WAHKIAKUM COUNTY FERRY TERMINAL PROJECT

UNDERWATER SOUND LEVELS ASSOCIATED WITH DRIVING STEEL PILES AT THE WAHKIAKUM COUNTY FERRY TERMINAL

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EXECUTIVE SUMMARY

This technical report describes the data collected during impact pile driving efforts for the Wahkiakum County Ferry Terminal Project, Puget Island, Washington in January 2010. A total of 4, 18-inch test piles were driven with 5/8-inch walls. Table 1 summarizes the results for each pile monitored. A confined bubble curtain utilizing a cloth containment system was tested as part of this project for its sound reduction properties. The confined bubble curtain consisted of a single bubble ring at the bottom and a nylon cloth shroud around the bubble ring which extended to approximately 2-3 feet above the waterline dependent on tidal flux.

Table 1 summarizes the average peak, average RMS and cumulative SEL values for each pile monitored. Background sound levels were unable to be recorded due to one of the contractors outboard skiffs running constantly between the pile and the hydrophone. The confined bubble curtain achieved average sound reductions ranging between 3 and 13 dB. The confined bubble curtain was modified on the last pile monitored by removing the nylon sheath on the outside which was acting as a lift bag to raise the weighted bottom bubble ring off the bottom and making it ineffective at reducing noise. Once the sheath was removed thus making it an unconfined bubble curtain we were able to achieve a 13 decibel noise reduction. This is greater than the 11 dB specified in the biological opinion. The biological opinion was written using the older thresholds of 180 dB peak and 150 dB RMS. The current thresholds are 206 dB peak and 187 dB SELcumulative.

Table 1: Summary Table of Monitoring Results.

Pile	Date	Mitigation Type	Average Peak (dB)	Average RMS (dB)	Number of Strikes	Average Reduction (dB)	Cumulative SEL_{cum} (dB)	Exceed 180 dB Peak?	Exceed 150 dB RMS?
1	1/12/10	Bubbles On	189	172	308	-	191	Y	Y
2	1/12/10	Bubbles On	188	169	315	3	177	Y	Y
		Bubbles Off	191	173	20	-	176	Y	Y
				Daily Total:	**643**		**194**		
3	1/13/10	Bubbles On	189	172	306	3	187	Y	Y
		Bubbles Off	192	174	170	-	188	Y	Y
4	1/13/10	Bubbles On	187	170	385	0	182	Y	Y
		Bubbles Off	187	169	757	-	195	Y	Y
5	1/13/10	Bubbles On	175	171	1069	13	187	N	Y
		Bubbles Off	188	174	31	-	181	Y	Y
				Daily Total:	**2718**		**200**		

INTRODUCTION

This technical report presents results of underwater sound levels measured during the driving of five 18-inch steel piles at the Wahkiakum County Ferry Terminal Project in January 2010.

The five piles were driven in three locations using a vibratory hammer first. Then an impact hammer was used to drive the pile the remainder of the way and a second pile was welded to the top of the first and then continued with impact driving. The water depths are dependent on tidal flux. The mitigation strategy used was a confined bubble curtain constructed by the contractor. The confined bubble curtain consisted of a single bubble ring at the bottom with a nylon sheath surrounding the ring at the bottom and extending up through the water to about 2 or 3 feet above the water line (tidal dependent). Piles were driven with and without the bubble curtain to determine baseline unmitigated noise levels. Figure 1 shows project area and Figure 2 shows the locations of monitored piles.

PROJECT DESCRIPTION

The piles were driven to test the effectiveness of a new modified TNAP developed by the UW APL. The project location is northeast of the Wahkaikum Ferry Terminal (Figure 1). Water depths at the monitoring locations varied from 10 feet to 12 feet deep. There was an approximate 3 foot tidal flux over a 6 hour period. No substantial currents were observed in the area monitored.

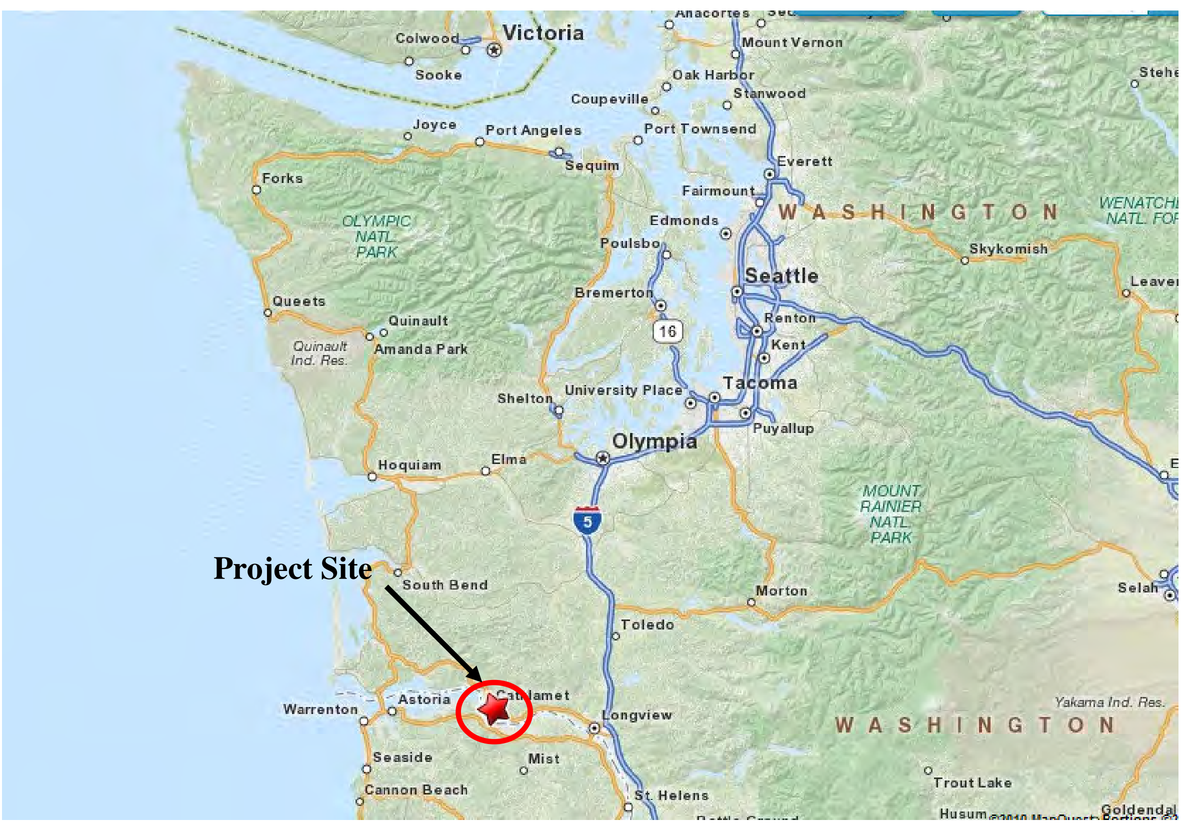


Figure 1: Location of Wahkaikum County ferry terminal.

