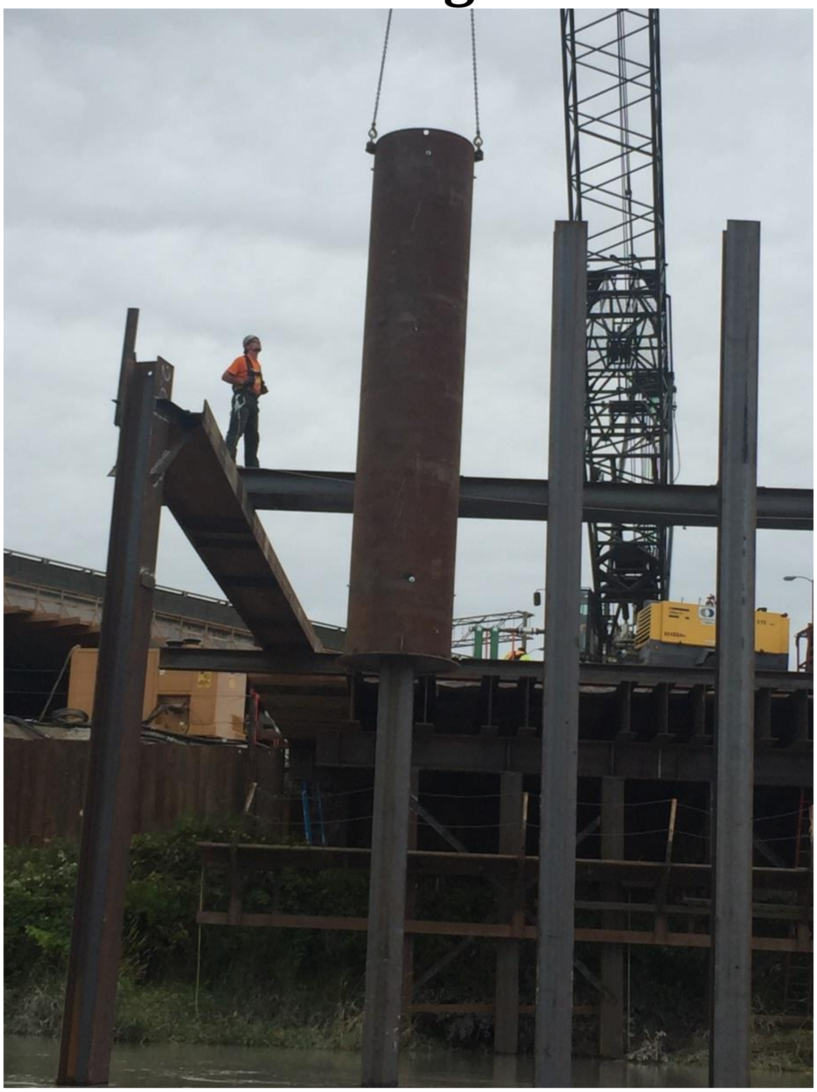
Underwater Sound Level Report: Puyallup River Bridge at I-5



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

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ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
s.d.	standard deviation
SEL	Sound Exposure Level
SL	sound level, regardless of descriptor
SPL	sound pressure level
USFWS	U.S. Fish and Wildlife Service
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the data collected during impact pile driving and monitoring of underwater sound levels from driving the 14-inch steel H-piles for the Washington State Department of Transportation (WSDOT) Interstate 5 (I-5) Tacoma HOV Project between July 2015 and October 2015. Data was collected for five 14-inch H-piles. Three of the piles monitored were located on the north side of the Puyallup River and two were located on the south side of the river. A confined bubble curtain was deployed for all but two piles impact driven in water depths greater than two feet (one un-attenuated pile on each side of the river) to attenuate potential underwater noise effects. All measurements were collected 10 meters from the pile at midwater depth. Measurements from 3H, where H is the water depth at the pile were not needed because 3H locations happened to be about the same distance as the10 meter locations.

For piles on the north side of the river, none of the monitored piles exceeded the cSEL threshold of 197 dB_{cSEL}. The peak attenuated sound levels measured ranged between 161 dB_{peak} and 181 dB_{peak}. Results of monitoring the impact pile driving operation are shown in Table 1.

Table 1: Summary of 14-in H-Piles Un-attenuated and Attenuated Underwater Sound Levels.

