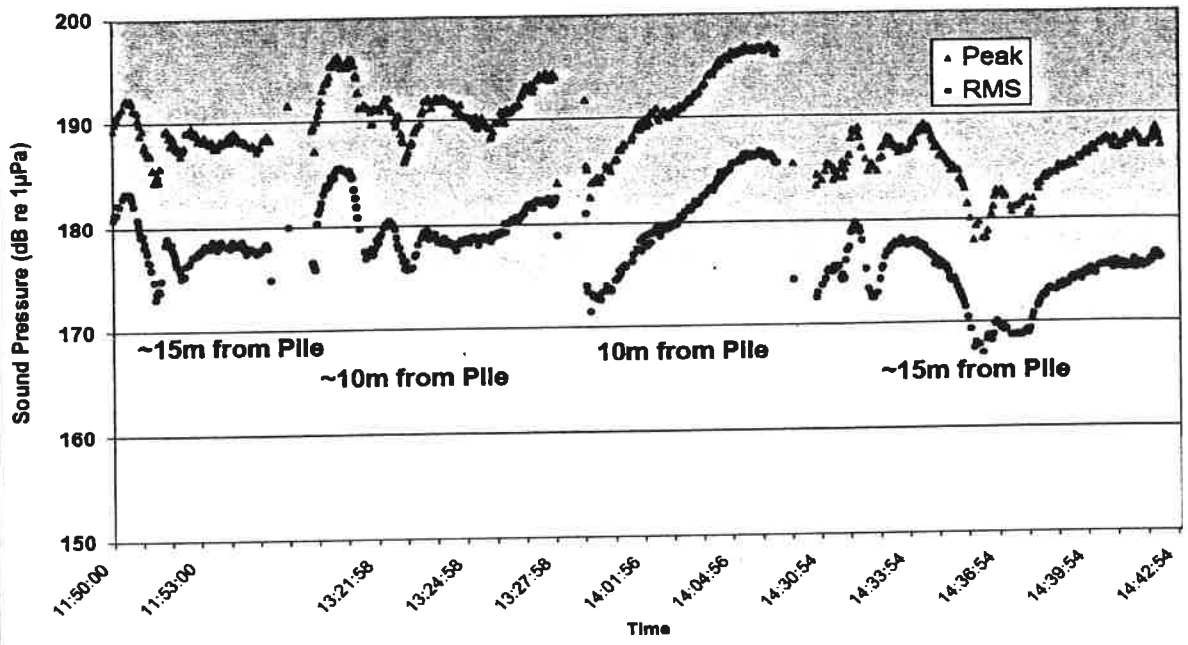
Berth 22 Underwater Sound Levels - Pile #284E - 12/21/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
13:51 - 14:07	On	-	-	-	-	-
	Off	**192**	185 - 196	**181**	176 - 186	174

Notes:	
	Pile # 284E
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

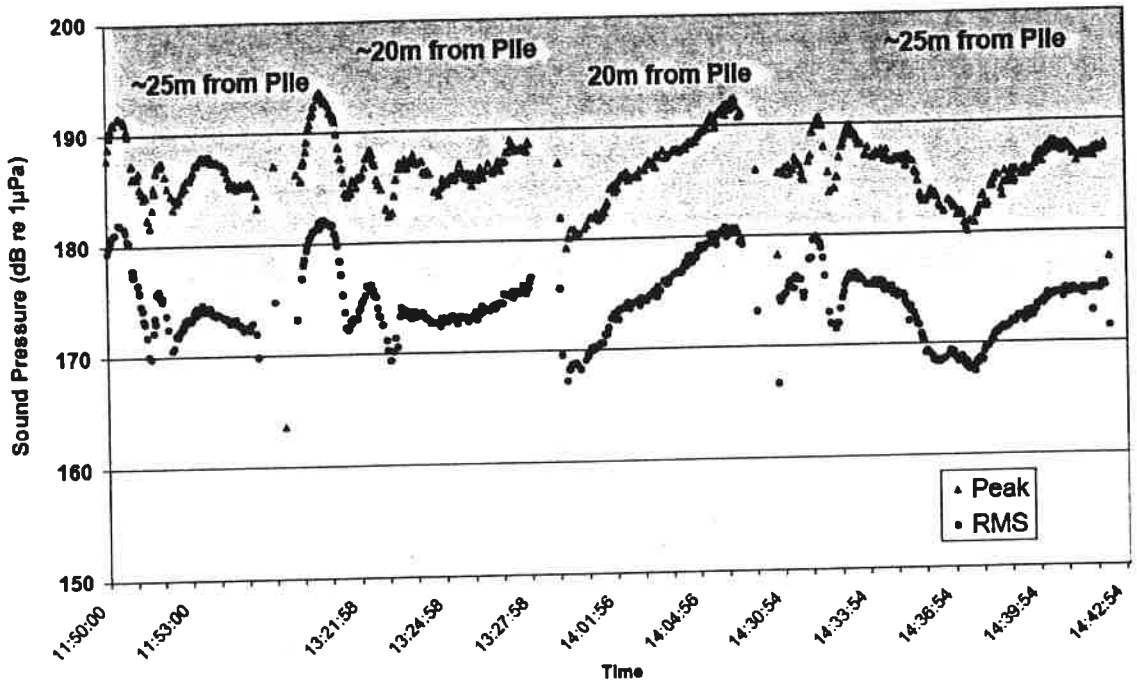
Berth 22 Underwater Sound Levels - Pile #286E - 12/21/04



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	Average	Range	Typical
14:26 - 14:44	On	-	-	-	-	-
	Off	**186**	179 - 187	**174**	169 - 179	N/A

Notes:	
	Pile # 286E
	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

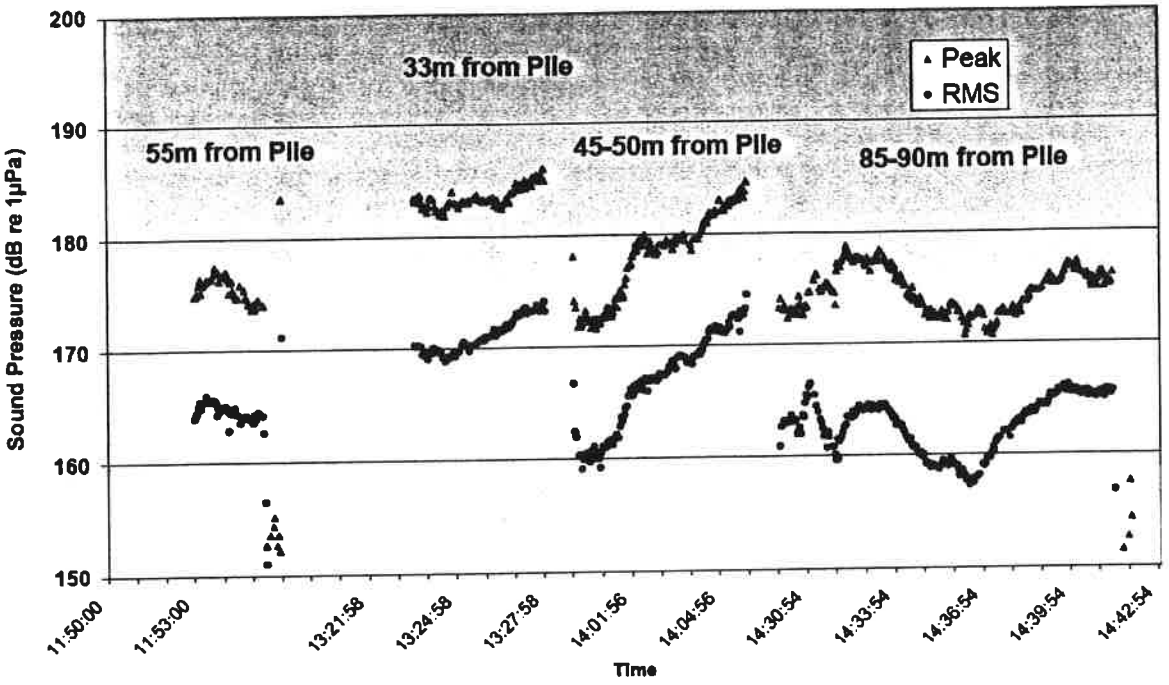
Berth 22 Underwater Sound Levels - Distant Measurements - 12/21/04



Pile	Time	Distance (meters)	Peak		RMS (35 msec time window)		SEL
			Average	Range	**Average**	Range	Typical
282E	11:43 - 11:56	25	**187**	187 - 187	**178**	175 - 182	N/A
283E	13:15 - 13:28	20	**187**	184 - 192	**175**	170 - 181	164
284E	13:51 - 14:07	20	**187**	181 - 191	**176**	169 - 180	168
286E	14:26 - 14:44	25	**186**	181 - 189	**173**	168 - 177	N/A

Notes:	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

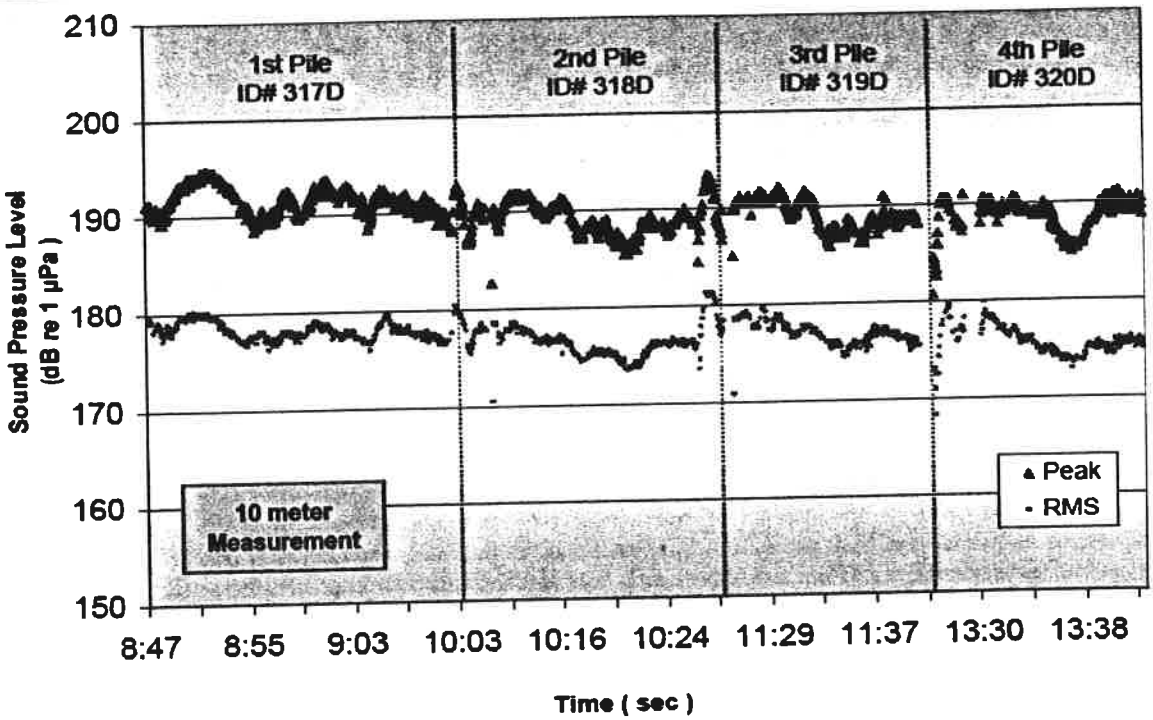
Berth 22 Underwater Sound Levels - Distant Measurements - 12/21/04



Pile	Time	Distance (meters)	Peak		RMS (35 msec time window)		SEL
			Average	Range	**Average**	Range	Typical
282E	11:43 - 11:56	55	**176**	174 - 176	**165**	163 - 165	N/A
283E	13:15 - 13:28	33	**184**	182 - 185	**171**	170 - 173	N/A
284E	13:51 - 14:07	45	**178**	173 - 183	**167**	162 - 172	N/A
286E	14:26 - 14:44	85	**173**	172 - 177	**161**	160 - 165	N/A

Notes:	DelMag D-62-22 Diesel Impact Hammer @ Setting #N/A
	24 Inch Octogonal Concrete Pile - 65 feet
	E Row Pile (~0 feet from shore) in 0 feet of water from MLLW

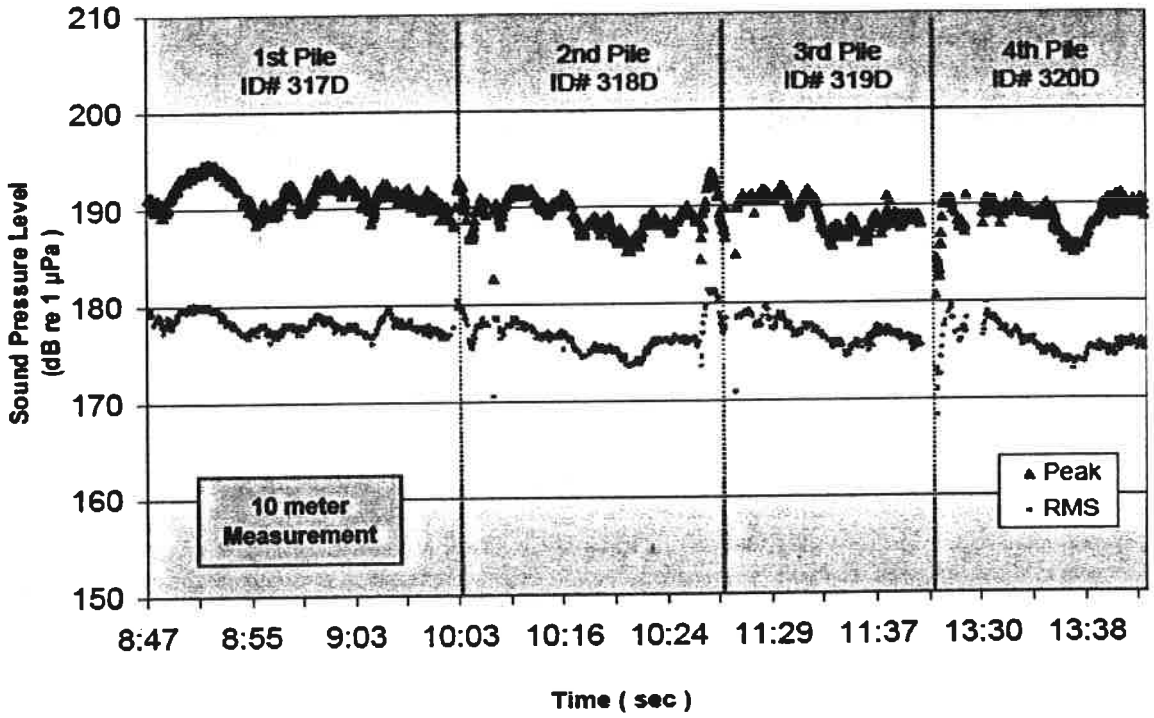
Berth 22 Underwater Sound Levels - Pile #317D - 01/25/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
08:36 - 09:09	On	**192**	189 - 195	**178**	176 - 180	168
	Off	**192**	190 - 193	**179**	178 - 180	167

