SR 529 EBEY SLOUGH BRIDGE REPLACEMENT PROJECT

UNDERWATER SOUND LEVELS ASSOCIATED WITH DRIVING 72-inch STEEL PILES AT THE SR 529 EBEY SLOUGH BRIDGE REPLACMENT PROJECT

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EXECUTIVE SUMMARY

This technical report describes the data collected during impact pile driving efforts for the SR 529 Ebey Slough Bridge Project between October 2010 and January 2011. A total of six, 72-inch piles were driven with 1-inch walls (Table 1). The peak unattenuated sound levels at ranged between 165 for the pile driven above the Ordinary High Water Mark (OHWM) and 208 for piles driven in the water (Table 1). Only one strike on Pile 6 exceeded the 206 dB threshold. A confined bubble curtain utilizing a single ring at the bottom of the pile was tested as part of this project for its sound reduction properties for the in-water piles at Pier 4. The noise reduction achieved by the unconfined bubble curtain ranged from 16 dB to 30 dB (Table 1).

Background sound levels ranged between 142 dB RMS for broadband measurements and 131 dB RMS for high pass filtered background (Table 1). The confined bubble curtain achieved an average sound reduction of 22 dB.

Table 1: Underwater Monitoring Results, SR 529 Ebey Slough Bridge Replacement Project.

Pier Number	Pile	Date	Mitigation Type	Peak (dB)	Average RMS (dB)	Single Strike SEL (dB)	Average Peak (dB)	Average Noise Reduction (dB)
3	1	10/22/10	None	199	187	171	195	-
2	2	11/10/10	None	165	153	143	163	-
4	3	1/11/11	Unconfined Bubble Curtain	214	189	182	208	30
	4	1/6/11	Unconfined Bubble Curtain	186	170	161	184	16
	5	1/6/11	Unconfined Bubble Curtain	205	185	176	203	22
	6	1/11/11	Unconfined Bubble Curtain	208	189	181	205	26

INTRODUCTION

This technical report presents results of underwater sound levels measured during the driving of six 72-inch steel piles at the SR 529 Ebey Slough Bridge Replacement Project between October 2010 and January 2011.

The six piles were driven in three separate locations on three bridge piers. The water depths are dependent on tidal flux, however for Piers 2 and 3 piles were driven above the Ordinary High Water Mark (OHWM). The project site is located just south of the city of Marysville, Washington. The piles were driven immediately east of the Ebey Slough Bridge on State Route (SR) 529 which is just east of Interstate 5 (Figure 1).

Project Description

- The 72-inch piles were driven to prepare for the construction of the bridge piers.
- The project location is just south of Marysville, Washington (Figure 1).
- Water depths at the hydrophone monitoring locations varied from eight feet to 12 feet deep depending on the tidal flux.
- There was an approximate four foot tidal flux over a six hour period.
- No substantial currents were observed in the area monitored.

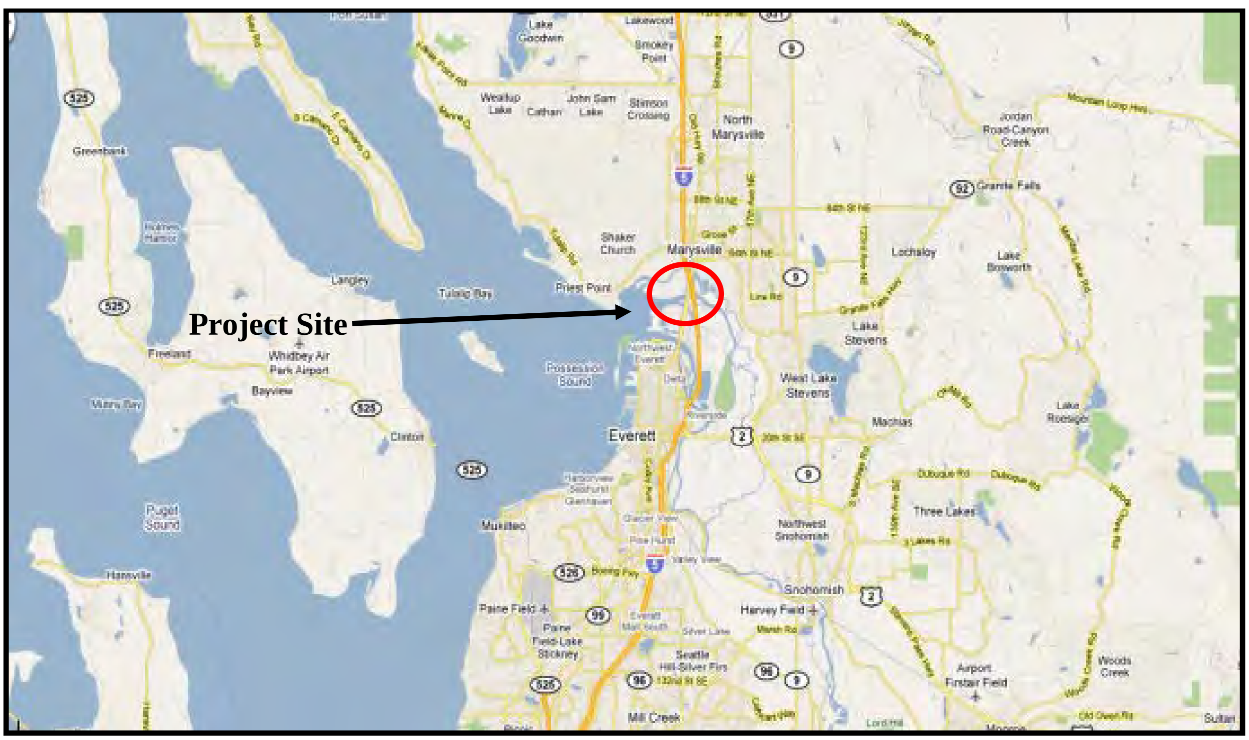


Figure 1: Location of SR 529 Bridge Replacement Project.

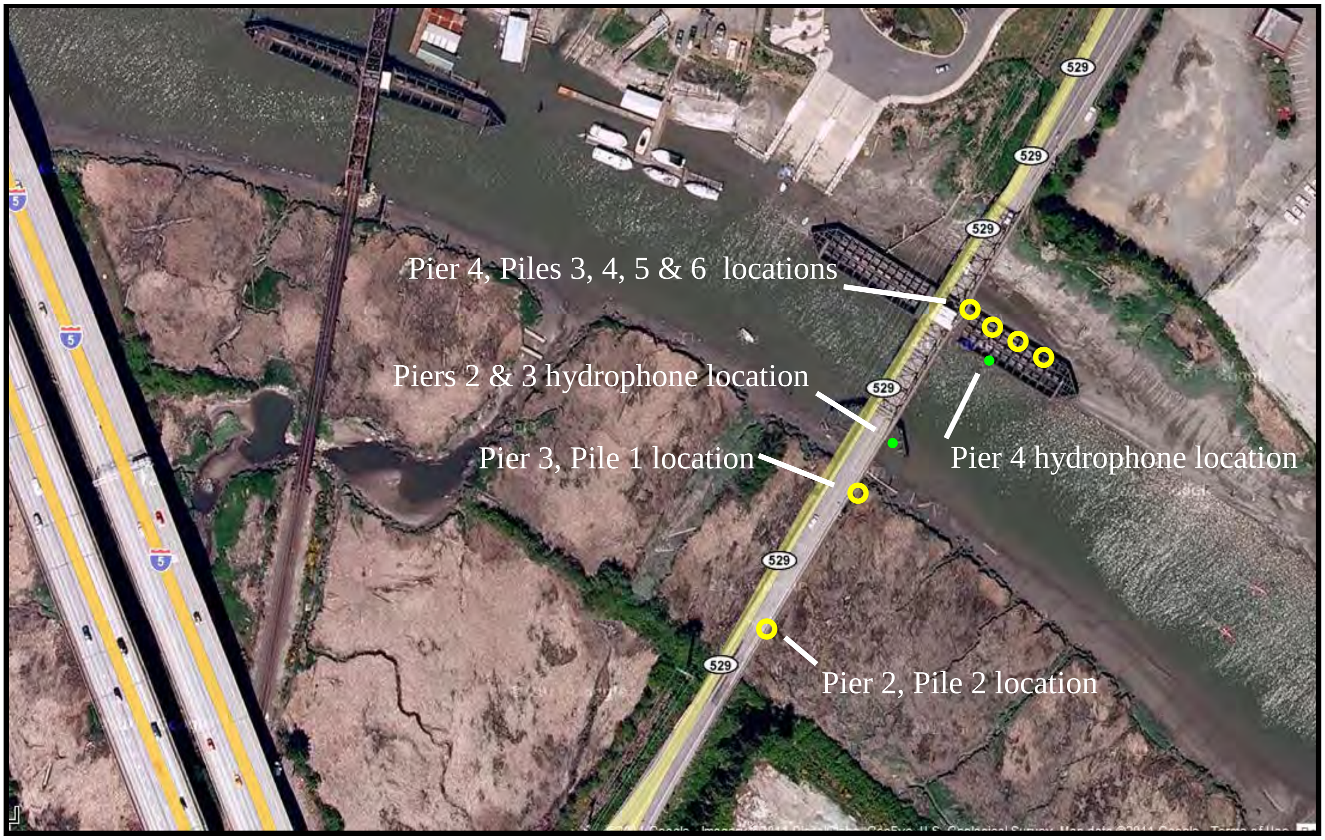


Figure 2: Approximate location of 72-inch piles and hydrophones at the SR 529 Ebey Slough Bridge Replacement Project.

○ **= 72-inch Steel Pile;** • **= Hydrophone**

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 National Marine Fisheries Service (NMFS) in criteria for judging impacts to marine mammals from underwater impulse-type sounds.

Rise time is used in waveform analysis to describe the characteristics of underwater impulses. Rise time is the time in microseconds (ms) it takes the waveform to go from background levels to absolute peak level.

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 (sum of squared pressures in the band)

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 (summing all frequencies) of a broadband sound exceeds the level in any single 1/3-octave band.

METHODOLOGY

Equipment

Underwater sound levels were measured near the pile (near field) using one Reson TC 4013 hydrophone deployed on a nylon cord off the side of the Ebey Slough bridge. The hydrophone was positioned at a distance of between 10 and 74 meters from the individual pile being monitored and at either mid-water level or one foot from the bottom depending on the stage of tidal flux. 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 (Figure 3). The output of the Nexus signal conditioner is received by a Dactron Photon 4-channel signal spectrum analyzer that is attached to an Itronix GoBook II laptop computer (Figure 3).

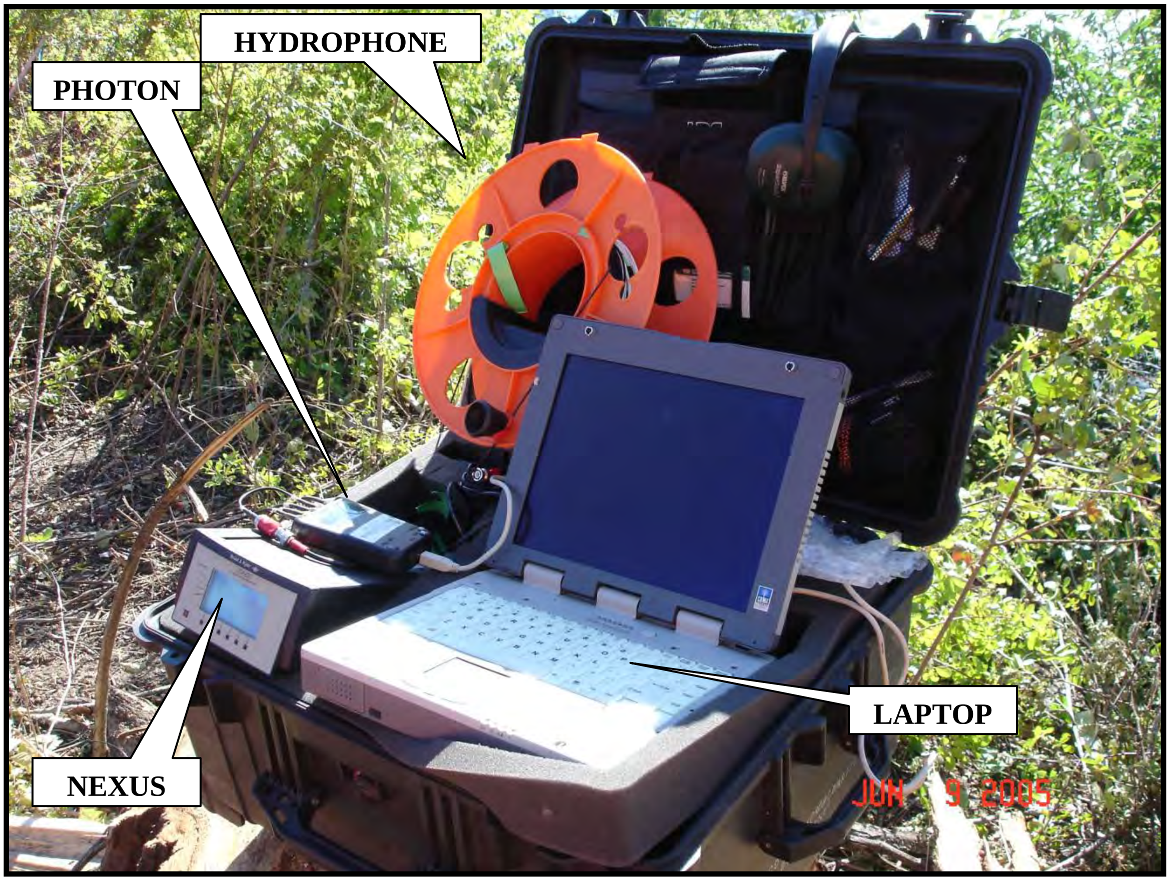


Figure 3: Near field acoustical monitoring equipment

The waveform of the pile strikes along with the number of strikes, overpressure minimum and maximum, absolute peak values, and RMS sound levels, integrated over 90% of the duration of the pulse, were captured and stored on the laptop hard drive for subsequent signal analysis. The system and software calibration is checked annually against a NIST traceable standard.

Calibration

The operation of the near field hydrophones were checked daily in the field using a GRAS type 42AC high-level pistonphone with a hydrophone adaptor. The pistonphone signal was 146 dB re: 1 μPa. The pistonphone signal levels produced by the pistonphone and measured by the measurement system were within 1.0 dB and the operation of the system was judged acceptable over the study period.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 41.7 μs (24,000 Hz). This sampling rate is more than sufficient for the bandwidth of interest for underwater pile driving impact sound and gives 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 high degree of variability between the absolute peaks for each pile 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.

Hydrophone Location

The location of the hydrophones is determined by allowing a clear line of sight between the pile and the hydrophone, with no other structures nearby. The distance from the pile to the hydrophone location was measured using a Bushnell Yardage Pro rangefinder. The hydrophone was attached to a weighted nylon cord anchored with a five-pound weight. The cord and hydrophone cables were lowered off the side of the bridge (Figure 4). For those piles driven above the OHWM the hydrophone was located in the water and as close as possible to the pile.

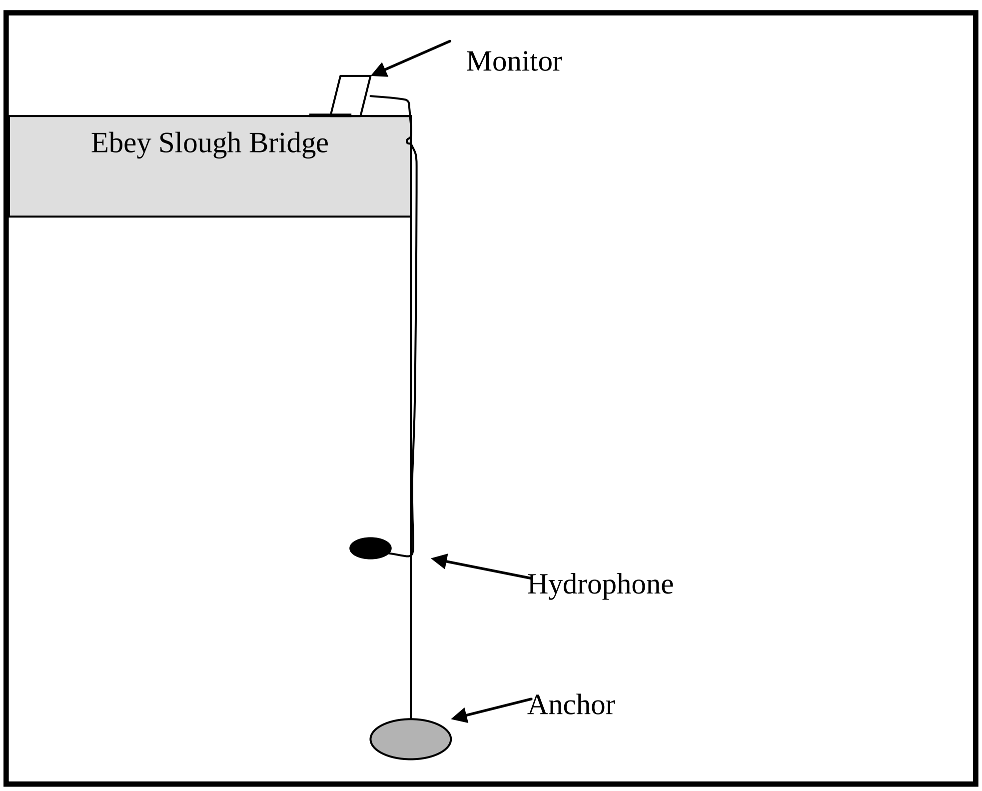


Figure 4: Diagram of hydrophone deployment configuration.

SEL

An estimation of individual SEL values was calculated for each pile strike by calculating a 1-second L_{eq} for each individual pile strike. As can be seen in equation 1 below the SEL is essentially a subset of the LEQ function. When the time interval for the L_{eq} is set to one second it is equal to the SEL.

$$L_{eq,T} = 10\lg\left(\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0{}^2}dt\right) \quad dB \qquad = \qquad SEL = 10\lg\left(\int_{-\infty}^{\infty} \frac{p^2(t)}{p_0{}^2}dt\right) \quad dB \qquad \text{(eq. 1)}$$

Through negotiations with the National Marine Fisheries (NMFS) it was determined that a cumulative threshold of 204 $dB_{SE}L$ would be used as the threshold for this project instead of the standard interim threshold of 187 dB_{SEL}.

Pier 3

A vibratory hammer was used to drive three piles welded together to a tip depth of approximately 220 feet. The pile was then driven an additional two feet to bearing depth with a diesel impact hammer. The diesel impact driver was a diesel hammer rated to a maximum of 246,390 foot pounds. This is the maximum energy output for the diesel hammer that can only be sustained for a few seconds at a time. Actual operation of the diesel hammer is more likely to be approximately 50% to 70% of this maximum energy for most pile installations.

Pier 2

A vibratory hammer was used to drive two piles welded together to approximately 183 feet depth. The pile was then spliced with a third pile and driven the additional 160 feet with an impact hammer.

Pier 4

A vibratory hammer was used to drive three piles welded together to a tip depth of approximately 228.5 feet. The pile was then driven an additional two feet to bearing depth with a diesel impact hammer. All four 72-inch piles were monitored for Pier 4.

Substrate

The substrate consisted of relatively soft sandy silt. Piles driven were open-ended hollow steel piles, 72-inches in diameter with a 1-inch wall thickness. All measurements were made between 10 meters and and 74 meters from the pile, midwater depth.

Confined Bubble Curtain Design

A confined bubble curtain with a single ring at the bottom was tested as a part of this project (Figure 5). The bubble curtain is placed around the pile being driven with the ring on the substrate. The compressor was attached with a separate hose on each half of the ring and maintained a flow of 32.91 cubic feet per minute per linear foot of pipe. The bubble curtain was constructed using 3-inch diameter Schedule 80 PVC pipe and 1/16-inch diameter air holes at ¾-inch on center in four rows. The manifold was attached to a square steel frame which weighted it to the substrate. The original drawing (Figure 5) indicates that there were four air filled bumpers/spacers on the inside of the ring to act as resilient pile guides. However, in the field these were not used because the ring was able to maintain adequate distance from the pile during operation.

