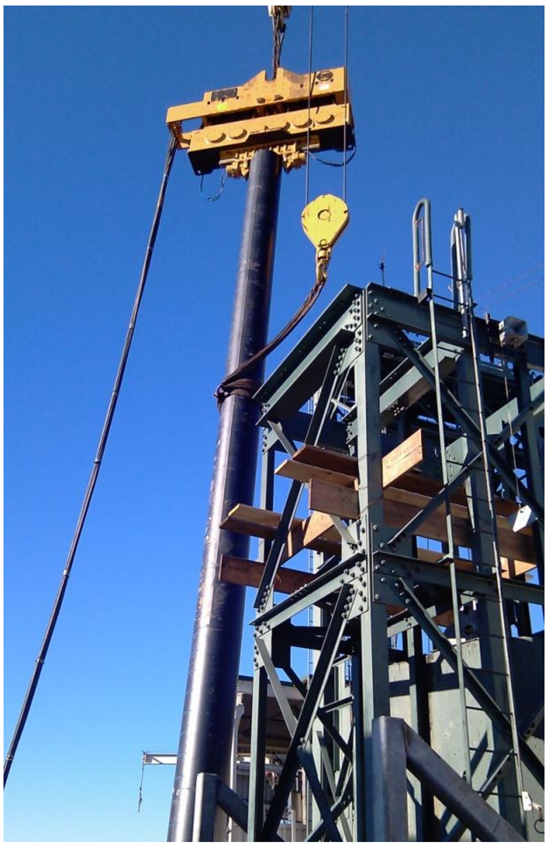
SEATTLE FERRY TERMINAL – BATTER PILE PROJECT

UNDERWATER VIBRATORY SOUND LEVELS FROM A BATTERED PILE INSTALLATION AT THE SEATTLE COLMAN DOCK



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EXECUTIVE SUMMARY

This technical report describes the data collected during vibratory pile driving of a 30-inch steel batter pile for the Seattle Ferry Terminal at Colman Dock on February 10, 2012. A single 30-inch pile was batter driven as part of this project. The broadband RMS sound levels ranged between 154 dB_{RMS} and 175 dB_{RMS} (Table 1). Based on the average RMS broadband source level the distance to the 120 dB_{RMS} threshold is calculated to be 11.5 miles. However, since the background sound levels near the Seattle Terminal collected in April of 2011 is 128 dB_{RMS} it will reach background levels before it reaches the 120 dB_{RMS} threshold at 3.4 miles. Using the daytime only background sound levels of 141 dB_{RMS} broadband the distance to background becomes 0.5 miles.

Table 1: Underwater Monitoring Results, Seattle Ferry Terminal at Colman Dock Project.

Pile	Date	Mitigation Type	Lower Frequency Range (Hz)	Average RMS (dB)	Cumulative SEL (dB)
1	2/10/12	None	Broadband	169	222
			7	168	222
			75	164	217
			150	163	216
			200	163	216

INTRODUCTION

This technical report presents results of underwater sound levels measured during the vibratory driving of one 30-inch steel pile at the Seattle Ferry Terminal on February 10, 2012.

The single pile was driven diagonally (batter pile) adjacent to the wing wall on the north side of slip 2. The project site is located just west of downtown Seattle on the north end of Colman Dock, Washington (Figure 1).

Project Description

- The 30-inch pile was driven to repair and enhance the strength of the north wing wall.
- The project location is just west of Seattle, Washington (Figure 1).
- Water depth at the hydrophone monitoring location was 42 feet deep (Figure 2).
- No substantial currents were observed in the area monitored.