Notes:	
	Pile # 317D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 119 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

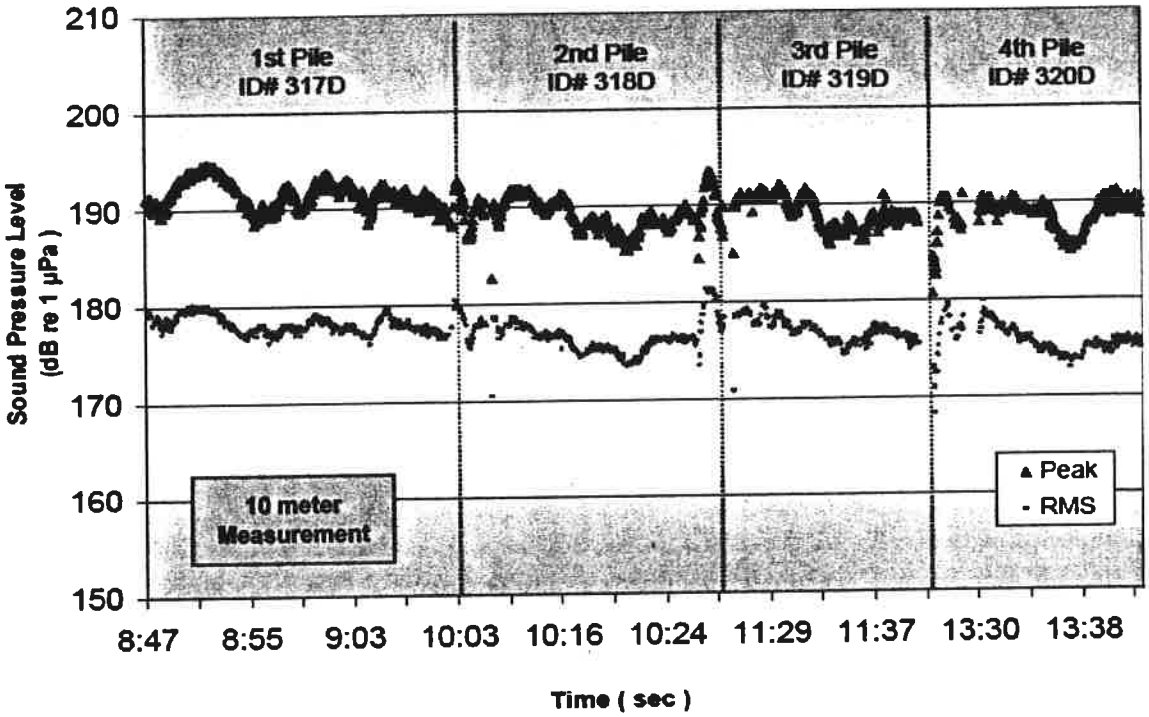
Berth 22 Underwater Sound Levels - Pile #318D - 01/25/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
10:00 - 10:26	On	**189**	183 - 193	**176**	171 - 181	167
	Off	-	-	-	-	-

Notes:	
	Pile # 318D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 119 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

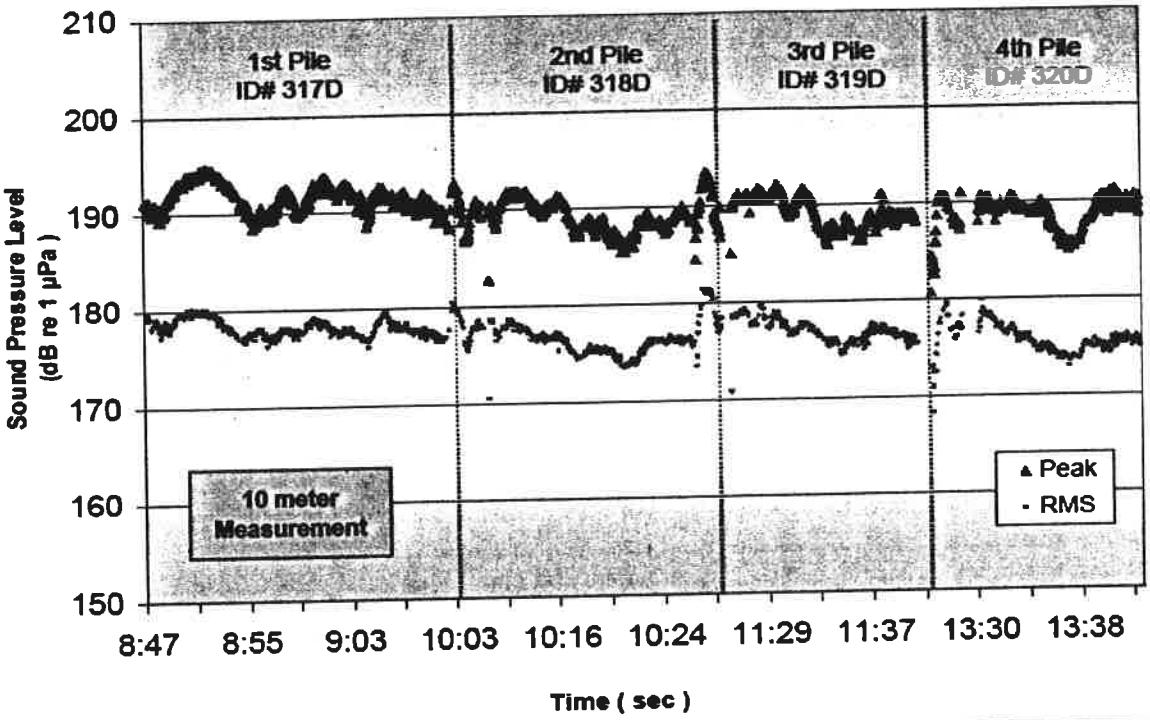
Berth 22 Underwater Sound Levels - Pile #319D - 01/25/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
11:15 - 11:40	On	**189**	185 - 194	**177**	171 - 181	167
	Off	-	-	-	-	-

Notes:	
	Pile # 319D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 119 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

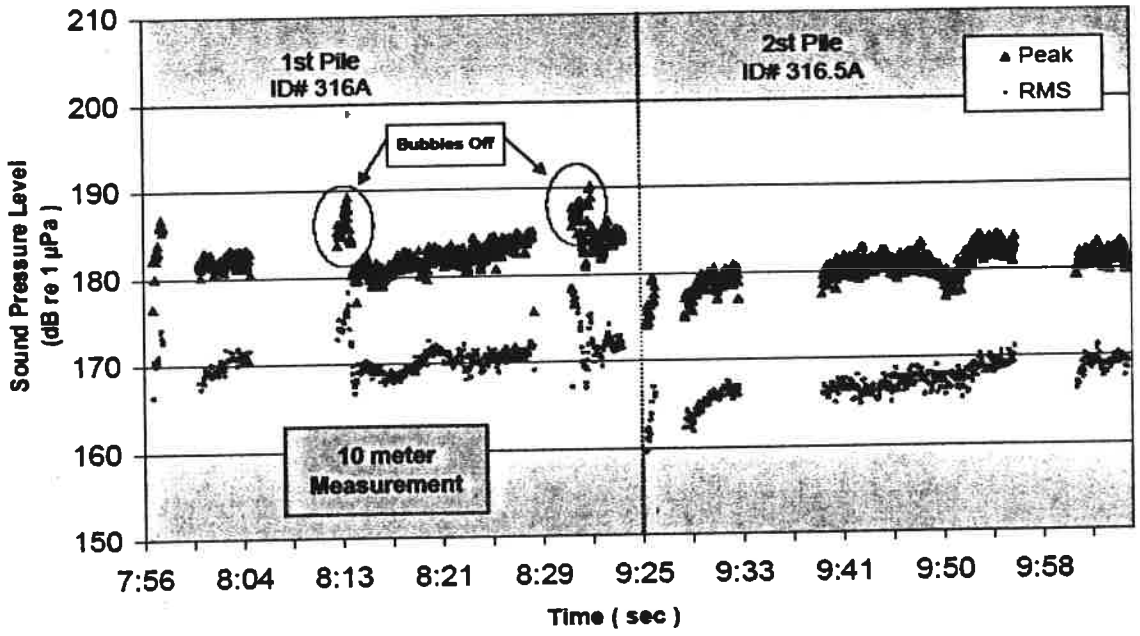
Berth 22 Underwater Sound Levels - Pile #320D - 01/25/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
13:19 - 13:42	On	**189**	181 - 191	**176**	168 - 180	169
	Off	-	-	-	-	-

Notes:	
	Pile # 320D
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 118 feet
	D Row Pile (~18 feet from shore) in 10 feet of water from MLLW

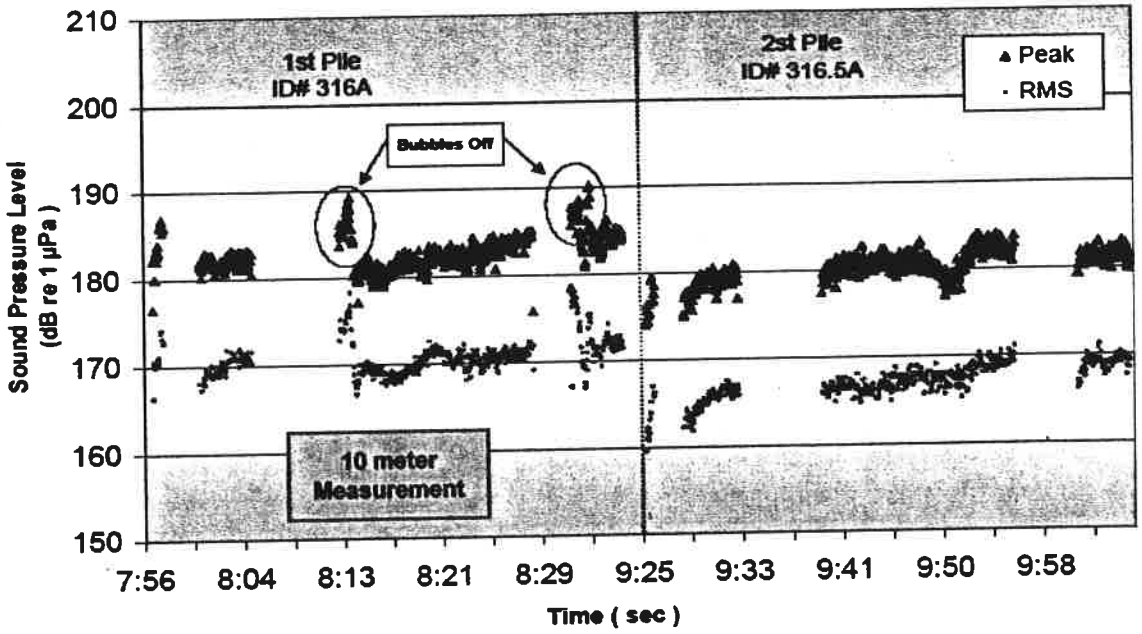
Berth 22 Underwater Sound Levels - Pile #316A - 02/14/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
07:52 - 08:32	On	**182**	177 - 185	**170**	167 - 173	158
	Off	**185**	180 - 189	**174**	168 - 178	160

Notes:	
	Pile # 316A
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 160 feet
	A Row Pile (~72 feet from shore) in 50 feet of water from MLLW

Berth 22 Underwater Sound Levels - Pile #316.5A - 02/14/05



Time	Bubble Curtain	Peak		RMS (35 msec time window)		SEL
		Average	Range	**Average**	Range	Typical
09:21 - 10:03	On	**181**	175 - 184	**167**	162 - 171	158
	Off	-	-	-	-	-

Notes:	
	Pile # 316.5A
	DelMag D-62-22 Diesel Impact Hammer @ Setting #4
	24 Inch Octogonal Concrete Pile - 160 feet
	A Row Pile (~72 feet from shore) in 50 feet of water from MLLW