Pile #	Date	Pile Size (inches)	cSEL Threshold (dB)	Peak at 10 meters (dB)	RMS (dB)	Single Strike SEL (dB)	Cumulative SEL (dB)	Exceedance?
1*	7/24/15	14	197	198	183	166	181	No
2	8/4/15	14	197	188	163	155	173	No
3	8/4/15	14	197	178	167	159	161	No
4*	10/5/15	14	197	203	180	164	189	No
5	10/5/15	14	197	191	174	160	184	No

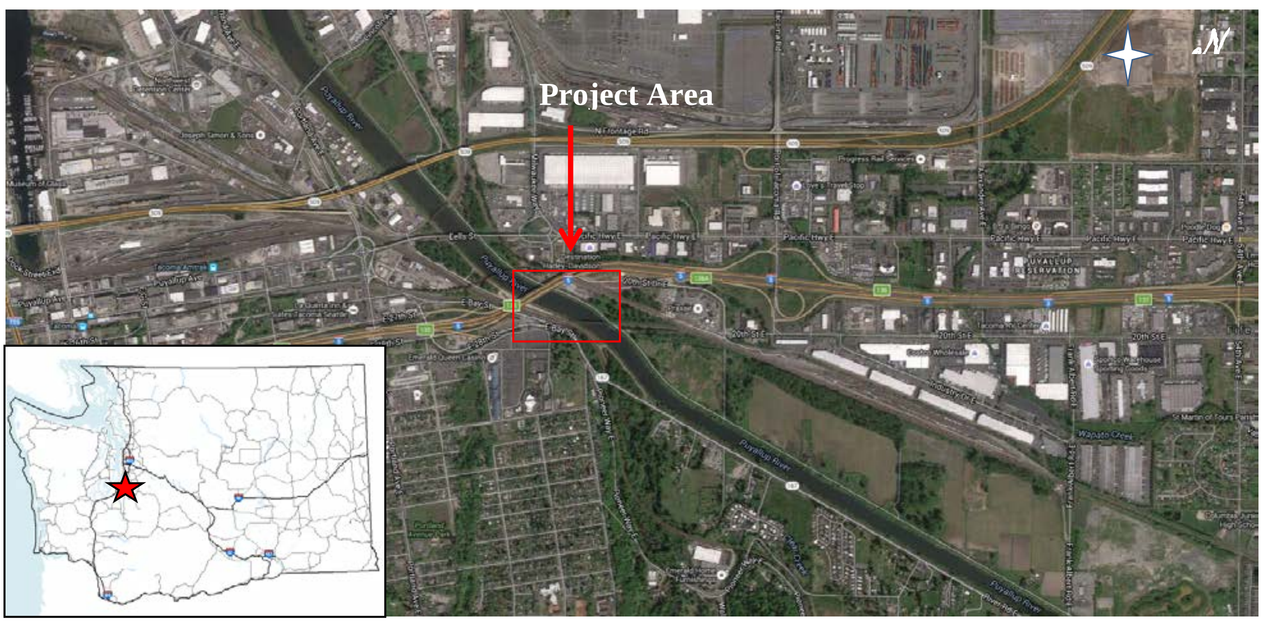
*un-attenuated

For piles on the south side of the river, none of the piles monitored exceeded the cSEL threshold of 197 dB_{cSEL}. The highest peak attenuated sound level ranged between 191 dB_{peak} and 203 dB_{peak}. A summary of results of monitoring the impact pile driving operation are shown in Table 1.

INTRODUCTION

WSDOT proposes to create two new HOV lanes, one in each direction of travel, along a 3.14-mile section of I-5 between Port of Tacoma Road and M Street. For constructability reasons the project is broken into three parts: M street to Portland Avenue HOV, Northbound Portland Avenue to Port of Tacoma Road HOV (NB) and Southbound Portland Avenue to Port of Tacoma Road (SB). HOV bypass lanes and ramp metering on existing lanes would be created on existing on-ramps at the Port of Tacoma Road/20th Avenue East interchange. The proposed NB and SB projects will construct two new crossings over the Puyallup River with a change in alignment and remove the existing Puyallup River I-5 bridges. The proposed NB project will construct a new I-5 northbound bridge over the Puyallup River. The proposed SB project will remove the existing bridge and construct the southbound I-5 bridge. Bridge demolition and new bridge construction would require the installation of permanent and temporary piles in the Puyallup River to support the new bridge crossings and the temporary work trestles.

Figure 1: I-5 Tacoma HOV Project Work Trestle



PROJECT AREA

The NB and SB project limits extend from milepost (MP) 134.62 to 136.63 along the I-5 corridor in Pierce County, beginning at Portland Avenue in Tacoma and ending at approximately the I-5/Port of Tacoma Road interchange in Fife, extending across the Puyallup River. They lie within Sections 1 through 4, 8 through 13, 37, and 38, Township 20 North, Range 3 East (USGS 1981).

All piles were driven with a vibratory hammer initially.

PILE INSTALLATION LOCATION

Five steel H-piles installed during the initial pile driving activity on the north and south side of the Puyallup River were monitored. Figure 3 indicates the approximate location of the temporary work trestles to construct the new Puyallup River crossing. A maximum of 250 piles were driven as part of the temporary work trestles and shaft casing templates.

The hydrophone is located at 10 meters from the piles. Monitoring at a range of 3H, where H is the water depth of the pile, was not necessary because the distance 3H was 10 meters or less.

Hydroacoustic monitoring of steel H-pile driving included:

- Measurement of noise levels at 10 meters from the pile.