Figure 2: Approximate location of test piles at the Wahkiakum ferry terminal. ○ = Steel Pile; ○ = Hydrophone

UNDERWATER SOUND LEVELS

CHARACTERISTICS OF UNDERWATER SOUND

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse, which are sometimes referred to as the SPL and RMS level respectively. The peak pressure is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound pressure level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The equation to calculate the sound pressure level is:

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

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. It has been used by National Marine Fisheries Service (NMFS) in criteria for judging impacts to marine mammals from underwater impulse-type sounds. The majority of literature uses peak sound pressures to evaluate barotraumas injuries to fish. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa.

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

METHODOLOGY

Underwater sound levels were measured near the pile (nearfield) using one Reson TC 4013 hydrophone deployed on a nylon cord between the pile and the ferry access bridge. The hydrophone was positioned at mid-water level. The hydrophone was located at a distance of between 11 and 13 meters from the individual pile being monitored. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer (Figure 3). The output of the Nexus signal conditioner is received by a Dactron Photon 4-channel signal spectrum analyzer that is attached to an Itronix GoBook II laptop computer (Figure 3).

Figure 3: Near field acoustical monitoring equipment

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

The operation of the nearfield hydrophones were checked daily in the field using a GRAS type 42AC high-level pistonphone with a hydrophone adaptor. The pistonphone signal was 146 dB re: 1 μPa. The pistonphone signal levels produced by the pistonphone and measured by the measurement system were within 1 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 (9,500 Hz). This sampling rate is more than sufficient for the bandwidth of interest for underwater pile driving impact sound and gives sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

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

A vibratory hammer was used to drive the piles initially. Then all piles were driven to bearing depth with a diesel hammer. The diesel impact driver was a DelMag D30-32 diesel hammer rated to a maximum of 75,940 foot pounds. This is the maximum energy output for the diesel hammer that can only be sustained for a few seconds at a time. Actual operation of the diesel hammer is more likely to be approximately 50% to 70% of this maximum energy for most pile installations.

The substrate consisted of sandy silt. Piles driven were four open-ended hollow steel piles, 18-inches in diameter with a 5/8-inch wall thickness. All measurements were made between 11 meters and 13 meters from the pile, midwater depth.

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 ferry bridge and kept in this location for all piles monitored (Figure 4).

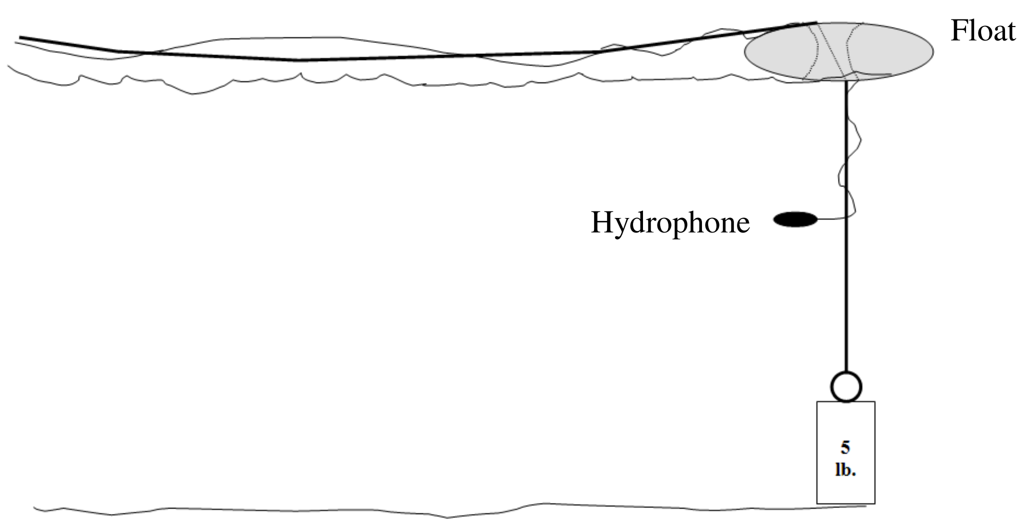


Figure 4: Diagram of hydrophone deployment configuration.

CONFINED BUBBLE CURTAIN DESIGN

A confined bubble curtain with a single ring at the bottom and a nylon outer shell attached to the bottom ring and at a single aluminum support ring midway along its length was tested as a part of this project (Figure 5). The bottom bubble ring of the confined bubble curtain was weighted with 150 pounds of weight. The bubble curtain is placed around the pile being driven with the ring on the bottom of the substrate and the nylon shell extending upwards and tied off on the barge up to a few feet above the surface waterline. The compressor which was attached with a separate hose on each half of the bottom ring maintained a flow of 32.91 cubic feet per minute per linear foot of pipe with an overall bubble flux of 3.0 cubic meters per linear meter of pipe. This design had some challenges which will be discussed later in this report.

