SR 520 WEST APPROACH BRIDGE NORTH

Underwater Sound Level Report: SR 520 West Approach Bridge North (WABN)

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ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
L_{50}	a statistical measure of the median value over the measurement period where 50 percent of the measured values are above the and 50 percent are below.
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
s.d.	standard deviation
SEL	Sound Exposure Level
SL	sound level, regardless of descriptor
SPL	sound pressure level
USFWS	U.S. Fish and Wildlife Service
WSF	Washington State Ferries
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the data collected during impact pile driving and monitoring of underwater sound levels for 40, 30-inch hollow steel piles for the Washington State Department of Transportation (WSDOT) West Approach Bridge North (WABN) Project between March 2016 and April 2016. 20 of the piles monitored were located on the west side of Foster Island and 20 of the piles were located on the east side of Foster Island in Union Bay near Lake Washington. A confined bubble curtain was deployed for all impact driven piles to attenuate potential underwater noise effects. All measurements were collected at 10 to 22 meters from the pile at midwater depth. Measurements from 3H, where H is the water depth at the pile were not needed because 3H locations happened to be about the same distance as the 10 to 22 meter locations.

Six of the monitored piles East of Foster Island exceeded the dB_{peak} threshold of 188 dB_{peak}. The peak attenuated sound levels measured ranged between 163 dB_{peak} and 197 dB_{peak}. An exceedance occurred for Pile 3 which likely resulted from the bubble curtain inadvertently being turned off prior to pile driving. This produced an un-attenuated peak sound level of 191 dB_{peak}. Piles 13, 16, 18, 19 and 20 also exceeded the threshold of 188 dB_{peak} and it was assumed that the pile was driven through a subsurface layer or obstruction that temporarily elevated the noise levels. Results of monitoring the impact pile driving operation are shown in Table 1.

Table 1: Summary of 30-inch Hollow Steel Piles Attenuated Underwater Sound Levels East of Foster Island.

East of Foster Island								
Pile #	Date	Pile Size (inches)	dB_{peak} Threshold (dB)	Peak at 10 meters (dB)	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)	Exceedance?
1	3/7/16	24	188	168	156	148	164	No
2	3/7/16	24	188	167	154	145	163	No
3	3/7/16	24	188	191	178	163	191	Yes
4	3/7/16	24	188	163	150	142	161	No
5	3/7/16	24	188	166	152	143	163	No
6	3/8/16	24	188	174	161	153	168	No
7	3/8/16	24	188	167	152	143	159	No
8	3/8/16	24	188	164	148	139	158	No
9	3/8/16	24	188	163	154	145	162	No
10	3/8/16	24	188	163	159	151	161	No
11	4/7/16	24	188	186	172	163	179	No
12	4/7/16	24	188	186	179	166	187	No
13	4/7/16	24	188	197	182	171	188	Yes

East of Foster Island								
Pile #	Date	Pile Size (inches)	dB_{peak} Threshold (dB)	Peak at 10 meters (dB)	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)	Exceedance?
14	4/8/16	24	188	183	176	166	181	No
15	4/8/16	24	188	184	174	165	182	No
16	4/13/16	24	188	190	176	166	184	Yes
17	4/13/16	24	188	185	170	160	186	No
18	4/13/16	24	188	195	183	170	192	Yes
19	4/13/16	24	188	191	176	166	188	Yes
20	4/13/16	24	188	191	178	168	194	Yes

One of the twenty monitored piles West of Foster Island exceeded the dB_{peak} threshold of 188 dB_{peak}. This exceedance occurred when the bubble curtained malfunctioned during pile driving for one pile (Pile 10, West of Foster) which produced an un-attenuated sound level measured at 209 dB_{peak}, this was the only pile West of Foster which exceeded the dB_{peak} threshold. The peak attenuated sound levels measured ranged between 163 dB_{peak} and 183 dB_{peak}. On 4/29/2016, there were three piles left to monitor, however, the contractors only had two piles remaining to drive. Instead of reporting results for 19 piles, the contractors ultimately needed to re-drive Pile 19 to ensure strength proofing. In consultation with the Services, the re-drive of Pile 19 was monitored and used as the data for Pile 20 in order to ensure environmental compliance. Results of monitoring the impact pile driving operation are shown in Table 2.

Table 2: Summary of 30-inch Hollow Steel Piles Attenuated Underwater Sound Levels West of Foster Island.

West of Foster Island								
Pile #	Date	Pile Size (inches)	dB_{peak} Threshold (dB)	Peak at 10 meters (dB)	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)	Exceedance?
1	3/2/16	24	188	166	158	147	163	No
2	3/3/16	24	188	171	165	153	169	No
3	3/3/16	24	188	172	165	155	171	No
4	3/3/16	24	188	175	167	156	170	No
5	3/8/16	24	188	181	174	163	180	No
6	3/8/16	24	188	178	170	160	178	No
7	3/9/16	24	188	183	176	165	183	No
8	3/9/16	24	188	178	172	160	178	No
9	3/11/16	24	188	176	172	159	177	No
10*	3/11/16	24	188	209	191	179	197	Yes
11	4/7/16	24	188	169	164	154	169	No
12	4/7/16	24	188	163	155	156	164	No

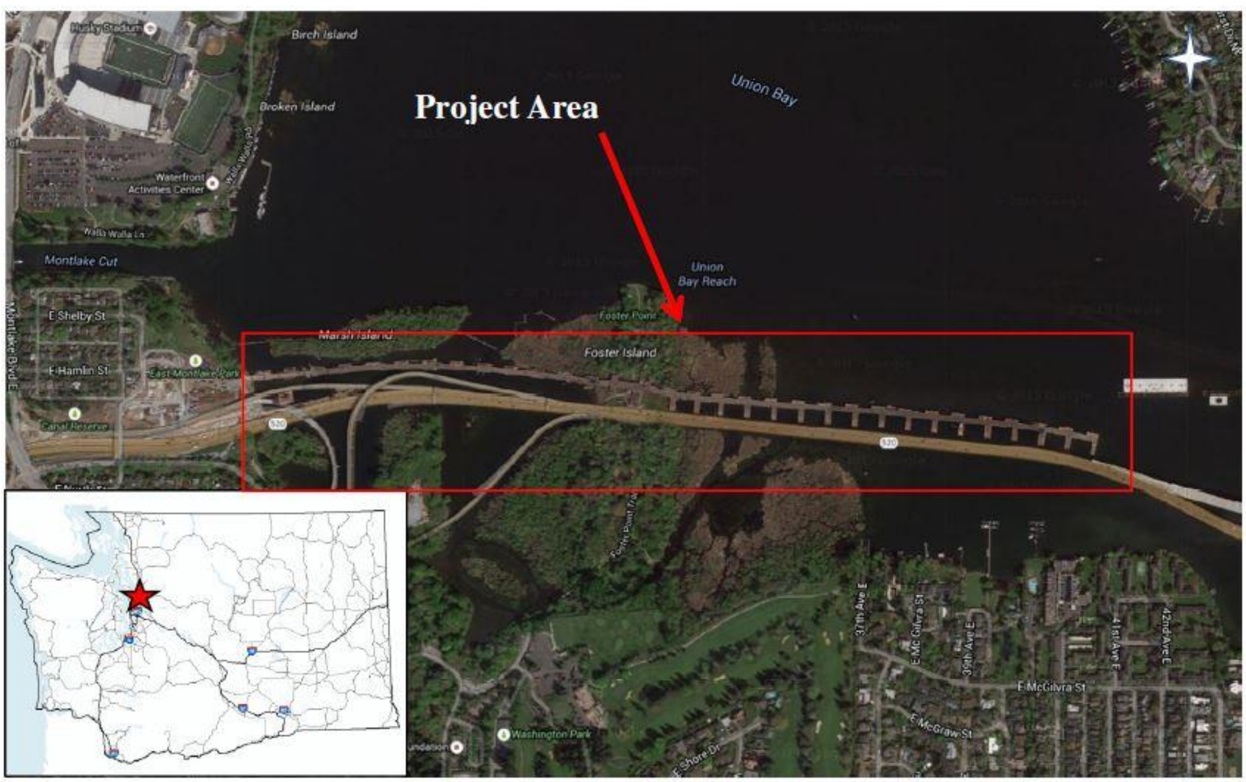
West of Foster Island								
Pile #	Date	Pile Size (inches)	dB_{peak} Threshold (dB)	Peak at 10 meters (dB)	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)	Exceedance?
13	4/11/16	24	188	181	162	153	172	No
14	4/11/16	24	188	182	166	158	171	No
15	4/11/16	24	188	173	158	150	159	No
16	4/28/16	24	188	171	159	151	157	No
17	4/28/16	24	188	168	151	143	170	No
18	4/29/16	24	188	171	159	150	158	No
19	4/29/16	24	188	181	163	154	169	No
20	4/29/16	24	188	181	167	157	169	No

*Bubble curtain malfunction resulted in un-attenuated sound

INTRODUCTION

The Washington State Department of Transportation (WSDOT) constructed temporary work trestles adjacent to the SR 520 Bridge (Figure 1). The trestles are necessary to provide a platform from which the construction workers can build the new bridge to the north of the existing SR 520 Bridge without interfering with traffic on the existing SR 520. This platform is also for drilled shafts that will be constructed adjacent to existing SR 520 bridge columns. The drilled shafts will be constructed deeper than the existing bridge columns, which will expose the existing bridge to risk of settlement if undermining occurs. Oscillators provide a means of torsionally installing deep casings for stability in certain soil conditions or where debris is anticipated that could hamper installation by conventional means (i.e., vibratory pile driving). Oscillators will likely be needed to install these casings near the existing bridge in order to mitigate the risk of damage to the existing in-service bridge. Because oscillators produce more torque and reaction forces than can safely be resisted by a barge or other floating work platform, a highly stable work platform would be required. Additionally, shaft casing templates may require sufficient stability to offset torsional reaction forces.

Figure 1: SR 520 West Approach Bridge North Project work trestle



PROJECT AREA

The project is located on the west end of SR 520 between Montlake Boulevard to the east and extends to the west side of Foster Island and Union Bay. Figure 1 indicates the location of the proposed work trestle. The work trestle project will impact up to 100, 30-inch steel piles to bearing capacity to support the work trestle.

Although there is an estimated total of 778 piles needed for the work trestle, not all of the piles will require proofing with an impact hammer. All piles were driven with a vibratory hammer initially, but some piles would need to be proofed to ensure that sufficient bearing capacity has been reached. Each work trestle is oriented so that the shaft or shafts can be reached by the drilling equipment and also in such a way that barges and skiffs carrying workers, equipment, and supplies can also access the platform.

For the West Approach Bridge North project, underwater and airborne noise monitoring was performed in Union Bay west of Foster island and east of Foster Island.

PILE INSTALLATION LOCATION

A minimum of ten steel piles installed during the initial pile driving activity west of Foster Island, five steel piling installed at the mid-point of the piling installation, and five steel piling installed at the end point and near completion of the piling installation were monitored, for a total of 20 piles, west of Foster Island. For east of Foster Island, ten steel piles installed initially, five at the mid-point of the piling installation and five at the end point or completion of pile installation, for a total of 20 piles, east of Foster Island.

The hydrophone is located at 10 meters from the piles where possible. In some cases, it was not safe or practical to locate the hydrophone within 10 meters of the pile. Therefore the hydrophone range varies from 10 to 22 meters from the pile throughout the monitoring area. Monitoring at a range of 3H, where H is the water depth of the pile, was not necessary because the distance 3H was 10 meters or less.

Hydroacoustic monitoring of steel pile driving included:

- Measurement of noise levels at 10 to 22 meters from the pile.

Table 3 lists the structure installed, the water depth, and the number and size of piles that were installed.

Table 3. Structures to be installed for the terminal retrofit and replacement

Structure	Water Depth	Structural Components Installed
Temporary Work Trestle	*5 feet to 10 feet*	*778, 30-inch hollow steel piles*

Figures 2 through 6 indicate the location of the piles monitored east and west of Foster Island. The hydrophones were placed at least 1 m (3.3 feet) below the surface at a range of 10 to 22 meters and midwater depth. Each pile has a clear acoustic line-of-sight between the pile and the hydrophone.

Figure 2: ***The locations of the first ten monitored piles west of Foster Island***

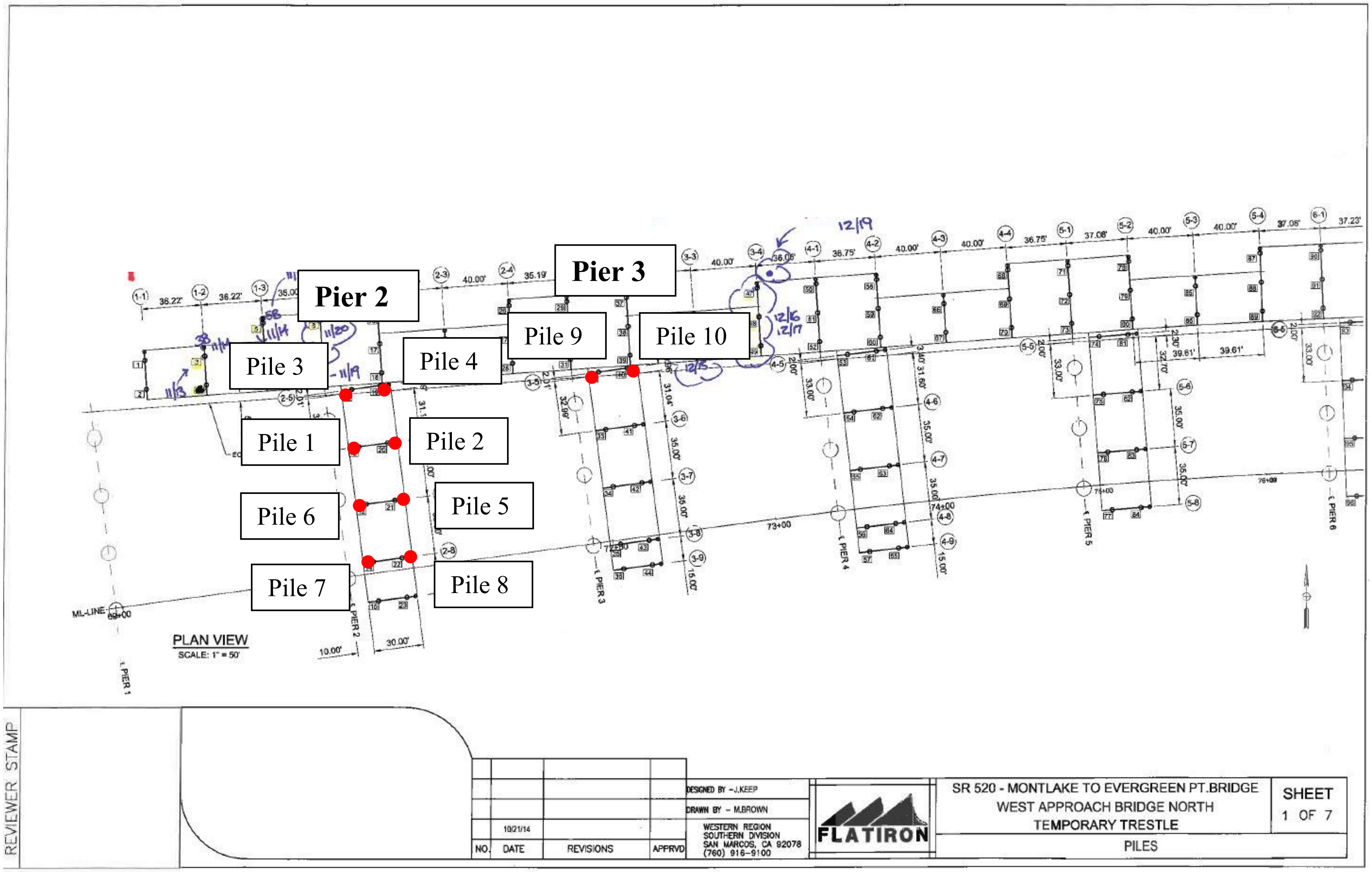


Figure 3: The locations of the middle five and last five monitored piles west of Foster Island

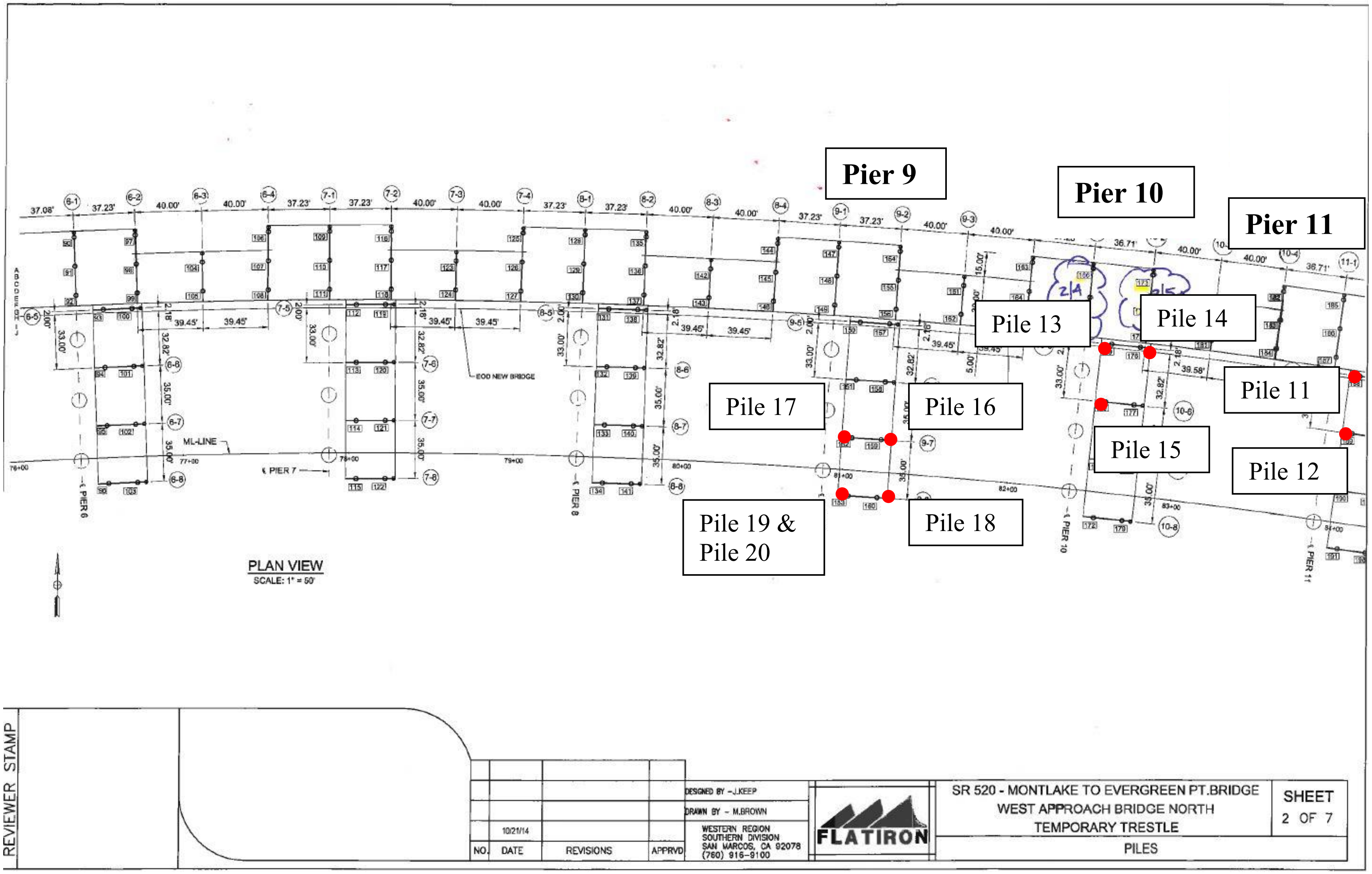


Figure 4: The locations of the first ten monitored piles, east of Foster Island, part 1