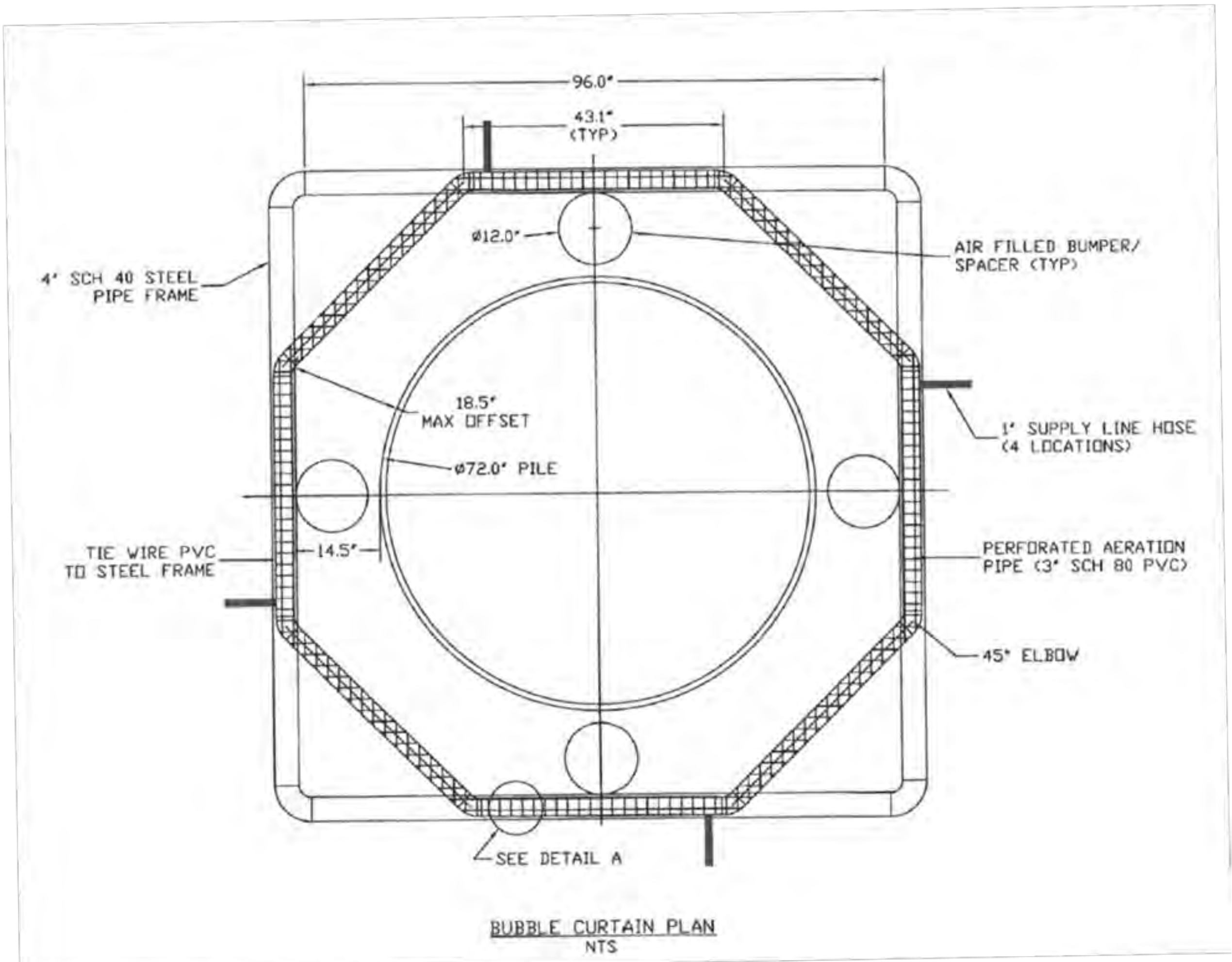


Figure 5: Diagram of unconfined bubble curtain.

RESULTS

Underwater Sound Levels

There are many interesting attributes of the waveforms of different piles and mitigation types that will become evident (Figures 6 to 17). A brief description of the piles and pile types that were tested are as follows:

Pier 3, Pile 1

All piles were driven with a diesel hammer. Pile 1 was driven 10 feet above the OHWM in water saturated soils. No mitigation was used on this pile because it was driven above the water line.

The results of monitoring for Pile 1(Table 2) indicates:

- The highest absolute peak from the hydrophone at 4 feet (midwater) is 199 dB_{peak} and did not exceed the 206 dB_{peak} interim threshold.
- The average RMS at 4 feet depth is 180 dB_{RMS}.
- The highest single strike Sound Exposure Level (SEL) for the peak strike at 4 feet water depth is 171 dB_{SEL}.

The waveform analysis for Pile 1 indicates that there was a relatively short delay between the initial onset of the impulse and the unattenuated absolute peak (rise time of 0.7 milliseconds) (Appendix A, Figure 9).

The 1/3rd Octave frequency distribution for Pile 1 (Figure 6)range between 125 Hz and 500 Hz and there are potentially three dominant frequencies at 125 Hz, 250 Hz and 500 Hz.

The attenuated cumulative SEL was calculated based on an individual single strike SEL calculated for each pile strike and calculated based on the total number of strikes and the highest single strike SEL value (Table 2). The cumulative SEL based on the total number of strikes and the highest single strike SEL value was 194 $dBSEL_{cum}$ after 192 strikes. The cumulative SEL calculated based on the SEL calculated for each pile strike was 168 $dBSEL_{cum}$. Therefore, the cumulative SEL using either method did not exceed the 204 $dBSEL_{cum}$ threshold set by the US Fish and Wildlife in the Biological Opinion for this project. It would have conservatively required 2239 strikes for Pile 1 to exceed this threshold. This estimate is based on the total number of strikes per day and the highest single strike recorded for the same day.

The cumulative SEL values calculated for each individual pile strike (Figure 7, blue line) were compared against the more conservative cumulative SEL calculation based on the total number of pile strikes (red dashed line). The two methods differ on average by about 44 decibels with the individual strike method being substantially lower.

Table 2: Summary of Underwater Sound Levels for the SR 529 Ebey Slough Bridge Replacement Project, 72-inch Steel Piles.

Pile	Date	Hydrophone Depth (feet)	Mitigation Type	Highest Absolute Peak (dB)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Total # of Strikes	Avg. Peak ± s.d. (Pascals)	Avg. dB_{peak}	Avg. Reduction[2] (dB)	Highest Single Strike SEL (dB)	Rise Time (millesec.)	Cumulative SEL (dB)
1	10/22/10	4	None[5]	199[1]	970 ± 250	180	192	5934 ± 1633	195	-	171	0.7	168
2	11/10/10	8	None[5]	165	32 ± 5	150	276[4]	142 ± 24	163	-	143	2.8	142
3	1/11/11	10	Bubbles Off	214	2742 + 550	189	26	25005 + 7727	208	-	182	0.3	-
			Bubbles On	177[1]	223 + 161	167	121	762 + 1178	178	30	158	7.1	155
			Bubbles Off	200	689 + 141	177	26	5794 + 1832	195	-	168	7.1	-
4	1/6/11	4	Bubbles Off	177	118 + 31	161	22	475 + 170	174	-	155	2.9	-
			Bubbles On	173	96 + 13	160	243	334 + 74	170	14	151	2.3	151
			Bubbles Off	186[1]	303 + 56	170	22	1567 + 301	184	-	161	1.1	-
			Bubbles On	179	42 + 40	152	88	195 + 192	166	18	155	1.3	-
5	1/6/11	14	Bubbles Off	205	1694 + 227	185	22	14067 + 1731	203	-	176	0.6	-
			Bubbles On	181	238 + 61	168	136	769 + 474	178	25	161	4.5	156
			Bubbles Off	184	785 + 328	178	29	5221 + 2103	194	-	159	0.3	-
			Bubbles On	177	206 + 23	166	73	584 + 119	175	19	156	3.1	-
			Bubbles Off	187	878 + 317	179	25	7328 + 2974	197	-	162	0.4	-
6	1/11/11	10	Bubbles Off	208	2837 + 413	189	21	18157 + 2705	205	-	181	0.7	-
			Bubbles On	172[1]	133 + 13	162	109	434 + 37	173	32	151	2.6	140
			Bubbles Off	181	672 + 155	177	19	4729 + 1484	193	-	156	0.6	-
			Bubbles On	173	141 + 24	163	124	474 + 100	174	19	151	1.6	-
									Average:	**22**			

[1] – Peak represents underpressure.
[2] – Average reduction is calculated by subtracting the average peak sound level for each mitigation strategy employed from the average peak unmitigated Pile 1.
[3] – A cumulative SEL of 204 dB was agreed upon between the Services and WSDOT for this project on the 72-inch piles.
[4] – Not all pile strikes monitored once it was clear that the cumulative SEL would only be exceeded after over a million pile strikes.
[5] – Pile driven above the Ordinary High Water Mark (OHWM).

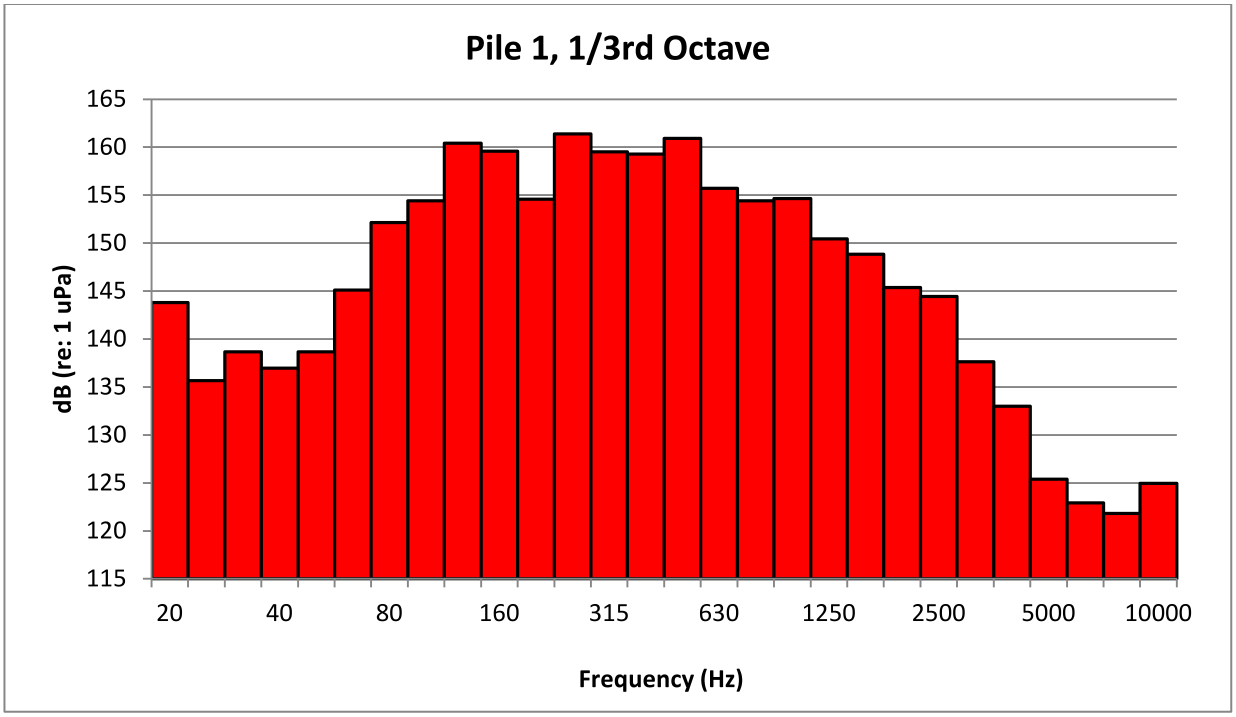


Figure 6: 1/3rd Octave frequency distribution for impact pile driving of Pile 1.

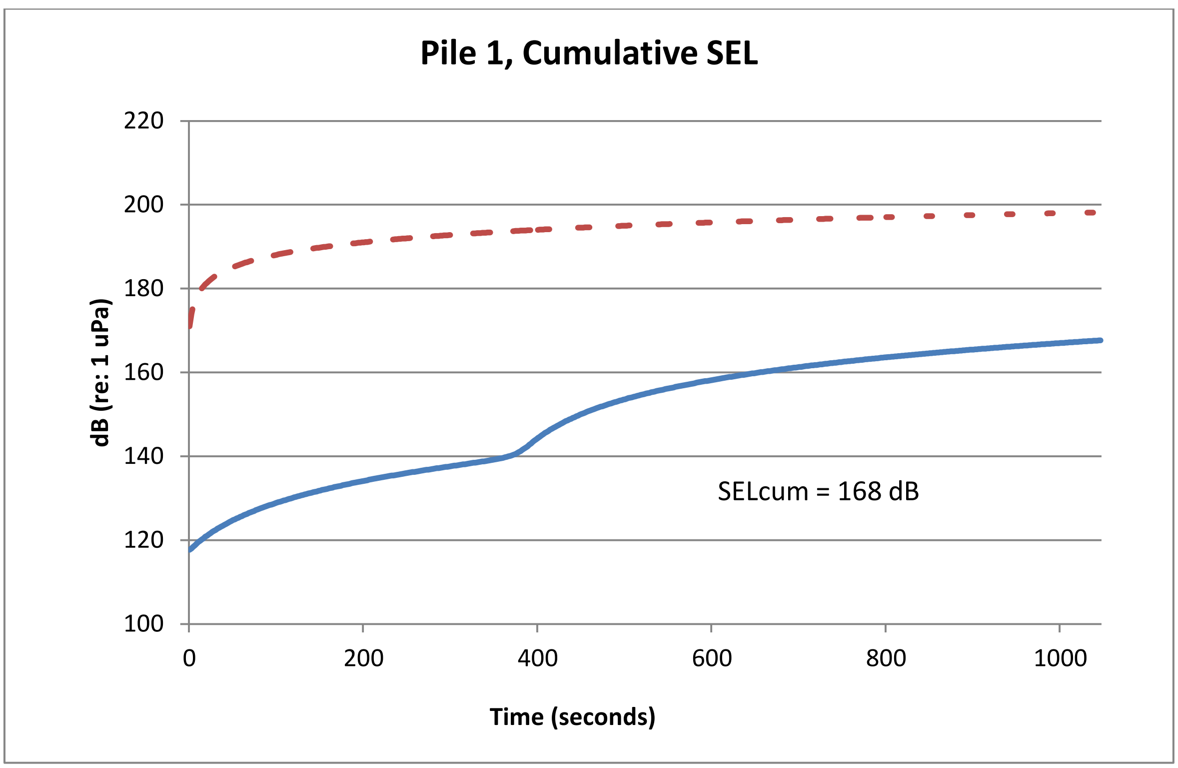


Figure 7: Cumulative SEL plot for Pile 1 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the total number of strikes (red-dashed).

Pier 2, Pile 2

Pile 2 was driven at Pier 2 approximately 230 feet above the OHWM in saturated soils. The hydrophone for Pile 2 was located 243 feet from the pile. No bubble curtain was used.

The results of monitoring for Pile 2 indicate (Table 2):

- The highest absolute peak at the hydrophone at 8 feet (midwater) is 165 dB_{peak} and did not exceed the 206 dB_{peak} interim threshold.
- The average RMS at 8 feet depth is 150 dB_{RMS}.
- The highest single strike SEL for the peak strike at 8 feet water depth is 143 dB_{SEL}.

The attenuated cumulative SEL did not exceed the 204 $dBSEL_{cum}$ threshold after 276 strikes and would not have exceeded until the pile was struck for 1,258,925 strikes (Table 2). The SEL was estimated for each individual pile strike by calculating a 1-second SEL for each pile strike. Plots of the cumulative SEL values for each pile strike (Figure 9, blue line) compares the calculated cumulative SEL based on the number of strikes (Figure 9, red dashed line). The two methods differ on average by about 31 decibels with the individual strike method being substantially lower. Neither method of calculating the cumulative SEL exceeded the 204 $dBSEL_{cum}$ threshold.

The dominant 1/3rd Octave frequency distribution for Pile 2 range between 250 Hz and 400 Hz with a peak at 250 Hz (Figure 8). There is a clear dominant lower frequency with relatively little energy at the lowest and highest frequencies. This is likely due to Pile 2 being driven 230 feet above the OHWM, which means that virtually all of the sound entering the water at the hydrophone is being transmitted through the substrate. The substrate will quickly attenuate the higher frequencies and some of the lower frequencies due to the compression of the substrate around the pile and over this distance.

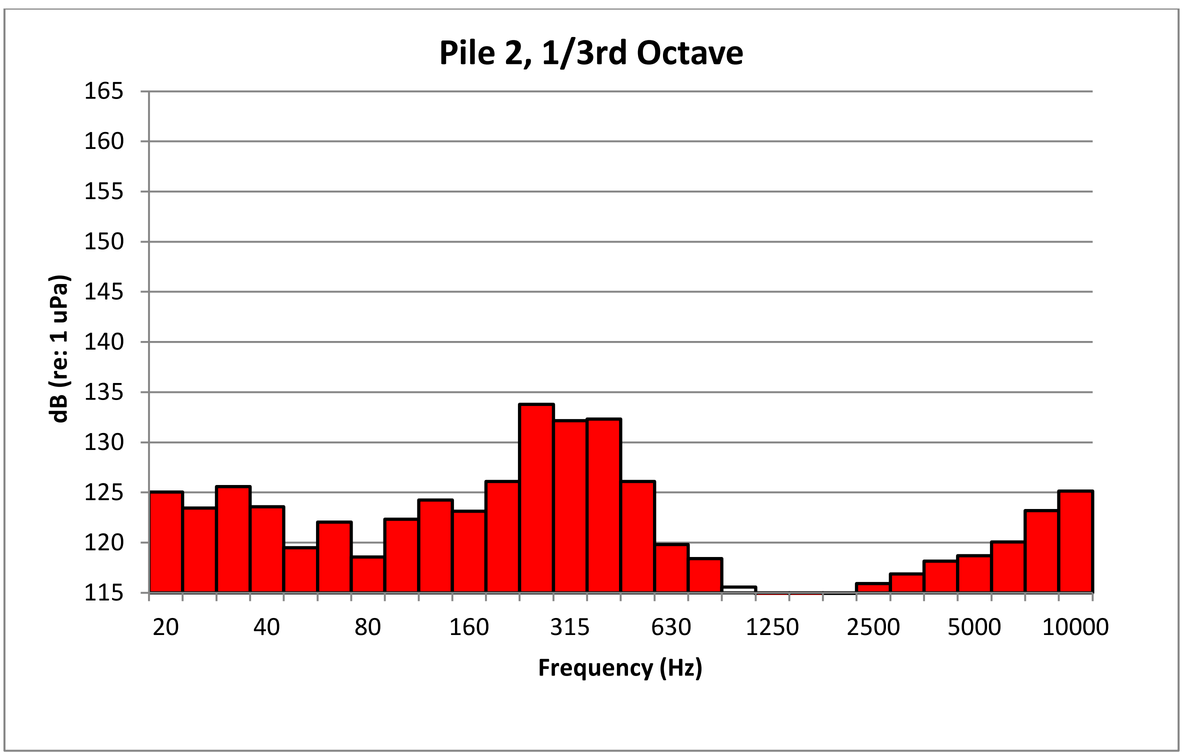


Figure 8: 1/3rd Octave frequency distribution for impact pile driving of Pile 2.

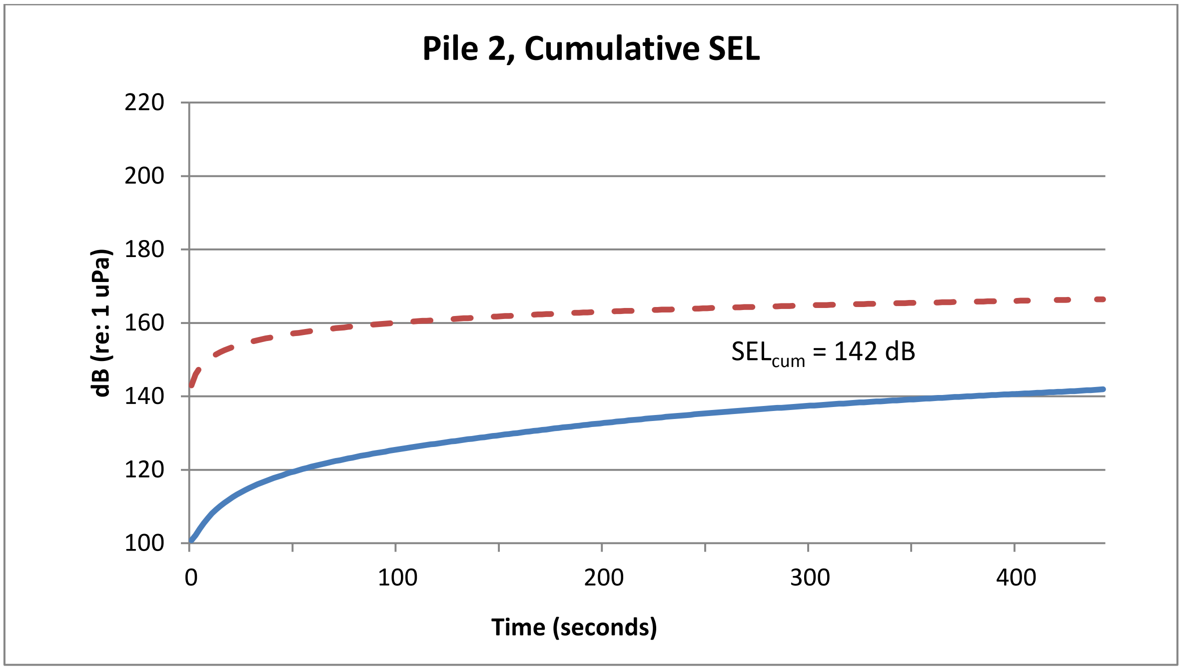


Figure 9: Cumulative SEL plot for Pile 2 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the number of strikes (red-dashed).