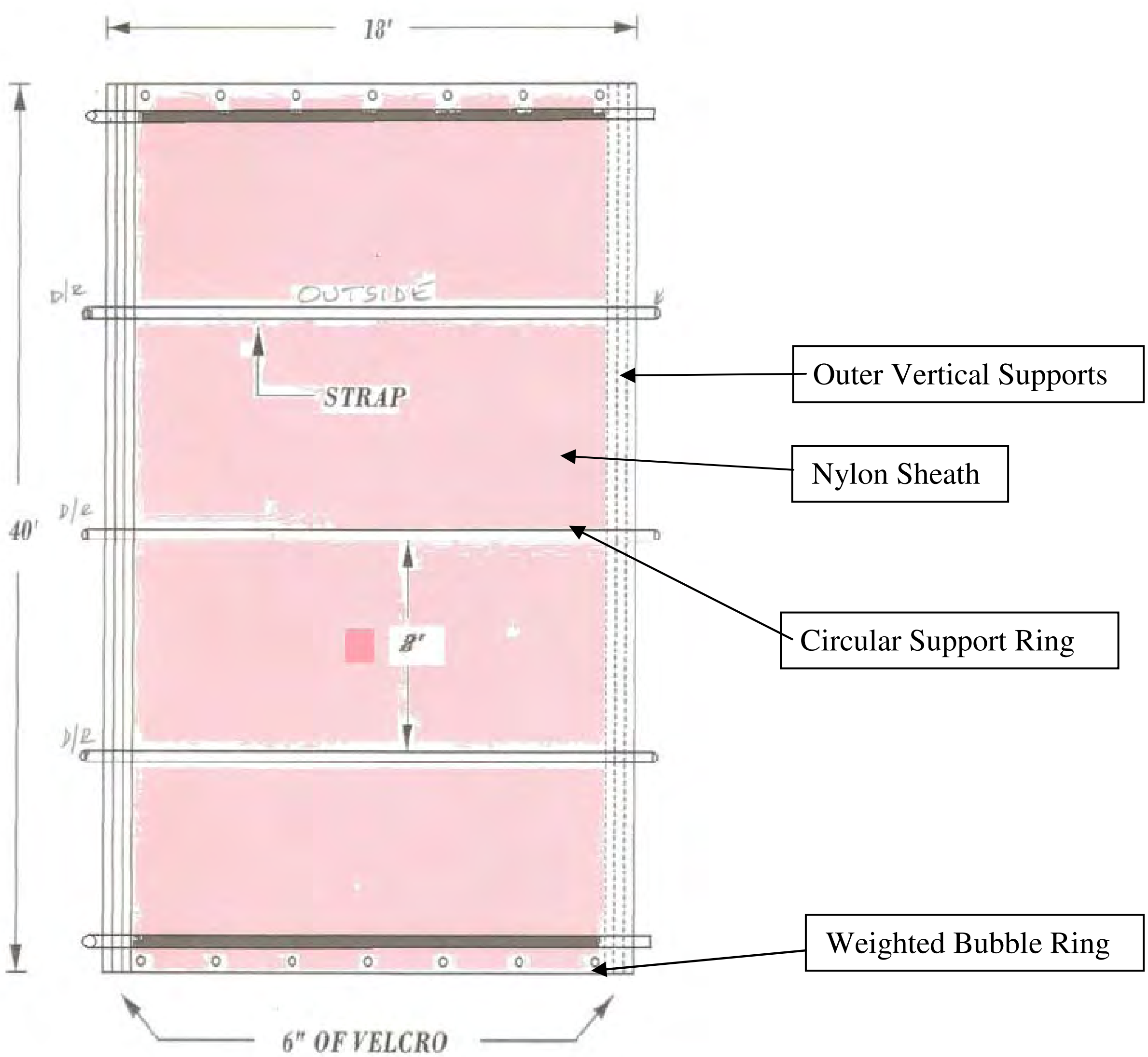


Figure 5: Diagram of confined bubble curtain.

RESULTS

UNDERWATER SOUND LEVELS

In the waveform figures below, each axis has the same scale for each pile. This will facilitate visual comparisons between piles with and without mitigation. There are many interesting attributes of the waveforms of different piles and mitigation types that will become evident. A brief description of the piles and pile types that were tested are as follows:

PILE 1

All piles were driven with a Del-Mag D30-32 diesel hammer. Pile 1 was driven in a water depth of 8 feet and utilized the confined bubble curtain for the entire drive with the bubbles on. The hydrophone for Pile 1 was located 11 meters from the pile. There was no data for the unmitigated condition.

Table 2 indicates the results of monitoring for Pile 1. The highest absolute peak from the hydrophone at 4 feet (midwater) is 194 dB_{peak}. The average RMS is 172 dB_{RMS}. The highest single strike SEL for the peak strike is 166 dB_{SEL}. As can be seen in Appendix A Figure 11 the waveform analysis for Pile 1 indicates that there was a relatively short delay between the initial onset of the impulse and the absolute peak (rise time of 3 milliseconds). This pile was not tested with the bubbles off due to a communication error.

The mitigated cumulative SEL in Table 2 exceeded the interim criteria of 187 dB_{SELcum} after 142 strikes or about half way through the drive.

PILE 2

Pile 2 was driven in water depth of 10 feet with a confined bubble curtain in place. The hydrophone for Pile 2 was located 11 meters from the pile. The bubbles were turned on for the first part of the drive but then turned off towards the end of the drive

Table 2 summarizes the results of monitoring for Pile 2. The highest absolute peak from the hydrophone at 5 feet (midwater) is 192 dB_{peak}. The average RMS is 169 dB_{RMS} with the bubble curtain on and 173 dB_{RMS} with the bubble curtain off. The highest single strike SEL for the peak strike at is 152 dB_{SEL} with the bubbles on and 163 dB_{SEL} with the bubbles off. As can be seen in Appendix A Figure 11 the waveform analysis for Pile 2 indicates that there was a relatively short delay between the initial onset of the impulse and the absolute peak (rise time of 4 milliseconds).

The cumulative unmitigated SEL in Table 2 did not exceed the criteria of 187 dB_{SELcum} after 20 strikes or the mitigated cumulative SEL after 315 strikes.

Figure 6 shows the differences between the few seconds when the bubble curtain was being effective and when the bubbles were completely turned off for Pile 2. Figure 6a indicates that the overall amplitude of the sound pressure levels was decreased when the bubble curtain was effective.

Table 2: Summary of Underwater Sound Levels for the Wahkiakum Ferry Terminal Project, Steel Piles.

Pile	Date	Mitigation Type	Hydrophone Depth (feet)	Peak (dB)	Avg. RMS ± s.d. (Pascals)	Avg. dB_{RMS}	Total # of Strikes	Avg. Peak ± s.d. (Pascals)	Avg. dB_{peak}	Avg. Reduction[1] (dB)	Single Strike SEL (dB)	Rise Time (millesec.)	Cumulative SEL (dB)	# of Strikes Over 187 dB (SEL_{CUM})
1	1/12/10	Bubbles On	4	194	416 ± 46	172	308	2964 ± 287	189	-	166	3	191	266
2	1/12/10	Bubbles On	5	179	297 ± 55	169	315	2520 ± 461	188	3	152	4	177	0
		Bubbles Off		192	444 ± 28	173	20	3572 ± 206	191	-	163	9	176	0
3	1/13/10	Bubbles On	5	188	395 ± 58	172	306	2759 ± 536	189	3	162	5.0	187	0
		Bubbles Off		195	507 ± 87	174	170	3954 ± 813	192	-	166	4.8	188	27
4	1/13/10	Bubbles On	5	189	323 ± 68	170	385	2368 ± 599	187	0	160	3.9	182	0
		Bubbles Off		195	294 ± 28	169	757	2157 ± 193	187	-	166	4.5	195	616
5	1/13/10	Bubbles On	6	185	350 ± 79	171	1069	568 ± 219	175	13	157	2.8	187	0
		Bubbles Off		194	481 ± 111	174	31	2777 ± 1138	188	-	166	1.3	181	0

[1] – Average reduction is calculated by subtracting the average peak sound level for the with bubbles scenario from the average peak unmitigated sound levels.

Figure 6b indicates that the effective bubble curtain was able to reduce most of the frequencies except for the lowest frequencies down to about 400 Hz. However, the amount that each frequency was reduced was only by a modest amount.

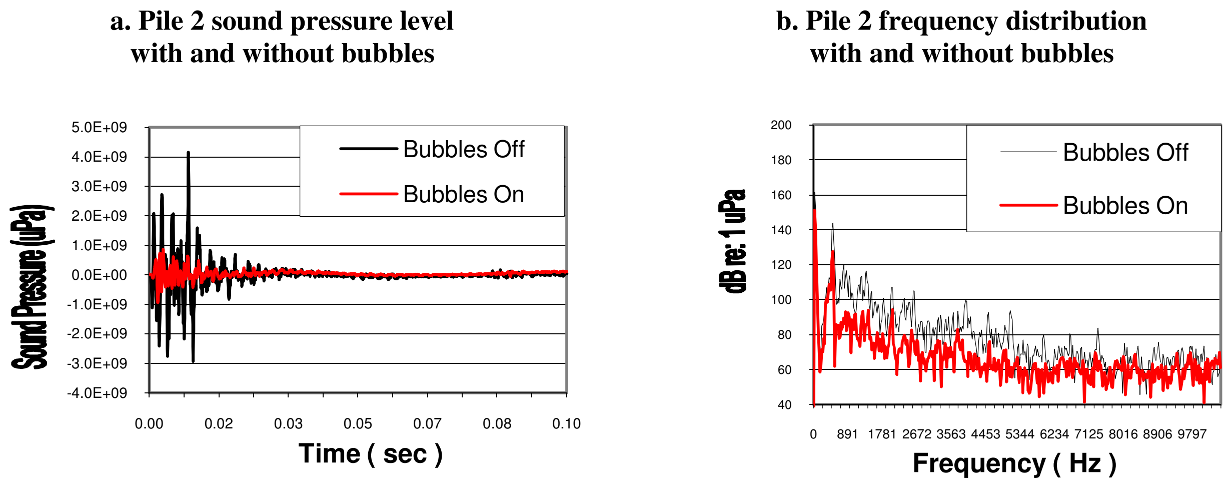


Figure 6: Waveforms and frequency spectral analysis for pile 2 with bubbles on and off.

