UNDERWATER VIBRATORY SOUND LEVELS FROM A STEEL AND PLASTIC ON STEEL PILE INSTALLATION AT THE ANACORTES FERRY TERMINAL

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

March 2012

Table of Contents

List of Tables i
List of Figures i
Executive Summary **1**
Introduction **2**
Project Description 2
Underwater Sound Levels **4**
Characteristics of Underwater Sound 4
Methodology **5**
Equipment 5
Calibration 6
Hydrophone Location 6
SEL 7
Results **8**
36-inch Piles 8
Plastic “Rubbing Piles” 12
Conclusions **16**
References **17**

List of Tables

Table 1: Underwater Monitoring Results, Anacortes Ferry Terminal Project. 1
Table 2: Summary of Underwater Sound Levels for the Anacortes Ferry Terminal Pile Project, 36-inch Steel Piles. 8
Table 3: Background Sound Level Results, Anacortes Ferry Terminal. 12
Table 4: Summary of Underwater Sound Levels for the Anacortes Ferry Terminal Pile Project, 36-inch Steel Piles. 12

List of Figures

Figure 1: Location of Anacortes Ferry Terminal Pile Project. 2
Figure 2: Approximate location of 36-inch piles, 13-inch piles and hydrophones at the Anacortes Ferry Terminal Pile Project. 3
Figure 3: Near field acoustical monitoring equipment 5
Figure 4: Diagram of hydrophone deployment configuration. 6
Figure 5: 1/3rd Octave frequency distribution for vibratory pile driving of Pile 1. 9
Figure 6: Cumulative SEL plot for Pile 1 showing the cumulative plot for SEL values calculated for the entire pile drive event (broadband vibratory). 9
Figure 7: 1/3rd Octave frequency distribution for vibratory pile driving of Pile 2. 10
Figure 8: Cumulative SEL plot for Pile 2 showing the cumulative plot for SEL values calculated for the entire pile drive event (broadband vibratory). 11
Figure 9: Cumulative SEL plot for both piles 1 and 2 showing the cumulative plot for SEL values calculated for both piles combined (broadband vibratory). 11
Figure 10: 1/3rd Octave frequency distribution for vibratory pile driving of Plastic Rubbing Piles. 14
Figure 11: Cumulative SEL plot for all plastic rubbing piles showing the cumulative plot for SEL values calculated for the all piles in one day (broadband vibratory). 14

EXECUTIVE SUMMARY

This technical report describes the data collected during vibratory pile driving of two 36-inch steel piles and four 13-inch plastic on steel piles for the Anacortes Ferry Terminal on February 6 and 10, 2012. Two 36-inch steel piles were vibratory driven as part of this project. Additionally four 13-inch steel piles with a plastic shell (plastic rubbing piles) were vibratory driven. The broadband RMS sound levels ranged between 168 dB_{RMS} and was 170 dB_{RMS} for the 36-inch piles and between 138 and 158 dB_{RMS} for the 13-inch plastic rubbing piles (Table 1).

Based on the highest average RMS broadband source level the distance to the 120 dB_{RMS} threshold is calculated to be 14.7 miles. However, since the background sound levels near the Anacortes Terminal collected in March of 2011 is 130 dB it will reach background levels before it reaches the 120 dB threshold at 3.2 miles for the 36-inch piles and 3.4 miles for the 13-inch plastic rubbing piles. Using the daytime only background sound levels of 133 dB broadband the distance to background becomes 2 miles for the 36-inch piles and 2.1 miles for the 13-inch plastic rubbing piles.

Table 1: Underwater Monitoring Results, Anacortes Ferry Terminal Project.

Pile	Date	Mitigation Type	Pile Diameter (inches)	Lower Frequency Range (Hz)	Average RMS (dB)	Cumulative SEL (dB re: 1μPa^2-sec)
1	2/6/12	None	36	Broadband	170	228
				7	170	228
				75	168	226
				150	165	223
				200	163	221
2	2/6/12	None	36	Broadband	168	220
				7	168	220
				75	166	218
				150	163	215
				200	162	214
1	2/10/12	None	13	Broadband	158	178
				7	158	178
				75	155	175
				150	152	171
				200	149	168
2	2/10/12	None	13	Broadband	141	171
				7	141	171
				75	140	170
				150	139	169
				200	138	168
3	2/10/12	None	13	Broadband	138	170
				7	138	170
				75	137	168
				150	135	167
				200	134	166
4	2/10/12	None	13	Broadband	145	167
				7	145	167
				75	143	165
				150	142	164
				200	141	163

INTRODUCTION

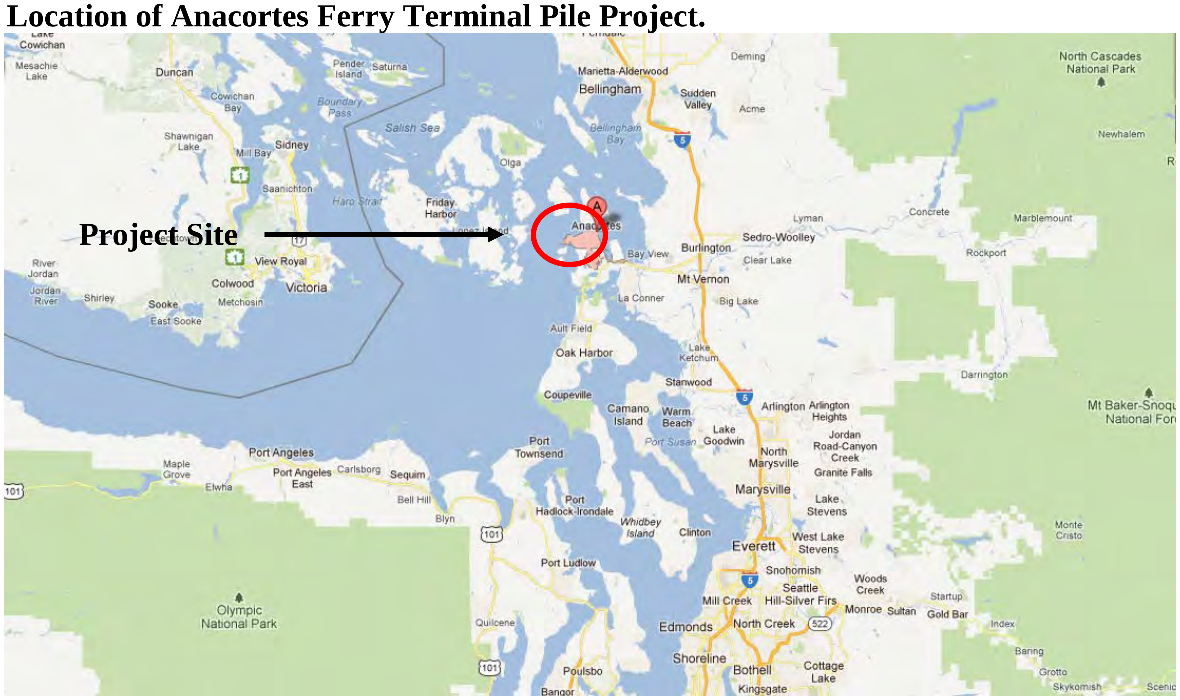
This technical report presents results of underwater sound levels measured during the vibratory driving of two 36-inch steel piles and four 13-inch plastic on steel piles at the Anacortes Ferry Terminal on February 6 and 10, 2012.