Pier 4, Pile 3

Pile 3 was driven at Pier 4 in approximately seven feet of water with the hydrophone 33 feet from the pile. The bubble curtain was used during the impact drive with the bubbles turned off briefly at the start of the drive, on in the middle of the drive and then off briefly at the end of the drive.

The results of monitoring for Pile 3 indicate (Table 2):

- The highest absolute peak of 214 dB$_{peak}$ was with the bubbles turned off, the hydrophone 10 feet deep and one foot from bottom.
- The average RMS at 10 foot depth ranged from 177 dB$_{RMS}$ to 189 dB$_{RMS}$ with the bubbles off and was 167 dB$_{RMS}$ with the bubbles turned on.
- The highest single strike SEL for the peak strike was 168 dB$_{SEL}$ with the bubbles turned off.

The attenuated cumulative SEL of 155 dBSEL$_{cum}$ did not exceed the 204 dBSEL$_{cum}$ threshold after 121 strikes (Table 2). The SEL was estimated for each individual pile strike while the bubble curtain was active by calculating a 1-second SEL for each pile strike. Plots of the cumulative SEL values for each pile strike (Figure 11, blue line) compares this against the calculated cumulative SEL based on the number of strikes (Figure 11, red dashed line). The two methods differ on average by about 32 decibels with the individual strike method being substantially lower. Neither cumulative SEL exceeded the 204 dBSEL$_{cum}$ threshold.

The 1/3rd Octave frequency distribution for Pile 3 shows that the dominant frequency was 50 Hz and a secondary lesser peak at 200 Hz (Figure 10). Most of the energy is below 500 Hz.

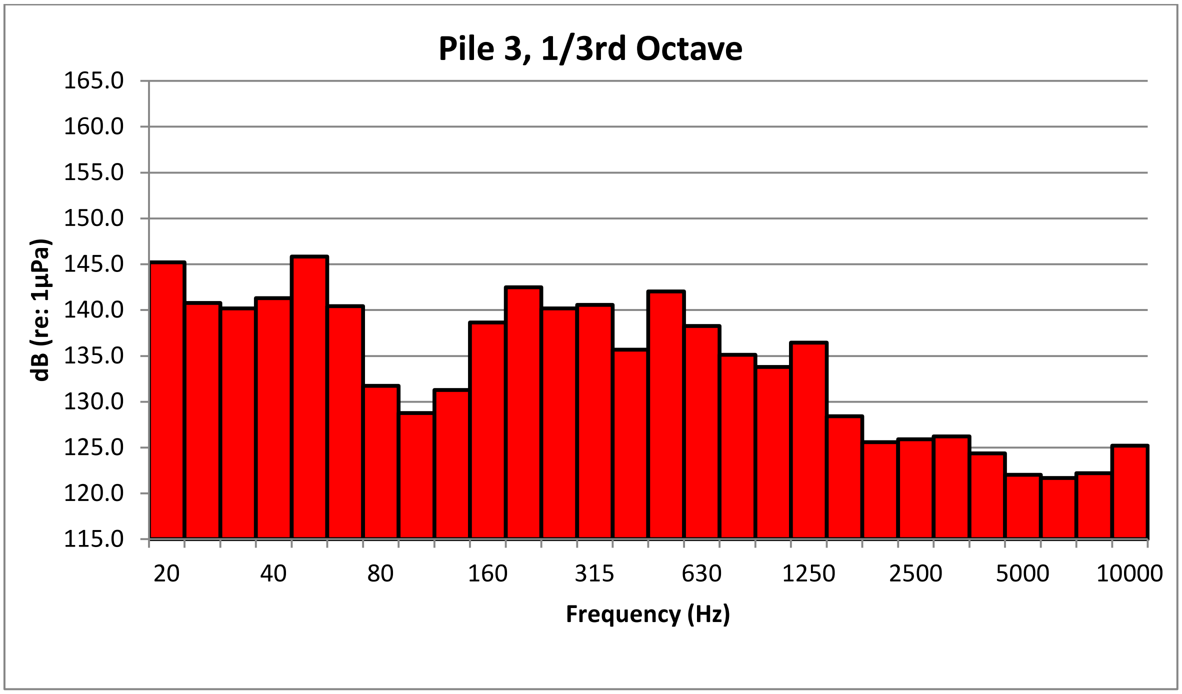


Figure 10: 1/3rd Octave frequency distribution for impact pile driving of Pile 3.

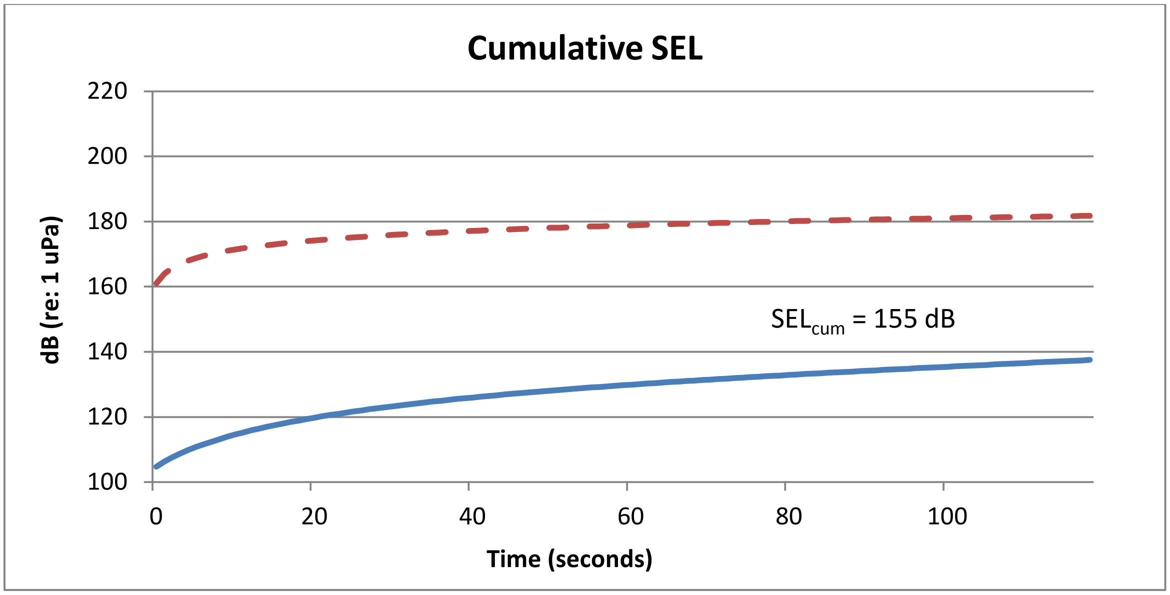


Figure 11: Cumulative SEL plot for Pile 3 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the number of strikes (red-dashed).

Pier 4, Pile 4

Pile 4 was driven at Pier 4 in approximately six feet of water. The hydrophone for Pile 4 was 49 feet from the pile in 15 feet of water, one foot from the bottom. The bubble curtain was used during the impact drive of Pile 3 with the bubbles turned off briefly at the start of the drive, on in the middle of the drive, off briefly near the end of the drive and then on again at the end of the drive.

The results of monitoring for Pile 4 indicates (Table 2):

- The highest absolute peak at the hydrophone at 14 feet depth (one foot from bottom) is 186 dB_{peak}.
- The average RMS at 14 feet depth ranged from 161 dB_{RMS} to 170 dB_{RMS} with the bubbles off and between 152 dB_{RMS} and 160 dB_{RMS} with the bubbles on.
- The highest single strike SEL for the peak strike at 14 feet water depth is 161 dB_{SEL} with the bubbles off.

The 1/3rd Octave frequency distribution for Pile 4 shows that the dominant frequency was 250 Hz and a lesser secondary peak at 40 Hz (Figure 12). Most of the energy was below 400 Hz.

The cumulative SEL of 151 $dBSEL_{cum}$ did not exceed the 204 $dBSEL_{cum}$ threshold after 331 strikes (Table 2). The attenuated SEL was estimated for each individual pile strike while the bubble curtain was active by calculating a 1-second SEL for each pile strike. The cumulative SEL value for each pile strike differs on average by about 43 decibels with the individual strike method (Figure 13). Neither cumulative SEL exceeded the 204 $dBSEL_{cum}$ threshold.

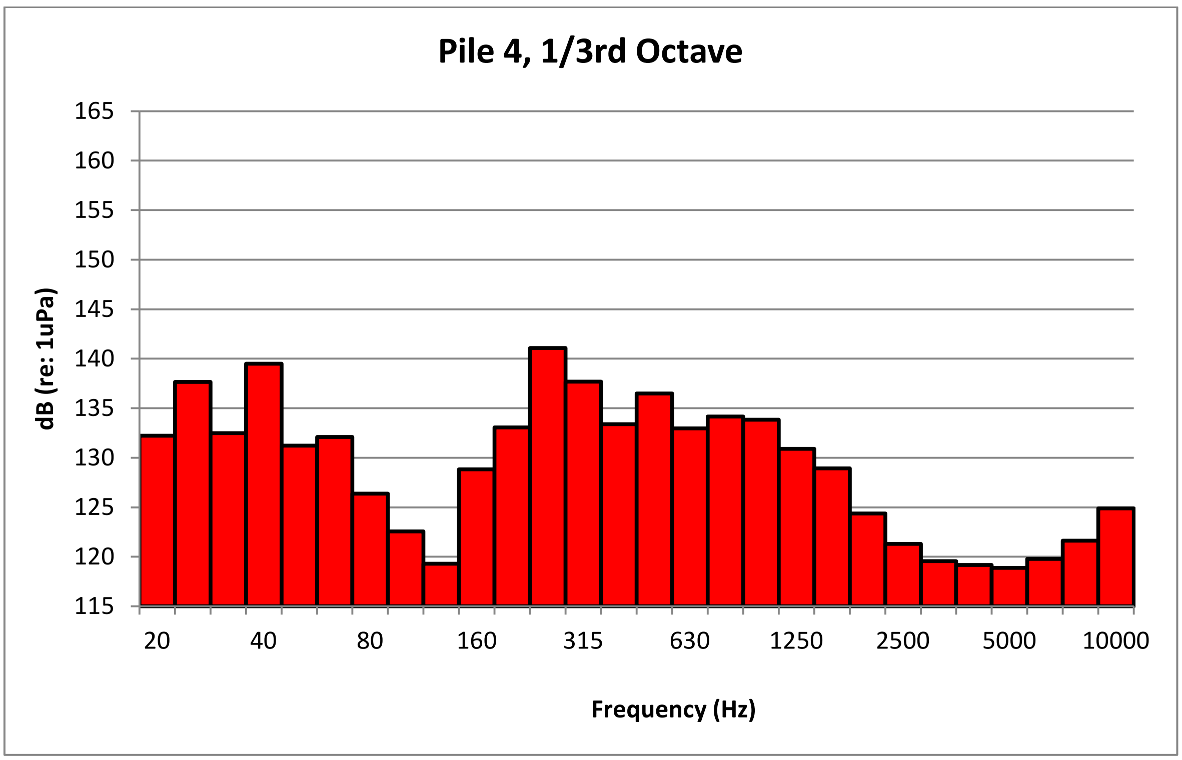


Figure 12: 1/3rd Octave frequency distribution for impact pile driving of Pile 4.

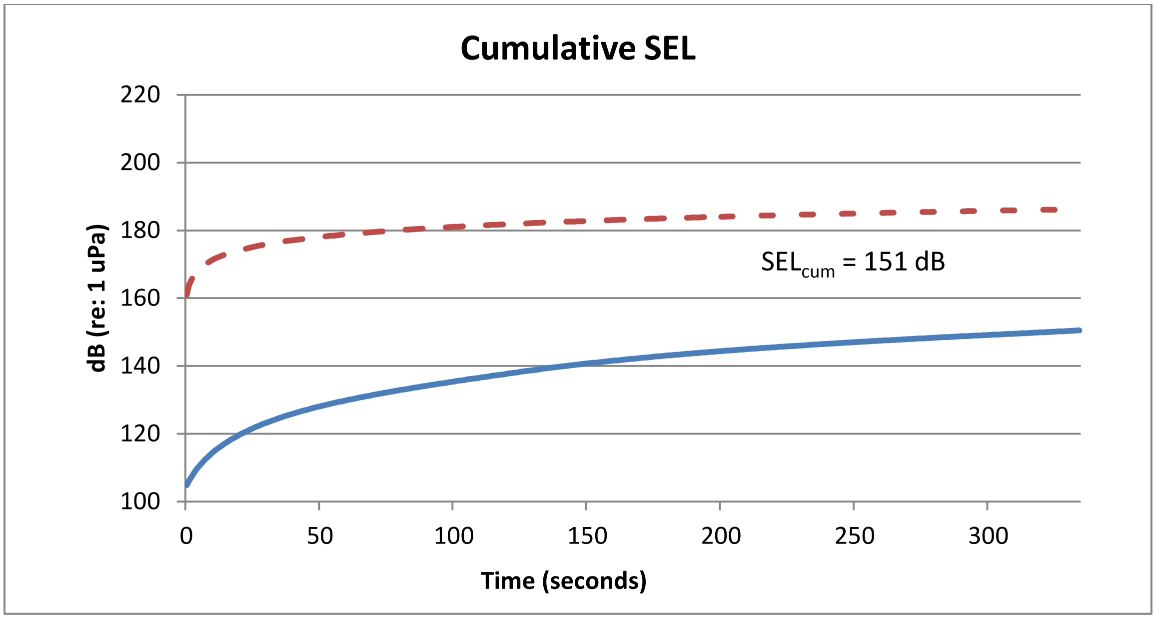


Figure 13: Cumulative SEL plot for Pile 4 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the number of strikes (red-dashed).

Pier 4, Pile 5

Pile 5 was driven at Pier 4 in approximately seven feet of water. The hydrophone for Pile 5 was 33 feet from the pile. The bubble curtain was used during the impact drive of Pile 5 with the bubbles turned off briefly at the start of the drive, on in the middle of the drive, and then off briefly at the end of the drive.

The results of monitoring for Pile 5 (Table 2) indicate:

- The highest absolute peak at the 10 foot hydrophone depth (one foot from bottom) was 205 dB_{peak}.
- The average RMS at 10 feet depth ranged between 178 dB_{RMS} to 179 dB_{RMS} with the bubbles off and between was 166 dB_{RMS} 168 dB_{RMS} and with the bubbles turned on.
- The highest single strike SEL for the peak strike at 10 feet water depth is 162 dB_{SEL}.

The 1/3rd Octave frequency distribution for Pile 5 indicates that the dominant frequency was 20 Hz and a lesser secondary peak at 200 Hz (Figure 14). Most of the energy is below 315 Hz.

The cumulative SEL of 156 $dBSEL_{cum}$ did not exceed the 204 $dBSEL_{cum}$ threshold after 209 strikes (Table 2). The SEL was estimated for each individual pile strike while the bubble curtain was active by calculating a 1-second SEL for each pile strike. The cumulative SEL values for each pile strike (Figure 15, blue line) differ by about 52 decibels with the individual strike method (red dashed line). Neither cumulative SEL exceeded the 204 $dBSEL_{cum}$ threshold.

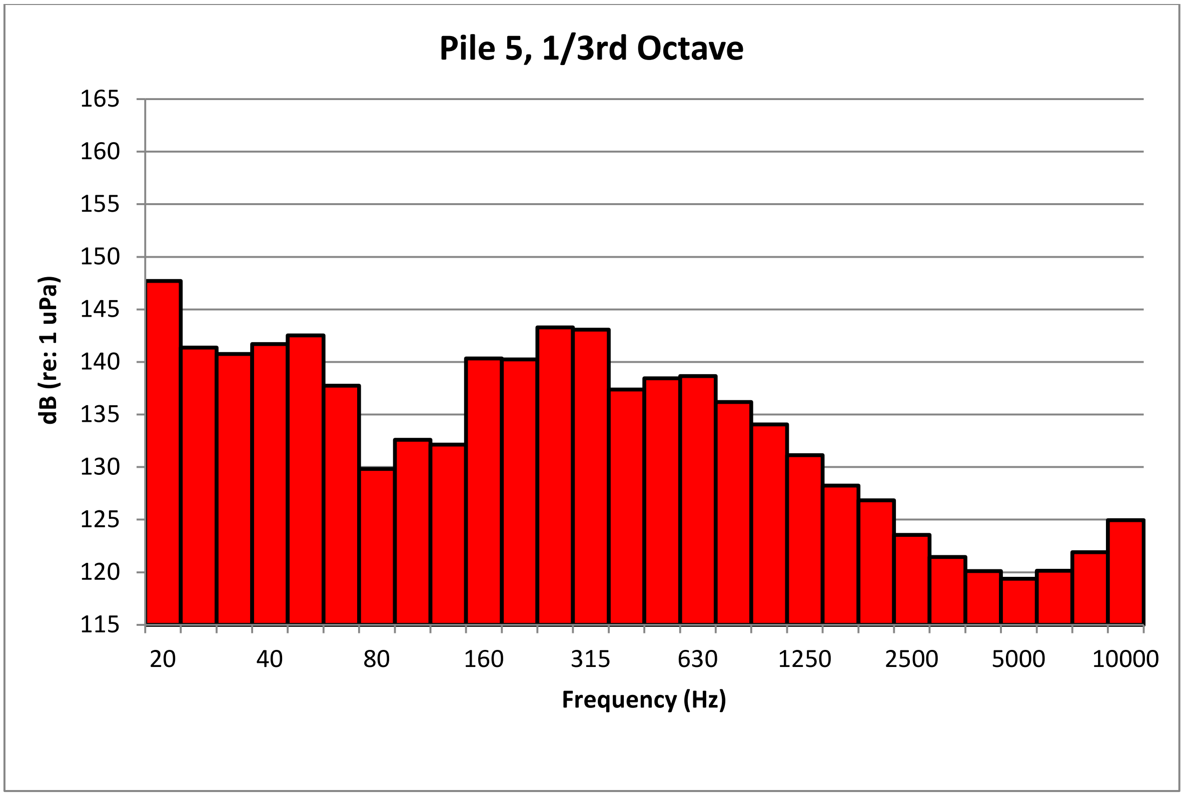


Figure 14: 1/3rd Octave frequency distribution for impact pile driving of Pile 5.

