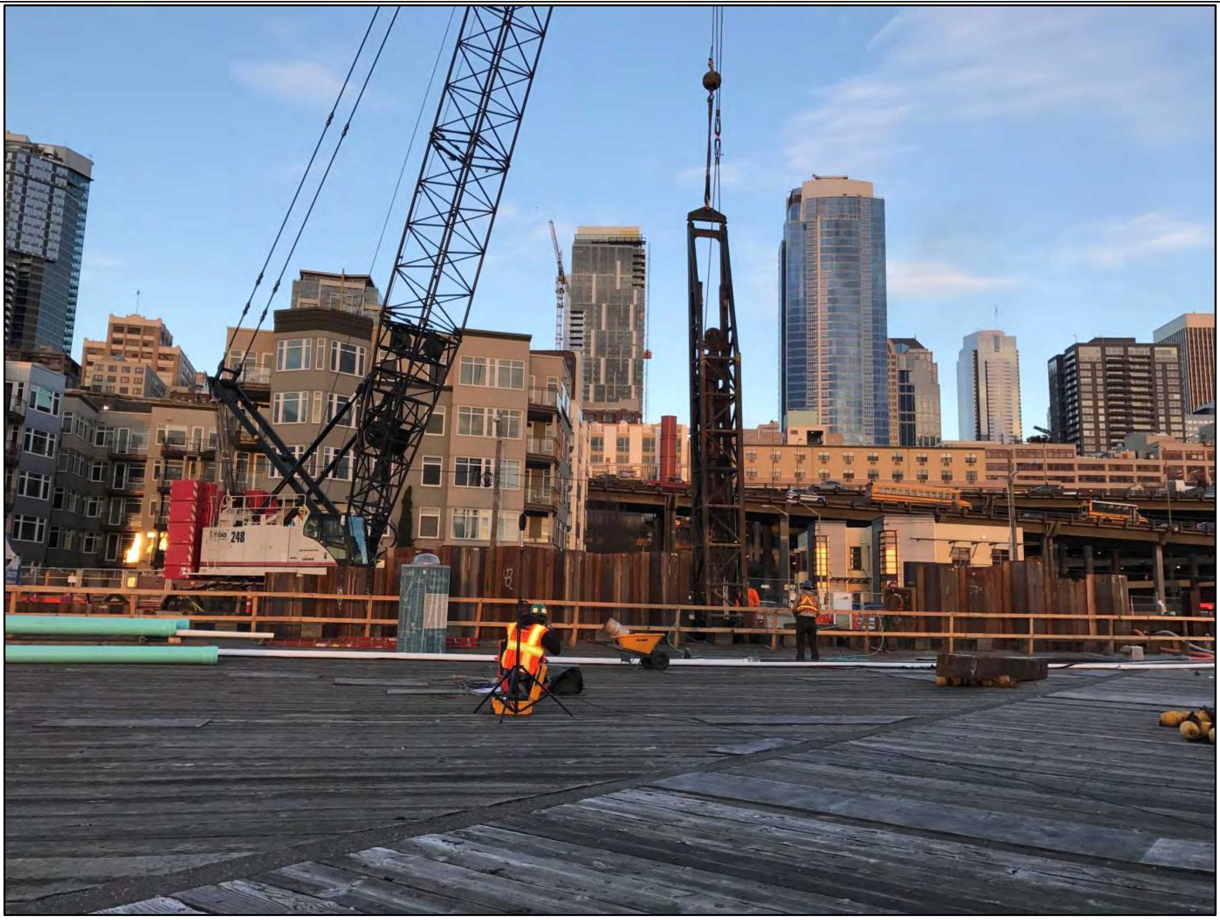


ELLIOTT BAY SEAWALL PROJECT SEASON 4 (2017) ACOUSTIC MONITORING REPORT (NWS-2011-778-WRD and NWR-2013-10650)

August 15, 2017

Prepared For:

City of Seattle Department of Transportation

Prepared By:

THE GREENBUSCH GROUP, INC.

1900 West Nickerson Street Suite 201
Seattle, Washington 98119

Table of Contents

List of Tables

List of Figures

1.0 EXECUTIVE SUMMARY

This Technical Report presents the results of airborne and underwater sound level measurements conducted in December, 2016 and January, 2017 during the removal of the first five concrete piles, installation of the first five steel sheet piles driven with a vibratory hammer and first five sheet piles driven with an impact hammer. This monitoring was conducted during Season 4 pile removal and installation activities for the Elliott Bay Seawall Project (“Project”).

In July, 2016, NOAA issued updated technical guidance for determining the effects of underwater sound on marine mammals titled “Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing”. Hydroacoustic data processing under this updated guidance differs from data processing and reporting requirement used during previous construction seasons. Underwater sound levels reported in this Technical Report were calculated using NOAA’s previous Guidance Documents dated January 31, 2012 to allow for comparison to data collected during previous construction seasons. Hydroacoustic data collected during Season 4 was also analyzed using the updated guidance. The results of this analysis are provided in the Appendix B.

Vibratory removal of concrete piles generated average underwater 10-second root mean square (RMS) sound levels ranging between 129 and 147 decibels (dB) re: 1 micropascal (μPa) and average peak values between 148 and 157 dB re: 1 μPa. Measured underwater sound levels from the removal of concrete piles with the vibratory hammer are summarized in Table 1.1 below.

Table 1.1 Measured Underwater Sound Levels from Concrete Pile Removal, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-1	7 Hz-20 kHz	147	162	3	**154**	122	149	3	**143**	127	151	2	**144**
	75 Hz-20 kHz	144	162	3	**152**	119	141	3	**134**	123	143	2	**135**
	150 Hz-20 kHz	144	158	3	**151**	119	141	3	**134**	123	143	2	**135**
	200 Hz-20 kHz	143	161	3	**151**	118	140	3	**134**	122	142	2	**135**
REM-2	7 Hz-20 kHz	147	161	3	**156**	124	154	4	**147**	121	155	3	**147**
	75 Hz-20 kHz	143	161	4	**152**	119	139	2	**133**	119	140	2	**133**
	150 Hz-20 kHz	144	161	4	**151**	118	138	3	**133**	119	140	2	**133**
	200 Hz-20 kHz	143	161	4	**151**	118	138	3	**132**	119	139	2	**133**
REM-3	7 Hz-20 kHz	142	164	4	**155**	126	154	4	**145**	123	155	3	**145**
	75 Hz-20 kHz	141	164	5	**152**	116	141	5	**135**	115	144	3	**133**
	150 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	114	143	4	**132**
	200 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	121	153	4	**135**
REM-4	7 Hz-20 kHz	146	161	3	**151**	117	149	3	**140**	133	153	3	**141**
	75 Hz-20 kHz	142	159	4	**148**	119	132	2	**130**	123	135	2	**130**
	150 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**130**
	200 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**129**
REM-5	7 Hz-20 kHz	153	168	3	**157**	139	150	3	**147**	137	151	2	**147**
	75 Hz-20 kHz	147	168	5	**153**	130	139	2	**135**	128	141	2	**135**
	150 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	125	141	2	**135**
	200 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	124	141	2	**135**

Note: Underwater sound levels were measured 35 to 40 feet (11 to 12 meters) from the piles. Reported sound levels have not been normalized to 10 meters, but are expected to be within 1 dB of normalized values calculated using the practical spreading model.

Average 10-second RMS airborne sound levels produced by the removal of concrete piles ranged between 87 and 96 dB re: 20 μPa at 50 feet (15 meters). Measured airborne sound levels are summarized in Table 1.2.

Table 1.2 Measured Airborne Sound Levels from Concrete Pile Removal, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-1	89	100	92
REM-2	94	100	96
REM-3	90	95	92
REM-4	85	91	87
REM-5	89	96	92

Note: Airborne sound levels measured 50 feet (15 meters) from the piles.

Vibratory sheet pile installation produced average underwater 10-second root mean square (RMS) sound levels ranging between 147 and 153 decibels (dB) re: 1 micropascal (μPa) and average peak values between 163 and 170 dB re: 1 μPa. Measured underwater sound levels generated by full powered vibratory pile driving are summarized in Table 1.3 below.

Table 1.3 Measured Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	7 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	75 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	150 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	200 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
VIB-2	7 Hz-20 kHz	151	174	5	**164**	135	155	5	**148**	133	155	5	**148**
	75 Hz-20 kHz	151	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	150 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	200 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**
VIB-3	7 Hz-20 kHz	154	174	3	**166**	129	159	4	**151**	139	159	3	**152**
	75 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**150**
	150 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**
	200 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**
VIB-4	7 Hz-20 kHz	154	170	4	**164**	131	154	5	**148**	137	156	3	**149**
	75 Hz-20 kHz	154	170	4	**164**	130	154	5	**148**	133	156	3	**148**
	150 Hz-20 kHz	154	170	4	**164**	130	154	5	**147**	133	156	3	**148**
	200 Hz-20 kHz	154	171	4	**164**	130	154	5	**147**	133	156	3	**148**
VIB-5	7 Hz-20 kHz	155	180	4	**170**	137	159	3	**153**	137	161	3	**153**
	75 Hz-20 kHz	154	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	150 Hz-20 kHz	155	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	200 Hz-20 kHz	154	179	4	**170**	137	158	3	**152**	135	161	3	**153**

Note: Underwater sound levels were measured 37 to 39 feet (11.3 to 11.9 meters) from the piles. Reported sound levels have not been normalized to 10 meters, but are expected to be within 1 dB of normalized values calculated using the practical spreading model.

Underwater sound levels produced by vibratory pile driving during Season 4 were below the sound levels predicted in the memorandum authored by The Greenbusch Group titled “EBSP Season 2 Hydroacoustic Monitoring Approach” dated October 6, 2014, as well as the anticipated sound levels listed in the Project’s Biological Opinion.

Average 10-second RMS airborne sound levels produced by vibratory sheet pile installation ranged between 101 and 107 dB re: 20 μPa at 50 feet (15 meters). Measured airborne sound levels are summarized in Table 1.4.

Table 1.4 Measured Airborne Sound Levels from Vibratory Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-1	98	114	107
VIB-2	97	107	103
VIB-3	93	104	101
VIB-4	95	106	101
VIB-5	95	107	102

Note: Airborne sound levels measured 50 feet (15 meters) from the piles.

Average underwater 90% RMS (RMS_{90}) sound levels generated by impact sheet pile driving ranged between 171 and 182 dB re: 1 μPa and produced average peak values ranging from 184 to 194 dB re: 1 μPa. Measured underwater sound levels generated by the diesel impact hammer are summarized in Table 1.5.

Table 1.5 Measured Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	75 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	150 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	200 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
IMP-2	7 Hz-20 kHz	182	191	1	**187**	166	179	1	**175**	155	164	1	**161**	**182**
	75 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	150 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	200 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
IMP-3	7 Hz-20 kHz	184	197	2	**192**	169	182	1	**179**	157	167	1	**164**	**187**
	75 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	150 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	200 Hz-20 kHz	183	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
IMP-4	7 Hz-20 kHz	183	199	2	**194**	168	185	2	**182**	156	170	2	**167**	**188**
	75 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	150 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	200 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
IMP-5	7 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	75 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	150 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	200 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**

Note: Underwater sound levels were measured 32 to 40 feet (10 to 12 meters) from the piles. Reported sound levels have not been normalized to 10 meters, but are expected to be within 1 dB of normalized values calculated using the practical spreading model.

Measured underwater sound levels generated by impact pile driving during Season 4 were below the anticipated sound levels provided in the Project's Biological Opinion.

The average airborne sound levels recorded during impact pile driving ranged between 107 and 111 dB re: 20 μPa and are summarized in Table 1.6.

Table 1.6 Measured Airborne Sound Levels from Impact Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1	96	113	107
IMP-2	103	110	108
IMP-3	99	114	109
IMP-4	99	114	111
IMP-5	96	112	109

Note: Airborne sound levels measured 50 feet (15 meters) from the piles.

Based on the highest average broadband RMS values, the distance required for underwater sound levels to reach the marine mammal detection (Level B) threshold of 120 dB re: 1 μPa was estimated to be up to 2,400 feet (731 meters) for the vibratory removal of concrete piles and up to 1.2 miles (1.9 kilometers) for vibratory driving of steel sheet piles. The distance necessary for the highest measured RMS_{90} sound level generated by impact driving of steel sheet piles to reach the 160 dB re: 1 μPa marine mammal detection (Level B) threshold was calculated to be up to 940 feet (287 meters).

Two background sound level measurements were conducted to document underwater sound levels in Elliott Bay in the absence of in-water construction activities. One set of measurements determined background sound levels near the pile driving activities (near shore) and the other set (far field) was conducted to verify the results of previous measurements made during Seasons 2 and 3 as well as by the Washington State Department of Transportation (WSDOT) in 2011. Average background sound levels are summarized in Table 1.7.

Table 1.7 Average Underwater Background Sound Levels, dB re: 1 μPa

Functional Hearing Group	Frequency Range	WSDOT Background Sound Level (2011)	Far Field Background Sound Level (2017)	Near Shore Background Sound Level (2017)
Low-Frequency Cetaceans	7 Hz – 20 kHz	130	128	127[1]
Mid-Frequency Cetaceans	150 Hz – 20 kHz	124	124	125
High-Frequency Cetaceans	200 Hz – 20 kHz	124	124	124
Pinnipeds	75 Hz – 20 kHz	127	126	126

1. Frequency range from 12.5 Hz to 20 kHz

Note: The median was used to report the average background sound levels

Source: WSDOT report titled "Compendium of Background Sound Levels for Ferry Terminals in Puget Sound" issued April, 2014

Utilizing the highest measured average underwater RMS sound level produced during vibratory steel sheet pile installation in each marine mammal functional hearing group and the average background sound levels ranging between 124 dB and 130 dB collected by WSDOT in 2011, the distances required to reach background sound levels (Level B) are up to 3,400 feet (1,036 meters).

The calculated distance required for the highest measured average RMS_{90} sound level of 182 dB produced by impact driving of steel sheet piles to reach background sound levels is up to 44.5 miles (71.6 kilometers) using the background sound data collected by WSDOT. However, these distances are reduced due to the proximity of adjacent land masses. The WSDOT background sound levels were used rather than the near shore data collected by Greenbusch in 2017 because the WSDOT data more accurately describes the environment where marine mammals are likely to be present.

2.0 INTRODUCTION

This Technical Report presents the results of airborne and underwater sound levels measured during the removal of concrete piles with a vibratory hammer and installation of steel sheet piles with both a vibratory and impact hammer during Season 4 (2016/2017 in-water work window) of the Elliott Bay Seawall Project ("Project").

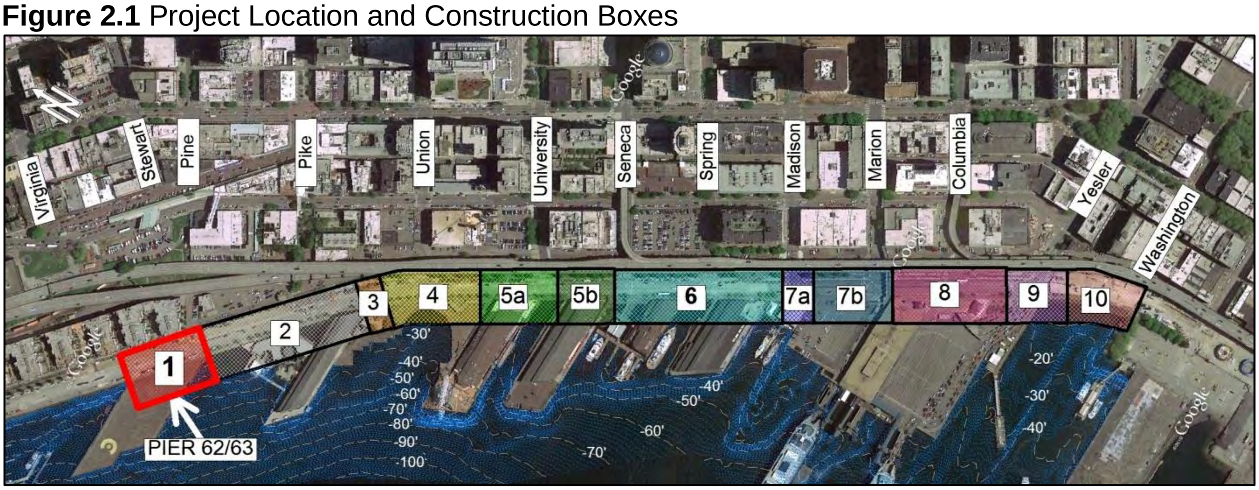
Consultation with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS) under the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) requires sound level monitoring for the first five unobstructed piles of each pile type and installation method. This Acoustic Monitoring Technical Report fulfills the requirements of the Project's Biological Opinion issued by NOAA and USFWS, and the MMPA Letter of Authorization (LOA), issued by NOAA.

The Project construction area is located at Pier 62/63 on Alaskan Way in Seattle, Washington. This area is located in Box 1 between Virginia Street and Stewart Street (see Figure 2.1). Airborne and underwater sound level measurements were conducted between December 27, 2016 and January 11, 2017 during the removal and installation of obstructed and unobstructed concrete piles and steel sheet piles.

Marine mammal monitoring began on December 27, 2016 and coincided with the beginning of acoustic monitoring. During Season 4, sound levels were measured for the first five concrete piles removed with a vibratory hammer. Sound levels were also measured during the installation of the first five steel sheet piles installed with a vibratory hammer and the first five sheet piles driven with an impact hammer. Pile driving during Season 4 occurred between the existing Seawall and Pier 62/63. As a result, an unobstructed acoustical path between the pile and hydrophones was not viable during all pile driving activities. Because an unobstructed acoustical path could not be established during all pile driving activities, underwater sound levels were also measured at varying distances during vibratory and impact pile driving to determine the site specific attenuation factor resulting from obstructed pile driving.

Pile installation with an impact hammer only occurred when the vibratory hammer was unable to drive the pile to the necessary depth, as required by the Project's LOA and Biological Opinion. No concrete or other types of piles were installed during Season 4.

Figure 2.1 Project Location and Construction Boxes



Source: Google Earth Pro, Mortenson/Manson

3.0 NOMENCLATURE

The auditory response to sound is a complex process that occurs over a wide range of frequencies and intensities. Decibel levels, or "dB," are a form of shorthand that compresses this broad range of levels with a convenient, logarithmic scale.

Decibels are defined as the squared ratio of the sound pressure level (SPL) with a reference sound pressure. The reference pressure for airborne sound is 20 micropascals (μPa) and for underwater sound the reference pressure is 1 μPa. The use of 20 μPa in air is convenient because 1 dB re: 20 μPa correlates to the human threshold for hearing. It is important to note that because of these different reference pressures, airborne and underwater sound levels cannot be directly compared.

The following descriptors are referenced in this Report:

- **Background Sound Level**

  The background sound level is the sound pressure level that describes the sound environment at a specified location during a specified time period and is also referred to as "ambient sound levels". The measured sound levels include contributions from all sound sources, both local and distance, excluding specific sound sources of interest or under investigation.

- **Peak**

  The peak sound pressure level is the instantaneous absolute maximum pressure observed during a measured event. Peak pressure can be presented as a pressure or dB referenced to a standard pressure (20 μPa for airborne and 1 μPa for underwater).

- **Root Mean Square (RMS)**

  The RMS level is the square root of the average squared-pressure over a given time period. For vibratory pile driving RMS levels are calculated over 10 second periods. In hydroacoustics, the RMS level has been used by the National Marine Fisheries Service (NMFS) in criteria for assessing impacts to marine mammals.

- **90% Root Mean Square (RMS_{90})**

  The RMS_{90} level is used for the analysis of impact pile driving and is the RMS level containing 90 percent of the energy in a pile strike. The RMS_{90} energy is established between the 5% and 95% of the pile energy and is calculated for each pile strike.

- **Sound Exposure Level (SEL)**

  The SEL is the squared sound pressure integrated or summed over time referenced to a standard pressure squared (20 μPa for airborne and 1 μPa for underwater) normalized to one second and converted to decibels.

- **Cumulative Sound Exposure Level (cSEL)**

  The cSEL is the SEL accumulated over time. In this report cSEL is calculated by adding the SEL corresponding to the absolute maximum peak pile strike to ten times the log of the number of pile strikes.

4.0 REGULATORY CRITERIA

Anticipated underwater sound levels from the Project's Biological Opinion are presented in Table 4.1 below.

Table 4.1 Predicted Unmitigated Underwater Sound Levels (ESA and MMPA Consultation)

Pile Type and Approximate Size	Method	Relative Water Depth of Piles	Average Sound Pressure Measured in dB re: 1 μPa	
			Peak	RMS
16.5 inch diameter precast concrete octagonal pile	Impact	~15 meters	188	176
Steel sheet pile pair, 48 inches long per pair	Vibratory (Installation and Removal)	~15 meters	182	165
Steel sheet pile pair, 48 inches long per pair	Impact (Installation Proofing)	~15 meters	205	190

Source: EBSP Updated Marine Mammal Monitoring and Mitigation Plan (April 2013), EBSP Biological Opinion (September 2013)

Since some of the piles driven in Season 1 exceeded the underwater sound levels indicated above, measured sound levels from Season 1 vibratory pile driving were used to estimate more realistic sound levels for subsequent EBSP pile installation. These predicted sound levels are included in a memorandum authored by The Greenbusch Group dated October 6, 2014 and were attached to the Season 2 Letter of Authorization (LOA) issued by NOAA. Table 4.2 provides these predicted underwater sound levels for vibratory pile installation based on data collected during Season 1.

Table 4.2 Predicted Unmitigated Underwater Sound Levels (Based on Season 1 Sound Levels)

Predicted Season 2 Sound Levels	Average / Maximum Sound Levels at 10 meters, dB re: 1 μPa		
	Peak	RMS	SEL[1]
Vibratory Sheet Pile Installation	188 / 196	163 / 169	163 / 169

1. 1-second SEL

Source: Greenbusch Memorandum titled "EBSP Season 2 Hydroacoustic Monitoring Approach" dated October 6, 2014

Sound levels provided in Table 4.1 and Table 4.2 are established 33 feet (10 meters) from the pile. RMS sound levels for piles driven with an impact hammer are RMS_{90} sound levels.

The Project's LOA and Biological Opinion require reporting of underwater sound levels generated by the first five unobstructed piles of each pile type and driving method shown in Table 4.1 above. These reported sound levels must include the frequency spectrum, ranges, means and standard deviation for the peak and RMS sound pressure levels for each marine mammal functional hearing group, as well as the estimated distance required for the RMS values to reach the marine mammal thresholds and background sound levels. During impact pile driving, the pile strike resulting in the absolute highest peak sound pressure level was used to calculate the cSEL of the pile drive.

As requested by NOAA during a conference call on September 22, 2014, sound levels measured during ramp-up activities are reported separately from sound levels measured during pile driving under full power. In addition, NOAA requested sound level data to include the range of SEL values.

Consultation with NOAA and USFWS under the MMPA and ESA also requires collection of underwater background sound levels. As a result of the September 22, 2014 coordination with NOAA, USFWS and SDOT, the parties agreed that background sound level data would be collected between 500 and 1,000 meters from the construction area to verify that sound levels reported by WSDOT in 2011 had not changed and that additional data would be collected approximately 10 meters from the monitored piles during Season 2. Although background sound level measurement locations for Season 4 are not specified in the Project's Biological Opinion or LOA, Season 4 background sound levels were collected in Elliott Bay to verify the underwater sound levels collected by WSDOT had not changed. An additional set of background data was collected near the pile driving locations.

5.0 PILE AND PILE DRIVING EQUIPMENT INFORMATION

During Season 4, all steel sheet pile installation was initiated with a vibratory hammer. In some instances, the vibratory hammer was unable to drive the piles to the required depth and it was necessary to drive the remainder of the pile with an impact hammer. The steel sheet pile wall consisted of two different types of sheet pile, AZ38 and AZ26, between 50 and 57 feet long. Two sheets of each type were welded together prior to being driven. All piles were driven to a minimum depth of 31 feet. Generally, the substrate the sheet piles were driven into was hard, rocky and covered with silt and marine debris. A photo of the seafloor is provided in Figure 5.1 below.

Figure 5.1. Seafloor on Southwest side of Pier 62/63

An APE 250VM Vibratory Driver/Extractor was used to remove concrete piles and install sheet piles. The APE 250VM operates at a frequency of 2,050 VPM with a maximum driving force of 269 tons. The suspended driver weight without the clamp is 15,400 pounds. A cut sheet of the APE 250VM Vibratory Driver/Extractor can be found in Appendix A of this Report. Table 5.1 and Table 5.2 present a summary of the concrete piles and sheet piles removed and driven with the vibratory hammer while sound level monitoring occurred.

Table 5.1 Summary of Concrete Piles Removed with a Vibratory Hammer, Feet

Pile ID	Date Removed	Sound Attenuation Method	Distance to Water's Edge	Water Depth	Drive Time (minutes)[1]
REM-1	12/27/16	None	3	6	6.3
REM-2			3	6	7.5
REM-3			3	6	4.0
REM-4			3	6	4.5
REM-5			3	6	7.5

1. Total drive time included in analysis, which only includes periods when the vibratory hammer was operating.

Table 5.2 Summary of Sheet Piles Driven with a Vibratory Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Drive Time (minutes)[1]
VIB-1	12/28/16	None	3	5	17.7
VIB-2			3	5	9.9
VIB-3			3	6	15.0
VIB-4			3	6	14.3
VIB-5			3	7	7.9

1. Total drive time included in analysis, which only includes periods when the vibratory hammer was operating.

In cases when the vibratory hammer was unable to drive the piles to the required depth, the piles were driven with an APE Model D50-52 Single Acting Diesel Impact Hammer with a maximum rated energy of 124,031 foot-pounds. The ram weighed 11,025 pounds with a maximum stroke height of 135 inches. The hammer operated at between 34 and 53 strikes per minute. Table 5.3 provides a summary of the sheet piles that required driving with the impact hammer while sound level monitoring occurred.

Table 5.3 Summary of Sheet Piles Driven with an Impact Hammer, Feet

Pile ID	Date Driven	Sound Attenuation	Distance to Water's Edge	Water Depth	Number of Strikes[1]
IMP-1	1/11/17	None	3	9	39
IMP-2			3	9	63
IMP-3			3	9	113
IMP-4			3	9	84
IMP-5			3	9	135

1. Number of strikes included in analysis.

6.0 MEASUREMENT METHODOLOGY

6.1 Equipment

Equipment used to collect airborne sound data during vibratory and impact pile driving are identified in Table 6.1.

Table 6.1 Airborne Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2250	1	Sound Level Analyzer	3006756
Brüel & Kjaer ZC0032	1	Preamplifier	24600
Brüel & Kjaer 4189	1	Microphone	2550228
Brüel & Kjaer 4231	1	Acoustic Calibrator	2545696

Table 6.2 identifies equipment used to monitor pile driving and background sound levels.

Table 6.2 Underwater Sound Measurement Equipment

Make and Model	Quantity	Description	Serial Number
Brüel & Kjaer Type 2270	1	Sound Level Analyzer	2679351
Reson TC-4013	4	Hydrophone	2513032
			0712213
			315200
			4714126
Brüel & Kjaer Type 2647-A	3	Charge Converter (1 mV/pC)	2638260
			2638259
			2582112
Brüel & Kjaer Type 2647-B	1	Charge Converter (10 mV/pC)	3019408
PCB 422E52	1	Charge Converter (10 mV/pC)	44744
G.R.A.S. Type 42AC	1	Pistonphone	201835
Brüel & Kjaer 1704-A-002	1	Signal Conditioner	101161
PCB Model 458B36	1	Signal Conditioner	1577
PCB Model 482A16	1	Signal Conditioner	2987
Tascam DR-680MKII	1	Digital Audio Recorder	0080239
Tascam DR-100MKII	1	Digital Audio Recorder	0460561

All measurement equipment for underwater monitoring was factory-calibrated within 1 year of the measurement date. Calibration tones were also recorded before each day of monitoring for verification of calibration factors during post-processing. Microphones were calibrated using the Brüel & Kjaer 4231 acoustic calibrator. Hydrophones were calibrated using the G.R.A.S. pistonphone.

Underwater sound levels near the pile driving were measured using two Reson TC-4013 hydrophones connected to the Brüel & Kjaer Type 2647-A charge converters and Brüel & Kjaer 1704-A-002 signal conditioner. The signal conditioner was connected to the Tascam DR-680MKII digital audio recorder, which recorded the signal as a WAV file at a sample rate of

96,000 samples per second for subsequent signal analysis. The Brüel & Kjaer Type 2270 allowed for real-time approximations of peak and cSEL sound levels while the measurements were being performed. Photos illustrating the airborne and underwater measurement equipment used near the pile driving are provided in Figure 6.1 through Figure 6.3.

Figure 6.1 Airborne Measurement Equipment

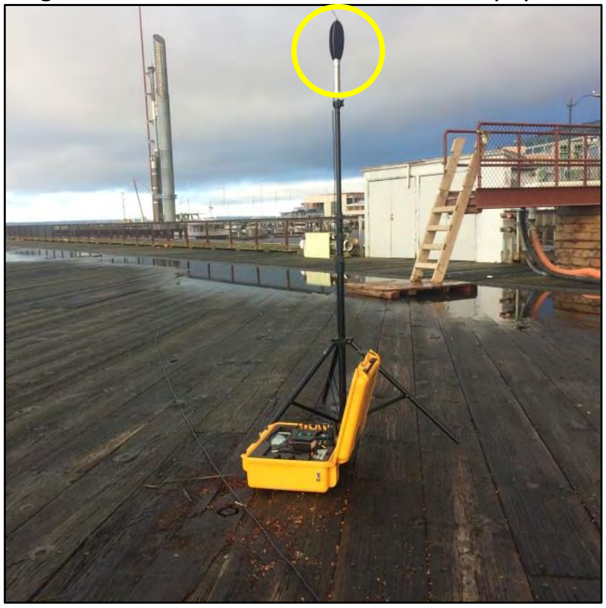
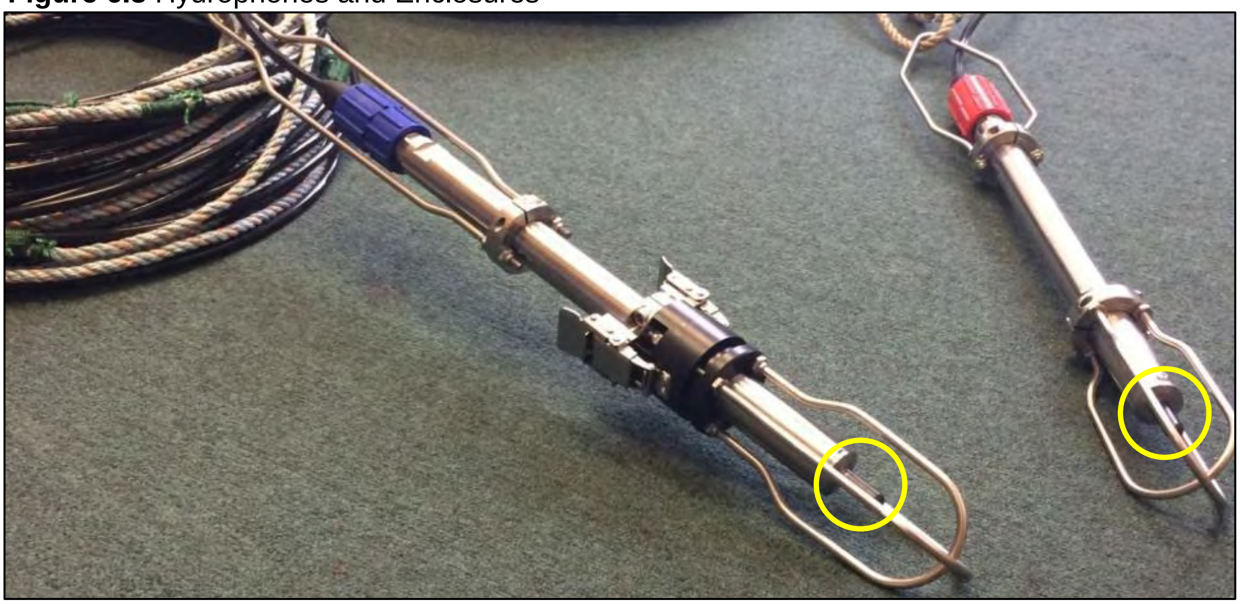


Figure 6.2 Hydroacoustic Equipment

Figure 6.3 Hydrophones and Enclosures



In addition to the two hydrophones deployed near the pile driving, an additional Reson TC-4013 hydrophone was positioned near the west side of the pier. This hydrophone was attached to a Brüel & Kjaer Type 2647-A charge converter and PCB Model 458B36 signal conditioner. The signal conditioner was attached to the Tascam DR-680MKII digital audio recorder, which also recorded the signals from the near field hydrophones. Simultaneously recording these signals simplified transmission loss calculations underneath Pier 62/63 during post processing.

Measurements were also conducted in Elliott Bay and the west side of Pier 62/63 during vibratory and impact pile driving to allow transmission loss to be calculated. Measurements at these locations were made using a Reson TC-4013 hydrophone attached to either the Brüel & Kjaer Type 2647-B or PCB 422E52 charge converter, which was connected to the PCB Model 482A16 signal conditioner. The signal conditioner was attached to the Tascam DR-100MKII audio recorder, which recorded the signal at 96,000 samples per second. A photo of the hydroacoustic monitoring equipment used at these locations is provided in Figure 6.4.

Figure 6.4. Far Field Hydroacoustic Equipment

6.2 Measurement Locations

Airborne sound level measurements were made approximately 50 feet (15 meters) from each pile. The distance between the microphone and pile was determined using a laser distance measurement device. The microphone was located 5 to 7 feet (1.5 to 2 meters) above the pier and a direct line of site was maintained between the microphone and the pile.

Hydrophones were lowered through holes drilled through Pier 62/63. As a result, the hydrophones were unable to be relocated throughout the day to maintain an unobstructed acoustical transmission path or a 33 foot (10 meter) distance from the piles. However, because all piles driven during Season 4 were located east of Pier 62/63, all sound emissions into Elliott Bay from pile driving were obstructed.

Hydroacoustic monitoring conducted during the removal of the first three concrete piles with the vibratory hammer was conducted using two hydrophones located between 35 and 37 feet (10.7 to 11.3 meters) from the piles. One hydrophone was positioned 3.3 feet (1 meter) below the surface and the second hydrophone was deployed 3.3 feet (1 meter) above the sea floor. One hydrophone located at mid-water depth was used to monitor sound produced from the removal of the fourth and fifth concrete piles. This hydrophone was positioned 40 to 43 feet (12 to 13 meters) from the piles.

Underwater sound levels were measured during vibratory pile installation using two hydrophones positioned 37 to 39 feet (11 to 12 meters) from the sheet piles. Two hydrophones were also used during impact pile driving and were located 32 to 40 feet (10 to 12 meters) from the piles being driven. During both vibratory and impact pile driving one hydrophone was deployed 3.3 feet (1 meter) above the sea floor and the other 3.3 feet (1 meter) below the surface.

The distance between the hydrophones and piles were verified for all monitored piles using a laser distance measurement device. Water depth was measured at all hydroacoustic measurement locations prior to deploying the hydrophones. The depth of the upper hydrophone was maintained by suspending the hydrophone 3.3 feet (1 meter) below a buoy. The lower hydrophone was fixed 3.3 feet (1 meter) above the sea floor by attaching the hydrophone to a weighted line.

In addition to the two near-field hydrophones, an additional hydrophone was deployed at mid-water depth near the northwest side of Pier 62/63 during the removal of concrete piles and vibratory pile driving. The hydrophone was located approximately 240 feet (73 meters) from the first three concrete piles removed with the vibratory hammer and approximately 400 feet (122 meters) from the removal of the fourth and fifth concrete piles. During vibratory pile driving of steel sheet piles the hydrophone was approximately 240 feet (73 meters) from pile driving. This hydrophone was relocated to the southwest side of Pier 62/63 approximately 220 feet (67 meters) away from impact pile driving.

During the removal of concrete piles, the far field hydrophone located in Elliott Bay was deployed from a drifting boat approximately 1,300 to 5,500 feet (396 to 1,676 meters) from the piles and 1,100 to 1,800 feet (335 to 549 meters) from the installation of the sheet piles with the vibratory hammer. These distances varied in an attempt to collect data at a variety of distances. During impact pile driving this hydrophone was deployed from the southwest corner of Pier 62/63, approximately 340 feet (104 meters) from the piles.

Unless otherwise noted, the results and distances between the hydrophones and piles in this Technical Report refer to the near field hydrophones.

In addition to water depth measurements, tidal information was obtained from NOAA Station #9447130 and was used to track tidal changes during construction and to calculate the resulting distance between the two hydrophones. Table 6.3 presents the depth of the hydrophones, water depth at the measurement location, distance between the hydrophones and distance between the hydrophones and the pile. Figures illustrating the airborne and underwater measurement locations are presented in Sections 8.0 and 9.0 of this Report.

Table 6.3 Hydrophone Location Summary, Feet

Pile ID	Hydrophone	Depth at Measurement Location[1]	Hydrophone Depth	Distance between Hydrophones	Distance to Pile
Concrete Pile Removal					
REM-1	Upper	14	3	8	36
	Lower		11		
REM-2	Upper	13	3	7	35
	Lower		10		
REM-3	Upper	13	3	7	37
	Lower		10		
REM-4	Mid-Water	14	8	N/A	43
REM-5	Mid-Water	14	8	N/A	40
Vibratory Installation					
VIB-1	Upper	13	3	7	39
	Lower		10		
VIB-2	Upper	13	3	7	39
	Lower		10		
VIB-3	Upper	14	3	8	38
	Lower		11		
VIB-4	Upper	14	3	8	37
	Lower		11		
VIB-5	Upper	15	3	9	37
	Lower		12		
Impact Installation					
IMP-1	Upper	12	3	6	40
	Lower		9		
IMP-2	Upper	12	3	6	37
	Lower		9		
IMP-3	Upper	12	3	6	35
	Lower		9		
IMP-4	Upper	12	3	6	33
	Lower		9		
IMP-5	Upper	12	3	6	32
	Lower		9		

1. Depth at start of pile drive

Source: NOAA Station #9447130

7.0 BACKGROUND SOUND LEVEL MEASUREMENT METHODOLOGY

Two sets of background underwater sound levels were measured in the absence of in-water construction activities to determine the distance required for the RMS sound levels produced by pile driving to attenuation to background sound levels and to satisfy the background sound measurement requirements of the ESA and MMPA consultation.