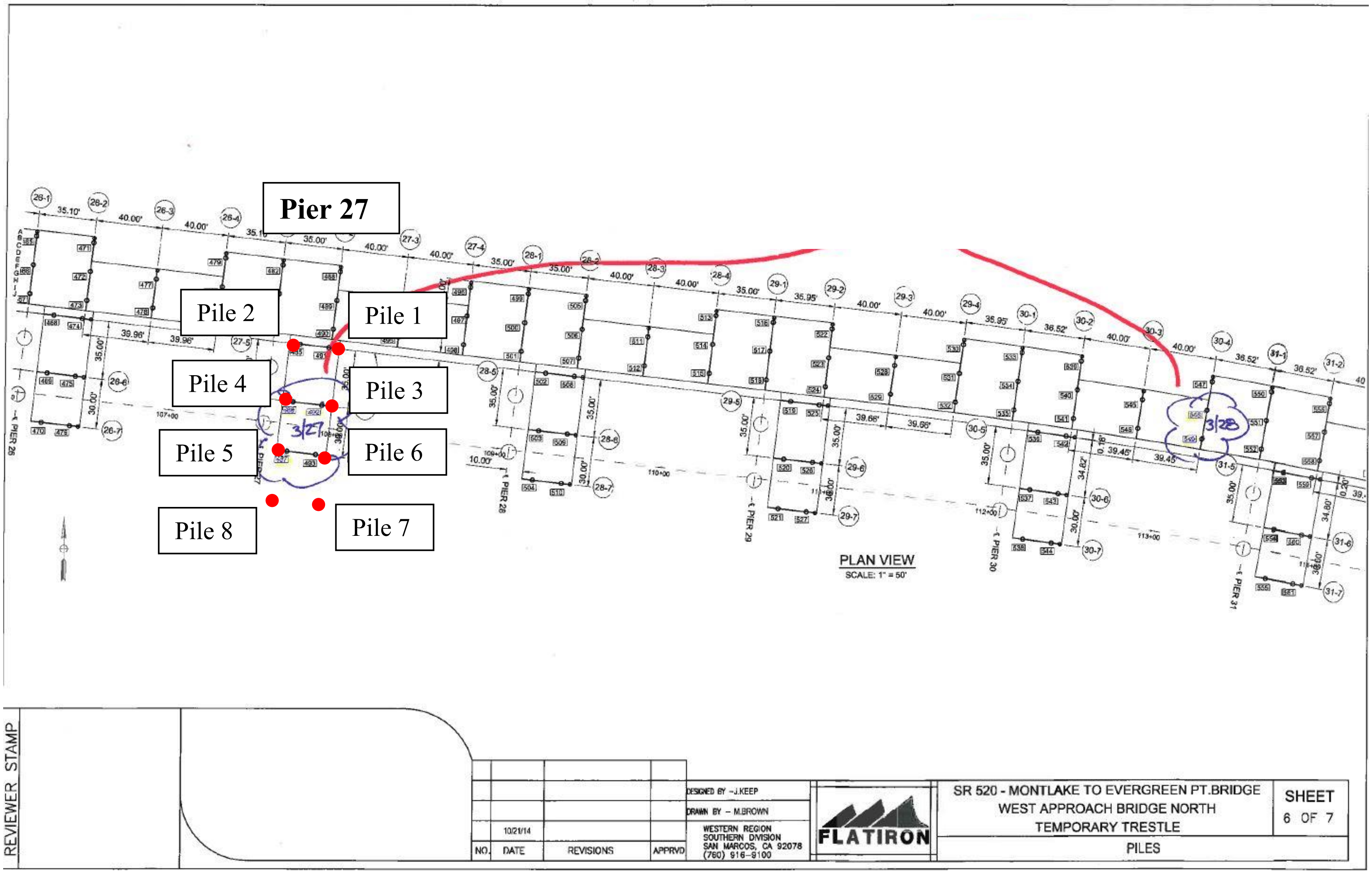


Figure 5: The locations of the first ten monitored piles east of Foster Island, part 2

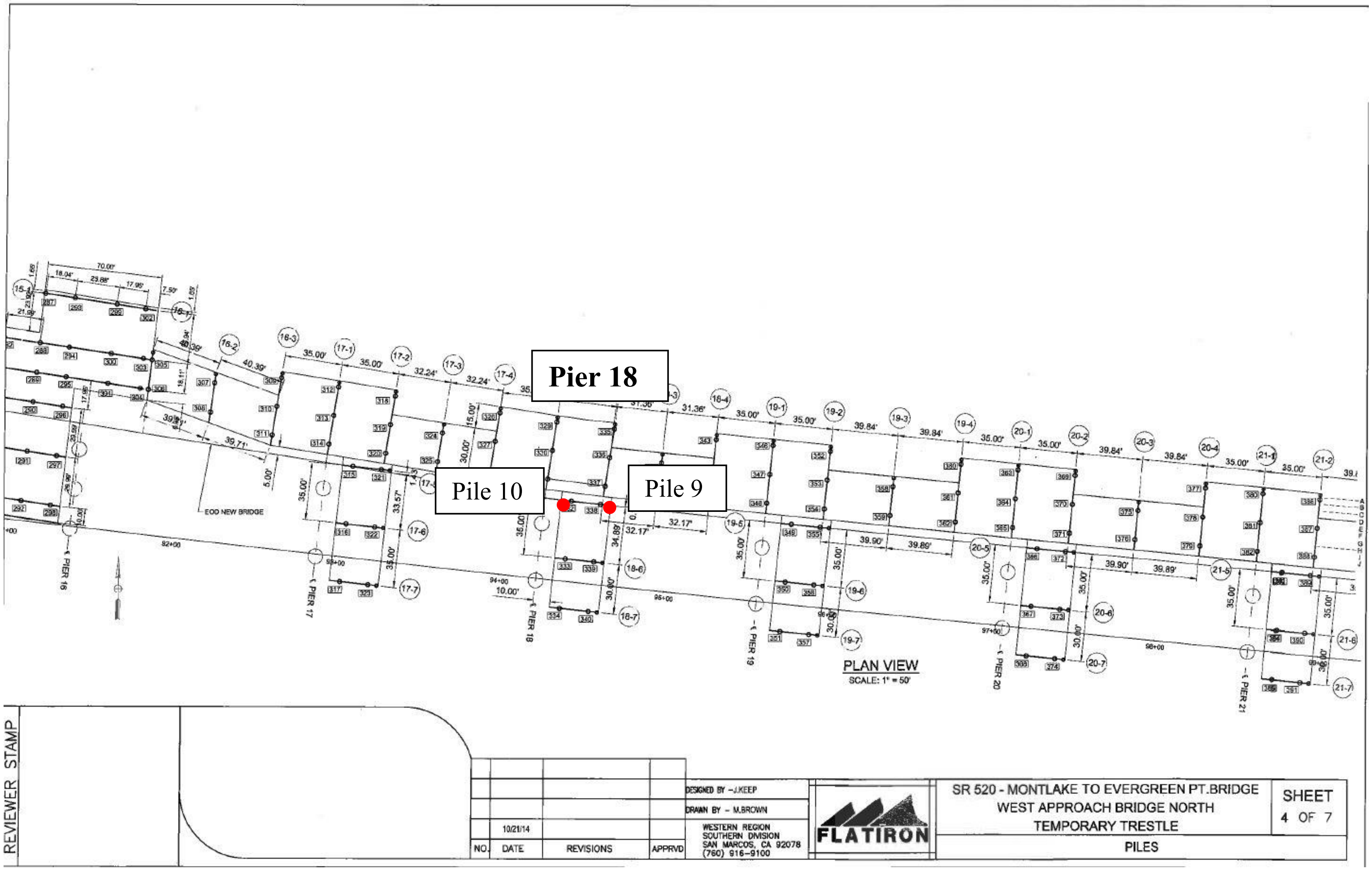
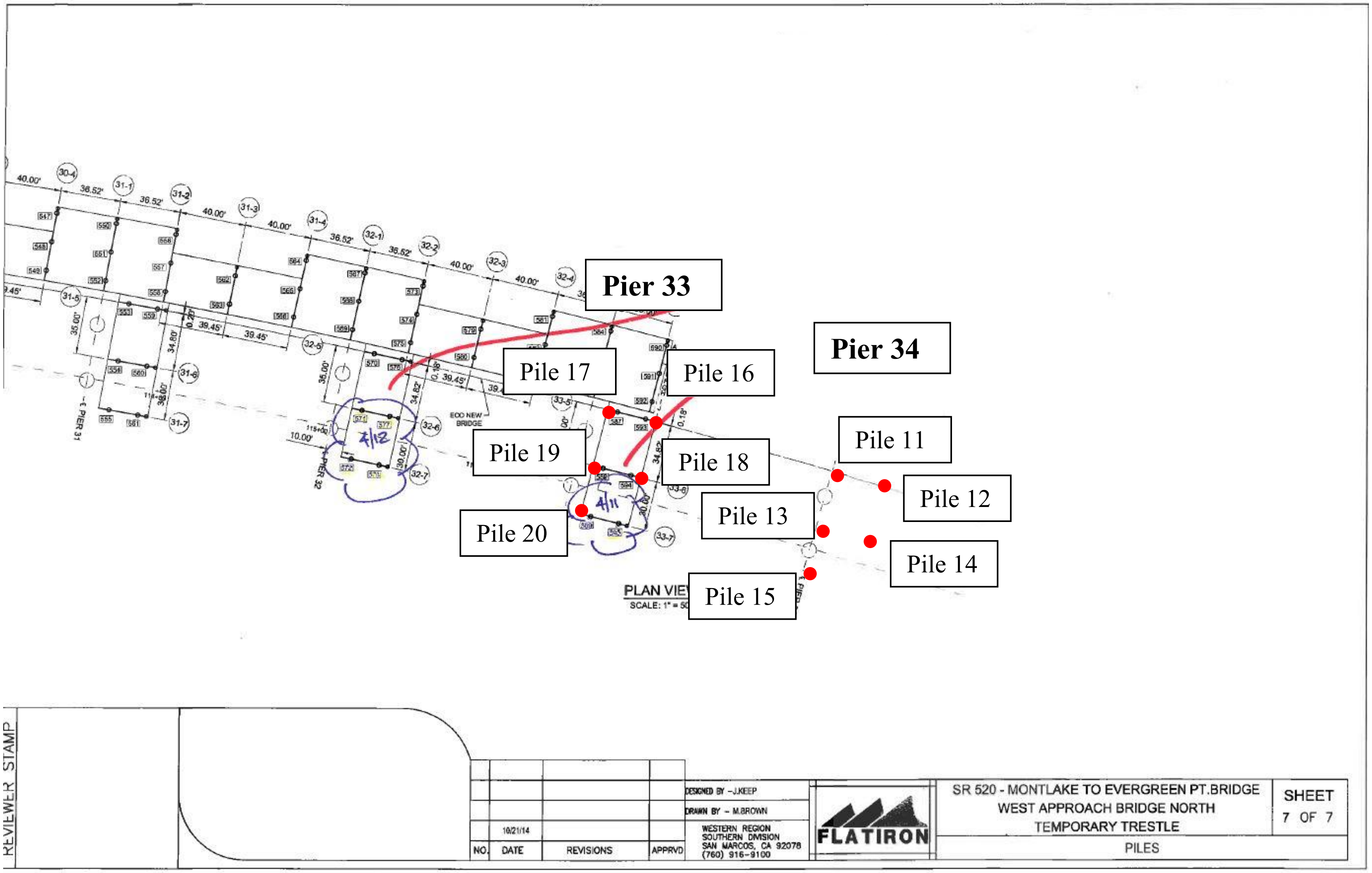


Figure 6: The locations of the middle five and last five monitored piles, east of Foster Island



UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse. The peak SPL is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The majority of literature uses peak sound pressures to evaluate barotrauma injury to fish. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa. The equation to calculate the sound pressure level is:

Sound Pressure Level (SPL) = 20 log (p/p_{ref}), where p_{ref} is the reference pressure (i.e., 1 μPa for water)

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. It has been used by the National Marine Fisheries Service (NMFS) in criteria for judging effects to marine mammals from underwater impulse-type sounds.

The L_{50} or 50^{th} percentile is a statistical measure of the median value over the measurement period where 50 percent of the measured values are above the L_{50} and 50 percent are below.

One-third octave band analysis offers a more convenient way to look at the composition of the sound and is an improvement over previous techniques. One-third octave bands are frequency bands whose upper limit in hertz is $2^{1/3}$ (1.26) times the lower limit. The width of a given band is 23% of its center frequency. For example, the 1/3-octave band centered at 100 Hz extends from 89 to 112 Hz, whereas the band centered at 1000 Hz extends from 890 to 1120 Hz. The 1/3-octave band level is calculated by integrating the spectral densities between the band frequency limits. Conversion to decibels is:

$$dB = 10*LOG \text{ (sum of squared pressures in the band)} \qquad \text{(eq. 1)}$$

Sound levels are often presented for 1/3-octave bands because the effective filter bandwidth of mammalian hearing systems is roughly proportional to frequency and often about 1/3-octave. In other words, a mammal's perception of a sound at a given frequency will be strongly affected by other sounds within a 1/3-octave band around that frequency. The overall level (acoustically summing the pressure level at all frequencies) of a broadband (20 Hz to 20 kHz) sound exceeds the level in any single 1/3-octave band.

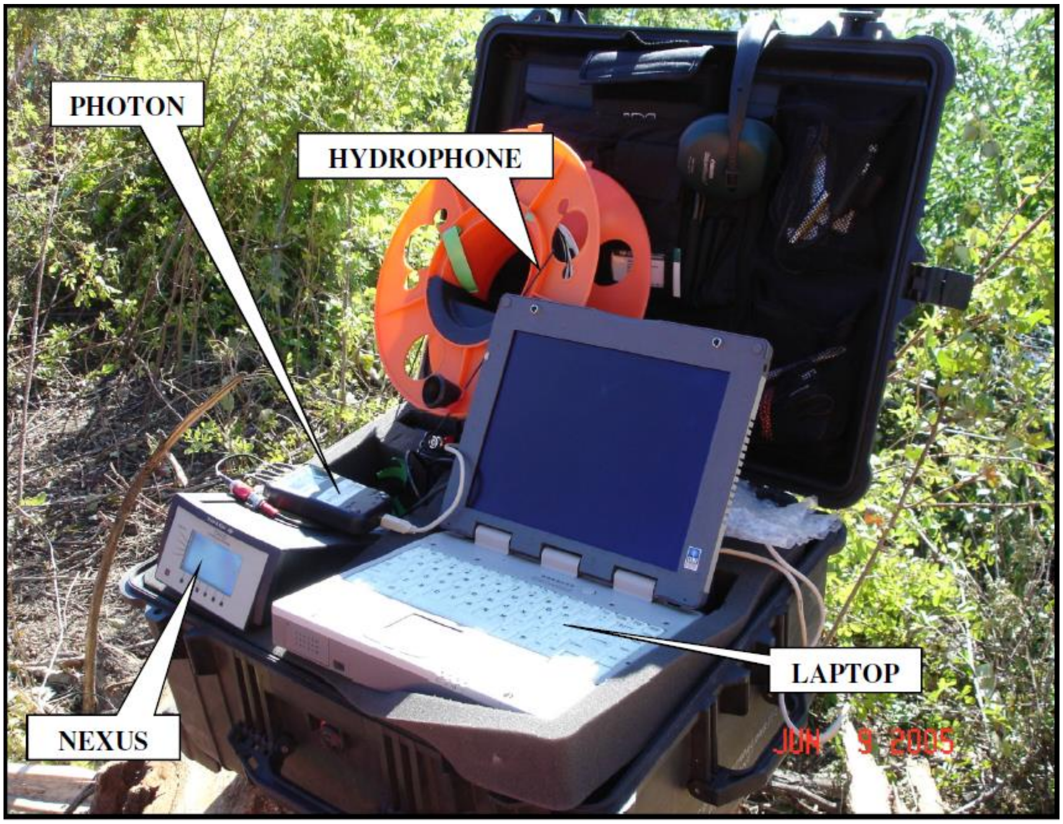
METHODOLOGY

Typical Equipment Deployment

The hydrophone was deployed from the shoreline near the piles. The monitoring equipment is outlined below and shown in Figure 7. The hydrophone was stationed and fixed with anchors and a surface float at a nominal distance of 10-22 meters from the pile.

A confined bubble curtain was deployed for all piles driven to attenuate underwater noise.

Figure 7: Near Field Acoustical Monitoring Equipment



Forty steel piles, initially vibratory driven, were monitored with the sound attenuation bubble curtain system active when proofed with an impact hammer.

Underwater sound levels were measured near the piles using a Reson TC 4013 hydrophone deployed on a weighted nylon cord from the monitoring location. The hydrophone was positioned at a distance of 10 meters in most cases and at mid-water depth. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer, shown in Figure 4. The output of the Nexus signal conditioner is received by a Brüel and Kjær Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer similar to the one shown in Figure 7.

The equipment captures underwater sound levels from the pile driving operations in the format of an RTPro signal file for processing later. The WSDOT has the system and software calibration checked annually against NIST traceable standard.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 20.8 μs (18,750 Hz). This sampling rate provides sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

Due to the variability between the absolute peaks for each pile impact strike, an average peak and RMS value is computed along with the standard deviation (s.d.) to give an indication of the amount of variation around the average for each pile.

The $RMS_{90\%}$ was calculated for each individual impact strike. Except where otherwise noted the $SEL_{90\%}$ was calculated for each individual impact strike using the following equation:

$$SEL_{90\%} = RMS_{90\%} + 10 \text{ LOG } (\tau) \qquad \text{(eq. 2)}$$

Where τ is the 90% time interval over which the $RMS_{90\%}$ value is calculated for each impact strike. Then the cumulative SEL (cSEL) is calculated by accumulating each of these values for each pile and each day.