Appendix B

Signal Analysis Figures

Port of Oakland Berth 22 Construction

Underwater Acoustical Monitoring Data

Berth 22 Pile Drive Signal Analysis - Pile #277A - 10 Meters - 8/3/04

Figure a. Waveform

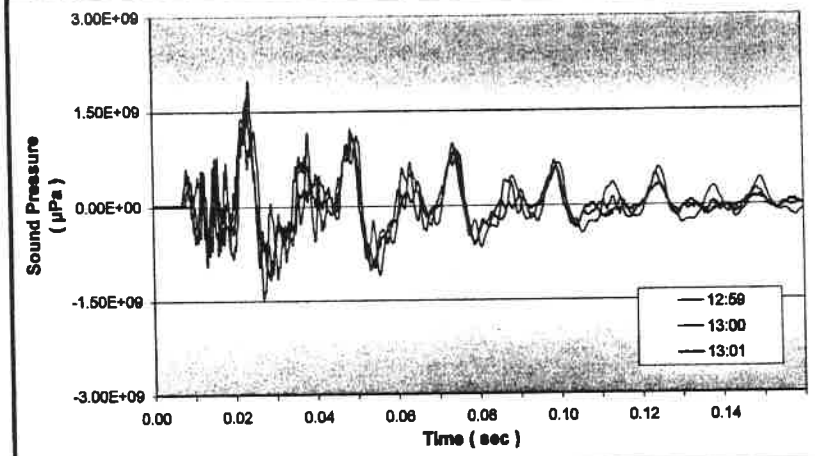


Figure b. Narrow Band Frequency Spectra

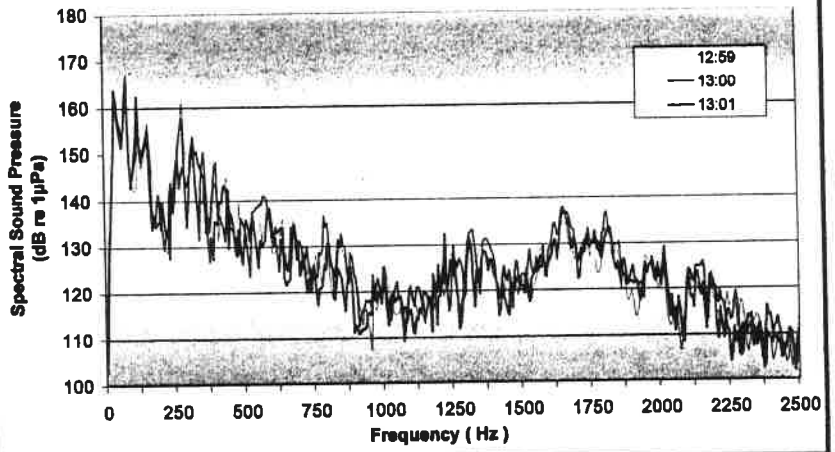


Figure c. Accumulation of Sound Energy

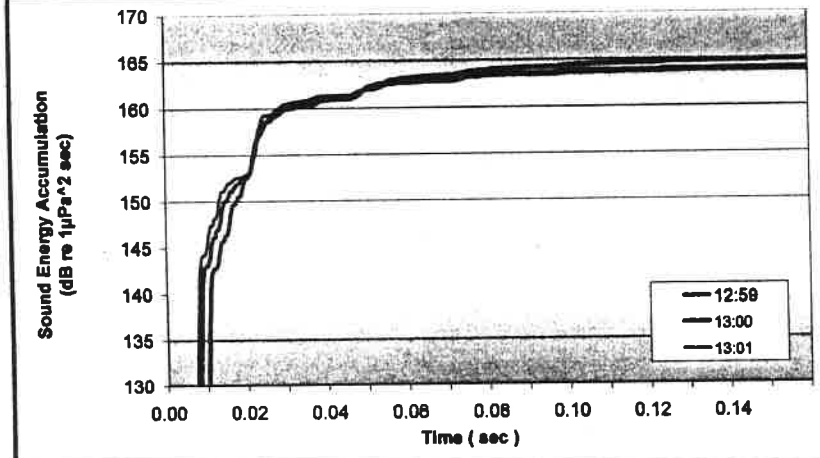


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

277A	Peak	RMS90%*	SEL
12:59 - No Bubbles	183	174	165
13:00 - No Bubbles	185	174	164
13:01 - No Bubbles	186	174	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average	187	174
Reported Maximum	190	176

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #284B - 10 Meters - 8/3/04

Figure a. Waveform

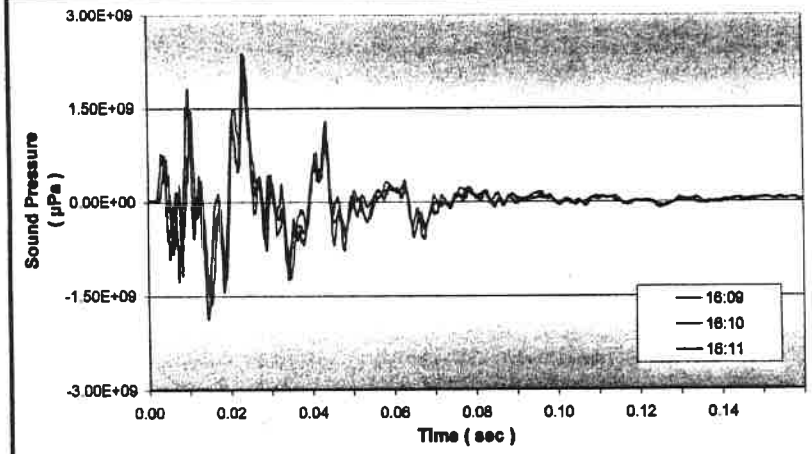


Figure b. Narrow Band Frequency Spectra

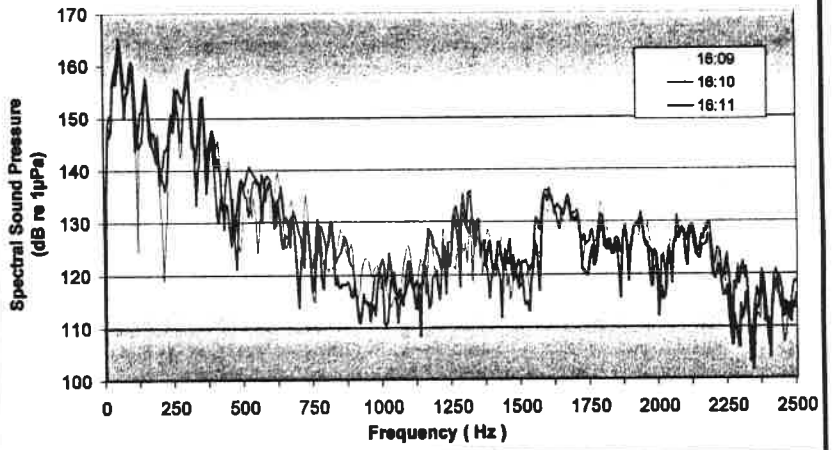


Figure c. Accumulation of Sound Energy

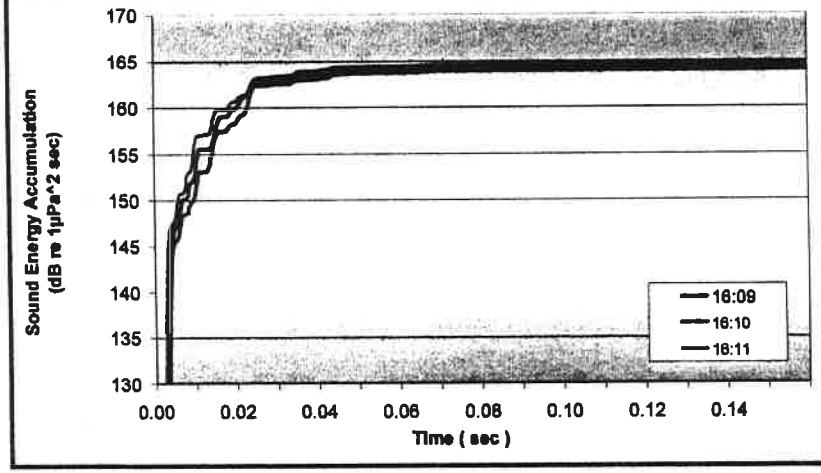


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

284B	Peak	RMS90%*	SEL
16:09 - No Bubbles	188	177	164
16:10 - No Bubbles	187	178	165
16:11 - No Bubbles	186	177	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average	186	175
Reported Maximum	190	178

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #284A - 10 Meters - 8/4/04

Figure a. Waveform

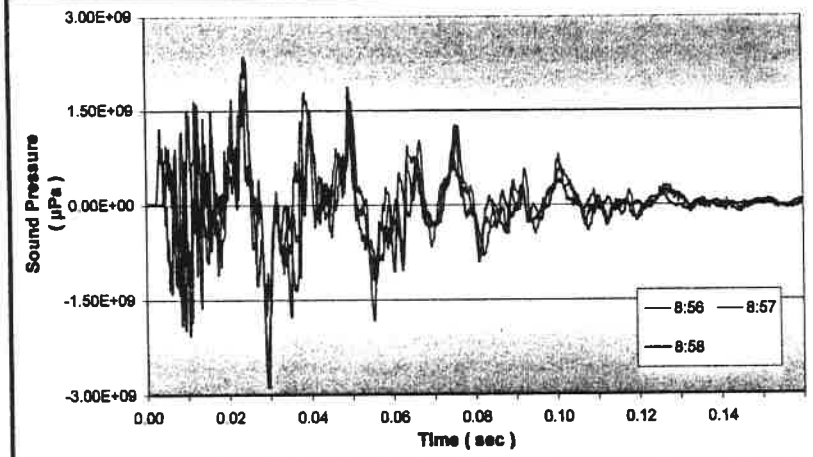


Figure b. Narrow Band Frequency Spectra

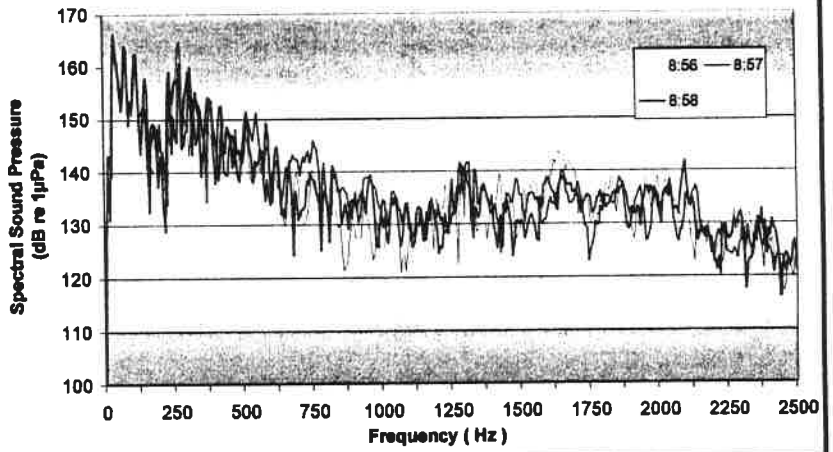


Figure c. Accumulation of Sound Energy

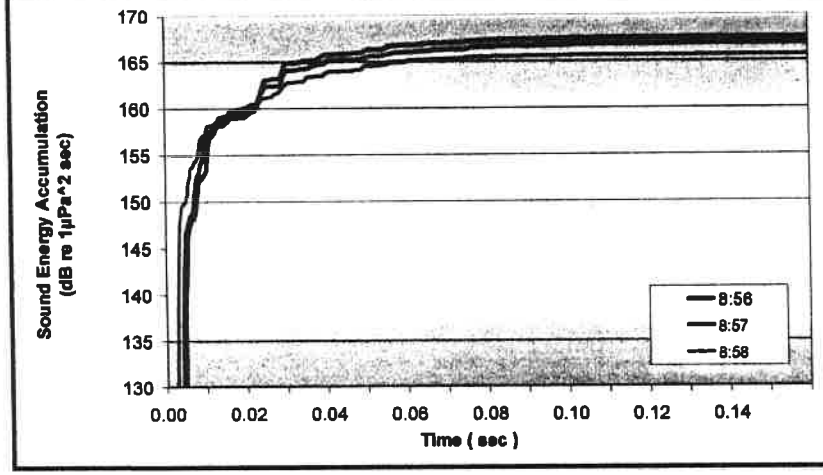


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

284A	Peak	$RMS_{90\%}$*	SEL
08:56 - No Bubbles	189	178	168
08:57 - No Bubbles	188	177	167
08:58 - No Bubbles	185	177	166

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average	188	176
Reported Maximum	194	178

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #285D - 10 Meters - 12/03/04

Figure a. Waveform

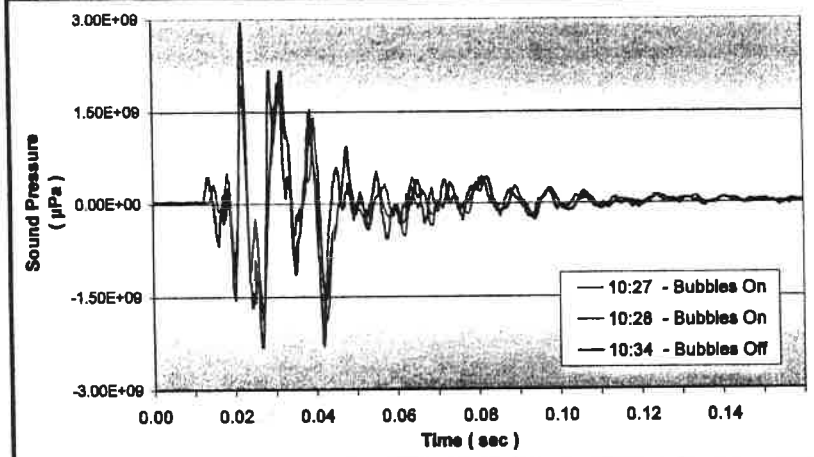


Figure b. Narrow Band Frequency Spectra

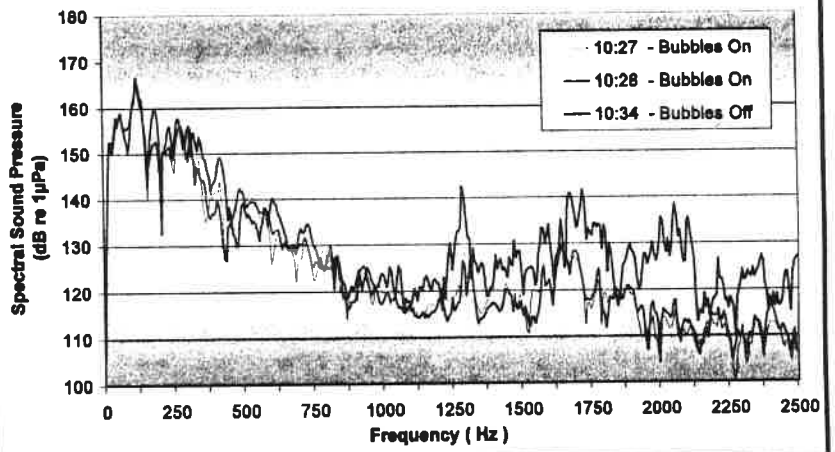


Figure c. Accumulation of Sound Energy

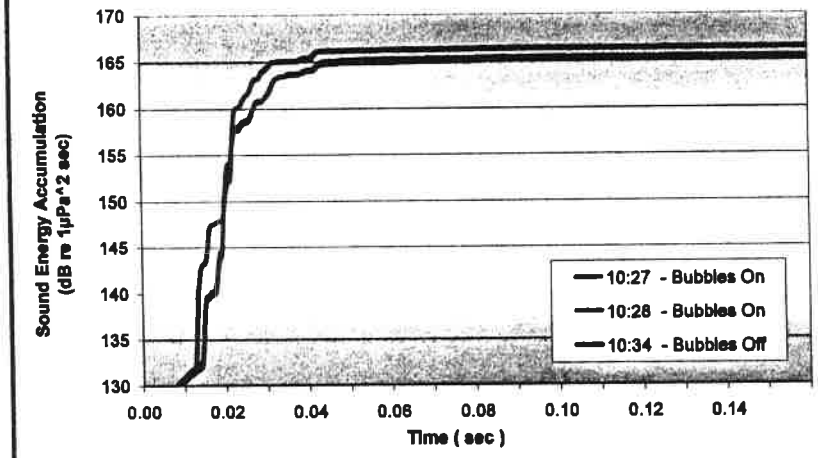


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

285D	Peak	RMS90%*	SEL
10:27 - Bubbles On	187	180	165
10:28 - Bubbles On	186	178	165
10:34 - Bubbles Off	189	181	166