The first set of background sound level measurements was made in Elliott Bay at multiple distances from Box 1 (see Figure 7.1). These far field measurements verified that background sound levels in Elliott Bay had not significantly changed from those measured by WSDOT in 2011.

A description of the equipment used to collect background sound data in Elliott Bay is provided in Section 6.1. The hydrophone was deployed at depths ranging between 100 and 200 feet (30 and 61 meters).

The second set of background sound level measurements was made near shore, approximately 280 feet (85 meters) west of Box 1 (see Figure 7.12). This location was selected based on site access, ability to secure equipment, water depth to ensure the hydrophone would remain submerged over the entire measurement duration and proximity to Season 4 pile driving locations.

Background hydroacoustic data collected near Box 1 used a Reson TC-4013 hydrophone attached to the PCB 422E52 10 mV/pC charge converter. This charge converter was attached to the Brüel & Kjaer 1704-A-002 signal conditioner, which amplified the signal. Data from the signal conditioner went into the Brüel & Kjaer Type 2270 sound level analyzer. The hydrophone was deployed at mid-water depth.

10-second RMS background sound data collected from 15 minutes after sunrise to 15 minutes before sunset was used to calculate the cumulative distribution function (CDF) of each marine mammal functional hearing group in accordance with the NOAA Guidance Document: "Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon" dated January 31, 2012. The marine mammal functional hearing groups are presented in Table 7.1.

Table 7.1 Marine Mammal Functional Hearing Groups

Functional Hearing Group	Low Frequency	High Frequency
Low-Frequency Cetaceans	7 Hz	20 kHz
Mid-Frequency Cetaceans	150 Hz	20 kHz
High-Frequency Cetaceans	200 Hz	20 kHz
Pinnipeds	75 Hz	20 kHz

Source: NOAA Guidance Document: "Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon" dated January 31, 2012

The overall broadband background sound levels for each hearing group described in Table 7.1 are reported as the 50th percentile of the CDFs.

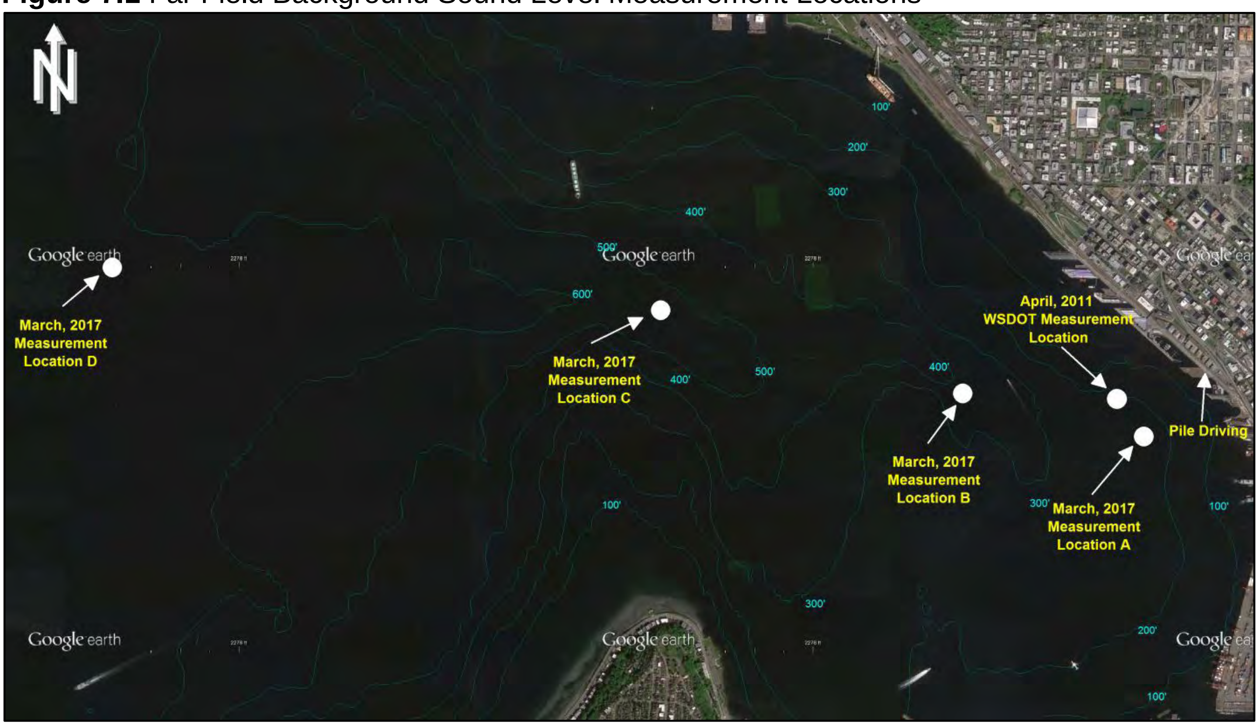
7.1 Far Field Background Sound Levels

Short-term far-field background sound level measurements were made during daytime hours at four locations west and southwest of Box 1 on March 4, 2017. Measurement distances were approximately 1,260 feet (384 meters), 4,800 feet (1,463 meters), 10,500 feet (3,200 meters) and 20,000 feet (6,096 meters) from Box 1. Measurements were made from a drifting boat at mid-water depth over durations of approximately 30 minutes per location.

WSDOT collected background sound levels in Elliott Bay over three consecutive 24-hour periods between April 19 and April 22, 2011. These measurements are presented in a report titled “Compendium of Background Sound Levels for Ferry Terminals in Puget Sound” issued in April 2014. Background sound levels measured in January 2015 during Season 2 and February 2016 during Season 3 demonstrated that underwater sound levels remained consistent with those collected by WSDOT. Short-term measurements made during Season 4 were used to further verify that sound levels remained consistent. By demonstrating that the short-term measurements conducted in March 2017 do not vary significantly from the daytime levels reported by WSDOT and those reported during Season 2 and Season 3, the long term data collected by WSDOT can be used to calculate the distance required for noise from pile driving to reach background sound levels.

Figure 7.1 below presents the locations of the March 2017 measurements during Season 4 and the approximate WSDOT 2011 measurement location.

Figure 7.1 Far Field Background Sound Level Measurement Locations



Source: Washington State Department of Transportation report “Compendium of Background Sound Levels for Ferry Terminals in Puget Sound” issued April, 2014

Equipment used to collect short term background sound data is shown in Figure 7.2.

Figure 7.2 Far Field Background Sound Measurement Equipment

10-second RMS values were used from short term measurements conducted in March 2017 to generate CDF plots for each marine mammal functional hearing group. These CDF plots are provided in Figure 7.3 through Figure 7.6.

Figure 7.3 CDF Plot, 7 Hz – 20 kHz

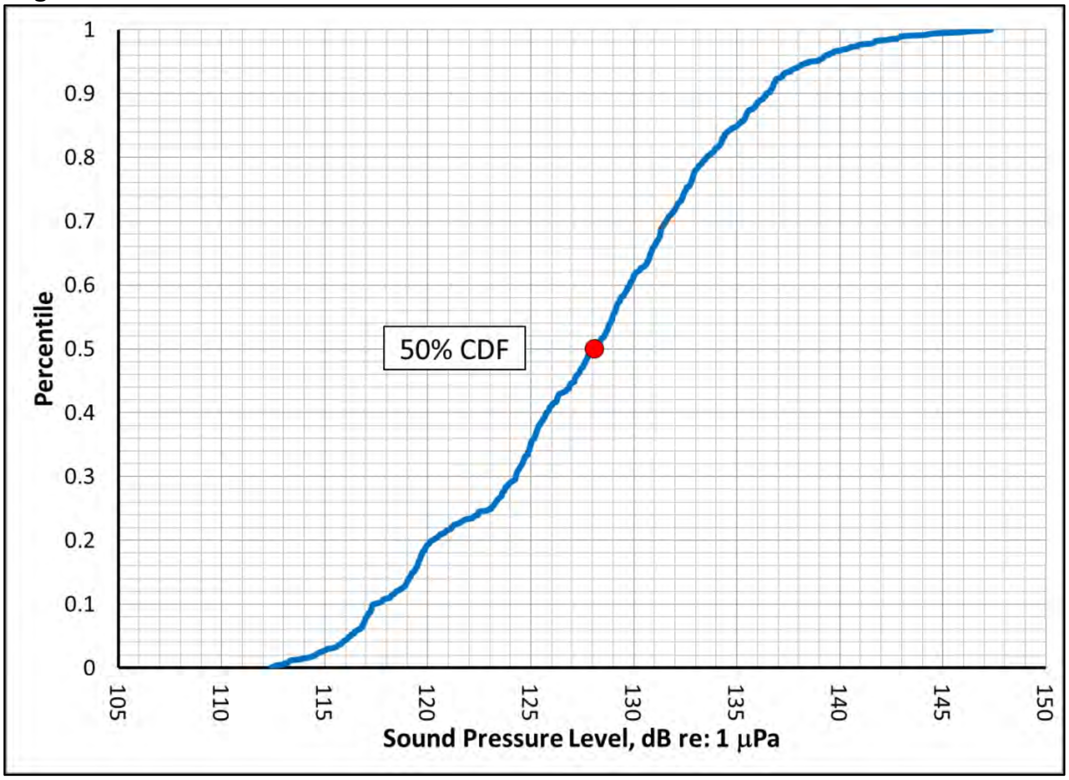


Figure 7.4 CDF Plot, 150 Hz – 20 kHz

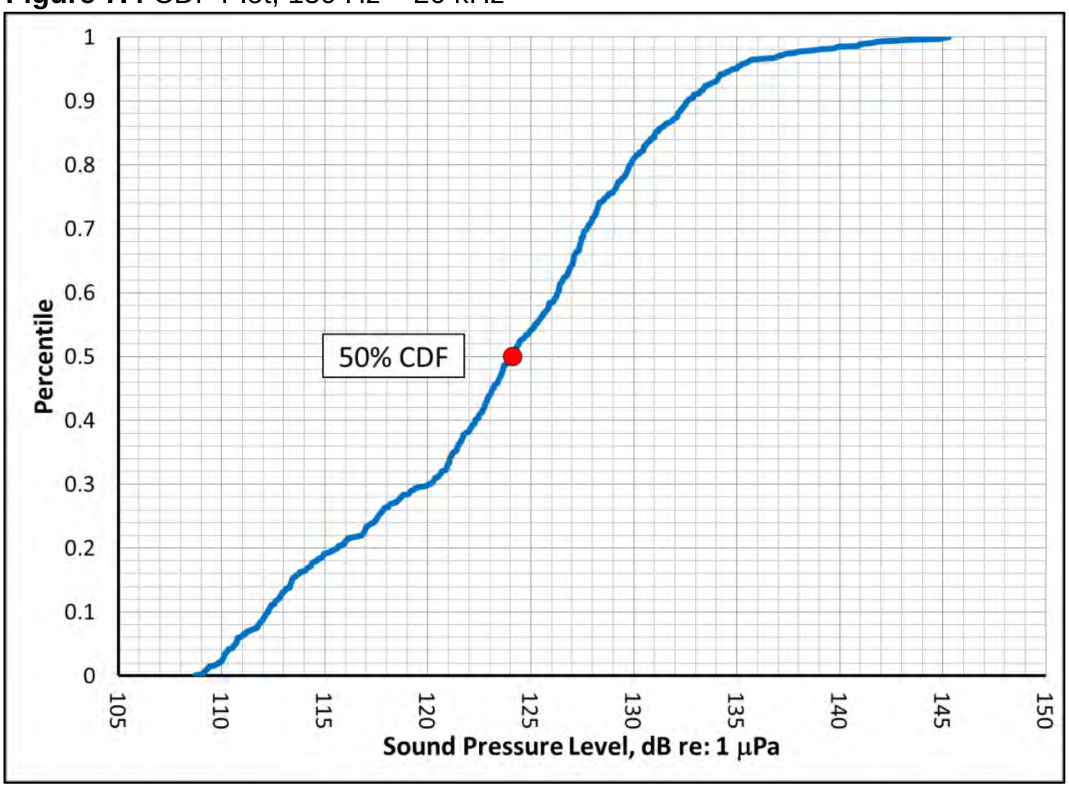


Figure 7.5 CDF Plot, 200 Hz – 20 kHz

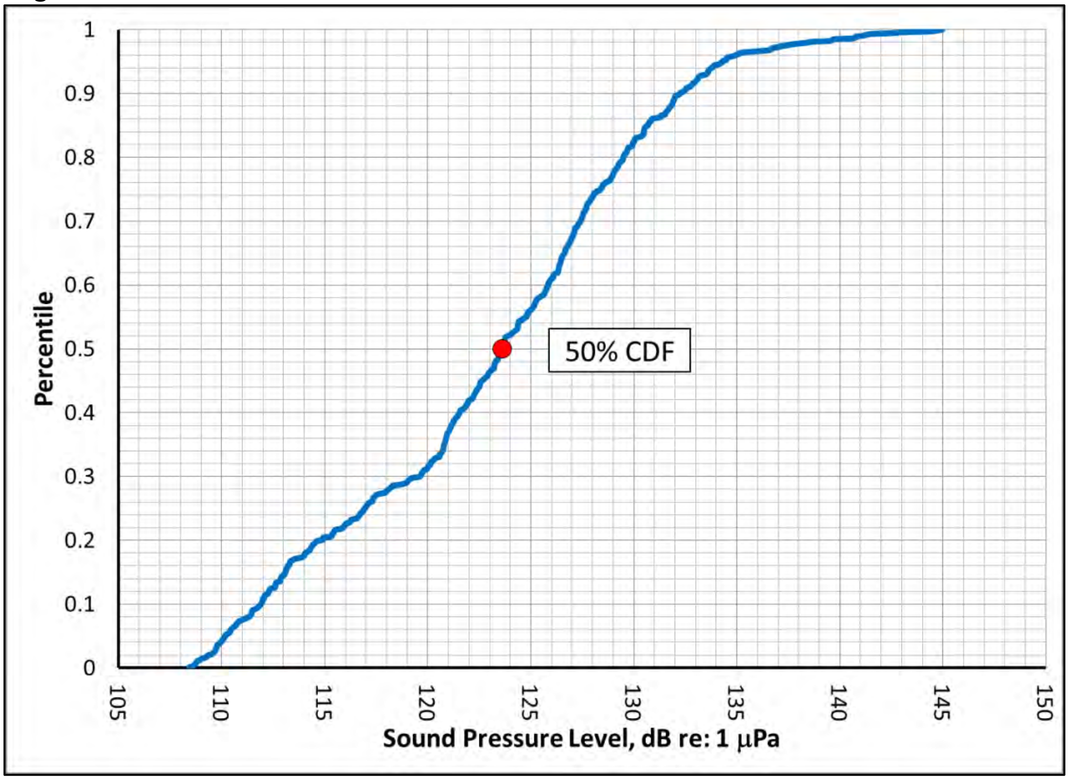
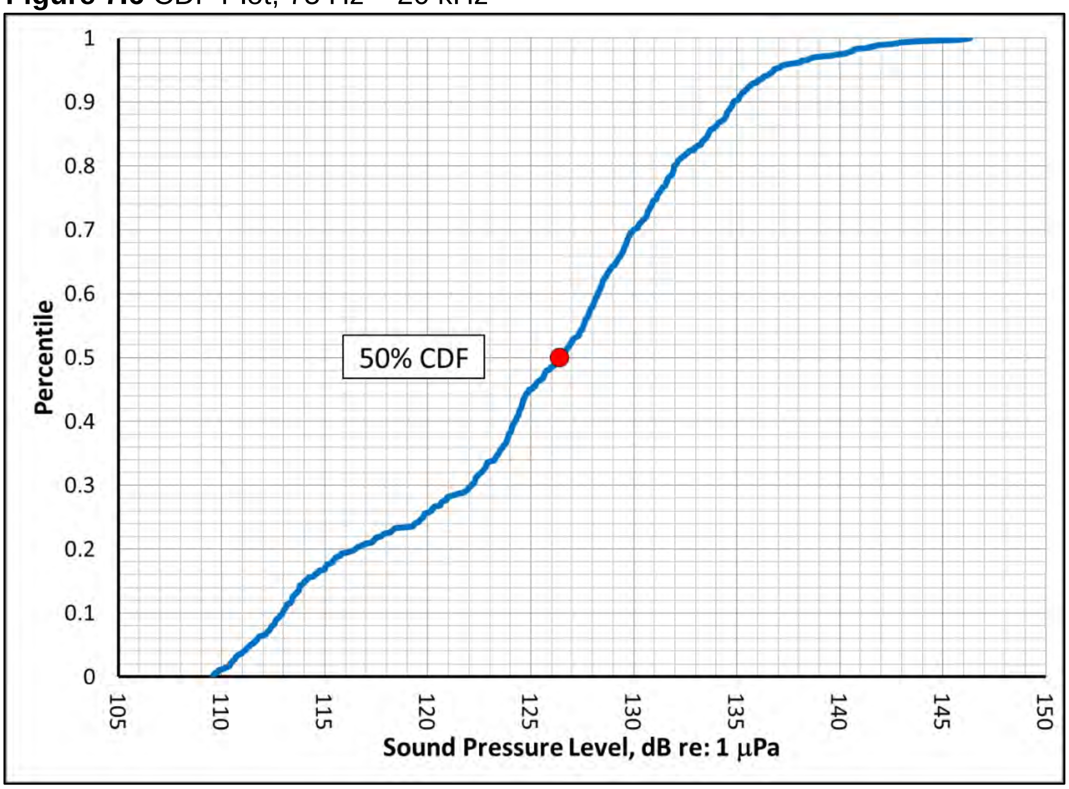


Figure 7.6 CDF Plot, 75 Hz – 20 kHz



The range, average and standard deviation (SD) of background sound levels measured in January 2015, February 2016 and March 2017 are presented for each functional hearing group in Table 7.2.

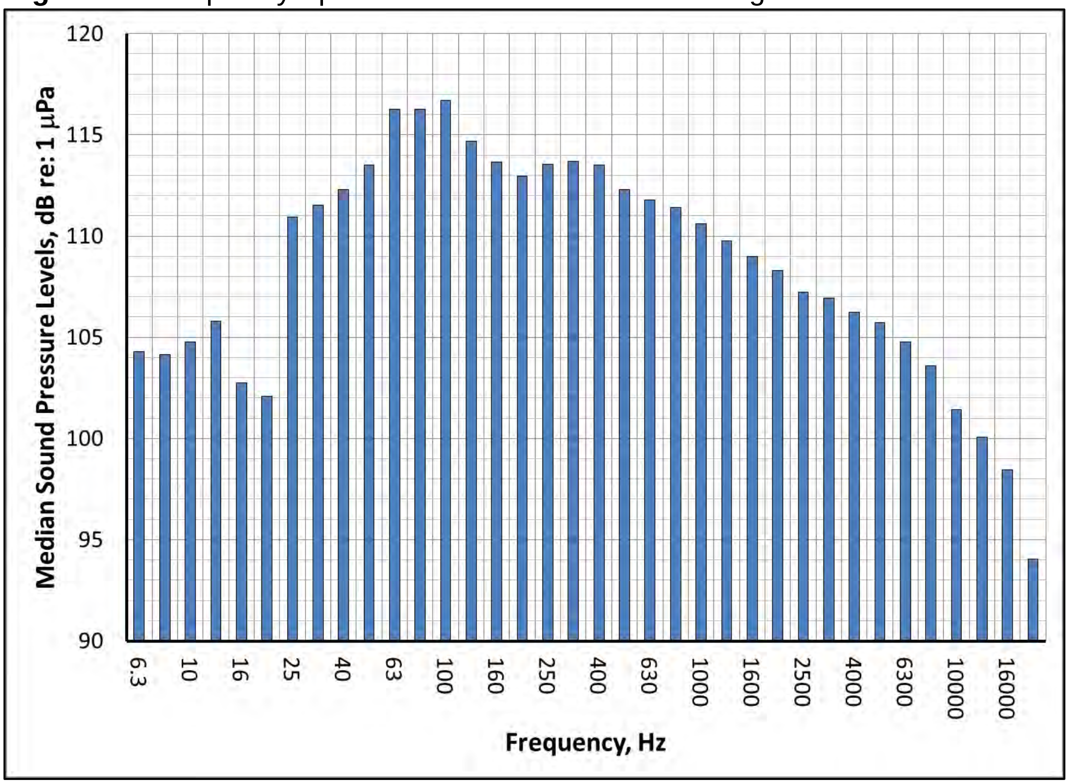
Table 7.2 Average Daytime Underwater Background Sound Levels in Elliott Bay, dB re: 1 μPa

Functional Hearing Group	Frequency Range	Background Sound Levels[1]											
		Short Term (2015)				Short Term (2016)				Short Term (2017)			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
Low-Frequency Cetaceans	7 Hz–20 kHz	122	170	9	**140**	113	152	8	**126**	112	147	7	**128**
Mid-Frequency Cetaceans	150 Hz–20 kHz	111	141	6	**120**	105	142	6	**119**	109	145	8	**124**
High-Frequency Cetaceans	200 Hz–20 kHz	110	140	6	**120**	105	141	6	**118**	108	145	8	**124**
Pinnipeds	75 Hz–20 kHz	114	142	6	**123**	106	145	6	**120**	110	146	8	**126**

1. The median was used to report the average background sound levels

The underwater 1/3 octave frequency spectrum of the median far field background sound levels measured by Greenbusch in March 2017 is provided in Figure 7.7.

Figure 7.7 Frequency Spectrum of Median far Field Background Sound Level



Time histories of the far field 10-second RMS background sound data collected by Greenbusch in March 2017 are provided in Figure 7.8 through Figure 7.11.

Figure 7.8 March 4, 2017 Far Field 10-Second RMS Background Sound Levels–Location A

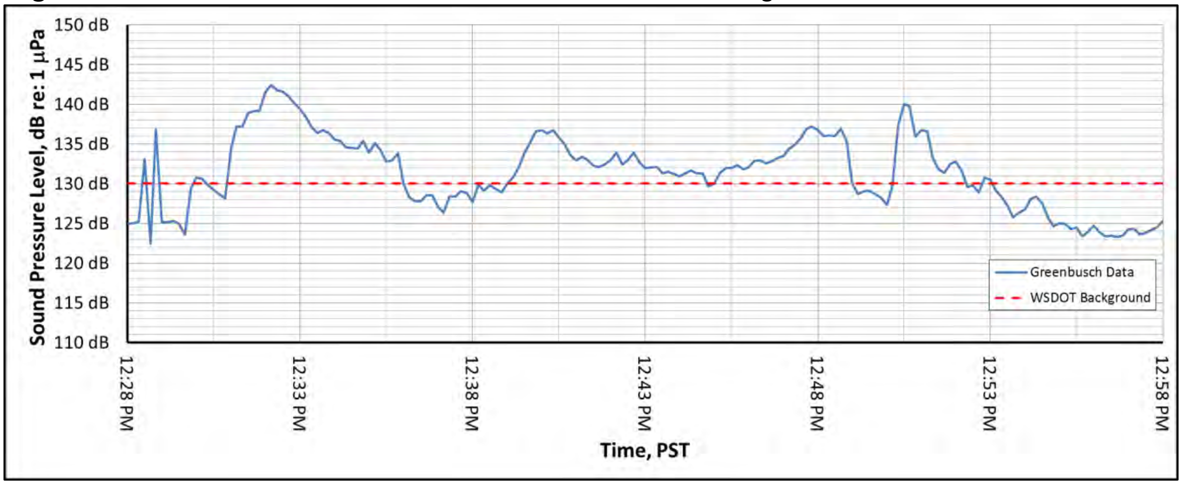


Figure 7.9 March 4, 2017 Far Field 10-Second RMS Background Sound Levels–Location B

Figure 7.10 March 4, 2017 Far Field 10-Second RMS Background Sound Levels–Location C

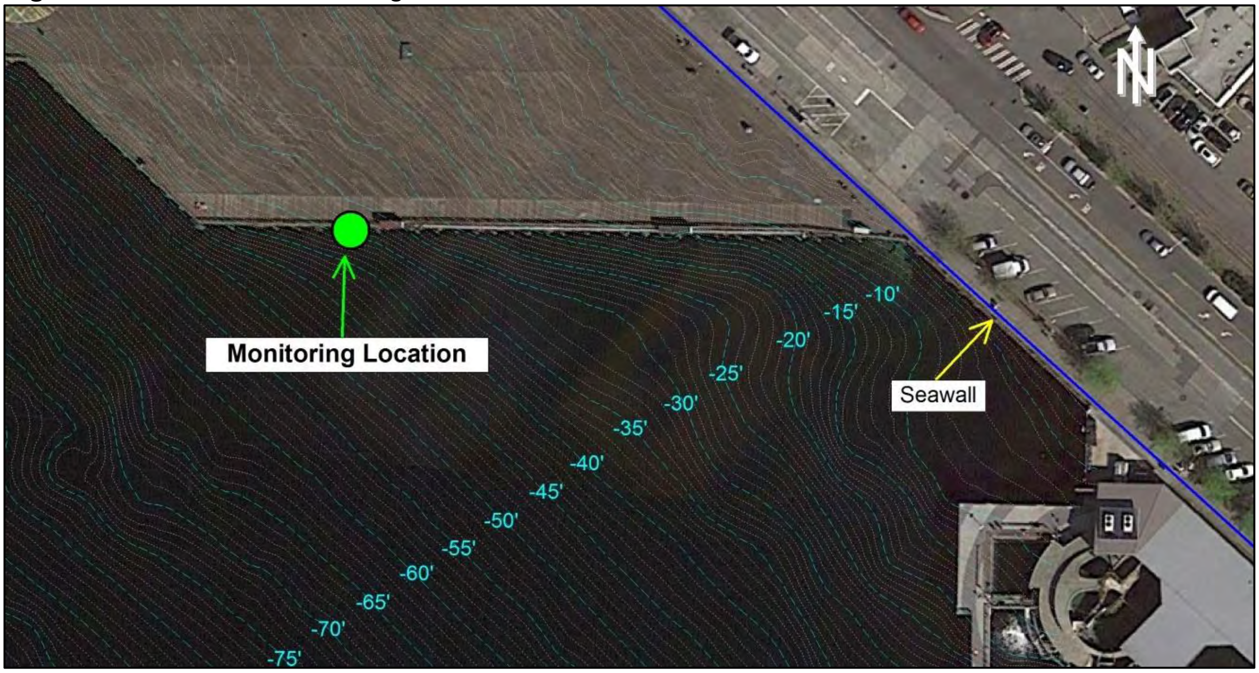
Figure 7.11 March 4, 2017 Far Field 10-Second RMS Background Sound Levels–Location D

The average background sound levels collected in March 2017 are within the range of daytime sound levels collected during Seasons 2 and 3 as well as by WSDOT. Due to the long term nature of the WSDOT measurements compared to the short-term data collected by Greenbusch in 2017, the average daytime background sound data collected by WSDOT were used to calculate the distance required for underwater RMS sound levels generated by pile driving to attenuate to background sound levels (see Section 10.2).

7.2 Near Shore Background Sound Levels

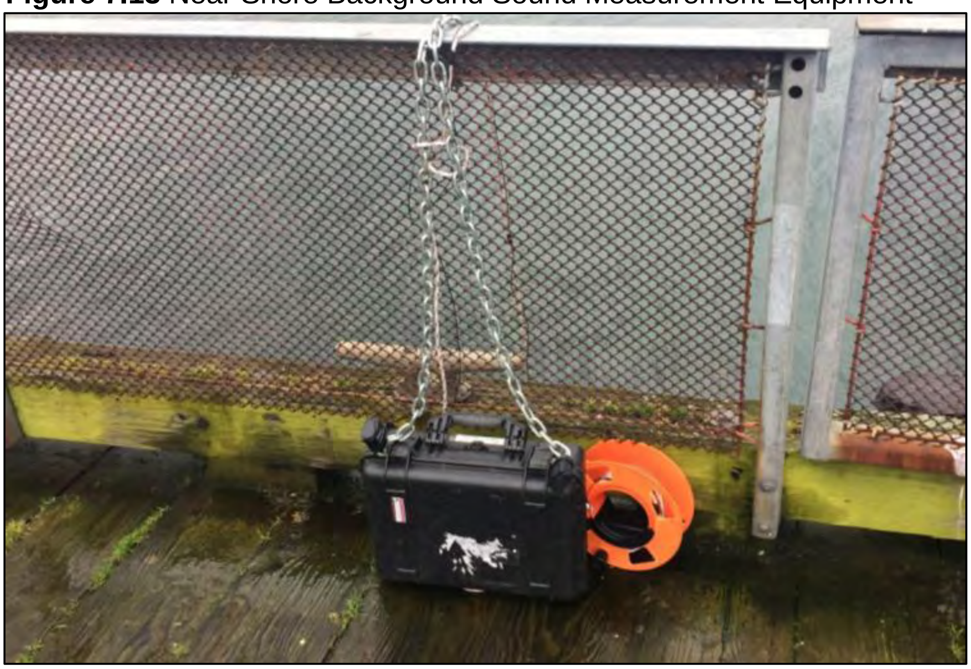
Continuous near-shore background sound level measurements were made between February 21 and February 24, 2017 approximately 280 feet (85 meters) west of Box 1. The hydrophone was positioned at mid-water depth and secured to Pier 62/63. These measurements were made at the request of NOAA to ensure that background sound levels near the monitored piles did not influence the measurements of pile driving. Figure 7.12 shows the near shore background sound level measurement location.

Figure 7.12 Near Shore Background Measurement Location



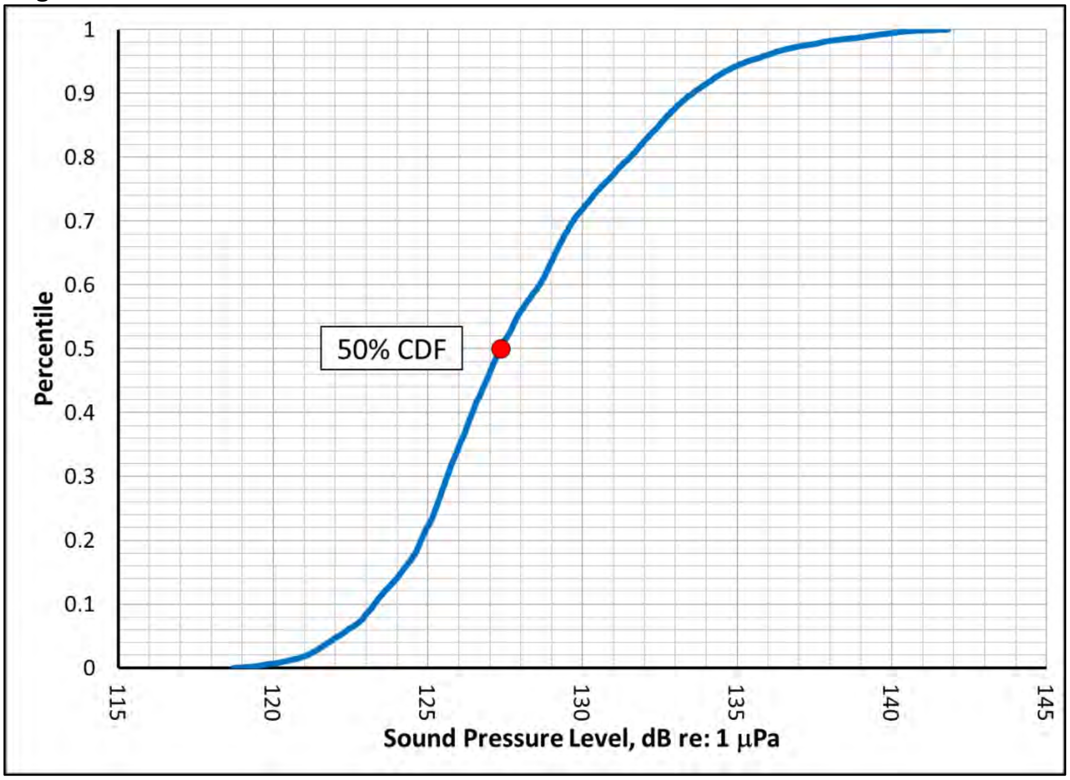
Equipment used to collect the near shore background sound level data is shown in Figure 7.13.

Figure 7.13 Near Shore Background Sound Measurement Equipment



10-second daytime background RMS values were used from these long-term near shore measurements to generate CDF plots for each marine mammal functional hearing group. These CDF plots are presented in Figure 7.14 through Figure 7.17.

Figure 7.14 CDF Plot, 7 Hz – 20 kHz



Note: CDF is calculated over the frequency range of 12.5 Hz to 20 kHz

Figure 7.15 CDF Plot, 150 Hz – 20 kHz

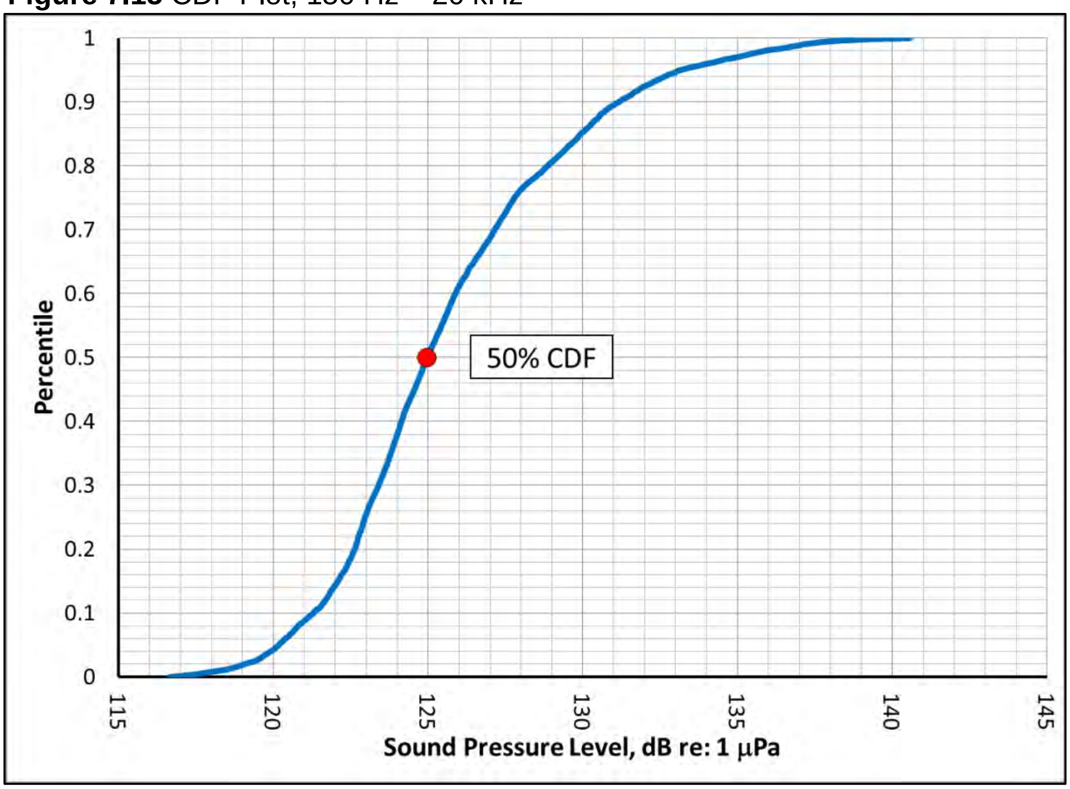


Figure 7.16 CDF Plot, 200 Hz – 20 kHz

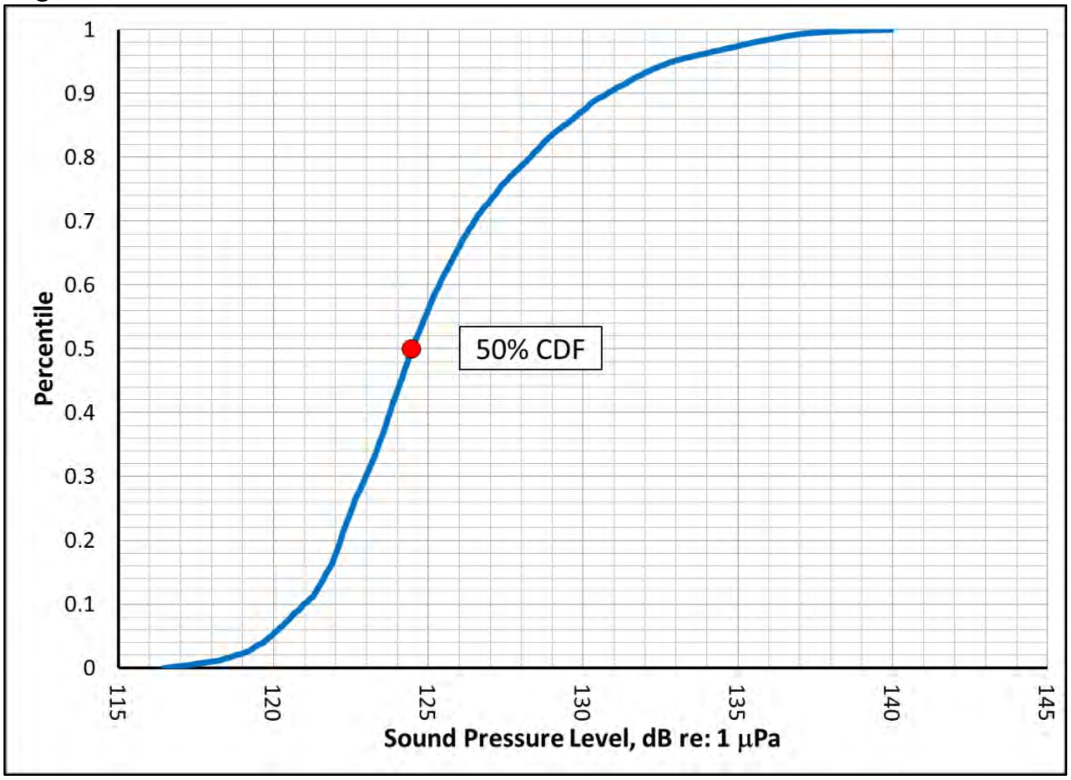
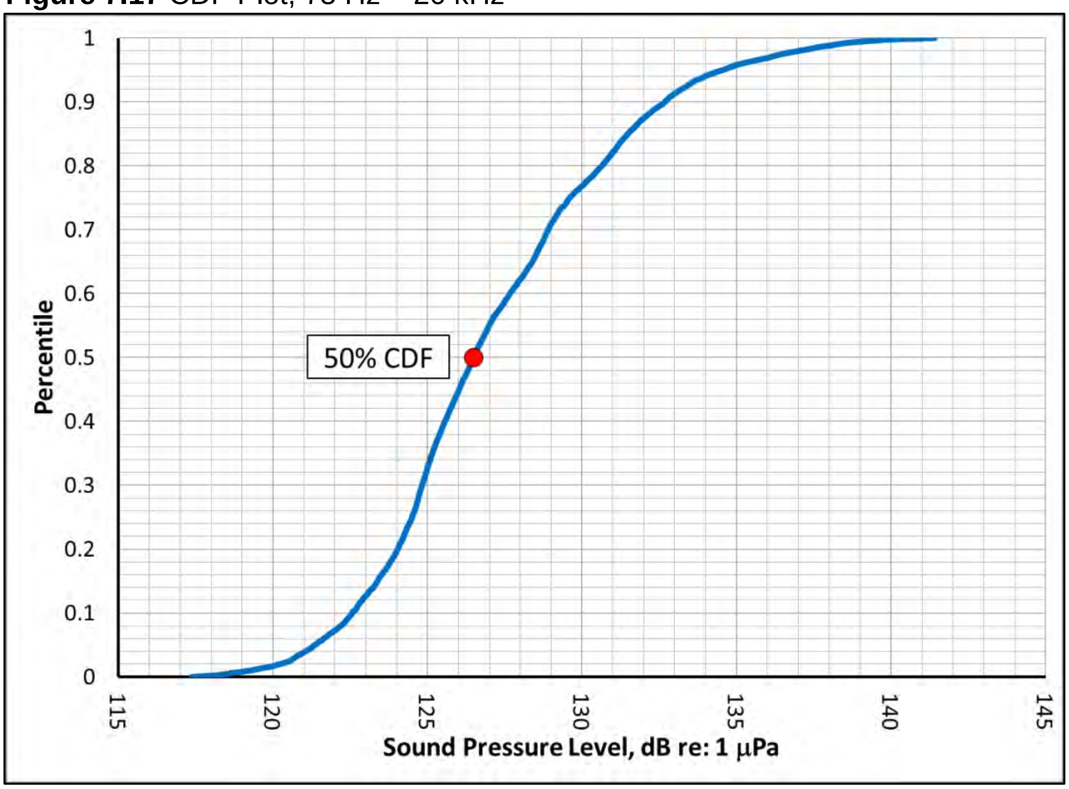


Figure 7.17 CDF Plot, 75 Hz – 20 kHz



The range, average and standard deviation (SD) of daytime background sound levels for each marine mammal functional hearing group calculated from the near shore background sound data is provided in Table 7.3.