PILE 3

Pile 3 was driven in water depth of 10 feet utilizing the confined bubble curtain. The hydrophone for Pile 3 was located 13 meters from the pile. The pile was driven with the confined bubble curtain in place.

Figure 7a indicates the difference between the two waveforms of the peak pile strike with and without the bubbles on. Figure 7b indicates the narrow band frequencies of the average of three successive pile strikes with and without the bubbles on. As Figure 7b shows there is little if any noise reduction with the bubbles turned on.

Table 2 indicates the highest absolute peak recorded for this pile was 195 dB_{peak} with the bubbles off. The highest unmitigated average RMS is 174 dB_{RMS}. The highest single strike SEL for the peak strike is 166 dB_{SEL} without the bubbles on. The average peak sound reductions achieved with the bubbles on is 3 dB.

The cumulative unmitigated SEL in Table 2 exceeded the criteria of 187 dB_{SELcum} after 142 strikes and the mitigated cumulative SEL did not exceed 187 dB_{SELcum} after 306 strikes.

a. Pile 3 Waveform with and without bubbles

b. Pile 3 frequency distribution with and without bubbles

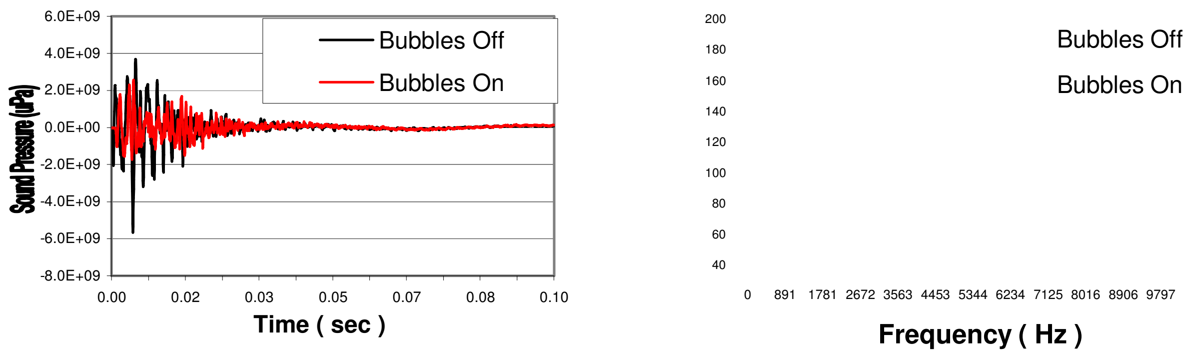


Figure 7: Waveforms and frequency spectral analysis for Pile 3 using a confined bubble curtain.

PILE 4

Pile 4 was driven in water depth of 10 feet with the bubble curtain in place and the bubbles turned on to begin.

Figure 8a indicates the difference between the peak strike waveform with and without bubbles. Figure 8a shows a modest reduction in the amplitude of the waveform with mitigation in place. Figure 8b indicates the narrow band frequencies of the average of three successive pile strikes with and without the bubbles on. As Figure 8b shows there is little if any noise reduction with the bubbles turned on.

Table 2 indicates the highest absolute peak recorded for this pile was 195 dB_{peak} with the bubbles off. The highest average RMS is without the bubbles is 170 dB_{RMS}. The highest single strike SEL for the peak strike is 166 dB_{SEL} without the bubbles. The cumulative unmitigated SEL in Table 2 exceeded the criteria of 187 dB_{SELcum} after 141 strikes and the mitigated cumulative SEL did not exceed 187 dB_{SELcum} after 385 strikes.

a. Pile 4 waveform with and without bubbles

b. Pile 4 frequency distribution with and without bubbles

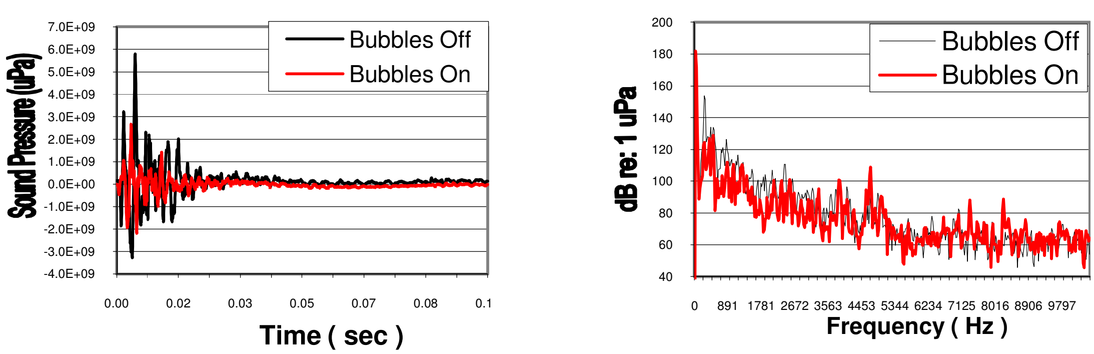


Figure 8: Waveforms and frequency spectral analysis for pile 4 using the TNAP.

PILE 5

Pile 5 was driven in water depth of 12 feet with the bubble curtain in place and the bubbles turned on to begin.

Figure 9a indicates the difference between the peak strike waveform with and without bubbles. Figure 9a shows an improved reduction in the amplitude of the waveform with the bubbles turned on.

In Figure 9b the narrow band frequencies of the average of three successive pile strikes comparing both with and without bubbles indicates that with mitigation there is a reduction in most of the mid range frequencies but not necessarily in the lowest and highest frequencies.

Table 2 indicates the highest absolute peak recorded for this pile was 194 dB_{peak} without bubbles. The highest average RMS is without bubbles off is 174 dB_{RMS}. The highest single strike SEL for the peak strike is 166 dB_{SEL} with bubbles off. The cumulative unmitigated SEL in Table 2 did not exceed the criteria of 187 dB_{SELcum} after 31 strikes and the mitigated cumulative SEL did not exceed 187 dB_{SELcum} after 1069 strikes. The average peak sound reductions achieved with the bubble curtain is 13 dB.

a. Pile P-8 with TNAP and bubbles **b. Pile P-8 (No Mitigation)**

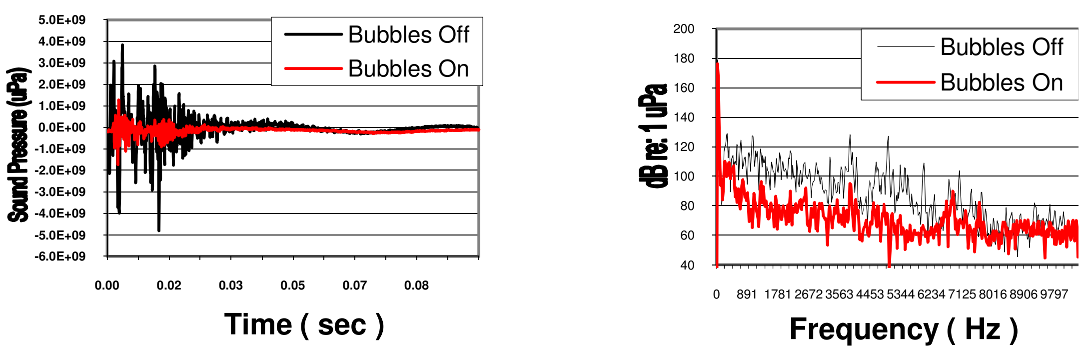


Figure 9: Waveforms and frequency spectral analysis for pile P-8 using the TNAP.