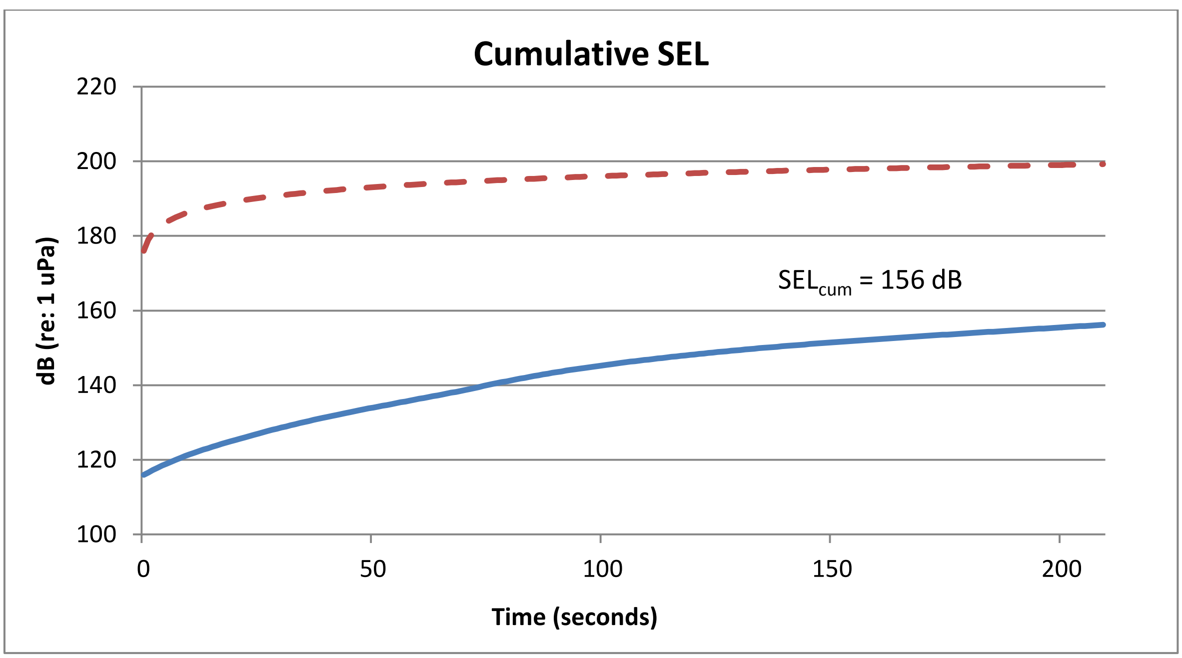


Figure 15: Cumulative SEL plot for Pile 5 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the number of strikes (red-dashed).

Pier 4, Pile 6

Pile 6 was driven at Pier 4 in approximately seven feet of water. The hydrophone for Pile 6 was 49 feet from the pile and one foot from the bottom. The bubble curtain was used during the impact drive of Pile 6 with the bubbles turned off briefly at the start of the drive, turned on and then off in the middle of the drive and back on at the end of the drive.

The results of monitoring for Pile 6 (Table 2) indicate:

- The highest absolute peak at the hydrophone at 10 feet depth (one foot from bottom) is 208 dB_{peak}.
- The average RMS at 10 feet depth ranged between 177 dB_{RMS} to 189 dB_{RMS} with the bubbles off and from 162 dB_{RMS} and 163 dB_{RMS} with the bubbles turned on.
- The highest single strike SEL for the peak strike at 10 feet water depth is 181 dB_{SEL}.

The 1/3rd Octave frequency distribution for Pile 6 indicates that the dominant frequency was 800 Hz (Figure 16). Most of the energy is below 1000 Hz.

The cumulative SEL of 140 $dBSEL_{cum}$ did not exceed the 204 $dBSEL_{cum}$ threshold after 233 strikes. The SEL was estimated for each individual pile strike while the bubble curtain was active by calculating a 1-second SEL for each pile strike. The cumulative SEL values for each pile strike (Figure 17, blue line) differ by about 72 decibels with the individual strike method (red dashed line). Neither cumulative SEL exceeded the 204 $dBSEL_{cum}$ threshold.

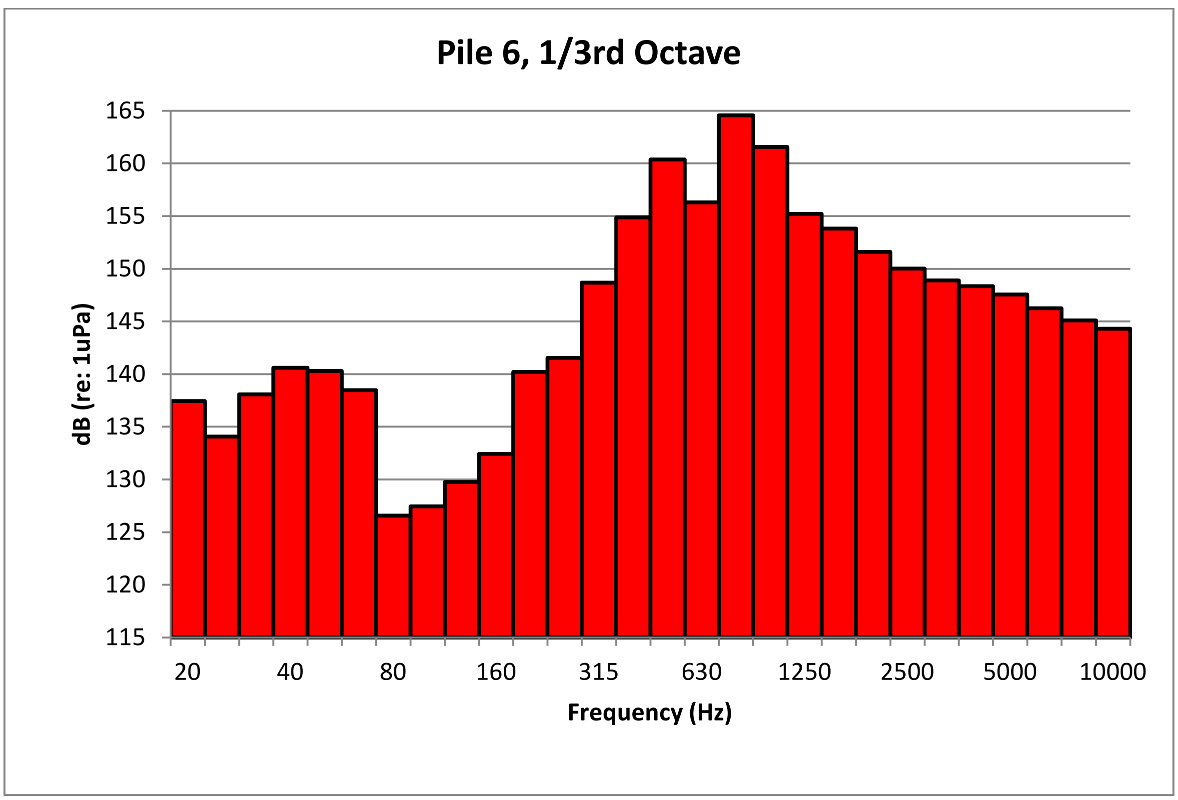


Figure 16: 1/3rd Octave frequency distribution for impact pile driving of Pile 6.

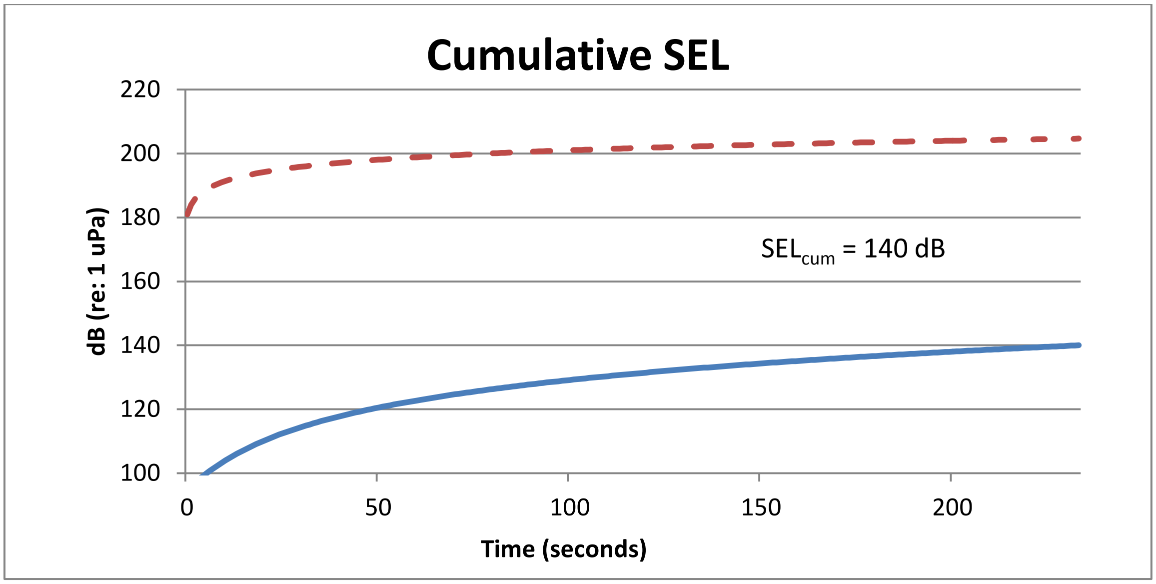


Figure 17: Cumulative SEL plot for Pile 6 showing the cumulative plot for SEL values calculated for each pile strike (blue) versus the more conservative SEL plot based on the number of strikes (red-dashed).

Pier 4, Vibratory Measurements

One pile was monitored during vibratory pile driving at Pier 4. The hydrophone was 33 feet from the pile in approximately 10 feet of water. No bubble curtain was used.

The highest measured absolute peak for vibratory driving was 182 dB_{peak}. The 30-second RMS values ranged from 148 to 166 dB_{RMS}. The overall average RMS is 155 dB_{RMS}.

The 1/3rd Octave frequency distribution for the pile driven using a vibratory hammer indicates that the dominant frequencies occur at about 20 Hz and a second peak at 1000 Hz (Figure 18). The secondary peak at 1000 Hz could have been due to turbulence from water movement past the piles upstream from the hydrophone. The substrate will quickly attenuate the higher frequencies and some of the lower frequencies due to the compression of the substrate around the pile.

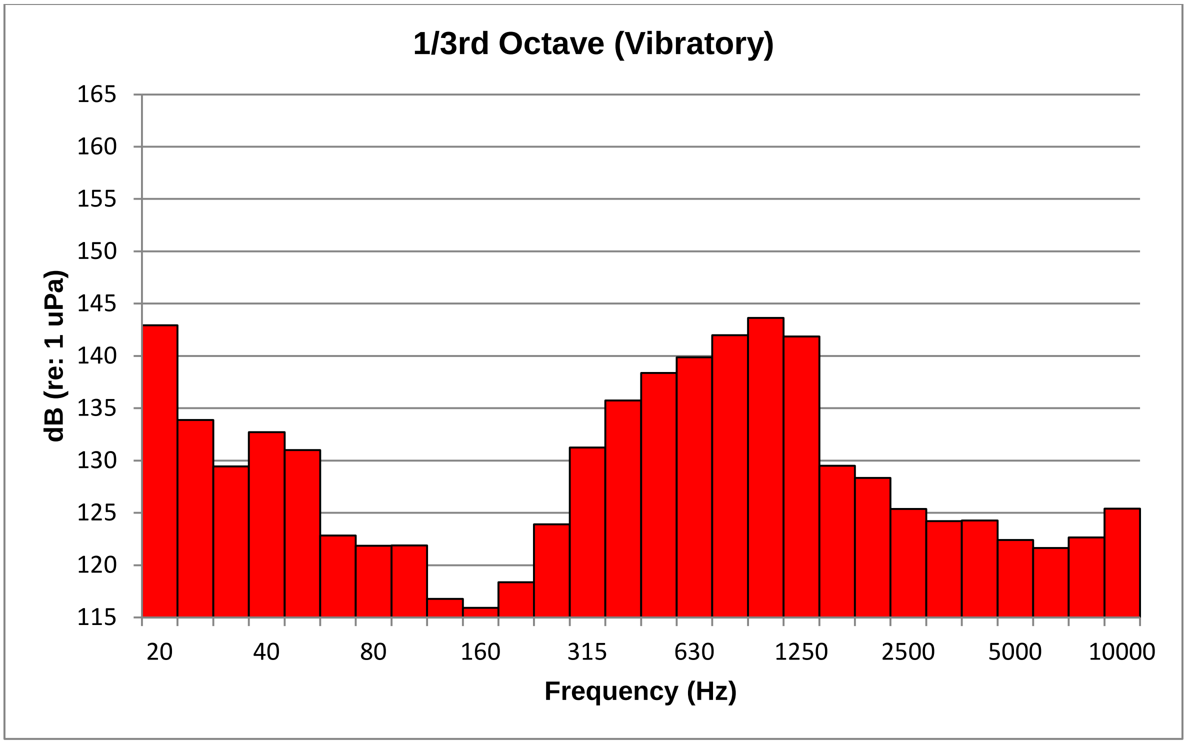


Figure 18: 1/3rd Octave frequency distribution for impact pile driving of Pile 2.

Background Measurements

Broadband Root Mean Square (RMS) (background) noise levels are reported in terms of the 30-second average continuous sound level and have been computed from the Fourier transform of pressure waveforms in 30-second time intervals. Although the methodology did not strictly follow the NOAA guidance on measuring background sound levels underwater, background RMS values were measured for eight minutes prior to pile driving activities on October 22, 2010. Average broadband (20 Hz to 10000 Hz) RMS background levels were 142 dB_{RMS}. The 1/3rd Octave band frequency distribution for the background noise measurements indicates a curious high frequency component between about 1,000 and 10,000 Hz (Figure 19). When a high pass filter was applied to remove all frequencies below 1,000 Hz, as the NOAA guidance recommends, background levels were lowered to 131 dB RMS.

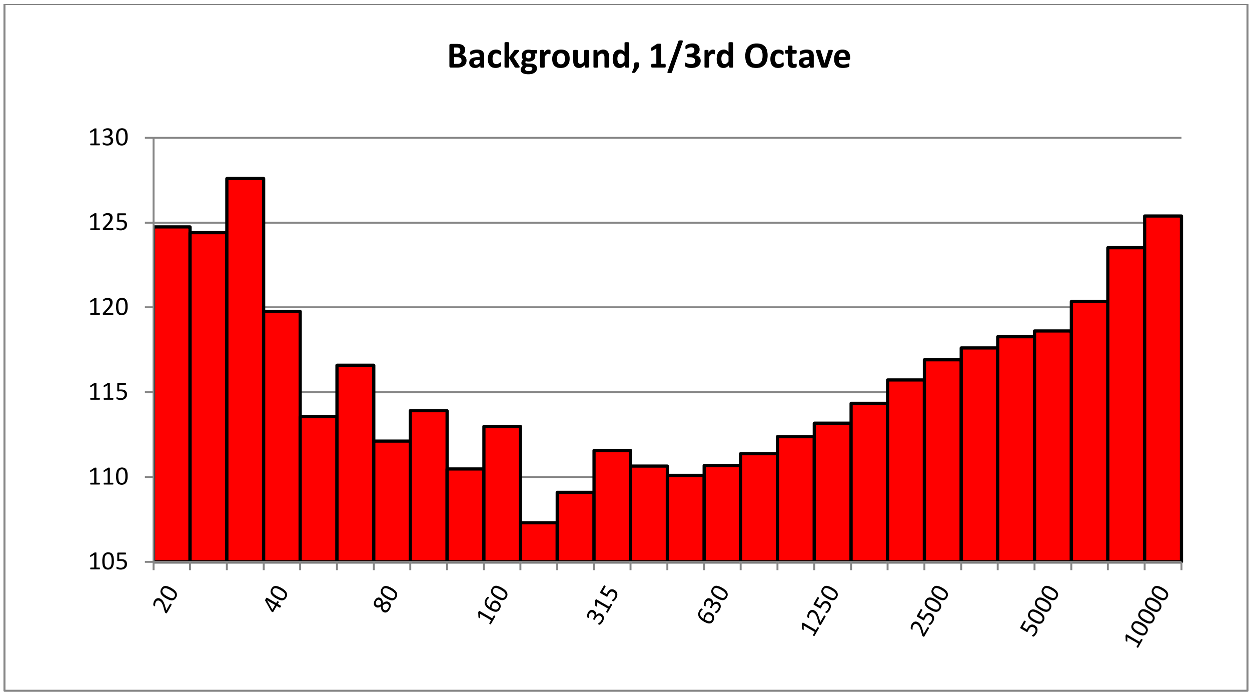


Figure 19: 1/3rd Octave frequency distribution for broadband background noise levels.

SEL

SEL was calculated for the single highest absolute peak strike for each pile and for each individual pile strike. None of the piles monitored exceeded threshold of 204 dB_{SEL} set for this project within the BO during a single day (12 hour period) using either method of calculation. The highest cumulative SEL calculated using the total number of strikes and the single strike SEL was 204 $dBSEL_{cum}$ for Pile 6. The highest cumulative SEL calculated using the SEL values for each individual pile strike was 168 for Pile 1.

Rise Time

Yelverton (1973) indicated rise time was the cause of injury. According to Yelverton, the closer the peak is to the front of the impulse wave the greater the chance for injury. In other words, the shorter the rise time the higher the likelihood for effects on fish. In all steel piles without effective mitigation, the rise times were relatively short. Piles with mitigation had relatively long rise times.

Airborne Noise Measurements

Un-weighted airborne impact pile driving measurements at the SR 529 Ebey Slough Bridge Replacement project were collected during impact pile driving during the month of January 2011 on two 72-inch diameter steel piles driven with an APE D-100-13 impact hammer. Airborne noise levels use the acoustic reference pressure of 20 microPa.

The airborne noise levels are measured in terms of the 5-minute average continuous sound level (5-minute L_{eq}):

(5 min)

$$L_{eq} = 10\log\left(\frac{1}{T}\int_{T} p(t)^2\,dt\right)$$

Where p(t) is the acoustic overpressure, T = 5 minutes and $0 < t < T$. RMS values are calculated by integrating the sound pressure averaged over some time period, in this case 5-minutes, in a similar way that the L_{eq} values are calculated. Therefore, in this instance, the 5-minute L_{eq} is the same as the RMS sound pressure level over a 5-minute period.

The 5-minute L_{eq} and L_{max} levels were measured with no weighting applied. The un-weighted airborne noise levels (L_{eq}/RMS), standardized to a distance of 50 feet to ranged between 98 and 99 dB (Table 3). The location where the measurements were collected was just northeast of Pier 4 and east of the bridge (Figure 20).

Table 3: Un-Weighted Airborne Monitoring Results for impact driving 72-inch steel piles.

Pier #	Distance To Pile (feet)	Measured Leq/RMS (dB)	Standardized Leq/RMS To 50 feet (dB)	Measured Lmax (dB)	Standardized Lmax To 50 feet (dB)
4	163	88.3	99	91.3	102
		87.7	98	89.6	100
		88.8	99	99.7	110
		Average:	**99**	**Average:**	**106**
2	33	103	99	106	102
		105	101	110	106
		106	102	109	105
		Average:	**101**	**Average:**	**105**

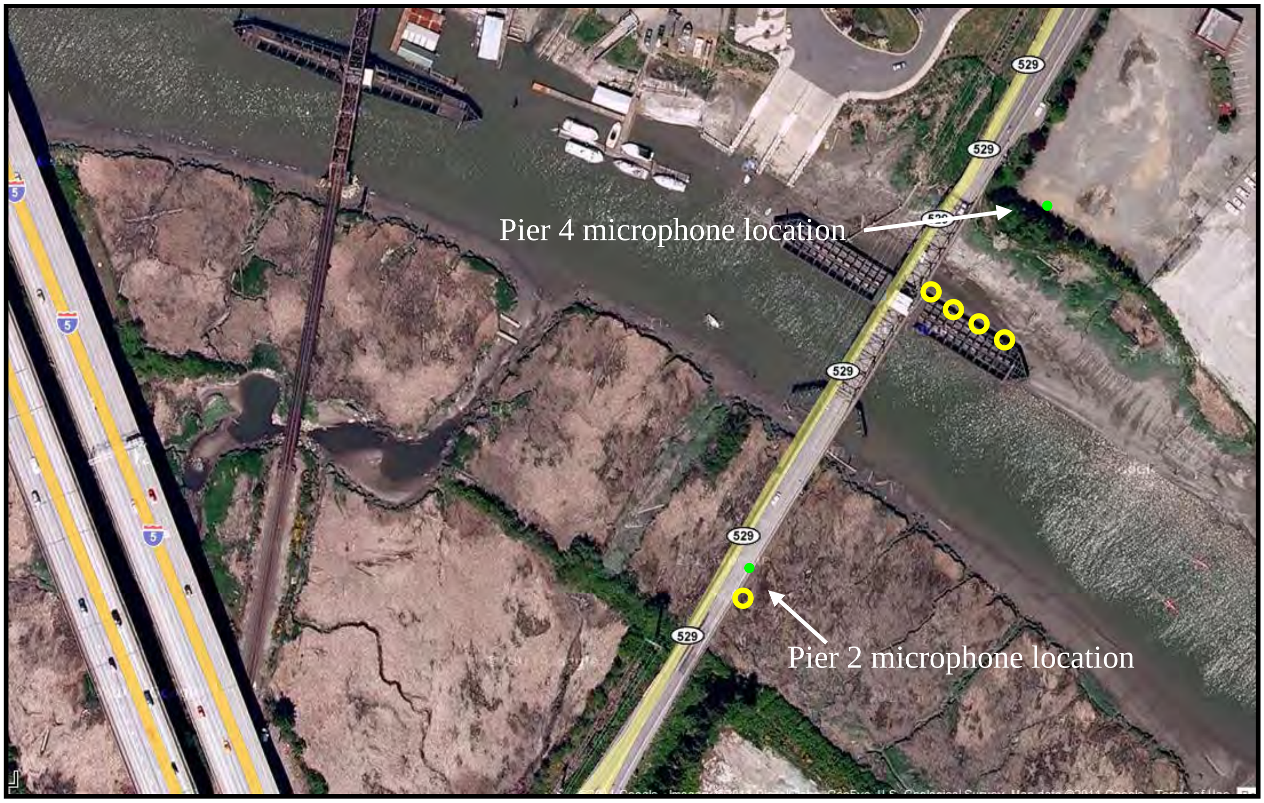


Figure 20: Location of airborne noise measurements at the SR 529 Ebey Slough Bridge Project.
○ = 72-inch Steel Pile; • = Airborne Microphone

The 1/3rd octave frequency distribution for the un-weighted airborne noise measurements indicate that the frequency distributions between measurements and between piles are relatively similar (Figure 21). In most cases the dominant energy occurs at approximately at 100 Hz with most of the sound energy occurring below 100 Hz. In a few instances there was a dominant frequency measured at around 1,000 Hz. This could have been produced by the occasional ringing of the pile during impact driving. In all cases the sound energy drops off sharply above 1,000 Hz.