Table 7.3 Average Daytime Near Shore Background Sound Levels, dB re: 1 μPa

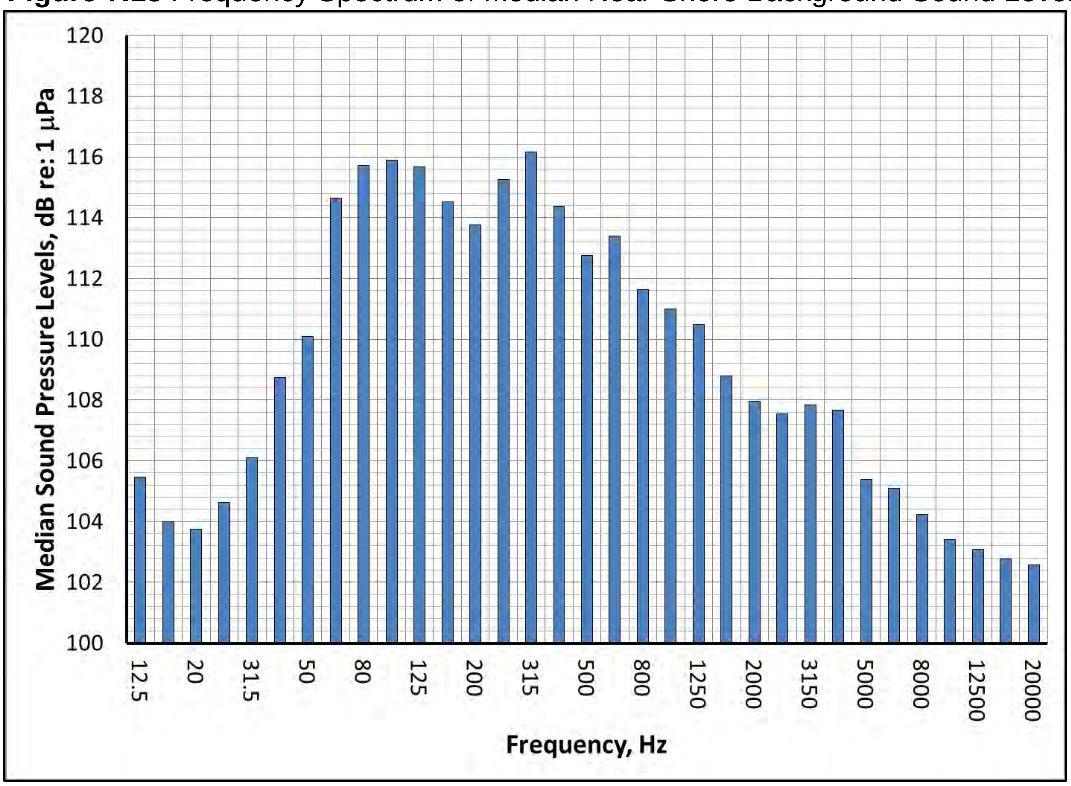
Functional Hearing Group	Frequency Range	Background Sound Levels (Greenbusch 2017)			
		Min	Max	SD	Average
Low-Frequency Cetaceans	7 Hz – 20 kHz	119	142	4	**127**
Mid-Frequency Cetaceans	150 Hz – 20 kHz	117	141	4	**125**
High-Frequency Cetaceans	200 Hz – 20 kHz	116	140	4	**124**
Pinnipeds	75 Hz – 20 kHz	117	141	4	**126**

1. Low frequency cetaceans were calculated over a frequency range of 12.5 Hz to 20 kHz

The median was used to report the average background sound levels

The underwater 1/3 octave frequency spectrum of the median near shore background sound levels is provided in Figure 7.18 below.

Figure 7.18 Frequency Spectrum of Median Near Shore Background Sound Level



Time histories of the near shore 10-second RMS background sound data collected by Greenbusch in February 2017 are provided in Figure 7.19 through Figure 7.21.

Figure 7.19 February 21, 2017 Near Shore 10-Second RMS Background Sound Levels

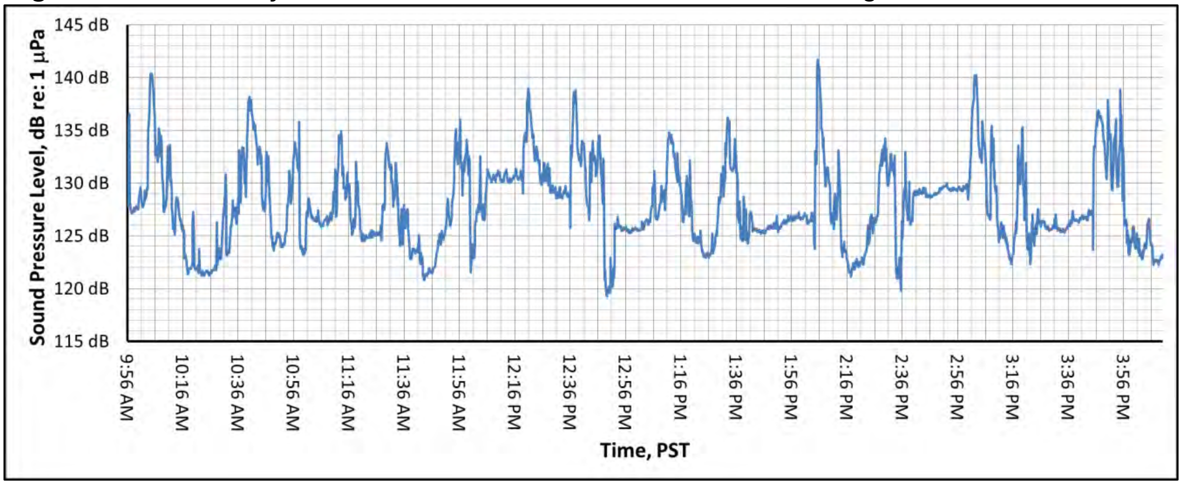


Figure 7.20 February 22, 2017 Near Shore 10-Second RMS Background Sound Levels

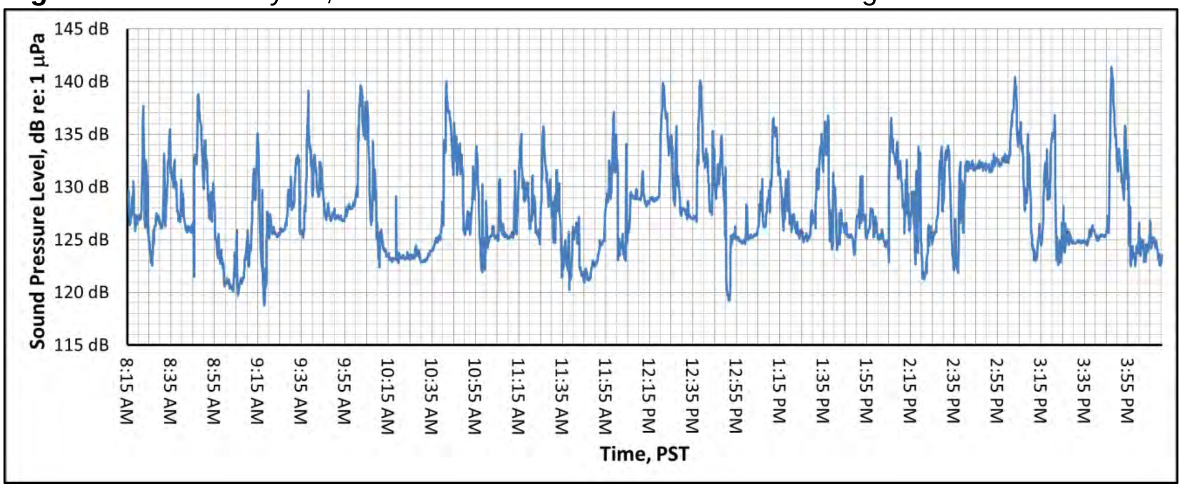
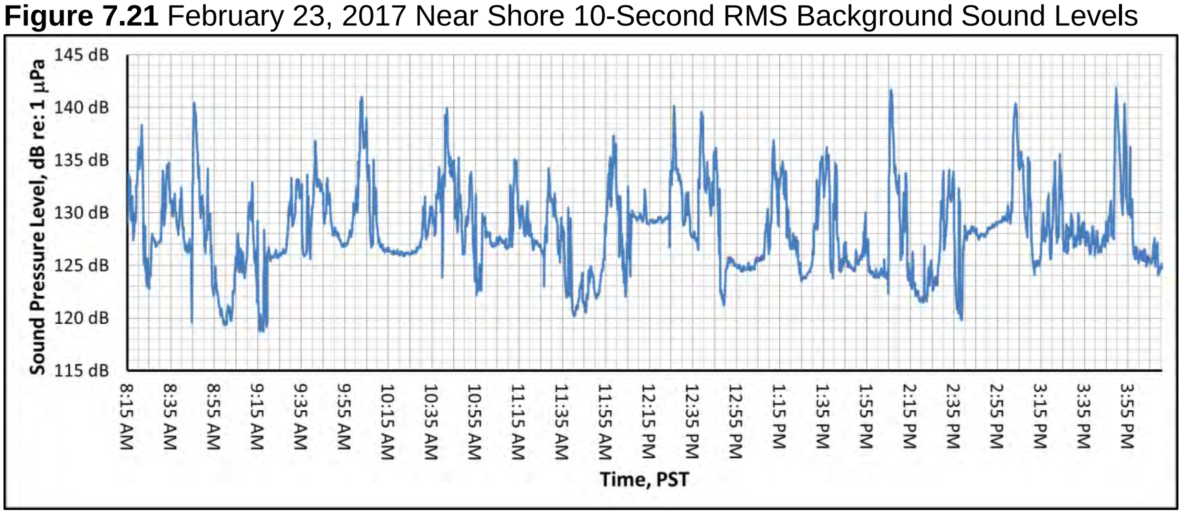


Figure 7.21 February 23, 2017 Near Shore 10-Second RMS Background Sound Levels



The data collected from near shore indicates that background sound levels did not contaminate or influence the near field measurements of pile driving.

8.0 CONCRETE PILE REMOVAL AND VIBRATORY SHEET PILES INSTALLATION ANALYSIS AND RESULTS

Airborne and underwater sound level measurements were made on December 27 and 28, 2016 during the removal of the first five concrete piles and the installation of the first five steel sheet piles driven with a vibratory hammer as required by the Project's ESA and MMPA consultation.

Hydroacoustic data collected during vibratory installation of the steel sheet piles was analyzed to determine the range, average and standard deviation of 10-second RMS, peak and SEL values for each marine mammal functional hearing group. Periods during the pile drive when pile installation was not occurring under full power are excluded from the analysis.

The data was down sampled from 96,000 samples per second to 48,000 samples per second and then analyzed for each functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group of interest. This filter provides a roll off of over 40 dB per decade. SEL values were calculated using 1-second RMS values.

Reported maximum and minimum values are the maximum or minimum value from either of the two hydrophones located approximately 10 meters away from pile driving. The standard deviation was calculated using decibel values. Average sound levels were calculated using the mean sound pressure from each hydrophone, converted to decibels and taking the logarithmic average of the two values.

During vibratory pile driving and removal of the first three concrete piles one hydrophone was deployed 3.3 feet (1 meter) below the surface and a second hydrophone was deployed 3.3 feet (1 meter) above the sea floor. Both hydrophones were positioned as close to 33 feet (10 meters) from the pile as feasible. One hydrophone was located at mid-water depth as close to 33 feet (10 meters) from the removal of the fourth and fifth concrete pile. The airborne and underwater sound level monitoring locations and the locations of the removed concrete and sheet piles driven with the vibratory hammer are shown in Figure 8.1 and Figure 8.2.

Figure 8.1 Removed Concrete Piles and Monitoring Locations

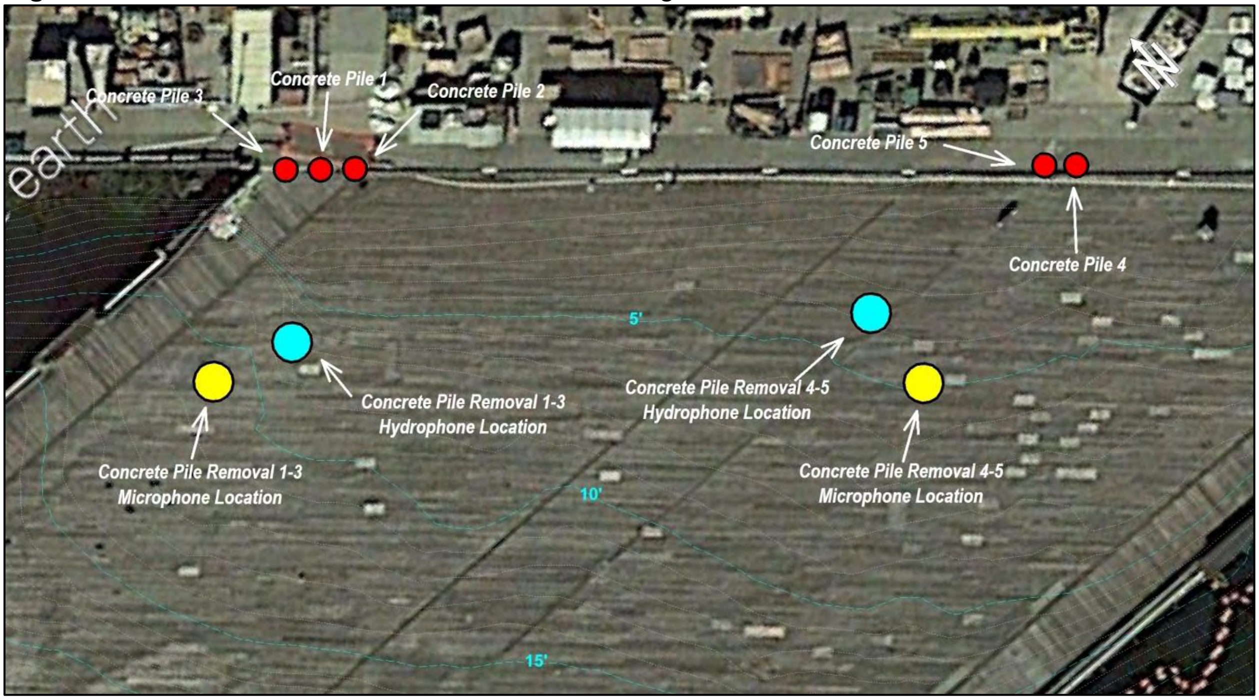


Figure 8.2 Sheet Pile and Monitoring Locations for Vibratory Pile Driving

A summary of underwater sound levels produced by the vibratory removal of the first five concrete piles removed on December 27, 2016 is provided in Table 8.1.

Table 8.1 Underwater Sound Levels from Concrete Pile Removal, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-1	7 Hz-20 kHz	147	162	3	**154**	122	149	3	**143**	127	151	2	**144**
	75 Hz-20 kHz	144	162	3	**152**	119	141	3	**134**	123	143	2	**135**
	150 Hz-20 kHz	144	158	3	**151**	119	141	3	**134**	123	143	2	**135**
	200 Hz-20 kHz	143	161	3	**151**	118	140	3	**134**	122	142	2	**135**
REM-2	7 Hz-20 kHz	147	161	3	**156**	124	154	4	**147**	121	155	3	**147**
	75 Hz-20 kHz	143	161	4	**152**	119	139	2	**133**	119	140	2	**133**
	150 Hz-20 kHz	144	161	4	**151**	118	138	3	**133**	119	140	2	**133**
	200 Hz-20 kHz	143	161	4	**151**	118	138	3	**132**	119	139	2	**133**
REM-3	7 Hz-20 kHz	142	164	4	**155**	126	154	4	**145**	123	155	3	**145**
	75 Hz-20 kHz	141	164	5	**152**	116	141	5	**135**	115	144	3	**133**
	150 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	114	143	4	**132**
	200 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	121	153	4	**135**
REM-4	7 Hz-20 kHz	146	161	3	**151**	117	149	3	**140**	133	153	3	**141**
	75 Hz-20 kHz	142	159	4	**148**	119	132	2	**130**	123	135	2	**130**
	150 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**130**
	200 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**129**
REM-5	7 Hz-20 kHz	153	168	3	**157**	139	150	3	**147**	137	151	2	**147**
	75 Hz-20 kHz	147	168	5	**153**	130	139	2	**135**	128	141	2	**135**
	150 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	125	141	2	**135**
	200 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	124	141	2	**135**

Note: Underwater sound levels were measured 35 to 40 feet (11 to 12 meters) from the piles.

A summary of underwater sound levels produced by the vibratory installation of the first five steel sheet pile driven on December 28, 2016 is provided in Table 8.2.

Table 8.2 Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	7 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	75 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	150 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	200 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
VIB-2	7 Hz-20 kHz	151	174	5	**164**	135	155	5	**148**	133	155	5	**148**
	75 Hz-20 kHz	151	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	150 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	200 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**
VIB-3	7 Hz-20 kHz	154	174	3	**166**	129	159	4	**151**	139	159	3	**152**
	75 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**150**
	150 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**
	200 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**
VIB-4	7 Hz-20 kHz	154	170	4	**164**	131	154	5	**148**	137	156	3	**149**
	75 Hz-20 kHz	154	170	4	**164**	130	154	5	**148**	133	156	3	**148**
	150 Hz-20 kHz	154	170	4	**164**	130	154	5	**147**	133	156	3	**148**
	200 Hz-20 kHz	154	171	4	**164**	130	154	5	**147**	133	156	3	**148**
VIB-5	7 Hz-20 kHz	155	180	4	**170**	137	159	3	**153**	137	161	3	**153**
	75 Hz-20 kHz	154	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	150 Hz-20 kHz	155	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	200 Hz-20 kHz	154	179	4	**170**	137	158	3	**152**	135	161	3	**153**

Note: Underwater sound levels were measured 37 to 39 feet (11 to 12 meters) from the piles.

Airborne sound data collected during vibratory removal of concrete piles and vibratory installation of the steel sheet piles was analyzed to determine the range and average of unweighted 10-second RMS values while piles were being driven under full power. These 10-second RMS values were calculated over a frequency range of 6.3 Hz to 20 kHz.

A summary of airborne sound levels generated by vibratory removal of concrete piles is provided in Table 8.3 below.

Table 8.3 Airborne Sound Levels from Removal of Concrete Piles, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-1	89	100	92
REM-2	94	100	96
REM-3	90	95	92
REM-4	85	91	87
REM-5	89	96	92

Note: Airborne sound levels measured 50 feet (15 meters) from the pile.

A summary of airborne sound levels generated by vibratory pile driving activities is provided in Table 8.4 below.

Table 8.4 Airborne Sound Levels from Vibratory Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-1	98	114	107
VIB-2	97	107	103
VIB-3	93	104	101
VIB-4	95	106	101
VIB-5	95	107	102

Note: Airborne sound levels measured 50 feet (15 meters) from the pile.

The airborne and underwater frequency spectrum associated with the highest 10-second RMS level, sound pressure levels collected during each pile drive, as well as hydrophone and pile location information are provided in the Appendix A of this Report.

9.0 IMPACT SHEET PILES ANALYSIS AND RESULTS

Collection of airborne and underwater sound data occurred on January 11, 2017 during impact installation of the first five pairs of sheet piles driven with the impact hammer, as required by the Project's ESA and MMPA consultation.

An unobstructed path between the piles and microphone used to collected airborne sound levels was maintained throughout the duration of each pile drive. 1-second RMS sound levels were used to analyze the airborne sound levels from the pile drives.

Hydroacoustic data collected during the impact driving of steel sheet piles were analyzed to determine the range, average and standard deviation of peak, RMS_{90}, and SEL values as well as the cSEL of each pile for each marine mammal functional hearing group as required by the ESA and MMPA consultation. Periods when pile driving was not occurring under full power were excluded from this analysis.

Reported maximum and minimum values are the maximum or minimum value from either of the two hydrophones located approximately 33 feet (10 meters) away from pile driving. Standard deviation was calculated using the decibel values and the average sound levels were calculated using the mean sound pressure levels.

Data analysis was conducted for each marine mammal functional hearing group by applying a band pass filter to remove frequencies from the signal that are not included in the functional hearing group being analyzed. This filter provides a roll off of more than -40 dB per decade.

The RMS_{90} was established between the 5^{th} percentile and 95^{th} percentile of each recorded pile strike. Figures illustrating the waveform produced by the pile strike that generated the absolute highest peak sound pressure level from each pile are provided in Appendix A of this Report. The green portion of these waveforms represents the duration of the strike containing 90% of the acoustical energy.

SEL values for impact pile driving of steel sheet piles were calculated for each pile strike over the duration of the strike containing 90% of the acoustic energy using the following formula:

$$\mathrm{SEL} = \mathrm{RMS(dB)} + 10\log_{10}(\tau)$$

Where τ is the time interval containing 90% of the acoustic energy in each pile strike.

cSEL values where calculated using the SEL value corresponding to the maximum peak pile strike using the following formula, which is required by the ESA documents:

$$\mathrm{cSEL} = \mathrm{SEL_{single}} + 10\log_{10}(n)$$

Where $\mathrm{SEL_{single}}$ is the SEL value corresponding to the pile strike which produced the highest peak sound pressure and *n* is the total number of pile strikes included in the analysis.

The airborne and underwater sound level monitoring locations and the locations of the sheet piles driven with the impact hammer are shown in Figure 9.1.

Figure 9.1 Sheet Pile and Monitoring Locations for Impact Pile Driving

A summary of near field underwater sound levels generated by impact pile driving on January 11, 2017 is provided in Table 9.1.

Table 9.1 Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	75 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	150 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	200 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
IMP-2	7 Hz-20 kHz	182	191	1	**187**	166	179	1	**175**	155	164	1	**161**	**182**
	75 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	150 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	200 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
IMP-3	7 Hz-20 kHz	184	197	2	**192**	169	182	1	**179**	157	167	1	**164**	**187**
	75 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	150 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	200 Hz-20 kHz	183	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
IMP-4	7 Hz-20 kHz	183	199	2	**194**	168	185	2	**182**	156	170	2	**167**	**188**
	75 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	150 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	200 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
IMP-5	7 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	75 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	150 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	200 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**

Note: Underwater sound levels were measured 32 to 40 feet (10 to 12 meters) from the piles.

Airborne sound levels generated by impact pile driving of steel sheet piles are summarized in Table 9.2.

Table 9.2 Airborne Sound Levels from Impact Pile Driving, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1	96	113	107
IMP-2	103	110	108
IMP-3	99	114	109
IMP-4	99	114	111
IMP-5	96	112	109

Note: Airborne sound levels measured 50 feet (15 meters) from pile driving

The number of pile strikes included in the underwater noise analysis, depth of the hydrophone, the water depth at the hydrophone and pile, the distance between the hydrophone and the pile, the distance from the pile to the water's edge and the depth into the substrate the pile was driven are summarized in Appendix A of this Report.

The underwater peak sound pressure levels measured over the duration of each pile drive, the underwater frequency spectrum associated with the pile strike that generated the highest absolute peak sound pressure level and the waveform of the pile strike are provided in Appendix A.

Appendix A also includes the 1-second broadband airborne sound levels measured over each pile drive and the frequency spectrum of airborne sound levels measured during the loudest pile strike.

10.0 MARINE MAMMAL DETECTION DISTANCES AND DISTANCE TO BACKGROUND

Background underwater sound level measurements were used in conjunction with data collected during vibratory and impact pile driving to estimate the distance required for underwater sound levels produced from pile driving to reach the marine mammal detection thresholds and existing background sound levels.

The National Marine Fisheries Service (NMFS) has defined underwater sound level thresholds for the disturbance and injury of marine mammals. These thresholds are provided in Table 10.1.

Table 10.1 Marine Mammal Disturbance Thresholds, dB re: 1 μPa (RMS)

Functional Hearing Group	Frequency Range	Underwater Sound Thresholds		
		Vibratory Pile Driving Disturbance Threshold (Level B)	Impact Pile Driving Disturbance Threshold (Level B)	Injury Threshold (Level A)
Cetaceans (small to large)	7 Hz-20 kHz	120	160	180
	150 Hz-20 kHz			
	200 Hz-20 kHz			
Pinnipeds	75 Hz-20 kHz	120	160	190

Source: National Marine Fisheries Service

The distance required for underwater sound generated by vibratory removal of concrete piles as well as impact and vibratory pile driving of steel sheet piles to reach the marine mammal disturbance and injury thresholds presented in Table 10.1 were calculated using the "practical spreading model" currently used by WSDOT and NOAA. The practical spreading formula is provided below.

$$\mathrm{SPL_{D2}} = \mathrm{SPL_{D1}} + \beta * \log_{10}\left(\frac{\mathrm{D_1}}{\mathrm{D_2}}\right)$$

Where SPL_{D1} is the sound pressure measured at a distance, D_1 and SPL_{D2} is the estimated sound pressure at a distance, D_2. β is the attenuation factor resulting from acoustic spreading over distance. The California Department of Transportation (Caltrans) has reported that β can range between 5 and 30 depending upon site specific conditions such as water depth, pile type, pile length and the substrate the pile is driven into. Currently NOAA uses the practical spreading model with β equaling 15, which results in a 4.5 dB reduction in underwater sound levels for each doubling of distance.

The distances required for underwater noise produced by pile driving during Season 4 are estimated by solving the practical spreading formula for D_2 resulting in the following:

$$\mathrm{D_2} = \mathrm{D_1} * 10^{\left(\frac{\mathrm{SPL_{D1}} - \mathrm{SPL_{D2}}}{15}\right)}$$

The highest measured average RMS sound levels from the removal of concrete piles as well as from the vibratory and impact driving of steel sheet piles were used to calculate the distances required for sound to reach the marine mammal disturbance and injury thresholds and the background sound levels measured by WSDOT.

Far field underwater sound data was collected in Elliott Bay between 1,300 and 5,500 feet (396 and 1676 meters) from vibratory pile driving on December 27 and 28, 2016 to calculate the site specific attenuation factor of obstructed pile driving. However, elevated sound levels in Elliott Bay and sound sources not related to pile driving complicated the calculations of the site specific attenuation factor.

Measurements made from the southwest corner and south side of Pier 62/63 as well as near field data collected during impact pile driving was used to calculate the site specific attenuation factor of obstructed sheet piles. The site specific attenuation factor was calculated for each pile strike using peak and single strike SEL values. The duration of each pile strike containing 90% of the acoustical energy varies at different distances. As a result the single strike SEL values used to calculate the site specific attenuation factors were calculated over the entire duration of the pile strike, not 90% of the energy. The median attenuation factors for each pile and across all pile strikes are summarized in Table 10.2.

Table 10.2. Site Specific Attenuation Factors

Pile ID	Median Attenuation Factor	
	Peak	SEL
IMP-1	37	34
IMP-2	39	36
IMP-3	42	37
IMP-4	40	37
IMP-5	36	33
Median of All Strikes	**39**	**36**

The median attenuation factors calculated for all pile strikes results in an 11 to 12 dB reduction in underwater sound pressure levels for each doubling of distance. The site specific attenuation factors suggest that underwater sound produced during obstructed pile driving attenuates more rapidly than predicted by the practical spreading model and the distance required for sound generated by obstructed pile driving to reach the marine mammal detection and background sound levels may be significantly less than predicted by the practical spreading model.

However, because data collected in Elliott Bay during pile driving was unable to be separated from elevated sound levels produced by activities not related to pile driving, the attenuation factor outside of the footprint of the pier was unable to be calculated. Therefore the standard attenuation factor of 15 was used to estimate the distances to marine mammal detection thresholds and background sound levels. Based on the site specific attenuation factors calculated during Seasons 3 and 4, the distances calculated using the practical spreading model are likely conservative.

10.1 Marine Mammal Detection and Injury Distances

The distances necessary for underwater sound levels to dissipate to the marine mammal disturbance and injury thresholds were estimated using the practical spreading model and the highest average RMS sound levels measured during the removal of concrete piles as well as vibratory and impact pile installation. The resulting distances from concrete pile removal as well as vibratory and impact pile driving of steel sheet piles are shown in Table 10.3 below.

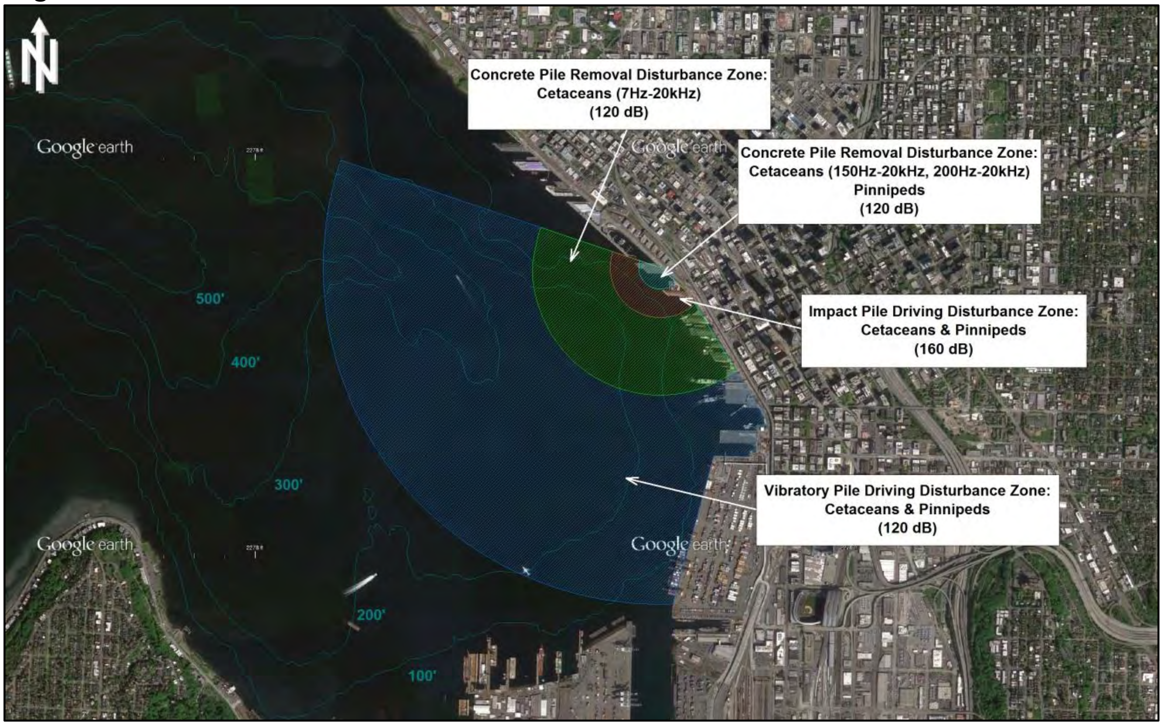
Table 10.3 Distances to Marine Mammal Thresholds from Pile Driving and Removal

Functional Hearing Group	Frequency Range	RMS	Marine Mammal Detection Thresholds		Distance to Threshold[2]	
			Disturbance (Level B)	Injury (Level A)	Disturbance (Level B)	Injury (Level A)
Concrete Pile Removal						
Cetaceans (small to large)	7 Hz-20 kHz	147	120	180	**2,400 feet**	**2.5 inches**
	150 Hz-20 kHz	135			**400 feet**	**0.5 inches**
	200 Hz-20 kHz	135				
Pinnipeds	75 Hz-20 kHz	135	120	190	**400 feet**	**0.1 inches**
Vibratory Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	153	120[1]	180	**1.2 miles**	**6.5 inches**
	150 Hz-20 kHz	153				
	200 Hz-20 kHz	153				
Pinnipeds	75 Hz-20 kHz	153	120[1]	190	**1.2 miles**	**1.5 inches**
Impact Pile Driving						
Cetaceans (small to large)	7 Hz-20 kHz	182	160	180	**910 feet**	**45 feet**
	150 Hz-20 kHz	182			**940 feet**	
	200 Hz-20 kHz	182				
Pinnipeds	75 Hz-20 kHz	182	160	190	**940 feet**	**9 feet**

1. Background sound levels exceed the 120 dB disturbance threshold for vibratory pile driving.
2. The practical spreading model was used to calculate the distances to the marine mammal thresholds. These distances are reduced when calculated using the attenuation factor derived from measurements of obstructed pile driving.

As shown in Table 10.3, the estimated distance required for sound generated by removal of concrete piles with the vibratory hammer to reach the 120 dB marine mammal disturbance threshold is between 400 feet and 2,400 feet (122 and 731 meters). Sound generated by vibratory pile driving is estimated to require 1.2 miles (1.9 kilometers) to reach the 120 dB marine mammal disturbance threshold and impact pile driving is estimated to require between 910 feet and 940 feet (277 and 287 meters) to reach the 160 dB marine mammal disturbance threshold. The distances used for marine mammal monitoring were greater than the distances calculated from data collected during Season 4. Figure 10.1 illustrates the areas where underwater sound levels are expected to exceed the marine mammal disturbance thresholds (120 dB for vibratory pile driving and 160 dB for impact pile driving).

Figure 10.1 Marine Mammal Disturbance Zones Based on Season 4 Data



10.2 Distance to Background Sound Levels

In addition to calculating the distance required for underwater sound levels to reach the marine mammal disturbance (Level B) and injury (Level A) thresholds, the distances required to reach background sound levels were also calculated. These distances were calculated using the background sound levels measured by WSDOT in April 2011. The WSDOT data was used rather than the near shore data collected by Greenbusch in 2017 because the WSDOT data more accurate describes the environment where marine mammals are likely to be present. These distances are provided in Table 10.4.

Table 10.4 Distances to Background Sound Levels Reported by WSDOT

Functional Hearing Group	Frequency Range	RMS, Highest Average (EBSP Season 4)	WSDOT Background Sound Level	Distance to Background[1]
Concrete Pile Removal				
Cetaceans	7 Hz-20 kHz	147	130	**510 feet**
	150 Hz-20 kHz	135	124	**210 feet**
	200 Hz-20 kHz	135	124	**210 feet**
Pinnipeds	75 Hz-20 kHz	135	127	**140 feet**
Vibratory Pile Driving				
Cetaceans	7 Hz-20 kHz	153	130	**1,390 feet**
	150 Hz-20 kHz	153	124	**3,400 feet**
	200 Hz-20 kHz	153	124	**3,380 feet**
Pinnipeds	75 Hz-20 kHz	153	127	**2,150 feet**
Impact Pile Driving				
Cetaceans	7 Hz-20 kHz	182	130	**17.3 miles**
	150 Hz-20 kHz	182	124	**44.5 miles**
	200 Hz-20 kHz	182	124	**44.5 miles**
Pinnipeds	75 Hz-20 kHz	182	127	**28.1 miles**

1. The practical spreading model was used to calculate the distances to the background sound levels. These distances are reduced when calculated using the attenuation factor derived from measurements of obstructed pile driving.

The estimated distance required for underwater sound produced by the vibratory removal of concrete piles to reach the background sound levels measured by WSDOT is up to 510 feet (155 meters). Sounds generated from sheet piles driven with the vibratory hammer are estimated to require up to 3,400 feet (1,036 meters) to attenuate to background sound levels and up to 44.5 miles for sheet piles driven with the impact hammer. However, the reported distances from impact pile driving are reduced due to the proximity of adjacent landmasses. Figure 10.2 and Figure 10.3 illustrate the areas where underwater sound created by the concrete pile removal and vibratory and impact installation of steel sheet piles are anticipated to exceed the background sound levels measured by WSDOT.