For those recordings where it was not possible to calculate the $SEL_{90\%}$ for each pile strike the cumulative SEL was calculated using the following equation.

$$cSEL = SEL_{90\%} + 10 \text{ LOG (total number of pile strikes)} \qquad \text{(eq. 3)}$$

The following thresholds were applied to this project.

For all 30-inch steel piles, east and west of Foster Island

- 188 dB_{peak} at 32.8 feet (10 meters)

RESULTS

Underwater Sound Levels

WSDOT monitored a total of 42, 30-inch hollow steel piles for underwater noise. Data from all piles are analyzed in the paragraphs below and summarized in Table 3.

East of Foster

Pile 1

Pile 1 is part of Pier 27, located east of Pile 2, west of Pier 28, and south of the existing work trestle. The pile had an absolute attenuated peak value of 168 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 156 dB_{RMS} and the attenuated cSEL was calculated to be 164 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 2

Pile 2 is part of Pier 27, located east of Pier 26, west of Pile 1, and south of the existing work trestle. The pile had an absolute attenuated peak value of 167 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 154 dB_{RMS} and the attenuated cSEL was calculated to be 163 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 3

Pile 3 is part of Pier 27, located east of Pile 4, west of Pier 28, and south of Pile 1. The pile had an absolute un-attenuated peak value of 191 dB_{peak} at 13 meters. This pile exceeded the 188 dB_{peak} threshold. This exceedance was due to the bubble curtain inadvertently being turned off prior to pile driving, resulting in un-attenuated sound levels for the pile. The un-attenuated $RMS_{90\%}$ was calculated at 178 dB_{RMS} and the un-attenuated cSEL was calculated to be 191 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 68 feet.

Pile 4

Pile 4 is part of Pier 27, located east of Pier 26, west of Pile 3, and south of Pile 2. The pile had an absolute attenuated peak value of 163 dB_{peak} at 13 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 150 dB_{RMS} and the attenuated cSEL was calculated to be 161 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 5

Pile 5 is part of Pier 27, located east of Pier 26, west of Pile 6, and south of Pile 4. The pile had an absolute attenuated peak value of 166 dB_{peak} at 17 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 152 dB_{RMS} and the attenuated cSEL was calculated to be 163 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 6

Pile 6 is part of Pier 27, located east of Pile 5, west of Pier 28, and south of Pile 3. The pile had an absolute attenuated peak value of 174 dB_{peak} at 17 meters. This pile has not exceeded the 188 dB_{peak}

threshold. The attenuated $RMS_{90\%}$ was calculated at 161 dB_{RMS} and the attenuated cSEL was calculated to be 168 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 7 feet.

Pile 7

Pile 7 is part of Pier 27, located east of Pile 8, west of Pier 28, and south of Pile 6. The pile had an absolute attenuated peak value of 167 dB_{peak} at 22 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 152 dB_{RMS} and the attenuated cSEL was calculated to be 159 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 3 feet.

Pile 8

Pile 8 is part of Pier 27, located east of Pier 26, west of Pile 7, and south of Pile 5. The pile had an absolute attenuated peak value of 164 dB_{peak} at 22 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 148 dB_{RMS} and the attenuated cSEL was calculated to be 158 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 9

Pile 9 is part of Pier 18, located east of Pile 10, west of Pier 19, and south of the existing work trestle. The pile had an absolute attenuated peak value of 163 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 154 dB_{RMS} and the attenuated cSEL was calculated to be 162 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 10

Pile 10 is part of Pier 18, located east of Pier 17, west of Pile 9, and south of the existing work trestle. The pile had an absolute attenuated peak value of 163 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 159 dB_{RMS} and the attenuated cSEL was calculated to be 161 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 11

Pile 11 is part of Pier 34, located east of Pier 33 and west of pile 12. The pile had an absolute attenuated peak value of 186 dB_{peak} at 13 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 172 dB_{RMS} and the attenuated cSEL was calculated to be 179 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 31 feet.

Pile 12

Pile 12 is part of Pier 34, located at the east end of the work trestle and east of pile 11. The pile had an absolute attenuated peak value of 186 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 179 dB_{RMS} and the attenuated cSEL was calculated to be 187 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 24 feet.

Pile 13

Pile 13 is part of Pier 34, located east of Pier 33, west of pile 14, and south of pile 11. The pile had an absolute attenuated peak value of 197 dB_{peak} at 10 meters. This pile exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 182 dB_{RMS} and the attenuated cSEL was calculated to be 188 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 130 feet.

Pile 14

Pile 14 is part of Pier 34, located at the east end of the work trestle, east of pile 13, and south of pile 12. The pile had an absolute attenuated peak value of 183 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 176 dB_{RMS} and the attenuated cSEL was calculated to be 181 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 15 feet.

Pile 15

Pile 15 is part of Pier 34, located at the east end of the work trestle, east of Pier 33, and south of pile 13. The pile had an absolute attenuated peak value of 184 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 174 dB_{RMS} and the attenuated cSEL was calculated to be 182 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 18 feet.

Pile 16

Pile 16 is part of Pier 33, located east of Pile 17, west of Pier 34, and south of the existing work trestle. The pile had an absolute attenuated peak value of 190 dB_{peak} at 10 meters. This exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 176 dB_{RMS} and the attenuated cSEL was calculated to be 184 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 45 feet.

Pile 17

Pile 17 is part of Pier 33, located east of pile 16, west of Pier 32, and south of the existing work trestle. The pile had an absolute attenuated peak value of 185 dB_{peak} at 12 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 170 dB_{RMS} and the attenuated cSEL was calculated to be 186 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 25 feet.

Pile 18

Pile 18 is part of Pier 33, located east of pile 19, west of Pier 34, and south of pile 16. The pile had an absolute attenuated peak value of 195 dB_{peak} at 10 meters. This exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 183 dB_{RMS} and the attenuated cSEL was calculated to be 192 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 96 feet.

Pile 19

Pile 19 is part of Pier 33, located east of Pier 32, west of pile 18, and south of pile 17. The pile had an absolute attenuated peak value of 191 dB_{peak} at 10 meters. This pile exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 176 dB_{RMS} and the attenuated cSEL was calculated to be 188 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 52 feet.

Pile 20

Pile 20 is part of Pier 33, located east of Pier 32, west of Pier 34, and south of pile 19. The pile had an absolute attenuated peak value of 191 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 178 dB_{RMS} and the attenuated cSEL was calculated to be 194 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 52 feet.

West of Foster

Pile 1

Pile 1 is part of Pier 2, located east of the shore of Lake Washington near Montlake, west of Pile 2, and south of Pile 3. The pile had an absolute attenuated peak value of 166 dB_{peak} at 16 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 158 dB_{RMS} and the attenuated cSEL was calculated to be 163 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 2

Pile 2 is part of Pier 2, located east of Pile 1, west of Pier 3, and south of Pile 4. The pile had an absolute attenuated peak value of 171 dB_{peak} at 12 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 165 dB_{RMS} and the attenuated cSEL was calculated to be 169 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 3 feet.

Pile 3

Pile 3 is part of Pier 2, located east of the shore of Lake Washington near Montlake, west of Pile 4, and south of the existing work trestle. The pile had an absolute attenuated peak value of 172 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 165 dB_{RMS} and the attenuated cSEL was calculated to be 171 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 3 feet.

Pile 4

Pile 4 is part of Pier 2, located east of Pile 3, west of Pier 3, and south of the existing work trestle. The pile had an absolute attenuated peak value of 175 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 167 dB_{RMS} and the attenuated cSEL was calculated to be 170 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 4 feet.

Pile 5

Pile 5 is part of Pier 2, located east of Pile 6, west of Pier 3, and south of Pile 2. The pile had an absolute attenuated peak value of 181 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 174 dB_{RMS} and the attenuated cSEL was calculated to be 180 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 11 feet.

Pile 6

Pile 6 is part of Pier 2, located east of the shore, west of Pile 5, and south of Pile 1. The pile had an absolute attenuated peak value of 178 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 170 dB_{RMS} and the attenuated cSEL was calculated to be 178 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 7 feet.

Pile 7

Pile 7 is part of Pier 2, located east of the shore, west of Pile 8, and south of Pile 6. The pile had an absolute attenuated peak value of 183 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 176 dB_{RMS} and the attenuated cSEL was calculated to be 183 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 15 feet.

Pile 8

Pile 8 is part of Pier 2, located east of Pile 7, west of Pier 3, and south of Pile 5. The pile had an absolute attenuated peak value of 178 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 172 dB_{RMS} and the attenuated cSEL was calculated to be 178 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 7 feet.

Pile 9

Pile 9 is part of Pier 3, located east of Pier 2, west of Pile 10, and south of the existing work trestle. The pile had an absolute attenuated peak value of 176 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 172 dB_{RMS} and the attenuated cSEL was calculated to be 177 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 5 feet.

Pile 10

Pile 10 is part of Pier 3, located east of Pile 9, west of Pier 4, and south of the existing work trestle. The pile had an absolute un-attenuated peak value of 209 dB_{peak} at 10 meters. This pile exceeded the 188 dB_{peak} threshold. This exceedance was due to a malfunctioning bubble curtain which resulted in the sound levels being un-attenuated. The un-attenuated $RMS_{90\%}$ was calculated at 191 dB_{RMS} and the un-attenuated cSEL was calculated to be 197 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 824 feet.

Pile 11

Pile 11 is part of Pier 11, located east of Pier 10, west of Pier 11, and south of the existing work trestle. The pile had an absolute attenuated peak value of 169 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 164 dB_{RMS} and the attenuated cSEL was calculated to be 169 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 12

Pile 12 is part of Pier 11, located east of Pier 10, west of Pier 11, and south of Pile 11. The pile had an absolute attenuated peak value of 163 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 155 dB_{RMS} and the attenuated cSEL was calculated to be 164 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 1 foot.

Pile 13

Pile 13 is part of Pier 10, located east of Pier 9, west of Pile 14, and south of the existing work trestle. The pile had an absolute attenuated peak value of 181 dB_{peak} at 12 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 162 dB_{RMS} and the attenuated cSEL was calculated to be 172 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 13 feet.

Pile 14

Pile 14 is part of Pier 10, located east of Pier 11, west of Pile 13, and south of the existing work trestle. The pile had an absolute attenuated peak value of 182 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 166 dB_{RMS} and the attenuated cSEL was calculated to be 171 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 13 feet.

Pile 15

Pile 15 is part of Pier 10, located east of Pier 9, west of Pier 11, and south of Pile 13. The pile had an absolute attenuated peak value of 173 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 158 dB_{RMS} and the attenuated cSEL was calculated to be 171 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 3 feet.

Pile 16

Pile 16 is part of Pier 9, located east of Pile 17, west of Pier 10, and south of the existing work trestle. The pile had an absolute attenuated peak value of 171 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 159 dB_{RMS} and the attenuated cSEL was calculated to be 157 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 17

Pile 17 is part of Pier 9, located east of Pier 8, west of Pile 16, and south of the existing work trestle. The pile had an absolute attenuated peak value of 168 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 151 dB_{RMS} and the attenuated cSEL was calculated to be 170 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 18

Pile 18 is part of Pier 9, located east of Pile 19 and 20, west of Pier 10, and south of Pile 16. The pile had an absolute attenuated peak value of 171 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 159 dB_{RMS} and the attenuated cSEL was calculated to be 158 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 2 feet.

Pile 19

Pile 19 is part of Pier 9, located east of Pier 8, west of Pile 18, and south of Pile 17. The pile had an absolute attenuated peak value of 181 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 163 dB_{RMS} and the attenuated cSEL was calculated to be 169 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 11 feet.

Pile 20

Pile 20 is part of Pier 9, located east of Pier 8, west of Pile 18, and south of Pile 17. The pile had an absolute attenuated peak value of 181 dB_{peak} at 10 meters. This pile has not exceeded the 188 dB_{peak} threshold. The attenuated $RMS_{90\%}$ was calculated at 167 dB_{RMS} and the attenuated cSEL was calculated to be 169 dB_{SEL}. The distance to the 188 dB_{peak} threshold using the practical spreading model from the pile location is 11 feet.

Table 4: Summary of Underwater Sound Levels for the SR 520 West Approach Bridge North Project, East of Foster Island

East of Foster Island													
Pile #	Pier #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	Single Strike $SEL_{90\%}$ (dB)	Peak L_{50} (dB)	$RMS_{90\%}$ L_{50} (dB)	Single Strike $SEL_{90\%}$ L_{50} (dB)	Cumulative SEL (dB)
1	27	3/7/2016 11:05 AM	30	10	3.5	223	168	156	148	165	152	140	164
2	27	3/7/2016 11:39 AM	30	10	3.5	201	167	154	145	164	151	139	163
3	27	3/7/2016 3:31 PM	30	13	3.5	87	191	178	163	188	179	166	191
4	27	3/7/2016 3:52 PM	30	13	3.5	26	163	150	142	162	152	141	161
5	27	3/7/2016 4:15 PM	30	17	3.5	112	166	152	143	163	151	139	163
6	27	3/8/2016 9:55 AM	30	17	3.5	106	174	161	153	170	157	146	168
7	27	3/8/2016 10:15 AM	30	22	3.5	88	167	152	143	165	149	139	159
8	27	3/8/2016 10:37 AM	30	22	3.5	70	164	148	139	161	148	136	158
9	18	3/8/2016 2:01 PM	30	10	1	85	163	154	145	161	154	142	162
10	18	3/8/2016 2:17 PM	30	10	1	58	163	159	151	161	159	148	161
11	34	4/7/2016 3:51 PM	30	13	16	195	186	172	163	179	171	160	179
12	34	4/7/2016 4:22 PM	30	10	8	161	186	179	166	185	178	165	187
13	34	4/7/2016 4:59 PM	30	10	8	188	197	182	171	187	179	166	188
14	34	4/8/2016 12:11 PM	30	10	8	61	183	176	166	180	175	164	181
15	34	4/8/2016 12:29 PM	30	10	8	53	184	174	165	182	176	164	182
16	33	4/13/2016 1:39 PM	30	10	14.5	186	190	176	166	188	176	164	184

Pile #	Pier #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	Single Strike $SEL_{90\%}$ (dB)	Peak L_{50} (dB)	$RMS_{90\%}$ L_{50} (dB)	Single Strike $SEL_{90\%}$ L_{50} (dB)	Cumulative SEL (dB)
East of Foster Island													
17	33	4/13/2016 2:35 PM	30	12	14.5	282	185	170	160	183	170	160	186
18	33	4/13/2016 3:44 PM	30	13	14.5	290	195	183	170	191	180	167	192
19	33	4/13/2016 4:09 PM	30	10	14.5	250	191	176	166	187	175	164	188
20	33	4/13/2016 4:57 PM	30	12	14.5	876	191	178	168	186	175	163	194

Table 5: Summary of Underwater Sound Levels for the SR 520 West Approach Bridge North Project, West of Foster Island

Pile #	Pier #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	Single Strike $SEL_{90\%}$ (dB)	Peak L_{50} (dB)	$RMS_{90\%}$ L_{50} (dB)	Single Strike $SEL_{90\%}$ L_{50} (dB)	Cumulative SEL (dB)
West of Foster Island													
1	2	3/2/2016 4:55 PM	30	16	4.5	110	166	158	147	164	157	144	163
2	2	3/3/2016 8:30 AM	30	12	4.5	86	171	165	153	169	164	150	169
3	2	3/3/2016 8:52 AM	30	10	4.5	93	172	165	155	172	164	153	171
4	2	3/3/2016 12:46 PM	30	10	4.5	65	175	167	156	174	165	153	170
5	2	3/8/2016 12:03 PM	30	10	4.5	57	181	174	163	180	174	162	180
6	2	3/8/2016 12:15 PM	30	10	4.5	87	178	170	160	177	170	158	178
7	2	3/9/2016 9:12 AM	30	10	4.5	99	183	176	165	182	176	164	183
8	2	3/9/2016 9:27 AM	30	20	4.5	85	178	172	160	177	172	159	178
9	3	3/11/2016	30	10	5	102	176	172	159	175	170	157	177

West of Foster Island													
Pile #	Pier #	Date & Time	Pile Diameter (inches)	Hydrophone Range (m)	Hydrophone Depth (feet)	Total Number Of Strikes	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	Single Strike $SEL_{90\%}$ (dB)	Peak L_{50} (dB)	$RMS_{90\%}$ L_{50} (dB)	Single Strike $SEL_{90\%}$ L_{50} (dB)	Cumulative SEL (dB)
		4:02 PM											
10*	3	3/11/2016 4:34 PM	30	10	5	92	209	191	179	205	191	177	197
11	11	4/7/2016 8:58 AM	30	10	3	87	169	164	154	168	163	149	169
12	11	4/7/2016 9:11 AM	30	10	3	139	163	155	146	161	156	143	164
13	10	4/11/2016 12:59 AM	30	12	6	439	181	162	153	176	164	151	172
14	10	4/11/2016 1:23 PM	30	10	6	229	182	166	158	175	163	151	171
15	10	4/11/2016 1:27 PM	30	10	6	117	173	158	150	172	160	148	159
16	9	4/28/2016 11:34 AM	30	10	6	150	171	159	151	169	156	145	157
17	9	4/28/2016 11:44 AM	30	10	6	154	168	151	143	165	159	148	170
18	9	4/29/2016 10:25 AM	30	10	6	171	171	159	150	169	157	146	158
19	9	4/29/2016 10:33 AM	30	10	6	181	181	163	154	176	163	151	169
20	9	4/29/2016 11:00 AM	30	10	6	69	181	167	157	175	163	152	169

*Bubble curtain malfunction resulted in un-attenuated sound

Daily Cumulative SEL

The daily cSEL's were calculated using an actual $SEL_{90\%}$ for each individual pile strike for each day and accumulated over that period (Table 6).

Table 6: Summary of daily cumulative SEL's

Day	Cumulative SEL
3/2/16	163
3/3/16	175
3/7/16	191
3/8/16	182
3/9/16	184
3/11/16	197
4/7/16	191
4/8/16	184
4/11/16	175
4/13/16	197
4/28/16	171
4/29/16	172

The daily cumulative SEL values ranged from 163 to 197 dB at the 10 meter location.

CONCLUSIONS

A total of 40, 30-inch hollow steel piles were monitored for the construction of the SR 520 West Approach Bridge North project, 20 piles east of Foster Island and 20 piles west of Foster Island. The underwater sound levels analyzed, produced the following results.

East of Foster Island

- Peak underwater attenuated sound levels between 10-22 meters varied in a range between 163 dB_{Peak} and 197 dB_{Peak}.
- The measured $RMS_{90\%}$ levels ranged between 150 dB_{RMS} and 183 dB_{RMS}.
- The distance measured from the pile location to the 188 dB_{peak} threshold ranged between 1 foot and 130 feet from the pile.