The two 36-inch steel piles were driven adjacent to a dolphin on the north side of the passenger gang way on the east side of the terminal. The project site is located just north of downtown Anacortes, Washington (Figure 1).

Project Description

- The two 36-inch piles were driven to repair and enhance the strength of the dolphin.
- The project location is just north Anacortes, Washington (Figure 1).
- Two hydrophones were deployed for the 36-inch piles.
  - 36 feet (11m) from pile #1 and pile #2 and 125 feet (38m) or 3H from pile #1 and #2 where H is the water depth at the pile. Due to equipment malfunction the data from 125 feet was not captured.
  - Hydrophone was deployed at a depth of 36 feet (0.85*H where H is the depth of water at the hydrophone, Figure 2).
  - Hydrophone was deployed 141 feet (43m) from plastic piles pile 1-4 at a depth of 26 feet. This distance follows the new guidance for the range of the hydrophone being at least 3H where H is the depth of the water at the pile (40 feet).
- No substantial currents were observed in the area monitored.

Figure 1: Location of Anacortes Ferry Terminal Pile Project.



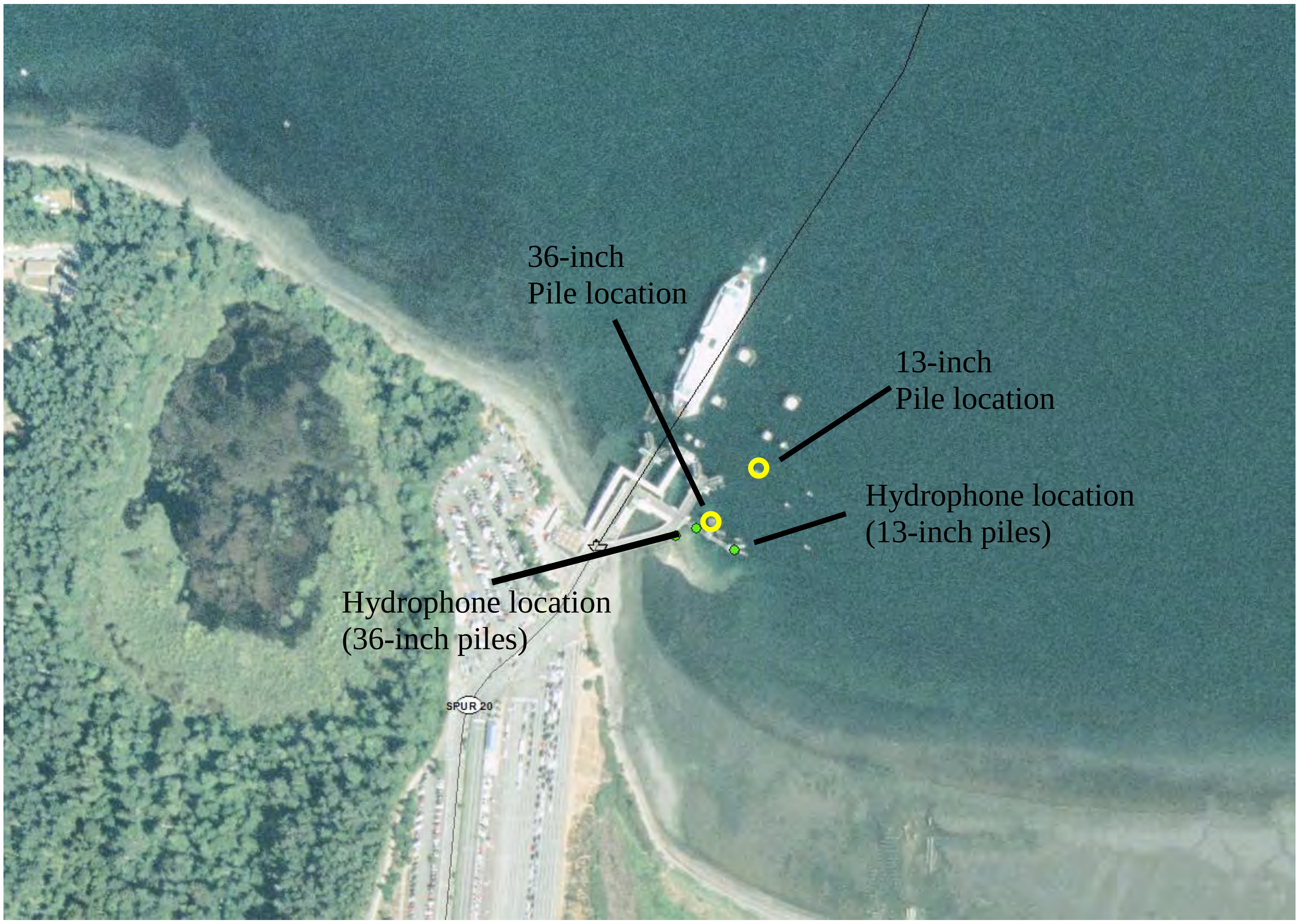


Figure 2: Approximate location of 36-inch piles, 13-inch piles and hydrophones at the Anacortes Ferry Terminal Pile Project.