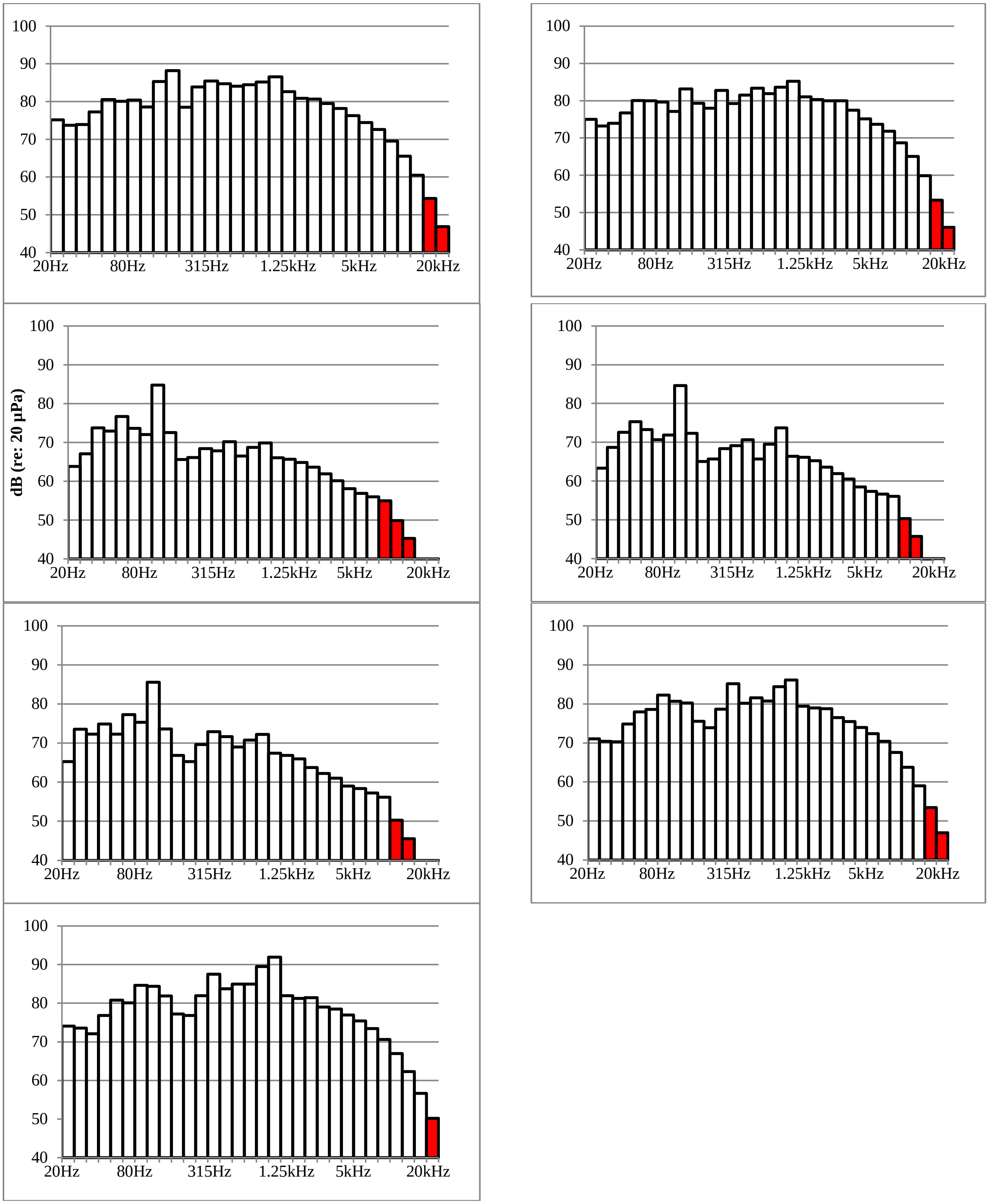


Figure 21: Comparison of 1/3rd Octave un-weighted airborne frequency distributions for the L_eq/RMS metric with an impact hammer on 72-inch steel piles.

CONCLUSIONS

A total of six 72-inch steel piles were monitored on three separate piers representing both in-water and above ordinary high water pile driving. Underwater and airborne noise measurements were collected for impact and vibratory pile driving.

- Peak underwater mitigated sound levels for piles driven in water ranged between 172 dB_{Peak} and 181 dB_{Peak}.
- Average mitigated RMS levels ranged between 152 dB_{RMS} and 168 dB_{RMS}.
- Cumulative Sound Exposure Levels (SEL) were calculated both for individual pile strikes and then summed as well as calculated using the peak strike SEL value and the total number of strikes.
- The difference between the two methods of calculating the cumulative SEL averaged between 32 dB and 72 dB with the method of calculating the SEL value for each individual pile strike being substantially lower.
- Neither method resulted in a cumulative SEL value that exceeded the 204 dB_{SEL} threshold set by the Services for this project.
- The bubble curtain performed well achieving an average of 22 dB of noise reduction with a range of between 14 and 32 dB. It is possible that the very soft substrate at this location provided some additional attenuation of the sound energy through the substrate and so provided some assistance to the bubble curtain.
- Average RMS levels for unweighted airborne noise levels from impact driving 72-inch steel piles ranged from 99 to 101 dB_{RMS} when standardized to a distance of 50 feet.

REFERENCES

Yelverton, John T., Donald R. Richmond, E. Royce Fletcher, and Robert K. Jones. 1973. Safe Distances from Underwater Explosions for Mammals and Birds. Lovelace Foundation for Medical Education and Research AD-766 952, Prepared for Defense Nuclear Agency.

APPENDIX A– STEEL PILE WAVEFORM ANALYSIS FIGURES

Pier 3, Pile 1 – No Mitigation, 10-feet Above OHWM

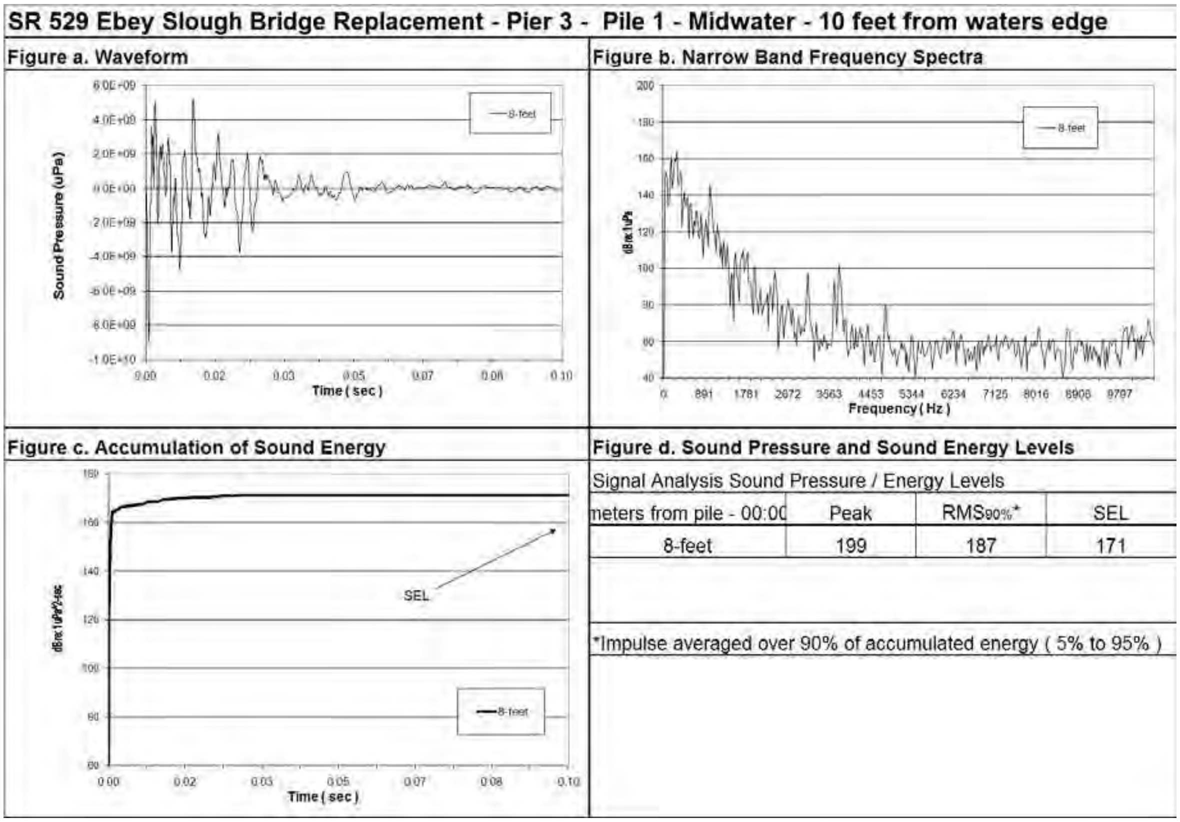
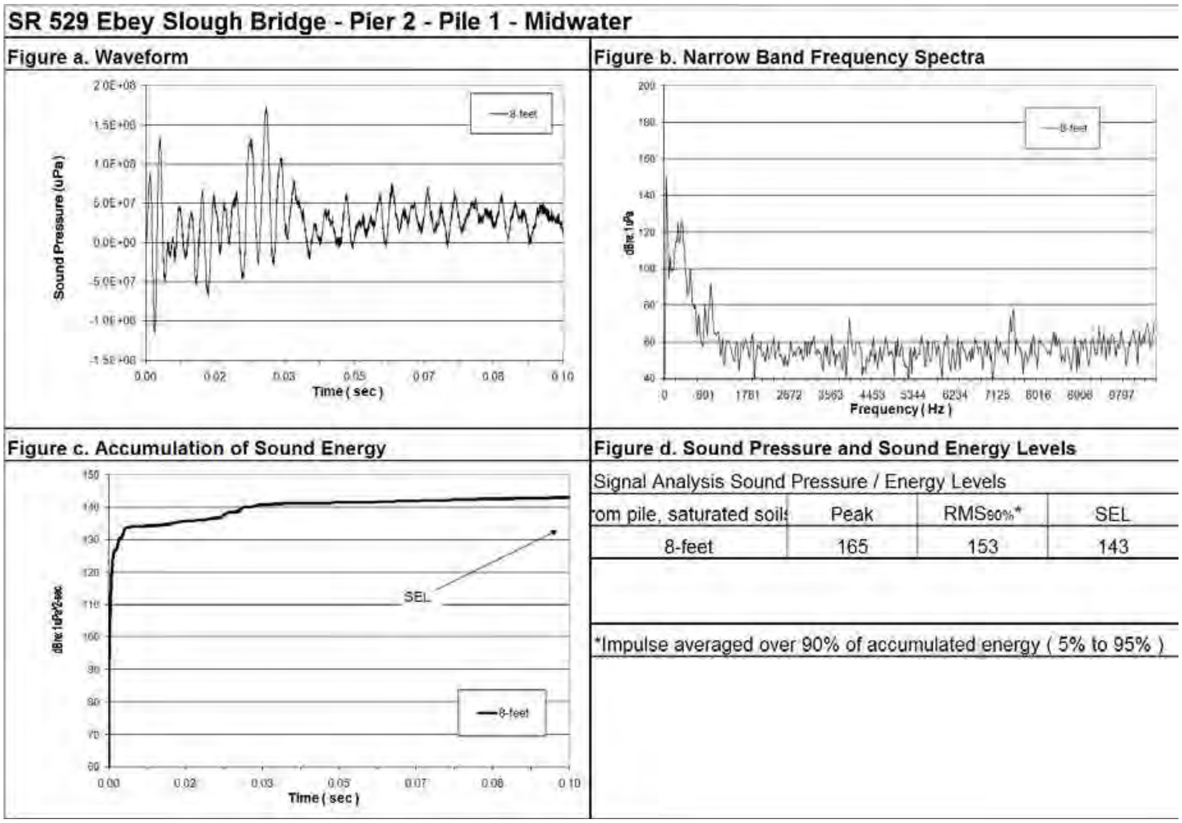


Figure 22: Waveform analysis of Pile 1 sound pressure levels with no mitigation, 10 feet above OHWM.

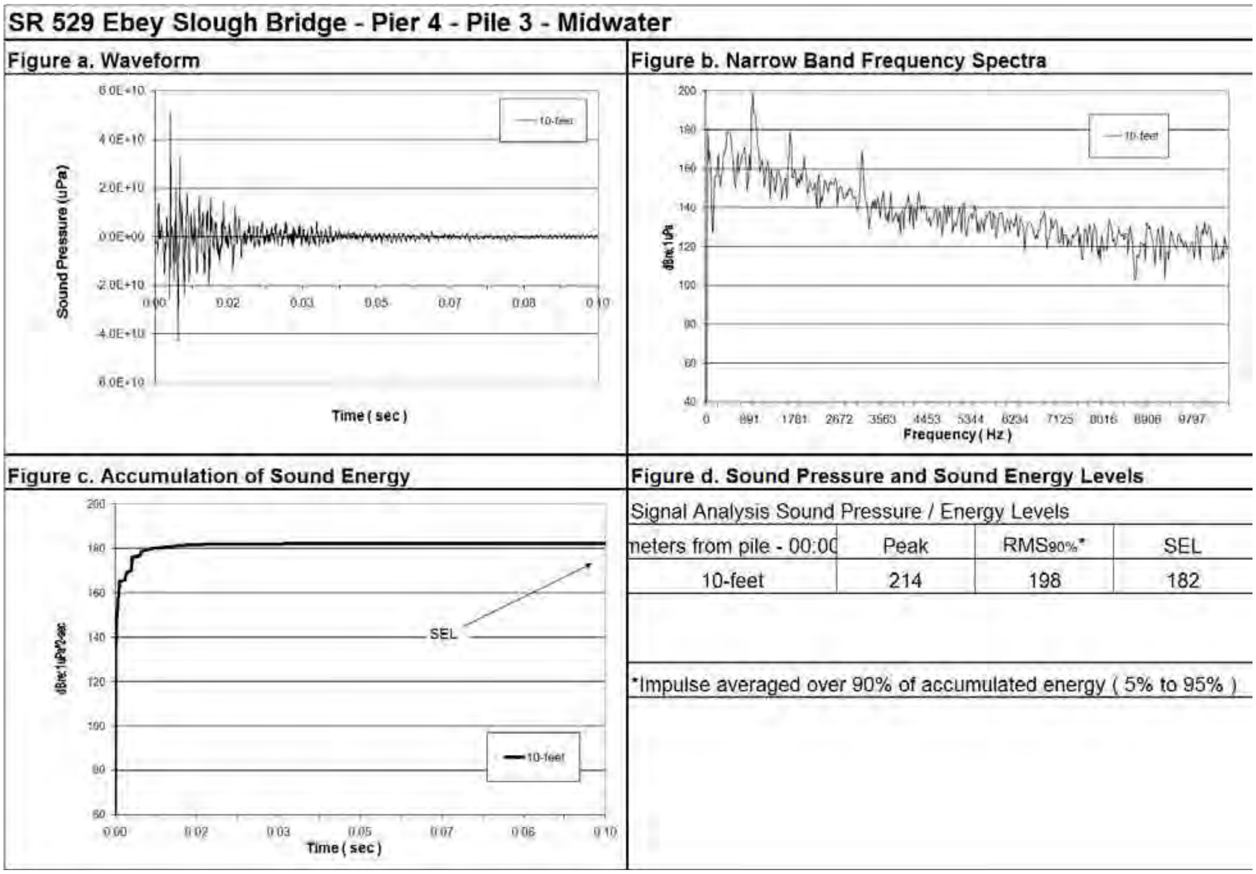
Pier 2, Pile 2 – No Mitigation, 230-feet Above OHWM



om pile, saturated soil	Peak	RMS90%*	SEL
8-feet	165	153	143

Figure 23: Waveform analysis of Pile 2 sound pressure levels 230 feet above the OHWM, midwater.

Pier 4, Pile 3 – without Bubbles On Start of Drive



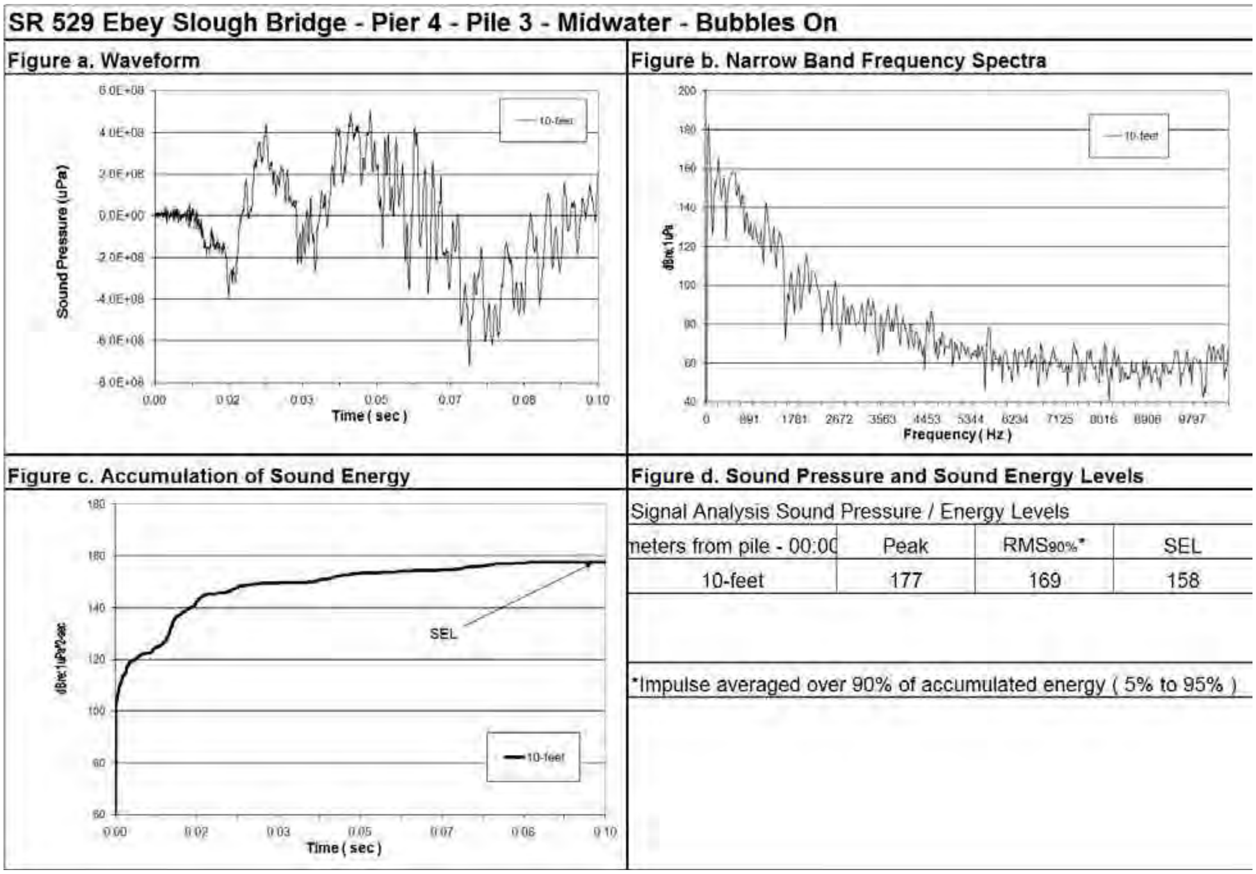
Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
10-feet	214	198	182

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

Figure 24: Waveform analysis of Pier 4, Pile 3 sound pressure levels with bubbles off first part of drive, midwater.