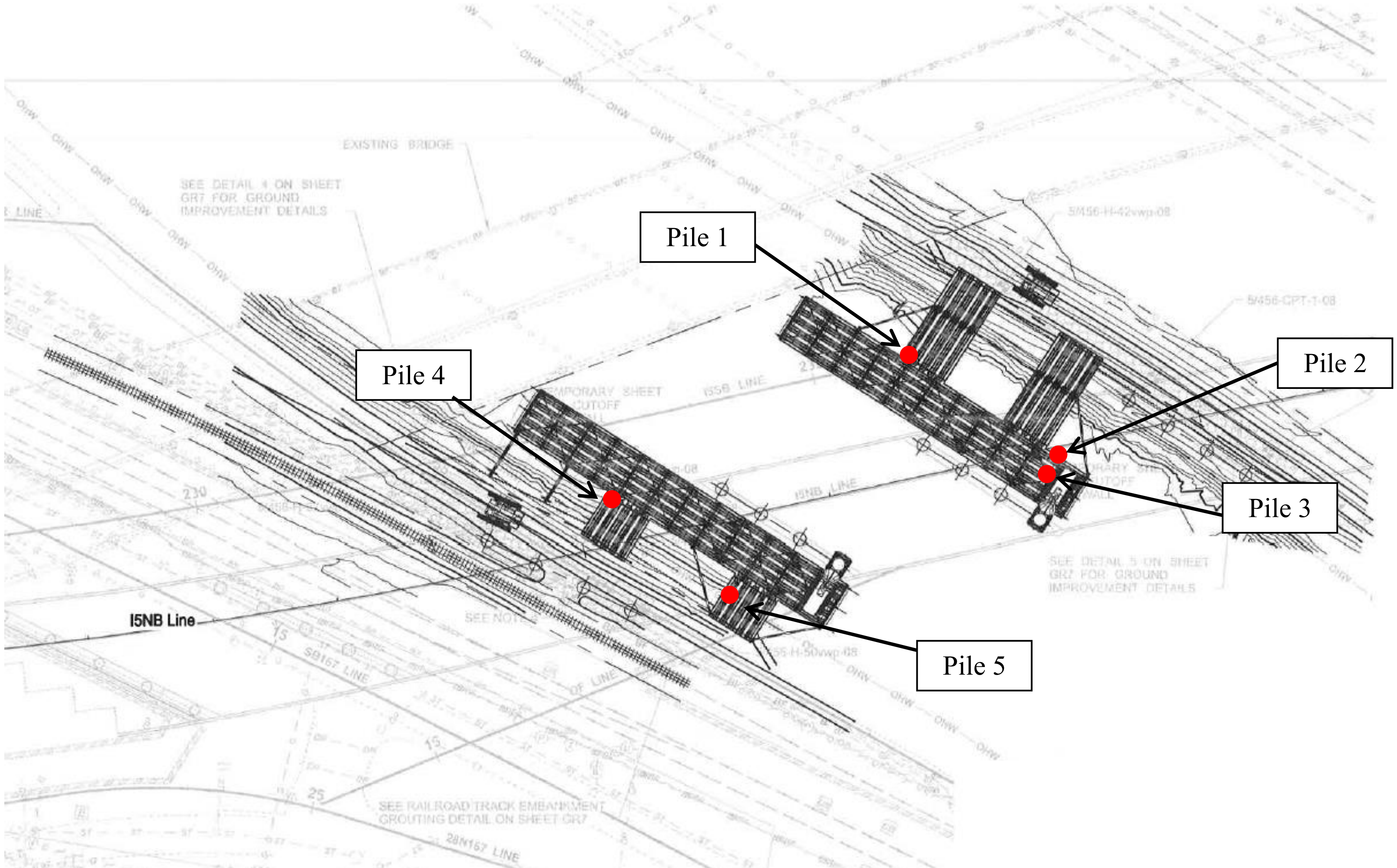
Table 2 lists the structure installed, the water depth, and the number and size of piles that were installed.

Table 2. Structures to be installed for the SR 520 West Approach Bridge North

Structure	Water Depth	Structural Components Installed
Temporary Work Trestle	*5 feet to 10 feet*	*Five 14-inch steel H-piles*

Figure 2 indicates the location of the piles monitored. The hydrophones were placed at least 1 m (3.3 feet) below the surface at a range of 10 meters and midwater depth. Each pile has a clear acoustic line-of-sight between the pile and the hydrophone.

Figure 2: The work trestles on the north and south shore of the Puyallup River



UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse. The peak SPL is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The majority of literature uses peak sound pressures to evaluate barotrauma injury to fish. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa. The equation to calculate the sound pressure level is:

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

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. It has been used by the National Marine Fisheries Service (NMFS) in criteria for judging effects to marine mammals from underwater impulse-type sounds.

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

dB = 10*LOG (sum of squared pressures in the band) (eq. 1)

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 (acoustically summing the pressure level at all frequencies) of a broadband (20 Hz to 20 kHz) sound exceeds the level in any single 1/3-octave band.