○ **= Piles;** • **= Hydrophone**

UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the Root Mean Square (RMS) pressure level and the Sound Exposure Level (SEL). The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, has been used by the National Marine Fisheries Service (NMFS) in criteria for judging impacts to marine mammals from underwater vibratory or continuous-type sounds. It can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa.

The SEL is the squared sound pressure integrated or summed over time referenced to the standard pressure squared times one second and then converted to decibels. Thus, if a sound having a level of 120 dB persists for 1 second the SEL produced by that sound is 120 dB re: $1\mu Pa^2$-sec. If that sound persists for 10 seconds, the SEL is 130 dB re: $1\mu Pa^2$-sec. If it persists for 100 seconds, the SEL is 140 dB re: $1\mu Pa^2$-sec, and so on. SEL is accumulated over time to produce the cumulative SEL. For vibratory pile driving the SEL is calculated based on the 10-second RMS values that are calculated over the period of the drive or over all drives for a particular day. The formula used to convert 10-second RMS values to an SEL value is:

$$RMS + 10*LOG_{10}(\tau)$$

Where τ is the time interval, or 10 seconds. Therefore the SEL is the 10-second RMS value plus 10. These individual SEL values are then accumulated over the pile drive or over the day for multiple piles and the cumulative SEL is calculated. There are currently no thresholds for marine mammals using a cumulative SEL.

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

$$dB = 10*LOG_{10} \text{ (sum of squared pressures in the band)}$$

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

METHODOLOGY

Equipment

Underwater sound levels were measured using one hydrophone (Reson TC 4013) deployed at 36 feet (11 meters) from the 36-inch piles (near field. For the 13-inch plastic on steel piles a single hydrophone (Reson TC 4013) was deployed at 141 feet (43 meters) from the pile which was as close as possible without interfering with the contractor. The hydrophone at 36 feet was deployed at a depth of 36 feet and the hydrophone at 141 feet was deployed at a depth of 26 feet. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer (Figure 3). The output of the Nexus signal conditioner is received by a Dactron Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer (Figure 3).

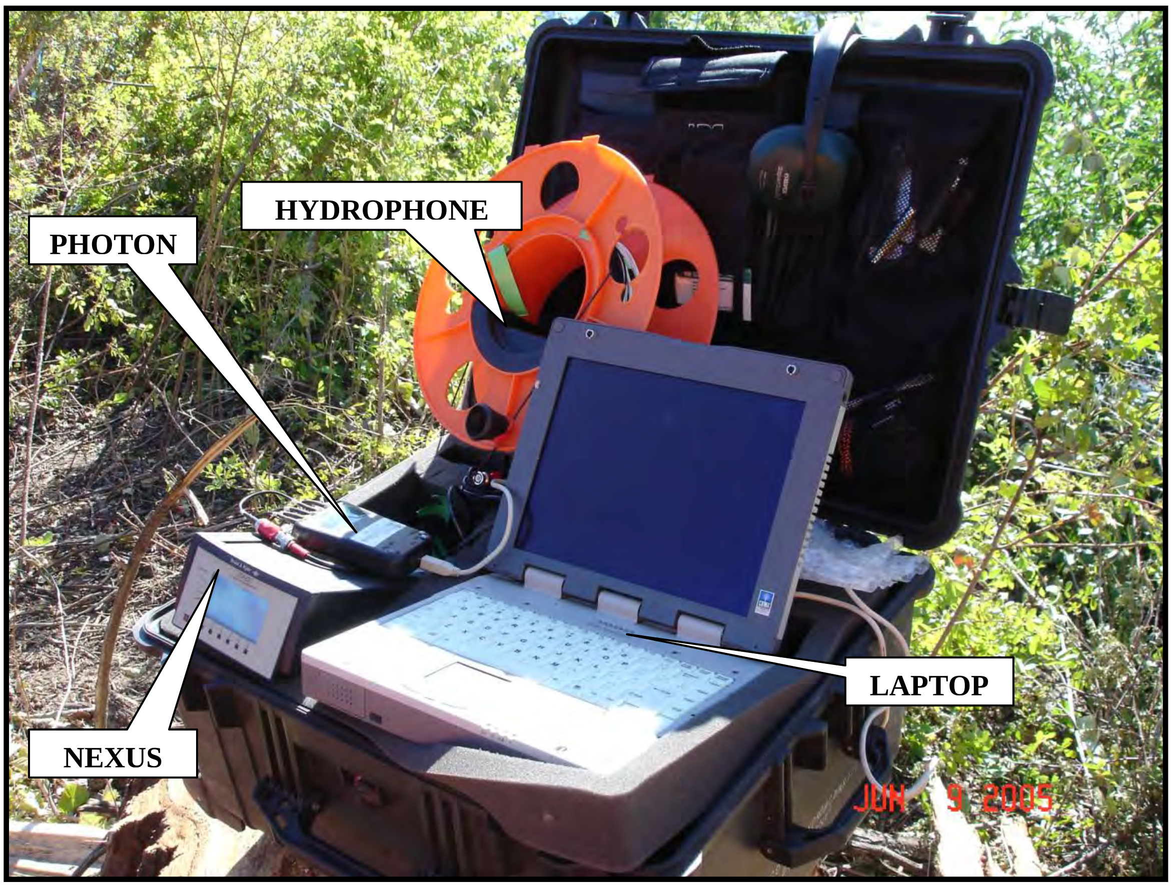


Figure 3: Near field acoustical monitoring equipment

The waveform of the pile drive sound levels for the duration of the pile drive were captured and stored on the laptop hard drive for subsequent signal analysis. The system and software calibration is checked annually against a NIST (National Institute of Standards and Technology) traceable standard.

Calibration

The operation of the near field hydrophone was checked daily in the field using a GRAS type 42AC high-level pistonphone with a hydrophone adaptor. The pistonphone signal was 134 dB re: 20 μPa. The pistonphone signal levels produced by the pistonphone and measured by the measurement system were within 0.2 dB and the operation of the system was judged acceptable over the study period.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 41.7 μs (24,000 Hz). This sampling rate is more than sufficient for the bandwidth of interest for underwater pile driving impact sound and gives sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

Due to the high degree of variability over time during the vibratory pile drive an average of the 10-second RMS values over the entire pile drive is calculated.