Pier 4, Pile 3 – with Bubbles On Middle of Drive



Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
10-feet	177	169	158

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

Figure 25: Waveform analysis of Pier 4, Pile 3 sound pressure levels with bubbles off first part of drive, midwater.

Pier 4, Pile 3 – with Bubbles Off End of Drive

SR 529 Ebey Slough Bridge - Pier 4 - Pile 3 - Midwater - Bubbles Off End

Figure a. Waveform

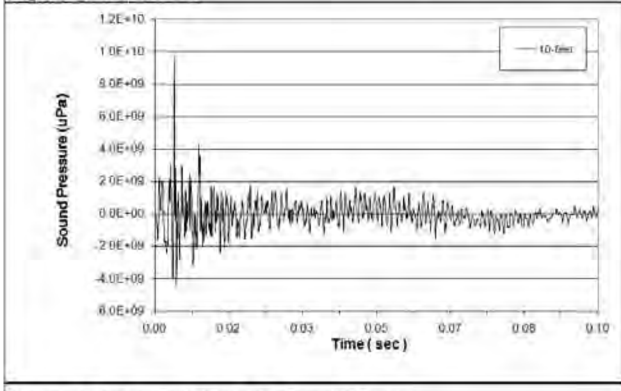


Figure b. Narrow Band Frequency Spectra

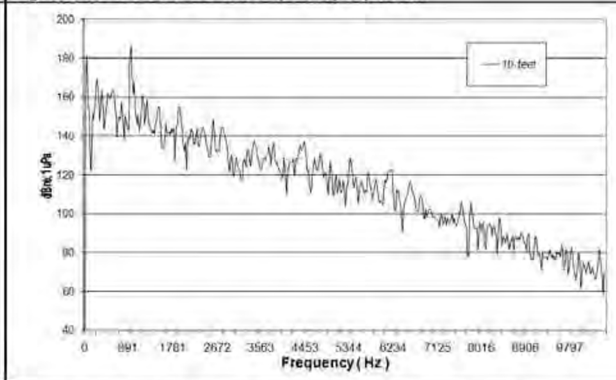


Figure c. Accumulation of Sound Energy

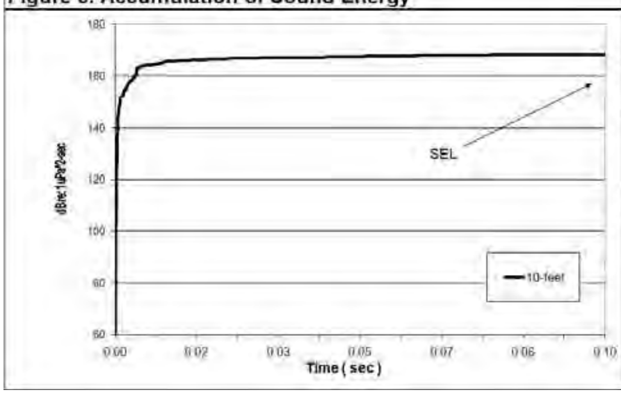


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
10-feet	200	179	168

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

Figure 26: Waveform analysis of Pier 4, Pile 3 sound pressure levels with bubbles off first part of drive, midwater.

Pier 4, Pile 4 – with Bubbles OFF Start of Drive

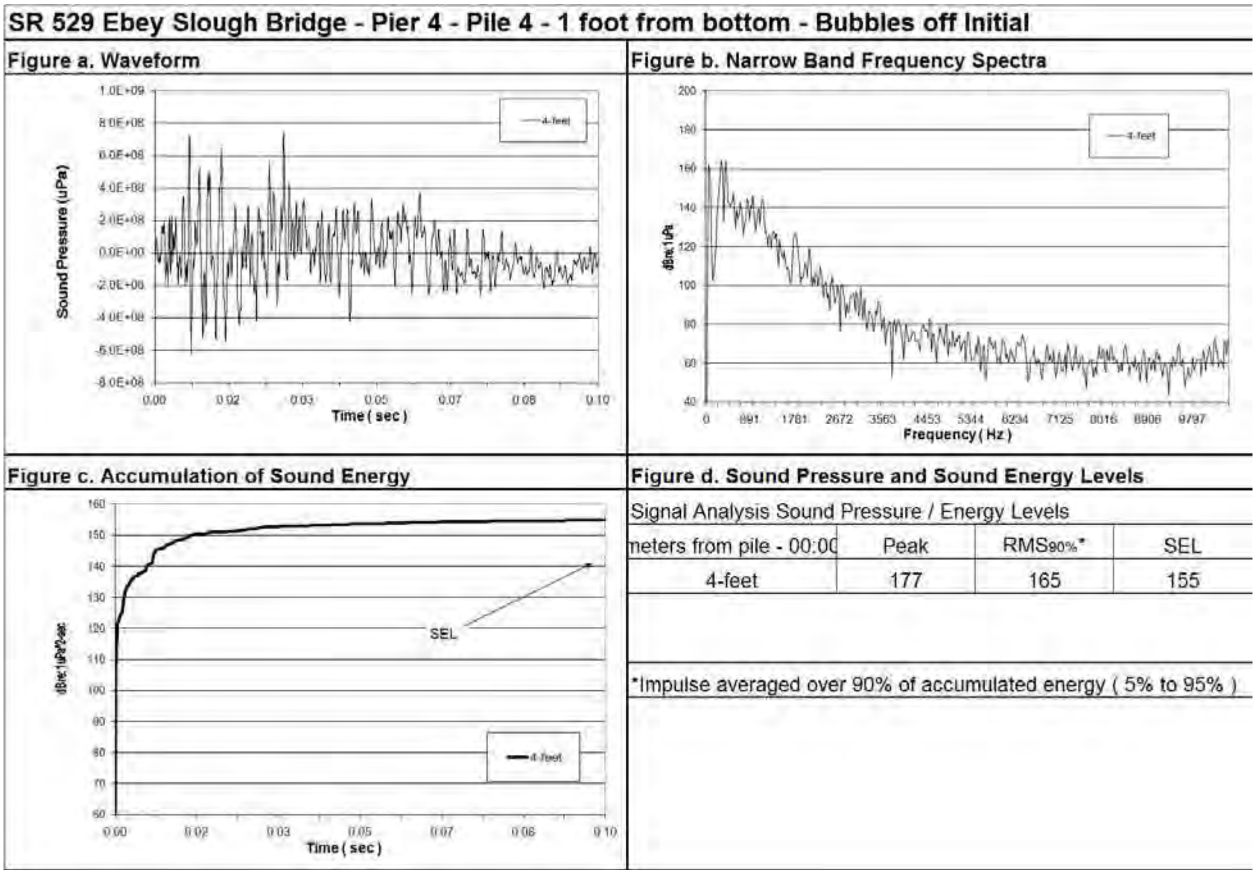


Figure 27: Waveform analysis of Pier 4, Pile 3 sound pressure levels with bubbles off first part of drive, midwater.

Pier 4, Pile 4 – with Bubbles On Middle of Drive

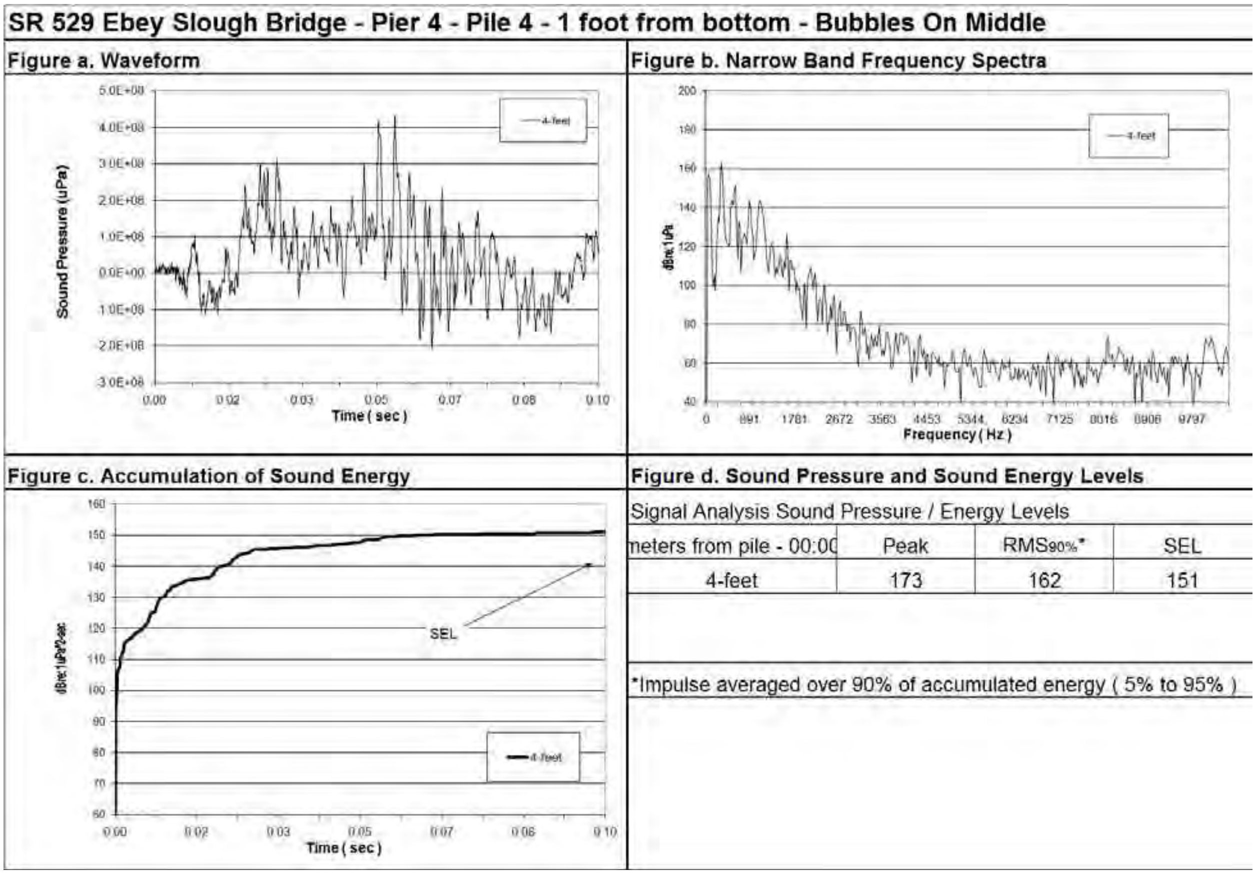
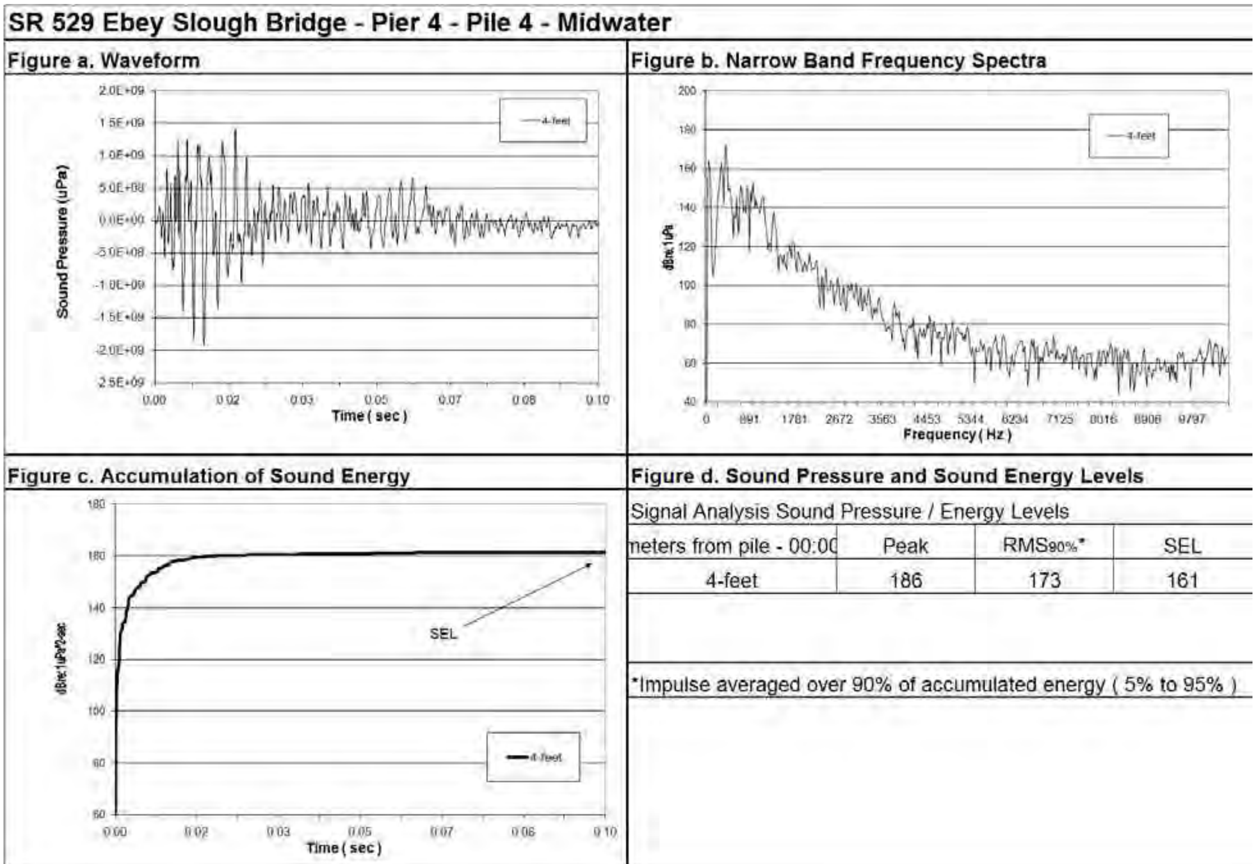


Figure 28: Waveform analysis of Pier 4, Pile 3 sound pressure levels with bubbles off first part of drive, midwater.

PiER 4 PIle 4 – Bubbles Off End of Drive



meters from pile - 00:00	Peak	RMS90%*	SEL
4-feet	186	173	161

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

Figure 29: Waveform analysis of Pile 1 sound pressure levels with 1st, 2nd and 3rd rings air on, Midwater.

PiER 4 PIle 4 – Bubbles ON End of Drive

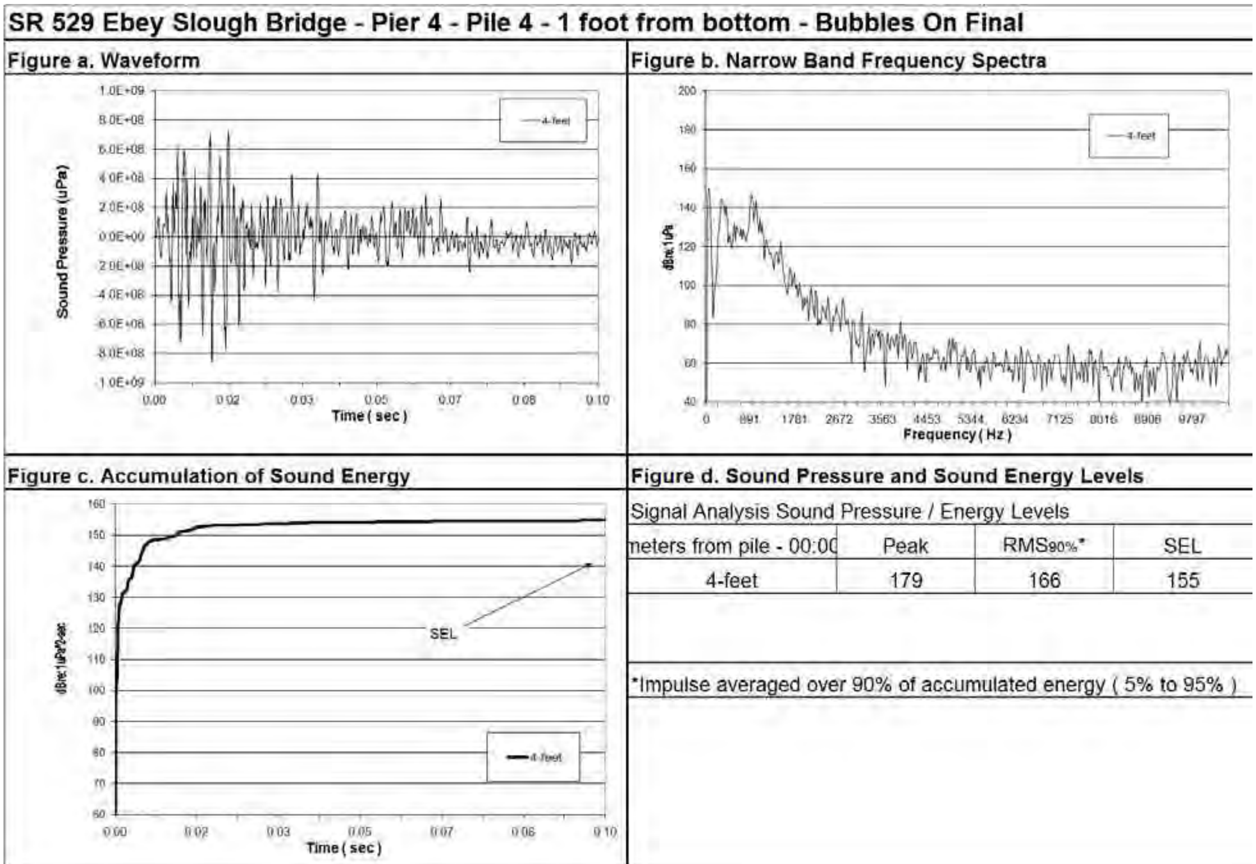
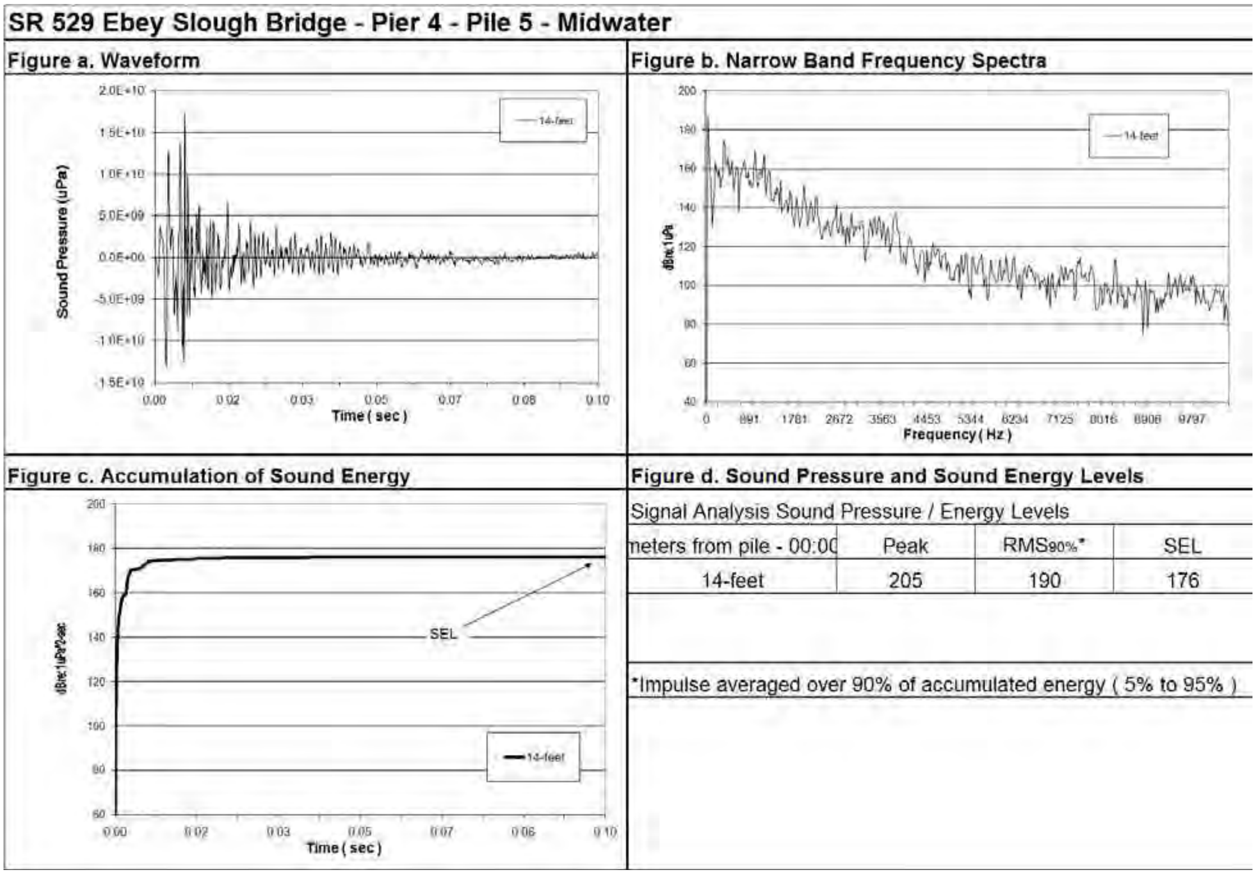


Figure 30: Waveform analysis of Pile 1 sound pressure levels with 1st, 2nd and 3rd rings air on, Midwater.