West of Foster Island

- Peak underwater attenuated sound levels varied in a range between 163 dB_{Peak} and 183 dB_{Peak}.
- Pile 10 was un-attenuated due to a malfunctioning bubble curtain resulting in an un-attenuated sound level of 209 dB_{peak}.
- The measured $RMS_{90\%}$ levels ranged between 151 dB_{RMS} and 191 dB_{RMS}.
- The distance measured from the pile location to the 188 dB_{Peak} threshold ranged between 2 foot and 824 feet from the pile.

Cumulative Sound Exposure Levels

- Cumulative Sound Exposure Levels (cSEL) for all piles driven on a particular day, ranged between 163 dB_{cSEL} and 197 dB_{cSEL}.
- cSEL for piles driven on a particular day East of Foster Island ranged between 182 dB_{cSEL} and 197 dB_{cSEL}.
- cSEL for piles driven on a particular day West of Foster Island ranged between 163 dB_{cSEL} and 197 dB_{cSEL}.

APPENDIX A WAVEFORM ANALYSIS FIGURES

Figure 8: Waveform Analysis of attenuated Pile 1, East of Foster 10M

WABN 24 Inch Pile 1 at 10m Broadband East of Foster Island

Figure a. Waveform

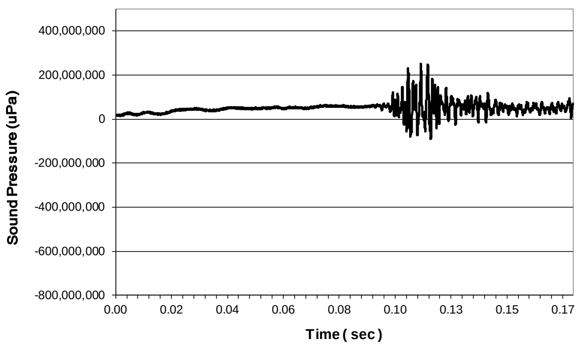


Figure b. Narrow Band Frequency Spectra

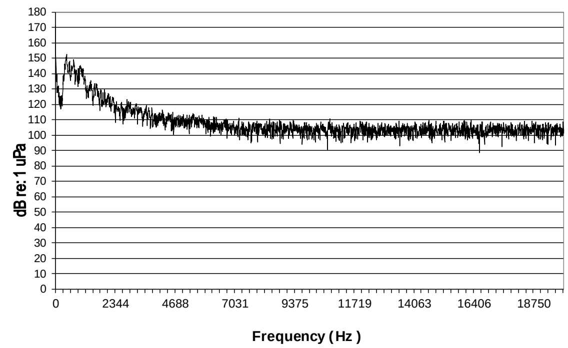


Figure c. Accumulation of Sound Energy

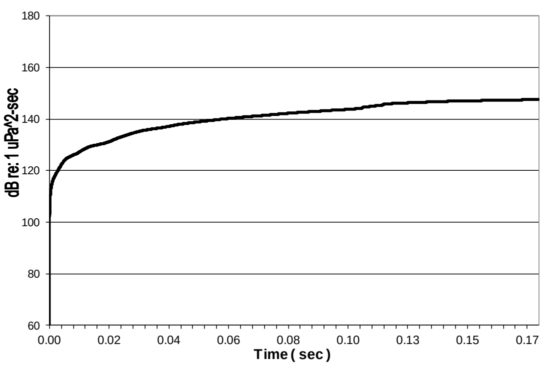


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
3.5-feet	168	156	148

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

Figure 9: Waveform analysis of attenuated Pile 2, East of Foster 10M

WABN 24 Inch Pile 2 at 10m Broadband East of Foster Island

Figure a. Waveform

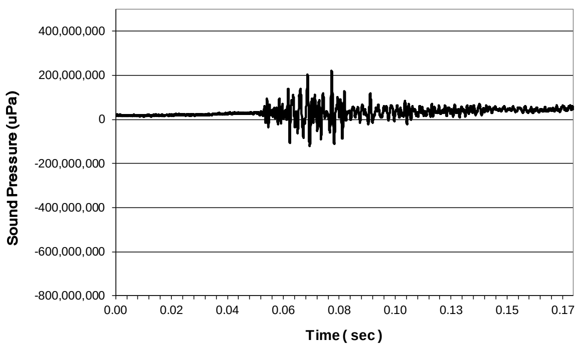


Figure b. Narrow Band Frequency Spectra

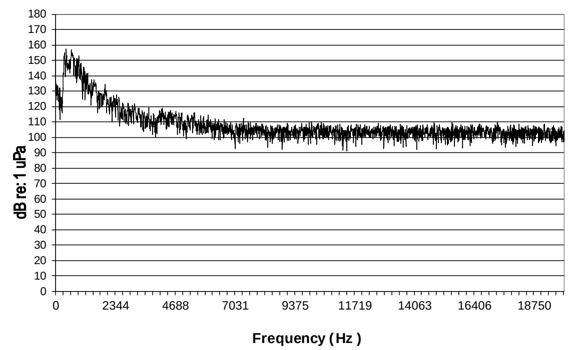


Figure c. Accumulation of Sound Energy

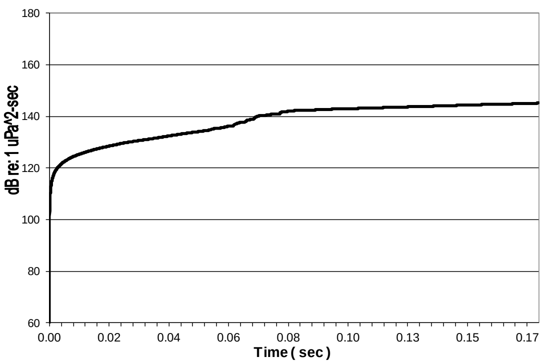


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
3.5-feet	167	154	145

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

Figure 10: Waveform analysis of attenuated Pile 3, East of Foster 13M

WABN 24 Inch Pile 3 at 13m Broadband East of Foster Island

Figure a. Waveform

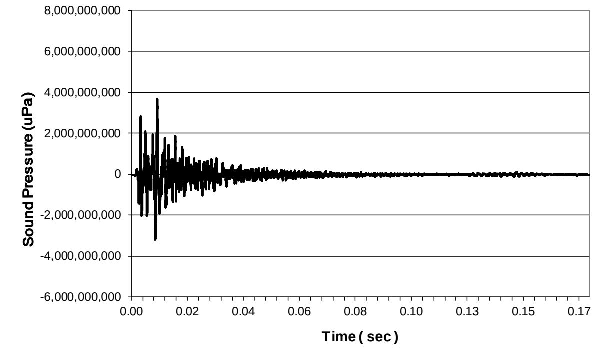


Figure b. Narrow Band Frequency Spectra

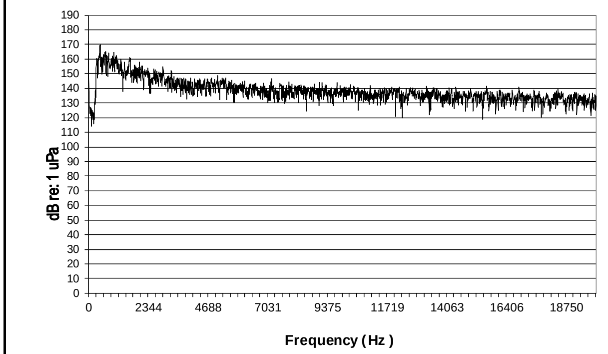


Figure c. Accumulation of Sound Energy

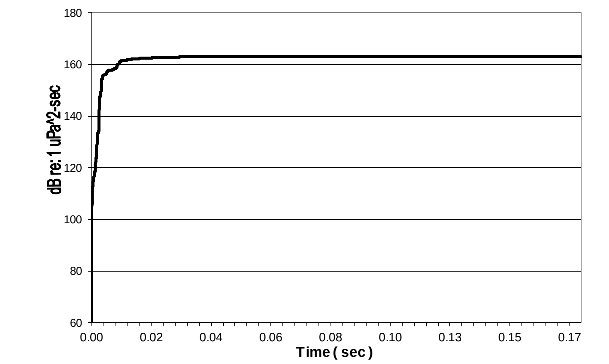


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
3.5-feet	191	178	163

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

Figure 11: Waveform analysis of attenuated Pile 4, East of Foster 13M

WABN 24 Inch Pile 4 at 13m Broadband East of Foster Island

Figure a. Waveform

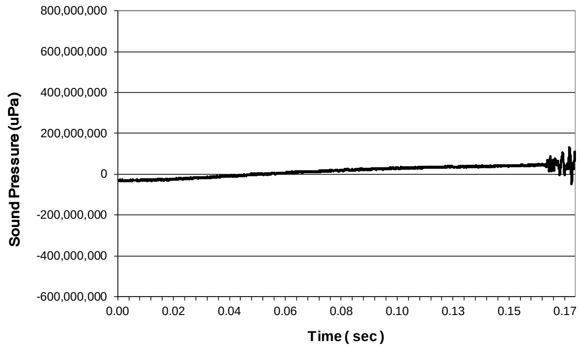


Figure b. Narrow Band Frequency Spectra

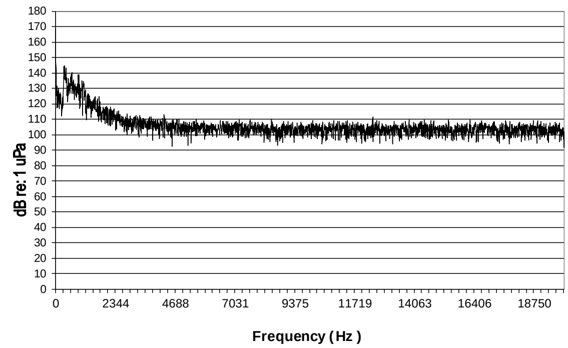


Figure c. Accumulation of Sound Energy

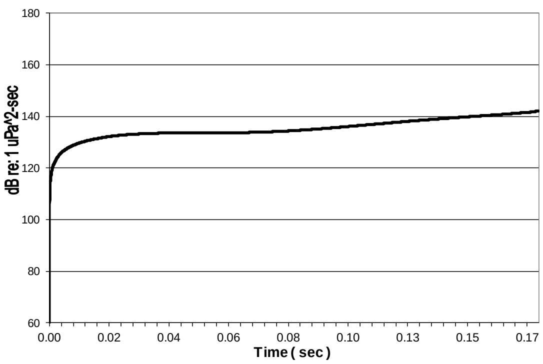


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
3.5-feet	163	150	142

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

Figure 12: Waveform analysis of attenuated Pile 5, East of Foster 17M

WABN 24 Inch Pile 5 at 17m Broadband East of Foster Island

Figure a. Waveform

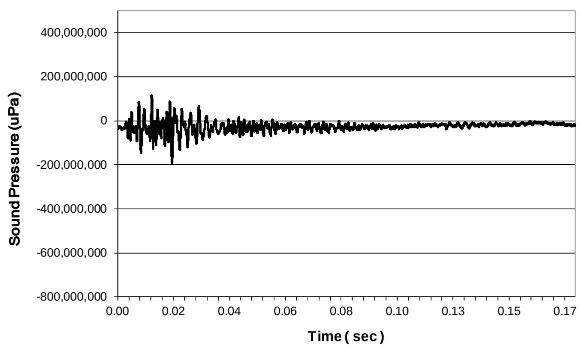


Figure b. Narrow Band Frequency Spectra

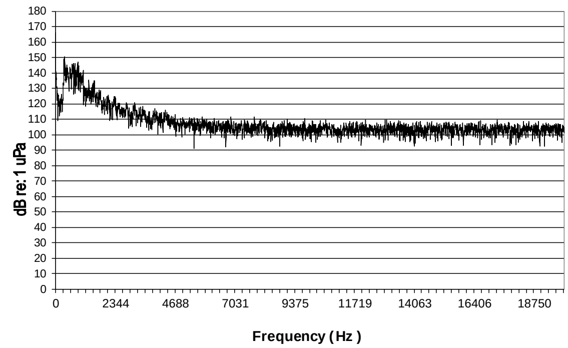


Figure c. Accumulation of Sound Energy

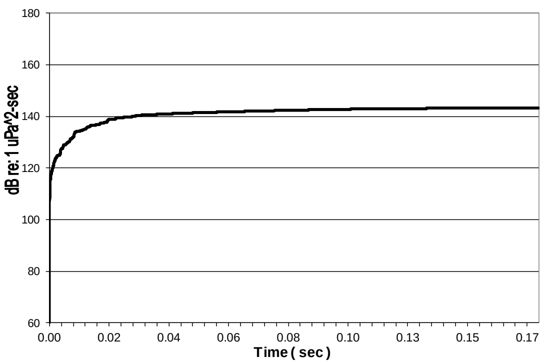


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
3.5-feet	166	152	143

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

Figure 13: Waveform analysis of attenuated Pile 6, East of Foster 17M

WABN 24 Inch Pile 6 at 17m Broadband East of Foster Island

Figure a. Waveform

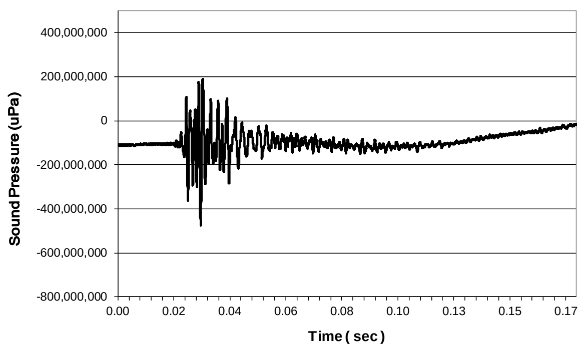


Figure b. Narrow Band Frequency Spectra

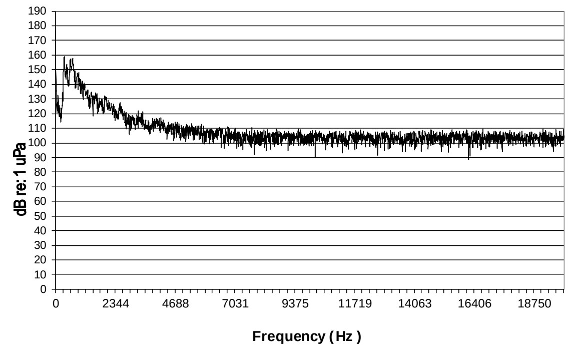


Figure c. Accumulation of Sound Energy

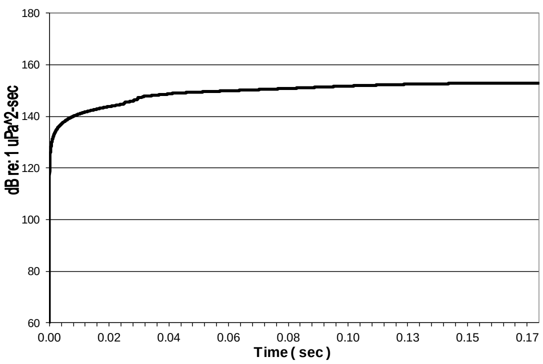


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
3.5-feet	174	161	153

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

Figure 14: Waveform analysis of attenuated Pile 7, East of Foster 22M

WABN 24 Inch Pile 7 at 22m Broadband East of Foster Island

Figure a. Waveform

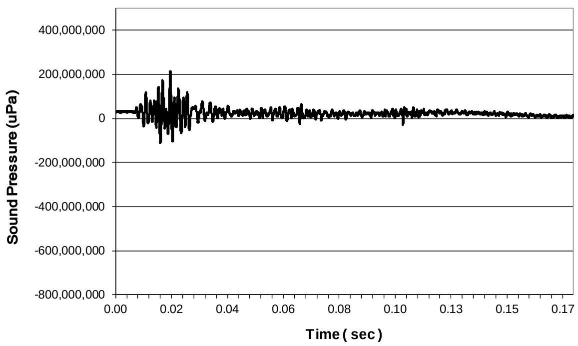


Figure b. Narrow Band Frequency Spectra

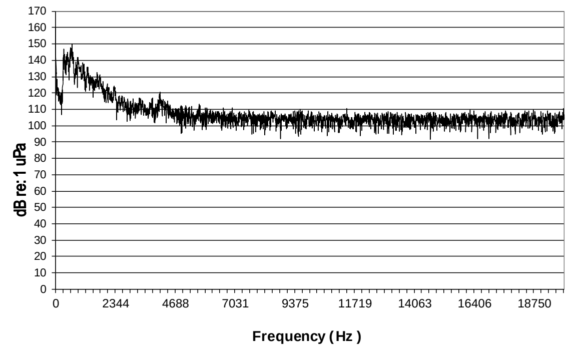