Hydrophone Location

The location of the hydrophones is determined by allowing a clear line of sight between the pile and the hydrophone, with no other structures nearby. The distance from the pile to the hydrophone location was measured using a Bushnell Yardage Pro rangefinder. The hydrophone was attached to a weighted nylon cord anchored with a five-pound weight. The cord and hydrophone cables were lowered off the side of the transfer span (Figure 4).

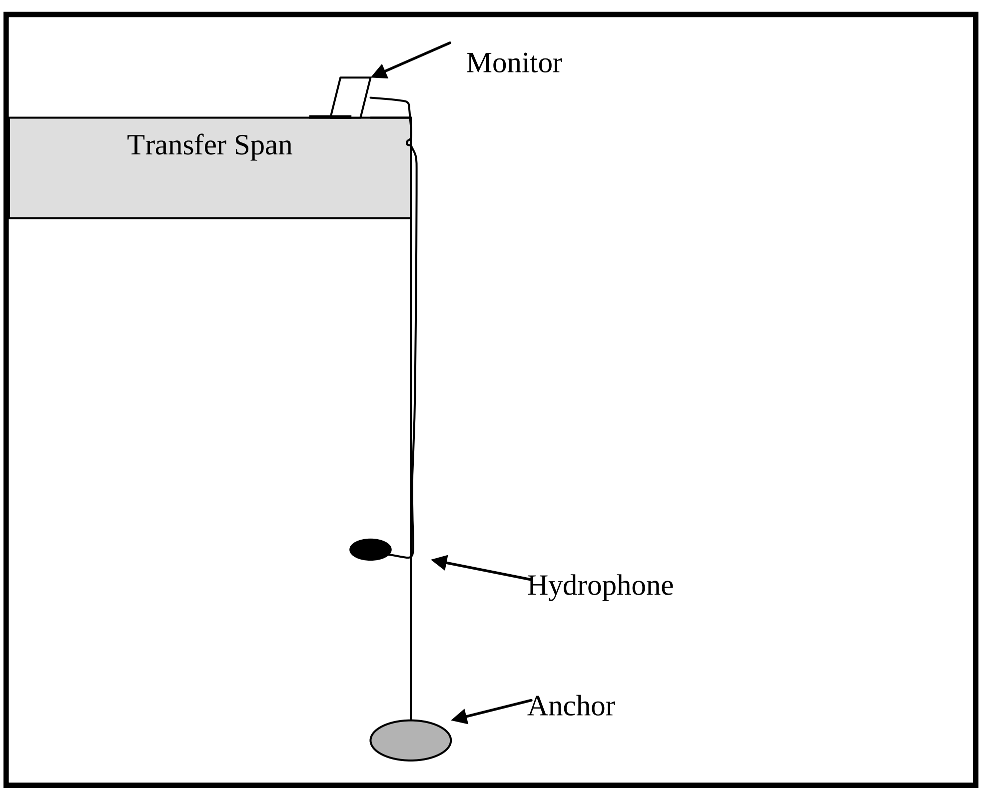


Figure 4: Diagram of hydrophone deployment configuration.

- One hydrophone was deployed for the 36-inch piles.
    - 36 feet (11m) from pile #1 and pile #2 and 125 feet (38m) or 3H from pile #1 and #2 where H is the water depth at the pile. Due to equipment malfunction the data from 125 feet was not captured.
    - Hydrophone was deployed at a depth of 36 feet (0.85*H where H is the depth of water at the hydrophone, Figure 2).
    - Hydrophone was deployed 141 feet (43m) from plastic piles pile 1-4 at a depth of 26 feet.

SEL

Individual SEL values were calculated based on each 10-second RMS value by using the formula in equation 1 below.

$$SEL = RMS + 10 * LOG_{10}(\tau) \qquad \text{(eq. 1)}$$

Where τ is the 10-second time interval for each RMS value.

RESULTS

36-inch Piles

Pile 1

The 36-inch piles were driven with an APE King Kong vibratory hammer. The drive was an exceptionally long drive lasting just over one hour. The results of monitoring for Pile 1 (Table 2) indicate:

- The average broadband RMS at 36 feet depth is 170 dB_{RMS}.
- The cumulative Sound Exposure Level (SEL) is 228 dB_{SEL} re: 1μPa^2-sec

Table 2: Summary of Underwater Sound Levels for the Anacortes Ferry Terminal Pile Project, 36-inch Steel Piles.

Pile	Date	Hydrophone Depth (feet)	Mitigation Type	Lower Frequency Range (Hz)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Cumulative SEL (dB re: 1μPa^2-sec)
1	2/6/12	37	None	Broadband	330 ±100	170	228
				7	322 ±98	170	228
				75	250 ±77	168	226
				150	180 ±65	165	223
				200	143 ±64	163	221
2	2/6/12	37	None	Broadband	249 ±167	168	220
				7	243 ±163	168	220
				75	192 ±132	166	218
				150	144 ±105	163	215
				200	119 ±94	162	214

The 1/3rd Octave frequency distribution for Pile 1 (Figure 5) indicates that the dominant frequency is at 40 Hz. This is a slightly higher frequency than has been observed in other measurements.

The highest average RMS value averaged over the entire pile driving event for both piles using broadband sound levels was 170 dB_{RMS} (Table 2). The highest cumulative SEL based on 10-second RMS + 10 from equation 1 above was 228 dB re: 1μPa^2-sec for the broadband signal (Figure 6). There are currently no cumulative SEL thresholds for vibratory pile driving associated with marine mammals or fish so this is for informational purposes only.