Figure 10.2 Areas Exceeding Background Sound Levels (WSDOT 2011)

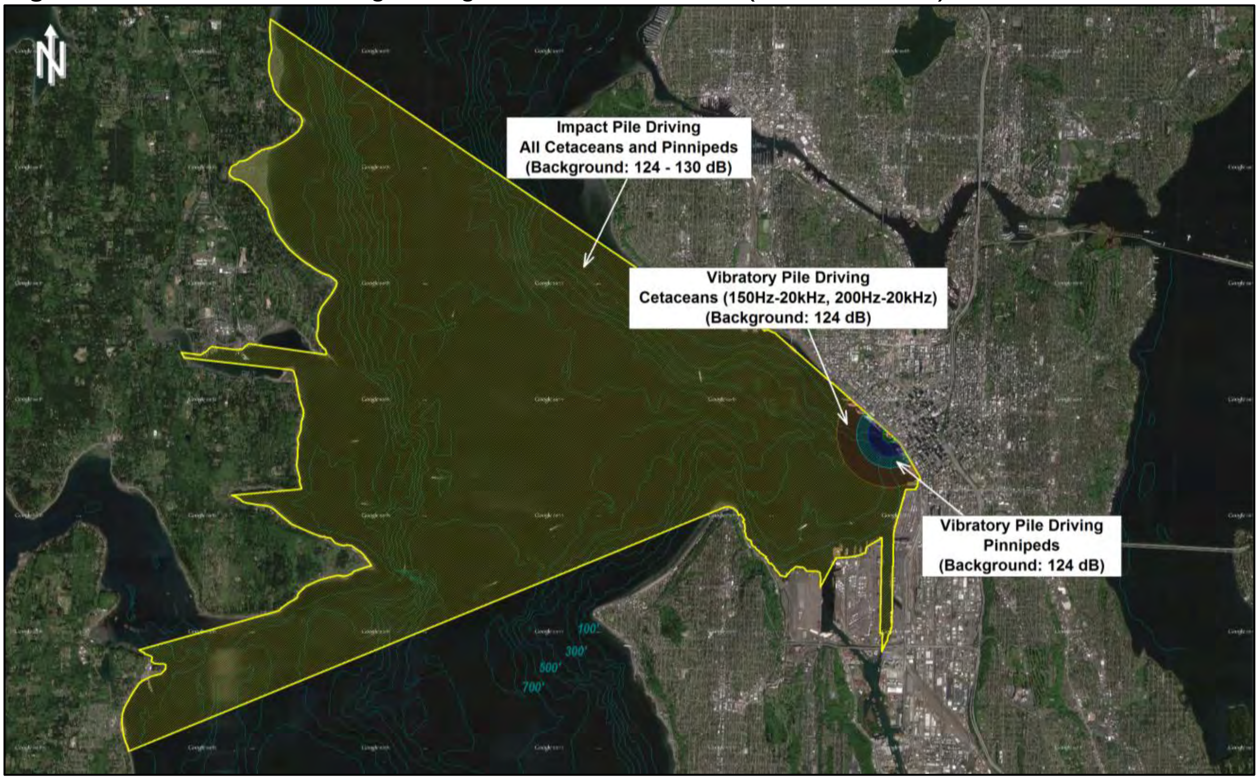
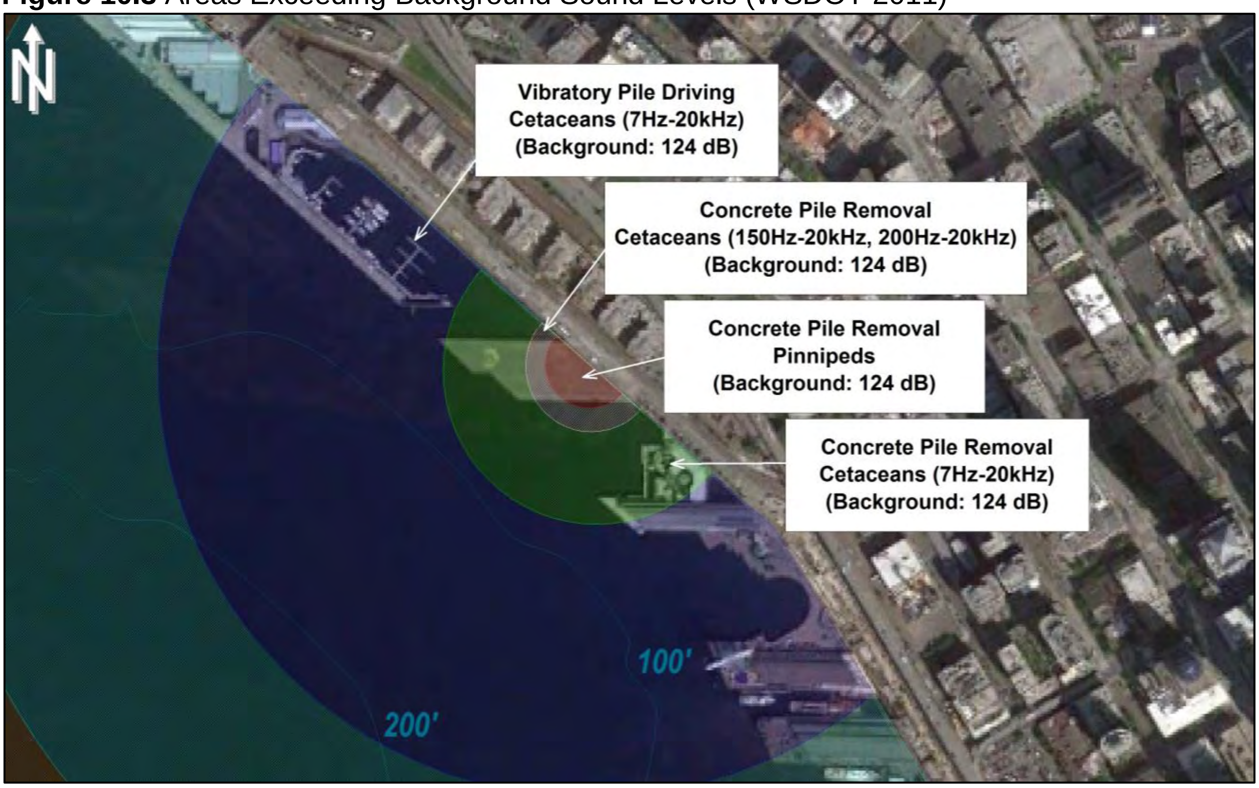


Figure 10.3 Areas Exceeding Background Sound Levels (WSDOT 2011)



10.3 Marine Mammal Monitoring

Monitors observed California sea lion and harbor seal within the monitoring zone; however, these animals did not exhibit any changes in behavior associated with pile removal or installation activities. Details of marine mammal monitoring are presented in a separate report entitled "Marine Mammal Monitoring Season 4 Annual Report, ------ 2017."

11.0 REFERENCES

California Department of Transportation. “Hydroacoustic Effects of Pile Driving on Fish.” November 2015.

Elliott Bay Seawall Project Updated Marine Mammal Monitoring and Mitigation Plan, April 2013.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar Soto, J. Lynch and P. Tyack. “Quantitative Measures of Air-Gun Pulses Recorded on Sperm Whales (Physeter macrocephalus) Using Acoustic Tags during Controlled Exposure Experiments.” October 2006.

National Marine Fisheries Service (NMFS) Marine Mammal Protection Act Season 4 Letter of Authorization (LOA), October 21, 2015.

NMFS Northwest Region and Northwest Fisheries Science Center. “Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals.” January 31, 2012.

NMFS Northwest Region and Northwest Fisheries Science Center. “Guidance Document: Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon.” January 31, 2012.

NOAA Fisheries National Marine Fisheries Service “Estimated Auditory Bandwidths for Marine Mammals and Fish.”

NOAA Fisheries National Marine Fisheries Service “Marine Mammal and Fish Injury and Disturbance Thresholds for Marine Construction Activity.”

NOAA and USFWS Biological Opinion. “The Elliott Bay Seawall Project Biological Opinion.” September 2013.

The Greenbusch Group. “Elliott Bay Seawall Project Season 2 Hydroacoustic Monitoring Approach.” October 6, 2014.

Washington State Department of Transportation. “Biological Assessment Preparation for Transportation Projects-Advanced Training Manual-Version 2015.”

Washington State Department of Transportation. “Compendium of Background Sound Levels for Ferry Terminals in Puget Sound.” April 2014.

Washington State Department of Transportation. “Seattle Ferry Terminal Background Sound Measurement Results, April 2011 – Technical Memorandum.” May 18, 2011.

Washington State Department of Transportation. “Underwater Noise Monitoring Plan Template.” August 2013.

12.0 APPENDIX

APPENDIX A

Table of Contents

List of Tables

Table of Figures

1.0 CONCRETE PILES REMOVED WITH VIBRATORY HAMMER

CONCRETE PILE REMOVAL 1

December 27, 2016

Table A-1 Concrete Pile Removal 1 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)	
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile
6.3 minutes	None	Upper: 3 Lower: 11	8	36	3	14	6

Table A-2 Concrete Pile Removal 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-1	89	100	92

Figure A-1 Concrete Pile 1 Airborne 10-Sec RMS

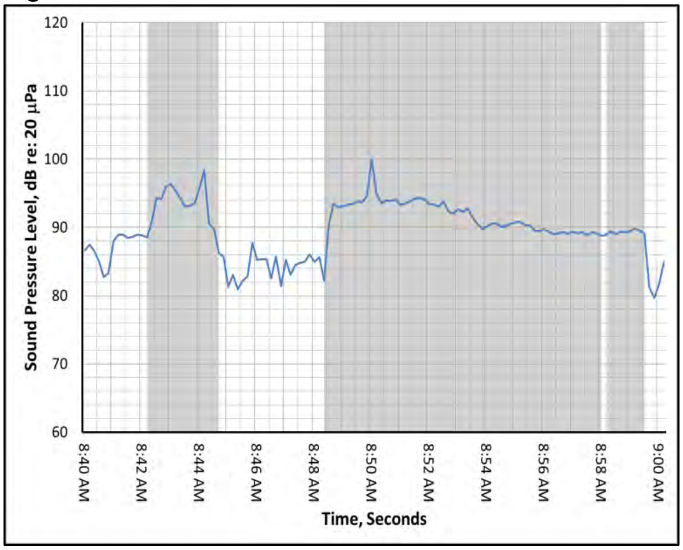


Figure A-2 Concrete Pile 1 Airborne Spectra

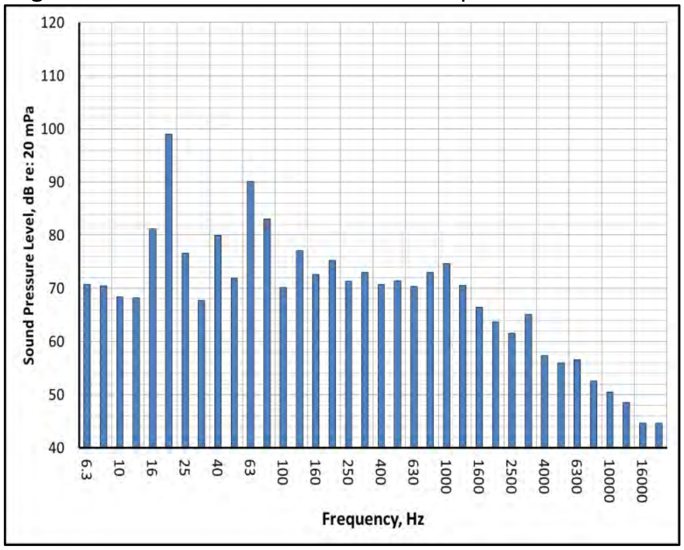


Table A-3 Concrete Pile Removal 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-1	7 Hz-20 kHz	147	162	3	**154**	122	149	3	**143**	127	151	2	**144**
	75 Hz-20 kHz	144	162	3	**152**	119	141	3	**134**	123	143	2	**135**
	150 Hz-20 kHz	144	158	3	**151**	119	141	3	**134**	123	143	2	**135**
	200 Hz-20 kHz	143	161	3	**151**	118	140	3	**134**	122	142	2	**135**

Figure A-3 Concrete Pile Removal 1 - Peak Sound Pressure, Pa

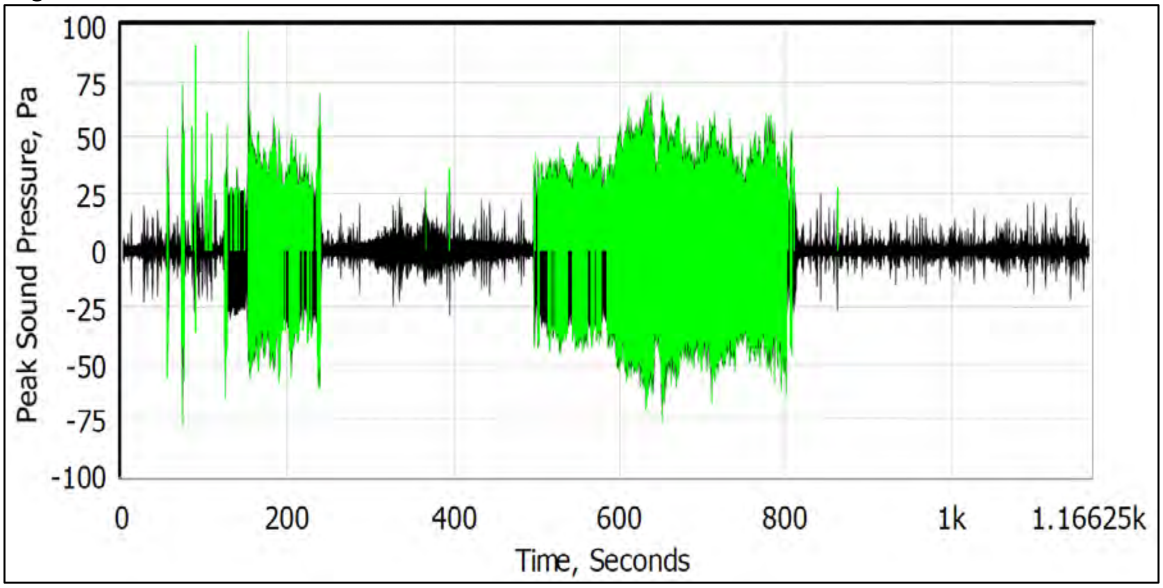
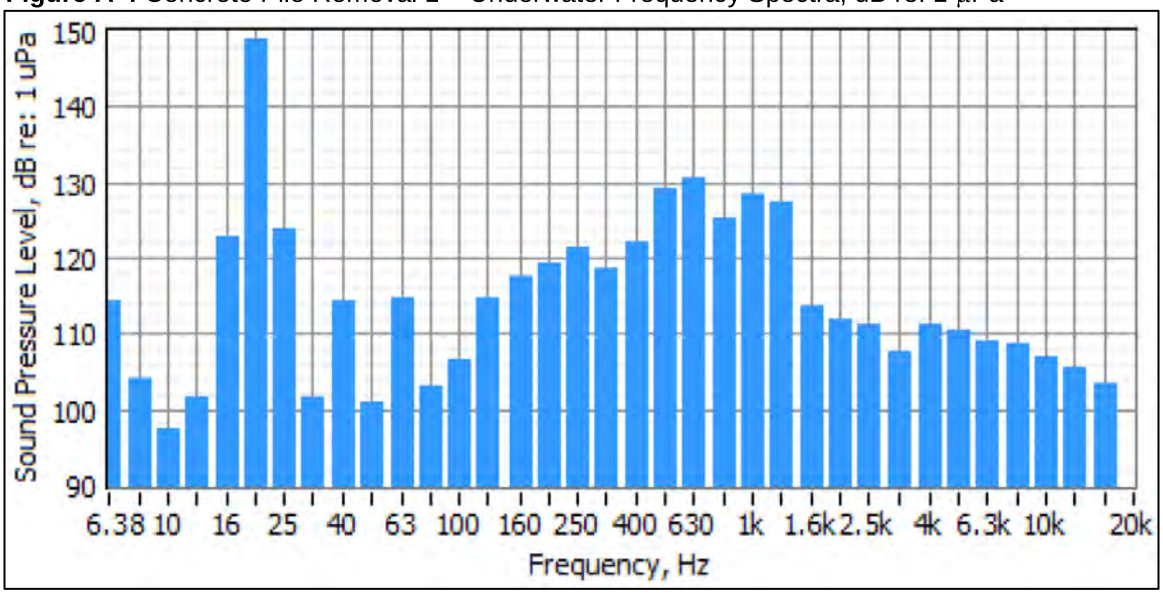


Figure A-4 Concrete Pile Removal 1 – Underwater Frequency Spectra, dB re: 1 μPa



CONCRETE PILE REMOVAL 2

December 27, 2016

Table A-4 Concrete Pile Removal 2 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)	
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile
7.5 minutes	None	Upper: 3 Lower: 10	7	35	3	13	6

Table A-5 Concrete Pile Removal 2 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-2	94	100	96

Figure A-5 Concrete Pile 2 Airborne 10-Sec RMS

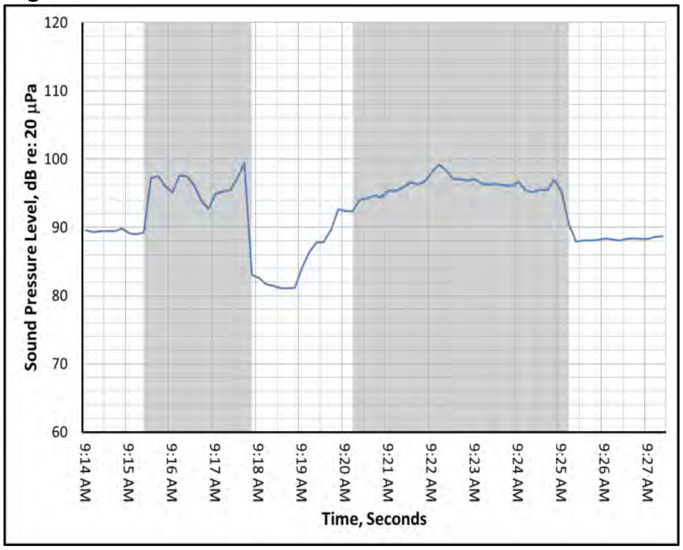


Figure A-6 Concrete Pile 2 Airborne Spectra

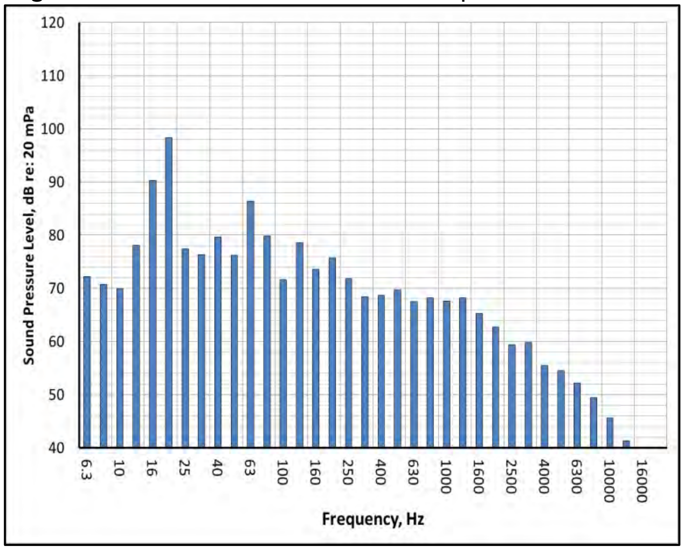


Table A-6 Concrete Pile Removal 2 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-2	7 Hz-20 kHz	147	161	3	**156**	124	154	4	**147**	121	155	3	**147**
	75 Hz-20 kHz	143	161	4	**152**	119	139	2	**133**	119	140	2	**133**
	150 Hz-20 kHz	144	161	4	**151**	118	138	3	**133**	119	140	2	**133**
	200 Hz-20 kHz	143	161	4	**151**	118	138	3	**132**	119	139	2	**133**

Figure A-7 Concrete Pile Removal 2 - Peak Sound Pressure, Pa

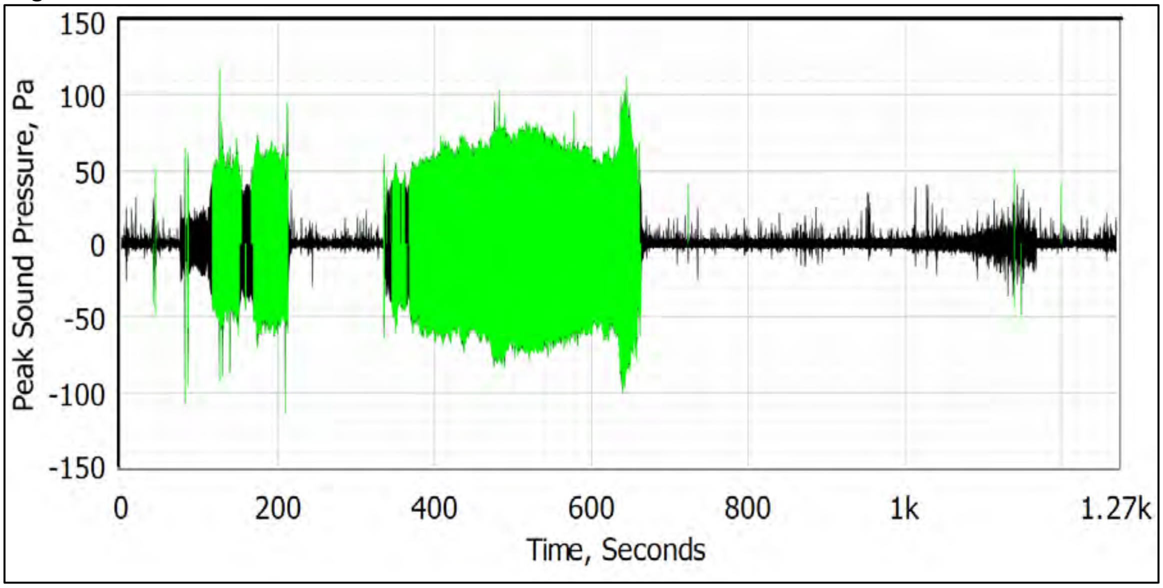
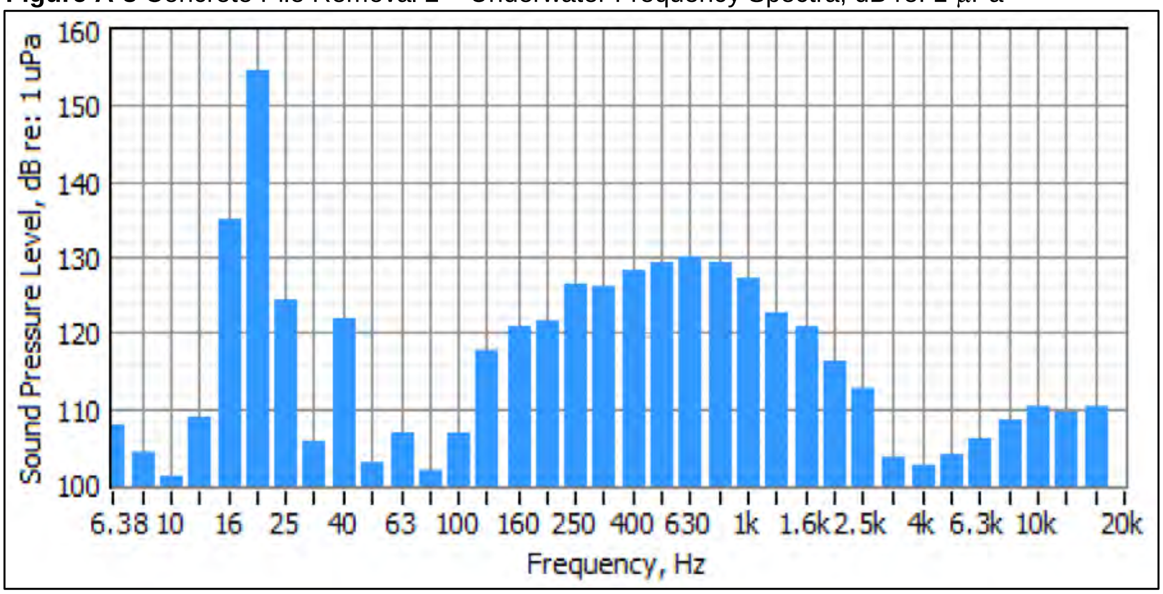


Figure A-8 Concrete Pile Removal 2 – Underwater Frequency Spectra, dB re: 1 μPa



CONCRETE PILE REMOVAL 3

December 27, 2016

Table A-7 Concrete Pile Removal 3 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)	
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile
4 minutes	None	Upper: 3 Lower: 10	7	37	3	13	6

Table A-8 Concrete Pile Removal 3 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-3	90	95	92

Figure A-9 Concrete Pile 3 Airborne 10-Sec RMS

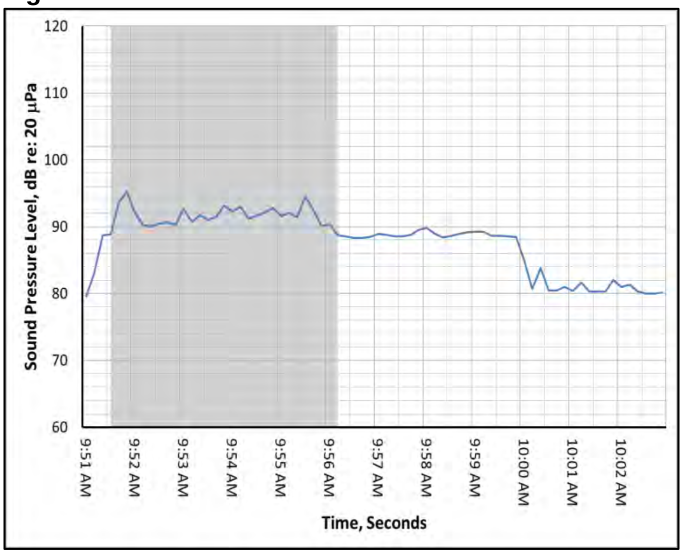


Figure A-10 Concrete Pile 3 Airborne Spectra

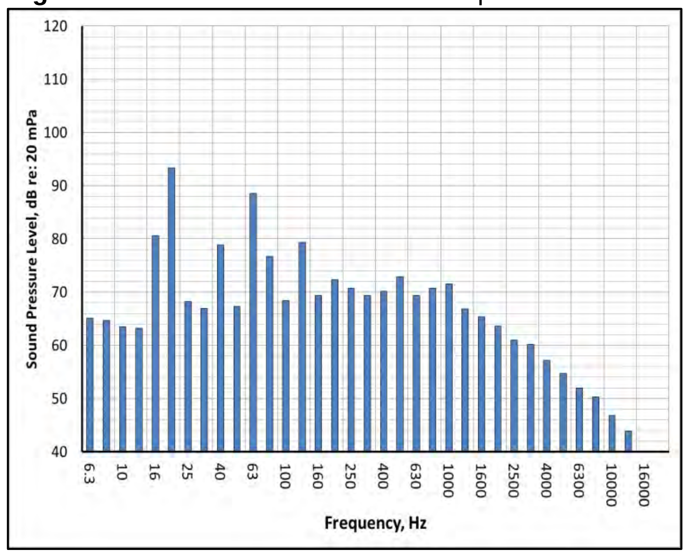


Table A-9 Concrete Pile Removal 3 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-3	7 Hz-20 kHz	142	164	4	**155**	126	154	4	**145**	123	155	3	**145**
	75 Hz-20 kHz	141	164	5	**152**	116	141	5	**135**	115	144	3	**133**
	150 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	114	143	4	**132**
	200 Hz-20 kHz	138	164	5	**151**	115	141	4	**132**	121	153	4	**135**

Figure A-11 Concrete Pile Removal 3 - Peak Sound Pressure, Pa

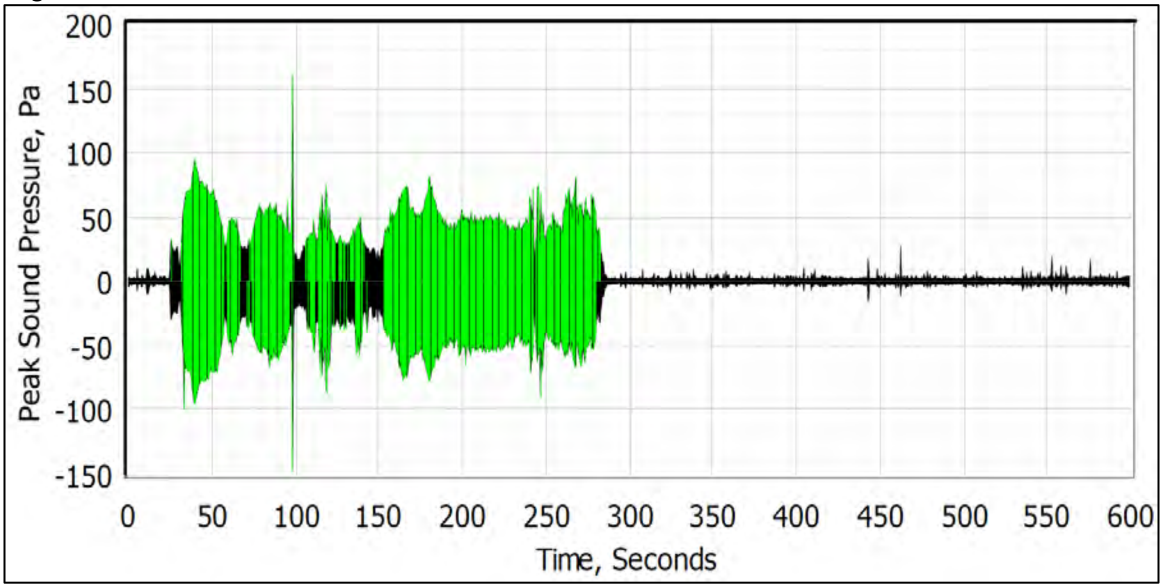
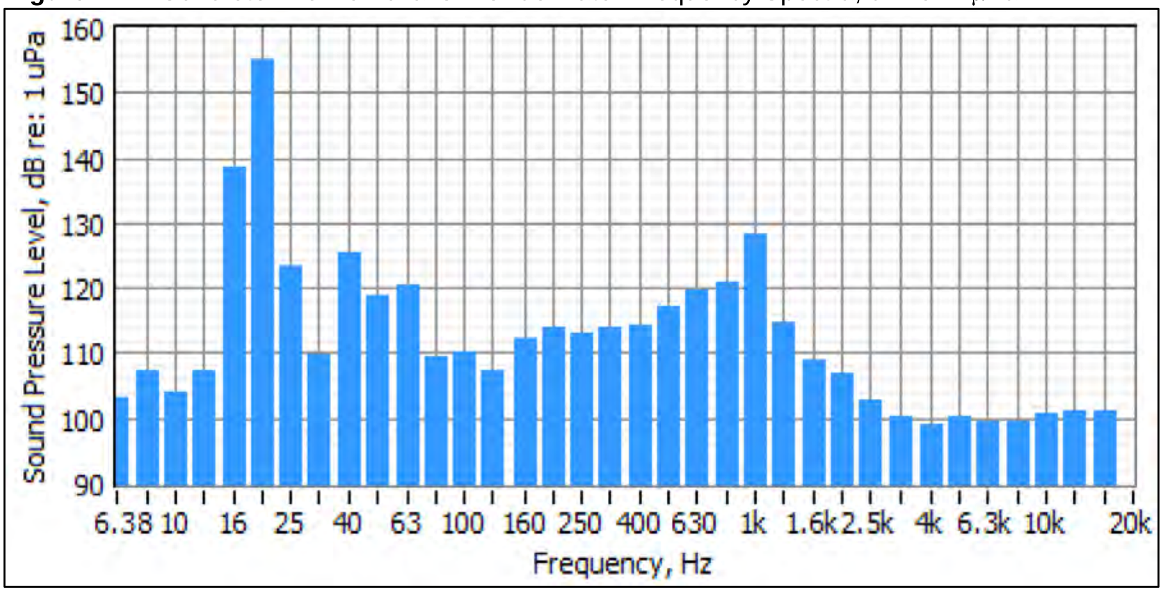


Figure A-12 Concrete Pile Removal 3 – Underwater Frequency Spectra, dB re: 1 μPa



CONCRETE PILE REMOVAL 4

December 27, 2016

Table A-10 Concrete Pile Removal 4 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)	
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile
4.5 minutes	None	8	N/A	43	3	14	6

Table A-11 Concrete Pile Removal 4 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
REM-4	85	91	87

Figure A-13 Concrete Pile 4 Airborne 10-Sec RMS

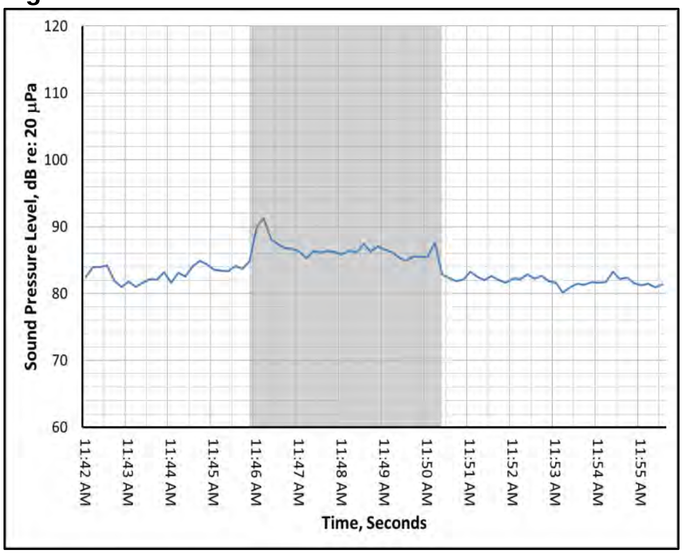


Figure A-14 Concrete Pile 4 Airborne Spectra

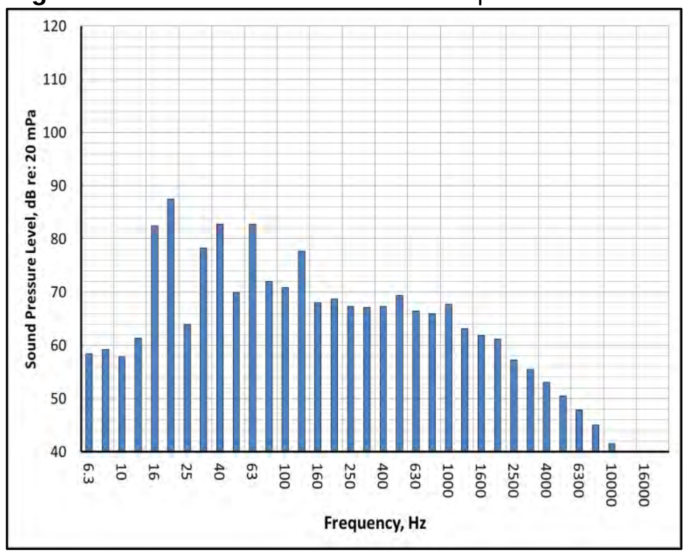


Table A-12 Concrete Pile Removal 4 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-4	7 Hz-20 kHz	146	161	3	**151**	117	149	3	**140**	133	153	3	**141**
	75 Hz-20 kHz	142	159	4	**148**	119	132	2	**130**	123	135	2	**130**
	150 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**130**
	200 Hz-20 kHz	142	159	4	**148**	118	131	3	**129**	119	134	3	**129**

Figure A-15 Concrete Pile Removal 4 - Peak Sound Pressure, Pa

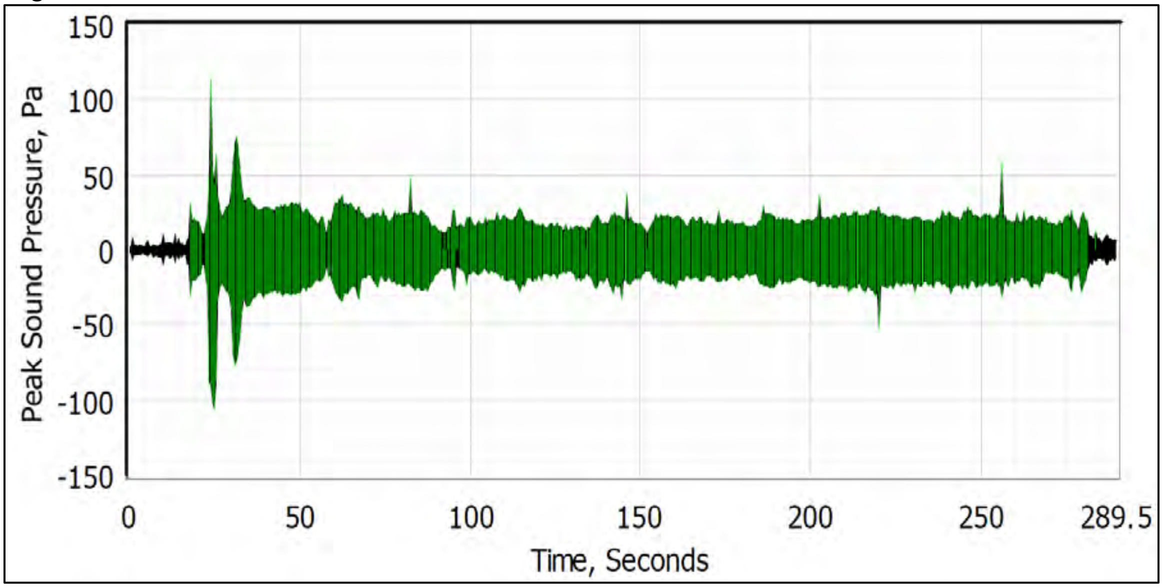
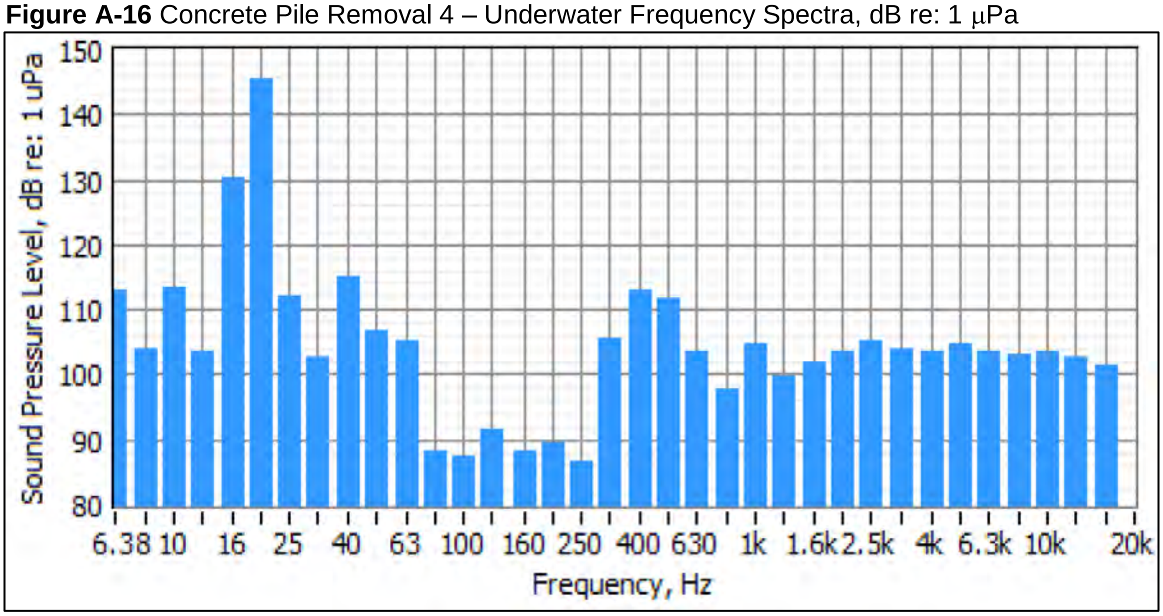