Figure c. Accumulation of Sound Energy

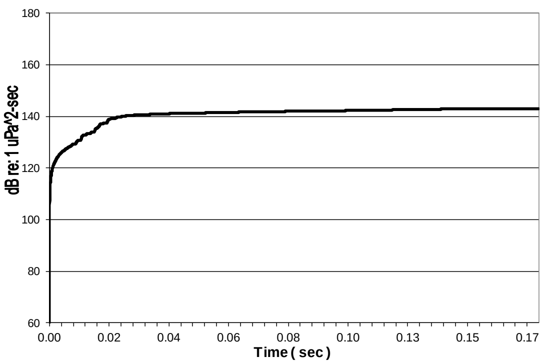


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
3.5-feet	167	152	143

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

Figure 15: Waveform analysis of attenuated Pile 8, East of Foster 22M

WABN 24 Inch Pile 8 at 22m Broadband East of Foster Island

Figure a. Waveform

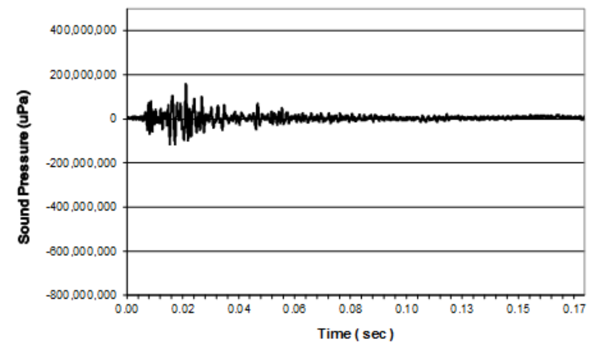


Figure b. Narrow Band Frequency Spectra

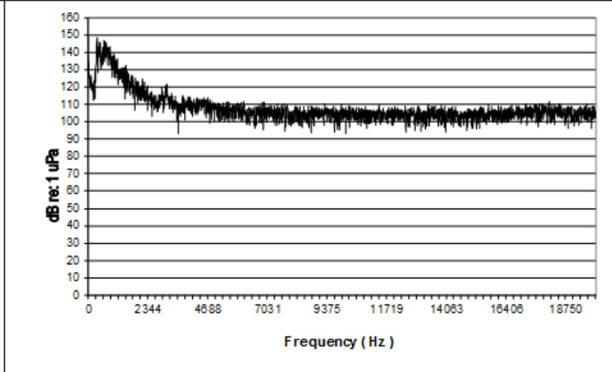


Figure c. Accumulation of Sound Energy

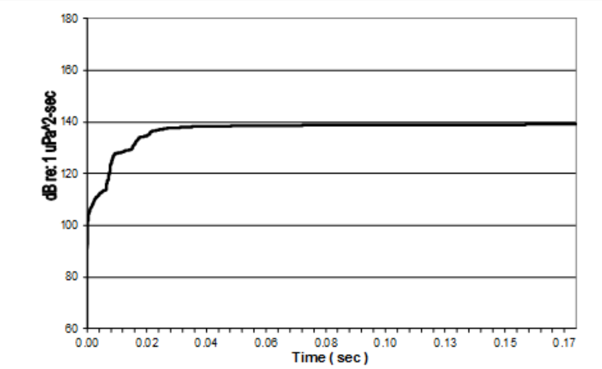


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
3.5-feet	164	148	139

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

Figure 16: Waveform analysis of attenuated Pile 9, East of Foster 10M

WABN 24 Inch Pile 9 at 10m Broadband East of Foster Island

Figure a. Waveform

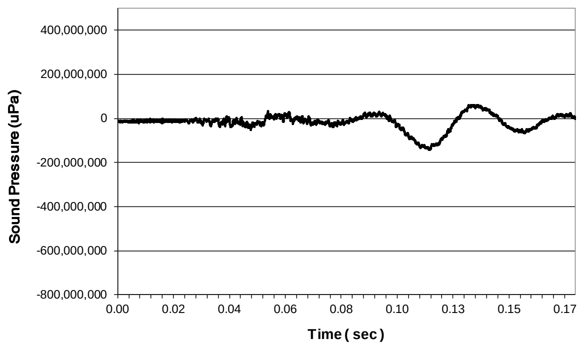


Figure b. Narrow Band Frequency Spectra

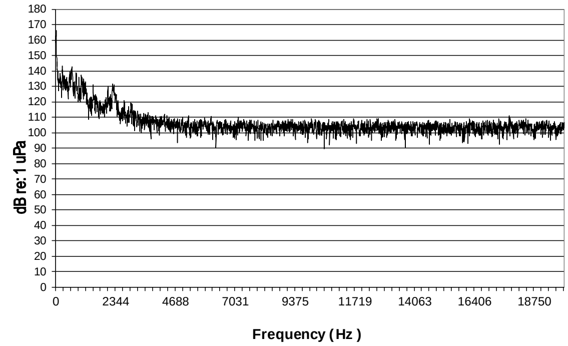


Figure c. Accumulation of Sound Energy

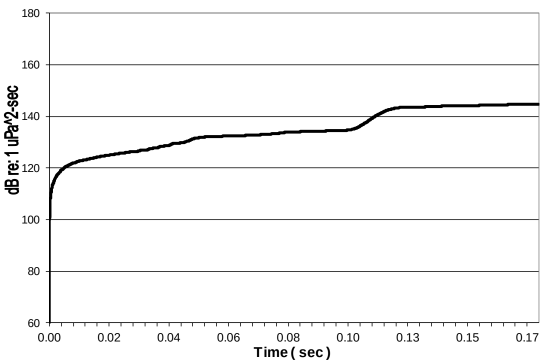


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
1-feet	163	154	145

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

Figure 17: Waveform analysis of attenuated Pile 10, East of Foster 10M

WABN 24 Inch Pile 10 at 10m Broadband East of Foster Island

Figure a. Waveform

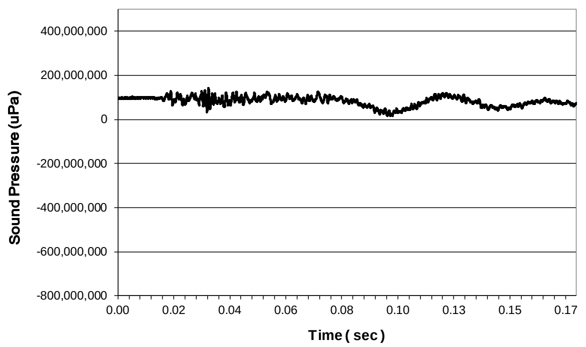


Figure b. Narrow Band Frequency Spectra

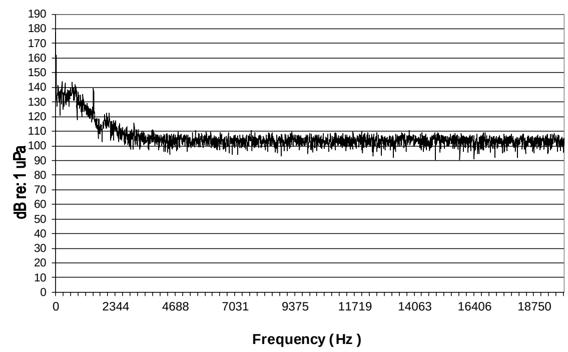


Figure c. Accumulation of Sound Energy

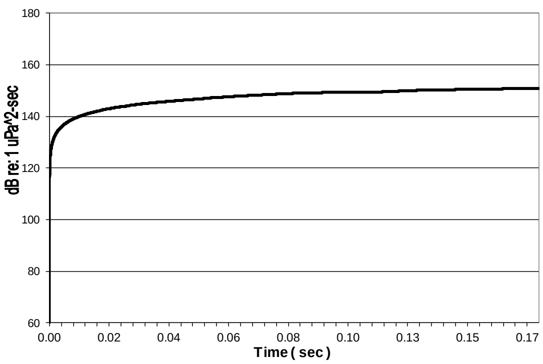


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
1-feet	163	159	151

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

Figure 18: Waveform analysis of attenuated Pile 11, East of Foster 13M

WABN 24 Inch Pile 11 at 13m Broadband East of Foster Island

Figure a. Waveform

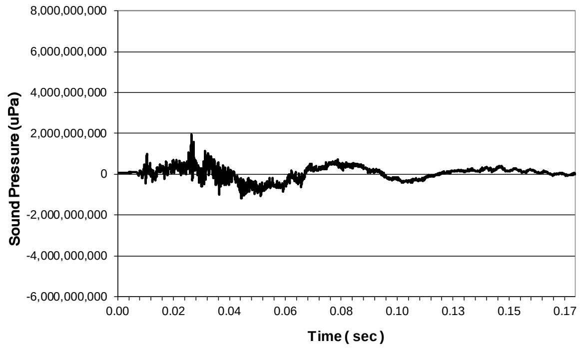


Figure b. Narrow Band Frequency Spectra

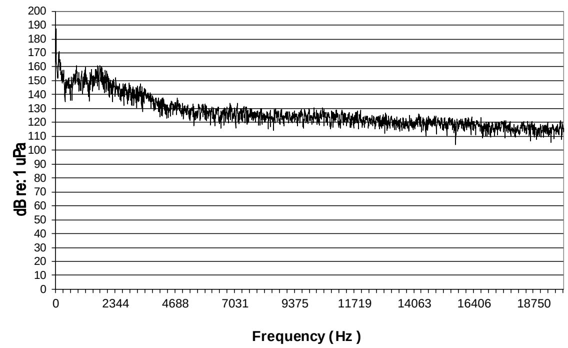


Figure c. Accumulation of Sound Energy

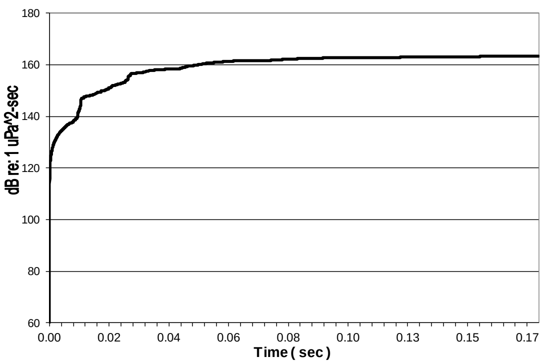


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
16-feet	186	172	163

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

Figure 19: Waveform analysis of attenuated Pile 12, East of Foster 10M

WABN 24 Inch Pile 12 at 10m Broadband East of Foster Island

Figure a. Waveform

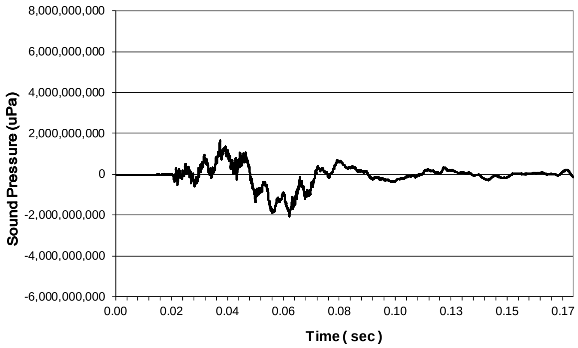


Figure b. Narrow Band Frequency Spectra

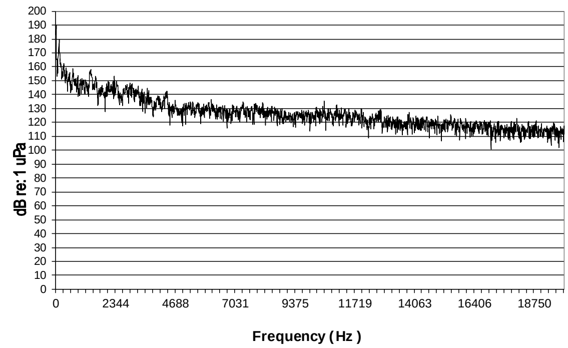


Figure c. Accumulation of Sound Energy

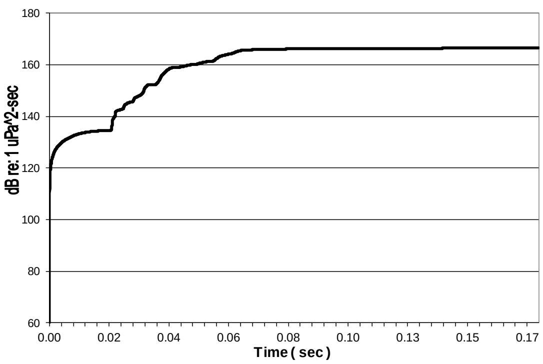


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
8-feet	186	179	166

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

Figure 20: Waveform analysis of attenuated Pile 13, East of Foster 10M

WABN 24 Inch Pile 13 at 10m Broadband East of Foster Island

Figure a. Waveform

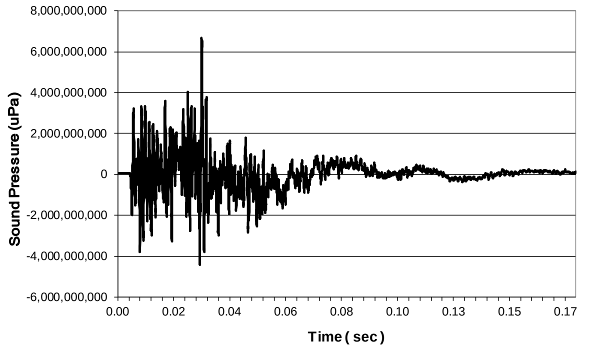


Figure b. Narrow Band Frequency Spectra

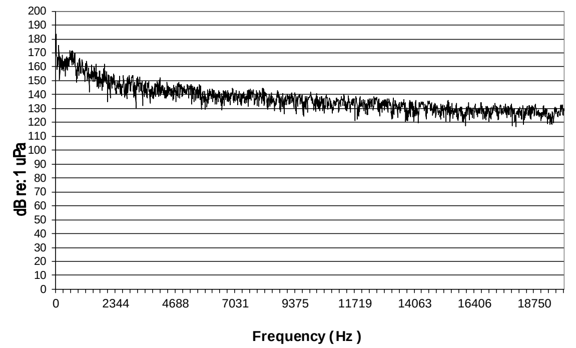


Figure c. Accumulation of Sound Energy

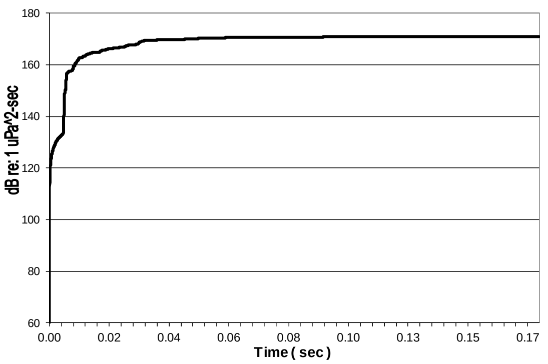


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
8-feet	197	182	171

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

Figure 21: Waveform analysis of attenuated Pile 14, East of Foster 10M

WABN 24 Inch Pile 14 at 10m Broadband East of Foster Island

Figure a. Waveform

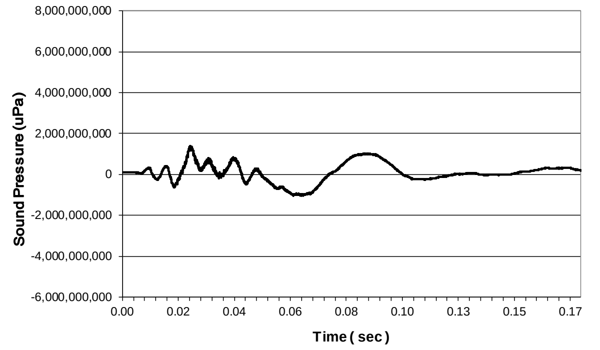


Figure b. Narrow Band Frequency Spectra

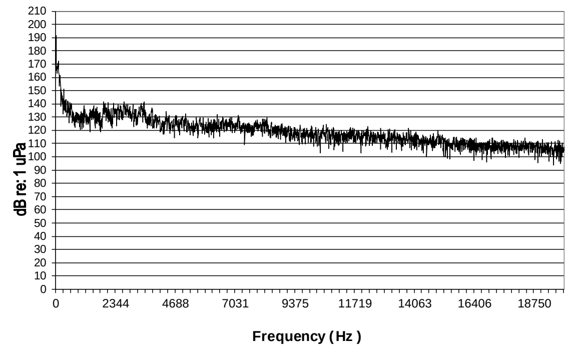


Figure c. Accumulation of Sound Energy

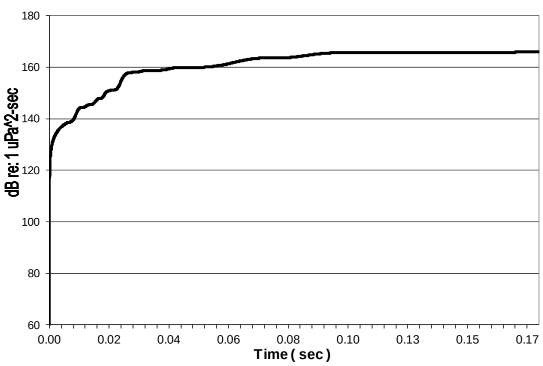


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
8-feet	183	176	166

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

Figure 22: Waveform analysis of attenuated Pile 15, East of Foster 10M

WABN 24 Inch Pile 15 at 10m Broadband East of Foster Island

Figure a. Waveform

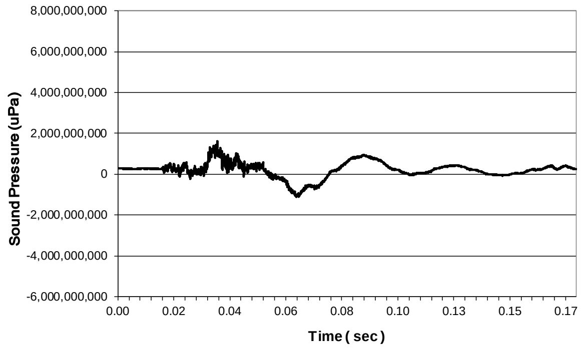


Figure b. Narrow Band Frequency Spectra

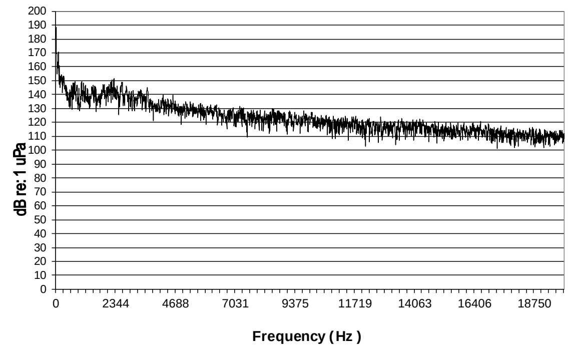


Figure c. Accumulation of Sound Energy

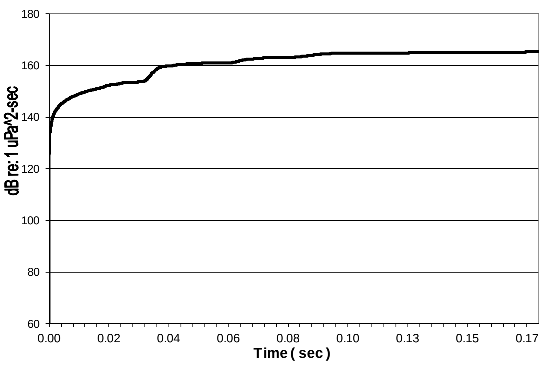


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