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	187 / 190	177 / 179
Reported Maximum (Bubbles On / Off)	188 / 190	178 / 179

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #286D - 10 Meters - 12/03/04

Figure a. Waveform

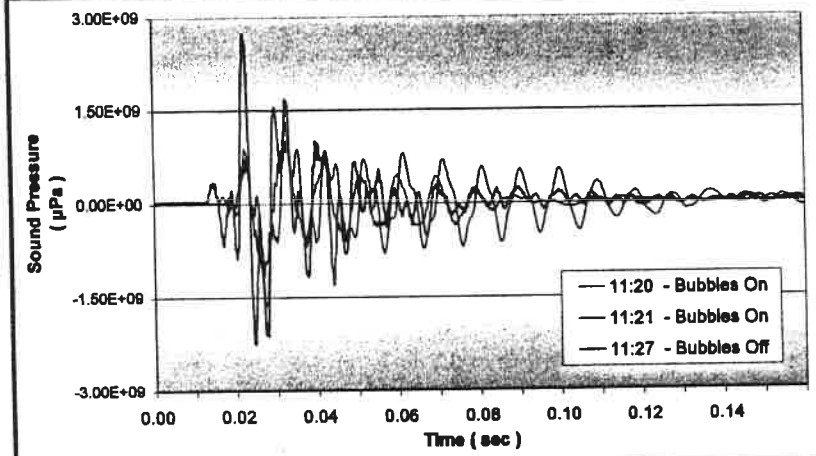


Figure b. Narrow Band Frequency Spectra

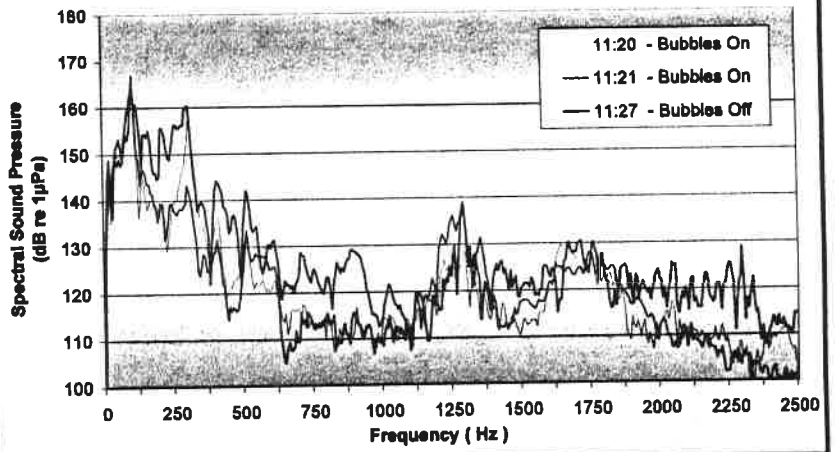


Figure c. Accumulation of Sound Energy

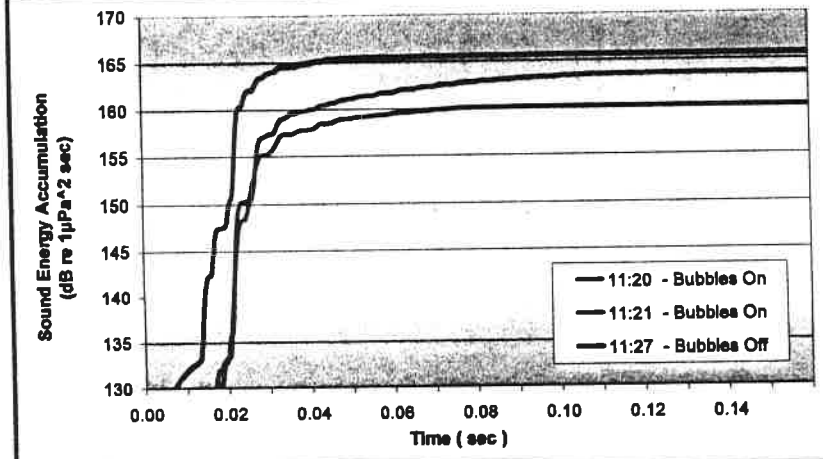


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

286D	Peak	RMS90%*	SEL
11:20 - Bubbles On	184	174	164
11:21 - Bubbles On	181	173	160
11:27 - Bubbles Off	189	181	166

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	188 / 191	178 / 179
Reported Maximum (Bubbles On / Off)	192 / 192	182 / 181

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #281B - 10 Meters - 12/03/04

Figure a. Waveform

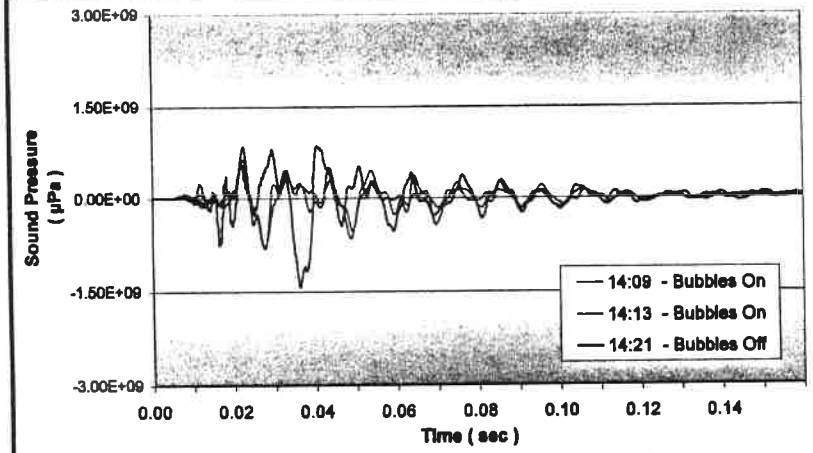


Figure b. Narrow Band Frequency Spectra

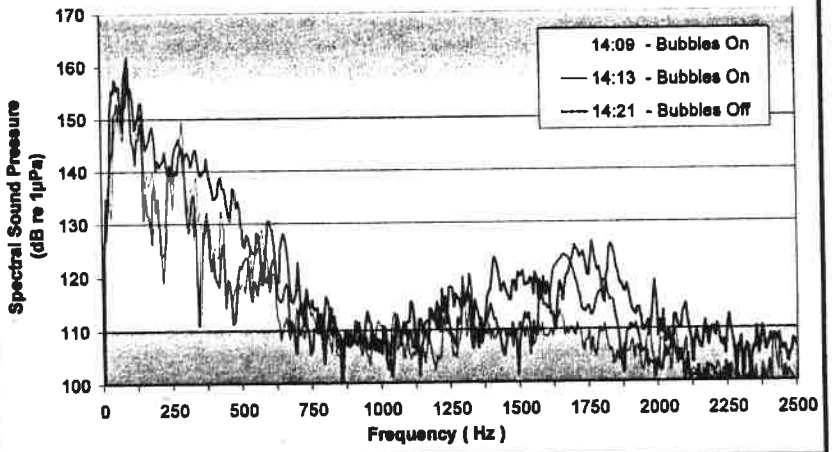


Figure c. Accumulation of Sound Energy

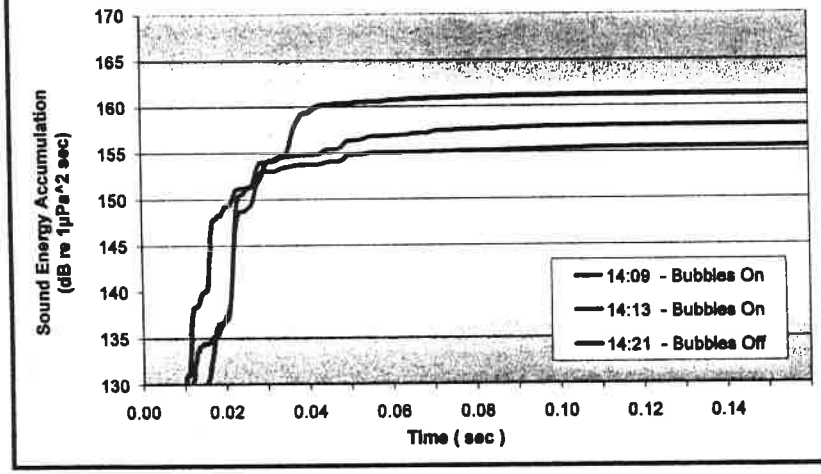


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

281B	Peak	RMS90%*	SEL
14:09 - Bubbles On	179	169	158
14:13 - Bubbles On	178	166	156
14:21 - Bubbles Off	183	173	161

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	180 / 184	167 / 172
Reported Maximum (Bubbles On / Off)	184 / 185	173 / 174

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #285B - 10 Meters - 12/07/04

Figure a. Waveform

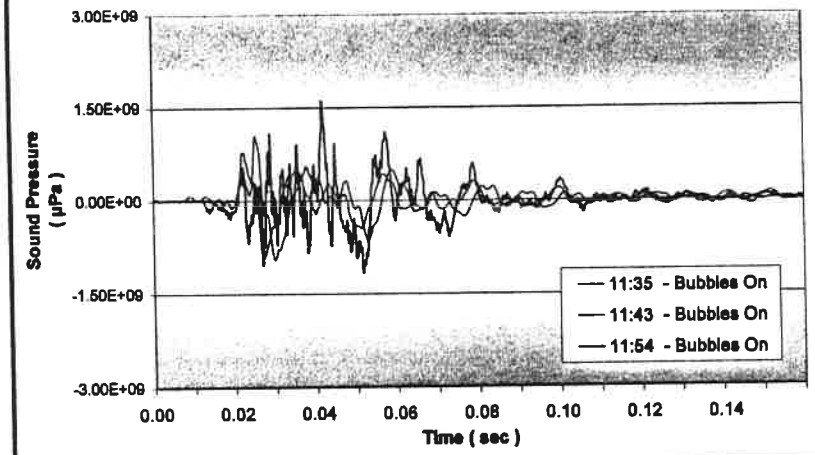


Figure b. Narrow Band Frequency Spectra

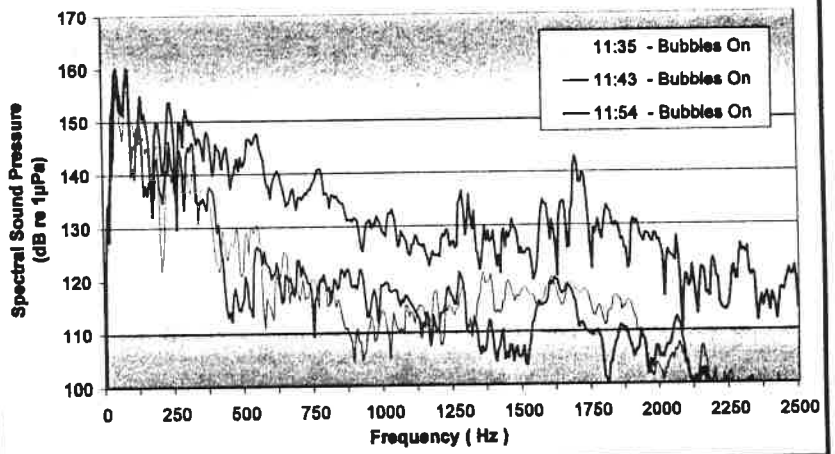


Figure c. Accumulation of Sound Energy

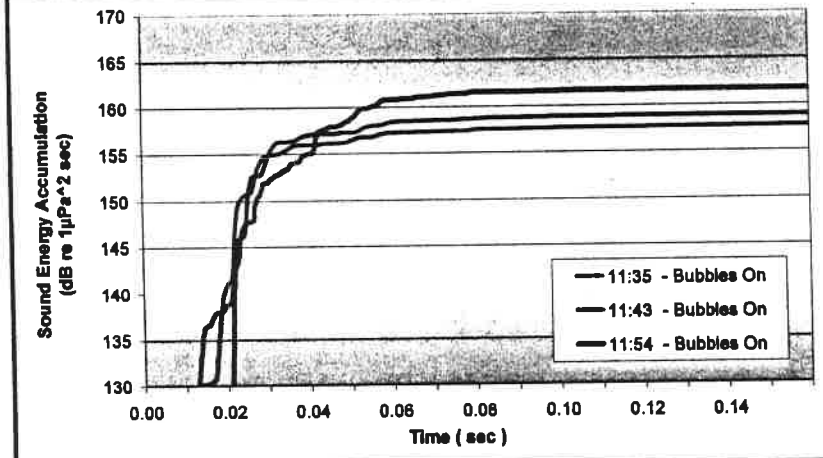


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

285B	Peak	$RMS_{90\%}$*	SEL
11:35 - Bubbles On	179	170	158
11:43 - Bubbles On	180	171	159
11:54 - Bubbles On	184	174	162