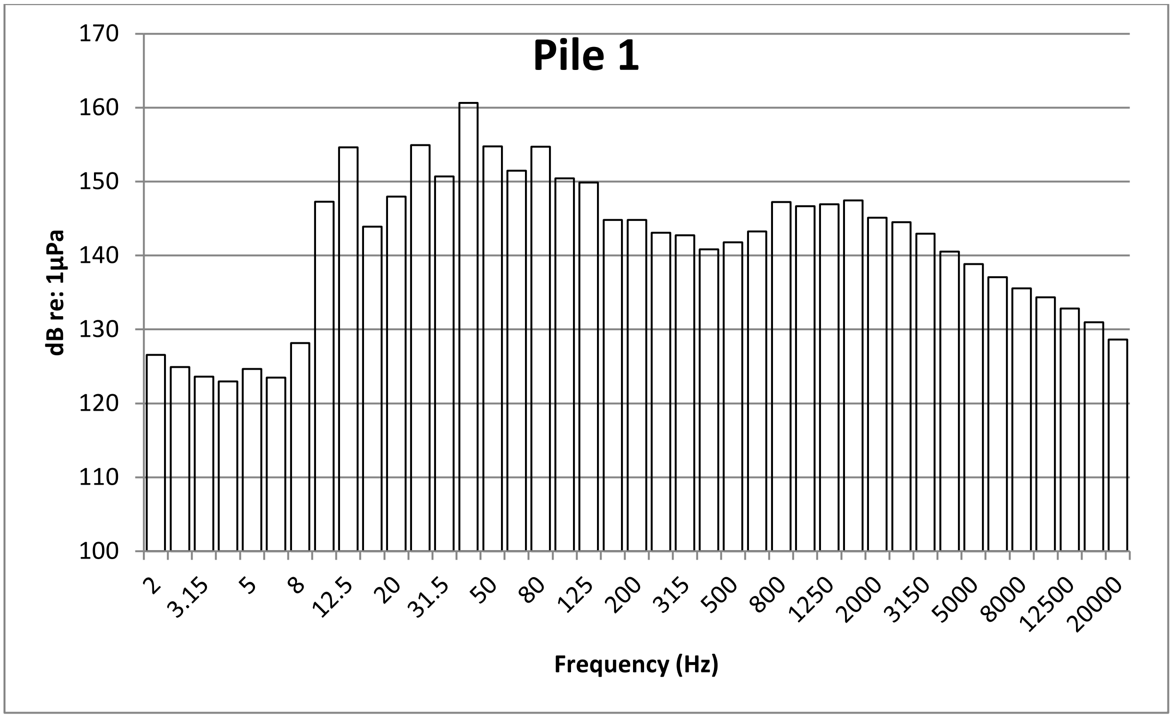


Figure 5: 1/3rd Octave frequency distribution for vibratory pile driving of Pile 1.

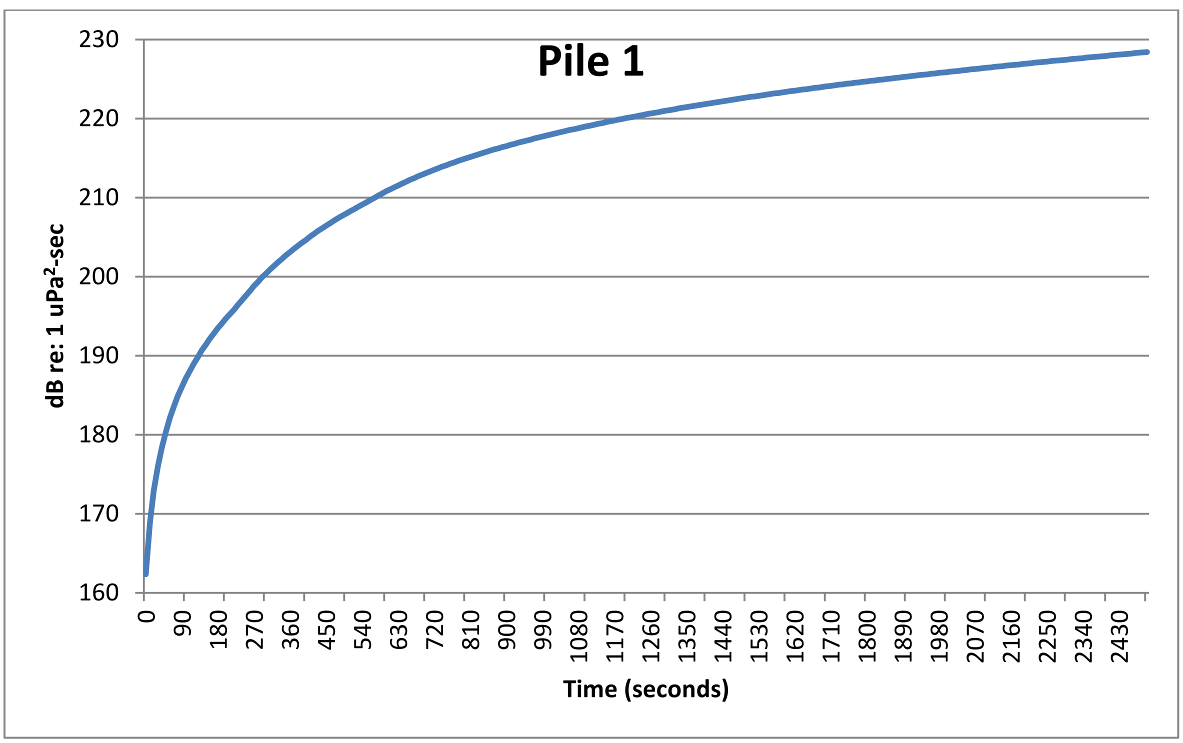


Figure 6: Cumulative SEL plot for Pile 1 showing the cumulative plot for SEL values calculated for the entire pile drive event (broadband vibratory).

Pile 2

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

- The average RMS at 37 feet depth is 168 dB_{RMS}.
- The cumulative Sound Exposure Level (SEL) for Pile 2 is 220 dB_{SEL} re: 1μPa^2-sec (Figure 8). Cumulative SEL for both piles monitored is 231 dB re: 1μPa^2-sec (Figure 9).
- There were two 36-inch piles monitored but three piles were driven this day but the third pile was not monitored.

The 1/3rd Octave frequency distribution for Pile 2 (Figure 7) indicates that the dominant frequency is at 40 Hz. This is a higher frequency than has been observed in other measurements but is similar to what was measured for Pile 1.