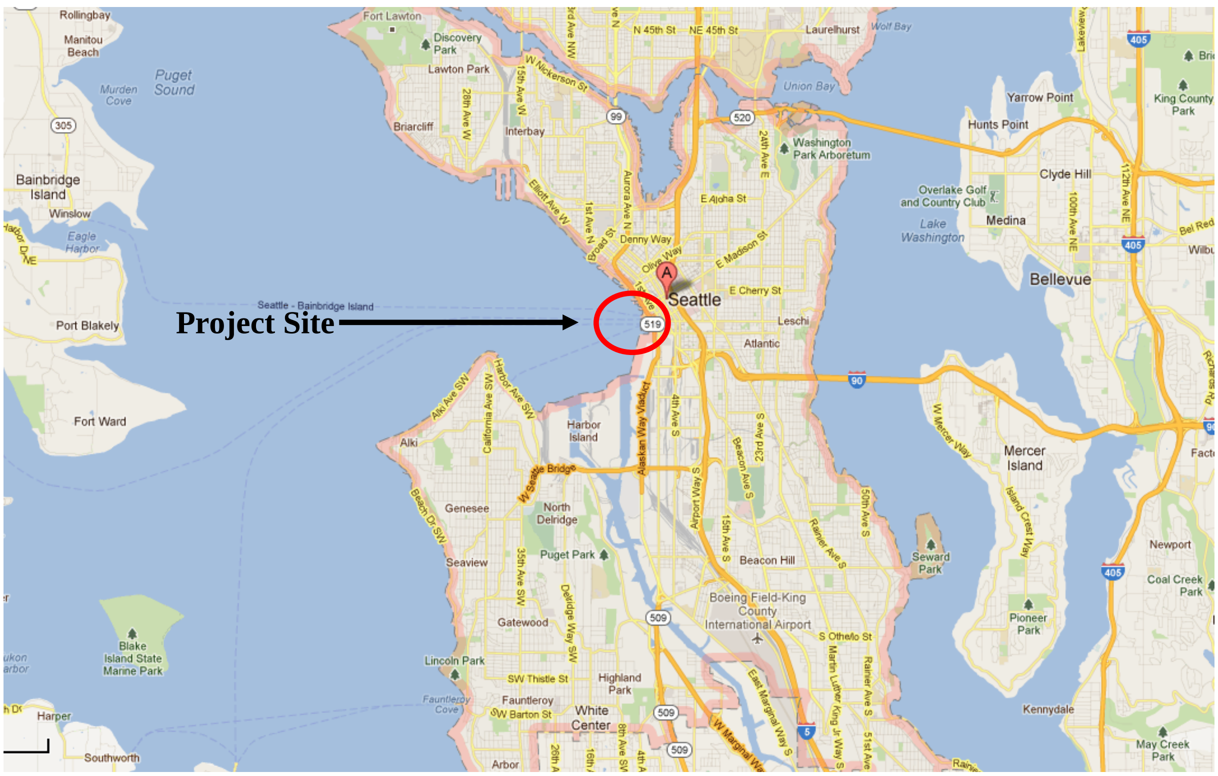

Figure 1: Location of Seattle Ferry Terminal Batter Pile Project.