During the previous four piles the anticipated noise reduction from the bubble curtain was not being achieved. While driving Pile 4 it was noticed by the contractor that the outer sheath of the bubble curtain was storing air causing it to bulge at the surface. Figure 10 indicates what was discovered on the fourth pile driven and suspected of happening during the pile driving of the first three piles while the bubbles were turned on. Figure 10 shows the peak levels for each individual pile strike of Pile 2 with the bubbles on towards the left side of the chart. The bubbles were then turned off and then the peak noise levels dropped but then rose to their highest levels. After about 30 seconds the bubbles were turned on again and the sound levels dropped indicating a reduction in the noise levels. But then the noise levels rose again after a few seconds.

What was determined was happening is that as the confined bubble curtain was filling with bubbles the noise levels initially lowered while the bottom ring was still on the bottom. But then because there were no rigid vertical supports to the nylon containment fabric or enough weight to keep the bottom ring on the bottom it filled with air and became a lift bag capable of lifting the

150 pound weighted bottom ring from the bottom. This made the bubble curtain ineffective by providing a gap at the bottom which allowed noise to escape past the mitigation. When the bubbles were turned off for a short time to test the effectiveness of the bubble curtain, the bottom ring settled to the bottom but there was still enough air in the water around the pile to provide some brief noise reduction. But then as the air escaped from the bubble curtain the noise levels were unmitigated. The bubbles were turned on again and the bubble curtain functioned normally for a few seconds until the bottom ring lifted again. It was decided on Pile 5 that the outer nylon sheath would be completely removed to ensure that the bubble ring remained on the bottom substrate and that bubbles completely covered the pile. This strategy provided a 13 dB noise reduction for Pile 5.

Old timber piles rising out of the bottom substrate also prevented the bottom ring from seating itself properly on the bottom at some locations. There is nothing that can be done to remedy this situation.

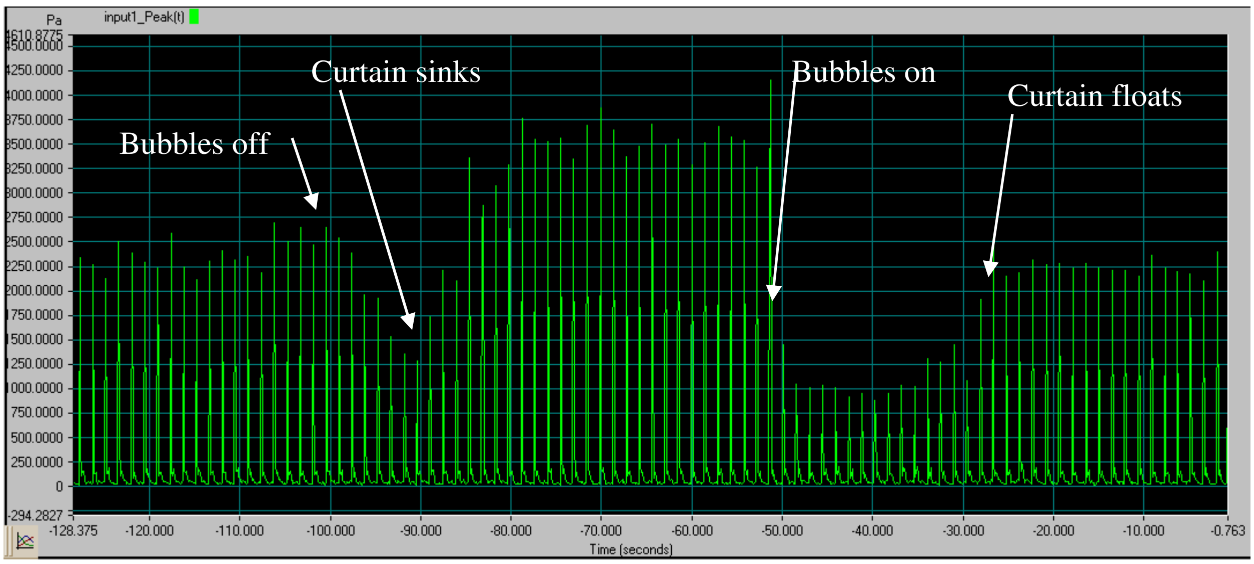


Figure 10: Chart of peak pile strikes with and without bubbles in confined bubble curtain.

SEL

SEL was calculated for the single highest absolute peak strike for each pile. All piles with the exception of pile 4 did not exceed the threshold of 187 dB_{SEL}.

A total of 643 pile strikes for the first two of five steel piles driven on 1/12/10 generated a cumulative SEL of 194 dB_{SEL} assuming a single strike SEL of 166 dB_{SEL}. A total of 2718pile strikes for the three remaining steel piles on 1/13/10 generated a cumulative SEL of 200 dB_{SEL} assuming a single strike SEL of 166 dB_{SEL}. Not all single strike SELs were at these levels and there were a few breaks in pile driving lasting a few minutes to hours each day.

Rise Time

Yelverton (1973) indicated rise time was the cause of injury. According to Yelverton (1973), the closer the peak is to the front of the impulse wave the greater the chance for injury. In other words, the shorter the rise time the higher the likelihood for effects on fish.

In all steel piles without effective mitigation the rise times were relatively short and those with mitigation had relatively long rise times. This could be an indication that the pile was ringing due to the relatively hard substrate or an indication of sound flanking where most of the energy was not traveling directly through the water but through the sediment up to the hydrophone. However, this relationship is not entirely clear.

