SR 520 BRIDGE

Concrete Pier Demolition Underwater Sound Levels: SR 520 East Approach Bridge Demolition

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ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
L_{50}	Statistical measure of the median value over the measurement period where 50 percent of the measured values are above the L_{50} and 50 percent are below.
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
$RMS_{90\%}$	The square root of the energy divided by the impulse duration
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
WSF	Washington State Ferries
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the data collected during demolition of the former SR 520 bridge concrete piers using hoe-rams on October 12, 2016. The August 6, 2016 monitoring plan required monitoring of four piers; two (2) at each end of the former SR 520 bridge. However, only two of the piers were monitored on the east side because the contractor used an alternative demolition technique where no hoe-rams were utilized for the other piers. The underwater monitoring of sound levels during demolition was performed on the east side of the former SR 520 bridge below the OHWM (Ordinary High Water Mark) on Lake Washington. The data was collected from a hydrophone, 3 meters deep, and placed at a fixed range of 10 meters to Pier 1 and 15 meters to Pier 2 where the hoe-rams were operating at midwater depth, 4 meter (14 feet) below the OHWM.

There was no mitigation used to attenuate the underwater operations. Two hoe rams were operating simultaneously. There was no exceedance of the dB_{peak} interim threshold for fish of 206 dB_{peak} at 10 meters. The peak un-attenuated sound levels measured ranged between 177dB_{peak} and 193 dB_{peak}. Results of monitoring the hoe-ram pier demolition operation are shown in Table 1.

During the monitoring of the pier demolition, there were no observable distressed fish or bird behavior in the immediate area.

Table 1: Summary of Hoe-Ram Pier Demolition Un-Attenuated Underwater Sound Levels.

Recording #	Date	Range Meters	Peak Threshold (dB)	Absolute Highest Peak (dB)	RMS90% (dB)	Single Strike SEL90% (dB)	Cumulative SEL (dB)	Exceedance?
1	10/12/16	10-15	206	193	174	163	168	No