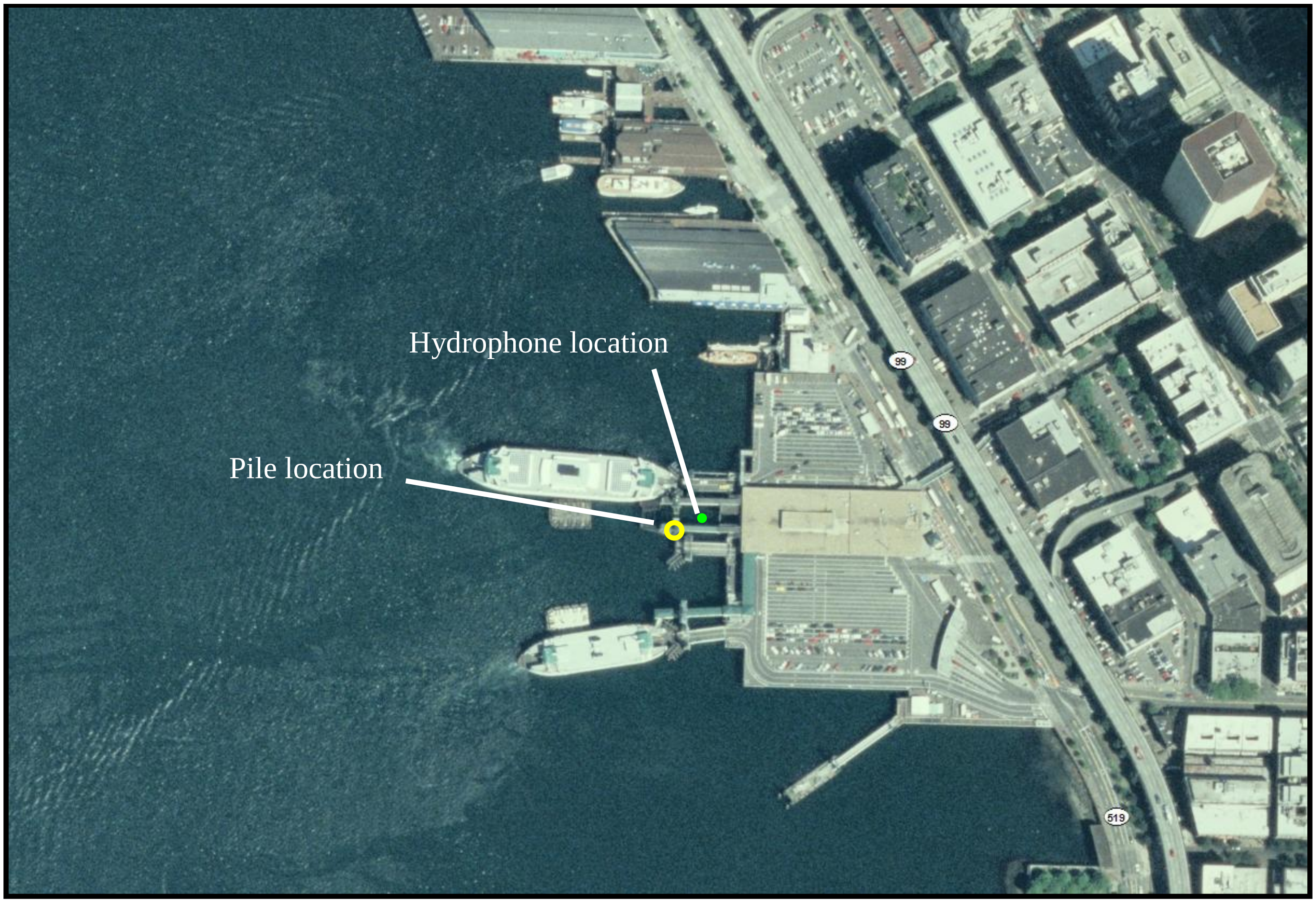

Figure 2: Approximate location of 30-inch pile and hydrophone at the Seattle Ferry Terminal Batter Pile Project.

○ = 30-inch Steel Pile; • = Hydrophone

UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise effects. 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:

$$RMS + 10*LOG(\tau)$$

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 convenient way to look at the frequency composition of 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

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

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 a single hydrophone near the pile (near field) using one Reson TC 4013 hydrophone deployed on a nylon cord off the side of the transfer span. The hydrophone was positioned at a distance of 10 meters from the pile being monitored and at 0.85 % of the water depth at the hydrophone location (37 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).