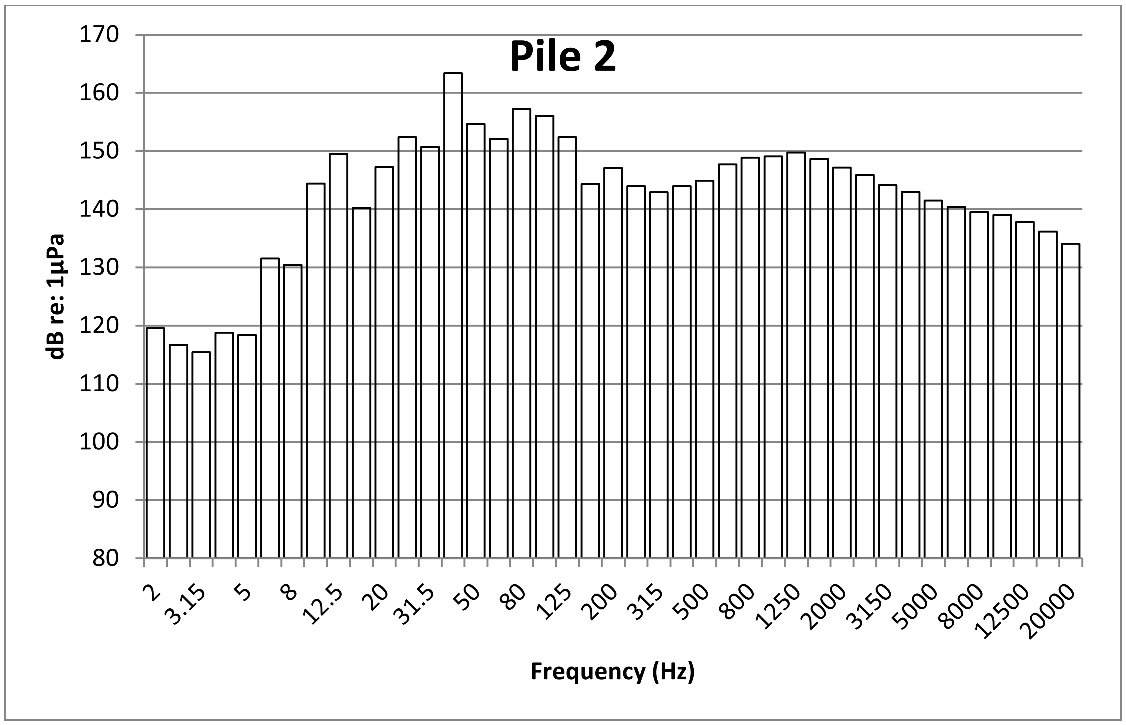


Figure 7: 1/3rd Octave frequency distribution for vibratory pile driving of Pile 2.

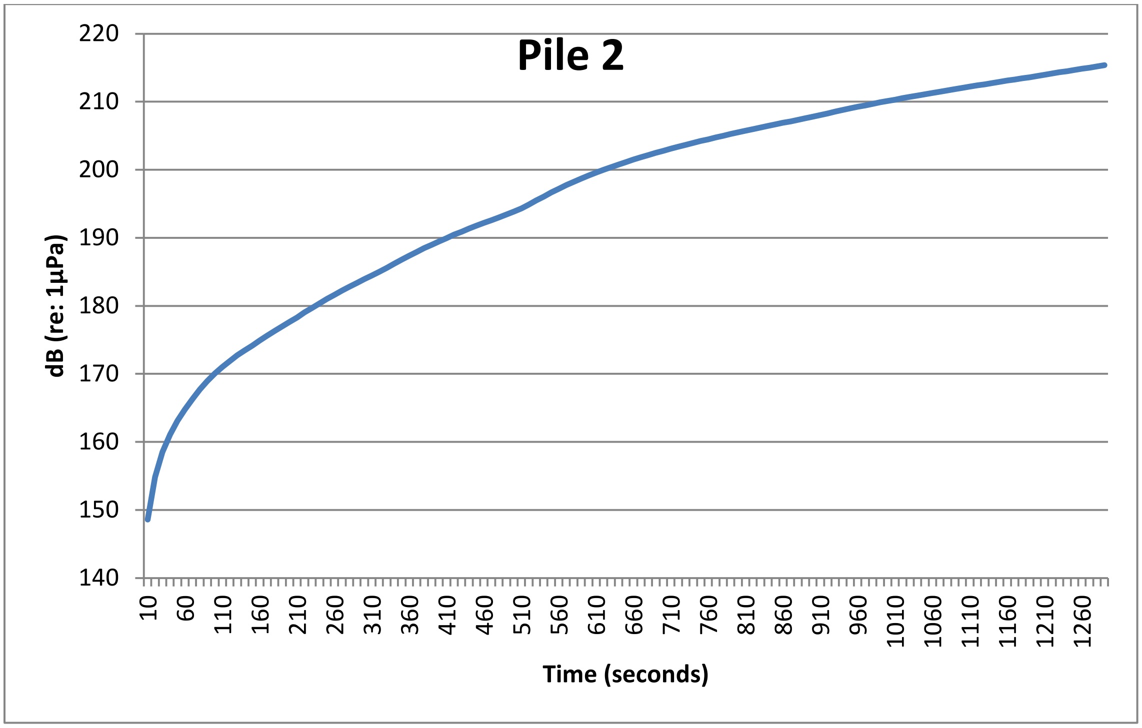


Figure 8: Cumulative SEL plot for Pile 2 showing the cumulative plot for SEL values calculated for the entire pile drive event (broadband vibratory).