Figure A-16 Concrete Pile Removal 4 – Underwater Frequency Spectra, dB re: 1 µPa



CONCRETE PILE REMOVAL 5

December 27, 2016

Table A-13 Concrete Pile Removal 5 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)	
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile
7.5 minutes	None	8	N/A	40	3	14	6

Table A-14 Concrete Pile Removal 5 – Airborne Sound Levels, dB re: 20 µPa

Pile ID	Minimum	Maximum	Average
REM-5	89	96	92

Figure A-17 Concrete Pile 5 Airborne 10-Sec RMS

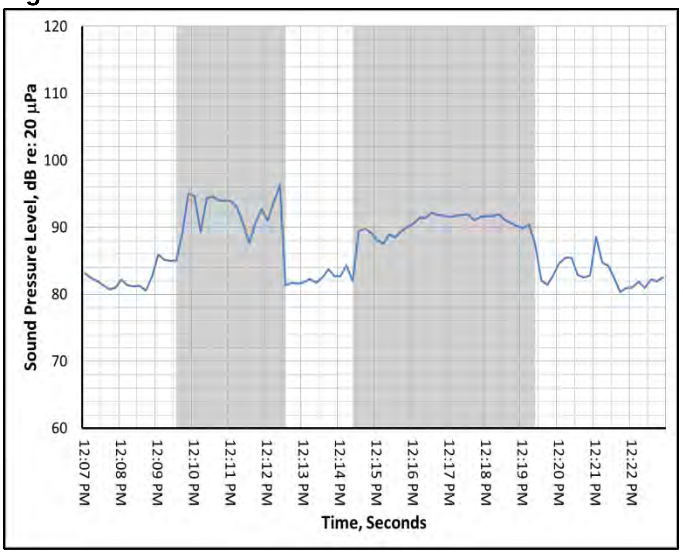


Figure A-18 Concrete Pile 5 Airborne Spectra

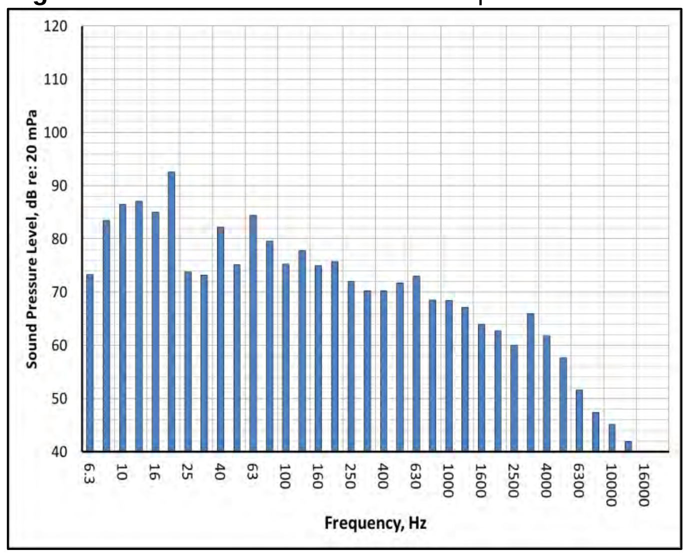


Table A-15 Concrete Pile Removal 5 – Underwater Sound Levels, dB re: 1 µPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
REM-5	7 Hz-20 kHz	153	168	3	**157**	139	150	3	**147**	137	151	2	**147**
	75 Hz-20 kHz	147	168	5	**153**	130	139	2	**135**	128	141	2	**135**
	150 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	125	141	2	**135**
	200 Hz-20 kHz	146	165	4	**152**	128	139	2	**135**	124	141	2	**135**

Figure A-19 Concrete Pile Removal 5 - Peak Sound Pressure, Pa

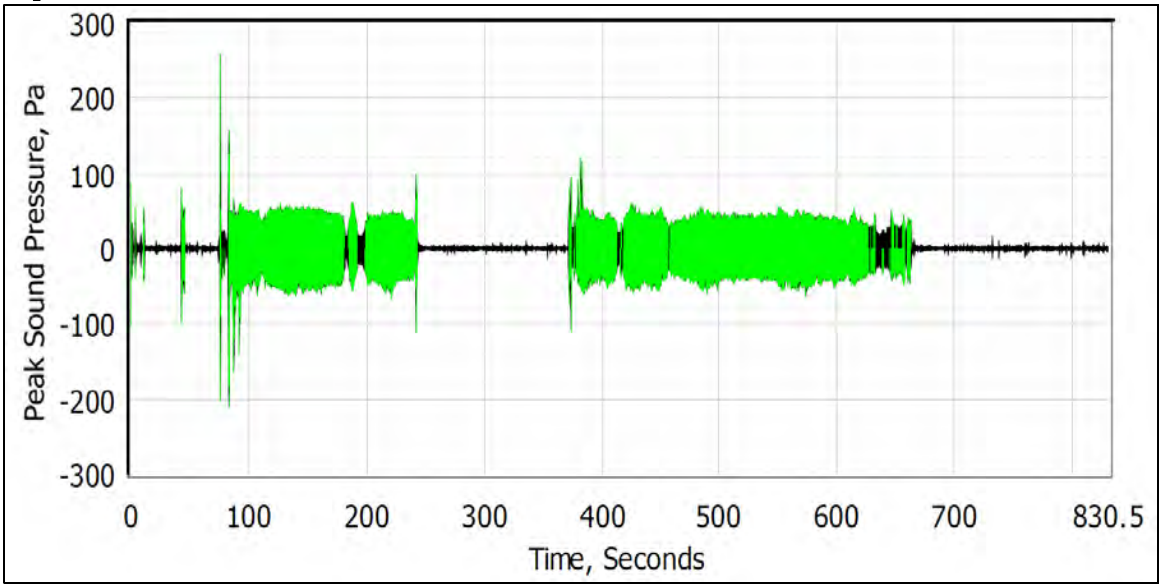
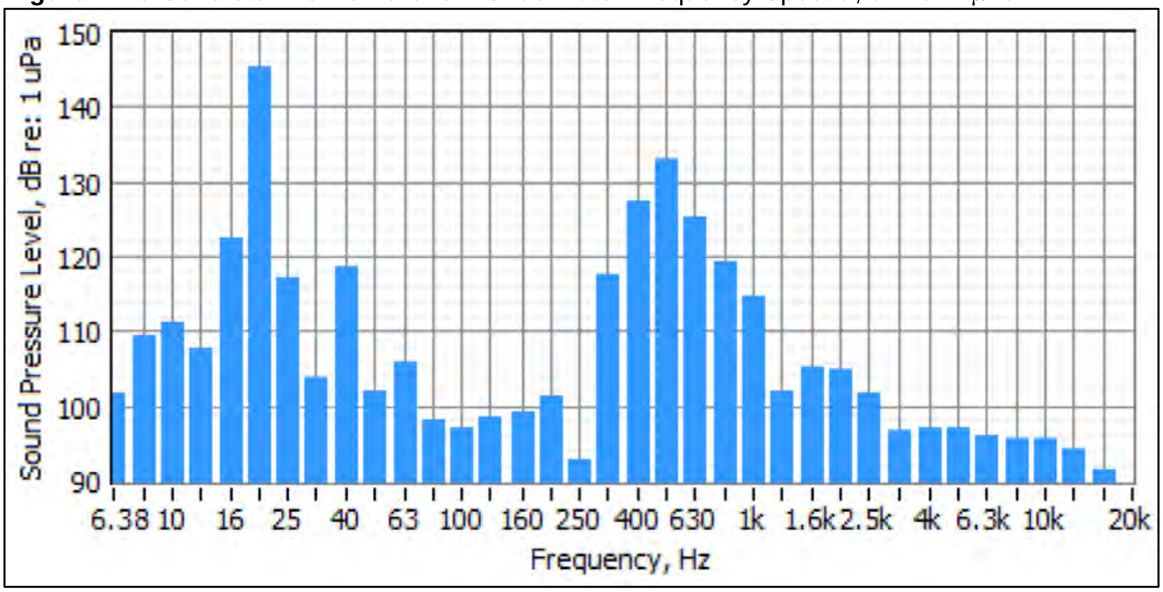


Figure A-20 Concrete Pile Removal 5 – Underwater Frequency Spectra, dB re: 1 μPa



2.0 SHEET PILES INSTALLED WITH VIBRATORY HAMMER

VIBRATORY SHEET PILE 1

December 28, 2016

Table A-16 Vibratory Sheet Pile 1 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
17.7 minutes	None	Upper: 3 Lower: 10	7	39	3	13	5	≥31

Table A-17 Vibratory Sheet Pile 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-1	98	114	107

Figure A-21 Vibratory Pile 1 Airborne 10-Sec RMS

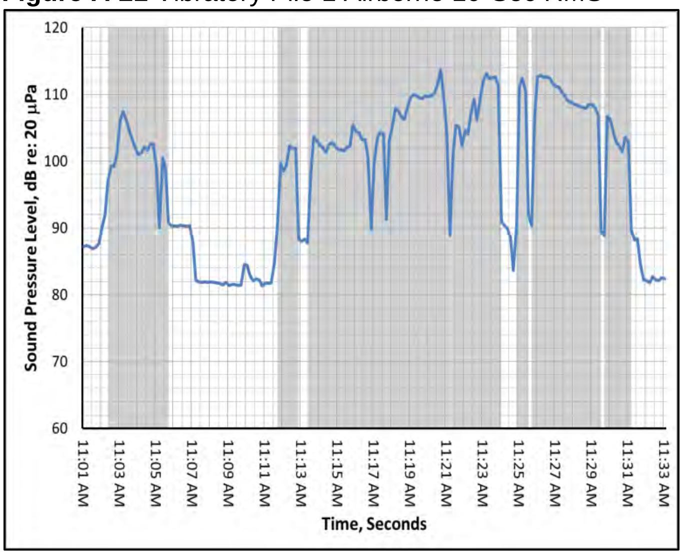


Figure A-22 Vibratory Pile 1 Airborne Spectra

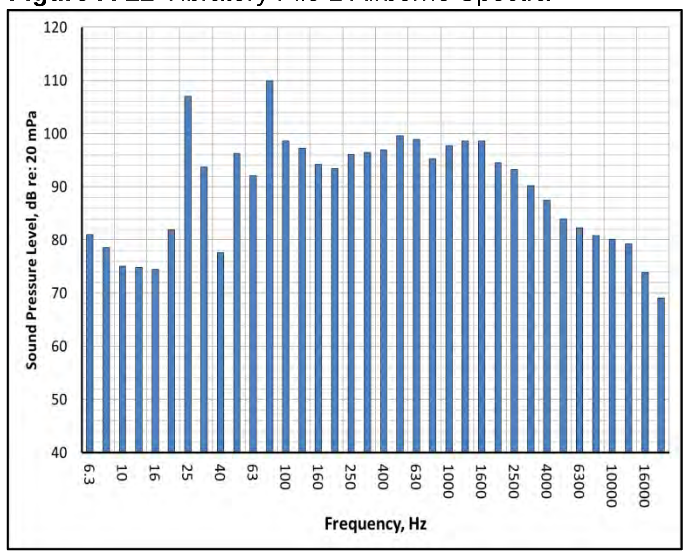


Table A-18 Vibratory Sheet Pile 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	7 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	75 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	150 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**
	200 Hz-20 kHz	155	180	5	**169**	135	161	5	**153**	135	162	4	**154**

Figure A-23 Vibratory Sheet Pile 1- Peak Sound Pressure, Pa

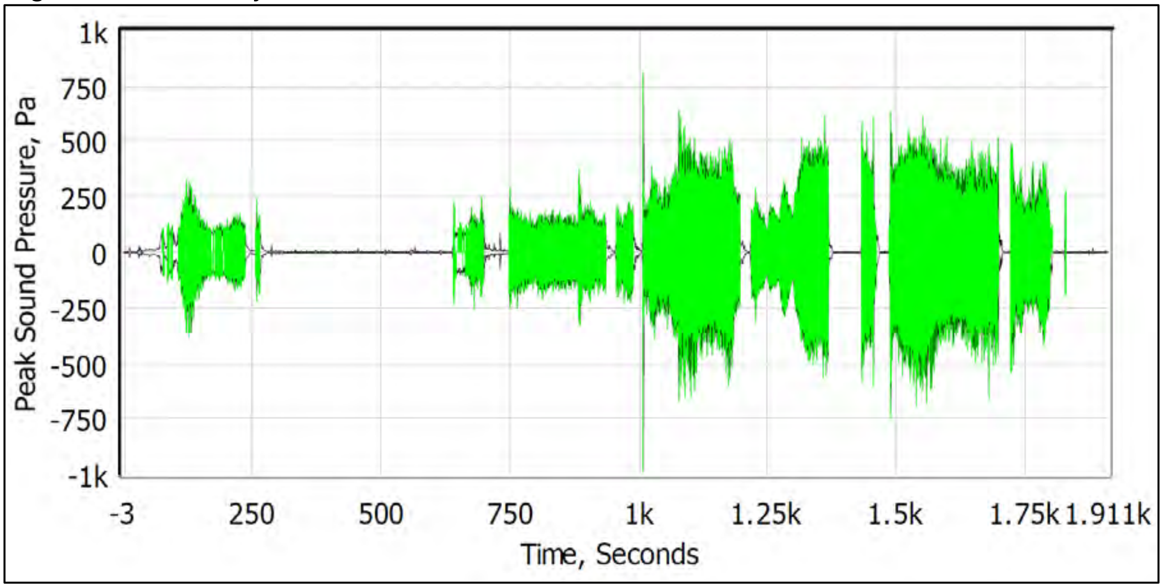
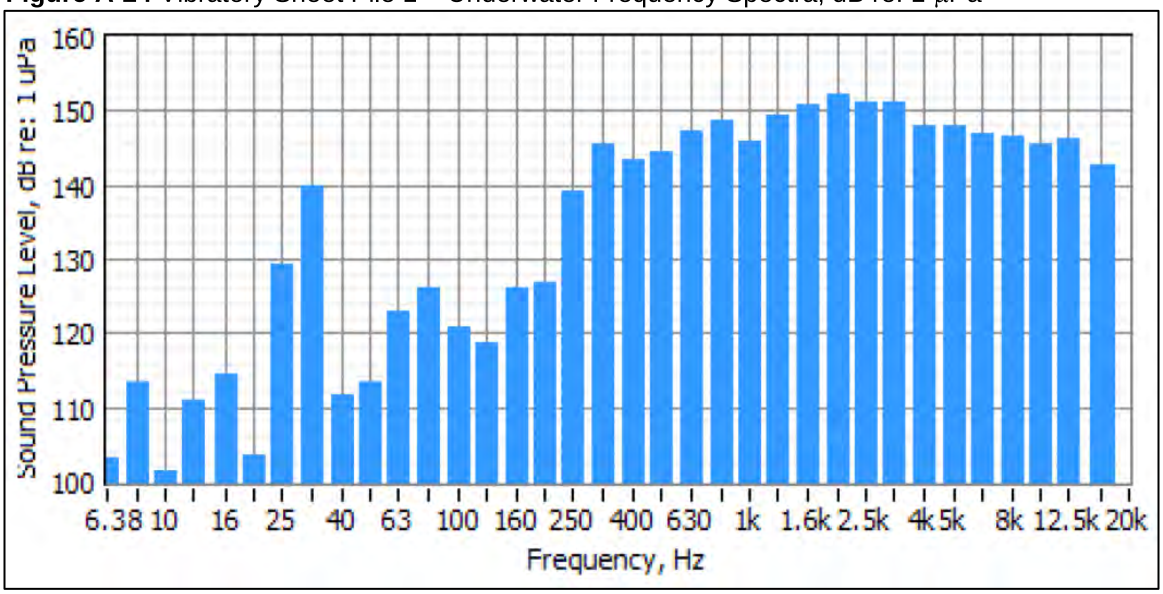


Figure A-24 Vibratory Sheet Pile 1 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 2

December 28, 2016

Table A-19 Vibratory Sheet Pile 2 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
9.9 minutes	None	Upper: 3	7	39	3	13	5	≥31
		Lower: 10						

Table A-20 Vibratory Sheet Pile 2 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-2	97	107	103

Figure A-25 Vibratory Pile 2 Airborne 10-Sec RMS

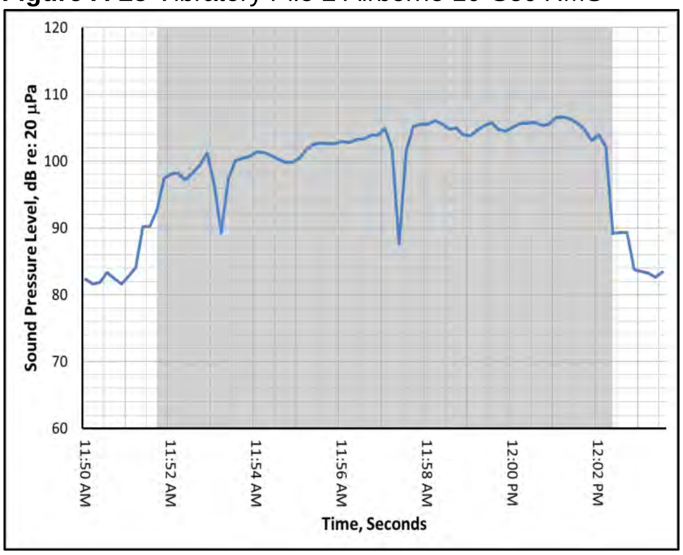


Figure A-26 Vibratory Pile 2 Airborne Spectra

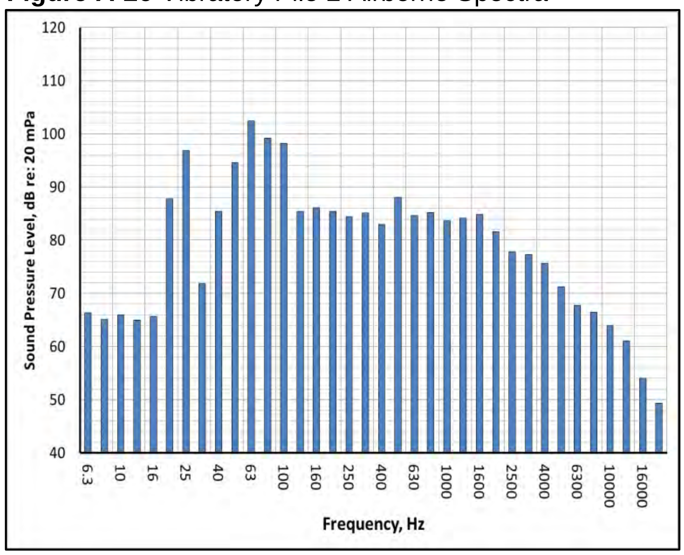


Table A-21 Vibratory Sheet Pile 2 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-2	7 Hz-20 kHz	151	174	5	**164**	135	155	5	**148**	133	155	5	**148**
	75 Hz-20 kHz	151	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	150 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**
	200 Hz-20 kHz	150	174	5	**163**	134	153	5	**147**	127	155	5	**147**

Figure A-27 Vibratory Sheet Pile 2- Peak Sound Pressure, Pa

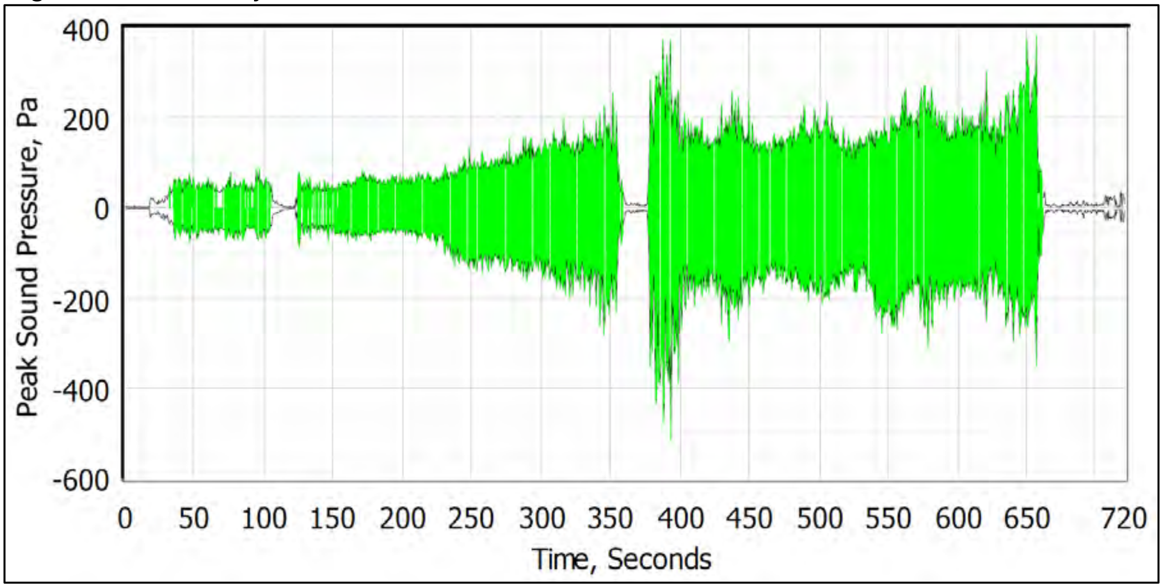
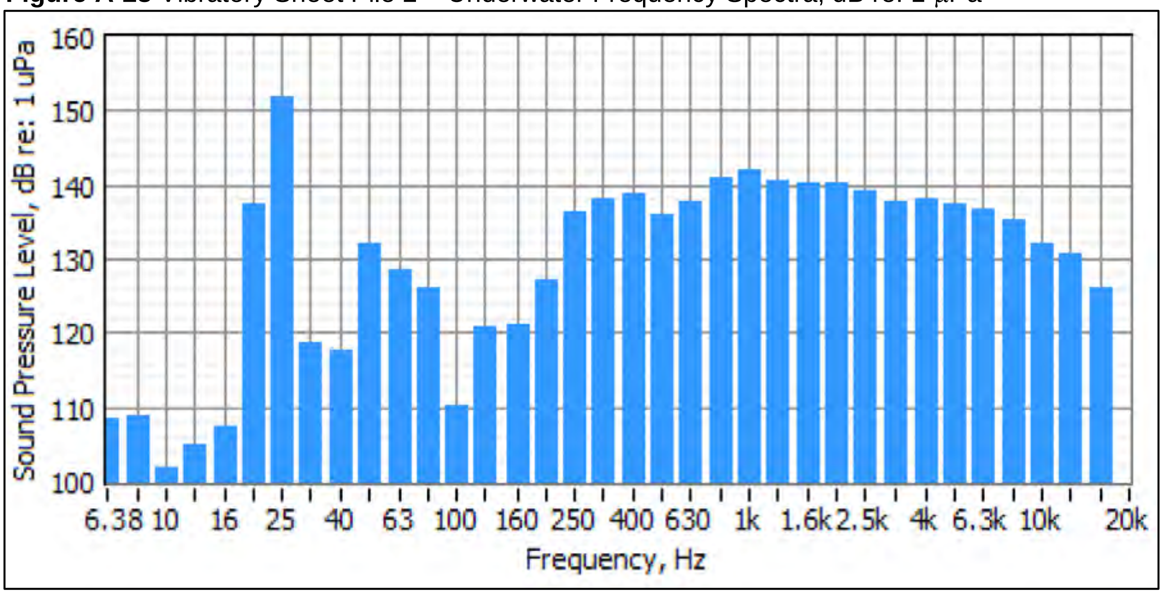


Figure A-28 Vibratory Sheet Pile 2 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 3

December 28, 2016

Table A-22 Vibratory Sheet Pile 3 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
15 minutes	None	Upper: 3	8	38	3	14	6	≥31
		Lower: 11						

Table A-23 Vibratory Sheet Pile 3 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-3	93	104	101

Figure A-29 Vibratory Pile 3 Airborne 10-Sec RMS

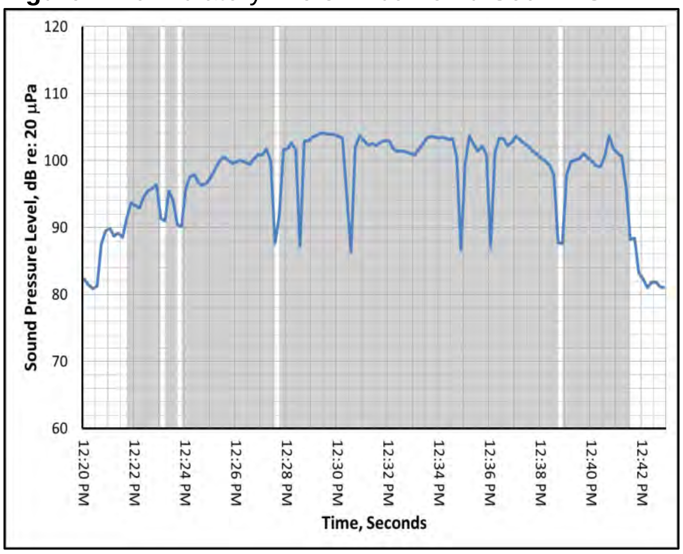


Figure A-30 Vibratory Pile 3 Airborne Spectra

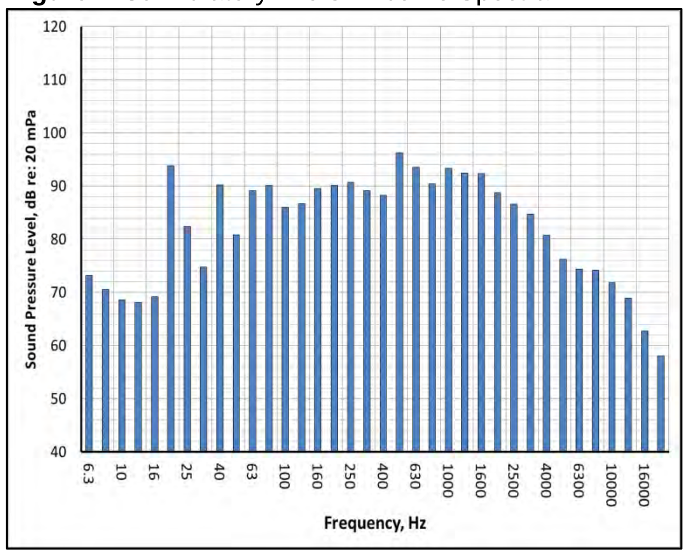


Table A-24 Vibratory Sheet Pile 3 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-3	7 Hz-20 kHz	154	174	3	**166**	129	159	4	**151**	139	159	3	**152**
	75 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**150**
	150 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**
	200 Hz-20 kHz	153	174	3	**165**	126	155	4	**149**	127	157	3	**149**

Figure A-31 Vibratory Sheet Pile 3- Peak Sound Pressure, Pa

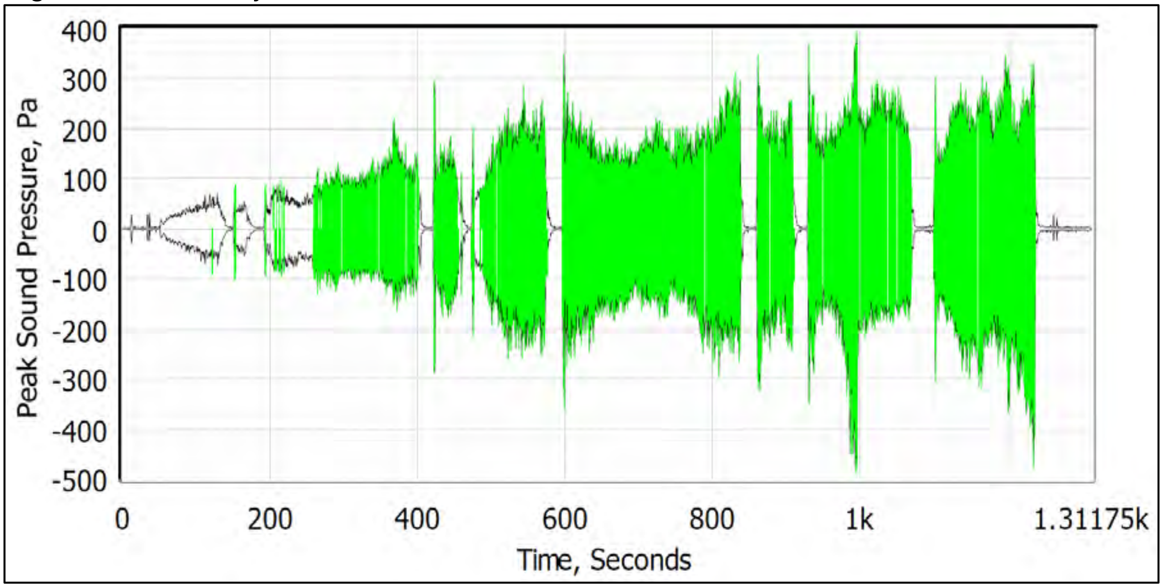
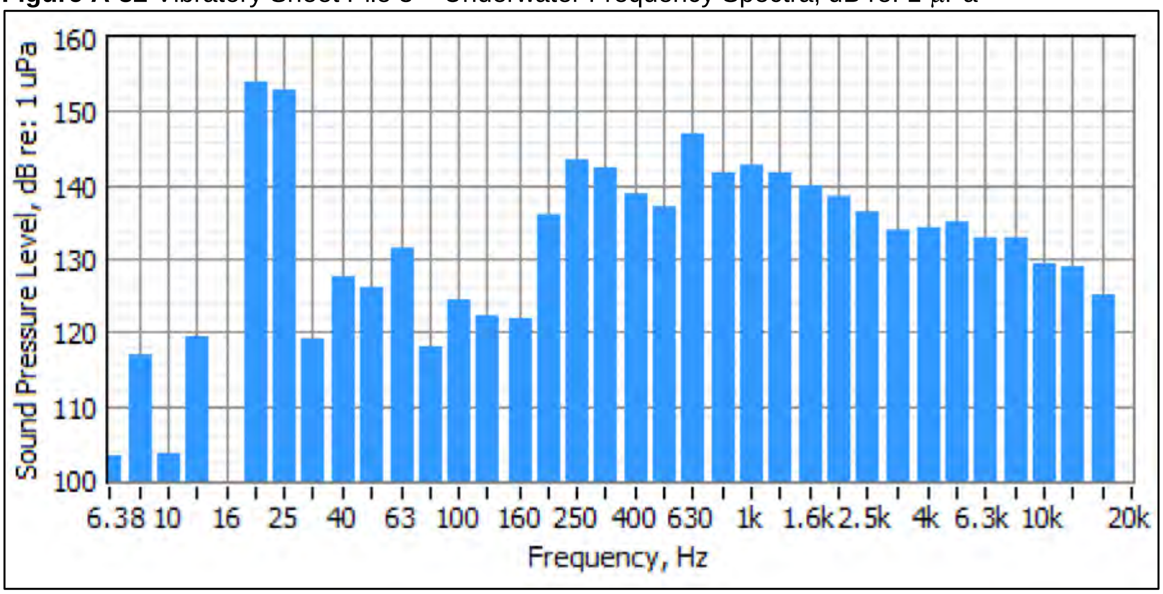


Figure A-32 Vibratory Sheet Pile 3 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 4

December 28, 2016

Table A-25 Vibratory Sheet Pile 4 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
14.3 minutes	None	Upper: 3 Lower: 11	8	37	6	14	6	≥31

Table A-26 Vibratory Sheet Pile 4 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-4	95	106	101

Figure A-33 Vibratory Pile 4 Airborne 10-Sec RMS

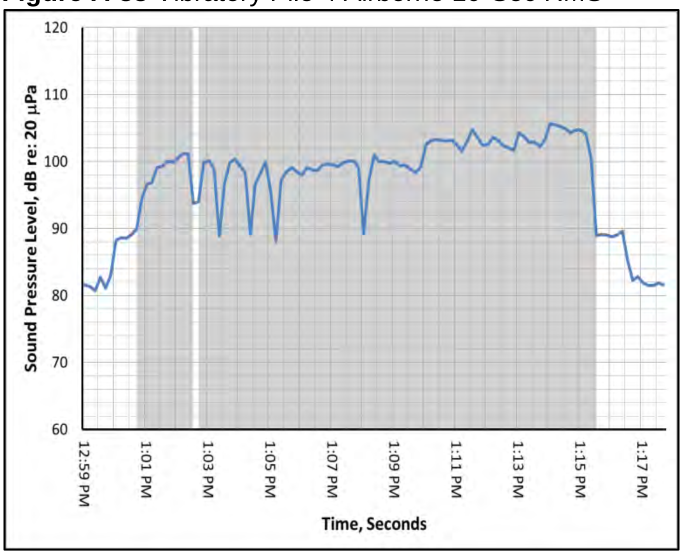


Figure A-34 Vibratory Pile 4 Airborne Spectra

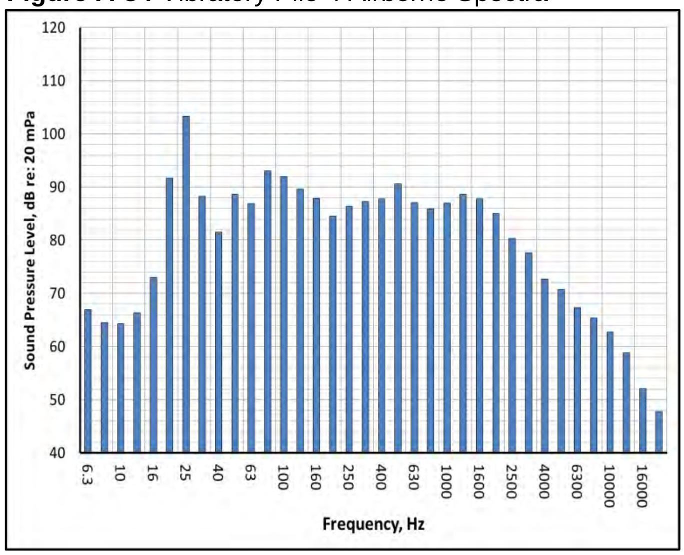


Table A-27 Vibratory Sheet Pile 4 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-4	7 Hz-20 kHz	154	170	4	**164**	131	154	5	**148**	137	156	3	**149**
	75 Hz-20 kHz	154	170	4	**164**	130	154	5	**148**	133	156	3	**148**
	150 Hz-20 kHz	154	170	4	**164**	130	154	5	**147**	133	156	3	**148**
	200 Hz-20 kHz	154	171	4	**164**	130	154	5	**147**	133	156	3	**148**

Figure A-35 Vibratory Sheet Pile 4 - Peak Sound Pressure, Pa

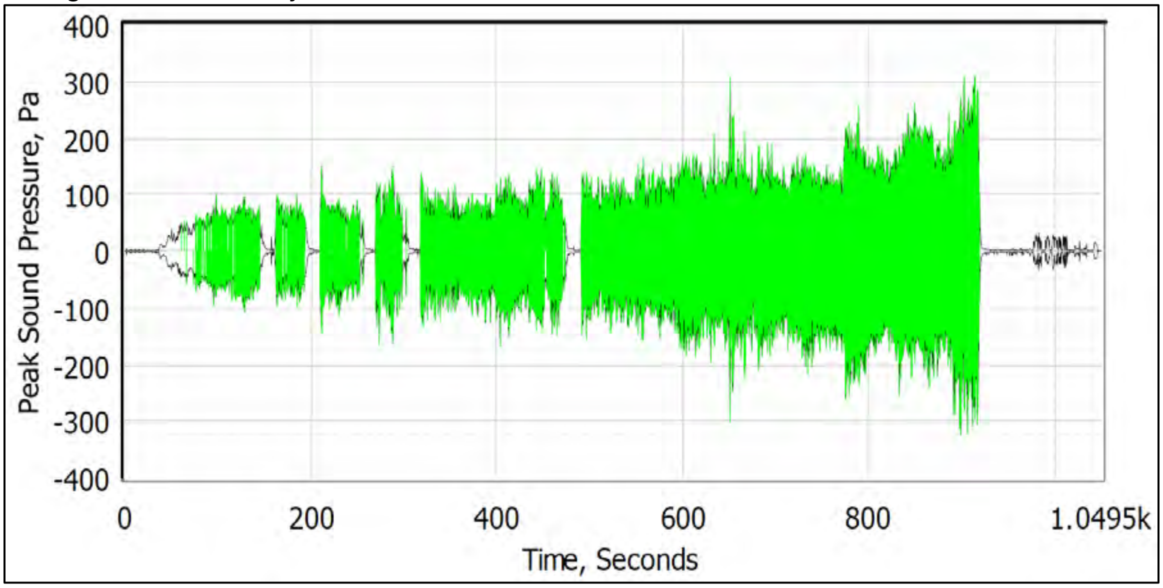
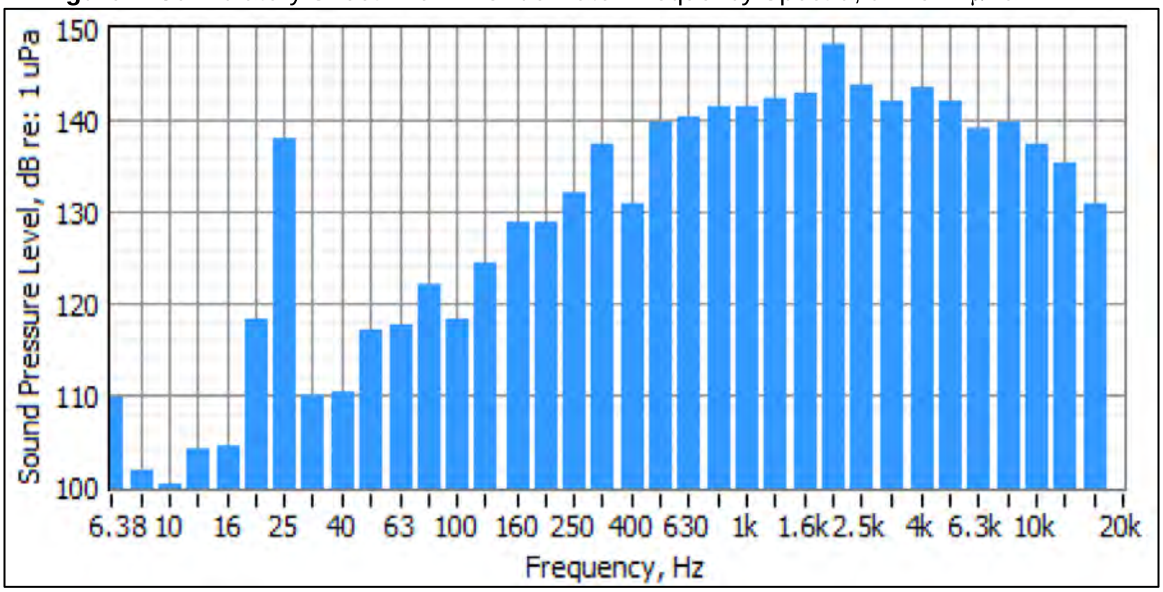