8-feet	184	174	165

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

Figure 23: Waveform analysis of attenuated Pile 16, East of Foster 10M

WABN 24 Inch Pile 16 at 10m Broadband East of Foster Island

Figure a. Waveform

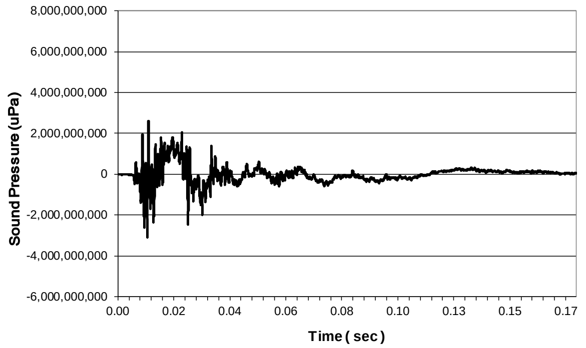


Figure b. Narrow Band Frequency Spectra

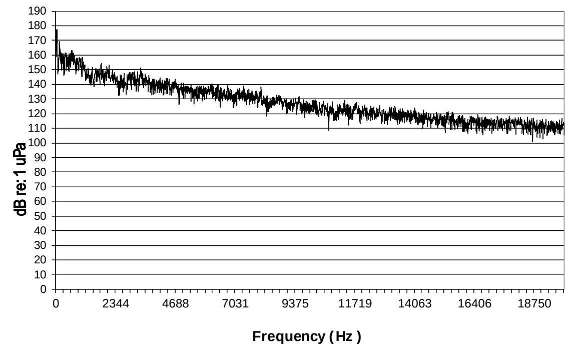


Figure c. Accumulation of Sound Energy

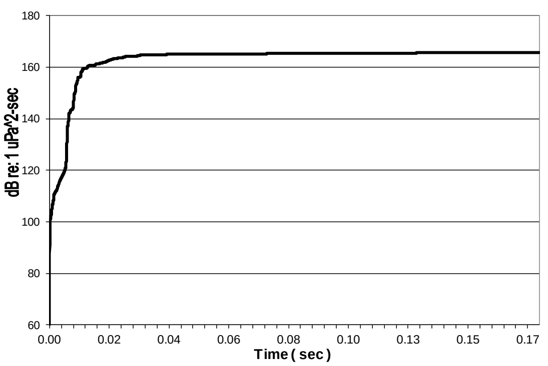


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
14.5-feet	190	176	166

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

Figure 24: Waveform analysis of attenuated Pile 17, East of Foster 12M

WABN 24 Inch Pile 17 at 12m Broadband East of Foster Island

Figure a. Waveform

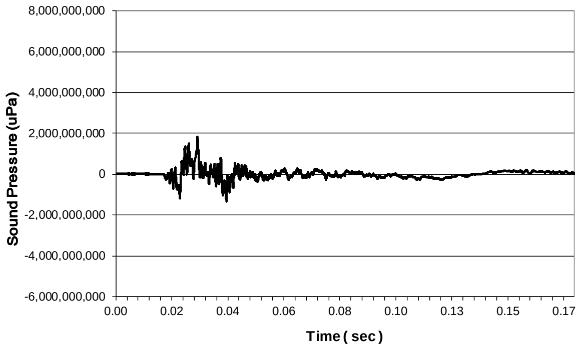


Figure b. Narrow Band Frequency Spectra

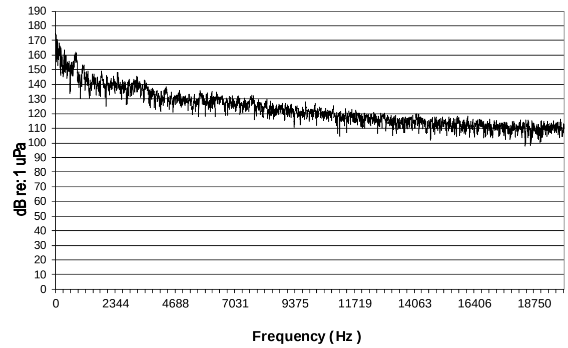


Figure c. Accumulation of Sound Energy

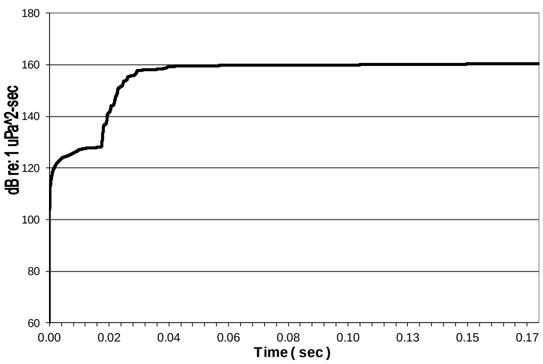


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
14.5-feet	185	170	160

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

Figure 25: Waveform analysis of attenuated Pile 18, East of Foster 13M

WABN 24 Inch Pile 18 at 13m Broadband East of Foster Island

Figure a. Waveform

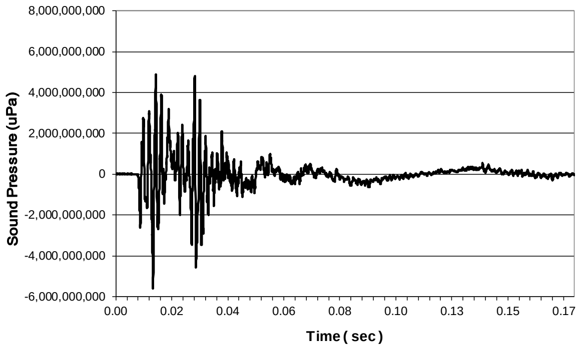


Figure b. Narrow Band Frequency Spectra

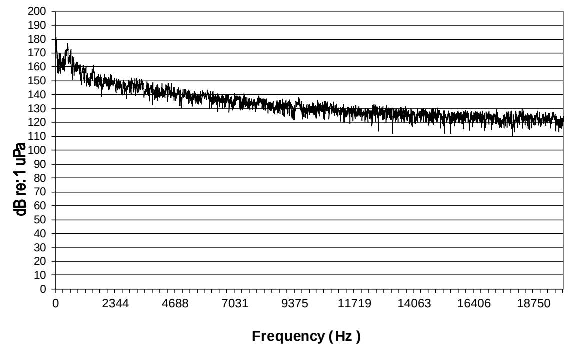


Figure c. Accumulation of Sound Energy

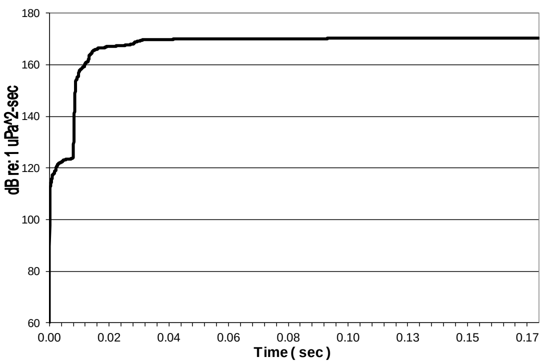


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
14.5-feet	195	183	170

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

Figure 26: Waveform analysis of attenuated Pile 19, East of Foster 10M

WABN 24 Inch Pile 19 at 10m Broadband East of Foster Island

Figure a. Waveform

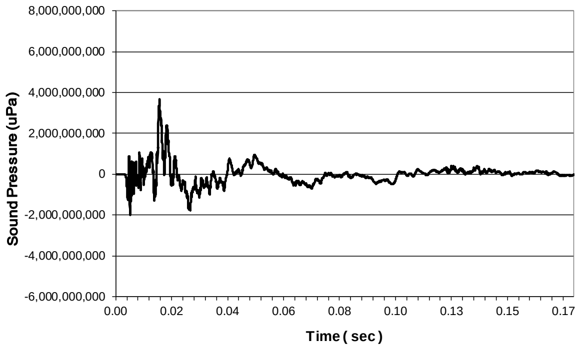


Figure b. Narrow Band Frequency Spectra

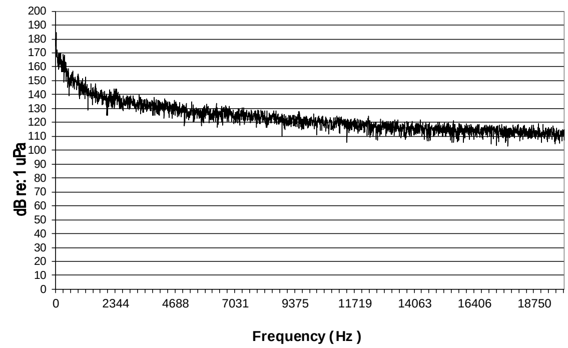


Figure c. Accumulation of Sound Energy

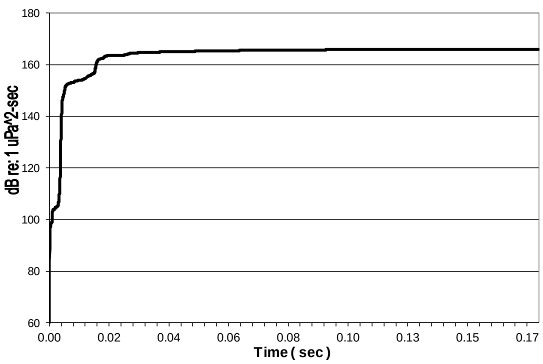


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
14.5-feet	191	176	166

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

Figure 27: Waveform analysis of attenuated Pile 20, East of Foster 12M

WABN 24 Inch Pile 20 at 12m Broadband East of Foster Island

Figure a. Waveform

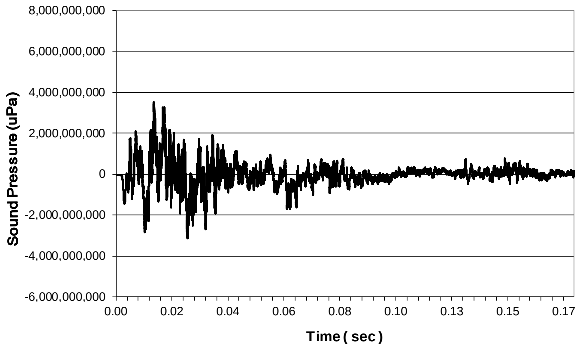


Figure b. Narrow Band Frequency Spectra

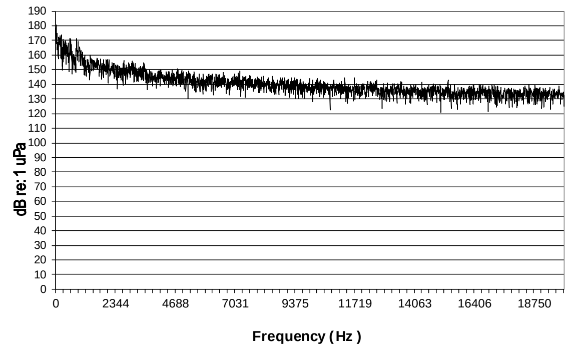


Figure c. Accumulation of Sound Energy

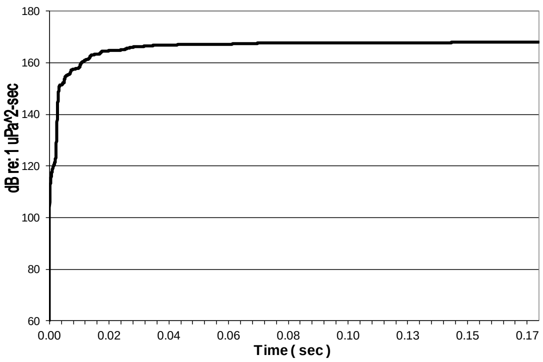


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
14.5-feet	191	178	168

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

Figure 28: Waveform Analysis of attenuated Pile 1, West of Foster 16M

WABN 24 Inch Pile 1 at 16m Broadband West of Foster Island

Figure a. Waveform

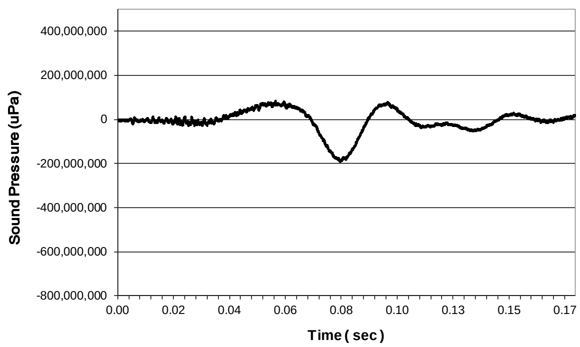


Figure b. Narrow Band Frequency Spectra

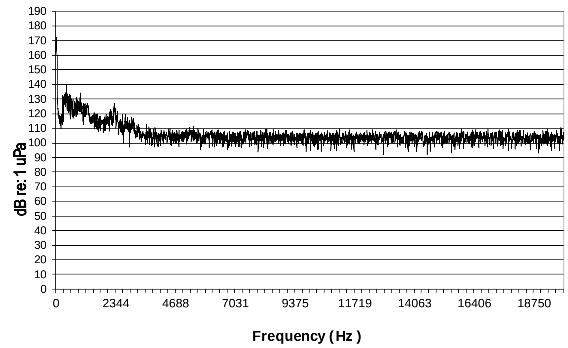


Figure c. Accumulation of Sound Energy

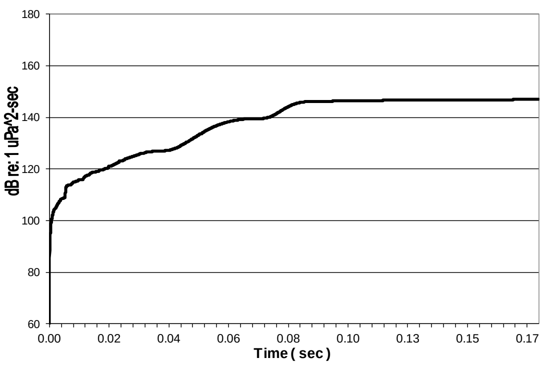


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
4.5-feet	166	158	147

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

Figure 29: Waveform analysis of attenuated Pile 2, West of Foster 12M

WABN 24 Inch Pile 2 at 12m Broadband West of Foster Island

Figure a. Waveform

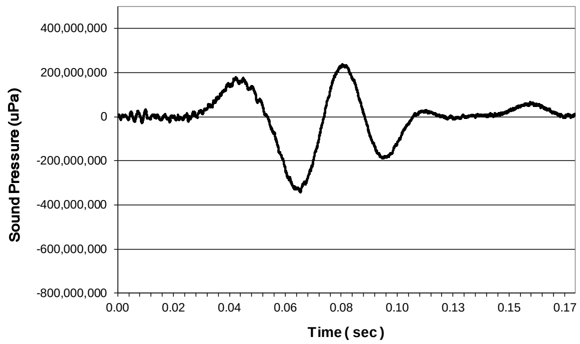


Figure b. Narrow Band Frequency Spectra

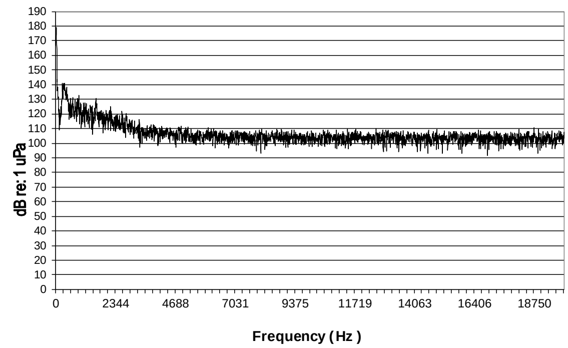


Figure c. Accumulation of Sound Energy

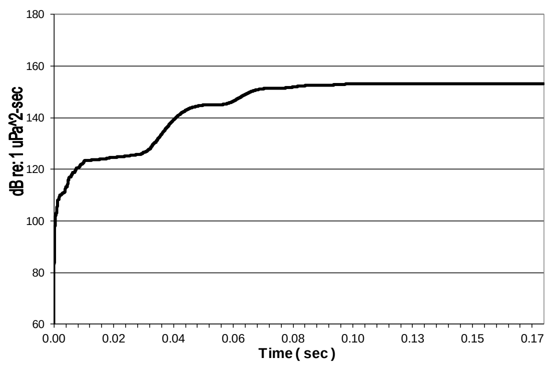


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	171	165	153

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

Figure 30: Waveform analysis of attenuated Pile 3, West of Foster 10M

WABN 24 Inch Pile 3 at 10m Broadband West of Foster Island

Figure a. Waveform

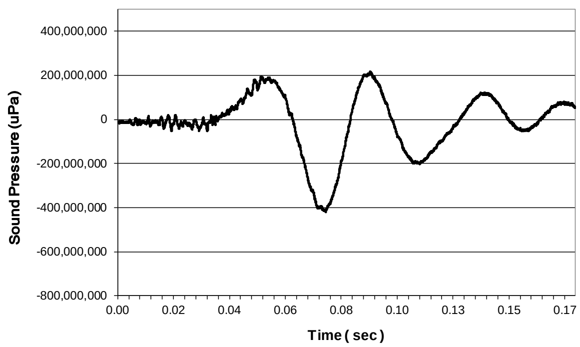


Figure b. Narrow Band Frequency Spectra

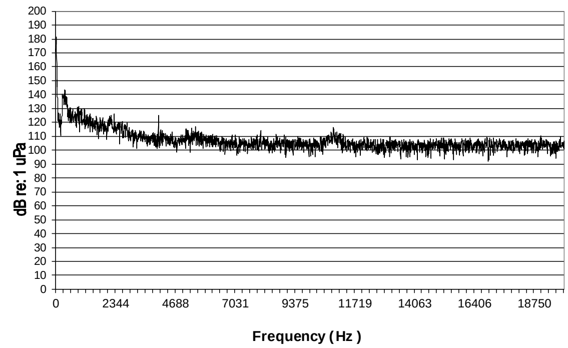


Figure c. Accumulation of Sound Energy

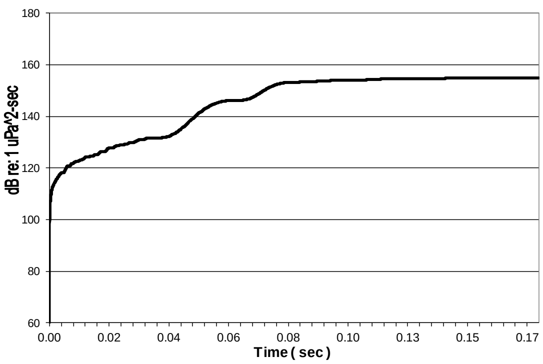


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	172	165	155

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

Figure 31: Waveform analysis of attenuated Pile 4, West of Foster 10M