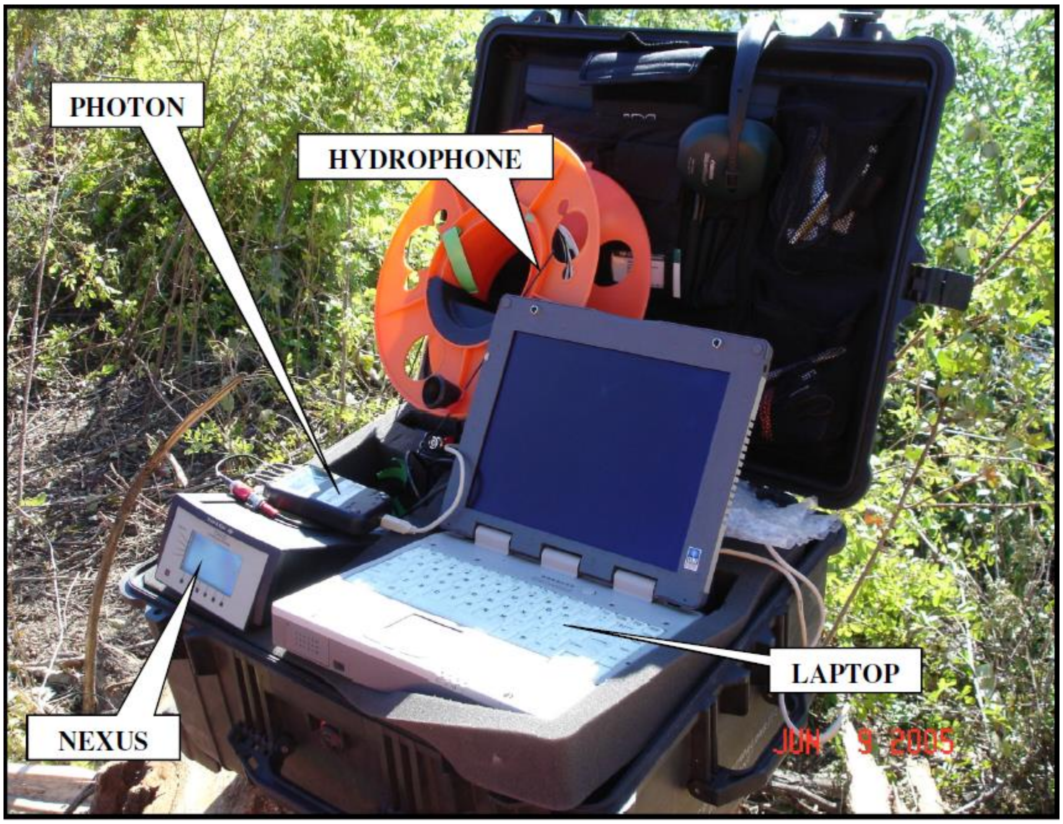
METHODOLOGY

Typical Equipment Deployment

The hydrophone was deployed from the shoreline near the piles. The monitoring equipment is outlined below and shown in Figure 7. The hydrophone was stationed and fixed with anchors and a surface float at a nominal distance of 10 meters from the pile.

A confined bubble curtain was deployed for all piles driven to attenuate underwater noise.

Figure 3: Near Field Acoustical Monitoring Equipment



Five steel H-piles, initially vibratory driven, were monitored with the sound attenuation bubble curtain system active when proofed with impact hammer. One pile on each side of the river was impacted without a bubble curtain active to test the effectiveness of the bubble curtain.

Underwater sound levels were measured near the piles using a Reson TC 4013 hydrophone deployed on a weighted nylon cord from the monitoring location. The hydrophone was positioned at a distance of 10 meters in most cases and at mid-water depth. 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, shown in Figure 7. The output of the Nexus signal conditioner is received by a Brüel and Kjær Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer similar to the one shown in Figure 7.

The equipment captures underwater sound levels from the pile driving operations in the format of an RTPro signal file for processing later. The WSDOT has the system and software calibration checked annually against NIST traceable standard.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 15.3 μs (25,600 Hz). This sampling rate provides 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 variability between the absolute peaks for each pile impact 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.

The $RMS_{90\%}$ was calculated for each individual impact strike. Except where otherwise noted the $SEL_{90\%}$ was calculated for each individual impact strike using the following equation:

$$SEL_{90\%} = RMS_{90\%} + 10 \text{ LOG } (\tau) \qquad \text{(eq. 2)}$$

Where τ is the 90% time interval over which the $RMS_{90\%}$ value is calculated for each impact strike. Then the cumulative SEL (cSEL) is calculated by accumulating each of these values for each pile and each day.

For those recordings where it was not possible to calculate the $SEL_{90\%}$ for each pile strike the cumulative SEL was calculated using the following equation.

$$cSEL = SEL_{90\%} + 10 \text{ LOG (total number of pile strikes)} \qquad \text{(eq. 3)}$$

The following peak thresholds were applied to this project.