Figure A-36 Vibratory Sheet Pile 4 – Underwater Frequency Spectra, dB re: 1 μPa



VIBRATORY SHEET PILE 5

December 28, 2016

Table A-28 Vibratory Sheet Pile 5 - Hydrophone and Pile Information

Drive Time	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
7.9 minutes	None	Upper: 3 Lower: 12	9	37	3	15	7	≥31

Table A-29 Vibratory Sheet Pile 5 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
VIB-5	95	107	102

Figure A-37 Vibratory Pile 5 Airborne 10-Sec RMS

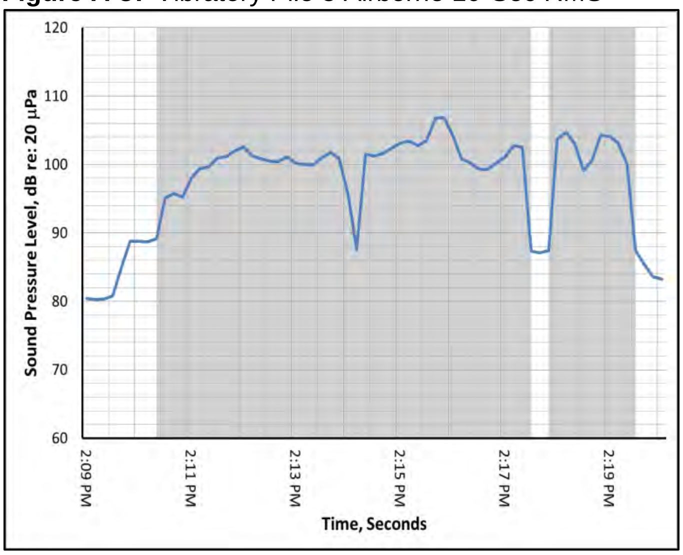


Figure A-38 Vibratory Pile 5 Airborne Spectra

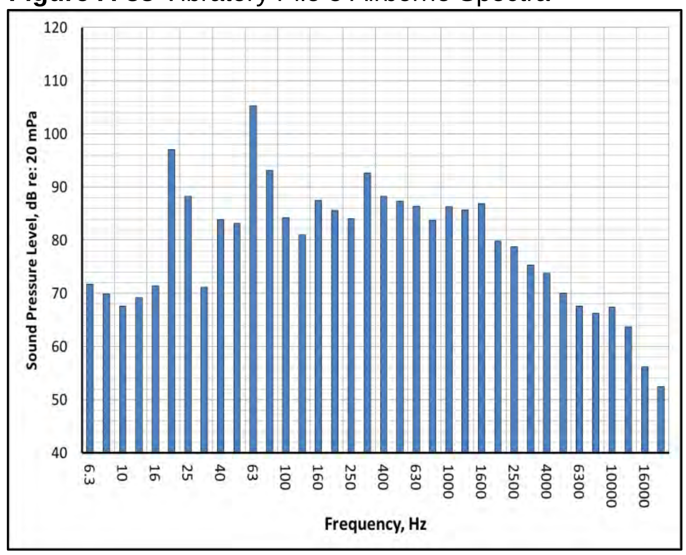


Table A-30 Vibratory Sheet Pile 5 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS				SEL			
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-5	7 Hz-20 kHz	155	180	4	**170**	137	159	3	**153**	137	161	3	**153**
	75 Hz-20 kHz	154	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	150 Hz-20 kHz	155	180	4	**170**	137	158	3	**152**	135	161	3	**153**
	200 Hz-20 kHz	154	179	4	**170**	137	158	3	**152**	135	161	3	**153**

Figure A-39 Vibratory Sheet Pile 5- Peak Sound Pressure, Pa

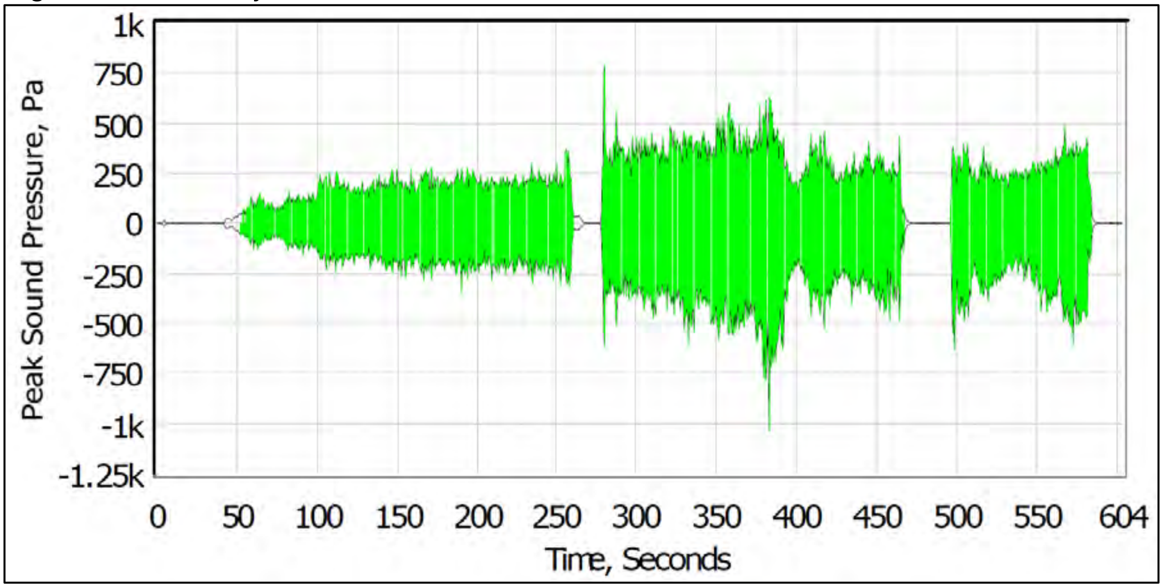
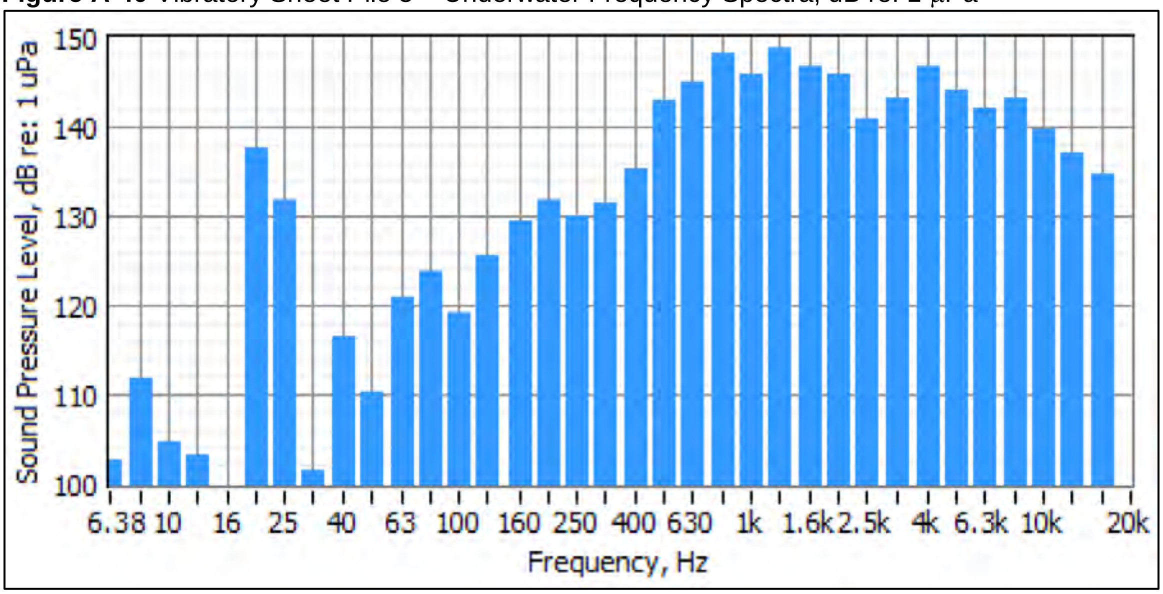


Figure A-40 Vibratory Sheet Pile 5 – Underwater Frequency Spectra, dB re: 1 μPa



3.0 SHEET PILES INSTALLED WITH IMPACT HAMMER

IMPACT SHEET PILE 1

January 11, 2017

Table A-31 Impact Sheet Pile 1 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
39	None	Upper: 3 Lower: 9	6	40	3	12	9	≥31

Table A-32 Impact Sheet Pile 1 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-1	96	113	107

Figure A-41 Impact Pile 1 Airborne 1-second RMS

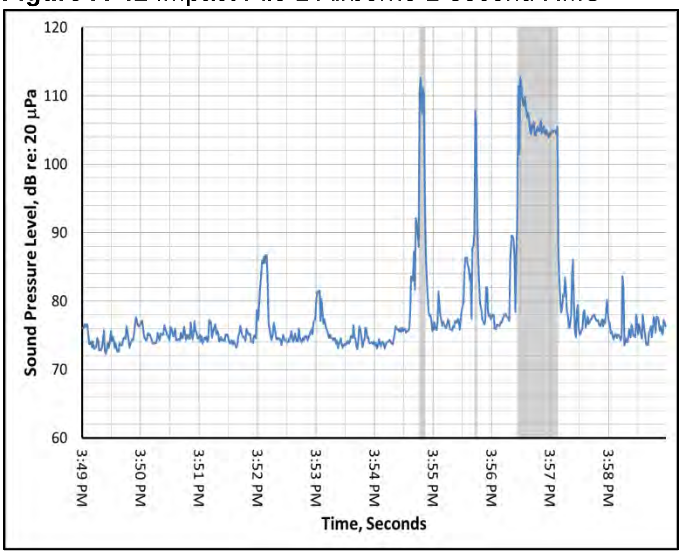


Figure A-42 Impact Pile 1 Airborne Spectra

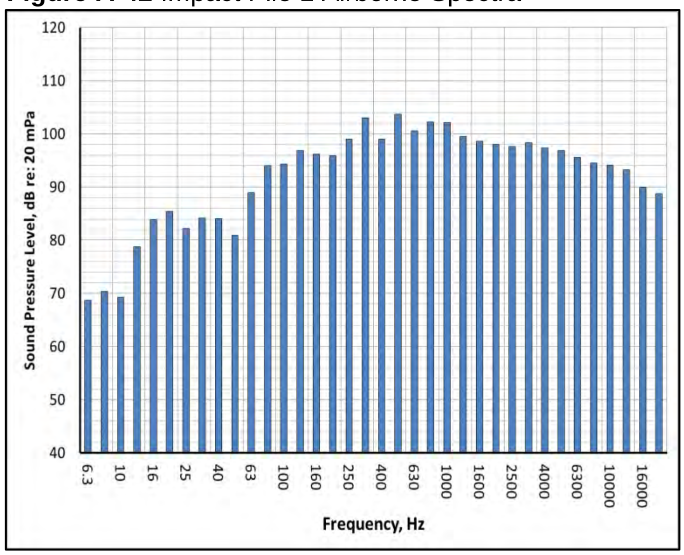


Table A-33 Impact Sheet Pile 1 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-1	7 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	75 Hz-20 kHz	174	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	150 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**
	200 Hz-20 kHz	175	189	3	**184**	160	176	3	**171**	147	162	2	**157**	**177**

Figure A-43 Impact Sheet Pile 1- Peak Sound Pressure, Pa

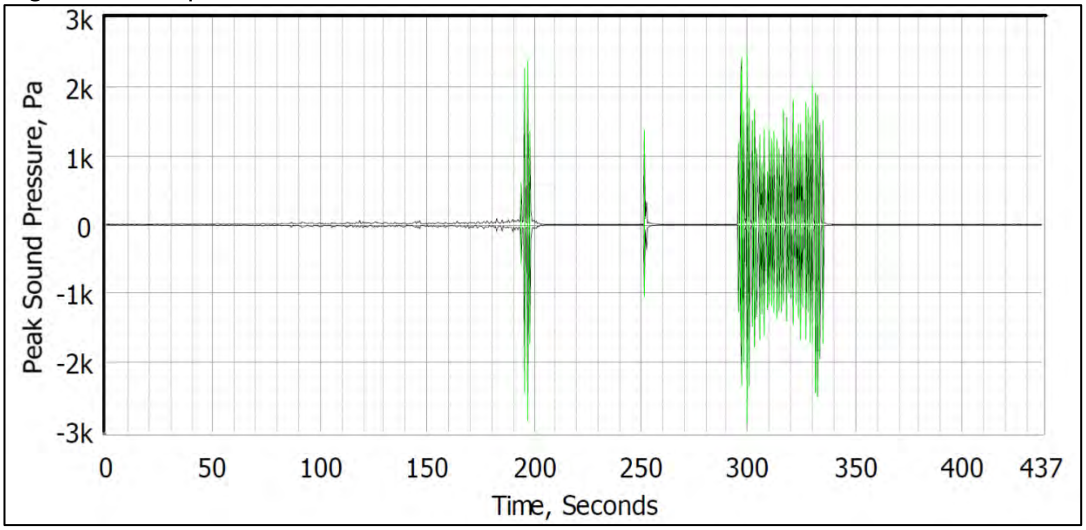


Figure A-44 Impact Sheet Pile 1 – Underwater Frequency Spectra, dB re: 1 μPa

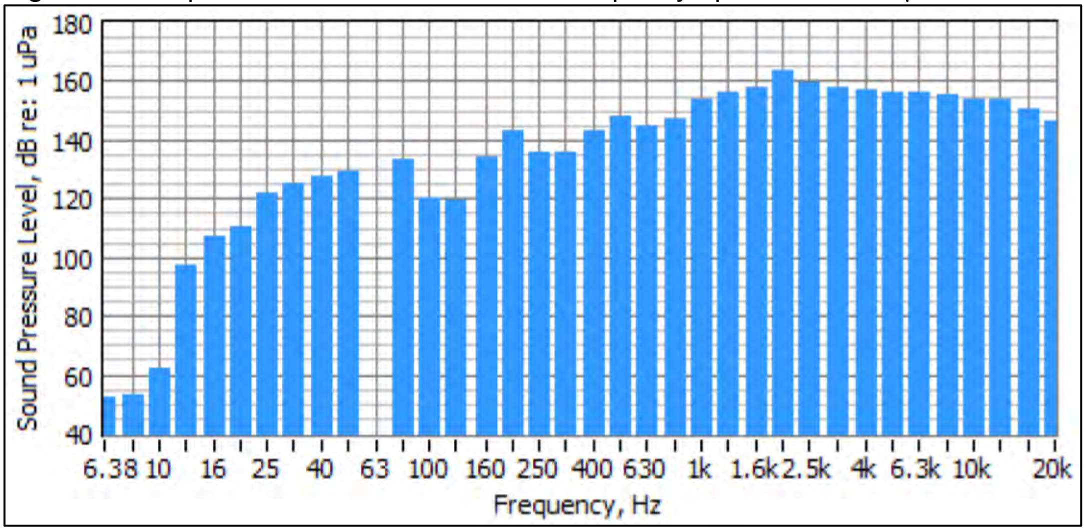
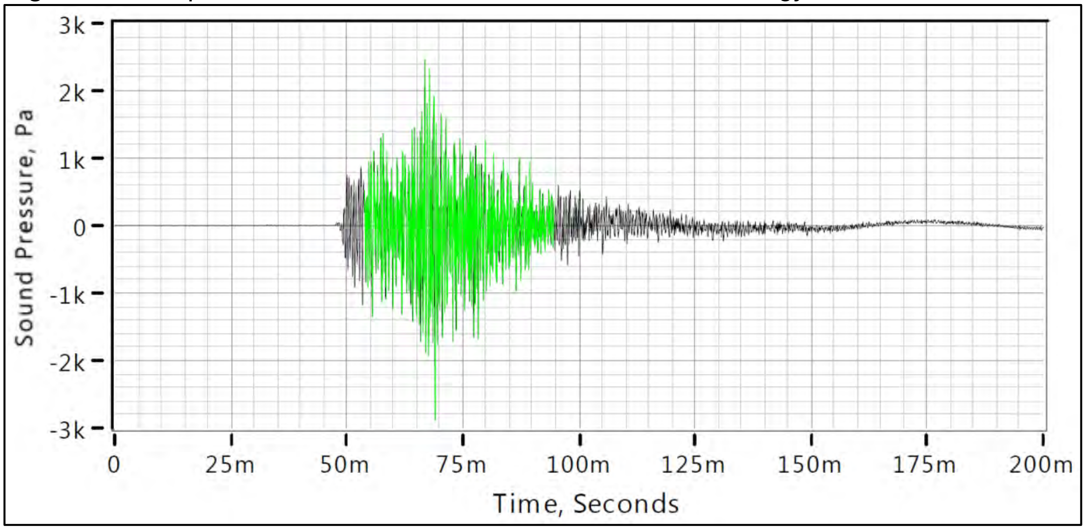


Figure A-45 Impact Sheet Pile 1 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 2

January 11, 2017

Table A-34 Impact Sheet Pile 2 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
63	None	Upper: 3	6	37	3	12	9	≥31
		Lower: 9						

Table A-35 Impact Sheet Pile 2 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-2	103	110	108

Figure A-46 Impact Pile 2 Airborne 1-second RMS

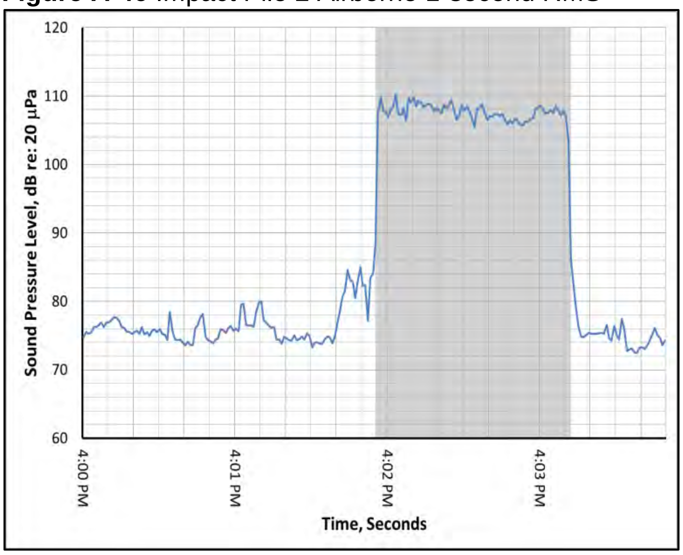


Figure A-47 Impact Pile 2 Airborne Spectra

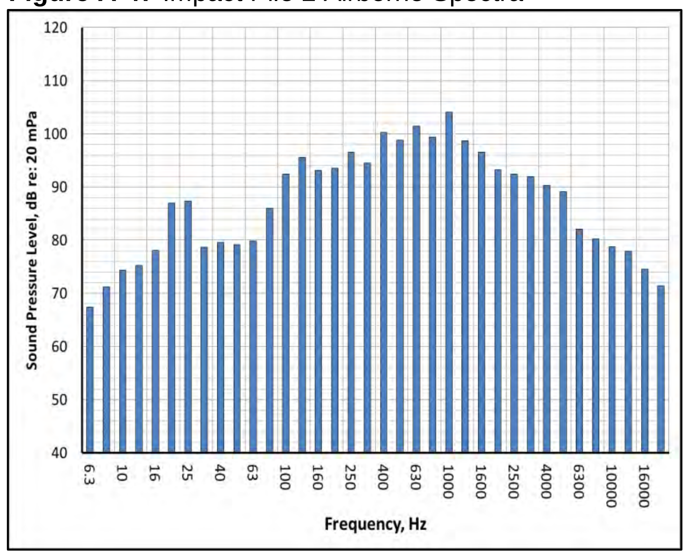


Table A-36 Impact Sheet Pile 2 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-2	7 Hz-20 kHz	182	191	1	**187**	166	179	1	**175**	155	164	1	**161**	**182**
	75 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	150 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**
	200 Hz-20 kHz	182	191	1	**187**	170	179	1	**175**	155	164	1	**161**	**182**

Figure A-48 Impact Sheet Pile 2- Peak Sound Pressure, Pa

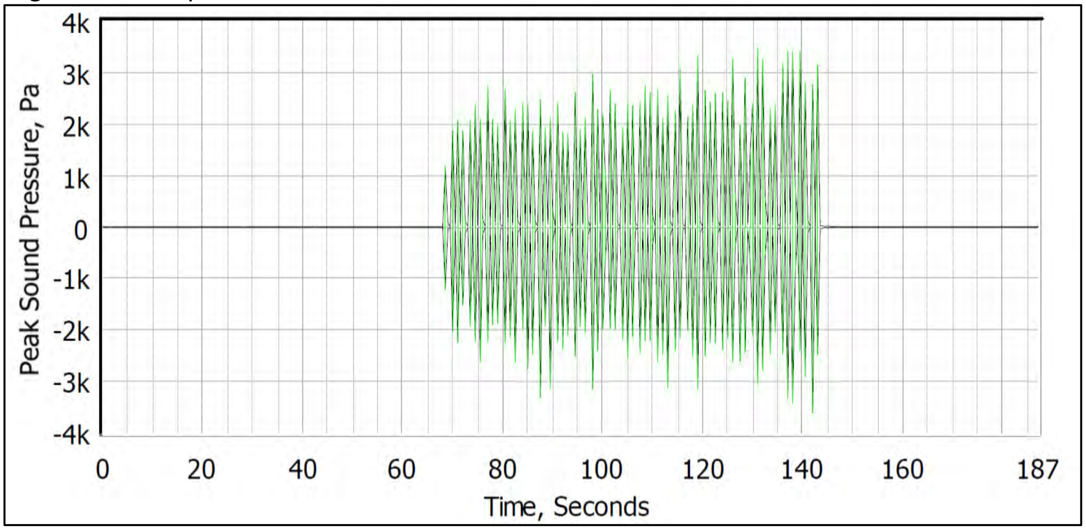


Figure A-49 Impact Sheet Pile 2 – Underwater Frequency Spectra, dB re: 1 μPa

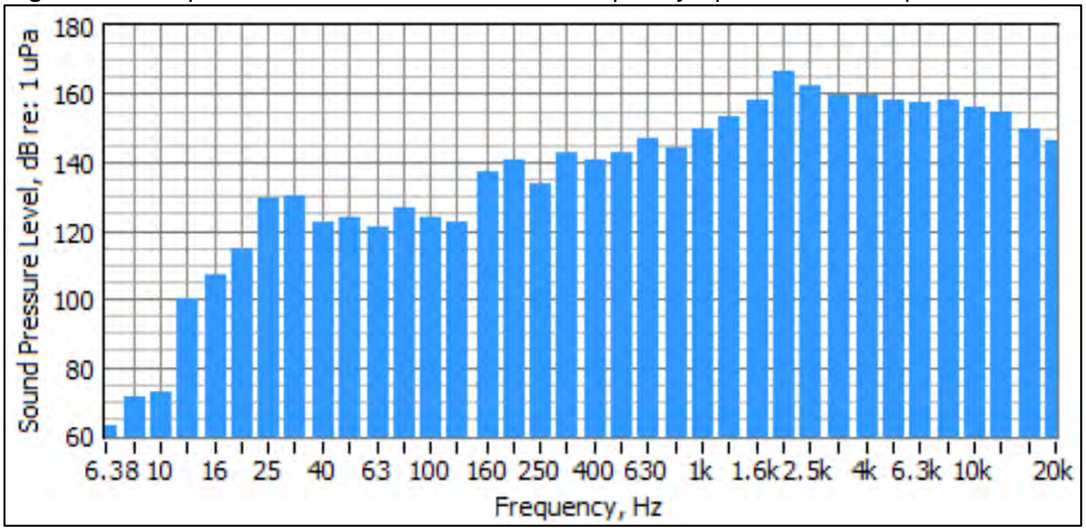
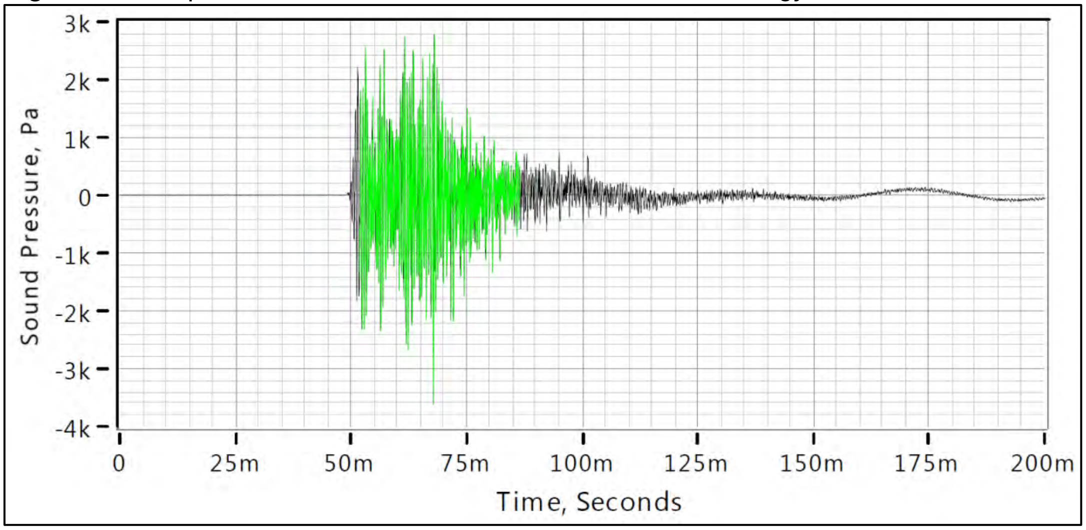


Figure A-50 Impact Sheet Pile 2 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 3

January 11, 2017

Table A-37 Impact Sheet Pile 3 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
113	None	Upper: 3 Lower: 9	6	35	3	12	9	≥31

Table A-38 Impact Sheet Pile 3 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-3	99	114	109

Figure A-51 Impact Pile 3 Airborne 1-second RMS

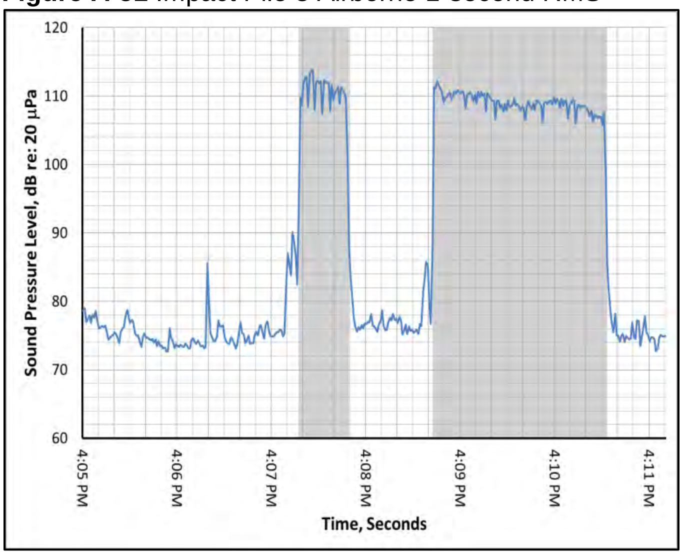


Figure A-52 Impact Pile 3 Airborne Spectra

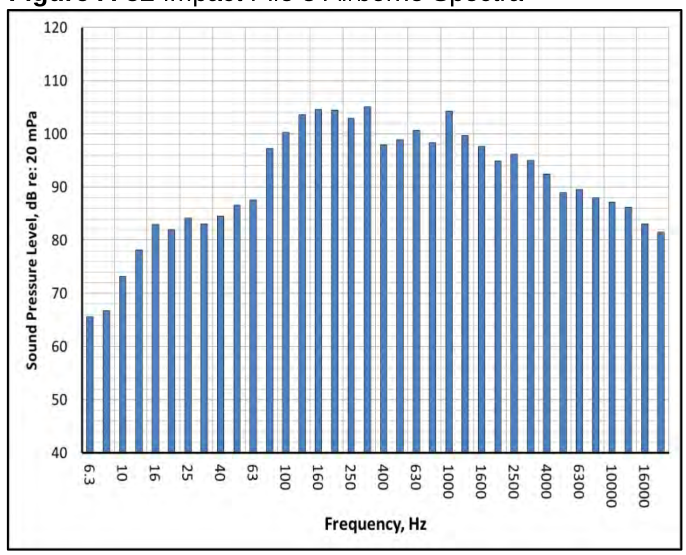


Table A-39 Impact Sheet Pile 3 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-3	7 Hz-20 kHz	184	197	2	**192**	169	182	1	**179**	157	167	1	**164**	**187**
	75 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	150 Hz-20 kHz	184	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**
	200 Hz-20 kHz	183	197	2	**192**	171	182	1	**179**	157	167	1	**164**	**187**

Figure A-53 Impact Sheet Pile 3- Peak Sound Pressure, Pa

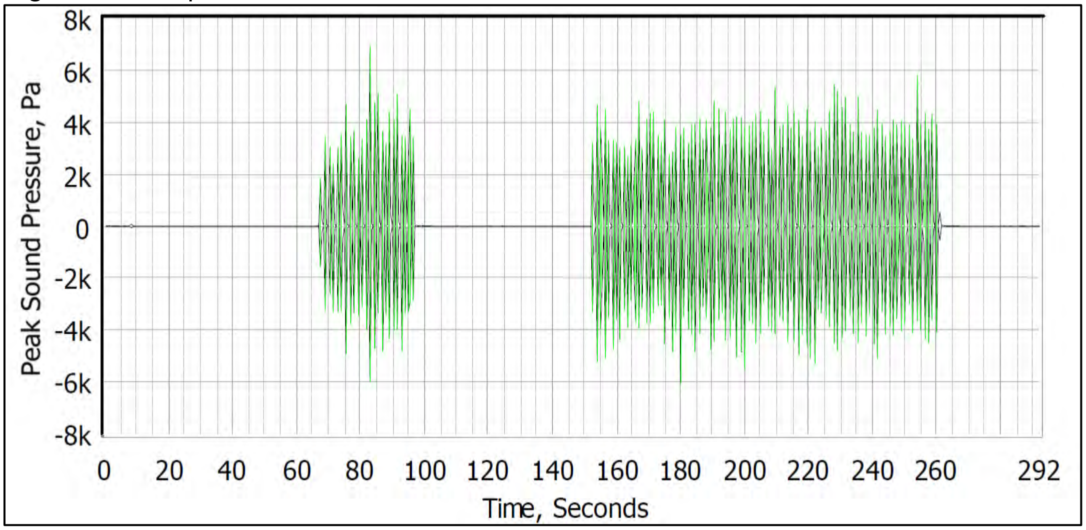


Figure A-54 Impact Sheet Pile 3 – Underwater Frequency Spectra, dB re: 1 μPa

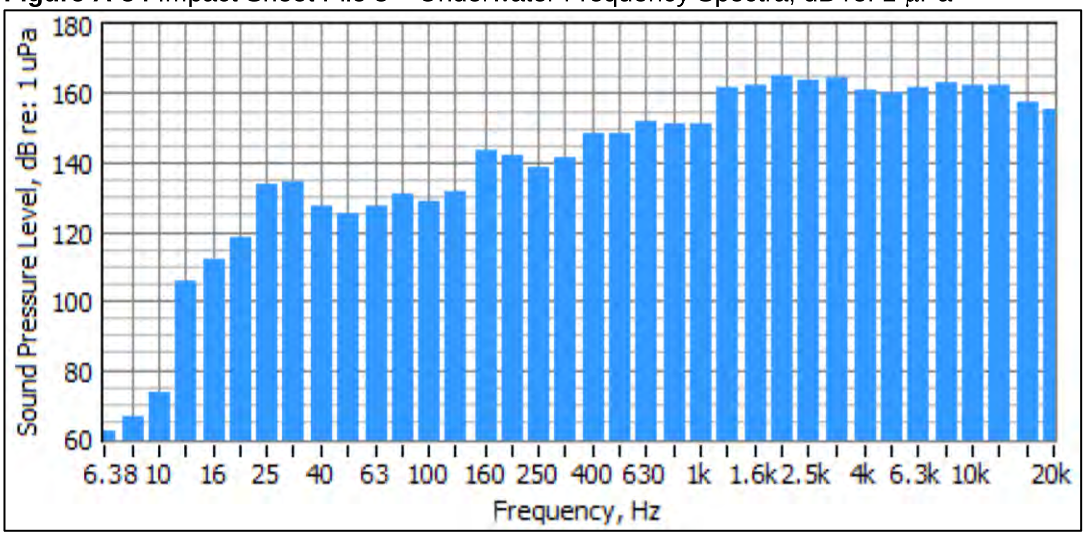
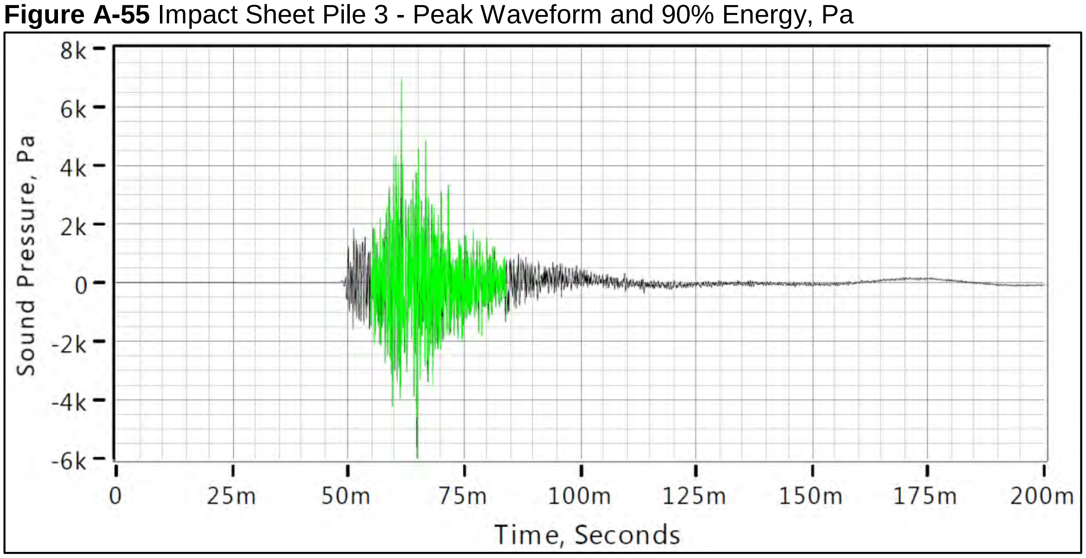


Figure A-55 Impact Sheet Pile 3 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 4

January 11, 2017

Table A-40 Impact Sheet Pile 4 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
84	None	Upper: 3 Lower: 9	6	33	3	12	9	≥31

Table A-41 Impact Sheet Pile 4 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-4	99	114	111

Figure A-56 Impact Pile 4 Airborne 1-second RMS

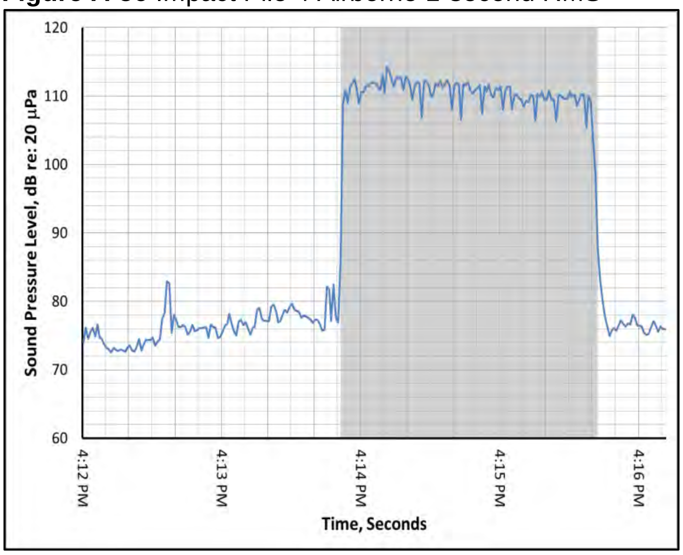


Figure A-57 Impact Pile 4 Airborne Spectra

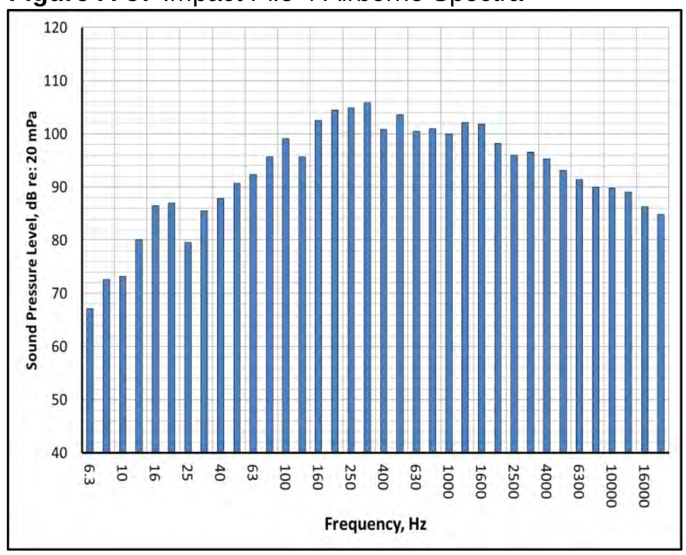


Table A-42 Impact Sheet Pile 4 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-4	7 Hz-20 kHz	183	199	2	**194**	168	185	2	**182**	156	170	2	**167**	**188**
	75 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	150 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**
	200 Hz-20 kHz	183	199	2	**194**	171	186	2	**182**	156	170	2	**167**	**188**