WABN 24 Inch Pile 4 at 10m Broadband West of Foster Island

Figure a. Waveform

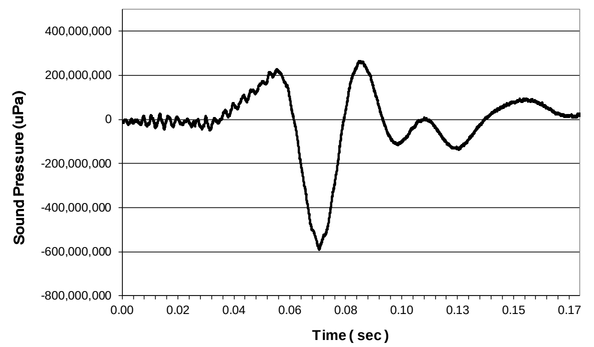


Figure b. Narrow Band Frequency Spectra

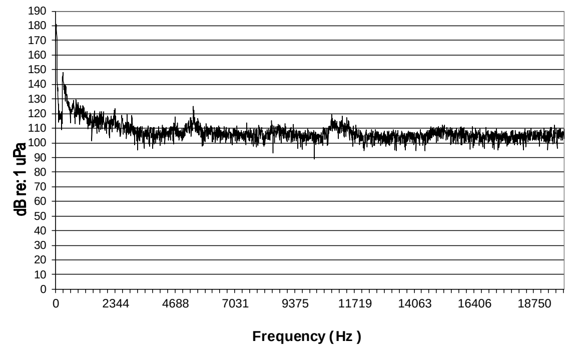


Figure c. Accumulation of Sound Energy

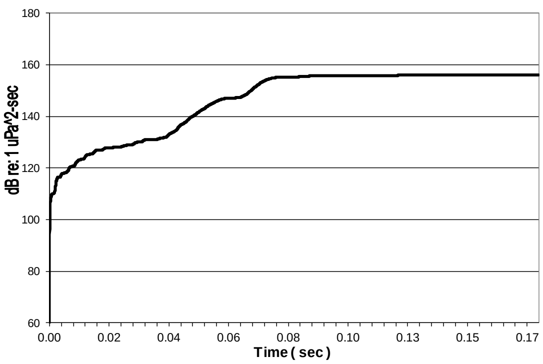


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	175	167	156

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

Figure 32: Waveform analysis of attenuated Pile 5, West of Foster 10M

WABN 24 Inch Pile 5 at 10m Broadband West of Foster Island

Figure a. Waveform

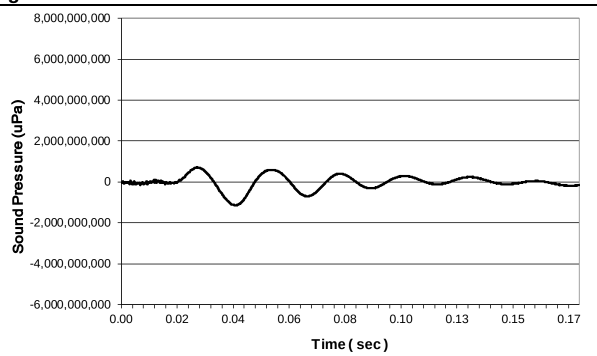


Figure b. Narrow Band Frequency Spectra

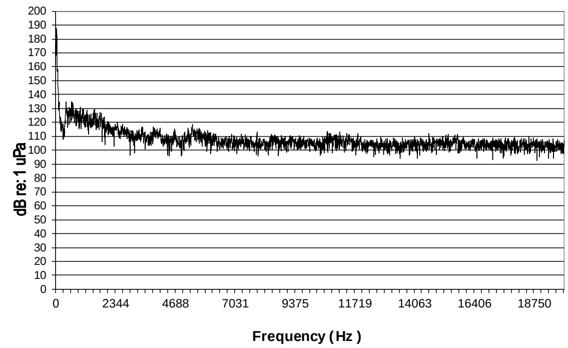


Figure c. Accumulation of Sound Energy

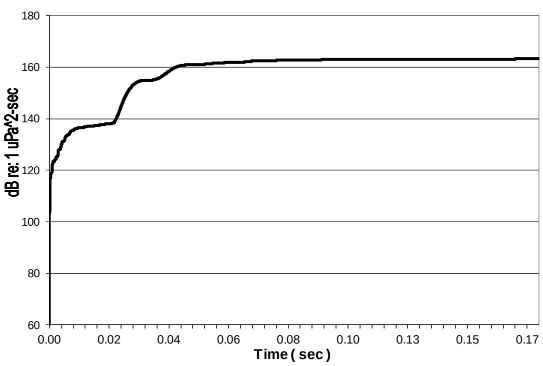


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	181	174	163

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

Figure 33: Waveform analysis of attenuated Pile 6, West of Foster 10M

WABN 24 Inch Pile 6 at 10m Broadband West of Foster Island

Figure a. Waveform

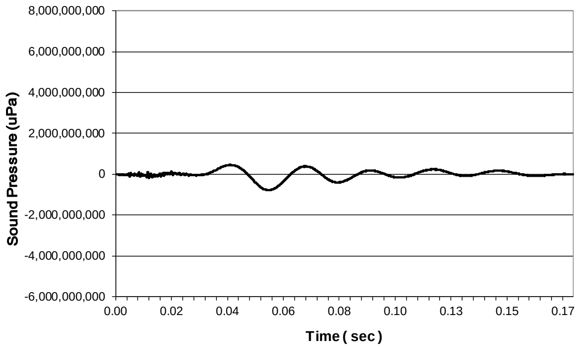


Figure b. Narrow Band Frequency Spectra

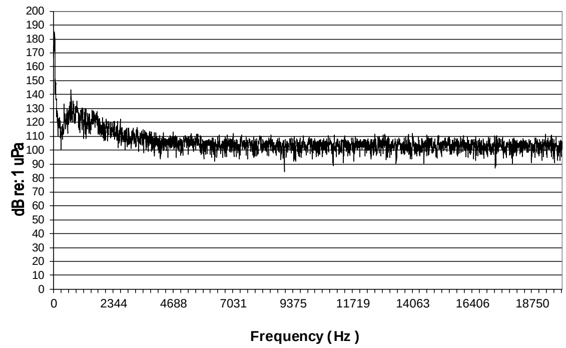


Figure c. Accumulation of Sound Energy

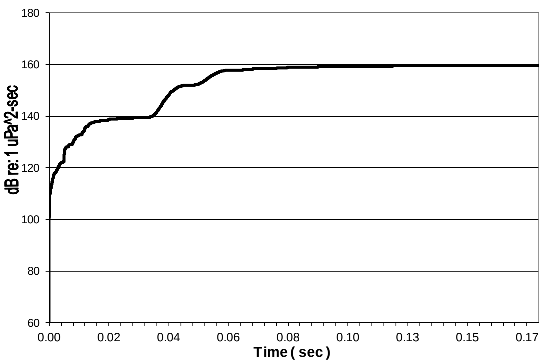


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	178	170	160

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

Figure 34: Waveform analysis of attenuated Pile 7, West of Foster 10M

WABN 24 Inch Pile 7 at 10m Broadband West of Foster Island

Figure a. Waveform

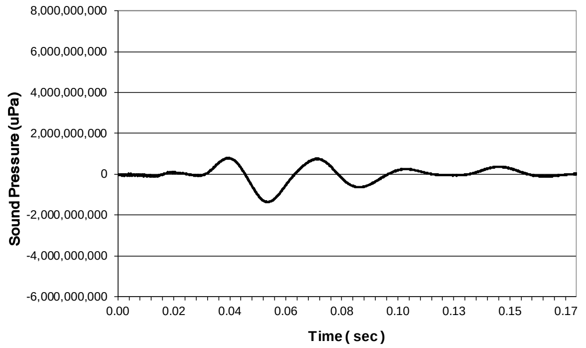


Figure b. Narrow Band Frequency Spectra

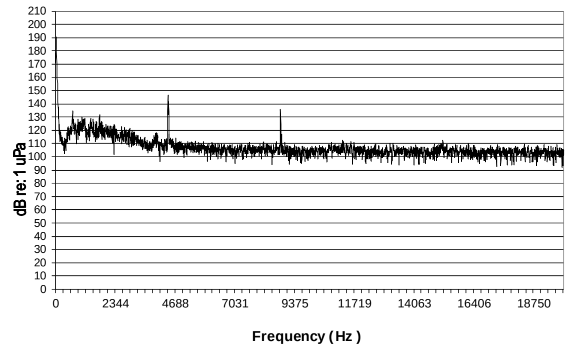


Figure c. Accumulation of Sound Energy

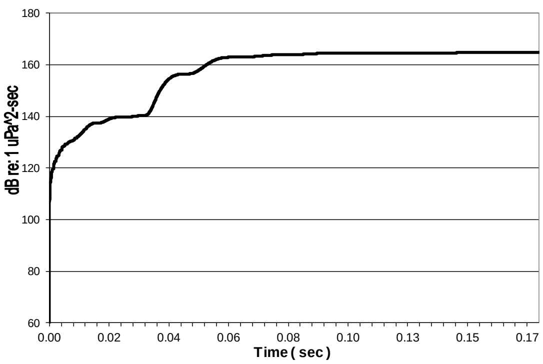


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	183	176	165

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

Figure 35: Waveform analysis of attenuated Pile 8, West of Foster 20M

WABN 24 Inch Pile 8 at 20m Broadband West of Foster Island

Figure a. Waveform

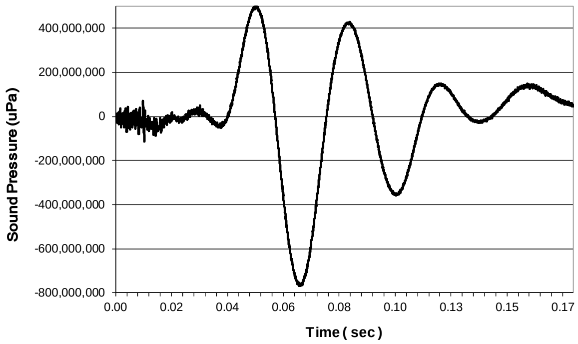


Figure b. Narrow Band Frequency Spectra

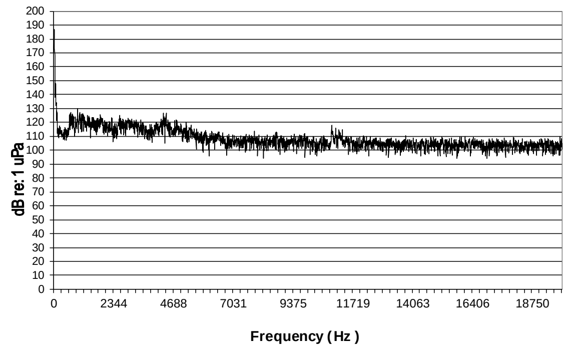


Figure c. Accumulation of Sound Energy

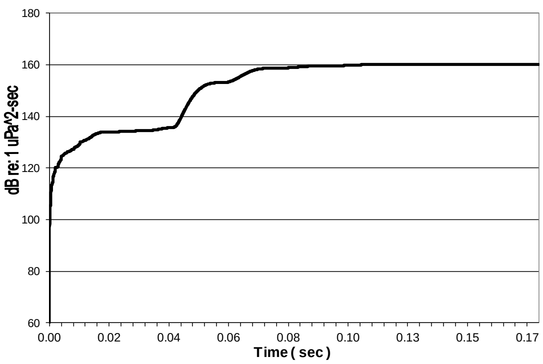


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
4.5-feet	178	172	160

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

Figure 36: Waveform analysis of attenuated Pile 9, West of Foster 10M

WABN 24 Inch Pile 9 at 10m Broadband West of Foster Island

Figure a. Waveform

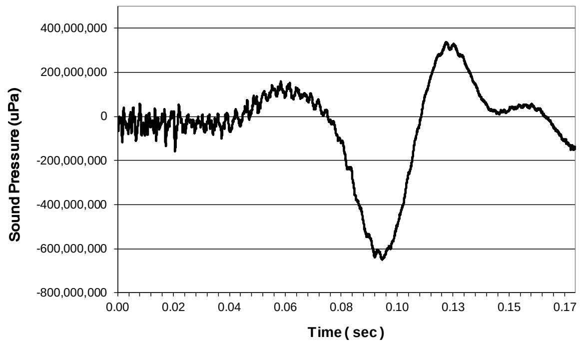


Figure b. Narrow Band Frequency Spectra

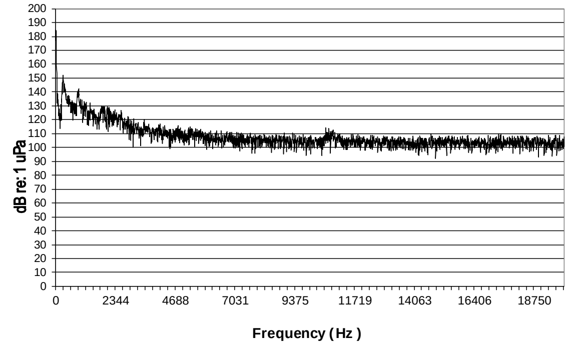


Figure c. Accumulation of Sound Energy

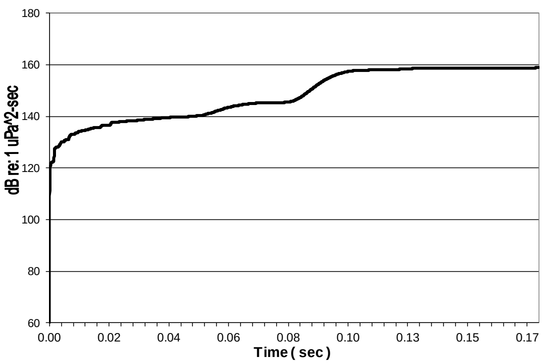


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
5-feet	176	172	159

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

Figure 37: Waveform analysis of attenuated Pile 10, West of Foster 10M

WABN 24 Inch Pile 10 at 10m Broadband West of Foster Island

Figure a. Waveform

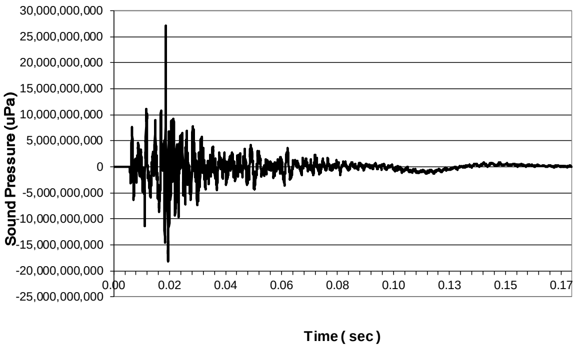


Figure b. Narrow Band Frequency Spectra

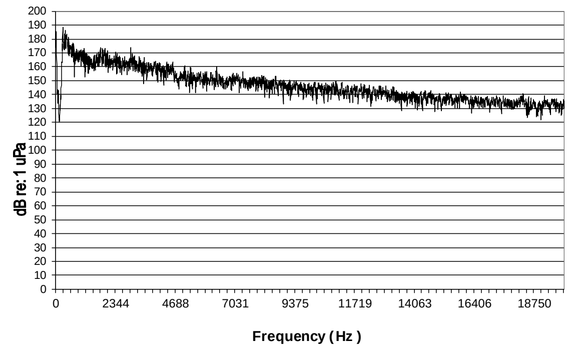


Figure c. Accumulation of Sound Energy

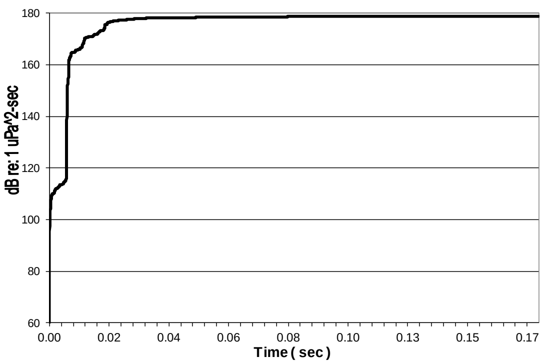


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
5-feet	209	191	179

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

Figure 38: Waveform analysis of attenuated Pile 11, West of Foster 10M

WABN 24 Inch Pile 11 at 10m Broadband West of Foster Island

Figure a. Waveform

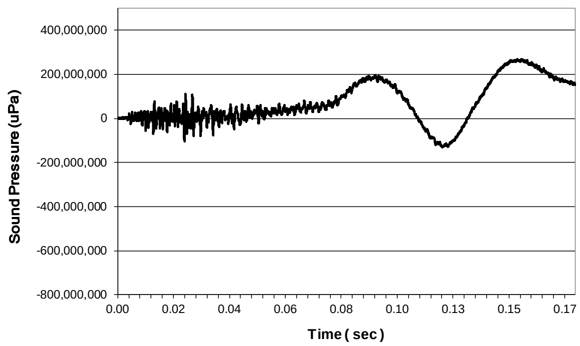


Figure b. Narrow Band Frequency Spectra

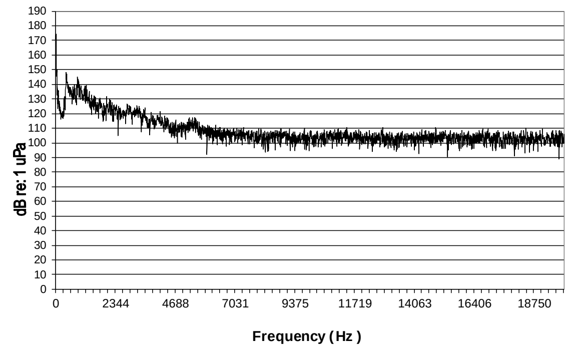


Figure c. Accumulation of Sound Energy

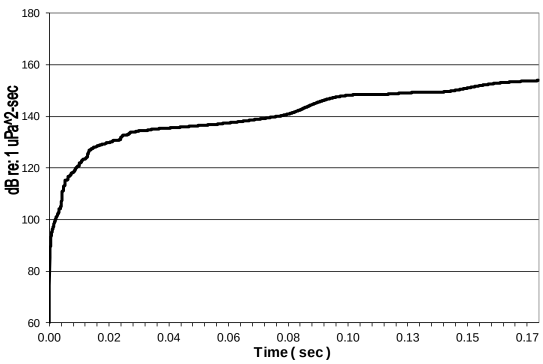


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
3-feet	169	164	154

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

Figure 39: Waveform analysis of attenuated Pile 12, West of Foster 10M

WABN 24 Inch Pile 12 at 10m Broadband West of Foster Island

Figure a. Waveform

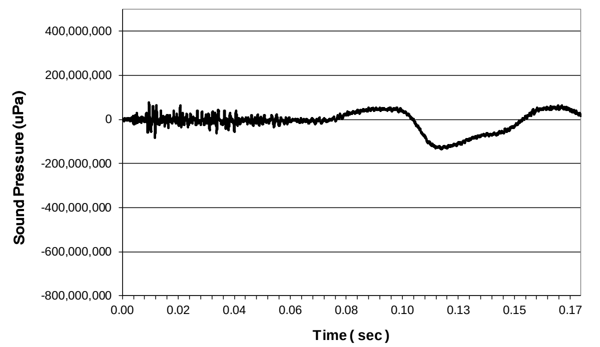


Figure b. Narrow Band Frequency Spectra

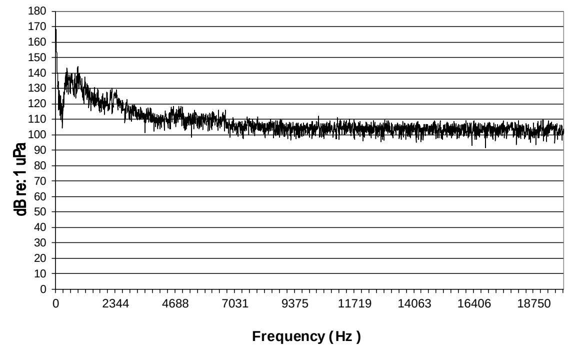


Figure c. Accumulation of Sound Energy