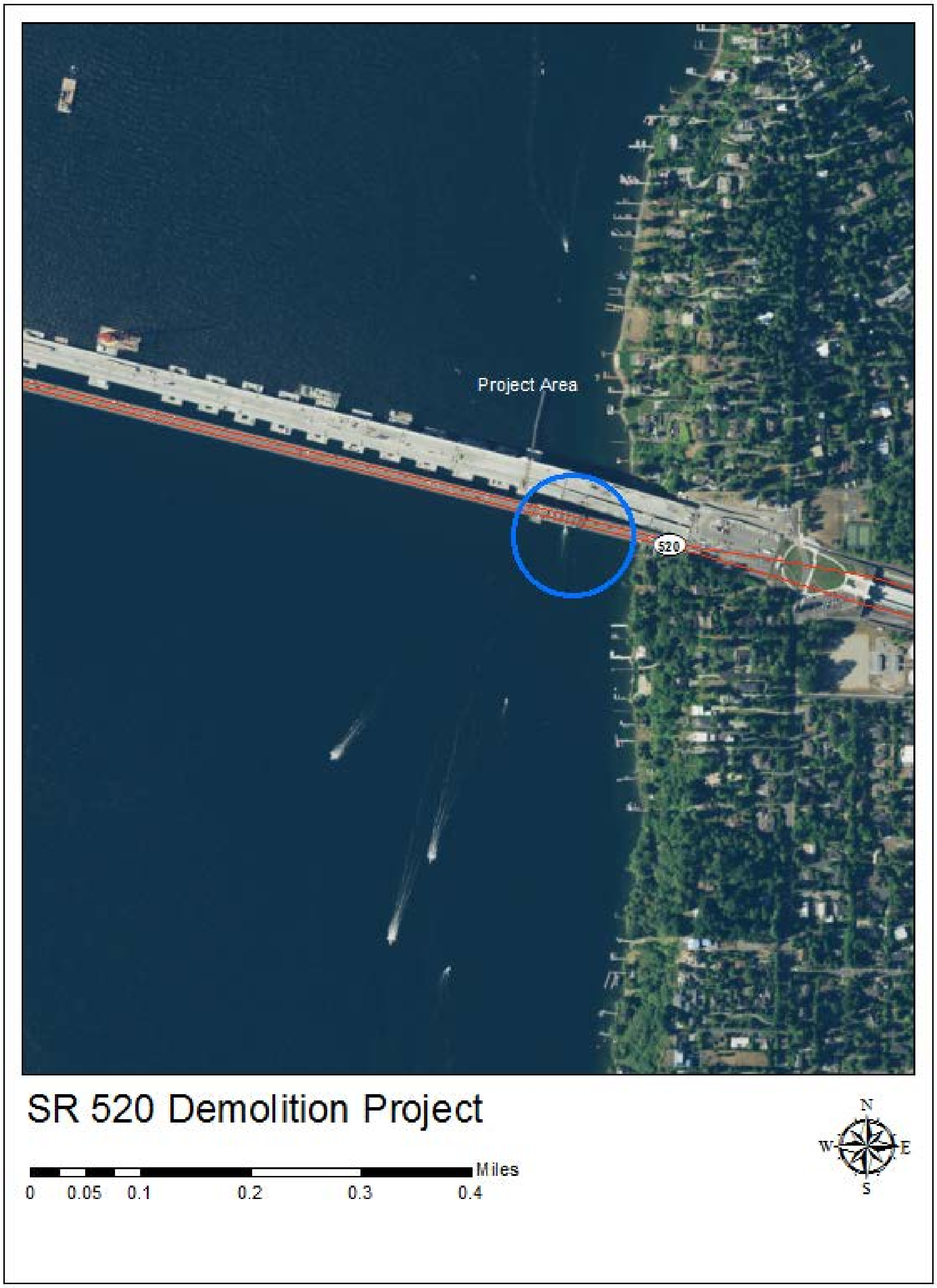
INTRODUCTION

The Washington State Department of Transportation (WSDOT) demolished existing concrete piers on the structurally deficient and functionally obsolete SR 520 floating bridge approaches; which were replaced by a new bridge. This report details the monitoring and underwater sound levels produced during demolition of two concrete piers on the eastside of Lake Washington. The contractor employed other methods to demolish the piers at the west side of the former SR 520 bridge, and so they were not monitored.

Project Area

The project is located in Township 25N, Range 5E, Section 24, Willamette Meridian, in King County, WA. on the southeastern side of the new SR 520 floating bridge, immediately west of the city of Medina in King County, WA. Specifically, the project is located within WRIA 8 (Cedar-Sammamish). Figure 1 indicates the approximate location of the concrete piers that were simultaneously demolished using hoe-rams.