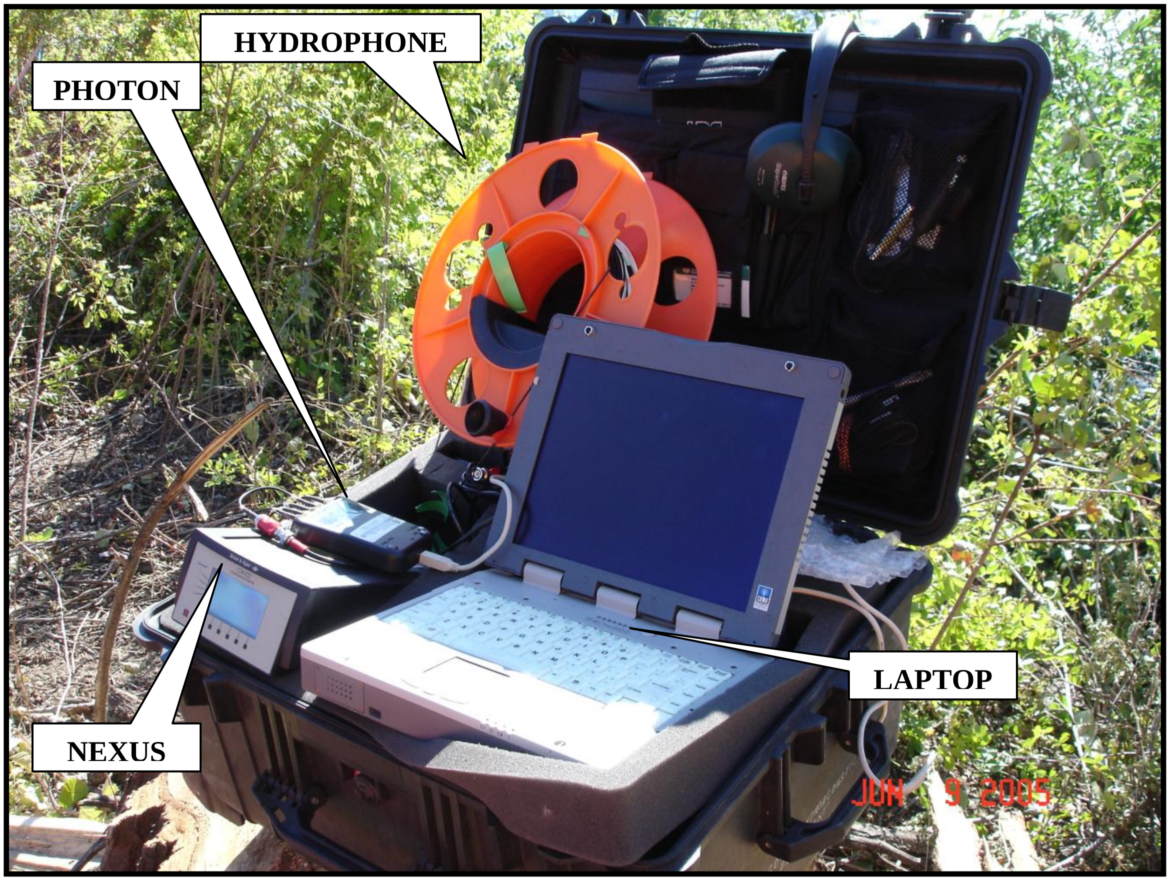

Figure 3: Near field acoustical monitoring equipment

A laptop hard drive captured and stored the waveform of the pile drive sound levels for the duration of the pile 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 hydrophone 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).

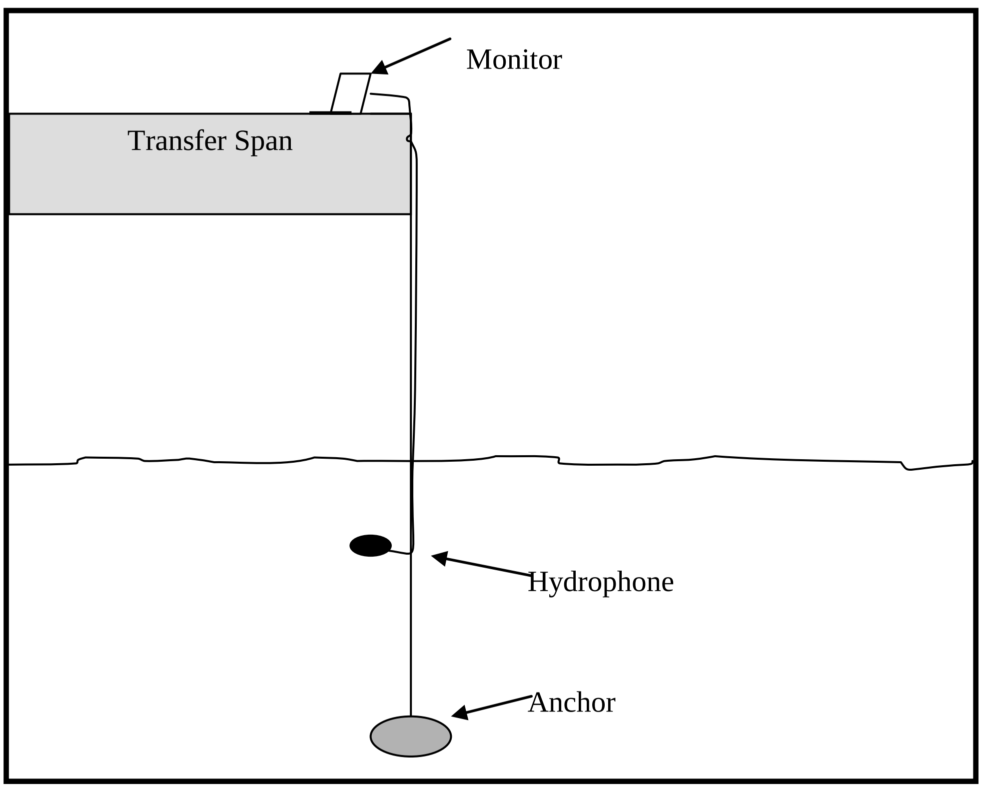

Figure 4: Diagram of hydrophone deployment configuration.