For H-piles
• 197 $dB_{C\text{-}SEL}$ at 32.8 feet (10 meters)

RESULTS

Underwater Sound Levels

WSDOT monitored a total of five 14-inch steel H-piles for underwater noise. Data from all piles are analyzed in the paragraphs below and summarized in Table 3.

North Side of Puyallup River

Pile 1

Pile 1 is located approximately 30 feet from the north shore of the Puyallup River (Figure 2). The pile was driven without the confined bubble curtain and had an absolute un-attenuated peak value of 198 dB_{peak} at 10 meters (Table 3). The un-attenuated $RMS_{90\%}$ was 183 $dB_{RMS90\%}$ (Table 3). The cSEL at 10 meters was 181 dB cSEL calculated based on the accumulation of the single strike SEL for each pile strike (Table 3) and did not exceed the 197 dB cSEL threshold for this project. The distance to the 197 dB_{cSEL} threshold using the practical spreading model from the pile location is 36 feet from the pile.

Pile 2

Pile 2 is located approximately 30 feet from the north shore of the Puyallup River and approximately 30 feet to the east of Pile 1 (Figure 2) and was driven using a confined bubble curtain. The pile had an absolute attenuated peak value of 188 dB_{peak} at 20 meters (Table 3). The attenuated $RMS_{90\%}$ was 163 $dB_{RMS90\%}$ at 20 meters. The cSEL at 20 meters calculated by accumulating the single strike SEL calculated for each pile strike is 173 dB_{cSEL} and did not exceed the 197 dB_{cSEL} threshold for this project (Table 3). The distance to the 197 dB cSEL threshold using the practical spreading model from the pile location is 68 feet.

Pile 3

Pile 3 is located approximately 30 feet east of Pile 2 and approximately 30 feet from the north shore of the Puyallup River (Figure 2). The pile was driven with a confined bubble curtain and had an absolute attenuated peak value of 178 dB_{peak} at 25 meters. The attenuated $RMS_{90\%}$ at 25 meters is 167 $dB_{RMS90\%}$ (Table 3). The cSEL at 20 meters calculated by accumulating the single strike SEL calculated for each pile strike is 161 dB_{cSEL} and did not exceed the 197 dB_{cSEL} threshold for this project (Table 3). The distance to the 197 dB_{cSEL} threshold using the practical spreading model from the pile location is 82 feet.

Table 3: Summary of Underwater Broadband Sound Levels for the I-5 Tacoma HOV Project

Pile #	Date & Time	H-Pile Diameter (inches)	Hydrophone Range (m)	Hydro phone Depth (feet)	Bubble Curtain Status	Total Number Of Strikes	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	Single Strike $SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Average Reduction (dB)[1]	Cumulative SEL (dB)
1	7/24/15 3:14 PM	14	10	2	Off	83	198	183	166	3821±1699	714±240	-	181
2	8/4/15 1:46 PM	14	20	4	On	135	188	163	155	834±372	125±46	11	173
3	8/4/15 2:06 PM	14	25	2	On	11	178	167	159	562±90	98±54	13	161
4	10/5/15 8:30 AM	14	10	2	Off	416	203	180	164	4831±1881	841±254	-	189
5	10/5/15 8:53 AM	14	10	2	On	557	191	174	160	1693+448	340+56	9	184

[1]-Average Peak back calculated to 10 meters to compare to un-attenuated average RMS to determine average reduction.

South Side of Puyallup River

Pile 4

Pile 4 is located approximately 30 feet from the south shore of the Puyallup River (Figure 2). This pile was driven without a confined bubble curtain and had an absolute un-attenuated peak value of 203 dB_{peak} at 10 meters. The un-attenuated $RMS_{90\%}$ at 10 meters is 180 $dB_{RMS90\%}$ (Table 3). The cSEL calculated based on each measured pile strike at 10 meters is 189 dB_{cSEL} and did not exceed the 197 dB_{cSEL} threshold for this project (Table 3). The distance to the 197 dB_{cSEL} threshold is 40 feet from the pile.

Pile 5

Pile 5 is located approximately 30 feet from the south shore of the Puyallup River and approximately 30 feet from Pile 4 (Figure 2). This pile was driven with a confined bubble curtain and had an absolute attenuated peak value of 191 dB_{peak} at 10 meters (Table 3). The attenuated $RMS_{90\%}$ at 10 meters is 174 $dB_{RMS90\%}$ (Table 3). The cSEL calculated based on each measured pile strike at 10 meters is 184 dB_{cSEL} and did not exceed the 197 dBcSEL threshold for this project (Table3). The distance to the 197 dB_{cSEL} threshold is 38 feet from the pile.

Daily Cumulative SEL

The daily cSEL's were calculated using an actual $SEL_{90\%}$ for each individual pile strike for each day and accumulated over that period (Table 4).

Table 4: Summary of daily cumulative SEL's

Day	10M
North Side of Puyallup River	
7/24/15	181
8/4/15	173
South Side of Puyallup River	
10/5/15	190

The daily cumulative SEL values ranged from 173 to 190 dB at the 10 meter location. None exceeded the 197 dB_{cSEL} threshold.