Pier 4, Pile 5 – with Bubbles OFF Start of Drive



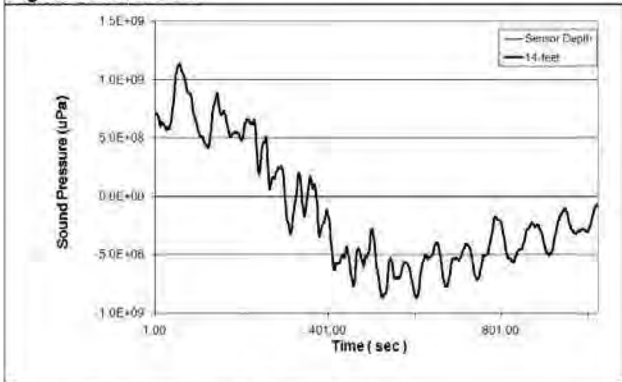
meters from pile - 00:00	Peak	RMS90%*	SEL
14-feet	205	190	176

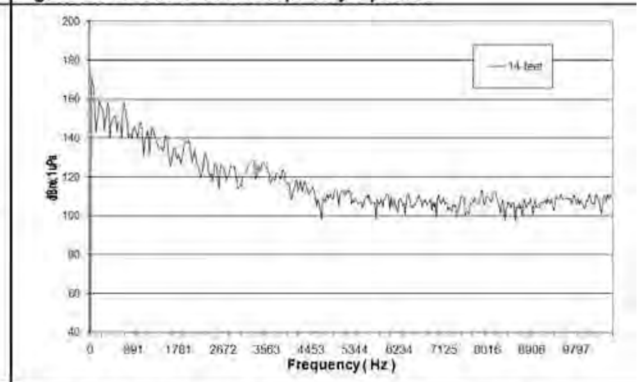
*Impulse averaged over 90% of accumulated energy (5% to 95%)

Figure 31: Waveform analysis of Pile 1 sound pressure levels with first and second ring air on, midwater.

Pier 4, Pile 5 – with Bubbles On Middle of Drive

SR 529 Ebey Slough Bridge - Pier 4 - Pile 5 - Midwater - Bubbles On Middle





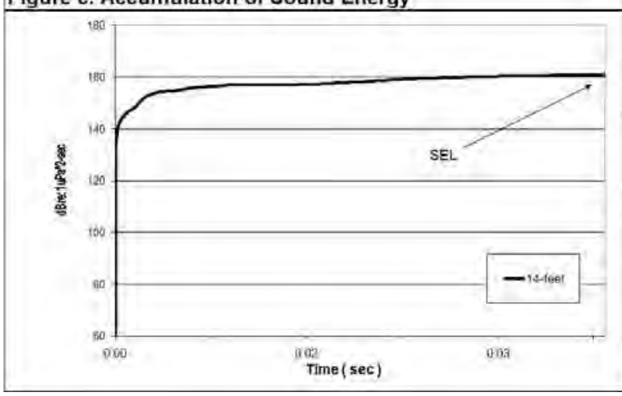


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
14-feet	181	175	161

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

Figure 32: Waveform analysis of Pile 1 sound pressure levels with first and second ring air on, midwater.

Pier 4, Pile 5 – with Bubbles OFF Middle of Drive

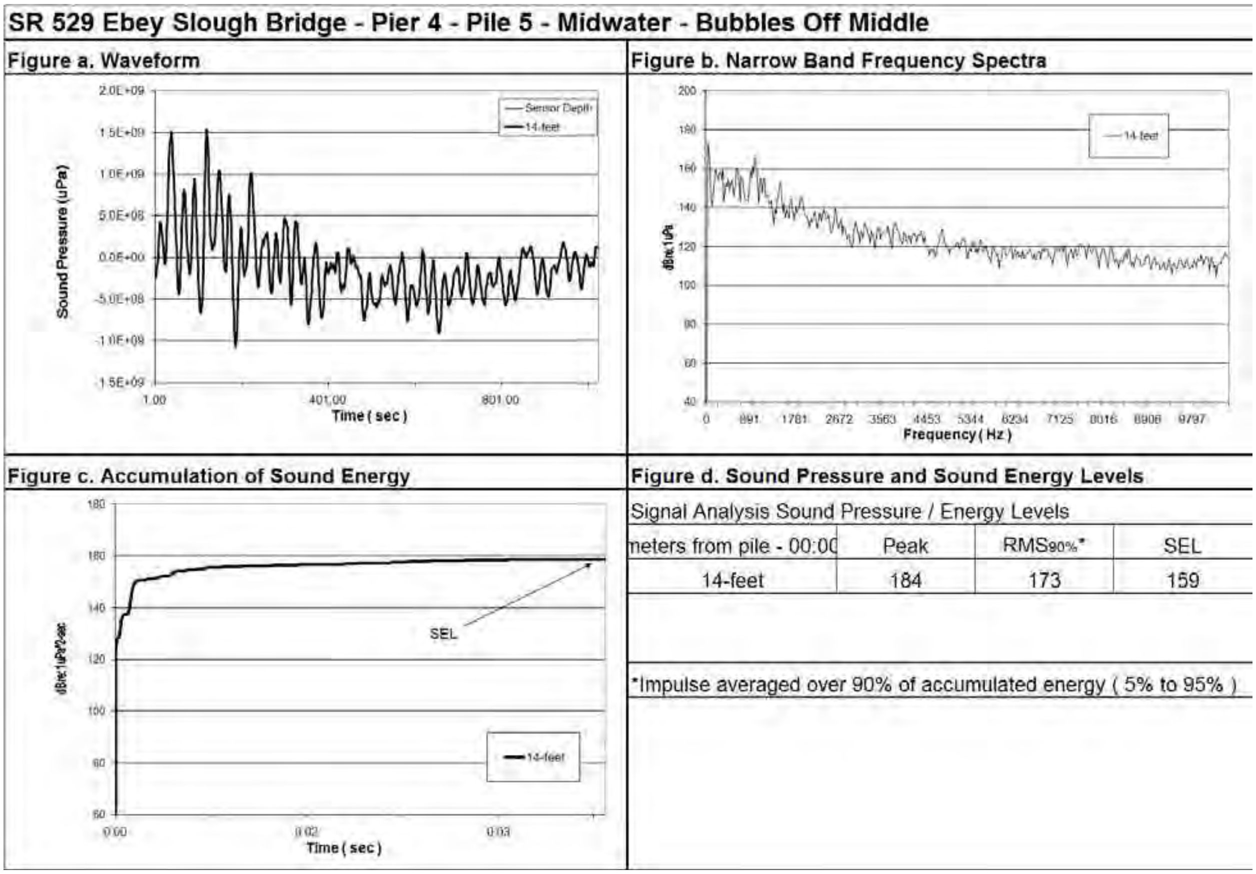


Figure 33: Waveform analysis of Pile 1 sound pressure levels with first and second ring air on, midwater.

Pier 4, Pile 5 – with Bubbles ON End of Drive

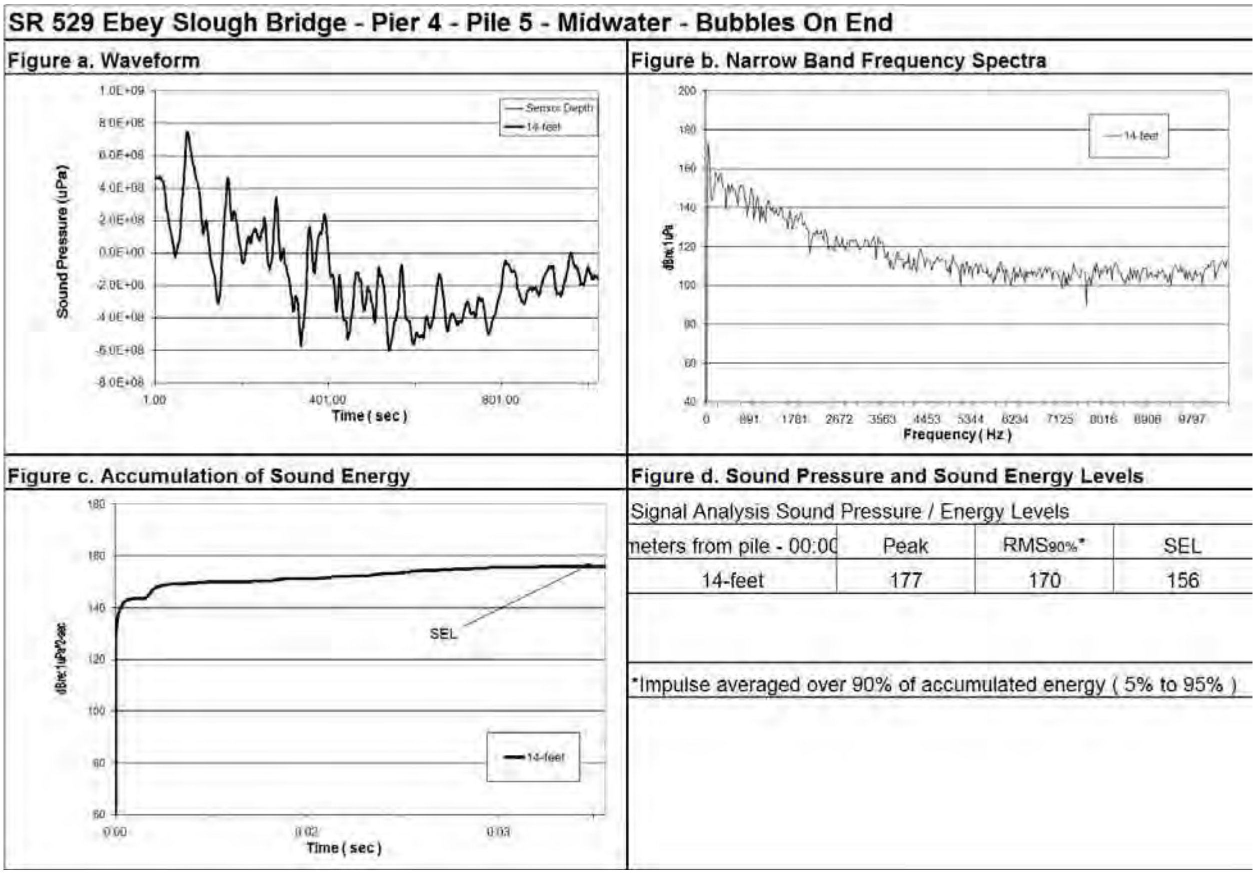


Figure 34: Waveform analysis of Pile 1 sound pressure levels with first and second ring air on, midwater.

Pier 4, Pile 5 – with Bubbles OFF End of Drive

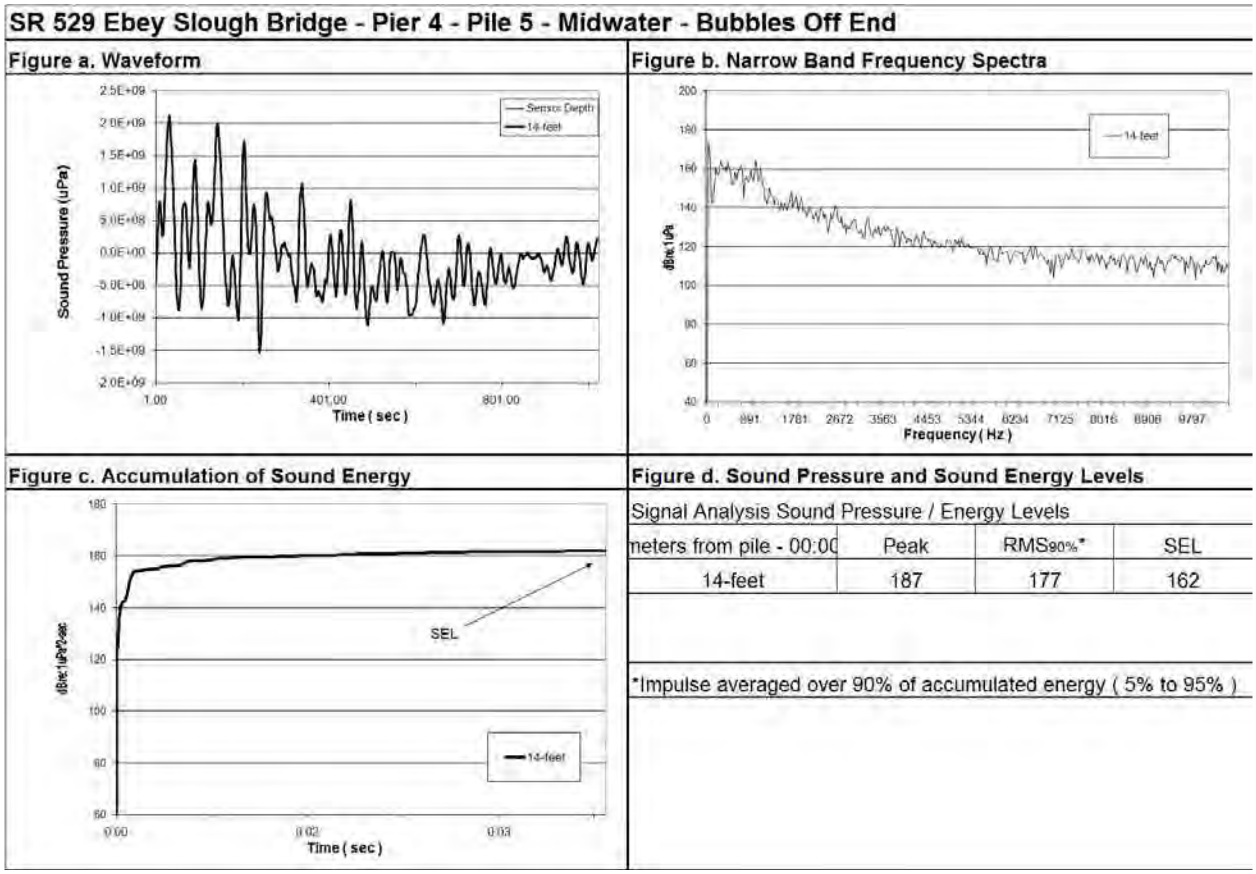
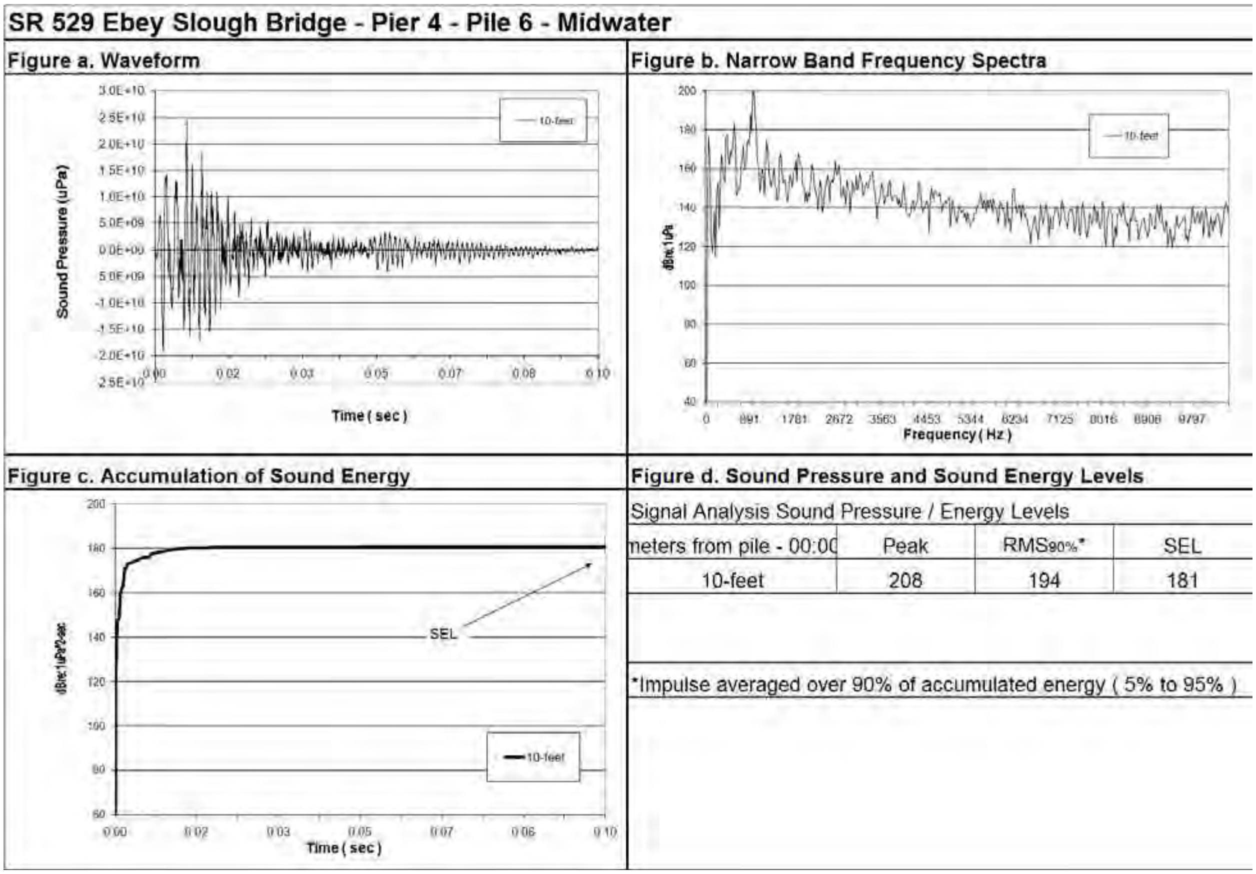


Figure 35: Waveform analysis of Pile 1 sound pressure levels with first and second ring air on, midwater.

Pier 4, Pile 6 – with Bubbles OFF Start of Drive



meters from pile - 00:00	Peak	RMS90%*	SEL
10-feet	208	194	181

Figure 36: Waveform analysis of Pier 4, Pile 6 sound pressure levels with bubbles off, midwater.