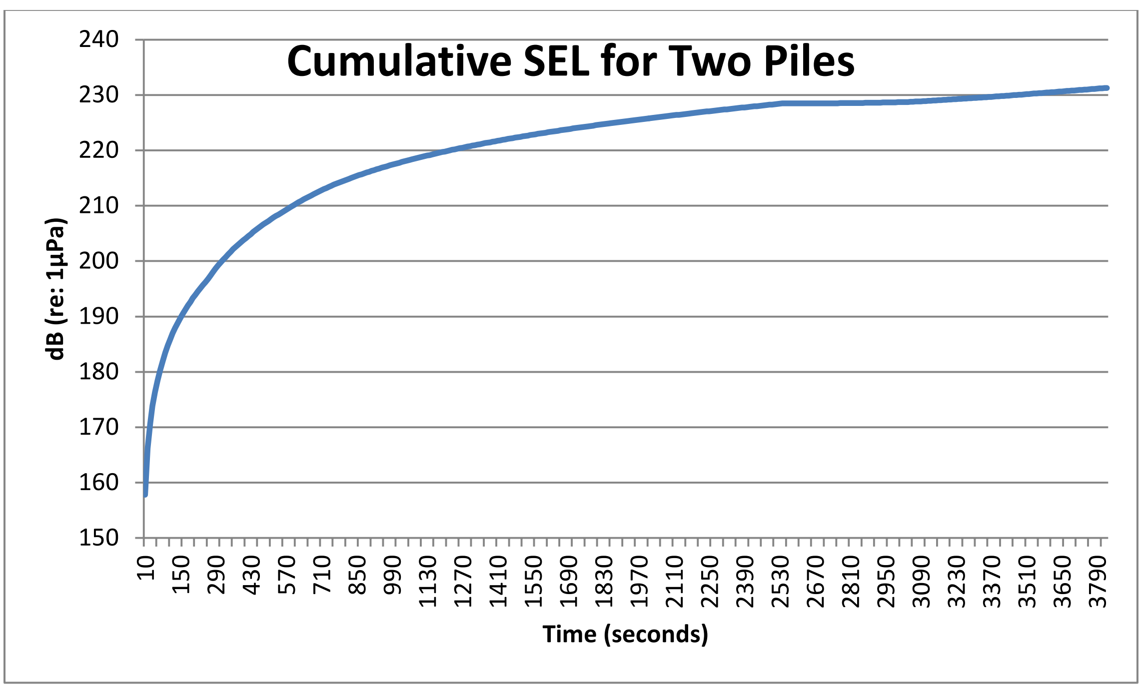


Figure 9: Cumulative SEL plot for both piles 1 and 2 showing the cumulative plot for SEL values calculated for both piles combined (broadband vibratory).

Background sound levels measured in March, 2011 was calculated to be 130 dB (Table 3). Since the 130 dB broadband background sound level is higher than the 120 dB threshold the 130 dB background sound level is used instead to determine the area of influence. Therefore, the distance calculated using the 170 dB_{RMS} source level and the 130 dB broadband sound level for combined day and night measurements is 3.2 miles. After the March 2011 background noise levels were analyzed NMFS has provided new guidance on measuring and analyzing underwater background sound levels. In this new guidance we are able to use daytime only measurements for calculating background sound levels if the pile driving will occur during daytime hours (NMFS, 2012). If we use just the daytime background sound level measurements (6 am to 6 pm) the background sound levels would be 133 dB_{RMS}. The distance to this new level would be 2 miles.

Table 3: Background Sound Level Results, Anacortes Ferry Terminal.

Frequency Range	Functional Hearing Group	72-h 50% Cumulative Density Function (dB)	Daytime 50% Cumulative Density Function (dB)
75 Hz to 20 KHz	Pinnipeds	124	125
150 Hz to 20 KHz	Mid Frequency Cetaceans	119	124
20 Hz to 20 KHz	N/A	130	133

Plastic "Rubbing Piles"

The 13-inch plastic 'rubbing piles' consist of a plastic coated steel rubbing pile. They were driven with a relatively small IOF 416 vibratory hammer between 30 seconds and 1.3 minutes per pile. The results of monitoring for these piles (Table 2) indicate:

- The highest average broadband RMS at 26 feet depth and a distance of 141 feet is 158 dB_{RMS}. The calculated source level at 10 meters would be 171 dB_{RMS}.
- The highest cumulative Sound Exposure Level (SEL) at 141 feet is 178 dB_{SEL} re: $1\mu Pa^2$-sec. The calculated source level at 10 meters would be 190 dB_{SEL} re: $1\mu Pa^2$-sec.

Table 4: Summary of Underwater Sound Levels for the Anacortes Ferry Terminal Pile Project, 36-inch Steel Piles.

Pile	Date	Hydrophone Depth (feet)	Mitigation Type	Lower Frequency Range (Hz)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Cumulative SEL (dB re: $1\mu Pa^2$-sec)
1	2/10/12	37	None	Broadband	83 ±21	158	178
				7	81 ±93	158	178
				75	59 ±67	155	175
				150	39 ±42	152	171
				200	28	149	168

Pile	Date	Hydrophone Depth (feet)	Mitigation Type	Lower Frequency Range (Hz)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Cumulative SEL (dB re: $1\mu Pa^2$-sec)
					±28		
2	2/10/12	37	None	Broadband	11 ±3	141	171
				7	11 ±3	141	171
				75	10 ±3	140	170
				150	9 ±3	139	169
				200	8 ±3	138	168
				Broadband	249 ±167	138	170
3	2/10/12		None	7	8 ±3	138	170
				75	7 ±3	137	168
				150	6 ±3	135	167
				200	5 ±2	134	166
4	2/10/12		None	Broadband	17 ±3	145	167
				7	17 ±3	145	167
				75	14 ±3	143	165
				150	12 ±2	142	164
				200	11 ±2	141	163

The 1/3rd Octave frequency distribution for Pile 1 (Figure 10) indicates that the dominant frequency is at 40 Hz. This is a higher frequency than has been observed in other measurements.

The cumulative SEL value for all for plastic rubbing piles driven in the same day was 189 dB re: $1\mu Pa^2$-sec (Figure 11). There are currently no cumulative SEL thresholds for vibratory pile driving associated with marine mammals or fish so this is for informational purposes only.