CONCLUSIONS

A total of five, 14-inch steel H-piles were monitored for the construction of the I-5 Tacoma HOV project. The underwater sound levels analyzed, produced the following results.

North Side of Puyallup River:

- Peak underwater attenuated sound levels at 10 meters varied in a range between 182 dB_{Peak} and 195 dB_{Peak} .
- The measured $RMS_{90\%}$ levels at 10 meters ranged between 166 dB_{RMS} and 171 dB_{RMS}.
- Cumulative Sound Exposure Levels (cSEL) at 10 meters for all piles driven on a particular day, ranged between 173 dB_{cSEL} and 181 dB_{cSEL} which did not exceed the 197 dB_{cSEL} threshold.
- The distance measured from the pile location to the 197 dB_{cSEL} threshold ranged between 68 feet and 82 feet from the pile.

South Side of Puyallup River:

- Peak underwater attenuated sound levels at 10 meters ranged between 191 dB_{Peak} and 203 $dB_{peak.}$
- The measured attenuated $RMS_{90\%}$ level of the 10 meter measurement was 174 dB_{RMS}.
- Cumulative Sound Exposure Levels (cSEL) for all piles driven at 10 meters on one day was 190 dB_{SEL}.
- The distance measured from the 10 meter location to the 197 dB_{cSEL} threshold is between 38 and 40 feet.

APPENDIX A WAVEFORM ANALYSIS FIGURES

Figure 4: Waveform Analysis of un-attenuated Pile 1, 10M

I-5 Tacoma HOV 14 inch H Pile 1 at 10m Broadband

Figure a. Waveform

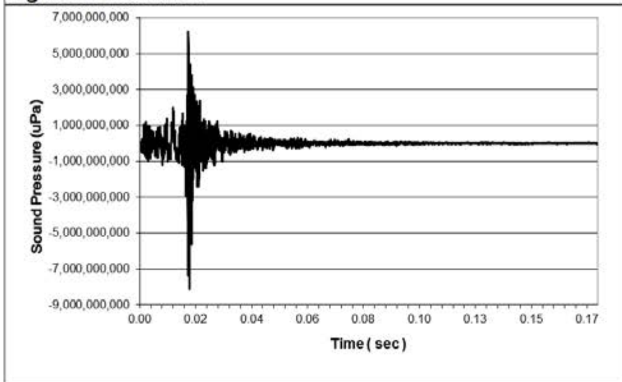


Figure b. Narrow Band Frequency Spectra

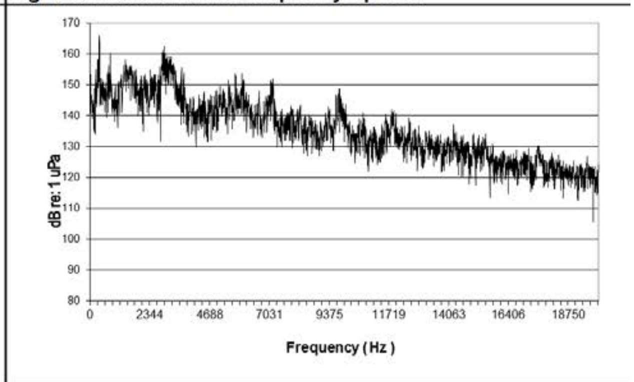


Figure c. Accumulation of Sound Energy

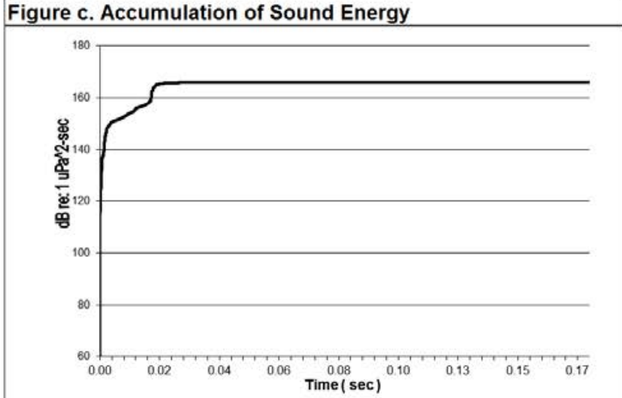


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

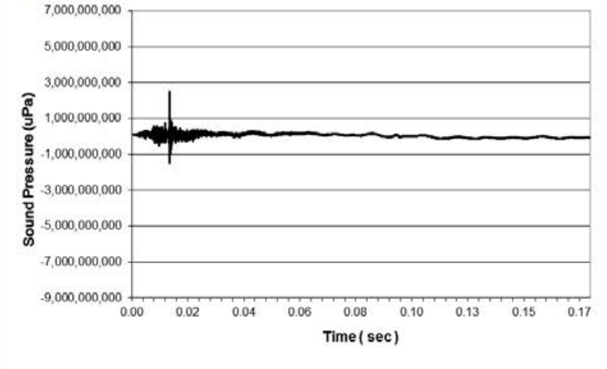
Sensor Depth	Peak	$RMS_{90\%}$*	SEL
2-feet	198	183	166