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	181 / 184	170 / 174
Reported Maximum (Bubbles On / Off)	184 / 187	171 / 175

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #281A - 10 Meters - 12/07/04

Figure a. Waveform

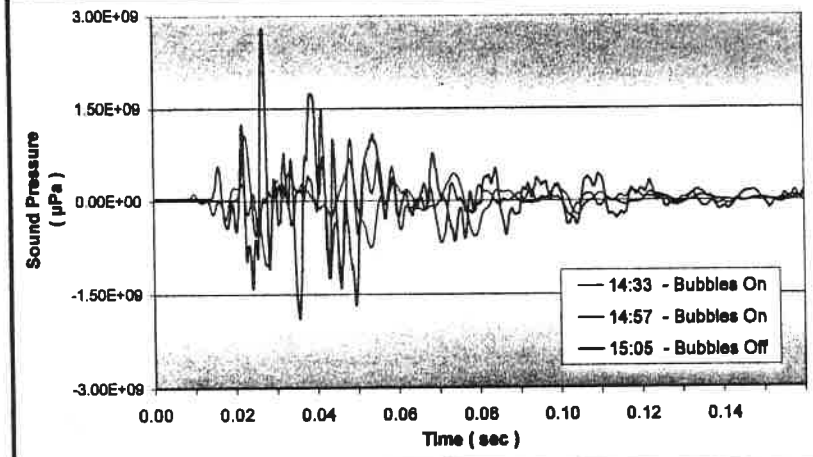


Figure b. Narrow Band Frequency Spectra

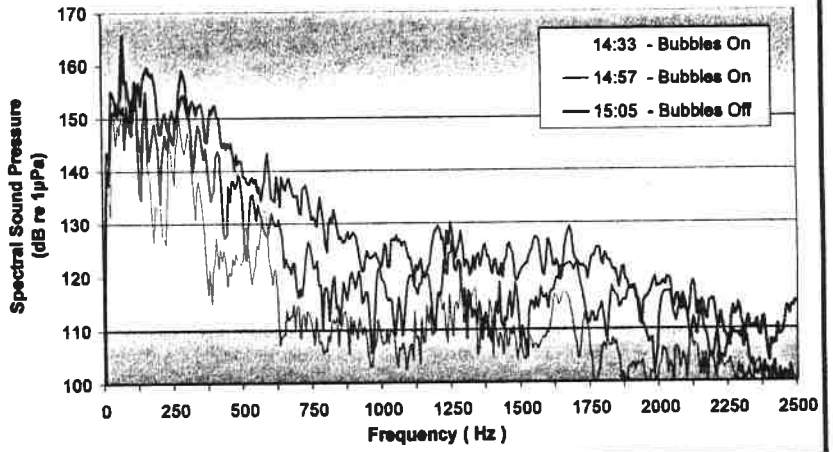


Figure c. Accumulation of Sound Energy

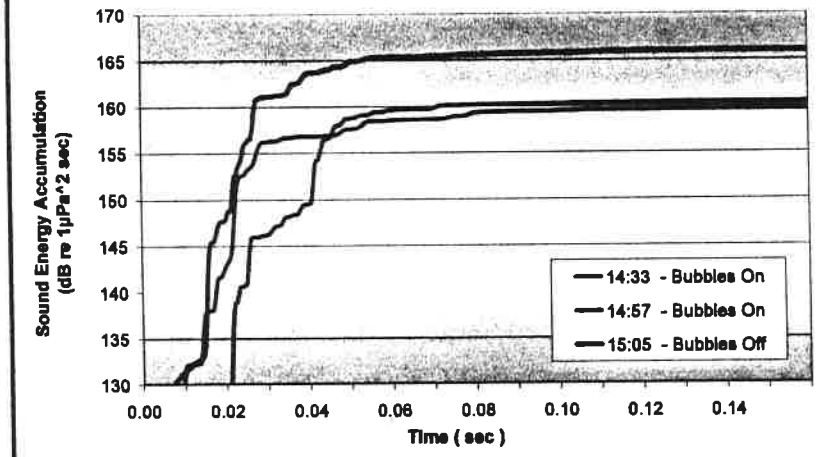


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

281A	Peak	$RMS_{90\%}$*	SEL
14:33 - Bubbles On	181	171	160
14:57 - Bubbles On	183	173	160
15:05 - Bubbles Off	189	177	166

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	180 / 187	169 / 177
Reported Maximum (Bubbles On / Off)	186 / 190	173 / 178

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #287C - 10 Meters - 12/20/04

Figure a. Waveform

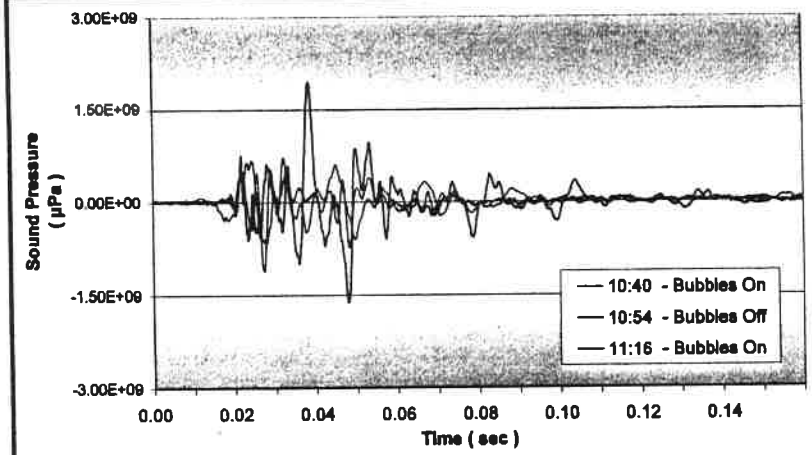


Figure b. Narrow Band Frequency Spectra

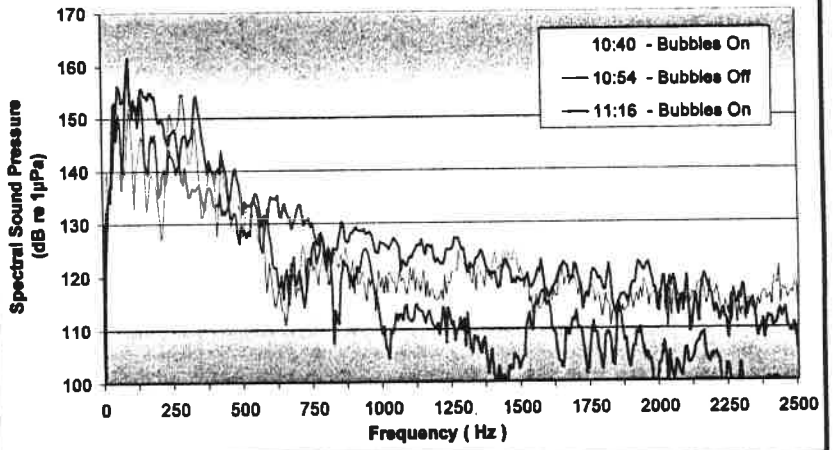


Figure c. Accumulation of Sound Energy

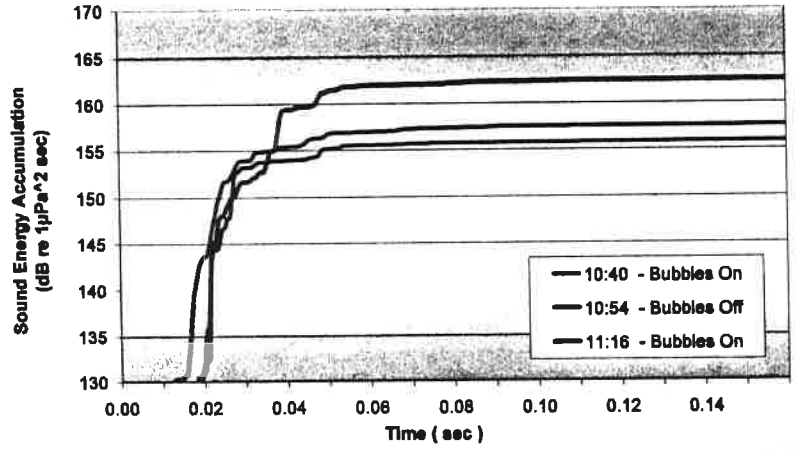


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

287C	Peak	$RMS_{90\%}$*	SEL
10:40 - Bubbles On	181	169	156
10:54 - Bubbles Off	177	170	158
11:16 - Bubbles On	186	174	162

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	181 / 183	169 / 171
Reported Maximum (Bubbles On / Off)	185 / 187	171 / 175

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #287B - 10 Meters - 12/20/04

Figure a. Waveform

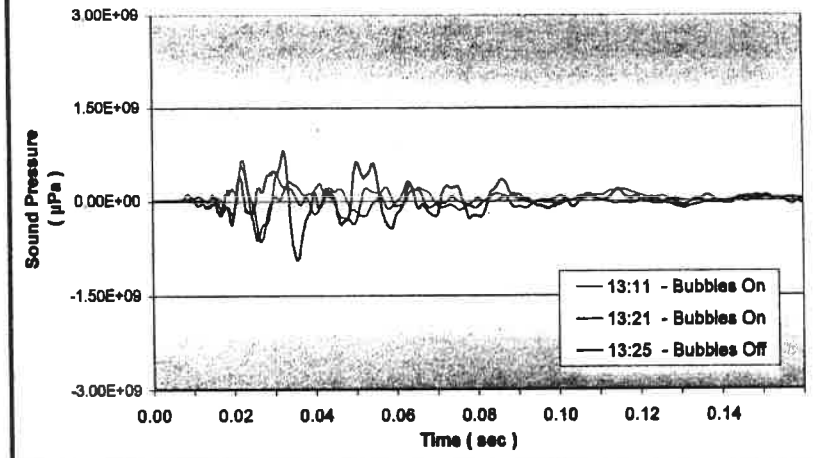


Figure b. Narrow Band Frequency Spectra

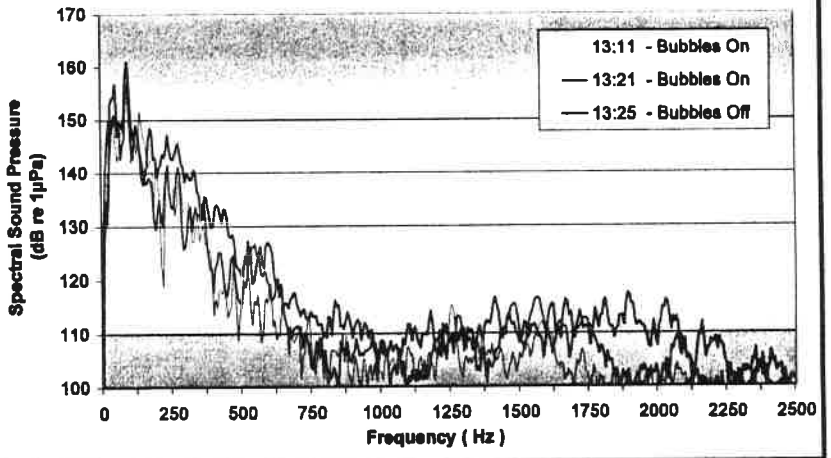


Figure c. Accumulation of Sound Energy

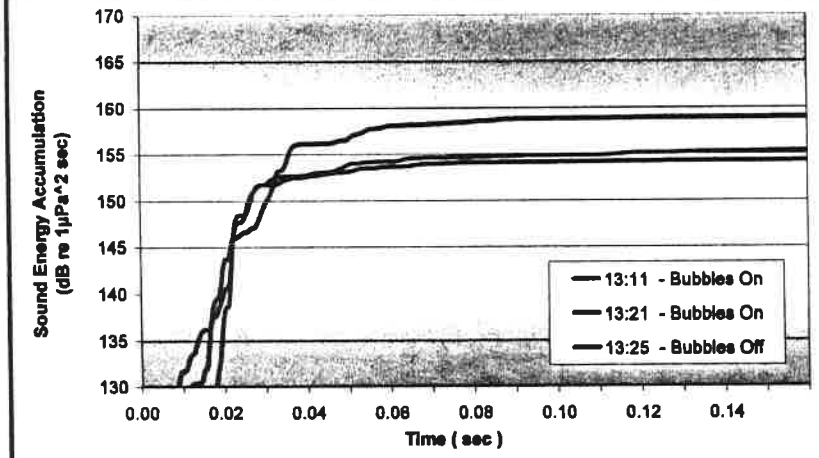


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

287B	Peak	$RMS_{90\%}$*	SEL
13:11 - Bubbles On	176	166	154
13:21 - Bubbles On	176	165	155
13:25 - Bubbles Off	179	170	159

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	177 / 183	167 / 171
Reported Maximum (Bubbles On / Off)	181 / 184	168 / 172

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #283E - 10 Meters - 12/21/04