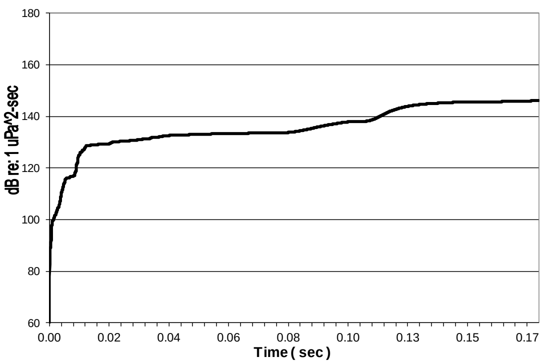


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
3-feet	163	155	146

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

Figure 40: Waveform analysis of attenuated Pile 13, West of Foster 12M

WABN 24 Inch Pile 13 at 12m Broadband West of Foster Island

Figure a. Waveform

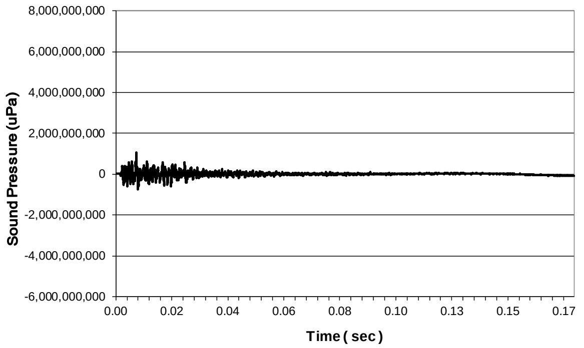


Figure b. Narrow Band Frequency Spectra

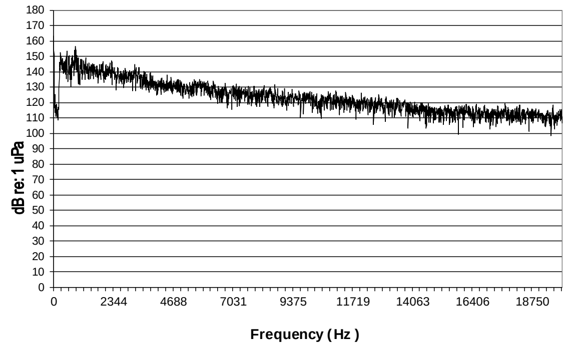


Figure c. Accumulation of Sound Energy

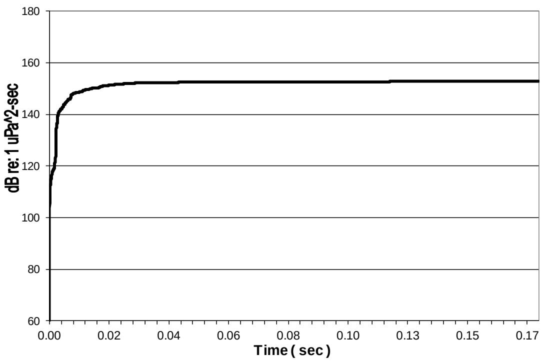


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	181	162	153

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

Figure 41: Waveform analysis of attenuated Pile 14, West of Foster 10M

WABN 24 Inch Pile 14 at 10m Broadband West of Foster Island

Figure a. Waveform

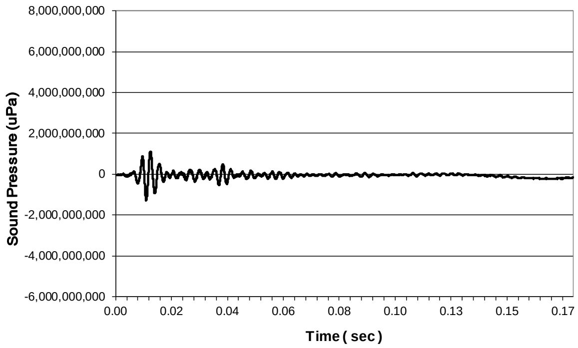


Figure b. Narrow Band Frequency Spectra

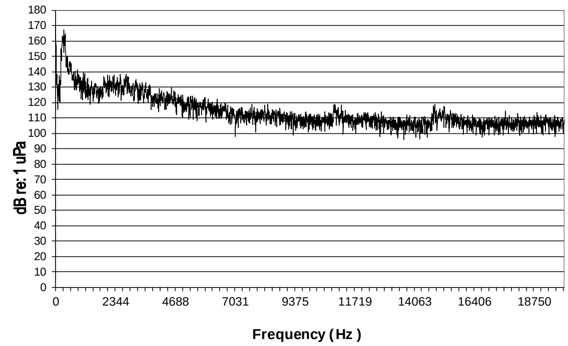


Figure c. Accumulation of Sound Energy

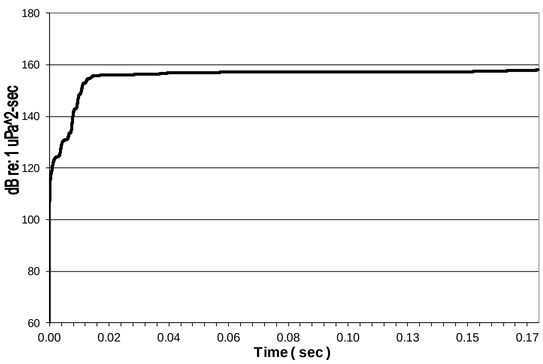


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	182	166	158

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

Figure 42: Waveform analysis of attenuated Pile 15, West of Foster 10M

WABN 24 Inch Pile 15 at 10m Broadband West of Foster Island

Figure a. Waveform

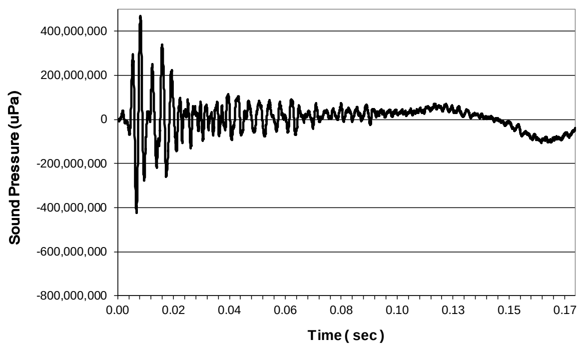


Figure b. Narrow Band Frequency Spectra

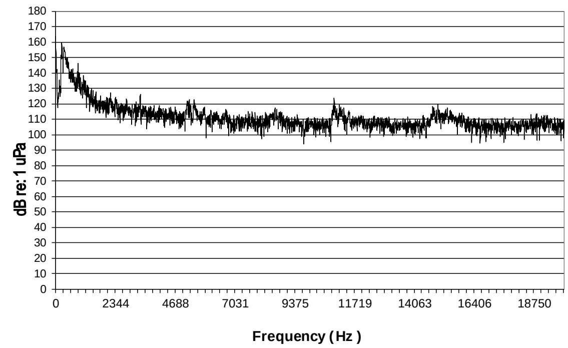


Figure c. Accumulation of Sound Energy

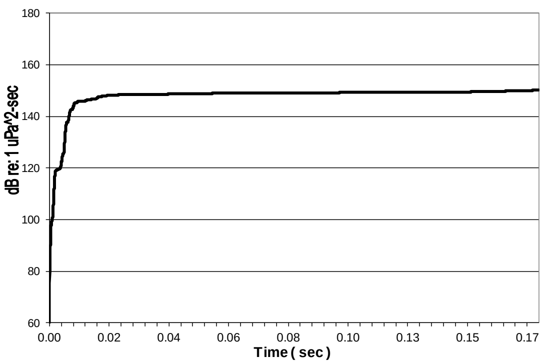


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	173	158	150

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

Figure 43: Waveform analysis of attenuated Pile 16, West of Foster 10M

WABN 24 Inch Pile 16 at 10m Broadband West of Foster Island

Figure a. Waveform

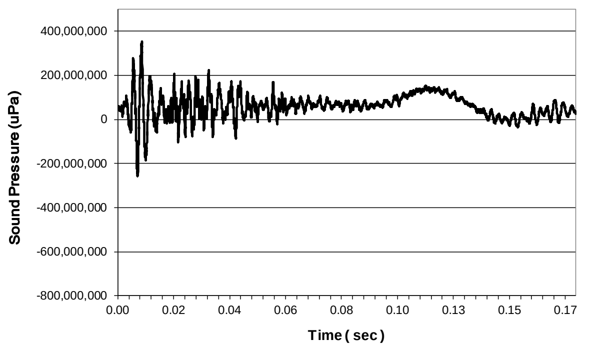


Figure b. Narrow Band Frequency Spectra

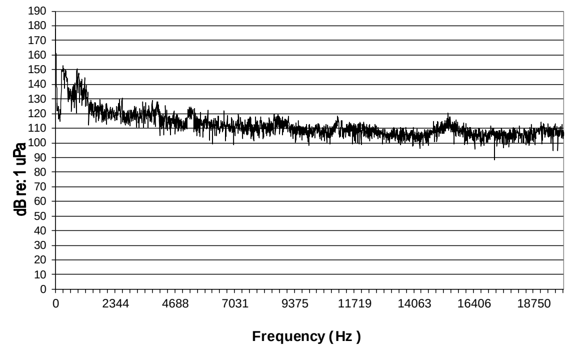


Figure c. Accumulation of Sound Energy

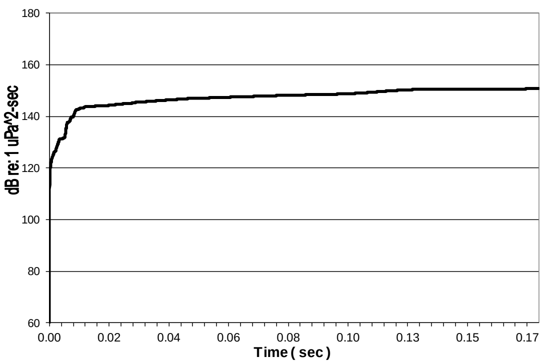


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	171	159	151

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

Figure 44: Waveform analysis of attenuated Pile 17, West of Foster 10M

WABN 24 Inch Pile 17 at 10m Broadband West of Foster Island

Figure a. Waveform

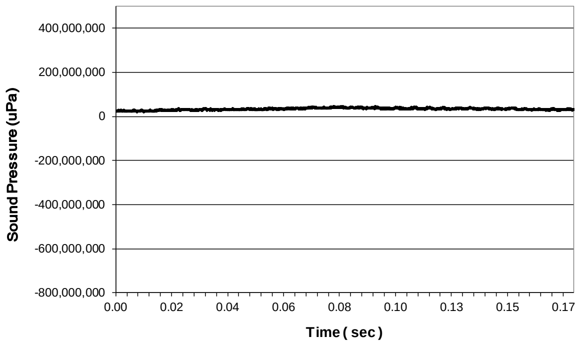


Figure b. Narrow Band Frequency Spectra

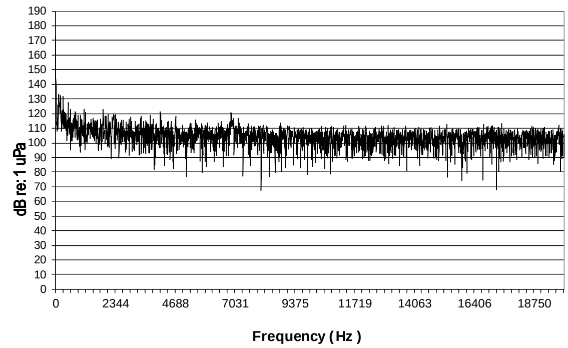


Figure c. Accumulation of Sound Energy

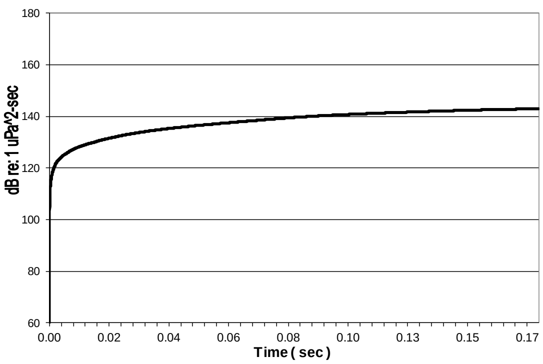


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	154	151	143

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

Figure 45: Waveform analysis of attenuated Pile 18, West of Foster 10M

WABN 24 Inch Pile 18 at 10m Broadband West of Foster Island

Figure a. Waveform

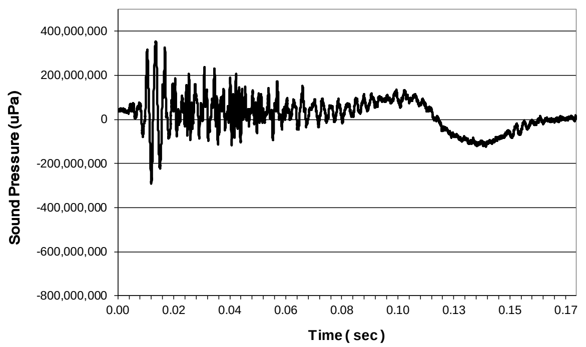


Figure b. Narrow Band Frequency Spectra

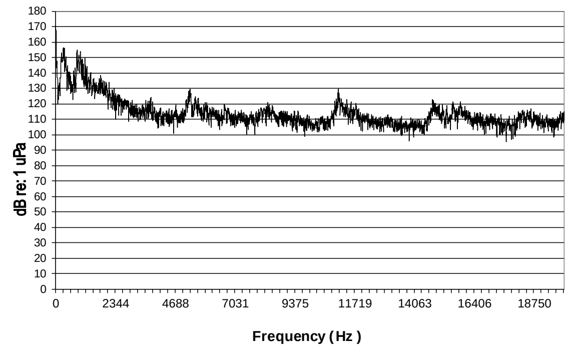


Figure c. Accumulation of Sound Energy

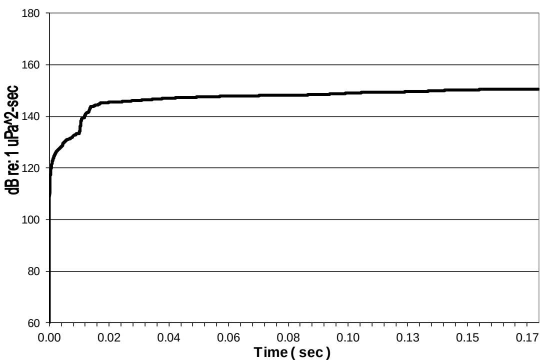


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	171	159	150

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

Figure 46: Waveform analysis of attenuated Pile 19, West of Foster 10M

WABN 24 Inch Pile 19 at 10m Broadband West of Foster Island

Figure a. Waveform

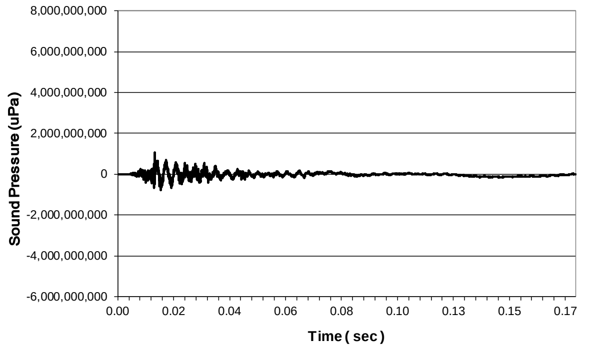


Figure b. Narrow Band Frequency Spectra

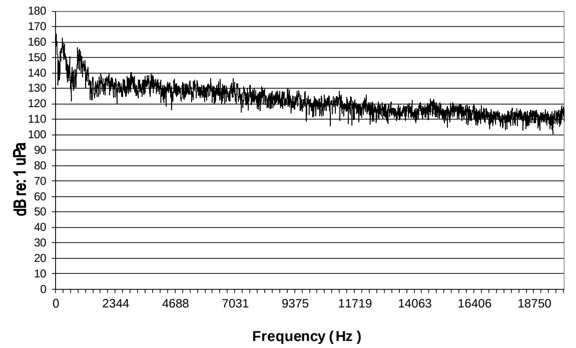


Figure c. Accumulation of Sound Energy

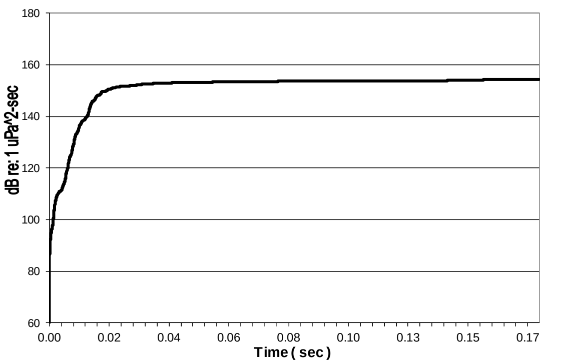


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	$RMS_{90\%}$*	SEL
6-feet	181	163	154

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

Figure 47: Waveform analysis of attenuated Pile 20, West of Foster 10M

WABN 24 Inch Pile 20 at 10m Broadband West of Foster Island

Figure a. Waveform

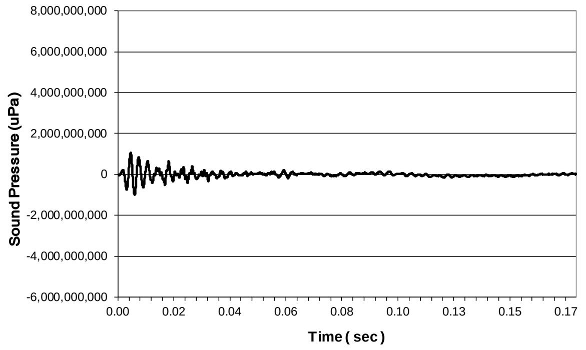


Figure b. Narrow Band Frequency Spectra

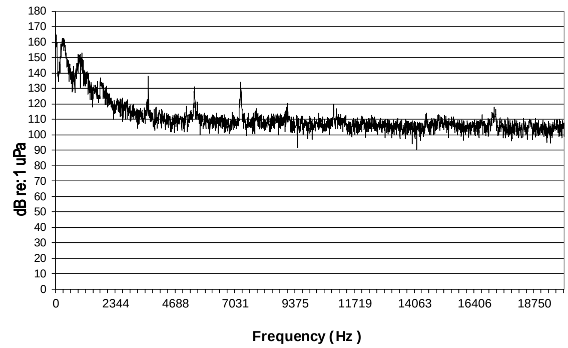


Figure c. Accumulation of Sound Energy

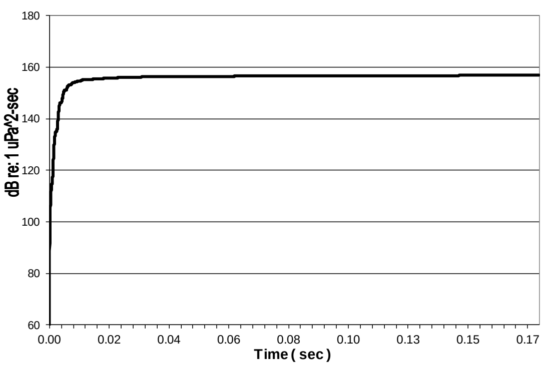


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
6-feet	181	167	157

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