Figure 1: SR 520 Bridge Project Demolition



Pier Demolition Location

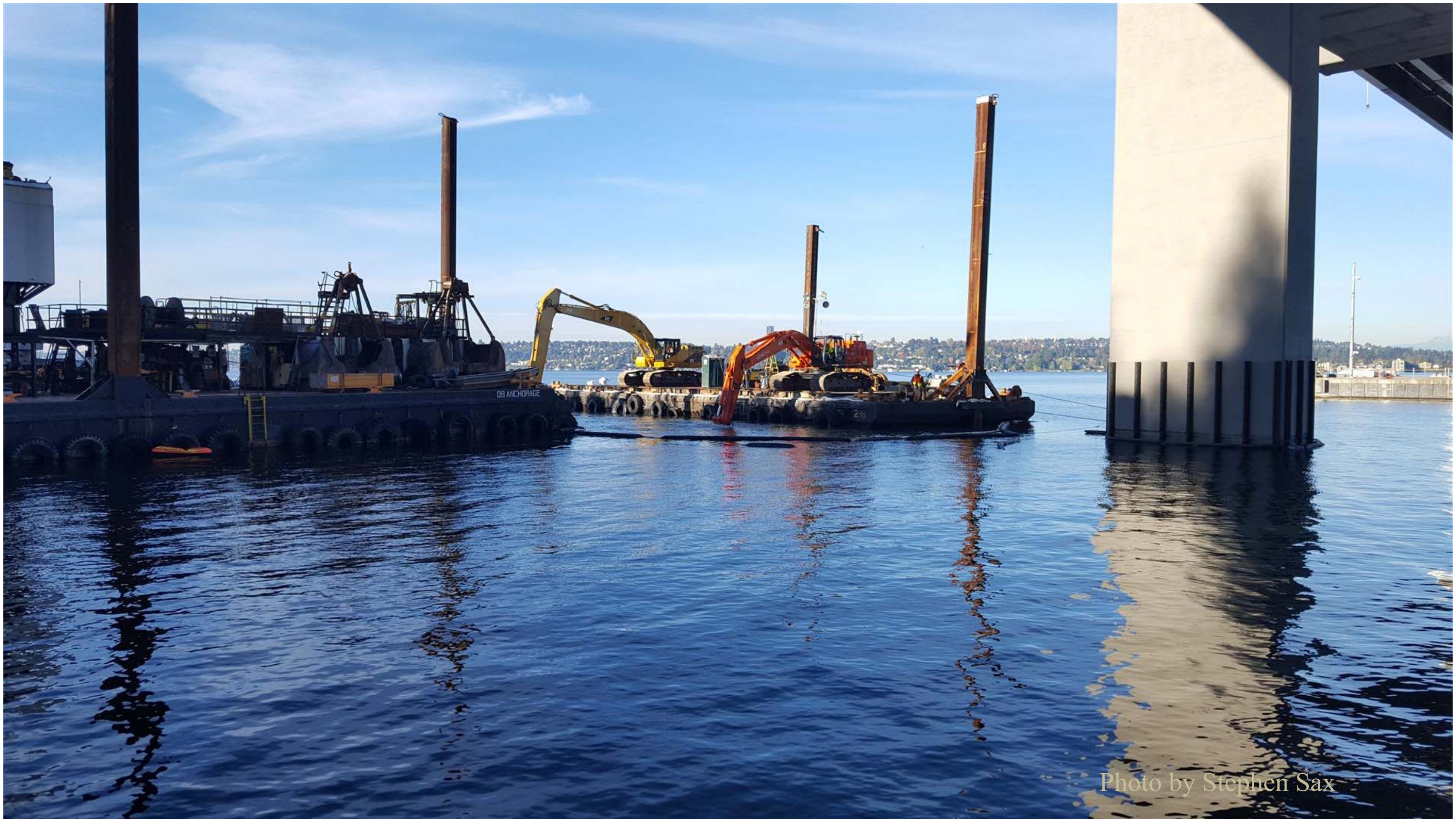
A total of two concrete piers located at the east approach of the former SR 520 bridge were monitored for underwater sound levels. At the time of monitoring, the tip/head of the hoe-rams were 4 meters (14 feet) below the OHWM of Lake Washington.
Table 2 lists the structure monitored, the water depth, and the pier type that was demolished.

Table 2. Pier demolition location

Structure Monitored	Water Depth	Type of structure
SR 520 east approach pier	*4.2 meter (14 feet)*	*Concrete Pier*

Figure 2 shows the location of the hoe rams on the barge, taken from the boat where the monitoring equipment was located. Each pier had a clear acoustic line-of-sight between the pier and the hydrophone.

Figure 2: The Relative Locations of the Hoe Rams during Monitoring of the piers



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 Pascale (Pa) or decibels (dB) referenced to a pressure of 1 micro Pascal (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.

The L_{50} or 50^{th} percentile is a statistical measure of the median value over the measurement period where 50 percent of the measured values are above the L_{50} and 50 percent are below.

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

Hydroacoustic monitoring was conducted during the demolition of two concrete piers from the former SR 520 Bridge. The piers were demolished with a hoe ram operating below the ordinary high water surface (OHWM). The underwater sound levels of the demolition of the piers were monitored while the tip/head of the hoe ram is underwater for a period between 2 and 5 minutes to get a representative sample.