Figure a. Waveform

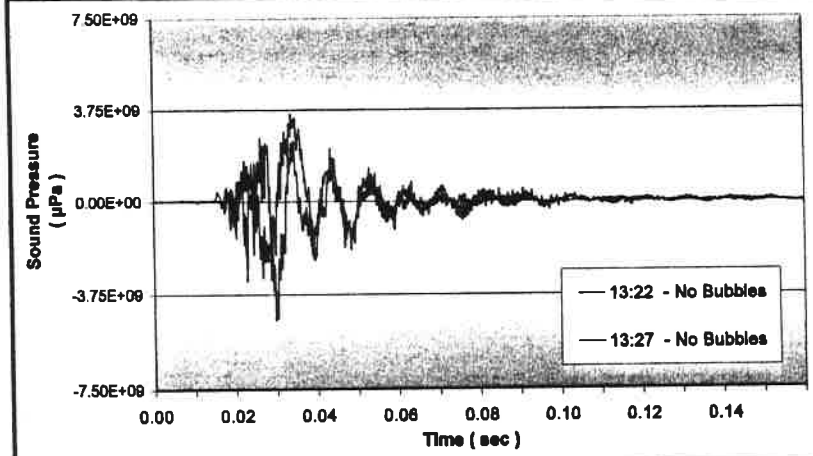


Figure b. Narrow Band Frequency Spectra

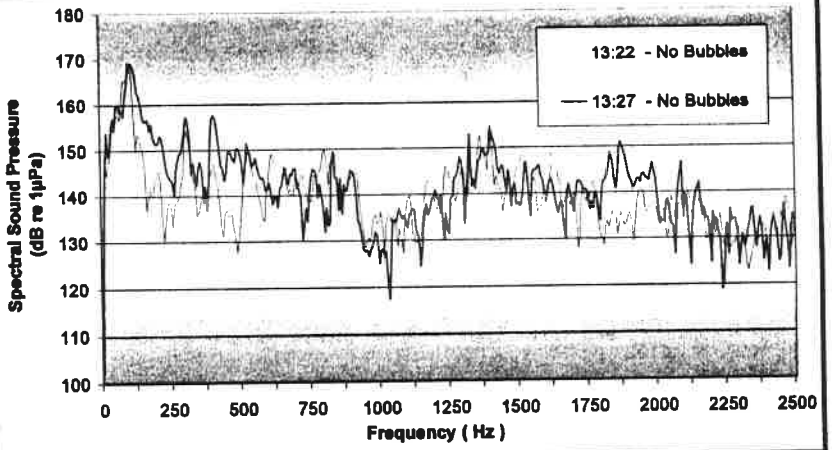


Figure c. Accumulation of Sound Energy

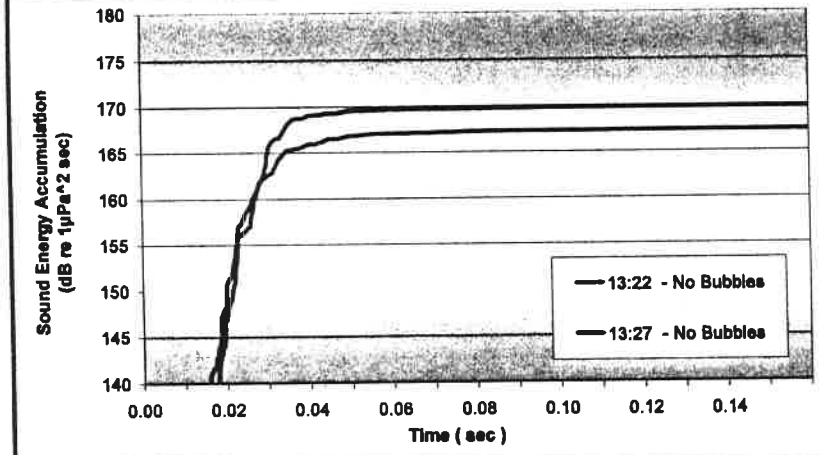


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

283E	Peak	RMS90%*	SEL
13:22 - No Bubbles	190	181	167
13:27 - No Bubbles	194	185	170

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (No Bubbles)	187	176
Reported Maximum (No Bubbles)	191	180

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #283E - 20 Meters - 12/21/04

Figure a. Waveform

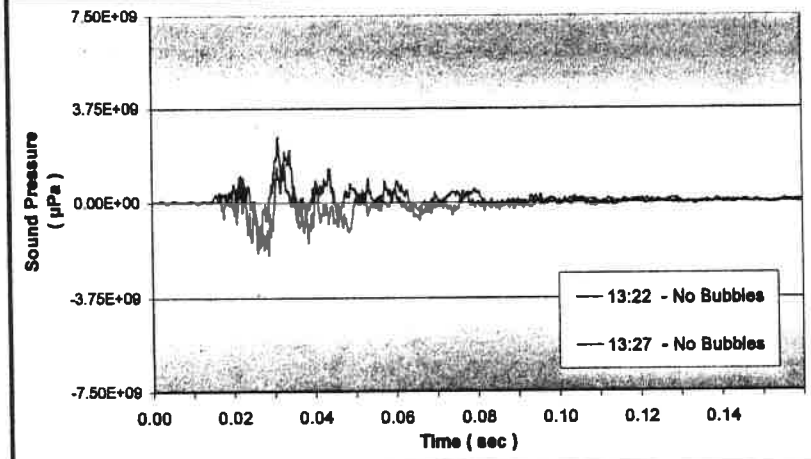


Figure b. Narrow Band Frequency Spectra

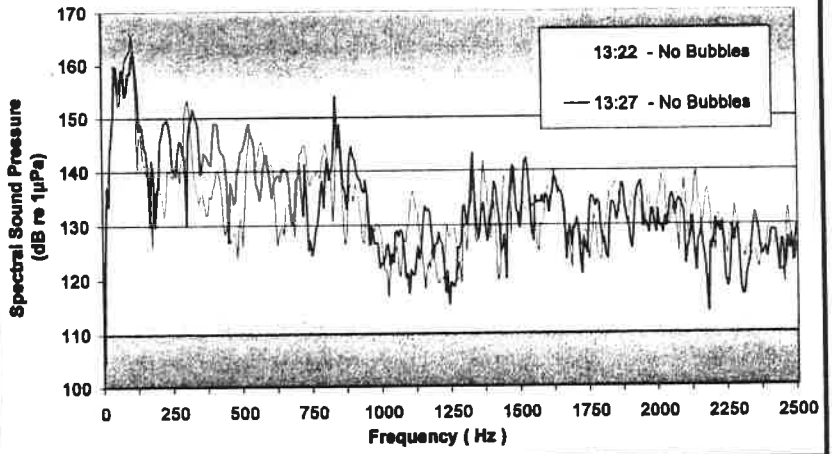


Figure c. Accumulation of Sound Energy

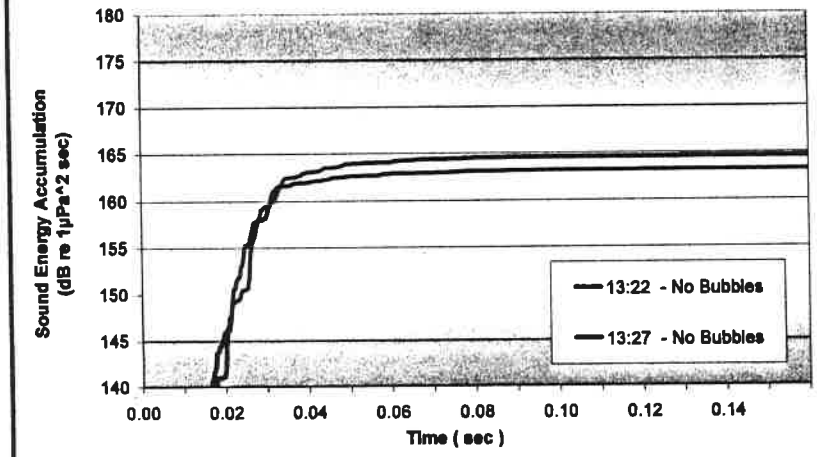


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

283E	Peak	$RMS_{90\%}$*	SEL
13:22 - No Bubbles	187	178	165
13:27 - No Bubbles	188	176	163

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (No Bubbles)	187	176
Reported Maximum (No Bubbles)	191	180

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #284E - 10 Meters - 12/21/04

Figure a. Waveform

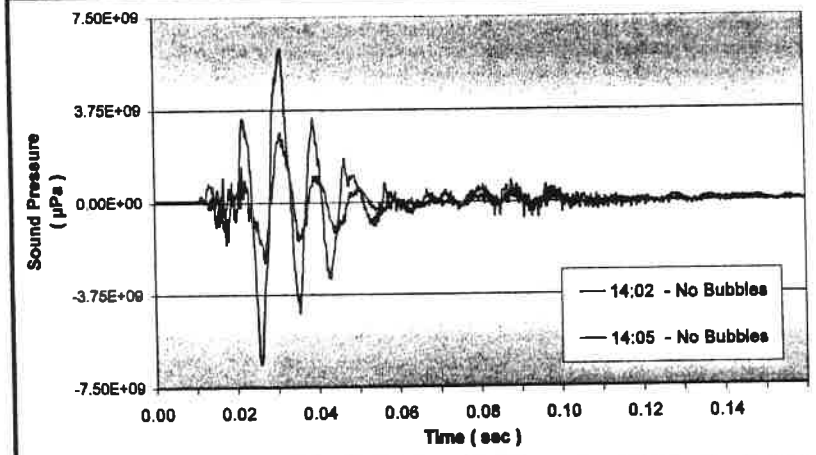


Figure b. Narrow Band Frequency Spectra

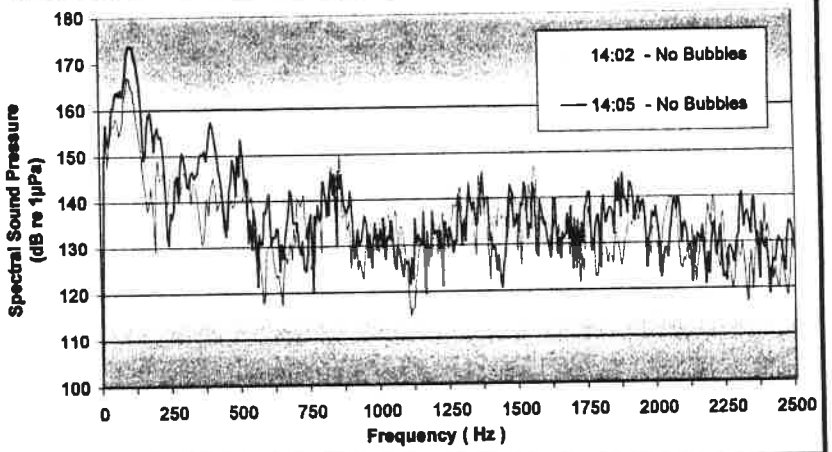


Figure c. Accumulation of Sound Energy

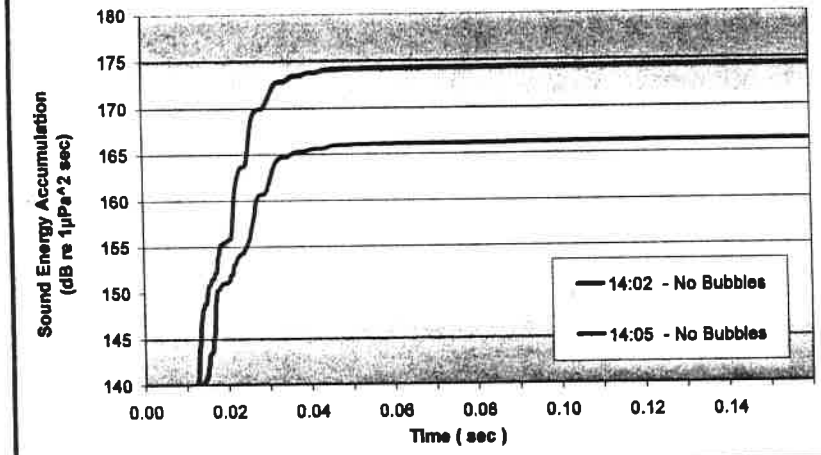


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

284E	Peak	$RMS_{90\%}$*	SEL
14:02 - No Bubbles	189	181	166
14:05 - No Bubbles	196	190	174

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{Impulse}$**
Reported Average (No Bubbles)	187	176
Reported Maximum (No Bubbles)	191	180

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #284E - 20 Meters - 12/21/04