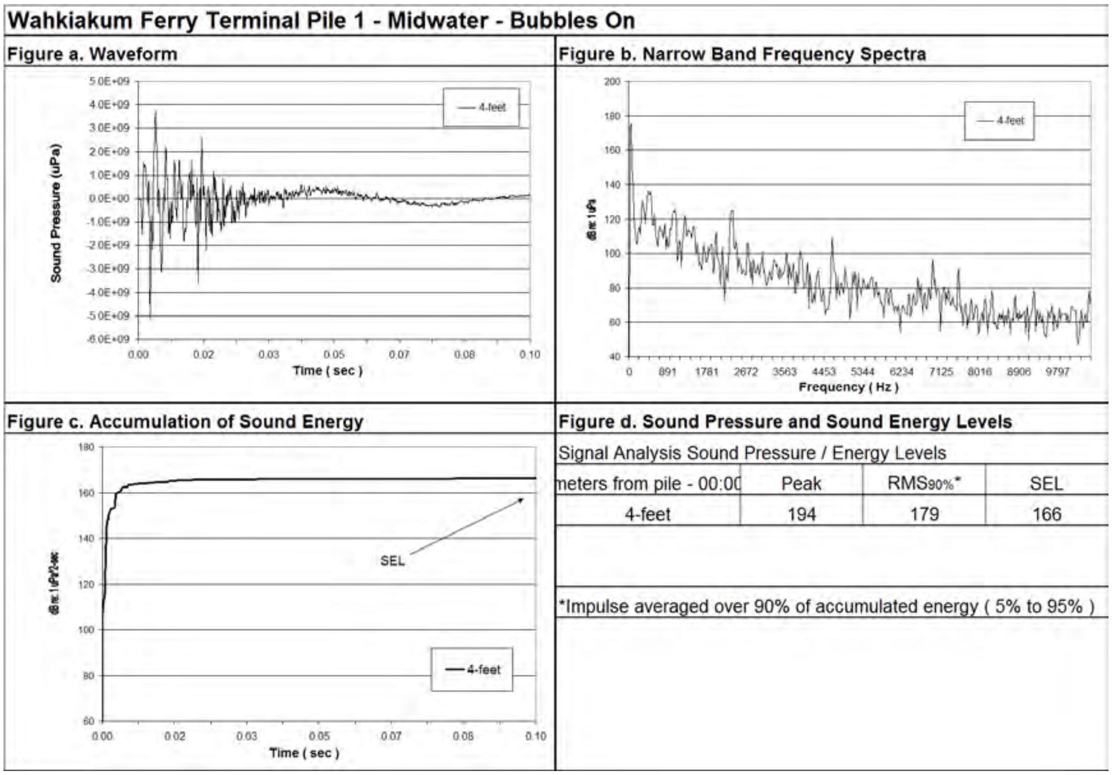
CONCLUSIONS

The confined bubble curtain ultimately provided an overall average noise reduction of 13 decibels. The bubble curtain was not performing adequately at first due to air being trapped within the nylon sheath and lifting the bottom bubble ring off of the substrate. Another factor keeping the bubble ring from seating properly on the substrate was the presence of old timber piles still present in the substrate. On some occasions the timber piles were immediately next to the steel pile being driven preventing the ring from making contact with the substrate.

As a result of these tests, it is recommended that future use of the confined bubble curtain in the current configuration should include vertical stiffeners or rigid material to keep air from being trapped in the outer sheath or to simply use an unconfined bubble curtain where tidal or river flows will allow. There is not much that can be done to eliminate the old wood piles from keeping the bubble ring from making contact with the substrate.

APPENDIX A– STEEL PILE WAVEFORM ANALYSIS FIGURES

PILE 1 – WITH BUBBLES



meters from pile - 00:00	Peak	RMS90%*	SEL
4-feet	194	179	166

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

Figure 11: Waveform analysis of Pile 1 sound pressure levels with mitigation, 4 feet water depth.

PILE 2 – WITH AND WITHOUT BUBBLES

Figure 12a

Wahkiakum Ferry Terminal Pile 2 - Midwater - Bubbles Off

Figure a. Waveform

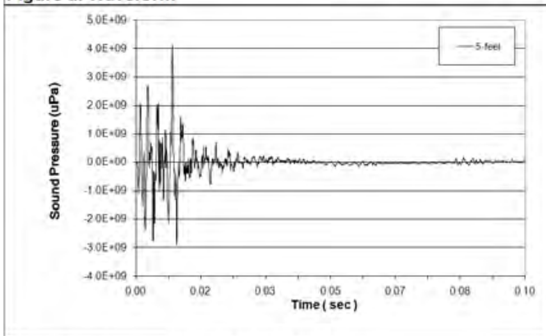


Figure b. Narrow Band Frequency Spectra

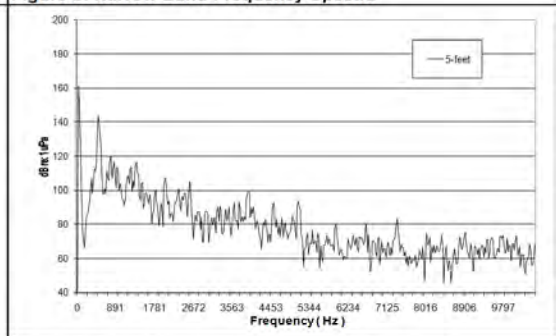


Figure c. Accumulation of Sound Energy

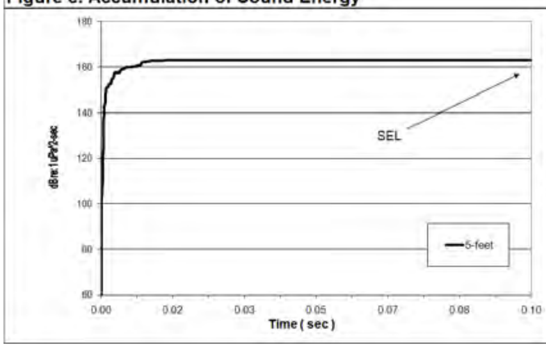


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	192	181	163

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

Figure 12b

Wahkiakum Ferry Terminal Pile 2 - Midwater - Bubbles On

Figure a. Waveform

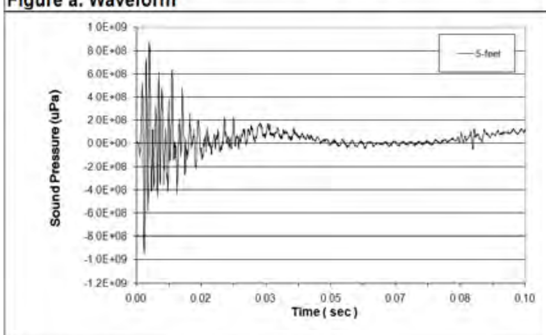


Figure b. Narrow Band Frequency Spectra

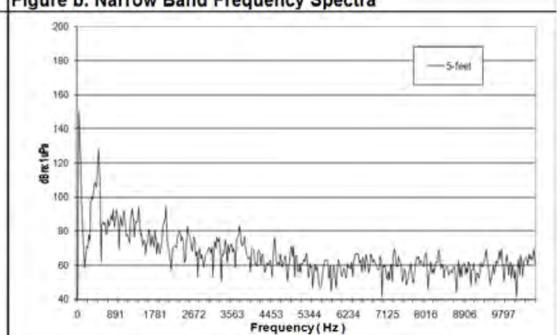


Figure c. Accumulation of Sound Energy

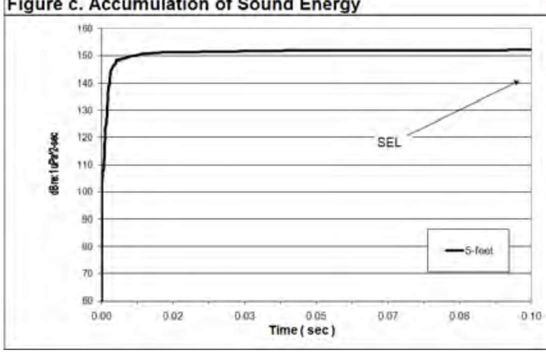


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	179	162	152

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

Figure 12: Waveform analysis of Pile 2 sound pressure levels with bubbles off (a) and bubbles on (b).