Hydroacoustic monitoring of demolition of the concrete piers include:

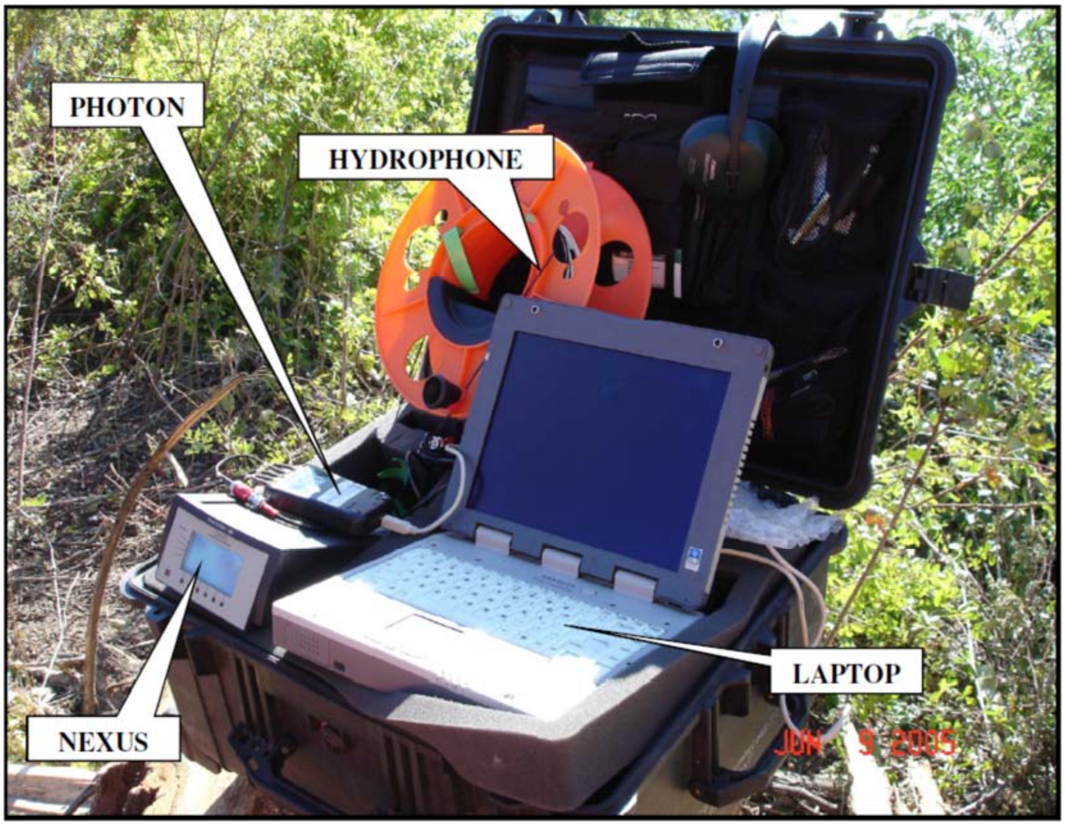
- Measuring underwater sound levels while hoe ram was 4 meters below the water surface.
- Two monitored signals of approximately 5 and 2 minutes duration.
- The contractor used two hoe-rams, model HB 4100, and the technical data specification are detailed as follows.

Carrier weight class	40 - 70 t
Service weight	4100 kg
Oil flow	250 - 320 l/min
Operating pressure	160 - 180 bar
Impact rate	280 - 550 blows/min
Working tool diameter	180 mm
Working length of tool	820 mm
Max. hydraulic input power	96 kW

Typical Equipment Deployment

The monitoring equipment is outlined below and shown in Figure 3.

Figure 3: Near Field Acoustical Monitoring Equipment



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 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 3. 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 3.

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.