Figure a. Waveform

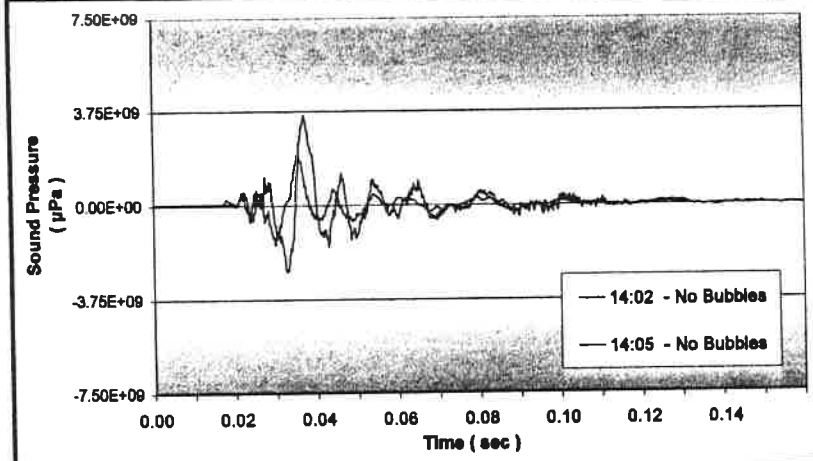


Figure b. Narrow Band Frequency Spectra

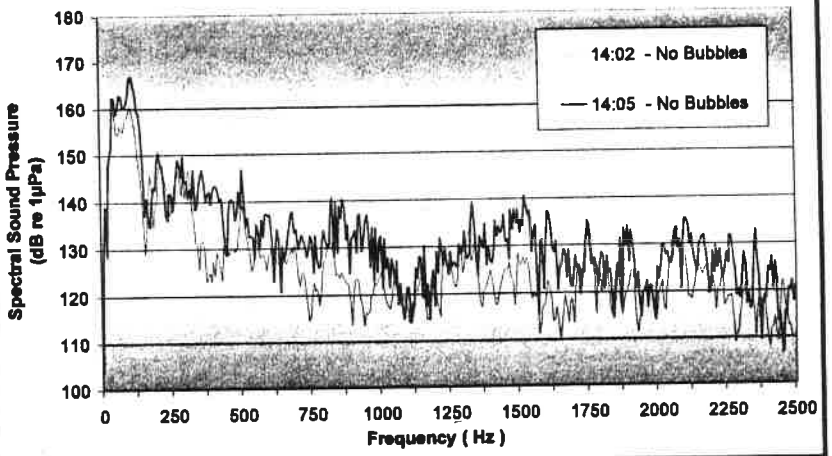


Figure c. Accumulation of Sound Energy

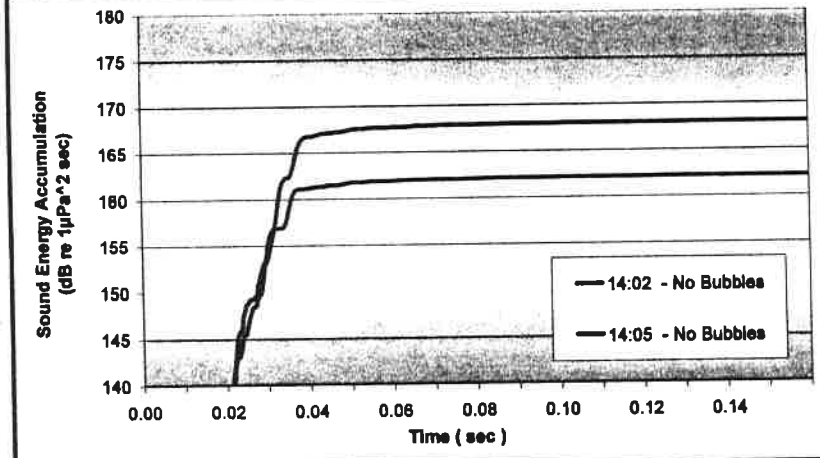


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

284E	Peak	RMS90%*	SEL
14:02 - No Bubbles	186	176	162
14:05 - No Bubbles	191	182	168

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$ **
Reported Average (No Bubbles)	187	176
Reported Maximum (No Bubbles)	191	180

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #317D - 10 Meters - 01/25/05

Figure a. Waveform

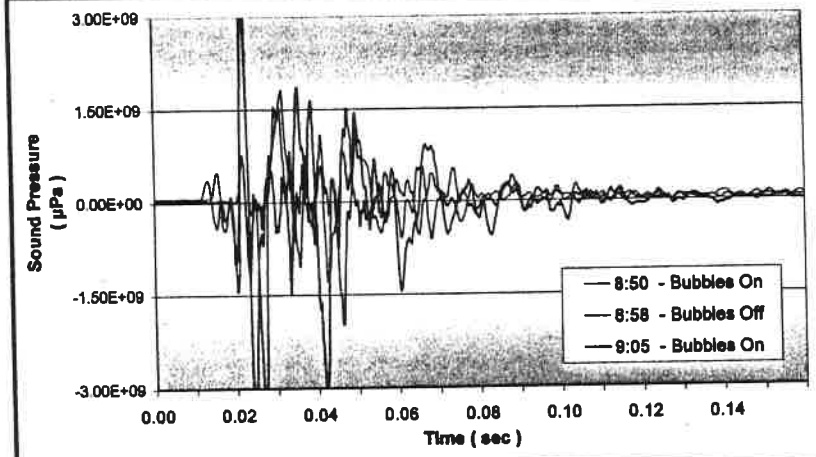


Figure b. Narrow Band Frequency Spectra

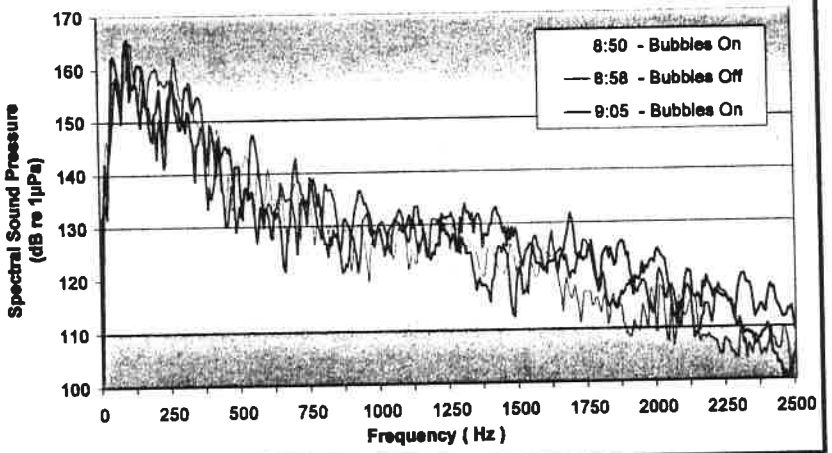


Figure c. Accumulation of Sound Energy

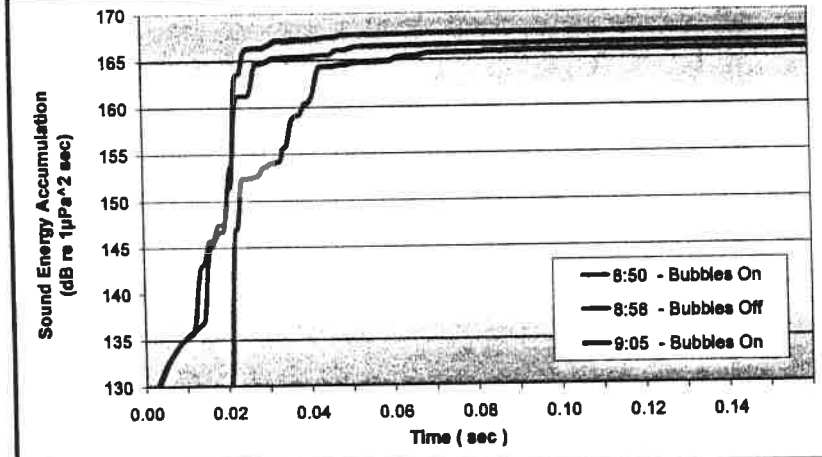


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

317D	Peak	$RMS_{90\%}$*	SEL
08:50 - Bubbles On	193	183	168
08:58 - Bubbles Off	191	181	167
09:05 - Bubbles On	190	179	166

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	192 / 192	178 / 179
Reported Maximum (Bubbles On / Off)	195 / 193	180 / 180

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #318D - 10 Meters - 01/25/05

Figure a. Waveform

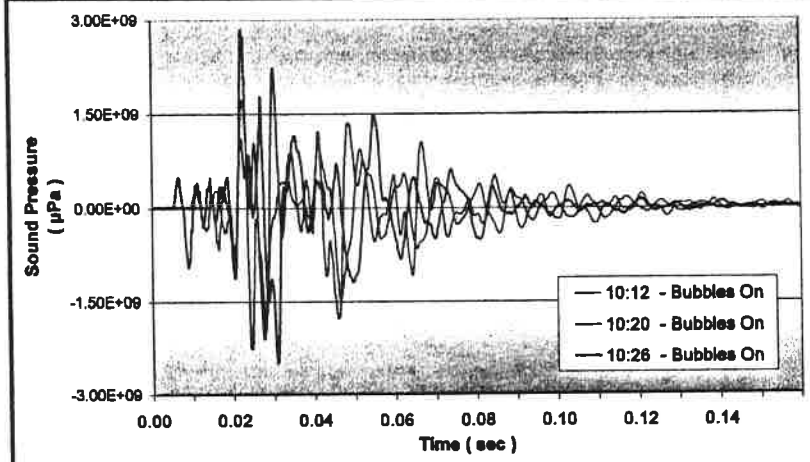


Figure b. Narrow Band Frequency Spectra

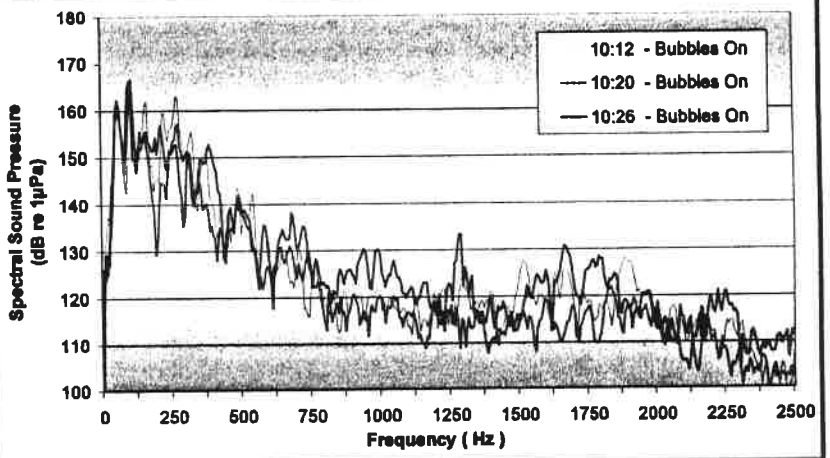


Figure c. Accumulation of Sound Energy

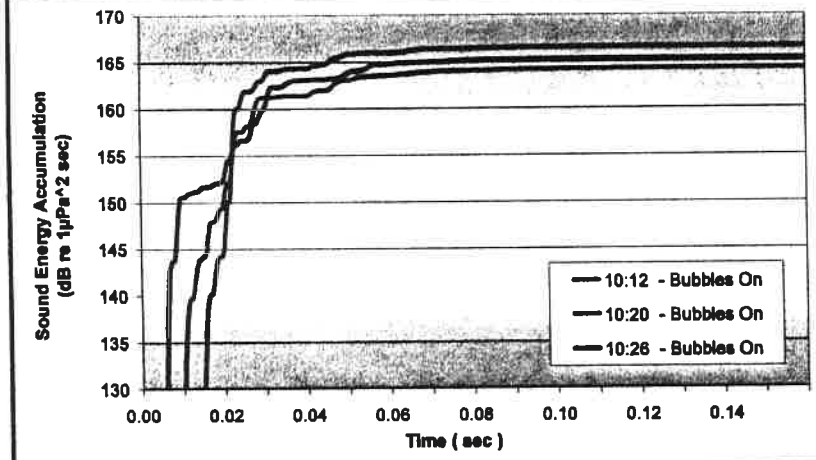


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

318D	Peak	$RMS_{90\%}$*	SEL
10:12 - Bubbles On	189	180	167
10:20 - Bubbles On	186	176	164
10:26 - Bubbles On	188	177	165

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	189 / N/A	176 / N/A
Reported Maximum (Bubbles On / Off)	193 / N/A	181 / N/A

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #319D - 10 Meters - 01/25/05

Figure a. Waveform

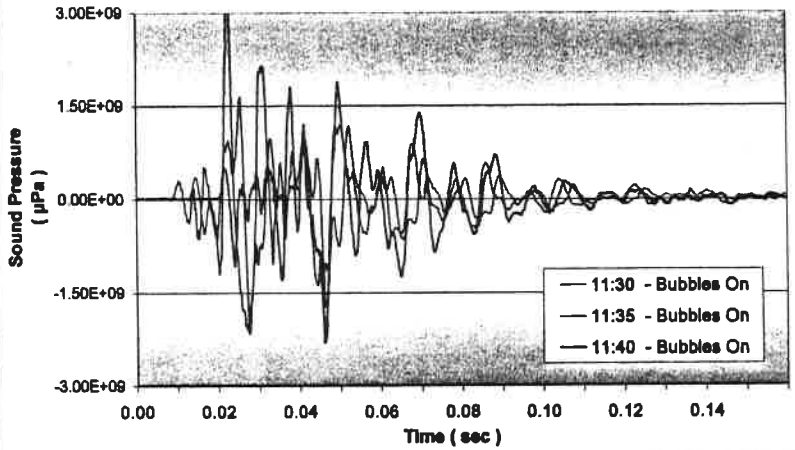


Figure b. Narrow Band Frequency Spectra

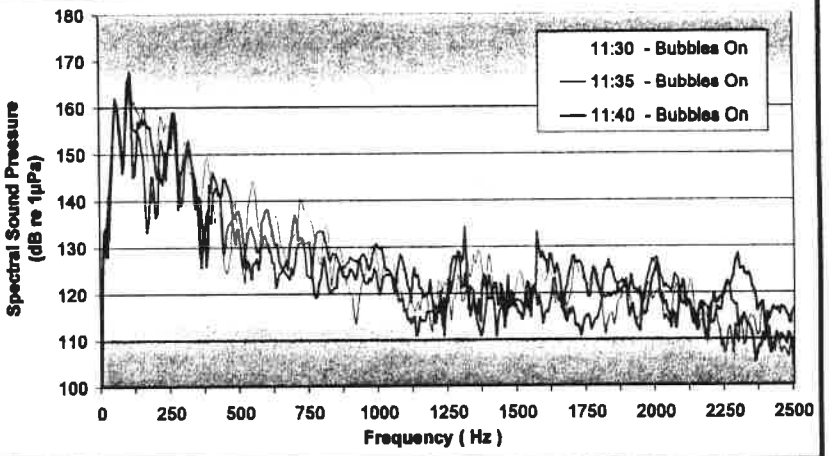


Figure c. Accumulation of Sound Energy

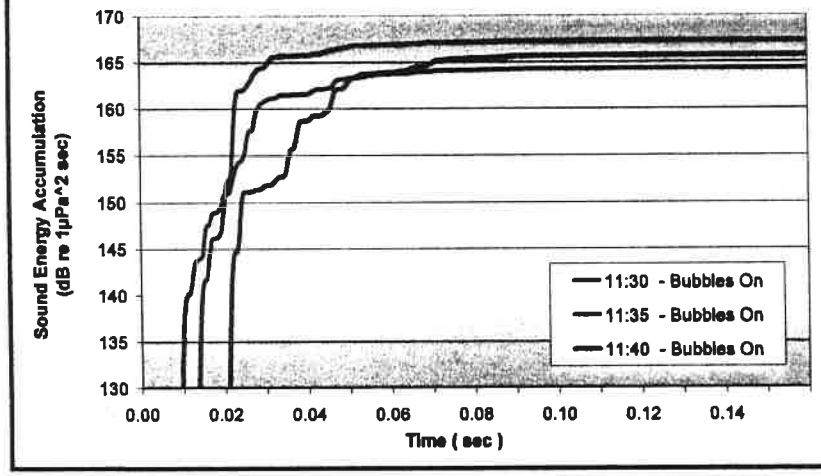


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

319D	Peak	$RMS_{90\%}$*	SEL
11:30 - Bubbles On	190	180	167
11:35 - Bubbles On	187	177	164
11:40 - Bubbles On	187	178	166