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

Underwater Sound Levels

Pile 1

All piles were driven with an APE Super Kong vibratory hammer. The results of monitoring for Pile 1 (Table 2) indicate:

- The average RMS at 37 feet depth is 168 dB_{RMS}.
- The Sound Exposure Level (SEL) is 210 dB_{SEL} re: 1μPa^2-sec.

The 1/3rd Octave frequency distribution for Pile 1 (Figure 6) indicates that the dominant frequency is at approximately 25 Hz. This is consistent with other reports on vibratory pile driving frequencies (Burgess and Blackwell, 2003; Laughlin 2010a, 2010b, 2011).

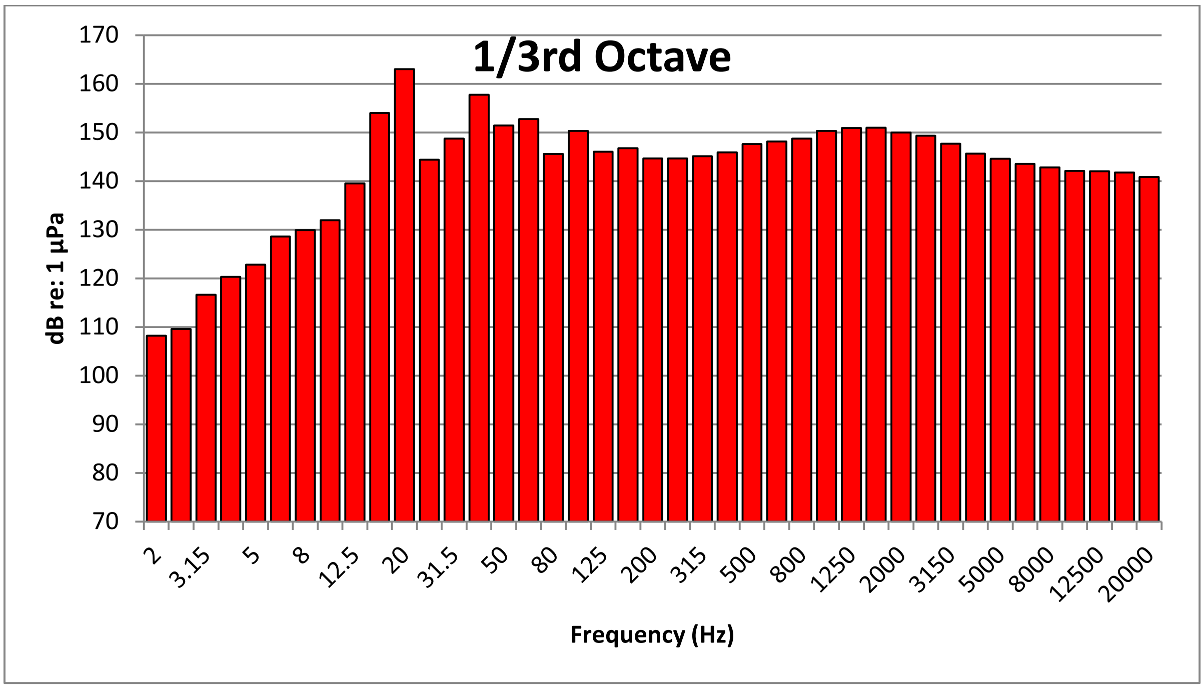

Figure 5: 1/3rd Octave frequency distribution for vibratory pile driving of Pile 1.

The average RMS value averaged over the entire pile driving event for broadband sound levels was 169 dB_{RMS} (Table 2). The highest cumulative SEL based on 10-second RMS + 10 from equation 1 above was 222 dB for the broadband signal (Figure 7). There are currently no cumulative SEL thresholds for vibratory pile driving associated with marine mammals or fish so this is for informational purposes only.