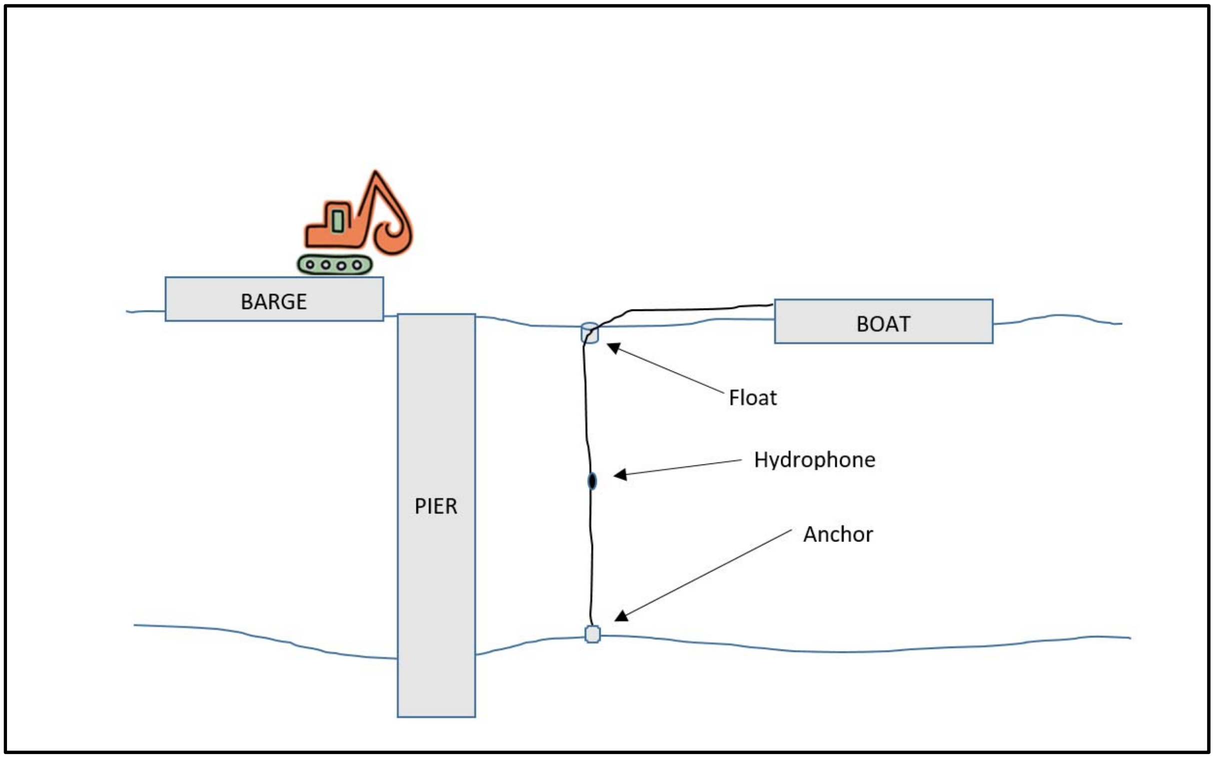
Signal analysis software provided with the Photon was set at a sampling rate of one sample every 20.8 μs (18,750 Hz). This sampling rate provides sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

Due to the variability between the absolute peaks for each impact strike, an L_{50} peak and L_{50} RMS value was computed to give an indication of the average value.

Hydrophone Location

The hydrophone was stationed and fixed with anchors and a surface float at a nominal distance of 10 meters (33feet) to 15 meters (49 feet) from the tip/head of the hoe rams. The hoe ram head/tips were submerged 4 meters (14 feet) below the OHWM. The distance from the pier to the hydrophone location was measured using a Bushnell Yardage Pro rangefinder. The hydrophone was attached to a weighted nylon cord anchored with 7.5 pound weights. The cord and hydrophone cables were lowered to a mid-water depth of 3 meters (10 feet) as shown in Figure 4, where H is the depth of the water at 10 meter from the demolition pier.

Figure 4: Diagram of Hydrophone Deployment Configuration.



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 was calculated for each impact strike. Then the cumulative SEL (cSEL) was calculated by accumulating each of these values for each pier and each day.

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

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

The following thresholds were applied to this project.

Pier Demolition

- 206 dB_{peak} at 32.8 feet (10 meters)

Calculation of distance using the practical spreading model where the 206 dB_{peak} threshold will occur is detailed as follows:

$$R_2 = R_1 * 10^{((\text{dB at } R_1 - \text{dB acoustic threshold})/15)}$$

Where R_1 is distance of a known or measured sound level, R_2 is the estimated distance that is required for a sound to attenuate to a prescribed acoustic threshold and 15 represents the attenuation factor for the practical spreading model.