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	189 / N/A	177 / N/A
Reported Maximum (Bubbles On / Off)	194 / N/A	181 / N/A

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #320D - 10 Meters - 01/25/05

Figure a. Waveform

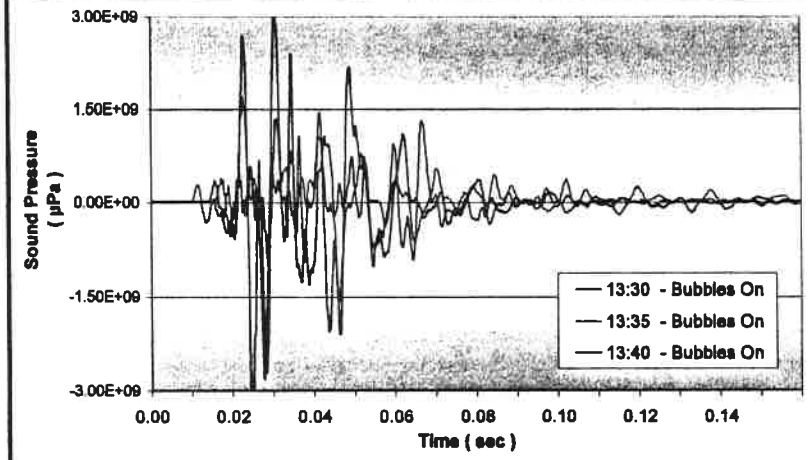


Figure b. Narrow Band Frequency Spectra

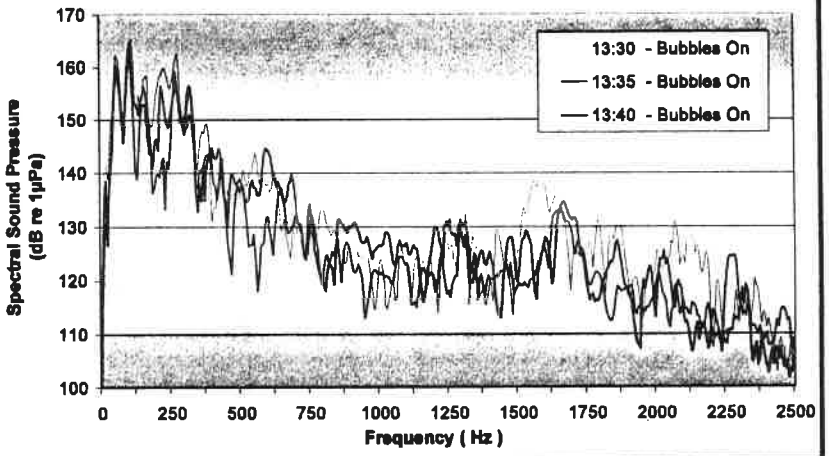


Figure c. Accumulation of Sound Energy

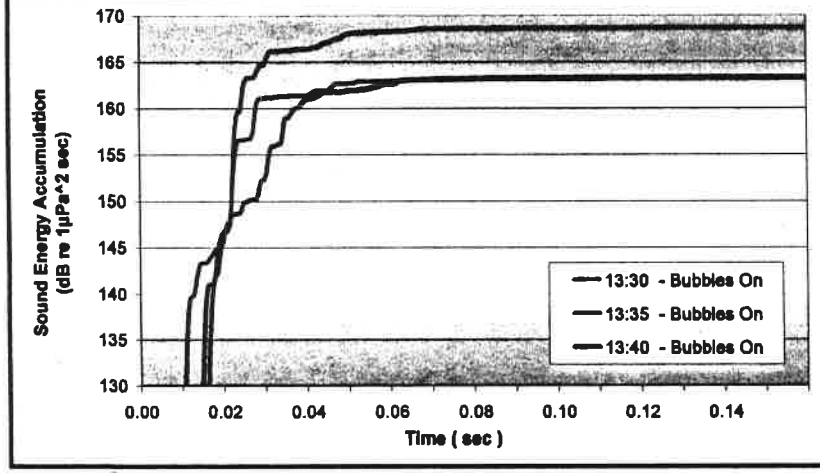


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

320D	Peak	$RMS_{90\%}$*	SEL
13:30 - Bubbles On	190	182	169
13:35 - Bubbles On	189	176	163
13:40 - Bubbles On	188	177	163

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	189 / N/A	176 / N/A
Reported Maximum (Bubbles On / Off)	191 / N/A	180 / N/A

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #316A - 10 Meters - 02/14/05

Figure a. Waveform

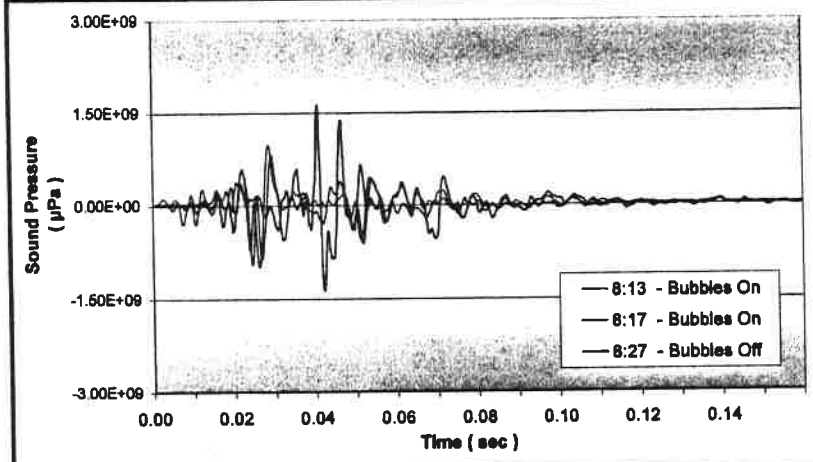


Figure b. Narrow Band Frequency Spectra

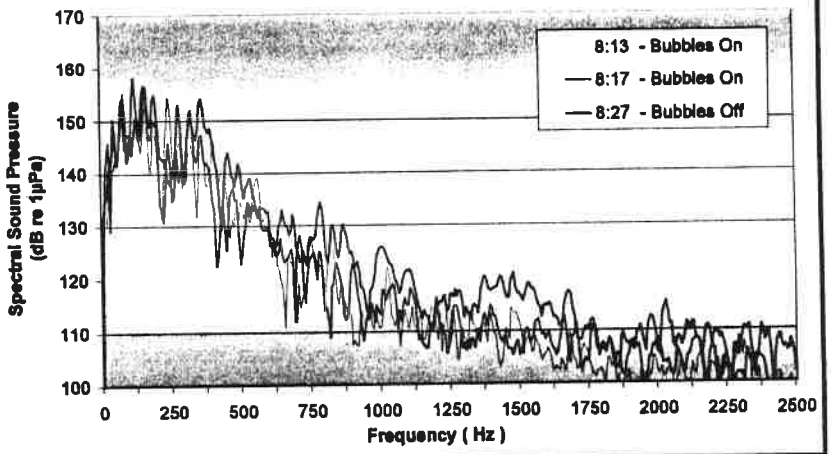


Figure c. Accumulation of Sound Energy

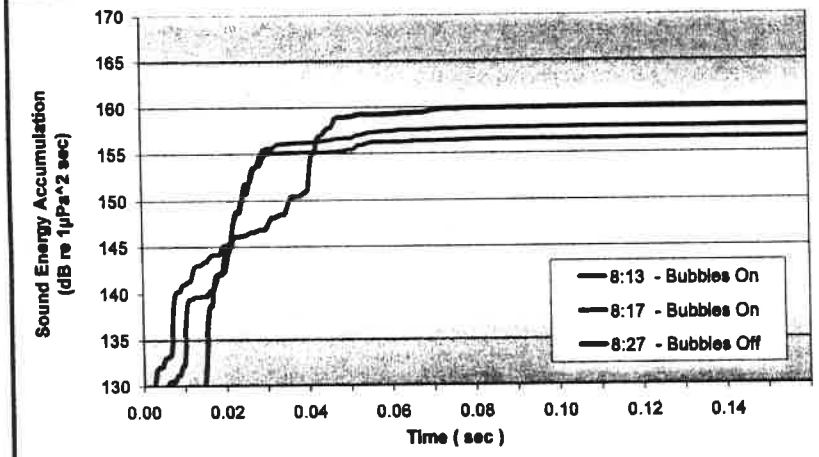


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

316A	Peak	$RMS_{90\%}$*	SEL
08:13 - Bubbles On	180	169	157
08:17 - Bubbles On	180	170	158
08:27 - Bubbles Off	184	173	160

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	182 / 185	170 / 174
Reported Maximum (Bubbles On / Off)	185 / 189	173 / 178

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

**Standard 35 msec "impulse" RMS time window

Berth 22 Pile Drive Signal Analysis - Pile #316.5A - 10 Meters - 02/14/05

Figure a. Waveform

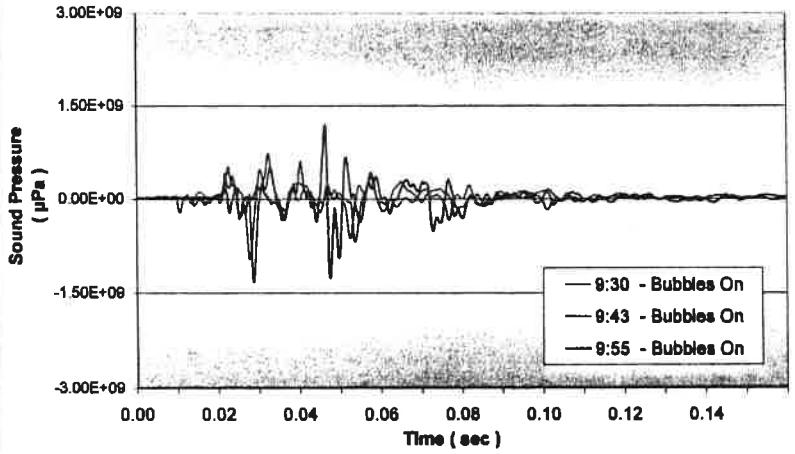


Figure b. Narrow Band Frequency Spectra

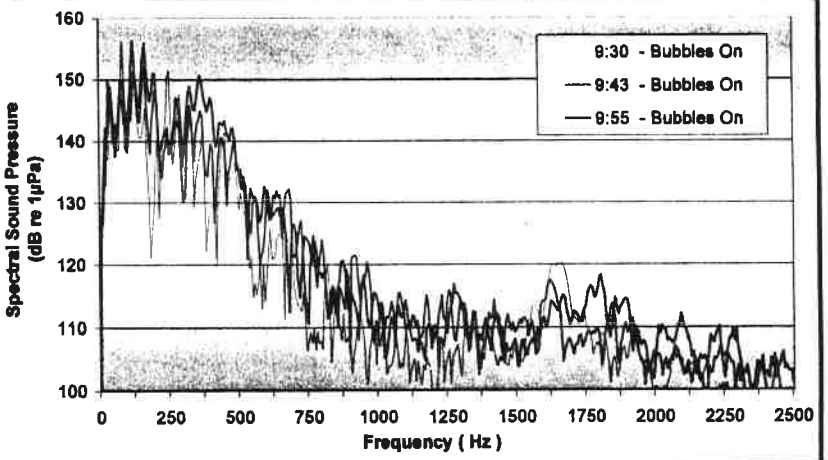


Figure c. Accumulation of Sound Energy

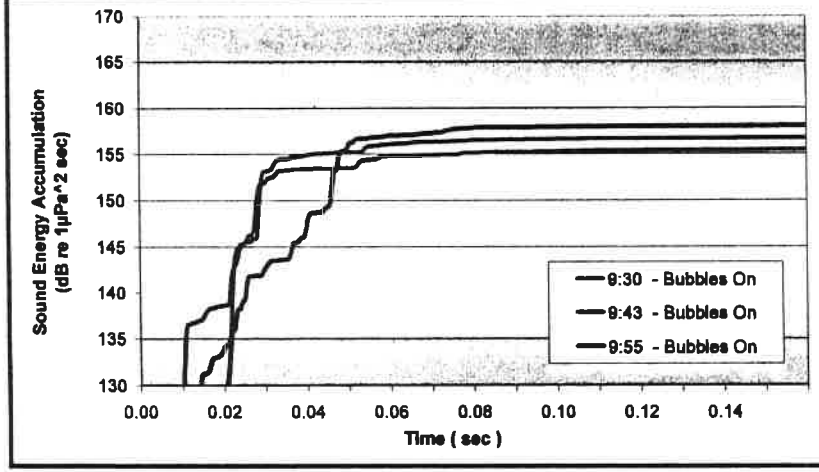


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

316.5A	Peak	RMS90%*	SEL
09:30 - Bubbles On	180	167	155
09:43 - Bubbles On	183	169	157
09:55 - Bubbles On	182	171	158

Typical Sound Pressure Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average (Bubbles On / Off)	181 / N/A	167 / N/A
Reported Maximum (Bubbles On / Off)	184 / N/A	171 / N/A

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

**Standard 35 msec "impulse" RMS time window