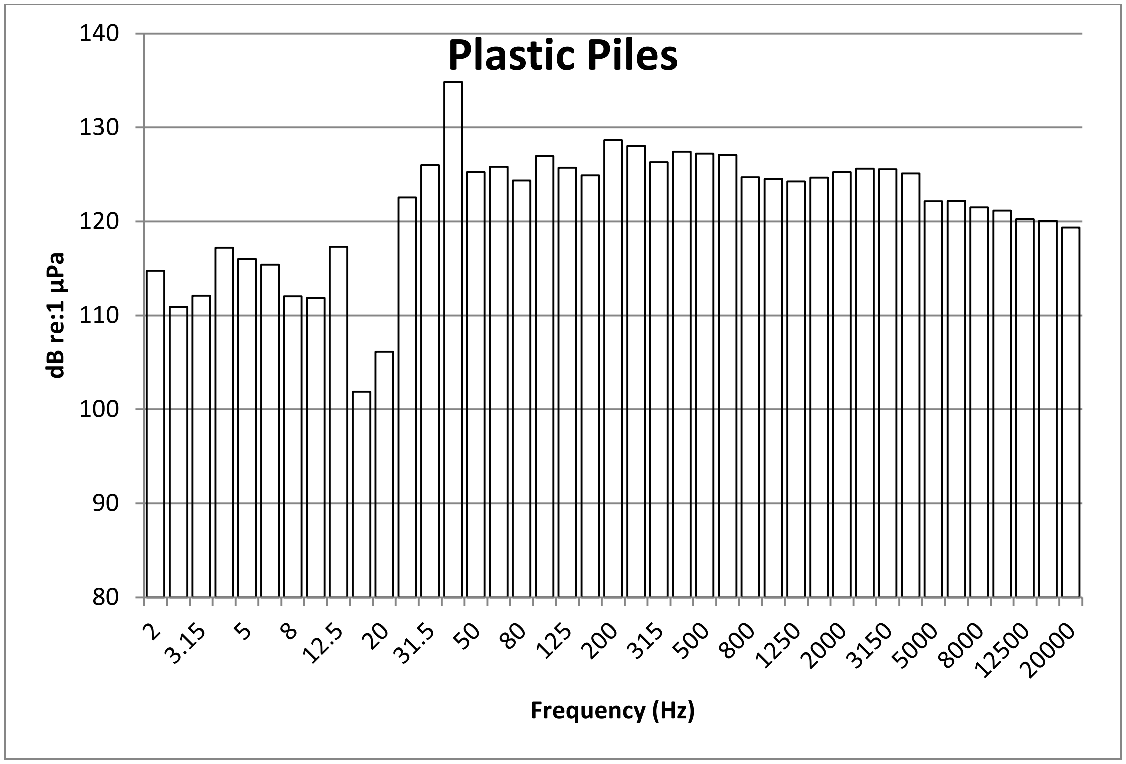


Figure 10: 1/3rd Octave frequency distribution for vibratory pile driving of Plastic Rubbing Piles.

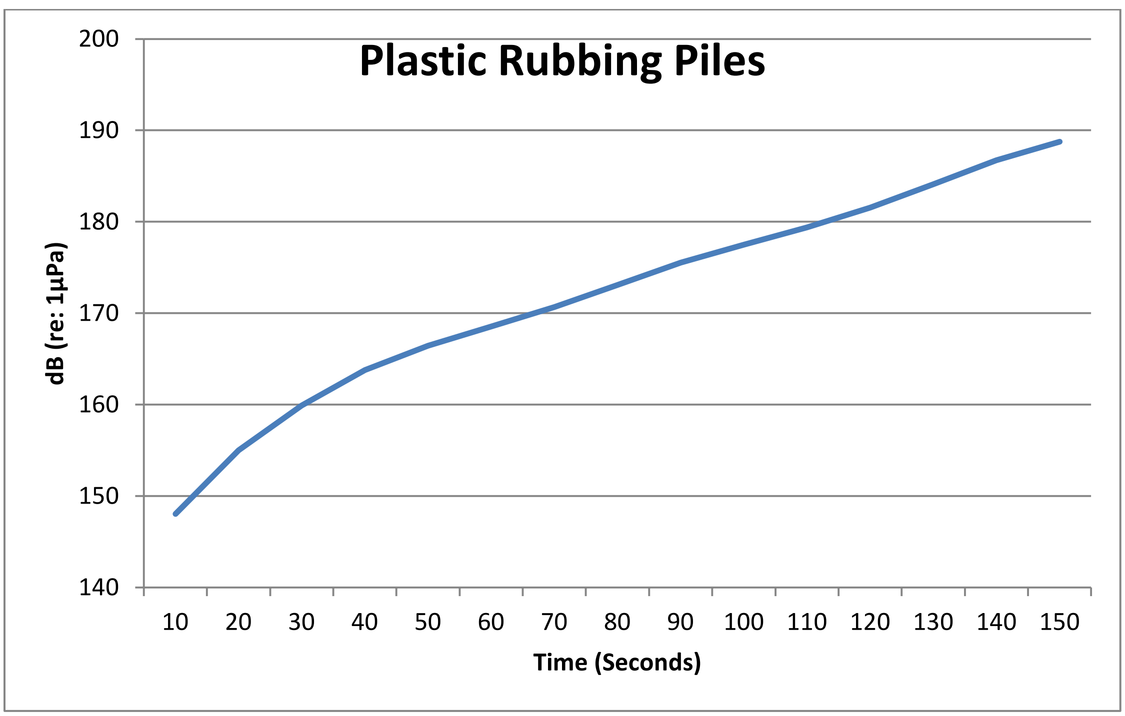


Figure 11: Cumulative SEL plot for all plastic rubbing piles showing the cumulative plot for SEL values calculated for the all piles in one day (broadband vibratory).

CONCLUSIONS

Two 36-inch steel piles and four 13-inch plastic rubbing piles were monitored in February 2012 during vibratory driving operations.

- Underwater 10-second broadband average RMS sound levels for piles vibratory driven in water ranged between 143 dB_{RMS} and 174 dB_{RMS} for the 36-inch piles and between 135 dB_{RMS} and 165 dB_{RMS} (at 33 feet) for the 13-inch plastic rubbing piles (at 141 feet).
- Average broadband RMS sound level was 170 dB_{RMS} for the 36-inch piles (at 33 feet) and 158 dB_{RMS} for the 13-inch plastic rubbing piles at 141 feet.
- Based on the average RMS broadband source level the distance to the 130 dB_{RMS} background sound level is calculated to be 3.2 miles for the 36-inch piles and 3.4 miles for the 13-inch plastic rubbing piles.
- Using the RMS broadband source level the distance calculated to the 133 dB daytime only broadband background sound level is 2 miles for the 36-inch piles and 2.1 miles for the 13-inch plastic rubbing piles.
- Cumulative Sound Exposure Levels (SEL) were calculated for both 36-inch piles and for all four 13-inch plastic rubbing piles monitored on a single day and the broadband SELcum is 231 dB re: 1μPa^2-sec for the 36-inch piles and 189 dB re: 1μPa^2-sec for the 13-inch plastic rubbing piles.

REFERENCES

NMFS. 2012a. Guidance Document: Data collection methods to characterize impact and vibratory pile driving source levels relevant to marine mammals. NMFS Memorandum.

NMFS. 2012b. Guidance Document: Data collection methods to characterize underwater background sound relevant to marine mammals in coastal nearshore waters and rivers of Washington and Oregon. NMFS Memorandum.