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

Figure 5: Waveform analysis of attenuated Pile 2, 20M

I-5 Tacoma HOV 14 inch H Pile 2 at 20m Broadband

Figure a. Waveform



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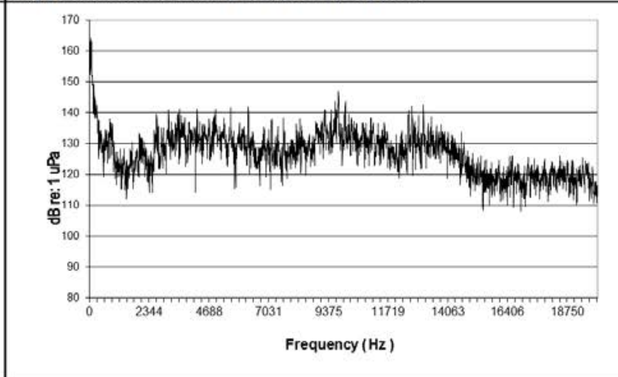


Figure c. Accumulation of Sound Energy

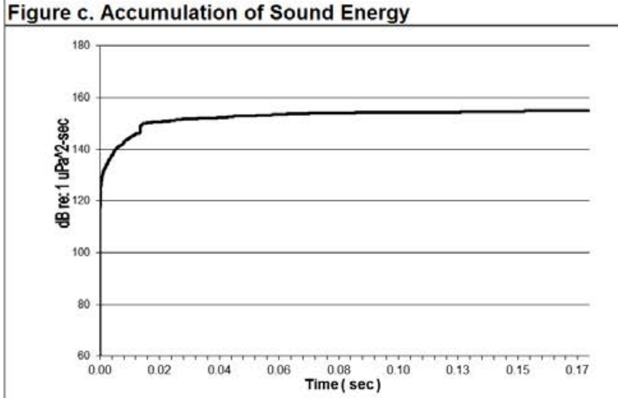


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

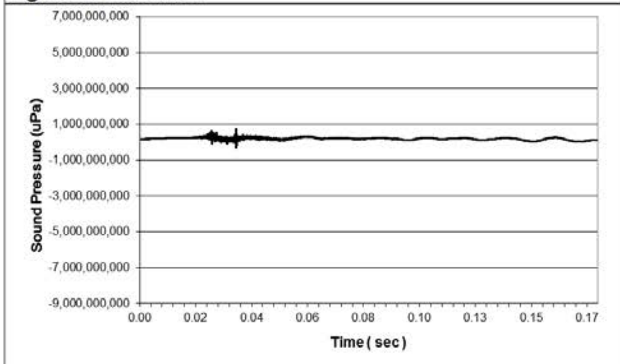
Sensor Depth	Peak	RMS90%*	SEL
4-feet	188	163	155

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

Figure 6: Waveform analysis of attenuated Pile 3, 25M

I-5 Tacoma HOV 14 inch H Pile 3 at 25m Broadband

Figure a. Waveform



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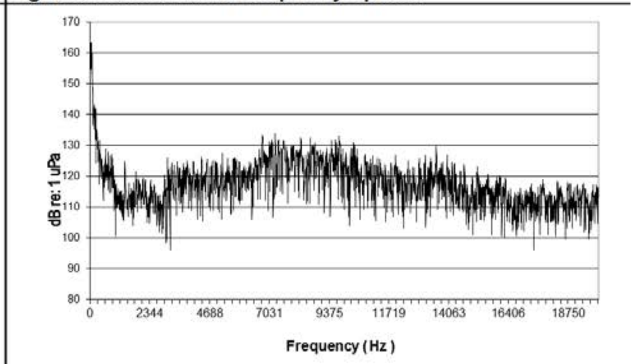


Figure c. Accumulation of Sound Energy

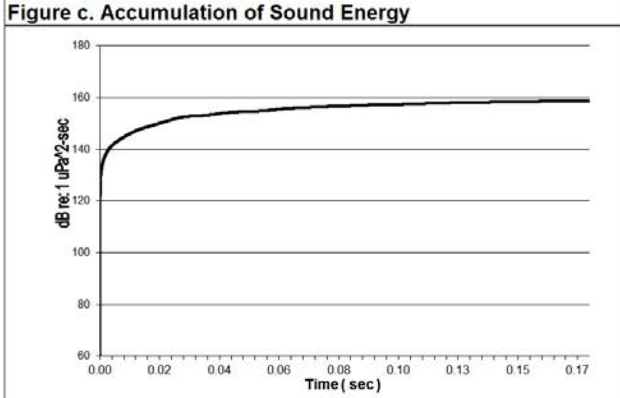


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

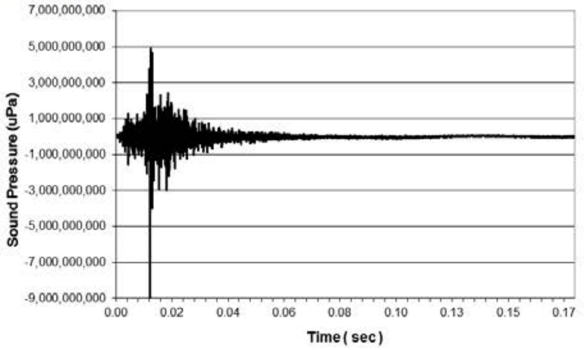
Sensor Depth	Peak	RMS90%*	SEL
2-feet	178	167	159