PILE 3 – WITH BUBBLES ON AND OFF

Figure 13a

Wahkiakum Ferry Terminal Pile 3 - Midwater - Bubbles Off

Figure a. Waveform

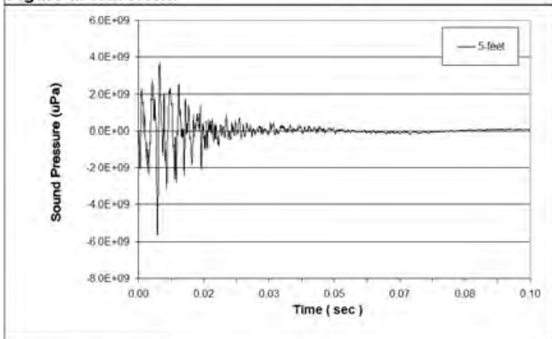


Figure b. Narrow Band Frequency Spectra

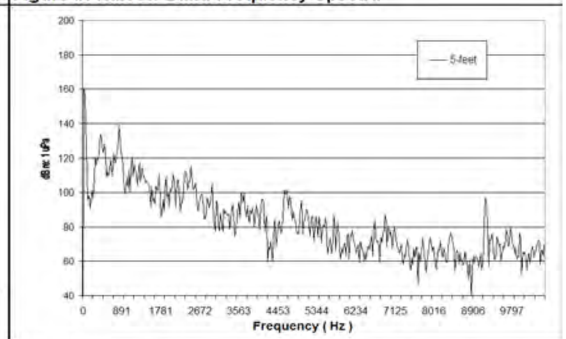


Figure c. Accumulation of Sound Energy

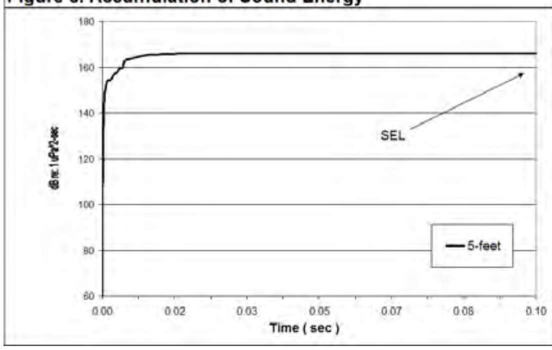


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	195	184	166

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

Figure 13b

Wahkiakum Ferry Terminal Pile 3 - Midwater - Bubbles On

Figure a. Waveform

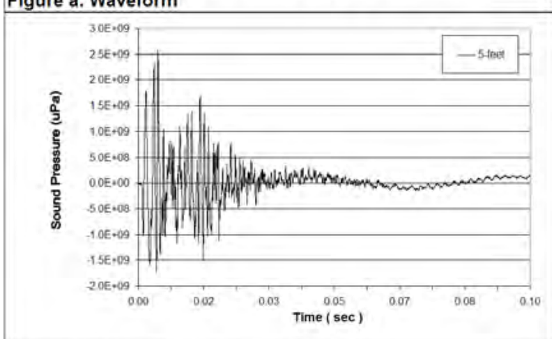


Figure b. Narrow Band Frequency Spectra

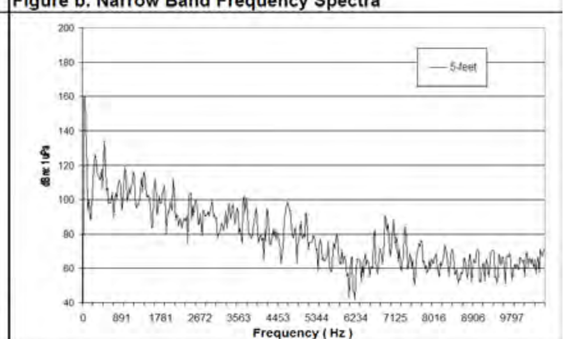


Figure c. Accumulation of Sound Energy

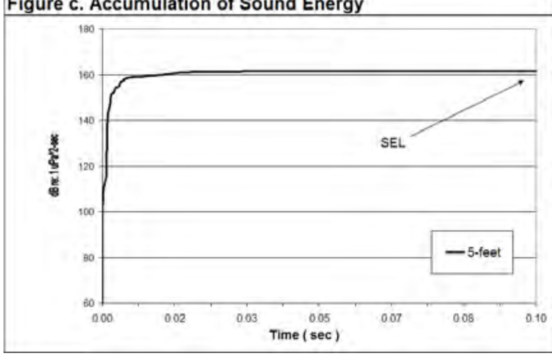


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	188	177	162

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

Figure 13: Waveform analysis of Pile 3 sound pressure levels without (a) and with Bubbles (b), midwater.