Figure A-58 Impact Sheet Pile 4- Peak Sound Pressure, Pa

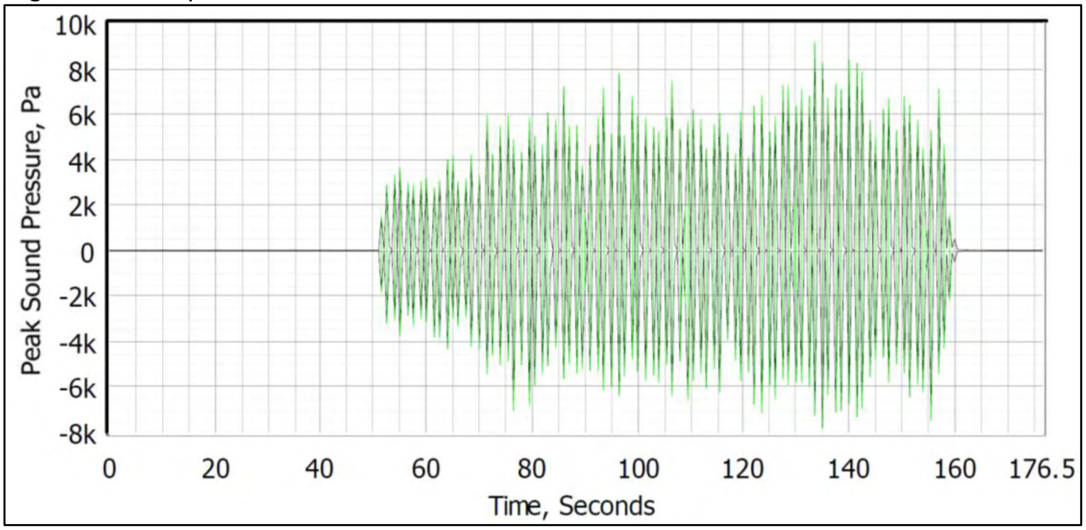


Figure A-59 Impact Sheet Pile 4 – Underwater Frequency Spectra, dB re: 1 μPa

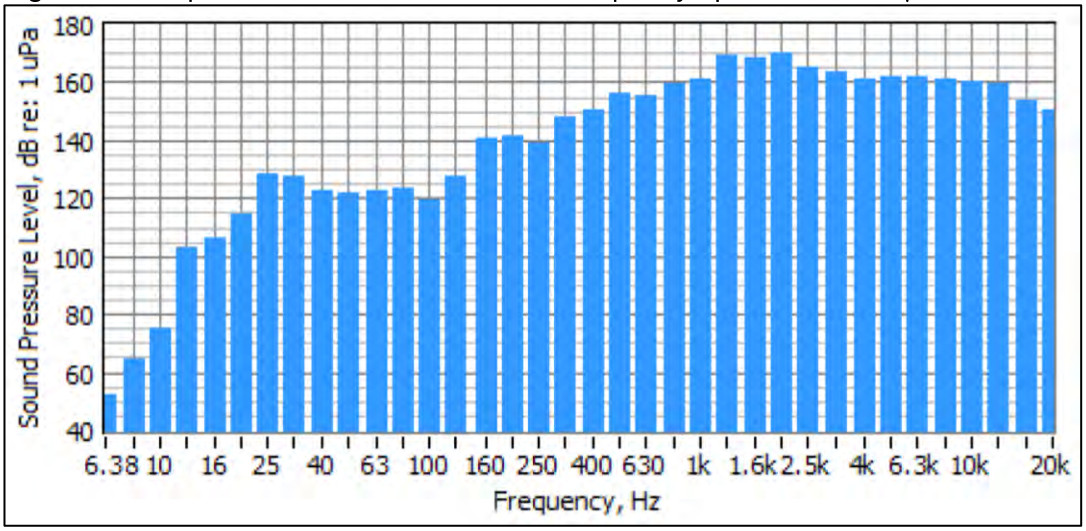
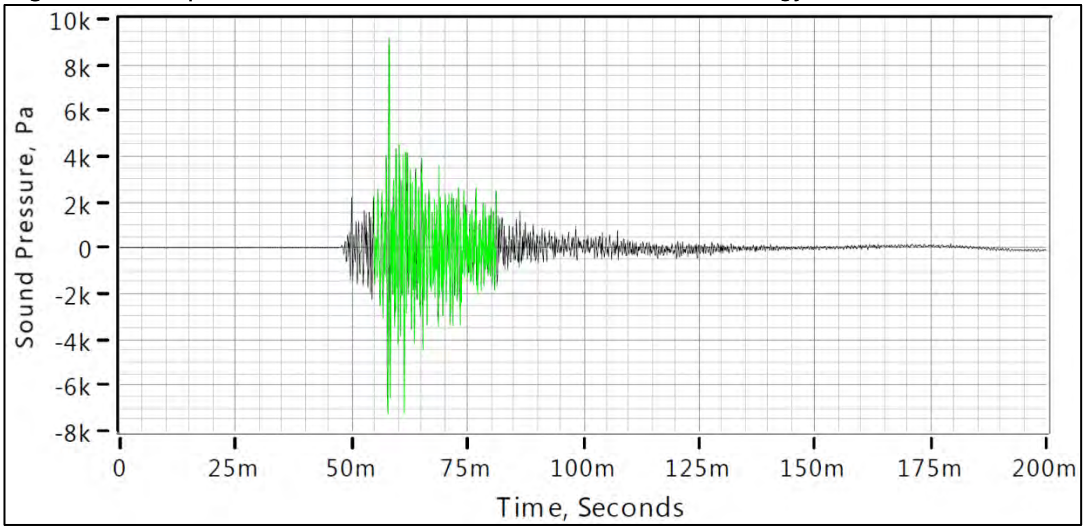


Figure A-60 Impact Sheet Pile 4 - Peak Waveform and 90% Energy, Pa



IMPACT SHEET PILE 5

January 11, 2017

Table A-43 Impact Sheet Pile 5 - Hydrophone and Pile Information

Number of Strikes	Sound Attenuation	Hydro Depth (Feet)	Distance (Feet)			Water Depth (Feet)		
			Between Hydros	Hydro to Pile	Water's Edge	Hydros	Pile	Depth into Substrate
135	None	Upper: 3 Lower: 9	6	32	3	12	9	≥31

Table A-44 Impact Sheet Pile 5 – Airborne Sound Levels, dB re: 20 μPa

Pile ID	Minimum	Maximum	Average
IMP-5	96	112	109

Figure A-61 Impact Pile 5 Airborne 1-second RMS

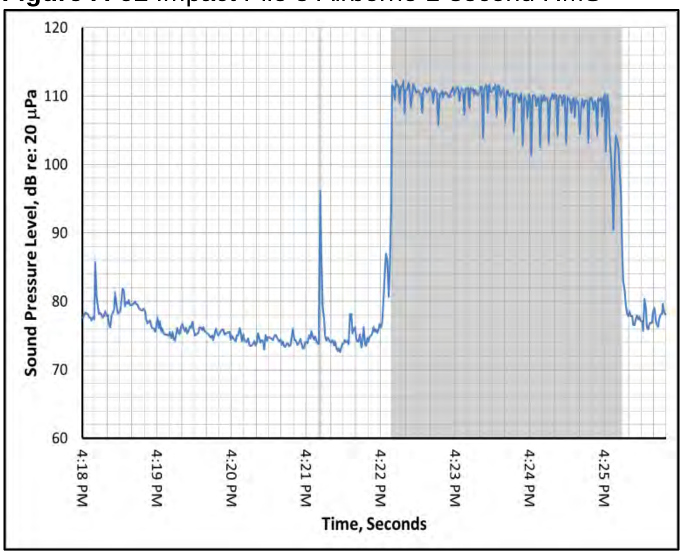


Figure A-62 Impact Pile 5 Airborne Spectra

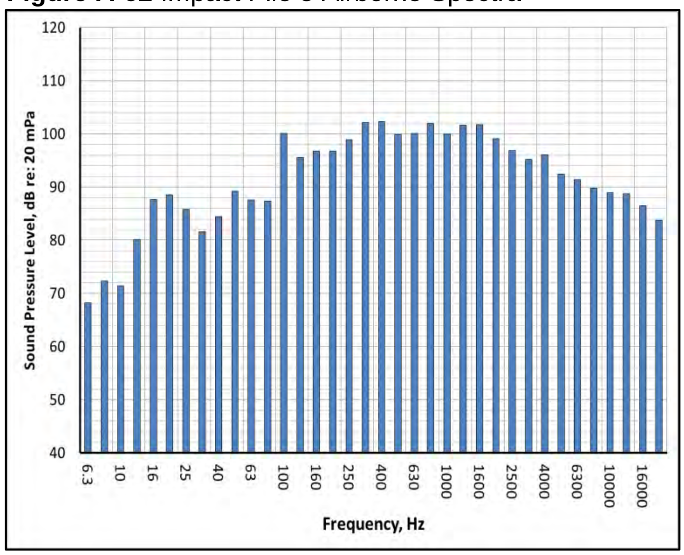


Table A-45 Impact Sheet Pile 5 – Underwater Sound Levels, dB re: 1 μPa

Pile ID	Frequency Range	Peak				RMS_{90}				SEL				cSEL
		Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	
IMP-5	7 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	75 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	150 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**
	200 Hz-20 kHz	180	198	2	**194**	166	183	2	**181**	151	168	2	**166**	**188**

Figure A-63 Impact Sheet Pile 5- Peak Sound Pressure, Pa

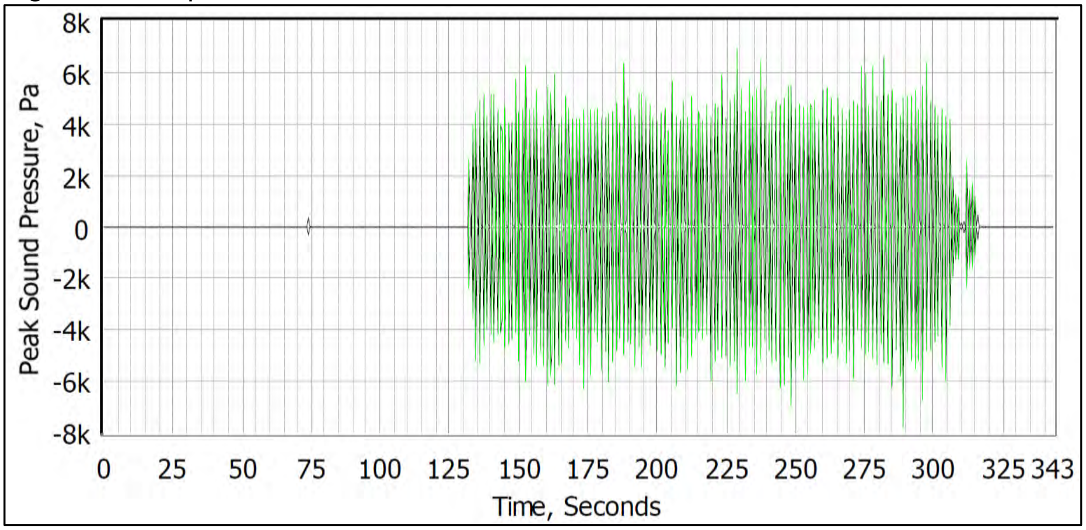


Figure A-64 Impact Sheet Pile 5 – Underwater Frequency Spectra, dB re: 1 μPa

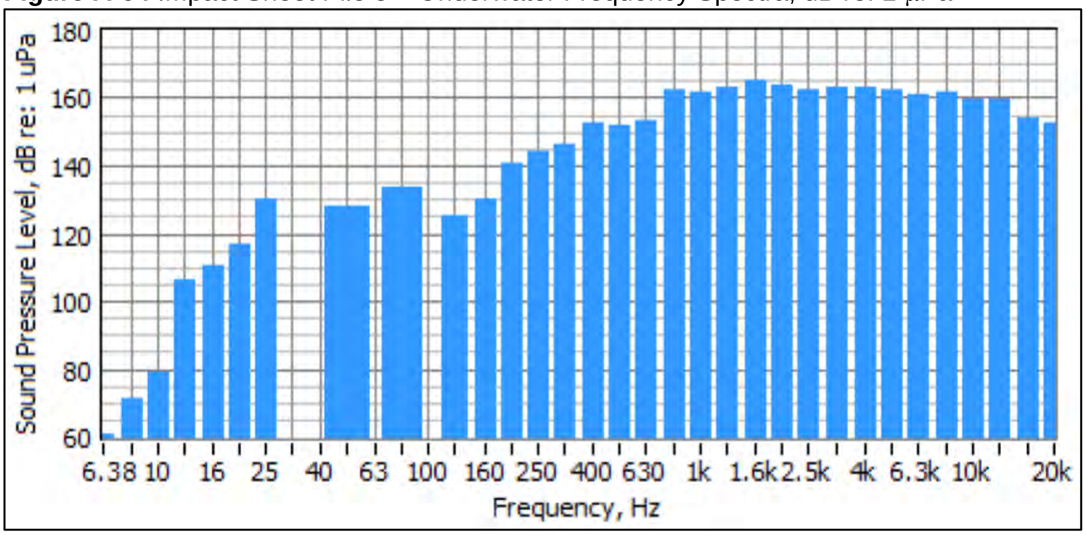
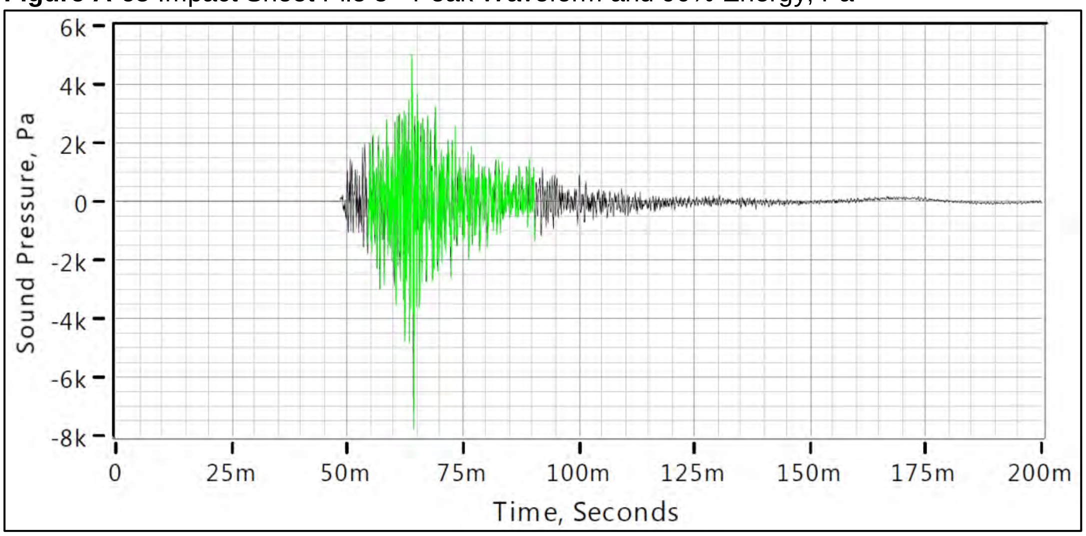


Figure A-65 Impact Sheet Pile 5 - Peak Waveform and 90% Energy, Pa



4.0 PILE DRIVER INFORMATION

Figure A-66 APE Model 250 Variable Moment Vibratory Driver/Extractor Information

APE Model 250 Variable Moment Vibratory Driver Extractor

The Worlds Largest Provider of Foundation Construction Equipment

SPECIFICATIONS	DATA
Eccentric Moment	4,500 in-lbs (51.85 kgm)
Drive Force	269 tons (2,389 kN)
Frequency Maximum (VPM)	0 - 2,050 vpm
Max Line Pull	99 tons (881 kN)
Bare Hammer Weight w/o Clamp	15,400 lbs (6,985 kg)
Throat Width	14.00 in (36 cm)
Length	69.00 in (175 cm)
Height w/o Clamp	102.00 in (259 cm)

APE Model 765 Power Unit

SPECIFICATIONS	DATA
Engine Type	Caterpillar C18 Tier II
Horse Power	765 HP (563 kW)
Drive Pressure	0 - 4,500 psi (310 bar)
Drive Flow	220 gpm (833 lpm)
Clamp Pressure	4,800 psi (69,618 bar)
Clamp Flow	10 gpm (3 lpm)
Engine Speed	2,100 rpm
Weight	20,000 lbs (9,072 kg)
Length	152 in (385 cm)
Width	82 in (208 cm)
Height	94 in (239 cm)
Hydraulic Reservoir	450 gal (1,703 L)
Fuel Capacity	150 gal (568 L)

Specifications may vary due to site conditions, specific hammer conditions or product set up.
Specifications may change without notice.
Consult the factory for details on any specific product (800) 248-8498.

WWW.APEVIBRO.COM
(800) 248-8498
webmaster@apevibro.com

Figure A-67 APE Model D50-52 Single Acting Diesel Impact Hammer Information

APE Model D50-52 Single Acting Diesel Impact Hammer

D50-52 in a stand-off

MODEL D50-52 (5.0 metric ton ram)

SPECIFICATIONS

Stroke at maximum rated energy	135 in (343 cm)
Maximum rated energy (Setting 4)	124,031 ft-lbs (167.44 kNm)
Setting 3	102,946 ft-lbs (138.98 kNm)
Setting 2	81,861 ft-lbs (110.51 kNm)
Minimum rated energy (Setting 1)	60,775 ft-lbs (82.05 kNm)

(Variable throttle allows for infinite fuel settings)

Maximum obtainable stroke	150 in (381 cm)
Maximum obtainable energy	144,243 ft-lbs (196 kNm)
Speed (blows per minute)	34-53

WEIGHTS (Approximate)

Ram	11,025 lbs (5,000 kg)
Anvil	2,255 lbs (1,023 kg)
Anvil cross sectional area	367.94 in² (2373.80 cm²)
Hammer weight (includes trip device)	25,882 lbs (11,737 kg)
Typical operating (weight with DB32 and pipe insert)	31,184 lbs (14,142 kg)

CAPACITIES

Fuel tank (runs on diesel or bio-diesel)	23.1 gal (87.4 liters)
Oil tank	4.4 gal (16.65 liters)

CONSUMPTION

Diesel or Bio-diesel fuel	4.16 gal/hr (16 liters/hr)
Lubrication	0.39 gal/hr (1.47 liters/hr)
Grease	8 to 10 pumps every 20 minutes of operation time.

Optional Variable Throttle Control.

STRIKER PLATE

Weight	1,036 lbs (470 kg)
Diameter	25 in (63.5 cm)
Area	491 in² (3167.74 cm²)
Thickness	8 in (20.32 cm)

CUSHION MATERIAL

Type/Qty	Micarta / 2 each
Diameter	25 in (63.5 cm)
Thickness	1 in (25.4 mm)

Type/Qty	Aluminum / 3 each
Thickness	1/2 in (12.7 mm)
Diameter	25 in (63.5 cm)
Total Combined Thickness	3.5 in (8.89 cm) 491 in²
Area	(3167.74 cm²)
Elastic-modulus	285 ksi (1,965 mpa)
Coeff. of restitution	0.8

Drive Base Assembly.

DRIVE CAP

DB 32:	2,436 lbs (1,104 kg)

INSERT WEIGHT

H-Beam insert for 12" (305 mm) and 14" (355 mm):	948 lbs (430 kg)
Large pipe insert for sizes 12" to 24" diameter:	1,830 lbs (830 kg)

MINIMUM BOX LEAD SIZE / OPERATING LENGTH

Minimum box leader size	8 in x 32 in (20.32 cm x 81.28 cm)
Operating length as described above	354 in (900 cm)

AMERICAN PILEDRIVING EQUIPMENT, INC.

Corporate Offices
7032 South 196th
Kent, Washington 98032 USA
(800) 248-8498 & (253) 872-0141
(253) 872-8710 Fax

Visit our WEB site:
www.apevibro.com
e-mail: ape@apevibro.com

APPENDIX B

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

Hydroacoustic data collected during Season 4 of the Elliott Bay Seawall Project was processed using previous Guidance Documents issued by NOAA dated January 31, 2012 as well as updated technical guidance issued in July, 2016 for determining the effects of underwater sound on marine mammals. This Appendix presents the analysis results from Season 4 under the updated guidance

2.0 UPDATED REGULATORY CRITERIA

In July, 2016 NOAA issued updated technical guidance for determining the effects of underwater sound on marine mammals titled “Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing”. This Technical Guidance divides marine mammals into five hearing groups. These hearing groups are summarized in Table A-1.

Table A-1 Marine Mammal Hearing Groups

Hearing Group	Generalized Hearing Range
Low-frequency (LF) cetaceans (baleen whales)	7 Hz – 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whaled, bottlenose whales)	150 Hz – 160 kHz
High-frequency (HF) cetaceans (true porpoise, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger & L. australis*)	275 Hz – 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz – 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz -39 kHz

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, July, 2016

The Technical Guidance utilizes dual threshold criteria for injury from impulsive sounds. These criteria are peak sound pressure and cSEL values accumulated over a 24-hour period. The peak sound pressure criteria are unweighted and the cSEL values are frequency-weighted for each marine mammal hearing group. Injury criteria from non-impulsive sound (i.e. vibratory pile driving) include only the 24-hour cSEL criteria. Injury thresholds provided in the updated Technical Guidance are summarized in Table A-2.

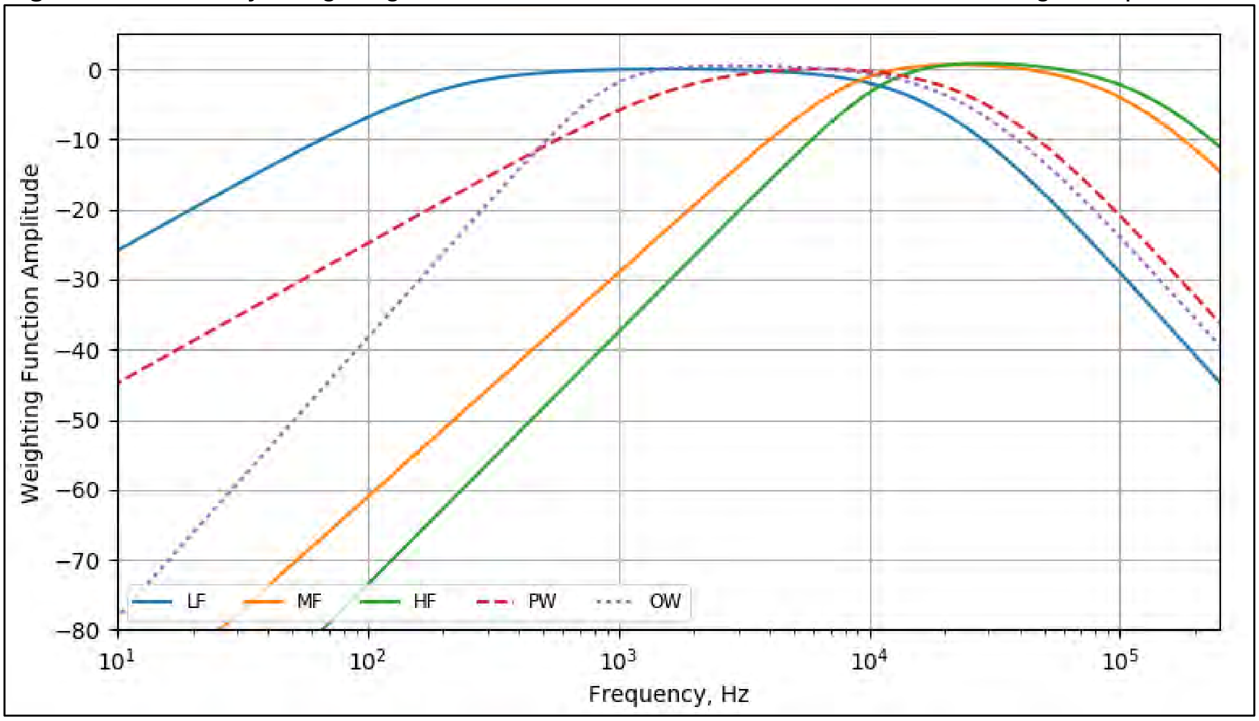
Table A-2 Injury Thresholds, dB re: 1 μPa

Hearing Group	Impulsive		Non-Impulsive
	Peak (unweighted)	cSEL (weighted)	cSEL (weighted)
Low-frequency (LF) cetaceans	219	183	199
Mid-frequency (MF) cetaceans	230	185	198
High-frequency (HF) cetaceans	202	155	173
Phocid pinnipeds (PW) (underwater)	218	185	201
Otariid pinnipeds (OW) (underwater)	232	203	219

Source: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing, July, 2016

The auditory weighting functions for each of the marine mammal functional hearing groups are illustrated in Figure A-1.

Figure A-1 Auditory Weighting Functions for Marine Mammal Functional Hearing Groups



3.0 ANALYSIS

All hydroacoustic data recorded during impact and vibratory pile driving was recorded at a sample rate of 96,000 samples per second. Data was analyzed to determine the range, median and standard deviation of SEL and peak values during periods of full power pile driving. Reported maximum and minimum values are the maximum or minimum value from either of the two hydrophones located approximately 10 meters away from pile driving. The standard deviation and median values were calculated using decibel values from both hydrophones.

SEL values reported from vibratory pile driving were calculated from 10-second blocks of data as required by the Project's LOA. Data was filtered for each marine mammal functional hearing group prior to calculating the SEL values. The cSEL levels were calculated from individual SEL levels and only the highest cSEL from either of the two hydrophones located approximately 10 meters from the pile is reported. Peak levels are unweighted and are included for vibratory pile driving for informational purposes only.

Reported SEL values from impact pile driving were calculated from 200-millisecond blocks of data and are weighted for each marine mammal hearing group. Peak sound levels are unweighted.

4.0 RESULTS

Time histories of each pile drive and the frequency spectra associated with the highest SEL value for each marine mammal functional hearing group are at the end of this Report. A summary of underwater sound levels produced by the removal of the first five concrete piles on December 27, 2016 is provided in Table A-3.

Table A-3 Underwater Sound Levels from Concrete Pile Removal, dB re: 1 μPa

Pile ID	Hearing Group	cSEL	SEL				Peak			
			Min	Max	SD	Avg	Min	Max	SD	Avg
REM-1	Low-Frequency (LF) Cetaceans	157	127	144	4	137	148	157	3	153
	Mid-Frequency (MF) Cetaceans	162	134	150	4	141				
	High-Frequency (HF) Cetaceans	164	136	151	4	143				
	Phocid Pinnipeds (PW)	151	124	137	3	131				
	Otariid Pinnipeds (OW)	152	122	138	4	132				
REM-2	Low-Frequency (LF) Cetaceans	157	128	144	4	135	146	164	4	156
	Mid-Frequency (MF) Cetaceans	167	134	154	3	140				
	High-Frequency (HF) Cetaceans	169	135	156	4	142				
	Phocid Pinnipeds (PW)	154	125	140	4	131				
	Otariid Pinnipeds (OW)	154	125	139	3	133				
REM-3	Low-Frequency (LF) Cetaceans	154	120	145	4	135	144	167	5	152
	Mid-Frequency (MF) Cetaceans	163	130	154	4	140				
	High-Frequency (HF) Cetaceans	164	132	156	4	142				
	Phocid Pinnipeds (PW)	150	119	139	3	130				
	Otariid Pinnipeds (OW)	150	118	140	3	131				
REM-4	Low-Frequency (LF) Cetaceans	149	124	136	2	134	146	163	4	149
	Mid-Frequency (MF) Cetaceans	156	131	149	4	140				
	High-Frequency (HF) Cetaceans	157	132	151	4	142				
	Phocid Pinnipeds (PW)	144	123	134	2	129				
	Otariid Pinnipeds (OW)	144	122	134	2	129				
REM-5	Low-Frequency (LF) Cetaceans	157	132	142	2	140	150	173	3	155
	Mid-Frequency (MF) Cetaceans	164	138	151	3	147				
	High-Frequency (HF) Cetaceans	166	140	152	3	149				
	Phocid Pinnipeds (PW)	152	130	140	2	135				
	Otariid Pinnipeds (OW)	151	128	140	2	134				

A summary of underwater sound levels produced by the vibratory installation of the first five steel sheet pile driven on December 28, 2016 is provided in Table A-4.

Table A-4 Underwater Sound Levels from Vibratory Pile Driving, dB re: 1 μPa

Pile ID	Hearing Group	cSEL	SEL				Peak			
			Min	Max	SD	Avg	Min	Max	SD	Avg
VIB-1	Low-Frequency (LF) Cetaceans	181	139	165	6	156	156	179	5	168
	Mid-Frequency (MF) Cetaceans	180	138	165	6	155				
	High-Frequency (HF) Cetaceans	181	139	166	6	156				
	Phocid Pinnipeds (PW)	179	139	164	6	155				
	Otariid Pinnipeds (OW)	181	140	165	6	156				
VIB-2	Low-Frequency (LF) Cetaceans	171	128	158	6	151	149	173	5	162
	Mid-Frequency (MF) Cetaceans	171	130	158	6	150				
	High-Frequency (HF) Cetaceans	172	131	159	6	151				
	Phocid Pinnipeds (PW)	169	126	157	6	149				
	Otariid Pinnipeds (OW)	171	128	158	6	151				
VIB-3	Low-Frequency (LF) Cetaceans	175	130	159	5	152	154	173	4	164
	Mid-Frequency (MF) Cetaceans	175	132	159	5	152				
	High-Frequency (HF) Cetaceans	176	133	161	5	152				
	Phocid Pinnipeds (PW)	172	129	157	5	150				
	Otariid Pinnipeds (OW)	174	130	159	5	151				
VIB-4	Low-Frequency (LF) Cetaceans	172	137	158	4	151	154	171	4	163
	Mid-Frequency (MF) Cetaceans	171	137	158	4	150				
	High-Frequency (HF) Cetaceans	172	138	158	4	150				
	Phocid Pinnipeds (PW)	170	135	157	4	150				
	Otariid Pinnipeds (OW)	172	137	158	4	152				
VIB-5	Low-Frequency (LF) Cetaceans	176	139	163	5	156	155	178	5	169
	Mid-Frequency (MF) Cetaceans	175	138	162	5	155				
	High-Frequency (HF) Cetaceans	175	139	162	5	156				
	Phocid Pinnipeds (PW)	174	138	161	5	154				
	Otariid Pinnipeds (OW)	175	139	162	5	155				

A summary of near field underwater sound levels produced during impact pile driving on January 11, 2017 is provided in Table A-5. Time histories of each pile driven with the impact hammer as well as the pile strike producing the highest absolute peak sound pressure and the frequency spectra associated with this pile strike for each marine mammal functional hearing group are provided at the end of this Report.

Table A-5 Underwater Sound Levels from Impact Pile Driving, dB re: 1 μPa

Pile ID	Hearing Group	cSEL	SEL				Peak			
			Min	Max	SD	Avg	Min	Max	SD	Avg
IMP-1	Low-Frequency (LF) Cetaceans	164	138	152	2	147	175	189	3	183
	Mid-Frequency (MF) Cetaceans	165	140	154	3	147				
	High-Frequency (HF) Cetaceans	165	140	154	3	148				
	Phocid Pinnipeds (PW)	163	137	152	2	146				
	Otariid Pinnipeds (OW)	165	138	153	2	148				
IMP-2	Low-Frequency (LF) Cetaceans	170	145	155	2	151	183	191	2	187
	Mid-Frequency (MF) Cetaceans	170	147	155	1	152				
	High-Frequency (HF) Cetaceans	171	148	155	1	152				
	Phocid Pinnipeds (PW)	170	145	154	2	151				
	Otariid Pinnipeds (OW)	171	146	155	2	152				
IMP-3	Low-Frequency (LF) Cetaceans	175	147	157	1	154	183	197	2	192
	Mid-Frequency (MF) Cetaceans	177	150	160	1	155				
	High-Frequency (HF) Cetaceans	177	150	160	1	155				
	Phocid Pinnipeds (PW)	175	147	157	1	154				
	Otariid Pinnipeds (OW)	176	148	158	1	154				
IMP-4	Low-Frequency (LF) Cetaceans	177	147	160	2	157	183	199	3	194
	Mid-Frequency (MF) Cetaceans	177	146	160	2	157				
	High-Frequency (HF) Cetaceans	178	146	160	2	157				
	Phocid Pinnipeds (PW)	176	145	159	2	156				
	Otariid Pinnipeds (OW)	178	147	160	2	157				
IMP-5	Low-Frequency (LF) Cetaceans	178	141	158	2	156	178	197	3	193
	Mid-Frequency (MF) Cetaceans	179	141	160	3	157				
	High-Frequency (HF) Cetaceans	179	141	160	3	157				
	Phocid Pinnipeds (PW)	178	141	158	2	156				
	Otariid Pinnipeds (OW)	179	142	159	2	157				