Initially, the NMFS and U.S. Fish and Wildlife Service (USFWS) did not evaluate potential effects from noise generated through the demolition of the concrete piers with a hoe ram. The only data available at that time was Dolat (1997) and, based on the misinterpretation of his results, it was assumed the sound levels would be similar to a vibratory hammer waveform. However, after closer examination of the Dolat (1997) paper it was found that he simplified the results of his measurements to approximate a sine wave form which for current analysis purposes is an inaccurate assumption. However, the SR 303 Manette Bridge Demolition Project report (2012) shows that the waveform from a hoe ram is nearly identical to impact pile driving waveforms.

RESULTS

Underwater Sound Levels

WSDOT monitored the simultaneous demolition of two concrete piers being demolished at the eastside of SR 520. Signal analysis is detailed below and summarized in Table 3.

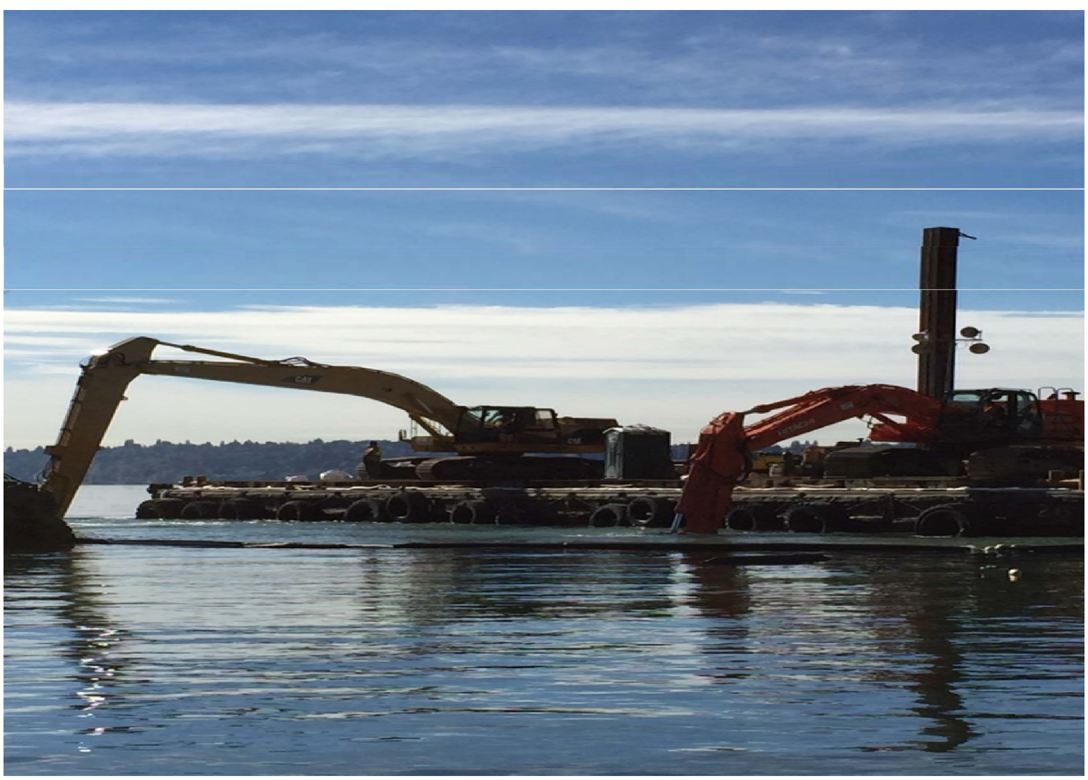
Pier 1

Data analysis indicates that the hoe rams working simultaneously at both of the concrete piers had an absolute un-attenuated peak value of 193 dB_{peak} at 10 meters (33 feet). This data shows that the hoe-rams did not exceed the 206 dB_{peak} threshold. The un-attenuated $RMS_{90\%}$ was measured at 174 dB_{RMS} and the un-attenuated cSEL was measured to be 163 dB_{cSEL}. The distance to the 206 dB_{peak} threshold using the practical spreading model from the pier location was 1.4 meters (4.6 feet) for the measurement located at 10 meters (33 feet).