PILE 4 – WITH BUBBLES ON AND OFF

Figure 14a

Wahkiakum Ferry Terminal Pile 4 - Midwater - Bubbles Off

Figure a. Waveform

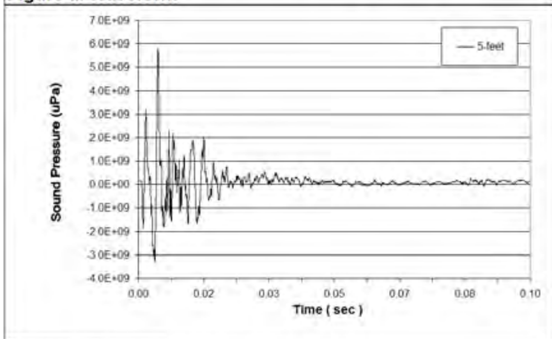


Figure b. Narrow Band Frequency Spectra

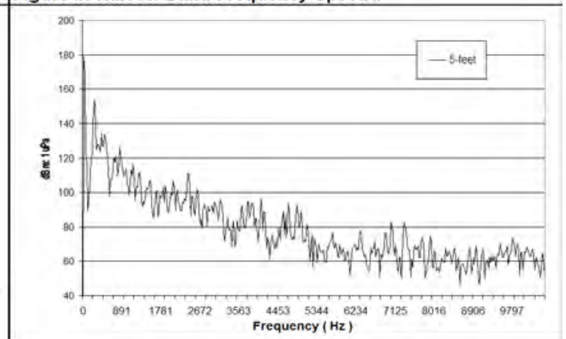


Figure c. Accumulation of Sound Energy

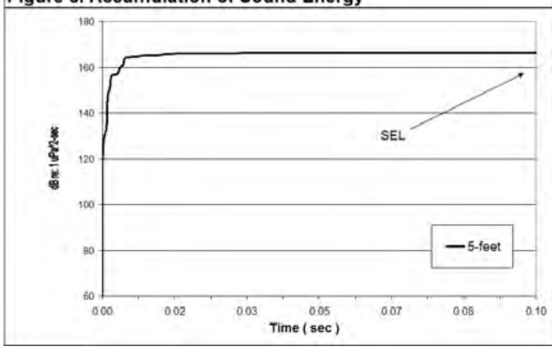


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	195	183	166

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

Figure 14b

Wahkiakum Ferry Terminal Pile 4 - Midwater - Bubbles On

Figure a. Waveform

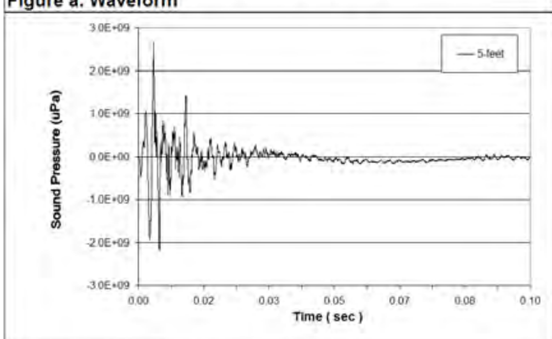


Figure b. Narrow Band Frequency Spectra

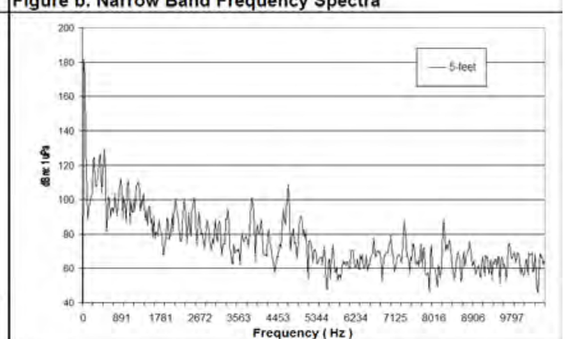


Figure c. Accumulation of Sound Energy

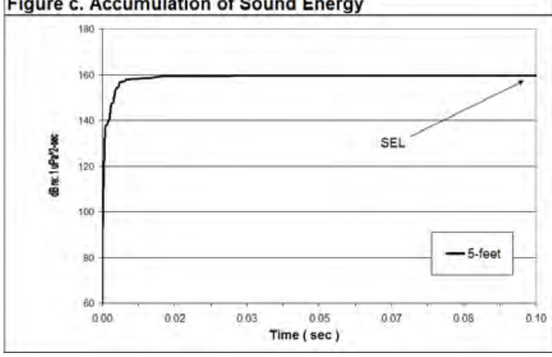


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

meters from pile - 00:00	Peak	RMS90%*	SEL
5-feet	189	174	160

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

Figure 14: Waveform analysis of Pile 4 sound pressure levels without (a) and with (b) bubbles, midwater.

PILE 5 – WITH BUBBLES ON AND OFF AND NO SHROUD

Figure 15a

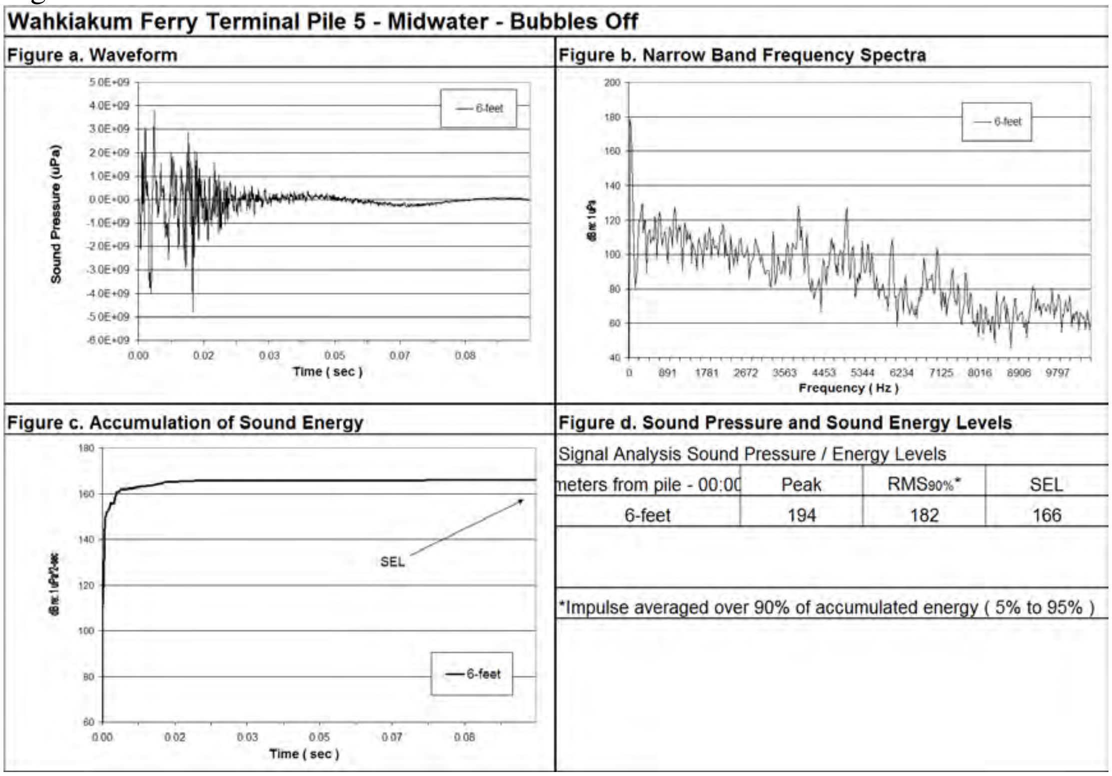


Figure 15b

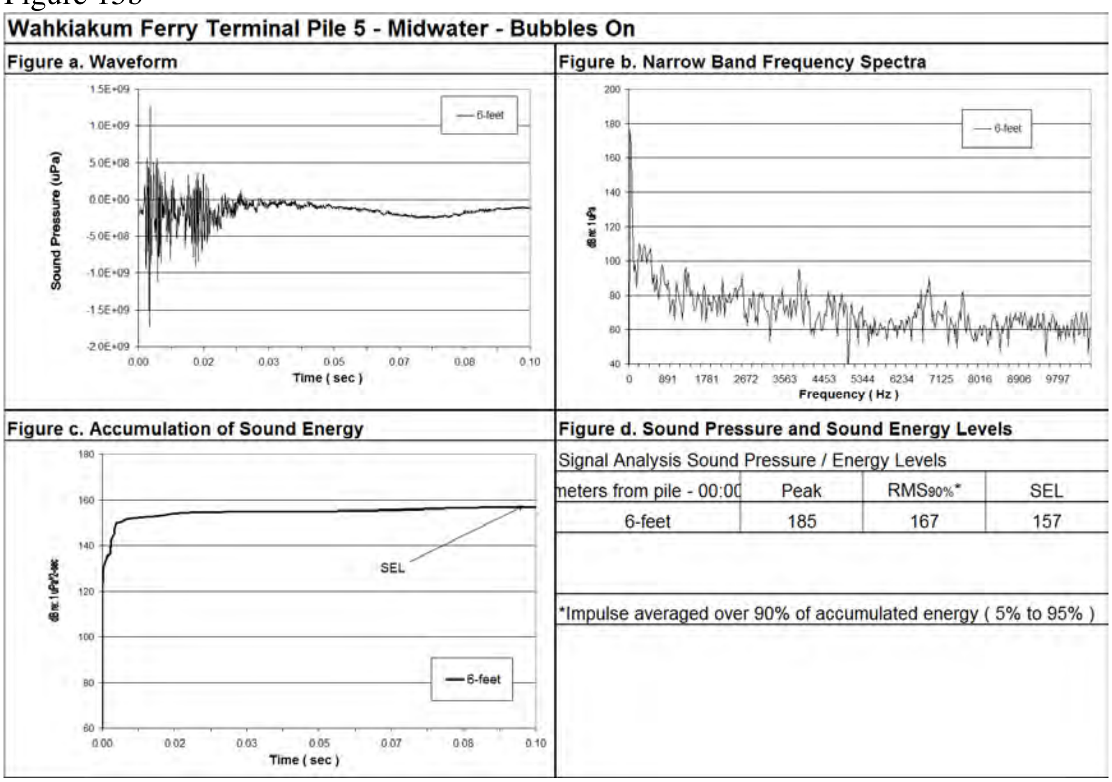


Figure 15: Waveform analysis of Pile 5 sound pressure levels without (a) and with (b) bubbles, midwater.