4.1 Vibratory Concrete Pile Removal

Figure A-2 Concrete Pile 1

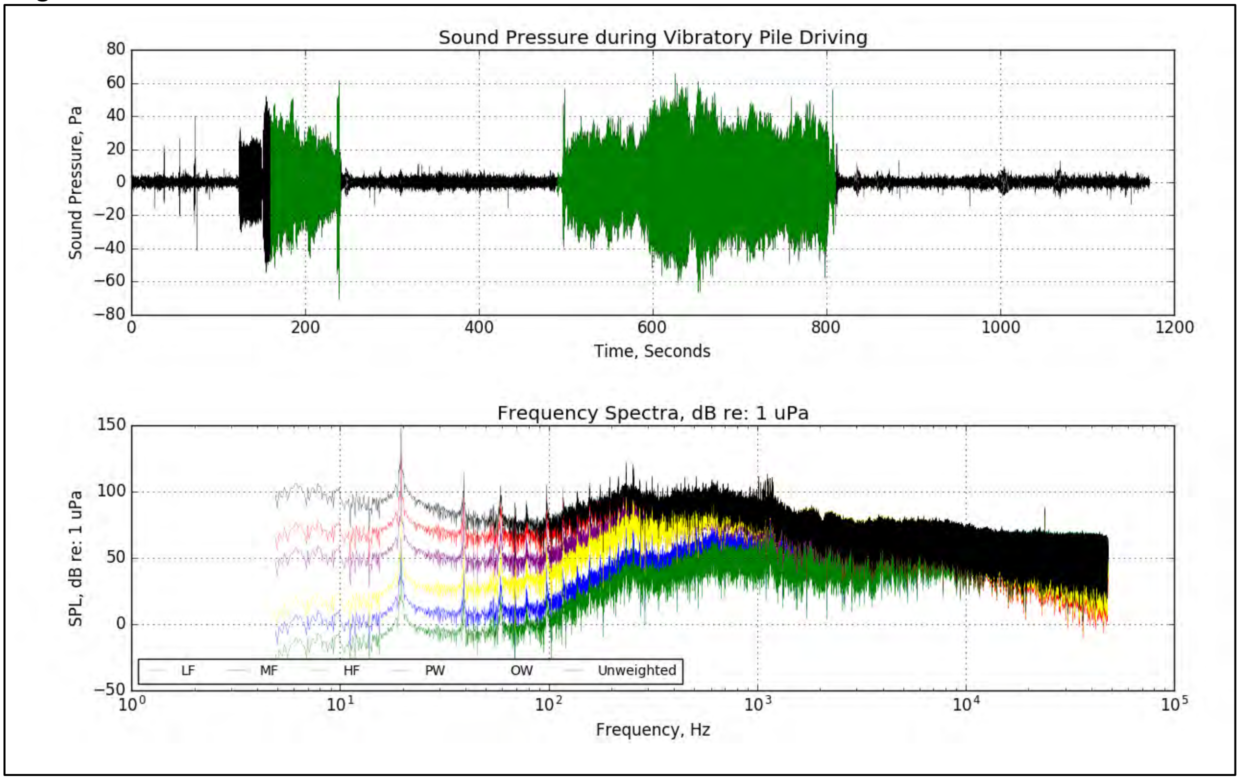


Figure A-3 Concrete Pile 2

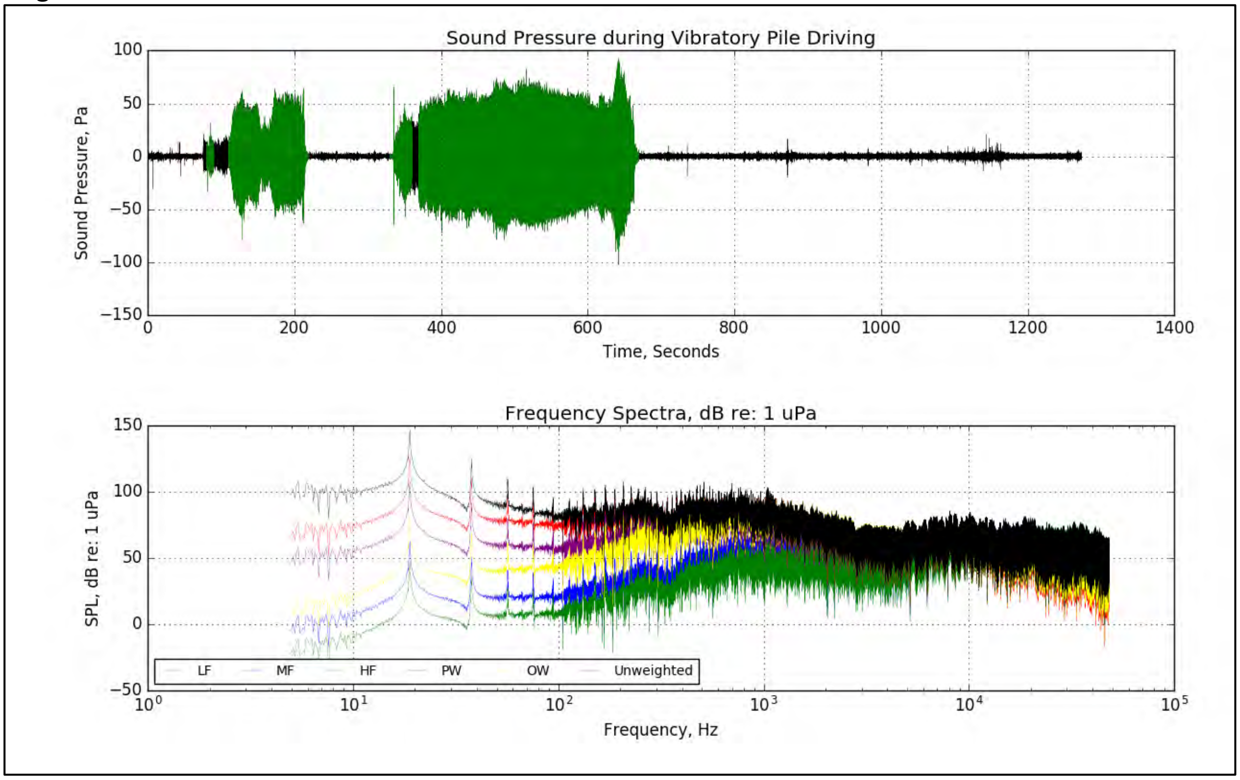


Figure A-4 Concrete Pile 3

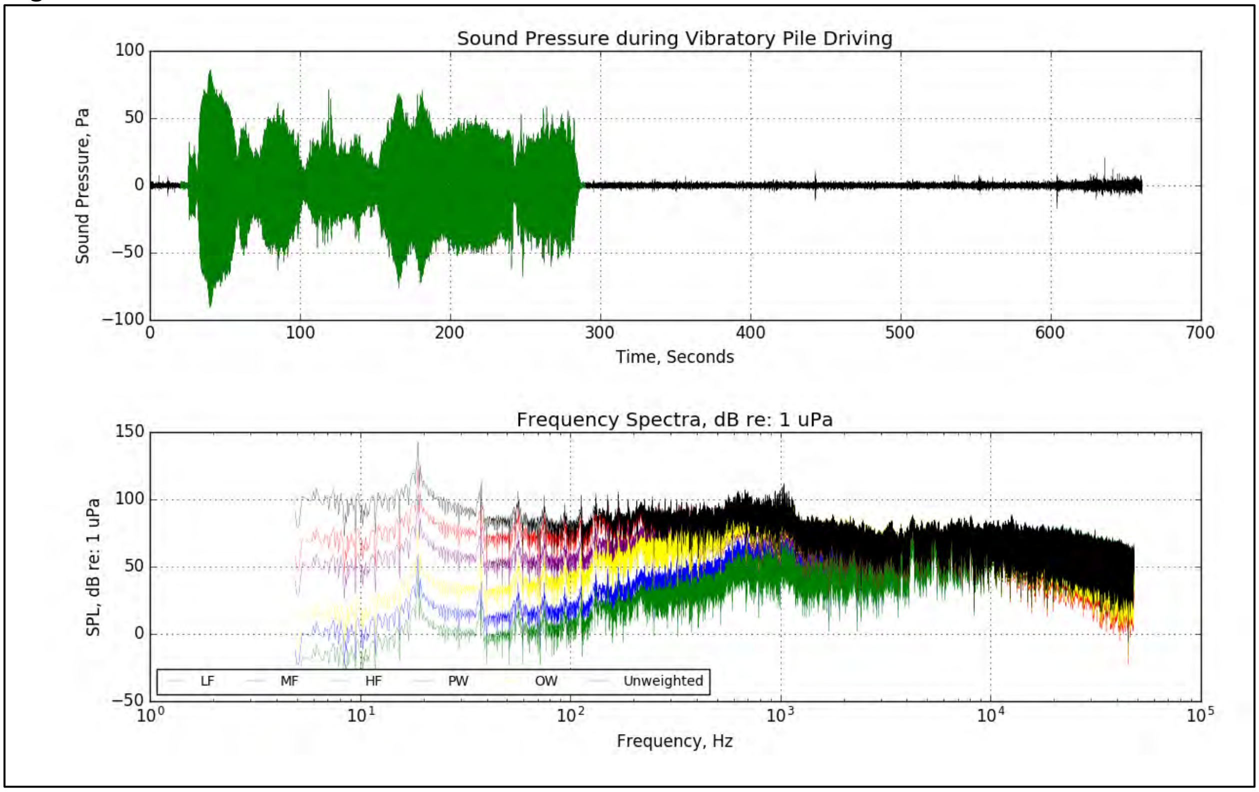


Figure A-5 Concrete Pile 4

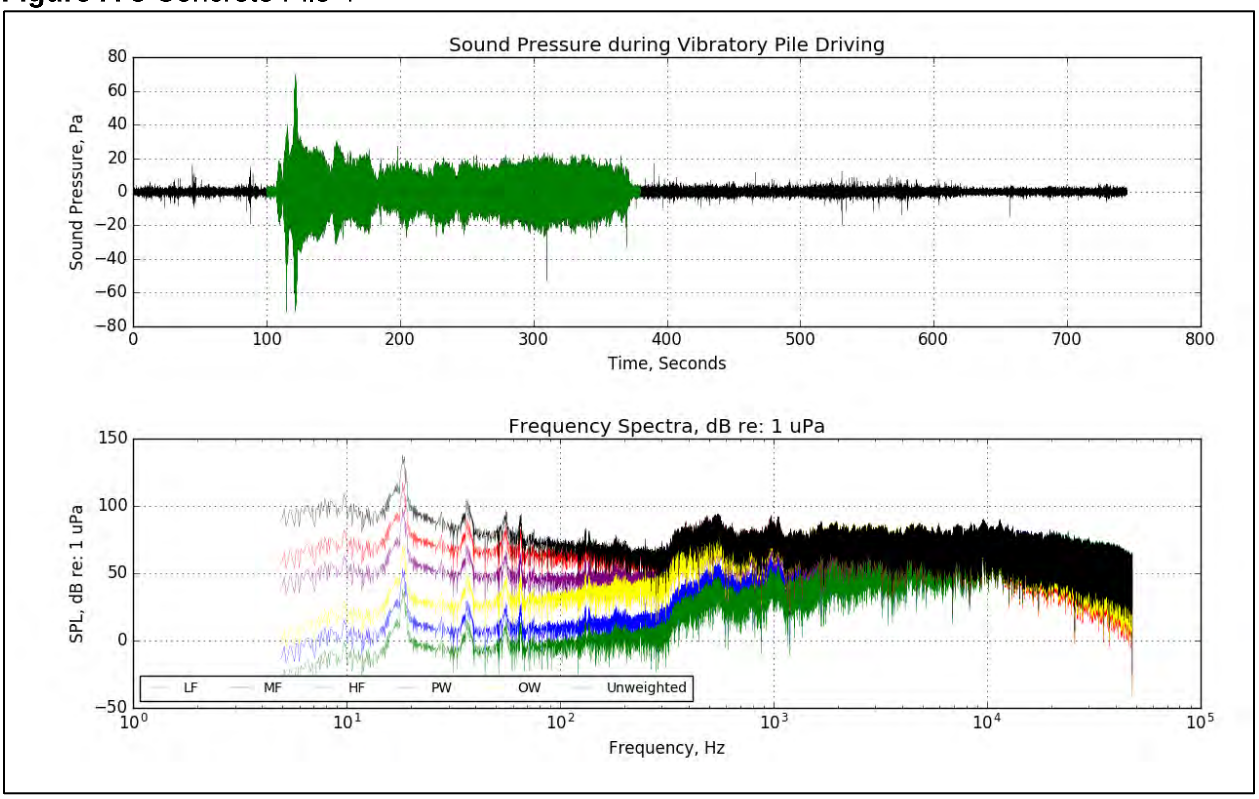
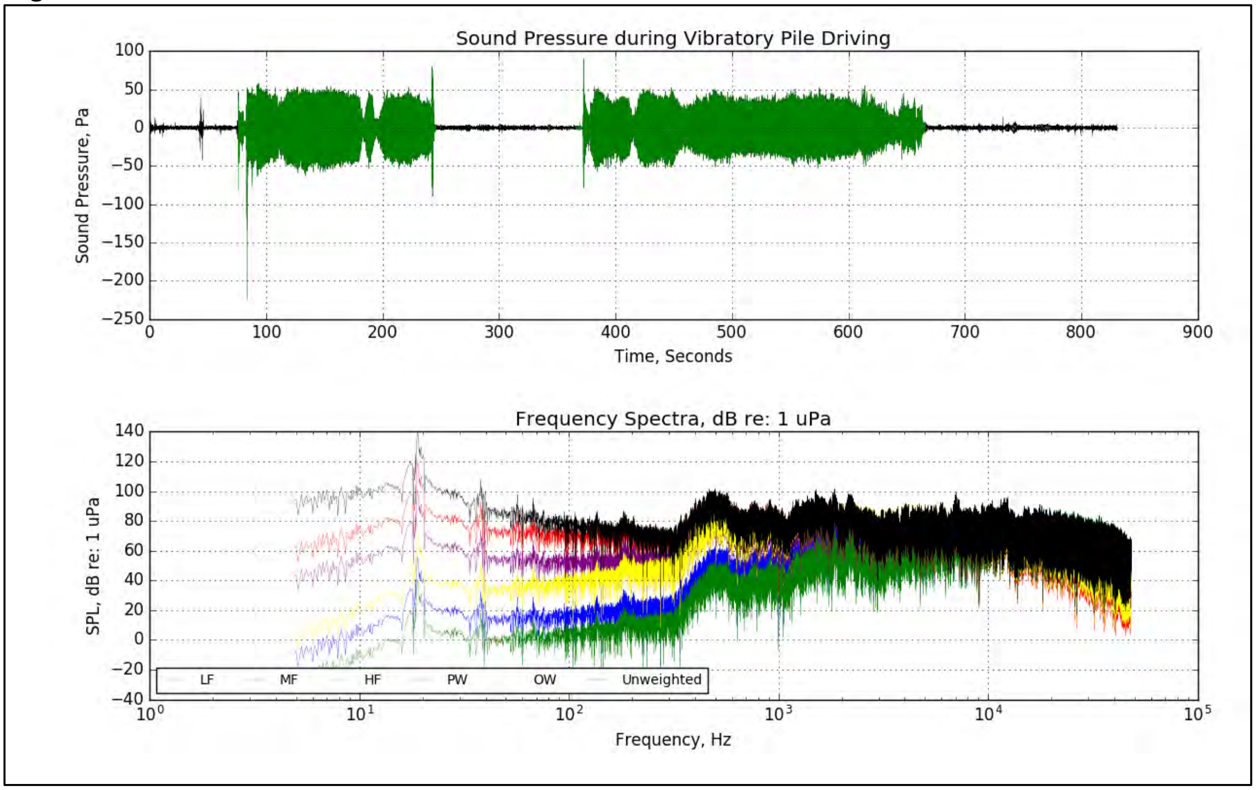


Figure A-6 Concrete Pile 5



4.2 Vibratory Sheet Pile Driving

Figure A-7 Vibratory Sheet Pile 1

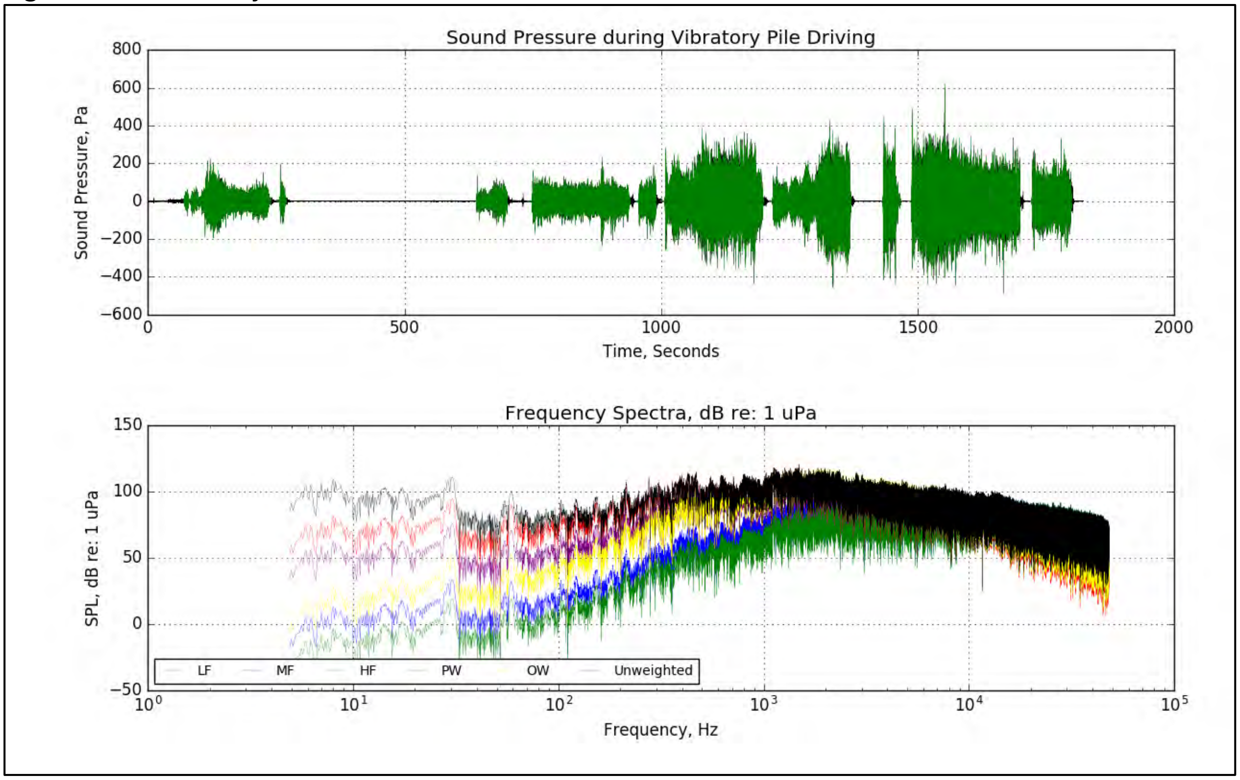


Figure A-8 Vibratory Sheet Pile 2

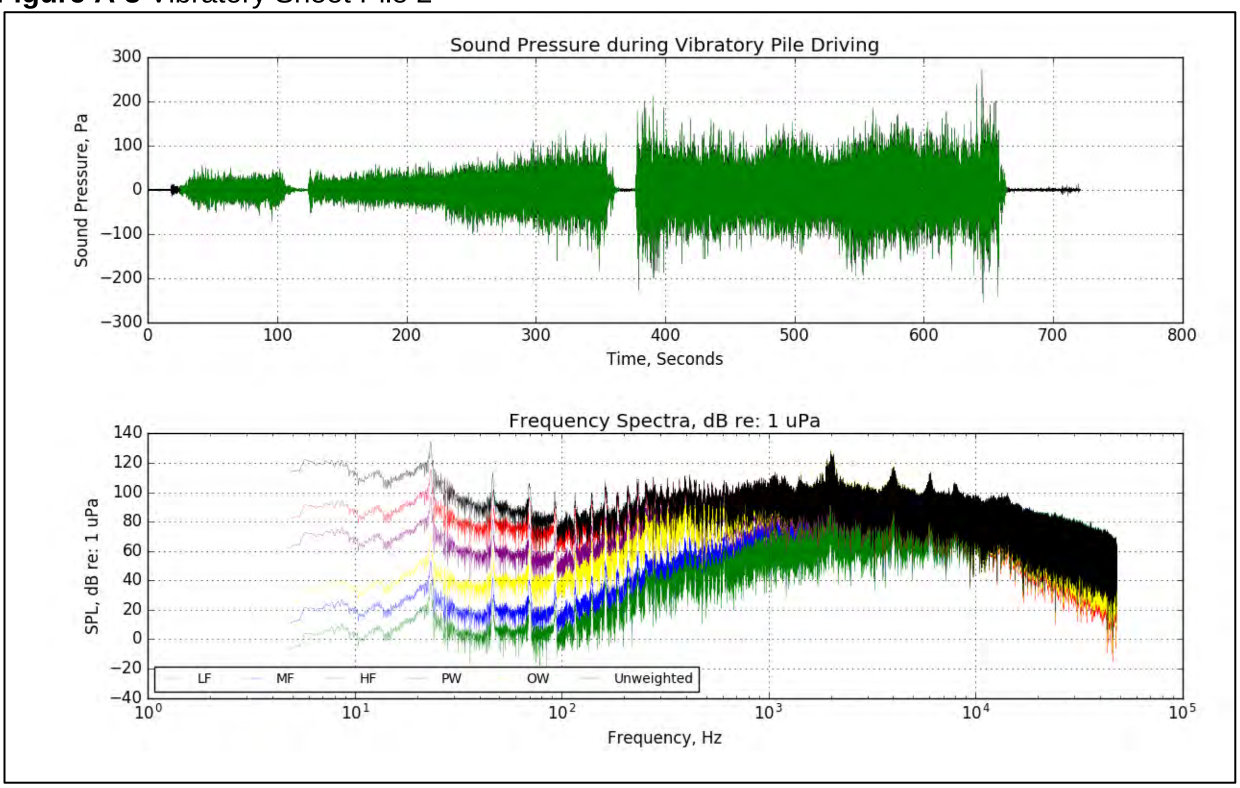


Figure A-9 Vibratory Sheet Pile 3

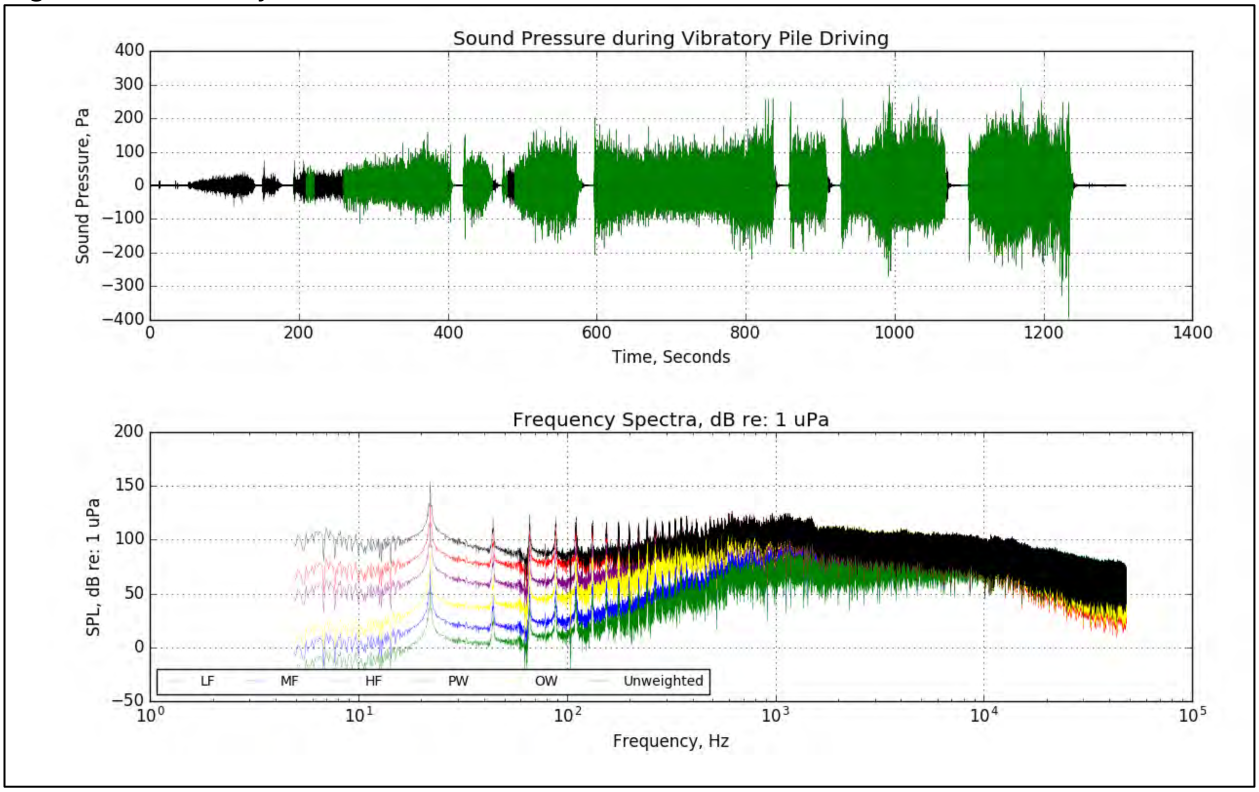


Figure A-10 Vibratory Sheet Pile 4

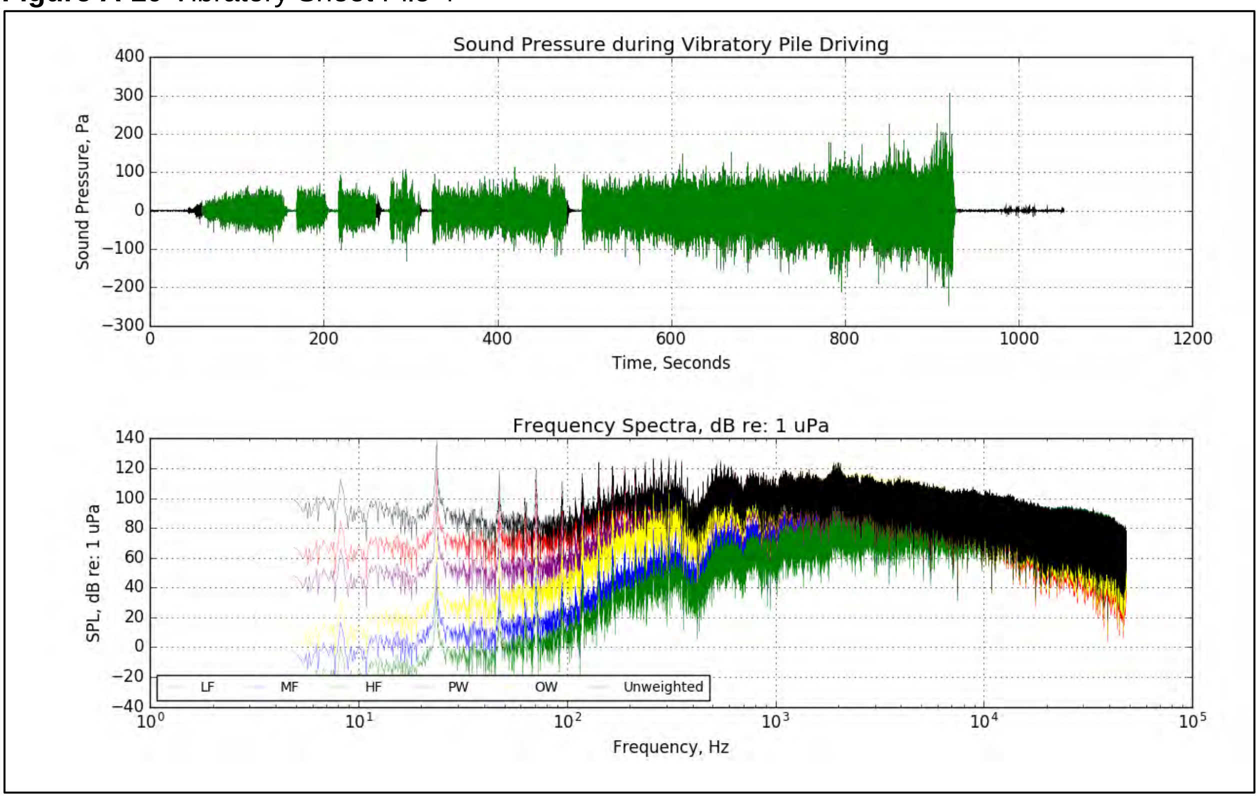
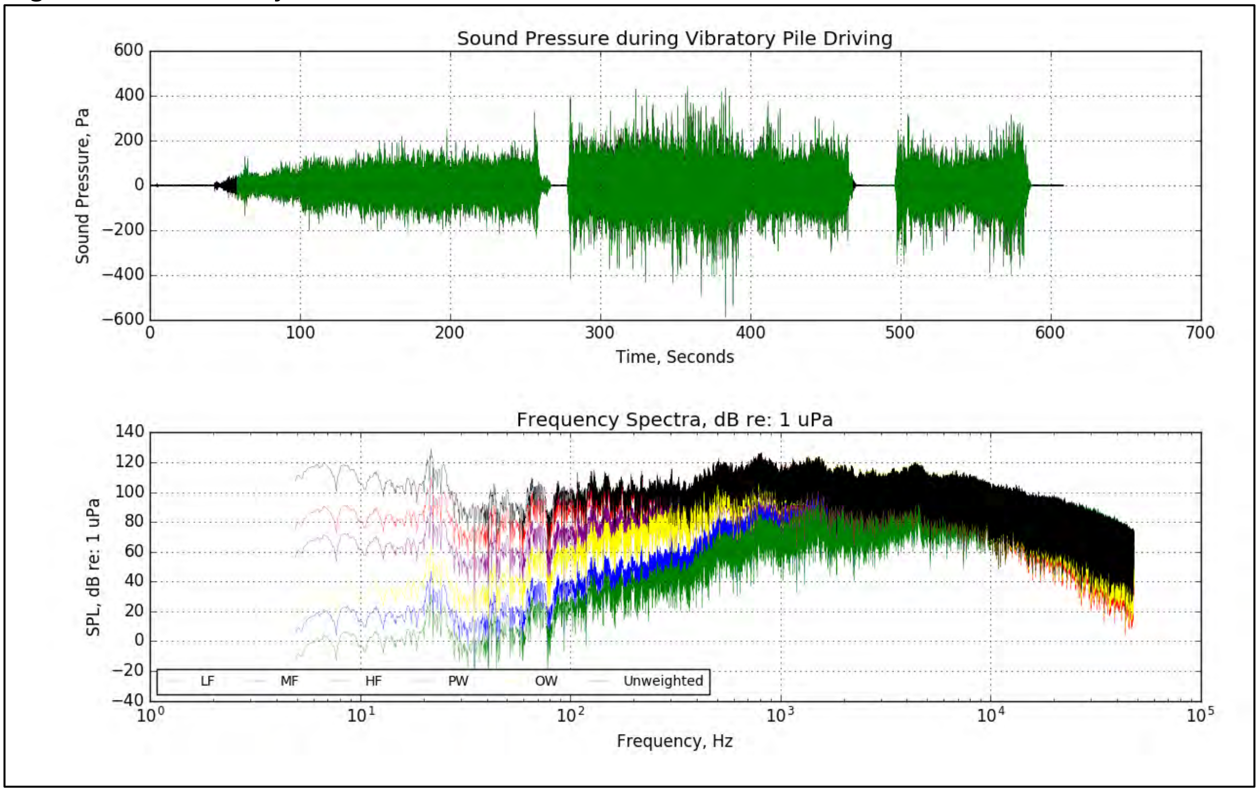


Figure A-11 Vibratory Sheet Pile 5



4.3 Impact Sheet Pile Driving

Figure A-12 Impact Sheet Pile 1

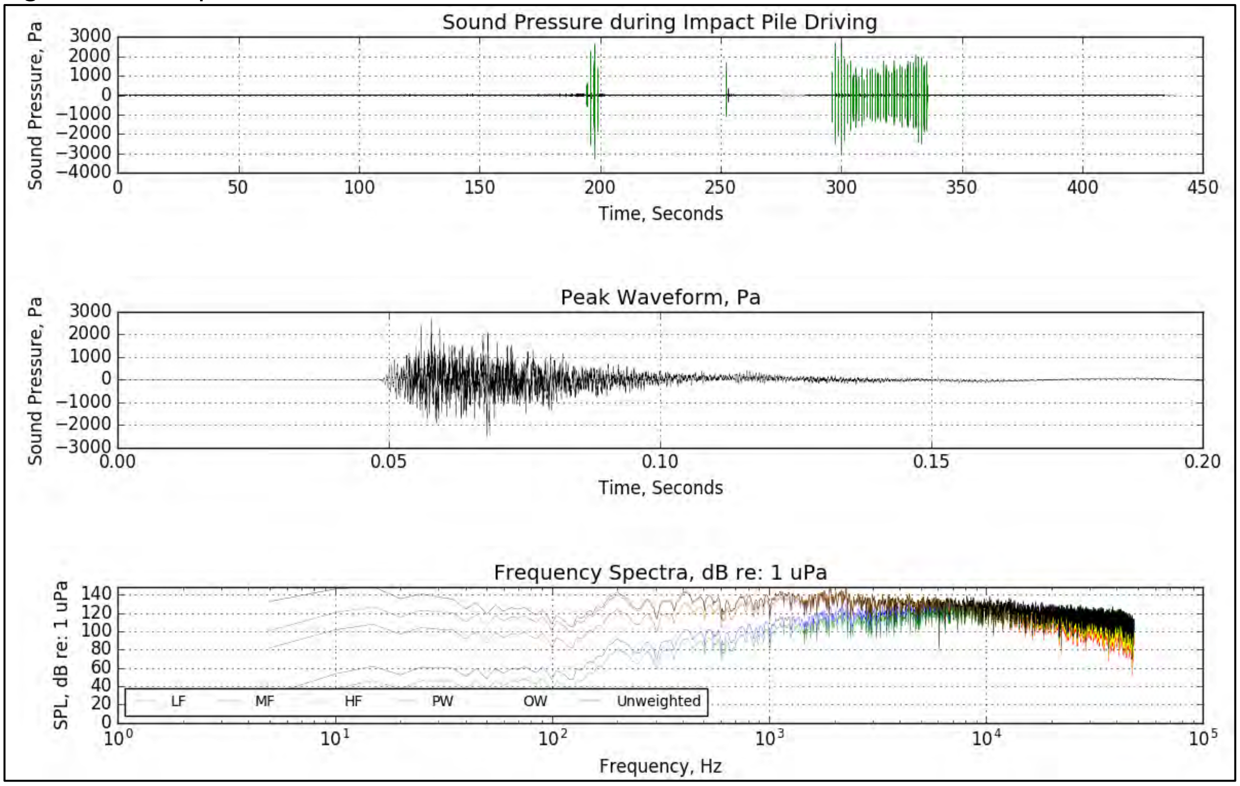


Figure A-13 Impact Sheet Pile 2

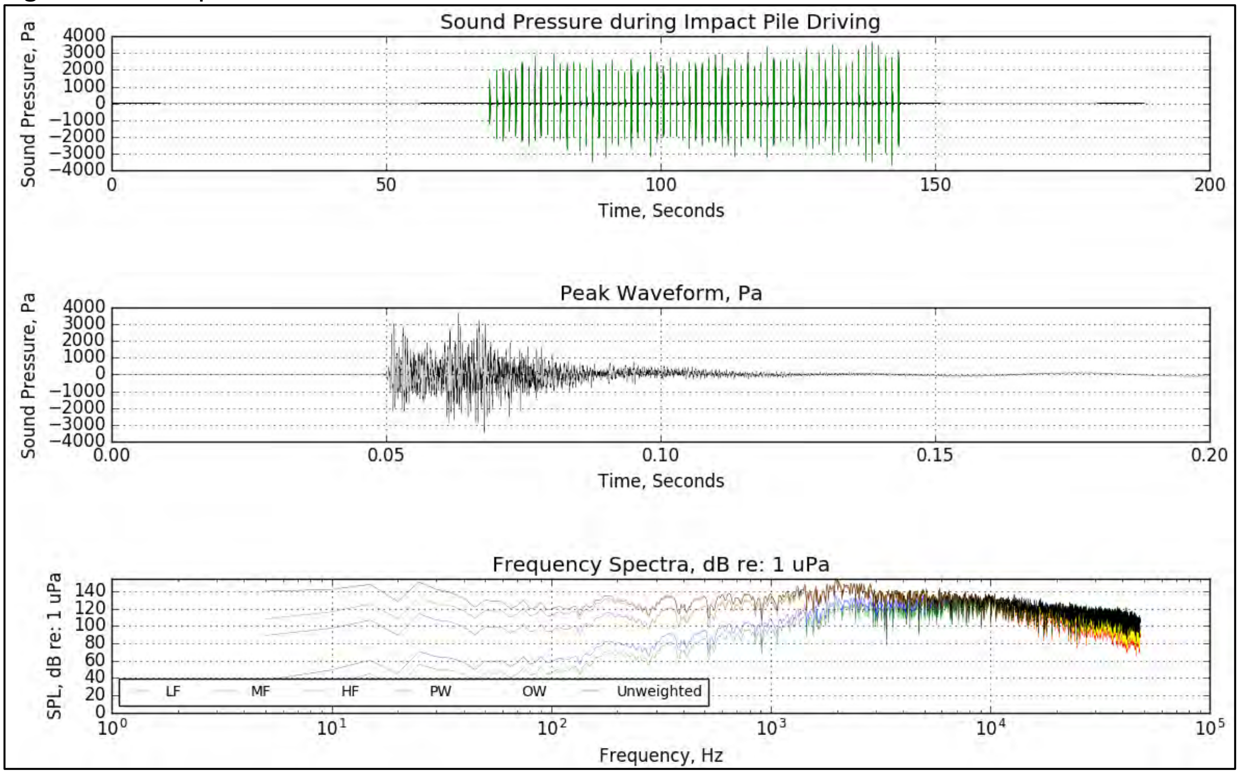


Figure A-14 Impact Sheet Pile 3

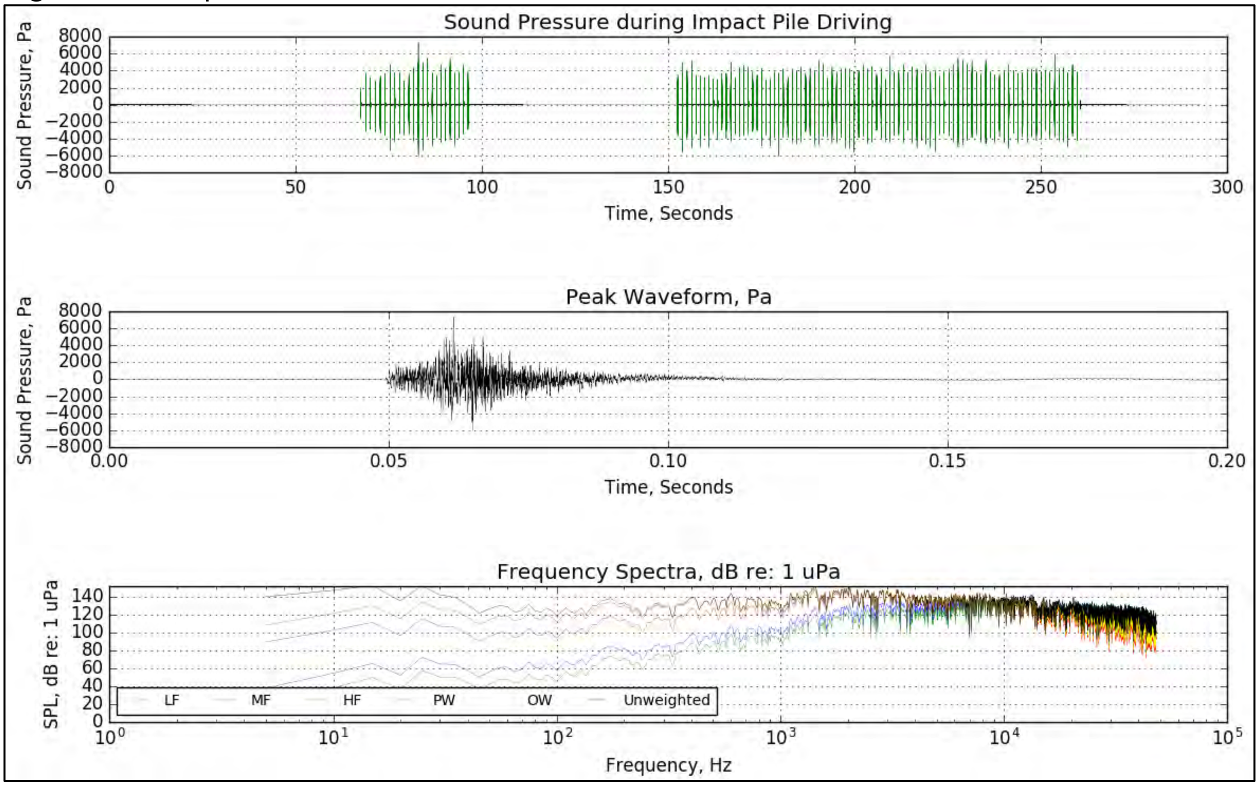


Figure A-15 Impact Sheet Pile 4

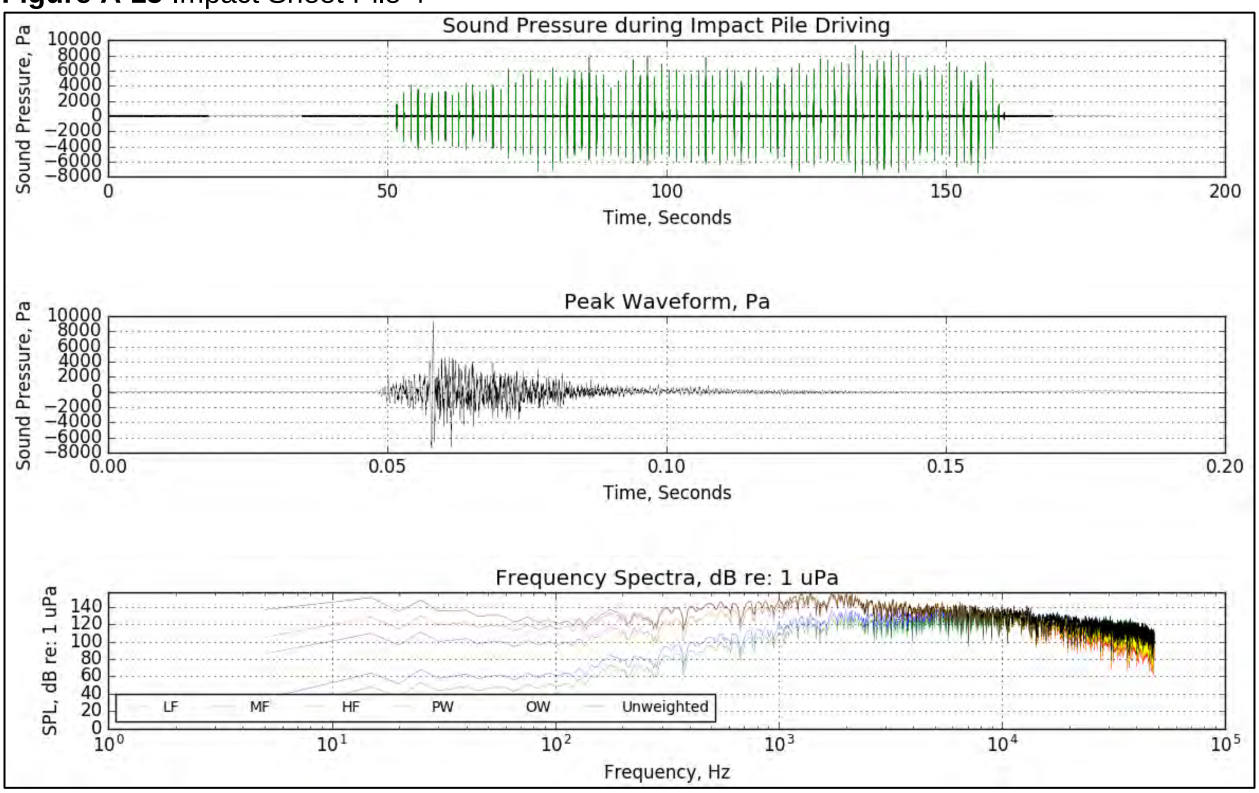


Figure A-16 Impact Sheet Pile 5