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

Figure 7: Waveform analysis of un-attenuated Pile 4, 10M

I-5 Tacoma HOV 14 inch H Pile 4 at 10m Broadband

Figure a. Waveform



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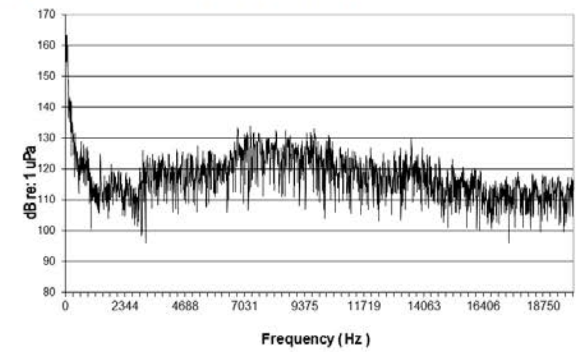

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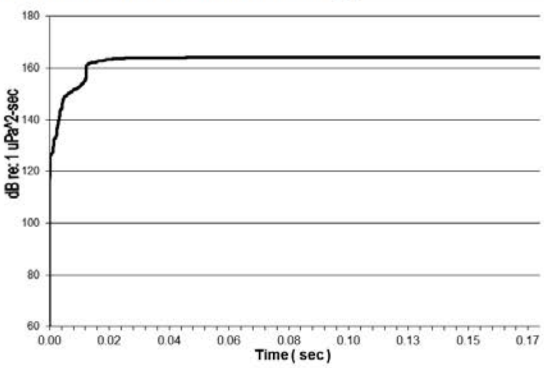


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

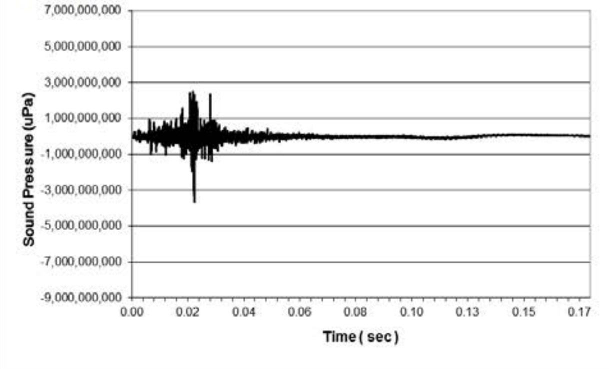
Sensor Depth	Peak	$RMS_{90\%}$*	SEL
2-feet	203	180	164

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

Figure 8: Waveform analysis of attenuated Pile 5, 10M

I-5 Tacoma HOV 14 inch H Pile 5 at 10m Broadband

Figure a. Waveform



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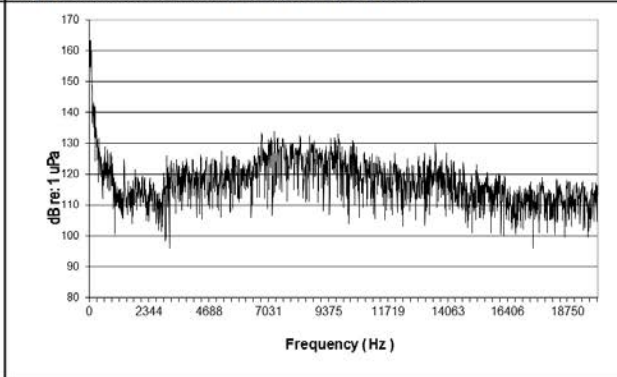

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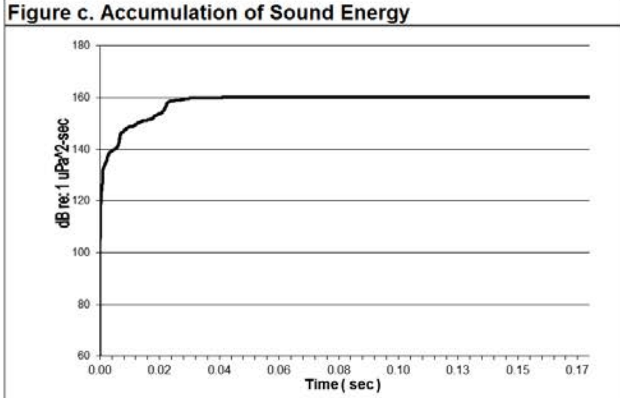

Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
2-feet	191	174	160

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