Pier 2

Pier 2 data analysis was attempted using a second signal but due to access constraints caused by the containment boom the analyst was not able to set the hydrophone at 10 meter from the second pier. The sound levels from the pier located closer to the hydrophone was dominating the sound levels from the second pier. At this point we do not have a formula to extrapolate the peak from 15 meter for the second hoe ram working at the Pier 2 as shown in Figure 5.

Figure 5: Site of Hoe Rams Pier 1 and 2 with containment.



Looking at the data for Pier 2 qualitatively, the absolute peak from the hoe ram located at 15 meters from the microphone fails to contribute to the peak of the sound levels measured at 10 meters because the difference between the two sound levels was approximately 10 dB. Therefore, using the following formula:

$$
\begin{aligned}
dB \quad &= 193\ dB^{peak} + 183\ dB^{peak} \\
&= 10^{(193/10} + 10^{(183/10)} \\
&= 2.19\ X\ 10^{19} \\
&= 10*LOG(2.19\ X\ 10^{19}) \\
&= 193 \text{ (i.e., no change)}
\end{aligned}
$$

The second hoe ram at 15 meters would not contribute any additional sound to the first hoe ram sound level.

Table 3: Summary of Underwater Sound Levels for the SR 520 Demolition East Side

Pier #	Date & Time	Hydrophone Range m(feet)	Hydrophone Depth meter (feet)	Total Number Of Strikes	Absolute Highest Peak (dB)	$RMS_{90\%}$ (dB)	Average $RMS_{90\%}$ Duration (Sec)	Single Strike $SEL_{90\%}$ (dB)	Peak L_{50} (dB)	$RMS_{90\%}$ L_{50} (dB)	Single Strike $SEL_{90\%}$ L_{50} (dB)	Cumulative SEL (dB)
1	10/12/2016 2:20 PM	10-15 (30-49)	3 (10)	1,750	193	174	0.030	163	186	173	157	171

Comparison to Previous Hoe Ram Measurements (Manette Bridge)

Comparing the concrete pier demolition at Manette Bridge, the average peak sound levels measured at Manette ranged from 183 dB_{peak} to 197 dB_{peak}, the average RMS90% sound levels ranged between 173 $dB_{RMS90\%}$ and 186 $dB_{RMS90\%}$ and the cumulative SEL ranged between 195 dB_{cSEL} and 196 dB_{cSEL} where the hoe ram was working out of the water (Table 4). For the SR 520 Pier Demolition project where the hoe ram was operating below the water, the average peak was within the same range, the average RMS was slightly below the range and the cumulative SEL was below the Manette Bridge level probably due to a shorter recording length at SR 520.

Table 4: Summary of Pier Demolition Results, SR 303 Manette Bridge Demolition Project.

Project	Average Peak (dB)	Average $RMS_{90\%}$ (dB)	Cumulative SEL (dB)
Manette Bridge	183	173	195
	197	186	196
SR 520	186	172	171

Comparing both sites where measurements were collected are listed as follows.

a) Both measurements were taken at a range of 10 meters from the demolition piers
b) With the exception of the cumulative SEL values the measurements from the hoe ram operating above the water versus below the water were approximately the same.
c) The cumulative SEL was higher at Manette because the cumulative SEL is dependent on the total number of strikes recorded and at Manette WSDOT recorded an average of more than 3,000 strikes while of the duration of the recorded signals for SR 520 were approximately 1/3 of the strikes at Manette.

Daily Cumulative SEL

The daily cSEL's were calculated using an actual $SEL_{90\%}$ for the two recorded signals and accumulated over that period (Table 5).

Table 5: Summary of daily cumulative SELs

Day	Cumulative SEL
10/12/2016	171

CONCLUSIONS

The underwater sound levels during the demolition of two concrete piers by hoe-rams were recorded.

The underwater sound levels analyzed are as follows.

- Peak underwater un-attenuated sound levels between varied in a range between 193 dB_{Peak} and 177dB_{Peak}.
- The measured $RMS_{90\%}$ levels ranged between 180$dB_{RMS90\%}$ and 160$dB_{RMS90\%}$.
- The distance measured from Pier 1 to the 206 dB_{peak} threshold using the practical spreading model was 1.4 meters from the pier.
- Underwater sound levels compared between the Mannette Bridge data and the SR 520 demolition data was that there was no substantial difference in sound levels when the hoe rams were above or below the water surface.
- Reporting results at Pier 2 was not possible due to challenges locating the hydrophone in the proper location because of containment access. An attempt to extract the data from Pier 2 was not possible because the hoe ram sound levels at Pier 1 overshadowed the sound levels from Pier 2.