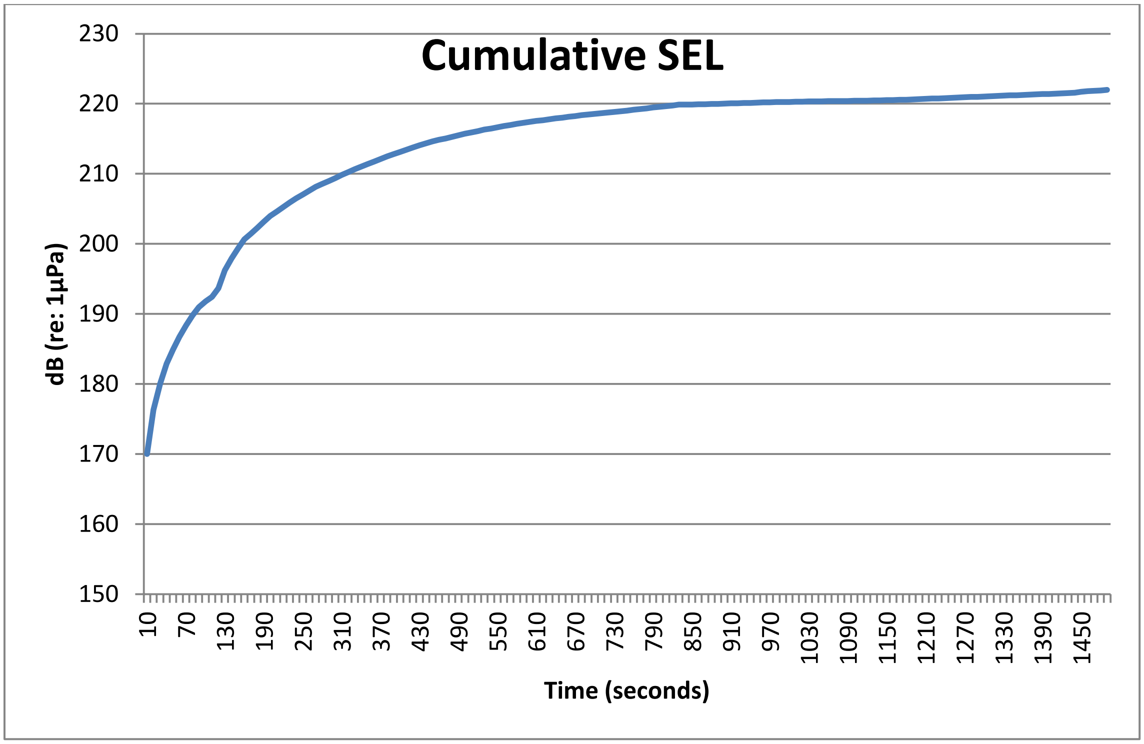

Figure 6: Cumulative SEL plot for Pile 1 showing the cumulative plot for SEL values calculated for the entire pile drive event (broadband vibratory).

Table 2: Summary of Underwater Sound Levels for the Seattle Ferry Terminal Batter Pile Project, 30-inch Steel Pile.

Pile	Date	Hydrophone Depth (feet)	Mitigation Type	Lower Frequency Range (Hz)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Cumulative SEL (dB)
1	2/10/12	37	None	Broadband	267 ±164	169	222
				7	263 ±166	168	222
				75	150 ±114	164	217
				150	138 ±114	163	216
				200	134 ±114	163	216

Background sound levels measured in April, 2011 was calculated to be 128 dB (Table 3). Since the 128 dB broadband background sound level is higher than the 120 dB threshold the 128 dB background sound level is used instead to determine the area of influence. Therefore, the distance calculated using the 169 dB_{RMS} source level and the 128 dB_{RMS} broadband sound level for combined day and night measurements is 3.4 miles. After the April 2011 background noise levels were analyzed we now have new guidance on measuring and analyzing underwater background sound levels. In this new guidance we 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 for the same time period the background sound levels would be 141 dB_{RMS}. The distance to this new level would be 0.5 miles.

Table 3: Background Sound Level Results, Seattle 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	126	127
150 Hz to 20 KHz	Mid Frequency Cetaceans	123	137
20 Hz to 20 KHz	N/A	128	141

CONCLUSIONS

One 30-inch steel pile was monitored in February 2012 during vibratory driving of a batter pile.

- Underwater 10-second broadband RMS sound levels for piles vibratory driven in water ranged between 154 dB_{RMS} and 175 dB_{RMS}.
- Average broadband RMS sound level was 169 dB_{RMS}.
- Based on the average RMS broadband source level the distance to the 120 dB_{RMS} threshold is calculated to be 11.5 miles.
- Using the RMS broadband source level the distance calculated to the 128 dB_{RMS} broadband background sound level is 3.4 miles.
- Using the daytime only broadband background sound levels of 141 dB_{RMS} the distance is 0.5 miles.
- Cumulative Sound Exposure Levels (SEL) were calculated and the broadband SELcum is 222 dB re: 1μPa^2-sec.

REFERENCES

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