Pier 4, Pile 6 – with Bubbles On Start of Drive

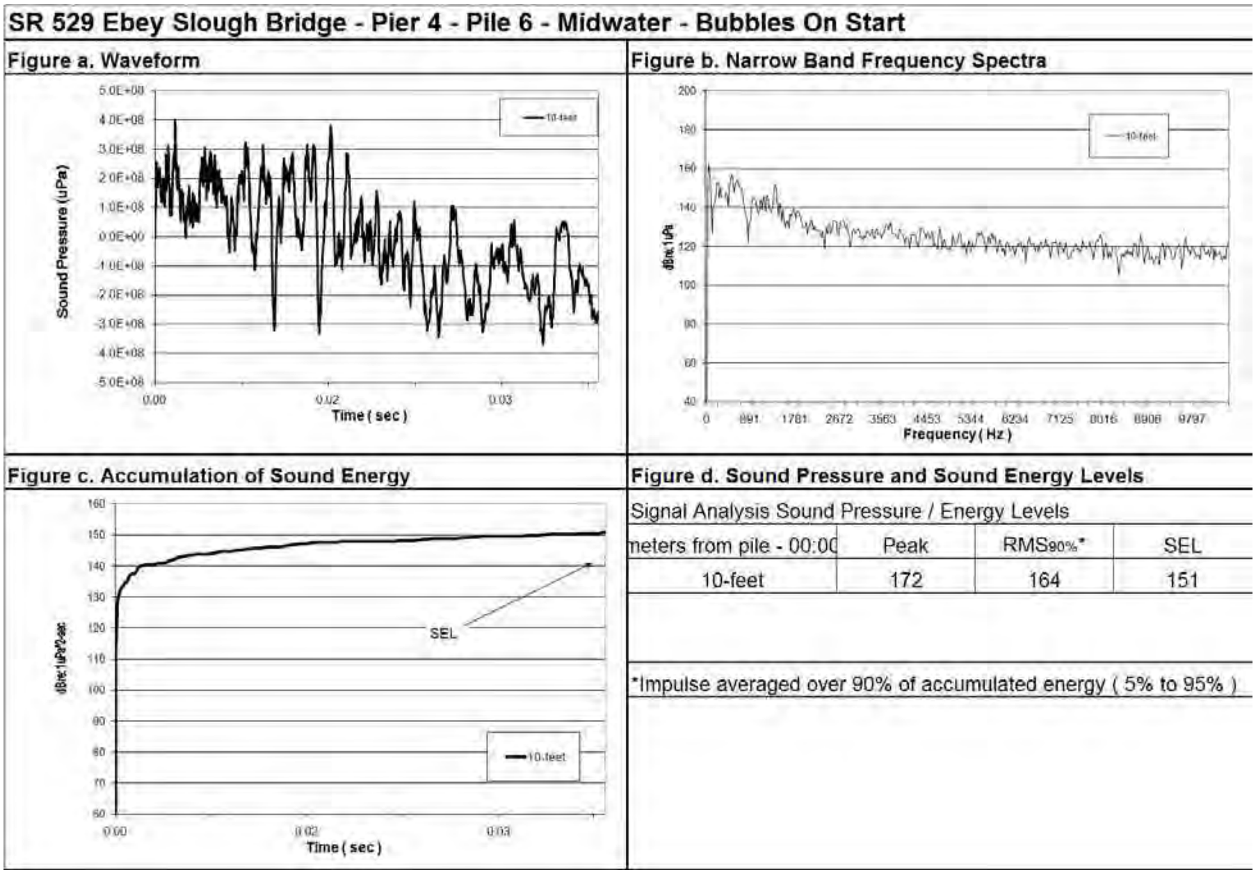
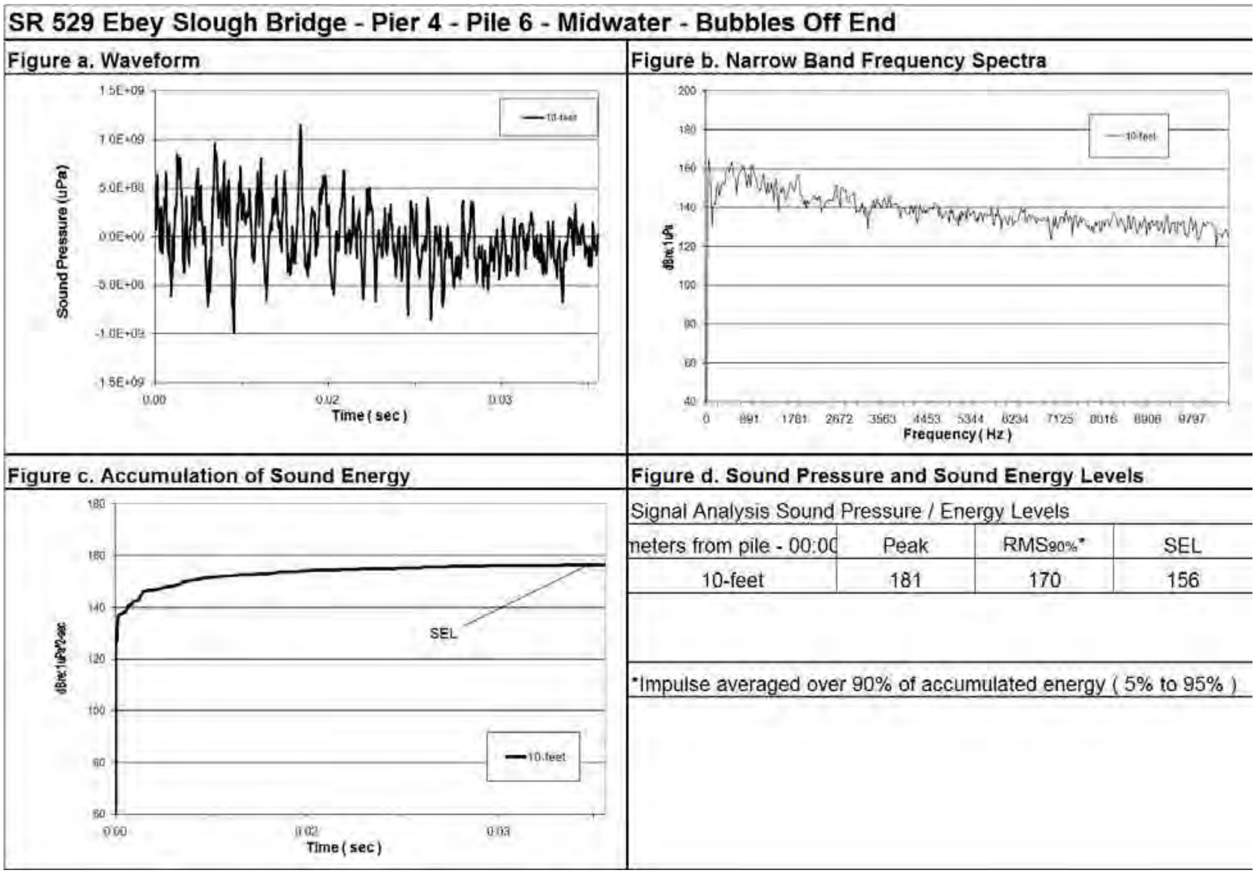


Figure 37: Waveform analysis of Pile 1 sound pressure levels with all rings on full for the second time near the end of the drive, midwater.

Pier 4, Pile 6 – with Bubbles OFF End of Drive



meters from pile - 00:00	Peak	RMS90%*	SEL
10-feet	181	170	156

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

Figure 38: Waveform analysis of Pile 1 sound pressure levels with all rings off at the end of the drive, midwater.

Pier 4, Pile 6 – with Bubbles On End of Drive

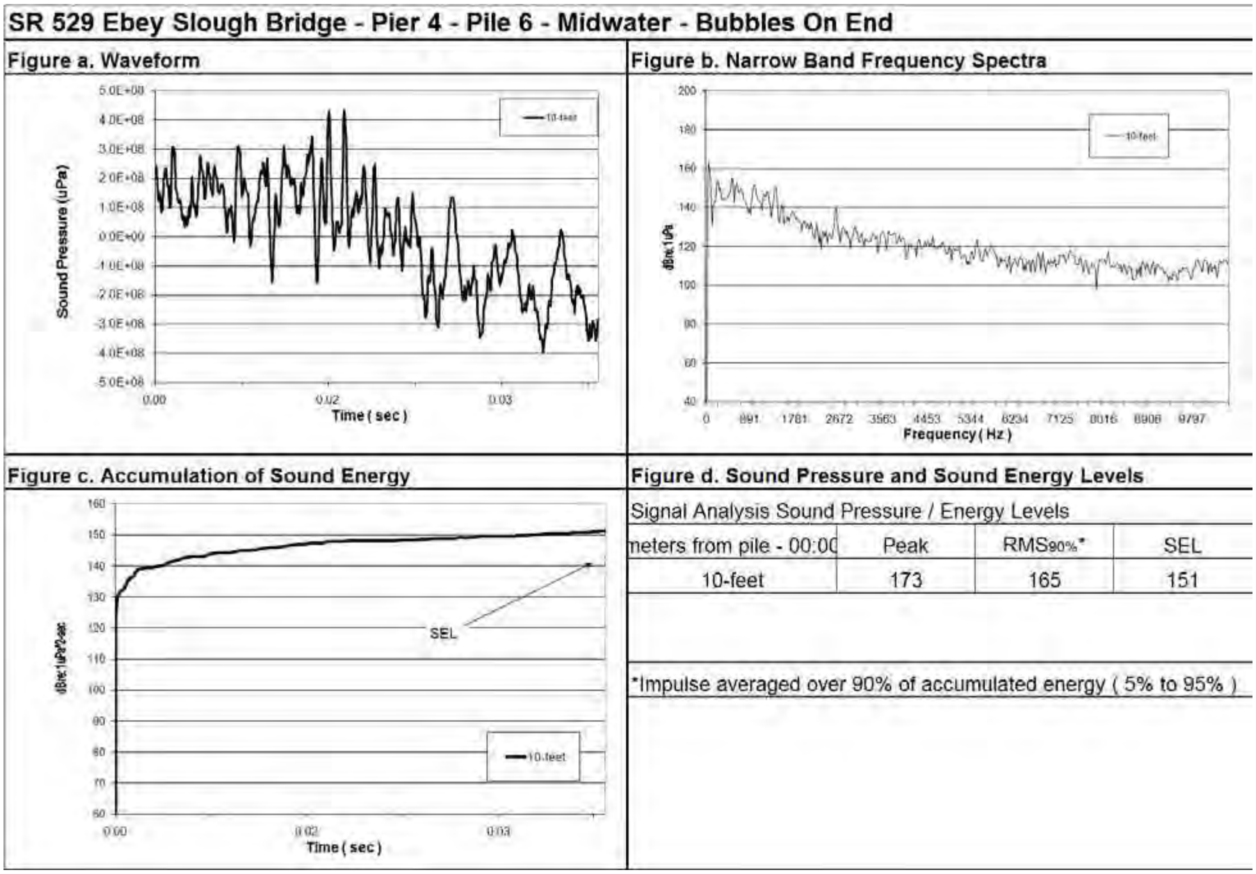


Figure 39: Waveform analysis of Pile 2 sound pressure levels with all bubbles off initial, midwater.

APPENDIX B– PILE DRIVING LOGS

Contract 7948
Structure
Location PIER 2
Hammer APE 600 SUPER KING
S/N
Ram Wt.
Pile Type 72"
Inspector [illegible]

Pile No. 2A (TEST PILE)
Date 11/9/10, 11/10/10
Cut Off Elev.
Ground Elev. 7.6
Final Tip Elev.
Length in Lead
Cut Off
Pay Lenght

TIP ~~Depth~~	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
-124.4	1453							
-125.4	1457							
-126.4	1502							
-127.4	1507							
-127.9 ~~-128.4~~	1511							
	1511 - 1518 STOPPED TO CHECK HAMMER							
-127.9 ~~-128.4~~	1518	START						
-128.4	1521							
-129.4	1538							
-130.1	1602 Stopped							
	1449	11/10/10		start			w/ D 100	
-130.4	1456	67						
-131.4	1458	65						
-132.4	1459	60						
-133.4	1500	55						
-134.4	1501	51						
-135.4	1503	52						
-136.4	1504	51						
-137.4	1506	47						

DOT Form 450-004
Revised 08/2008

Notes

11/9/10
@1538 DRIVING NOTICEABLY HARDER

11/10/10 – USED D100 DIESEL HAMMER

DOT Form 450-004
Revised 08/2008

Contract 7948

Structure

Location Pier 2

Hammer D 100

S/N

Ram Wt.

Pile Type 72"

Inspector

Pile No. 2A (test PILE)

Date 11/10/2010

Cut Off Elev.

Ground Elev. 7.6

Final Tip Elev.

Length in Lead

Cut Off

Pay Lenght

Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
-138.4	1507	49						
-139.4	1509	42						
-140.4	1510	45						
-141.4	1511	40						
-142.4	1512	37						
-143.4	1513	36						
-144.4	1514	35						
-145.4	1516	32						
-146.4	1517	33						
-147.4	1518	34						
-148.4	1519	31						
-149.4	1520	33						
-150.4	1520	34						
-151.4	1521	30						
-152.4	1522	26						
-153.4	1523	22						
-154.4	1524	26						
-155.4	1525	28						
-156.4	1526	25						

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Notes

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Contract 7948	Pile No. 2/A
Structure	Date
Location Pier 2	Cut Off Elev.
Hammer D180	Ground Elev. 7.6
S/N	Final Tip Elev.
Ram Wt.	Length in Lead
Pile Type 72"	Cut Off
Inspector Randy Hooper	Pay Lenght

Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
-157.4	1527	26						
-158.4	1528	25						
-159.4	1529	19						
-160.4	1530	24						
-161.4	1531	21						
-162.4	1532	23						
-163.4	1533	22						
-164.4	1534	24						
-165.4	1535	27						
-166.4	1536	27						
-167.4	1537	25						
-168.4	1538	25						
-169.4	1539	25						
-170.4	1540	25						
-171.4	1541	25						
-172.4	1542	26						
-173.4	1543	25						
-174.4	1544	22						
-175.4	1545	29						

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Revised 08/2008

Notes

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Revised 08/2008

Contract 7948

Structure EBEY SLOUGH BR

Location Pier 2

Hammer D100

S/N

Ram Wt.

Pile Type 72"

Inspector [illegible]

Pile No. 2A (TEST PILE)

Date 11/10/10, 11/22/10

Cut Off Elev.

Ground Elev. 7.6

Final Tip Elev.

Length in Lead

Cut Off

Pay Lenght

TIP ~~Depth~~	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
-176.4	1546	27						
-177.4	1547	25						
-178.4	1548	25						
-179.4	1549	25						
-180.4	1550	25						
-181.4	1551	25						
-182.4 / -183.4		25 / 25						
~~1031~~	1031-1034	67		91	For 4"			11/22/10
	1035	11		39	less than 1"			
	1037	25		40				

DOT Form 450-004
Revised 08/2008

Notes

11/22/10 RE-STRIKE on 11/22/10 w/ D100

DOT Form 450-004
Revised 08/2008

Contract 7948		Pile No. 3A	
Structure		Date 10/20/10, 10/22/10	
Location PIER 3		Cut Off Elev.	
Hammer APE - KING KONG		Ground Elev. 8.6'	
S/N		Final Tip Elev.	
Ram Wt.		Length in Lead	
Pile Type 72"		Cut Off	
Inspector [illegible]		Pay Lenght	

TIP ~~Depth~~	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
-209.4	1110							
-209.9	1110	stopped						
-210.4	1113	start-stopped						
-210.9	1109-1111	start/		STOPPED,			HAMMER	NOT
		155		42			WORKING	PROPERLY
-210.9-211.4	1921-1923							
		202		40				
-212.4	1924-1930	319		38				
-212.9	1933	PILE WENT		.5' -			PDA EQUIPMENT BROKE OFF PILE	
		11/2/10						
	0838-0840	81 BLOWS -		PILE WENT				1 7/8"

DOT Form 450-004
Revised 08/2008

Notes

10/22/10 used D100-13 HAMMER WHEN DRIVING, PDA EQUIPMENT ATTACHED TO PILE

11/2/10 USED D100-13 HAMMER W/ PDA EQUIPMENT FOR RESTRIKE

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4A

Contract 7948	Pile No. 4A
Structure EBEY SLOUGH BR	Date 1/3/11, 1/6/11
Location PIER 4	Cut Off Elev.
Hammer SUPER KONG	Ground Elev.
S/N	Final Tip Elev.
Ram Wt.	Length in Lead
Pile Type 72"	Cut Off
Inspector [illegible]	Pay Lenght

AT TEMPLATE ~~Depth~~	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
180	1623							
185	1823							
187	1624		STOPPED		TO		SPLICE	
AT WATER 175	1530		START		1/6/11		USED SUPER KONG	
180	1533							
185	1536							
190	1539							
195	1540							
200	1542							
205	1543							
210	1544							
215	1545							
220	1546							
225	1547							
230	1548							
235	1550		STOPPED					
237.4	1707		START		1/6/11		USED D-100	
238	1709	87			38			
239	1713	125			39			

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Notes

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4A

Contract	7948	Pile No.	4A
Structure	EBEY SLOUGH BR	Date	7/6/11
Location	PIER 4	Cut Off Elev.	
Hammer	APE D-100	Ground Elev.	
S/N		Final Tip Elev.	
Ram Wt.		Length in Lead	
Pile Type	72"	Cut Off	
Inspector	[illegible]	Pay Lenght	

AT WATER ~~Depth~~	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
239.4	1714	72			40			-230.9

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Notes

7/7/11 - TOP OF TEMPLATE 17.4'
PILE AT 248.3' MARK AT TOP OF TEMPLATE

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4B

Contract 7948
Structure EBEY SLOUGH BR
Location PIER 4
Hammer SUPER KING
S/N
Ram Wt.
Pile Type 72"
Inspector

Pile No. 4B (TEST PILE)
Date 12/30/10, 1/4/11
Cut Off Elev.
Ground Elev.
Final Tip Elev.
Length in Lead
Cut Off
Pay Lenght

AT TEMPLATE Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
188'	1133							
189'	1134							
190'	1135							
195'	1139							
200'	1141							
205'	1143							
210'	1145							
215'	1146							
220'	1147							
225'	1148							
230'	1149							
235'	1151							
240'	1151							
243'	1152							
233'	0840	START		1/4/11				
233.5'	0903	905			39			-226.0
233.5'	0910-0911	35			38			-226.0

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Notes

1/4/11 USED D-100 DIESEL HAMMER
WATER 11' DOWN FROM TOP OF TEMPLATE

1/5/11 - TOP OF TEMPLATE 17.4'
243.4' MARK AT TOP OF TEMPLATE

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4C

Contract 7948

Structure EBEY SLOUGH BR

Location PIER 4

Hammer SUPER KONG

S/N

Ram Wt.

Pile Type 72"

Inspector

Pile No. 4C (TEST PILE)

Date 12/28/10, 1/4/11

Cut Off Elev.

Ground Elev.

Final Tip Elev.

Length in Lead

Cut Off

Pay Lenght

AT TEMPLATE Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
187'	1536							
188'	1537							
189'	1538							
190'	1539							
195'	1544							
200'	1547							
205'	1550							
210'	1553							
215'	1553							
220'	1556							
225'	1557							
230'	1558							
235'	1559							
240'	1600							
245'	1601							
247'	1602	STOPPED						
234.5	1005	START		1/4/11				
*235	1017	222			38			-229.6
235	1017	5 / 203			39 / 37			-229.6

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Notes

1/4/11 - USED D-100 DIESEL HAMMER

* WATER LEVEL 12.5' DOWN FROM TOP OF TEMPLATE

** " " 12.6' " " " "

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4C

Contract 7948	Pile No. 4C
Structure EBEY SLOUGH BR	Date 1/4/11
Location PIER 4	Cut Off Elev.
Hammer D-100	Ground Elev.
S/N	Final Tip Elev.
Ram Wt.	Length in Lead
Pile Type 72"	Cut Off
Inspector [illegible]	Pay Lenght

Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
** 236	1023	235			37			-230.6
** 236.5	1030	270			38		STOPPED	-231.1

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Notes

** 1/4/11 - WATER LEVEL 12.6' FROM TOP OF TEMPLATE

1/7/11 - TOP OF TEMPLATE ELEVATION 17.4'
248.5' MARK AT TOP OF TEMPLATE

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Contract 7948 | Pile No. 4D

Structure EBEY SLOUGH BR | Date 1/6/11

Location PIER 4 | Cut Off Elev.

Hammer SUPER KING | Ground Elev.

S/N | Final Tip Elev.

Ram Wt. | Length in Lead

Pile Type 72" | Cut Off

Inspector MP | Pay Lenght

*AT TEMPLATE Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
186.5	1310			START	1/6/11			
188	1313							
189	1314							
190	1315							
195	1320							
200	1323							
205	1326							
210	1328							
215	1329							
220	1330							
225	1331							
230	1332							
235	1334							
240	1335							
245	1336							
** 246.8	1337			STOPPED				
AT WATER 235.8	1644			START		w/	D-100	
236	1645	27			37			-228.4
237	1648	111			38			-229.4

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Notes

* TEMPLATE WITH MAT ELEV – 18.7'

** TEMPLATE w/o MAT ELEV – 17.4'
WATER LEVEL – 9.8' FROM TEMPLATE

1/7/11 – TOP OF TEMPLATE 17.4'
PILE AT 247.8' MARK AT TEMPLATE

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Contract 7948	Pile No. 47D
Structure EBEY SLOUGH BR	Date 1/6/11
Location PIER 4	Cut Off Elev.
Hammer APE D-100	Ground Elev.
S/N	Final Tip Elev.
Ram Wt.	Length in Lead
Pile Type 72"	Cut Off
Inspector MD	Pay Lenght

AT WATER Depth	Time	BPF	BPI	STK	BPM	C	Ult. Rest.	Tip Elev.
238	1652	143			39			-230.4

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Notes

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