Cumulative Sound Exposure Levels

- Cumulative Sound Exposure Level (cSEL) was 171 dB_{cSEL}.
- RMS90% calculated duration averaged 0.03 seconds per strike.

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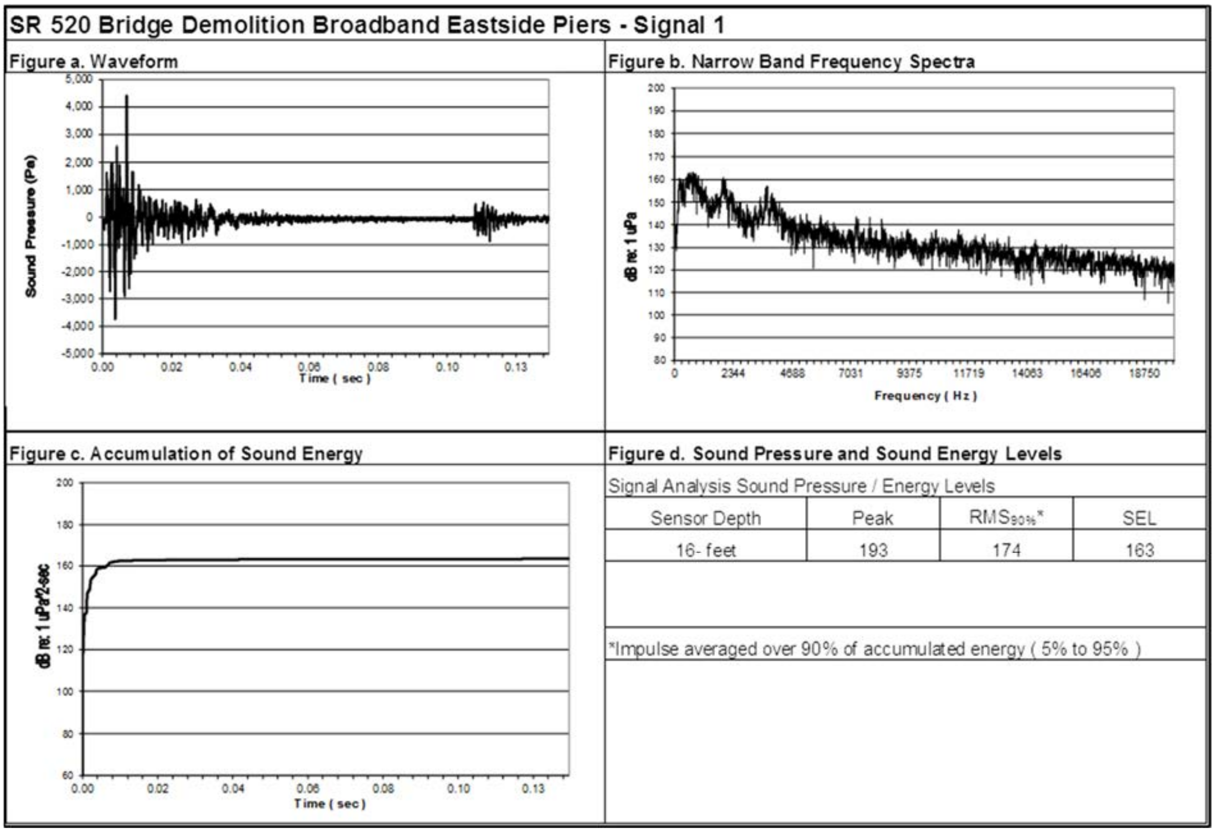
APPENDIX A WAVEFORM ANALYSIS FIGURES

Figure 6: Waveform analysis of Demolition Pier 1 Signal 1



Sensor Depth	Peak	RMS90%*	SEL
16- feet	193	174	163

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